The Chilean rhubarb is a large-leaved plant that grows to more than two metres tall. © Stan Shebs. CC BY-SA 3.0.

The management of Chilean rhubarb (*Gunnera tinctoria*)

Measures and associated costs

Scientific name(s)	*Gunnera tinctoria* (Molina) Mirbel
Common names (in English)	Chilean rhubarb
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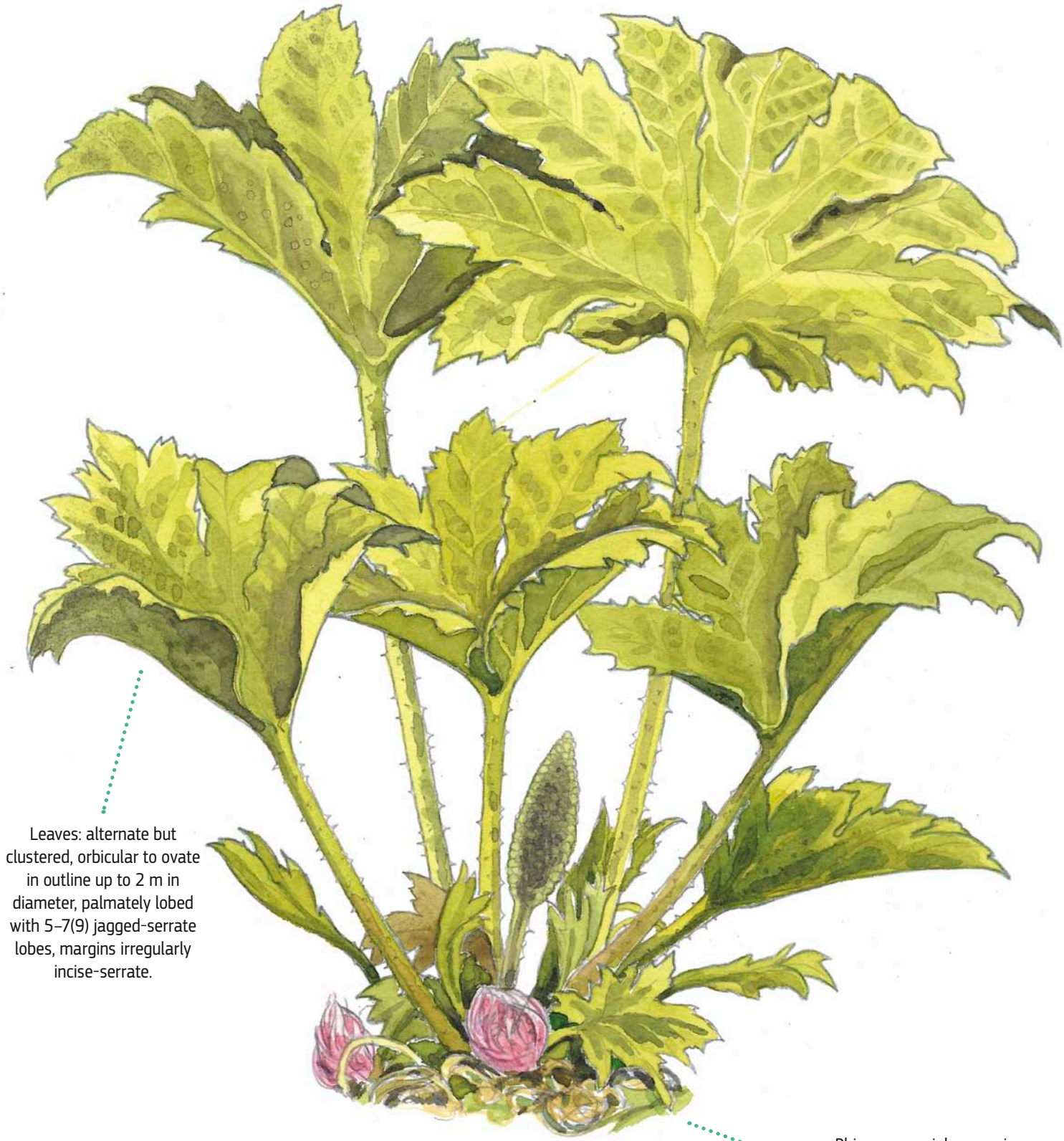
Common names

BG	–
HR	Čileanska gunera
CZ	Batora chilská
DA	Farvegunnera
NL	Gewone gunnera
EN	Chilean rhubarb
ET	Tšiili gunnera
FI	Värigunnera
FR	Rhubarbe géante du Chili
DE	Chilenischer Riesenrhabarber
EL	–
HU	Chilei óriáslapu
IE	Gunnaire
IT	Rabarbaro gigante
LV	Krāsu gunnera
LT	Čilinė gunera
MT	–
PL	Gunera brazylijska
PT	Gigante
RO	–
SK	Gunera farbiarska
SL	Čilenska gunera
ES	Nalca
SV	Röd jättegunnera

Main features of the species



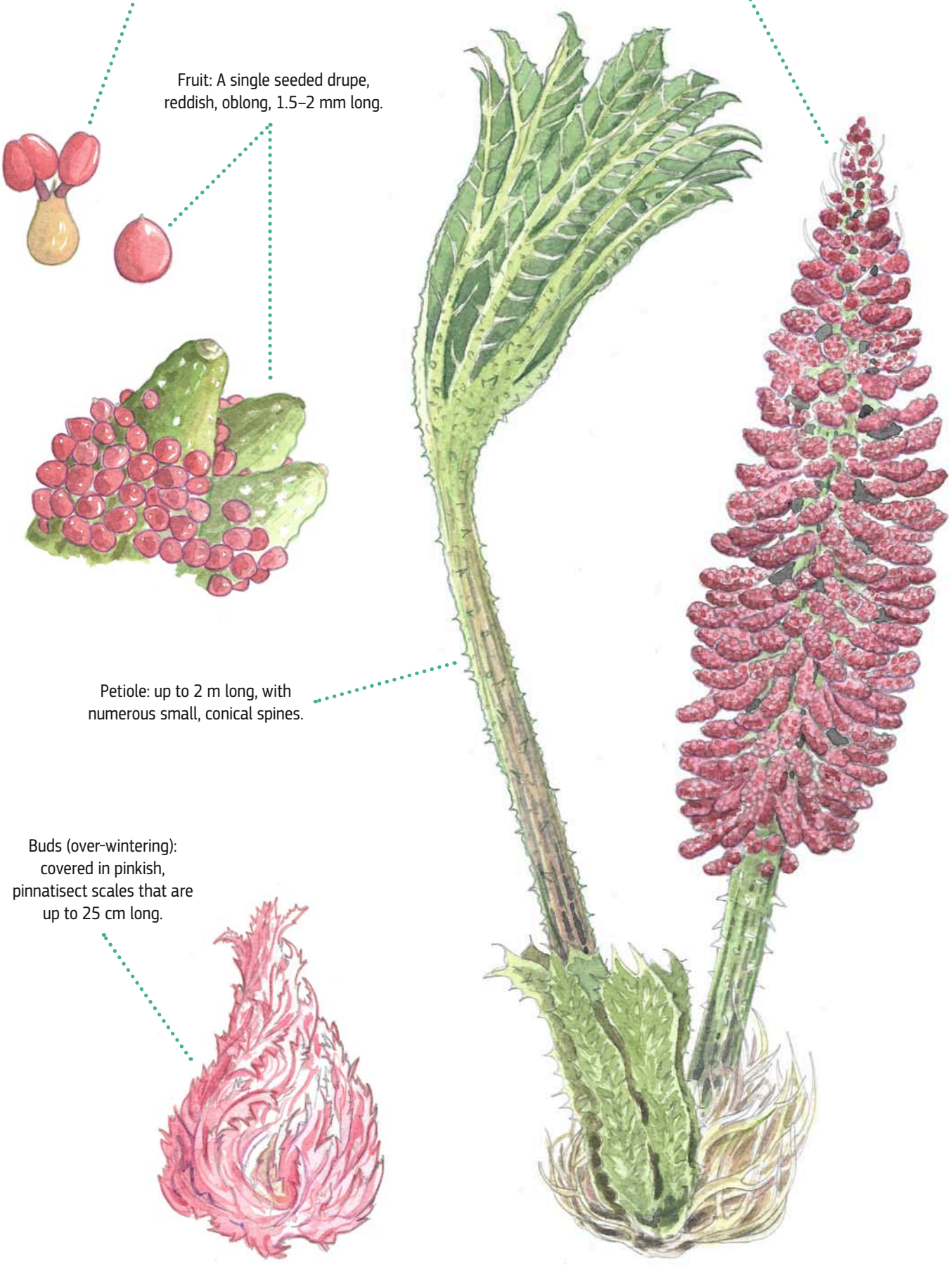
Leaves: alternate but clustered, orbicular to ovate in outline up to 2 m in diameter, palmately lobed with 5–7(9) jagged-serrate lobes, margins irregularly incise-serrate.

Rhizomes: mainly occurring above-ground (up to 3.5 m long and up to 20-25 cm in cross section).

Flowers: tiny green female or hermaphrodite densely packed on the inflorescence branches, sessile, apetalous, with minute sepals, about 1 mm long.

Inflorescences: A panicle up to 1 m long, with relatively stout branches up to 8 cm.

Fruit: A single seeded drupe, reddish, oblong, 1.5–2 mm long.



Petiole: up to 2 m long, with numerous small, conical spines.

Buds (over-wintering): covered in pinkish, pinnatisect scales that are up to 25 cm long.

Summary of the measures, emphasizing the most cost-effective options.

The Chilean rhubarb, *Gunnera tinctoria*, is a popular ornamental plant that has been introduced to gardens globally and, where environmental conditions are suitable, has escaped, become established and locally invasive, mainly in Ireland, Britain, the Azores (Portugal), and New Zealand. Its introduction via the horticultural trade has been mainly intentional, although knowledge of unintentional pathways of introduction is lacking. As seeds are available for purchase on the internet, it is possible that its introduction goes undetected by the relevant authorities even if prevention measures are in place, although the significance of this market as a pathway of introduction is unclear and much of the available seeds might not be viable.

Preventing the introduction of this species into Member States where it is not currently present requires banning the import, sale, propagation, and distribution of plant material, including seeds. Botanical gardens can act as a source of propagules that could become established if suitable environmental conditions allow, although information on the presence of established or invasive populations close to gardens is lacking.

Eradication from botanical gardens in Member States where conditions for growth are suitable, or could be become suitable given predicted climatic changes, would thus be a useful approach to prevent the escape of this species into the wild and the formation of established and possibly invasive populations.

Where potential sources of propagules are identified and the environmental conditions for growth and development are suitable, **early detection** measures ('search and destroy' programmes), repeated annually, would allow the identification of individual plants and their removal before they can reach sexual maturity (probably between 2 and 5 years, depending on the environmental conditions) or form an extensive rhizome system, thus effectively preventing their spread. Rapid control measures through mechanical removal are feasible only for juvenile plants that have not yet achieved sexual maturity.

Rigorous studies aimed at identifying **effective and sustainable control measures** are lacking. Information on control measures within the EU is limited to a small number of short-term trials in Ireland and the Azores. Extensive herbicide control measures have been conducted in New Zealand, while recent control programmes have been conducted in the Hebrides, UK. Four major issues hamper the control and eradication of this species: (1) the formation of a long-lived and extensive rhizome system (>1 m in length and 6-25 cm in diameter) with pre-formed leaves that facilitates early and rapid annual re-growth and rapid spread (average annual rhizome growth is 2-24 cm); (2) the production of a large number of seeds that become incorporated into a large, persistent soil seed bank, ranging between 10,000 and 100,000 seeds m^{-2}, depending on local environmental conditions; (3) the large size of mature plants, including its rhizome system (*Gunnera tinctoria* is among the largest herbaceous species in the world), which makes its removal (including small fragments) logistically difficult; and (4) the occurrence of this species predominantly in wet habitats, where herbicide use is restricted and mechanical control might not be feasible and/or could result in the spread of viable propagules. Sustainable control measures should account for the size and demography of established or invasive populations, including the characteristics of the soil seed bank, the longevity of the rhizome system, as well as associated environmental and socio-economic considerations. To date, short-term trials have shown that chemical or integrated chemical and mechanical measures are effective at reducing the standing biomass, although recruitment from the rhizome system or from the seed bank has been observed at the end of a number of these trials. The effective control of this species requires the development of long-term strategies that are based on the use of multiple measures targeting different life stages and that are repeated for several years.

There are a number of research gaps that need to be addressed to develop effective control measures. There is a need for additional information on the most effective method(s) to target the rhizome and how long these approaches would need to be implemented to ensure that no re-growth occurs (trials from New Zealand indicate that helicopter boom or wand systems, or basal bark application methods can be used to target the rhizome). Information on the probability of successful recruitment from the seed bank after the removal of the standing vegetation is also necessary. At present, little quantitative data is available on the minimum duration of any control programme that ensures the successful control of this species (control to zero density), although a minimum of 4 to 10 years has been suggested for chemical or integrated chemical and mechanical measures, while 'search and destroy' programmes should likely be conducted permanently. Knowledge of how climate change could affect the distribution and invasive potential of this species is needed to identify regions/areas that are particularly susceptible, as well as for assessing the effectiveness of control efforts in the future. Knowledge of the capacity of this species for rapid adaptation in its introduced range is also needed to estimate its future distribution.

The most pressing needs to **prevent the introduction and spread** of this species within the EU include: (1) an improved knowledge of its ecology and biology with a view towards the development of evidence-based long-term and sustainable management measures; (2) increasing public awareness of the invasive nature of this species and issues associated with its control; (3) appropriate legal mechanisms that limit the currently illegal horticultural trade (internet trading), including import and cultivation restrictions or escape from private gardens and the enforcement of appropriate management measures where the species is already populating. Additional information is urgently needed on the time required for *Gunnera* to achieve sexual maturity (at least two years but often five years). This information is critical to the development of effective early detection and control measures, as this will determine the timing of control/eradication measures after the early detection of this species as well as the timing of repeated control measures after the initial application of chemical or combinations of mechanical and chemical control measures, including those aimed at controlling the soil seed bank.

Complete eradication in Member States where this species is already established or invasive is unlikely and any management interventions should be carefully assessed in terms of their likely efficacy, prior to their implementation. The focus should be on problematic invasive populations and the eradication of newly recorded or isolated individuals, or small populations. Ideally, annual control measures should be put in place to destroy all seedlings and standing biomass. The costs of the control of mature individuals or populations are expected to be high and would need to include the costs for the disposal of removed plant material and the control of the seed bank, although these costs have not been quantified.

While the effectiveness of glyphosate at controlling this species has been shown in various trials across the invasive range of this species, at least in the short term, its use in the future will depend on the renewal of the approval of glyphosate as a pesticide in accordance with the EU's Plant Protection Product Regulation (Regulation (EC) N° 1107/2009), with a decision expected by the end of November 2017 (ECHA 2017). Trials conducted in the Azores and New Zealand indicate that Triclopyr butoxyethyl and Metsulfuron methyl, whose use is approved in the EU, are effective at killing the entire plant, including the rhizome.

While the focus of this report is on conventional herbicide and mechanical removal-control and eradication treatments that are directed at the host plant, more attention should be given in the future to indirect control measures that are focussed on the prokaryotic cyanobacterial symbiont. In common with the other species within its genus, *Gunnera tinctoria* forms a unique intracellular symbiosis with nitrogen-fixing cyanobacteria (*Nostoc*) (Osborne *et al*., 1991; Osborne and Sprent, 2002; see Gioria and Osborne, 2013), which can be advantageous in N-limited environments, where this species is often invasive, although it is a good competitor also in high-nutrient environments (Bergman *et al*., 1992; Gioria and Osborne, 2013). Given that this symbiosis appears to be an almost obligate requirement for this and all other *Gunnera* species, the possibility to control *G. tinctoria* by acting on the symbiont should be explored.

This species could potentially hybridise with the other giant alien and established *Gunnera* species, for instance *G. manicata*, with which is frequently confused. Prevention, early detection, and management of both species would be advisable.

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 importing (pre-border measure), selling, breeding, growing, and cultivation, as required under Article 7 of the IAS Regulation, targeting intentional introduction of plants and propagules of *G. tinctoria*.

MEASURE DESCRIPTION

This measure includes pre-border restrictions on the import of this species, as well as post-border measures aimed at preventing the introduction, sale, propagation, and cultivation of this species *via* the creation of an effective biosecurity infrastructure.

Gunnera tinctoria is a popular ornamental plant. Intentional introduction for ornamental purposes in botanical gardens and in public parks and gardens, especially around ponds and water courses, represent the pathway of introduction of this species from which most of the currently established and invasive populations are likely to have originated.

The horticultural trade, including the sale of seeds on the internet with their delivery by postal and courier services, is also a pathway of intentional introduction, although there is no information on the demand and supply of seeds or seedlings in Member States or globally. The interest in the use of this species in private gardens within regions where the climate is suitable for its establishment (although it might not be sufficient in determining its persistence in a community) is high. *Gunnera tinctoria* received the Award of Garden Merit in 2006 by the Royal Horticultural Society (RHS 2011; see Gioria and Osborne, 2013). After its recognition as a global invasive plant (Global Invasive Species Database 2017), it was removed from the list of plant species recommended for gardening by the Royal Horticultural Society, but its giant congeneric species *Gunnera manicata* is still included in the list, and their website provides information on 57 suppliers of seeds/plants in Great Britain alone (RHS 2017), while seeds of both species are available from suppliers globally. This suggests that seed trade for this species is substantial. Moreover, a pilot investigation conducted in Ireland indicated that seeds of one species are often sold as those of the other species, so that it is not possible to know which species is actually introduced. Thus, the import, sale, propagation, and growth of both species need to remain banned.

As botanical gardens have acted as the main source of introduction of established and invasive populations globally (Silva *et al.*, 1996; Williams *et al.*, 2005; Fennell *et al.*, 2010; Gioria and Osborne, 2013), banning the importation of propagules of these species for use in botanical and public gardens, where they are allowed to reach sexual maturity, will effectively prevent introductions that could lead to the establishment, and ultimately, the spread of this species. A ban on intentional introductions into botanical gardens in all Member States, even in those where this species is not likely to become invasive, is important as they could act as a source of propagules that could be unintentionally transported to other Member States where this species could become established.

The currently applied EU wide complete ban on cultivation, import and sale is essential. Specific agencies/authorities should develop control measures to mitigate the import through internet trading of seeds, which significantly contribute to the spread of the species

EFFECTIVENESS OF MEASURE

The effectiveness of a complete ban on the import, sale, and propagation of this species requires a solid understanding of the volumes and main actors in the trade of seeds and plants of *Gunnera tinctoria*.

Ultimately, the effectiveness of this set of measures depends on the resources dedicated to their implementation, with the costs expected to be high. Effective pre- and post-border interventions will require high industry compliance, with all actors in the ornamental trade industry supporting such a ban, including importers of these species, plant propagation and production nurseries, wholesale suppliers, public retail outlets (specialist nurseries, garden centres, hardware stores, etc.), as well as public, business, and government consumers (see Hulme *et al.*, 2017 for a discussion of these measures). Awareness campaigns targeting the general public, focusing on the impacts of this species (and its congener) and the

costs associated with its control, could substantially improve the effectiveness of this ban (see additional prevention table below). Awareness campaigns targeting the directors of botanical and public gardens should also improve the effectiveness of this ban.

EFFORT REQUIRED

This ban should be in place permanently.

RESOURCES REQUIRED

Banning the import, sale, propagation, and cultivation/storage of propagules of this species requires the development of an effective biosecurity infrastructure at the EU and Member State levels, including mechanisms to check compliance. This measure requires screening of all incoming travellers at the Member State level, including shipping containers and mail items, as well as all traders in seeds and seedlings of this species.

Resources should also be dedicated to promoting campaigns aimed at increasing awareness of the risks associated with this species and targeting private citizens, directors of botanical and public gardens, and those involved in the horticultural trade.

These measures are especially needed in Member States or regions where a mild climate, with a high rainfall and/or humid conditions, together with the availability of suitable (mainly disturbed) habitats (Osborne and Sprent, 2002; Fennell *et al.*, 2012), would favour establishment.

Detailed modelling studies, including species distribution models based on remote sensing techniques as well as mechanistic models, such as that of Fennell *et al.* (2012), would improve our capacity to identify the regions currently susceptible to invasion, as well as to predict longer term changes in distribution associated with climate and land use changes.

SIDE EFFECTS

No side effects are foreseeable.

ACCEPTABILITY TO STAKEHOLDERS

Opposition from botanical gardens and industry to import and sales bans could be strong. In particular, some dissent and opposition is expected from botanical gardens that advertise this species as a major attraction. Depending on the size of the trade in seeds and seedlings of these species, there is likely to be opposition from plant propagation and production nurseries, gardeners, wholesale suppliers, and public sale retailers, as well as companies selling seeds on the internet. Opposition from the general public could be mitigated by awareness campaigns that describe the impacts of this species if it becomes established and the costs and issues associated with its control and eradication. If effective, such campaigns would reduce the demand of seeds or plants, ultimately improving the effectiveness of pre- and post-border restrictions.

ADDITIONAL COST INFORMATION

Implementation costs will include the costs necessary to modify national legislations and border controls, especially checks at points of entry of horticultural products, staff training and the establishment of agencies/authorities for enforcing the ban on the sale, propagation and distribution of *Gunnera* species, including the trade in seeds. Awareness campaigns on the invasiveness of this species could be costly.

Failure in preventing the introduction of this species would result in increased costs for early detection, surveillance, and management or eradication. Given the expected high costs and technical difficulties associated with the control of this species, stopping the intentional introduction of *G. tinctoria* is likely to be more effective at preventing its establishment rather than other stages of the management process, including early detection and rapid eradication. However, as the costs of implementing a ban of this kind would be high, knowledge of the probability of successful establishment from propagules and plants introduced by the horticultural trade and botanic gardens in each Member State is essential to make an informed decision about the cost-benefits of this ban.

The costs of a ban on import, sale, and propagation could be reduced by sharing them with those associated with the prevention of other invasive alien plants.

LEVEL OF CONFIDENCE[1]

Medium.

The ban on this species is new, thus information on its effectiveness or costs is lacking. It is plausible to expect that the costs of prevention measures will be high, although this will depend on the size of the trade in propagules of this species and its congener. This measure should greatly reduce the probability of introduction of this species into Member States where this species is currently absent.

1 See Appendix

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

MEASURE DESCRIPTION

While Member States are required to identify potential pathways of unintentional introduction for the species (as per the regulation), one general measure to reduce the risk of introduction is the undertaking of a public awareness campaign.

Preventing the unintentional introduction of this species will require: (1) conducting risks assessments aimed at identifying unintentional pathways of introduction and developing specific management measures for each pathway, (2) determining the probability of successful establishment of unintentionally introduced propagules by assessing seed viability and longevity under different environmental conditions that resemble those experienced by propagules of this species during unintentional transport, and (3) developing awareness campaigns.

The movement of people associated with travel, tourism, recreation or relocation could result in the unintentional transport of seeds and other plant material by air, train, vehicles, or by boat, attached to hiking boots, recreation gear, in checked luggage, or the tyres of vehicles, among others. *Gunnera tinctoria* possesses small, fleshy, oblong fruits that can become attached to footwear and recreation gear, as well as within the tyre treads of vehicles (Gioria and Osborne, 2009; 2013). Awareness campaigns should be conducted in Member States where this species is currently established or invasive, focusing in areas where populations are present. Information on the invasiveness of this species, impacts, and costs associated with its control should be included in tourist guides, including tourism and travel websites, with leaflets provided by tourism information offices, museums, and providers of recreational and sporting activities, as well as at points of entry, including airports, train stations, and ferry terminals. Moreover, information on its invasiveness should be provided to people travelling from South American countries, where this species is native. This measure could be combined with specific border control policies aimed at preventing the importation of seeds and seedlings of this plant.

EFFECTIVENESS OF MEASURE

At present no information is available on the number of propagules unintentionally introduced into Member States where this species occurs, nor on the probability of successful establishment from these propagules.

The main dispersal agent of seeds of this species include anthropogenic-related activities (movement of contaminated soil, unintentional transport during recreational activities as well as long-distance dispersal by car and other vehicles, as well as grazing by cattle, mainly sheep grazing). Birds and small mammals, as well as water can also contribute effectively to the long-distance

spread of this species, although quantitative information on zoochory and hydrochory dispersal of this species is needed (Gioria and Osborne, 2013), and whether some propagules could be introduced into some Member States through these means.

Awareness campaigns in areas (and Member States) where this species is established or invasive could be effective at reducing the risk of unintentional introduction into Member States where this species is not yet present. This measure should be effective not only at preventing the unintentional introduction of this species into new areas/regions but also at preventing its further spread within Member States where it is already established. Moreover, such campaigns would also reduce the demand for plants or seeds and thus increase the effectiveness of a ban on the import, sale, and propagation of this species (and its congener).

Although seeds and rhizome fragments could be unintentionally introduced into Member States where this species is not present in association with the movement of people, the risks of successful establishment of seeds or plant material will depend on factors such as the environmental conditions during transport and transport duration, which will affect propagule viability, as well as on the environmental conditions at the sites of introduction, habitat suitability, and climatic conditions. This species grows in mild, moist climates, in the native as well as in the invasive distribution range (Gioria and Osborne, 2013). While seeds under natural conditions can germinate throughout the year, except for winter months, they fail to germinate at temperatures at or below 15 °C (Gioria and Osborne, 2013). Moreover, seed imbibition is a requirement for germination. Gioria and Osborne (2013) found that a high percentage (>70%) of seeds germinated after one year from dispersal under natural conditions, suggesting that seeds could survive for a long period of time and, if accidentally returned to the soil, they could germinate if, after seed imbibition, the conditions for the breaking of dormancy and germination are met. However, recruitment by seeds is typically low and under natural conditions the vast majority of seeds fail to germinate (Gioria and Osborne, 2013). While seeds in Ireland do not seem to be dormant (Gioria and Osborne, 2013), information on dormancy type and requirements for breaking dormancy throughout the native and non-native distribution range of this species is

needed. Recent estimates indicate that some seeds of *G. tinctoria* can persist for over 70 years (Fennell *et al.*, 2014).

Lowering the probability of unintentional introductions by awareness campaigns, combined with a low probability of seedling establishment under natural conditions, is likely to be effective at preventing the establishment of this species, even in Member States where climatic conditions are suitable for growth and development. However, there is evidence that the number of plants establishing from seed under natural conditions is increasing (Osborne, unpublished), so that additional preventative measures may be required in the future. Knowledge of the probability of successful establishment from seeds introduced unintentionally would improve our understanding of the efforts required to effectively prevent the introduction and establishment of this species.

EFFORT REQUIRED

Awareness campaigns should be in place permanently.

RESOURCES REQUIRED

The resources required would primarily be those required for the establishment of teams for the preparation and distribution of communication material to Member States where this species is currently established or invasive, as well as its inclusion in travel literature.

The overall effort will ultimately depend on the importance of unintentional introductions *via* the movement of people in promoting the successful establishment of this species.

SIDE EFFECTS

No side effects are expected for this measure.

ACCEPTABILITY TO STAKEHOLDERS

This measure should be acceptable to most stakeholders.

ADDITIONAL COST INFORMATION

The cost of inaction includes the costs associated with the establishment and spread of this species. Failure in preventing the unintentional introduction of this species could result in increased costs for early detection, surveillance, management and/or eradication. Given the expected high costs and technical difficulties associated with the management of this species, costs aimed at reducing the unintentional introduction of propagules *via* awareness campaigns and specific campaigns targeting tourists are expected to be substantially lower than those incurred at other stages of the invasion process. However, improved understanding of the probability of seedling establishment from unintentionally introductions and the formation of established populations is necessary for determining the cost-effectiveness of this measure.

LEVEL OF CONFIDENCE[1]

Medium.

No measures are currently in place to mitigate unintentional introductions *via* the movement of people. However, the risk of establishment of *G. tinctoria* (and *G. manicata*) from unintentionally introduced propagules is probably low. Awareness campaigns should thus be sufficient in mitigating the risks of establishment of this species and its congener in Member States where they are currently not present (although they might be present in botanic and public/private gardens).

1 See Appendix

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

Non-removal surveillance strategy.

MEASURE DESCRIPTION

This measure includes spatial prioritisation efforts aimed at detecting the target species across all sites where the presence of this species is expected, even where it has not been detected before (these sites would not be removed from the list of sites where the surveillance sampling is needed; Hauser and McCarthy, 2009; Guillera-Arroita *et al.*, 2014).

Spatial prioritisation efforts should account for (1) the probability of detecting this species, based on the proximity of potential sources of introduction (for example botanical and private gardens), suitable environmental conditions for growth, including climatic suitability, and the dispersal capacity of this species (by seeds and plant fragments); (2) the probability of identifying individual plants, especially seedlings (early-emerged *Gunnera* seedlings might be overlooked by untrained staff); (3) survey costs, which depend on the availability of trained staff and the size and characteristics of the areas to be monitored; and (4) the benefits associated with early detection, which are high given the complexity and high costs required for the management and eradication of established populations.

The Chilean rhubarb. © Archive of Institute Symbiosis.

EFFECTIVENESS OF MEASURE

There is no information on the effectiveness of surveillance strategies for *Gunnera tinctoria*.

As this species is often confused with rhubarb species such as the ornamental rhubarb (*Rheum palmatum*) and the cultivated rhubarb (*Rheum* × *hybridum*), particularly at the juvenile stage (NNSS, 2017), surveillance for juveniles might be difficult. There is also the possibility of confusion of *Gunnera* seedlings with those of *Tussilago* and *Petasites* species, both of which have similar morphologies and growth requirements. As these are common species, it is questionable whether seedlings of these species could or should be removed based only on the possibility that they might be *Gunnera* species.

The use of non-removal surveillance strategy is likely to be more effective than 'removal' surveillance strategies, where sites are removed from the list of those to be monitored, based on the lack of detection of this species.

Early detection is likely to be a highly effective measure to prevent the establishment of this species in other Member States, especially if individual plants are found before they become sexually mature. Early detection would also minimize any long-term effects on native communities and ecosystems associated with established or invasive populations, and thus the efforts and associated costs necessary to restore invaded communities/ecosystems after the control of this species. A further benefit of early detection is the knowledge acquired on the dispersal capacity and modes of dispersal of this species, the probability of establishment in different habitat/ecosystem types, and the duration of a lag-phase between the introduction, establishment, and spread (*sensu* Richardson *et al.,* 2000). Records from Ireland, in fact, indicate that there is a long lag period between the introduction of this species and the invasion phase (Fennell *et al*., 2010; Gioria and Osborne 2013).

EFFORT REQUIRED

Spatial prioritisation efforts should focus on areas close to where this species is present or its presence is suspected, and where it is known to have been introduced in the past. However, as seeds are dispersed by anthropogenic means, by water and by birds, and roadsides are a common habitat (Williams *et al*., 2005; Gioria and Osborne, 2013), a broader distributional range should be considered where its presence is known or suspected in a Member State.

Early detection programmes would need to be carried out throughout the growing season every year, especially if unintentional introductions are suspected. This argument is reinforced by the fact that seeds germinate asynchronously over an extended period of time (Gioria and Osborne, 2013), before and after the germination of seeds of native species in invaded habitats. Attention should be paid to locating new seedlings that have established from germinated seeds late in the growing season. Early detection and subsequent control would prevent the formation of any significant vegetative biomass, including significant storage reserves in the rhizome that would support growth the following year.

As this species has been commonly planted in botanical and private/public gardens globally (Osborne *et al.,* 1991: Gioria and Osborne, 2013), efforts should be made in the proximity of gardens and along watercourses that originate or flow through those gardens. As this species requires high rainfall and/or humidity levels (Gioria and Osborne, 2013), efforts should focus on habitats and regions where these conditions occur. In regions where climatic conditions are suitable for growth, preferred habitats in the invaded range include disturbed ground, coastal areas, waterways, roads, quarries, abandoned farmland (Gioria and Osborne, 2013), and degraded peatland (Botelho and Peñil, 2013). Species distribution models could be useful in identifying the regions where this species is more likely to become invasive, based on the current distribution as well as climatic and environmental conditions and socio-economic considerations (Fennell *et al*., 2012). These models can be used to prioritise the implementation of control or preventative measures by the relevant authorities. The use of former or pre-existing programmes aimed at surveying the flora of individual Member States, or the presence of alien species, should considerably reduce the efforts required to detect this species.

As *Gunnera tinctoria* is such a large and distinctive plant, the use of unmanned aircraft vehicles (UAV) to survey areas potentially supporting established or invasive populations, which has been recommended in monitoring plant invasions (see Müllerová *et al*., 2017), would probably be the most cost-effective option for landscape-scale surveillance operations, providing information on the distribution of invasive populations as well as small established populations, and possibly, individual plants. The use of fixed-wing remote sensing technology for detecting invasions by coniferous species is being developed in New Zealand and early indications are that the costs are about $0.30c per hectare after data processing (Raal P., pers. comm.).

RESOURCES REQUIRED

Costs for the development of an early detection national team, if not yet in place.

Costs for collecting information from herbaria, to determine whether, when and where this species has been introduced into a Member State.

Costs for collecting information on the horticultural trade of this species.

Costs for the training of staff, including cost of travel for experts in the identification of *Gunnera tinctoria*. As

G. tinctoria has a preference for disturbed habitats and abandoned farmland and its presence is often associated with other alien or invasive species or problematic native weeds (Gioria and Osborne, 2009, 2010), it is possible to reduce the costs by training staff in the identification of this as well as other invasive or potentially invasive alien species.

Developing citizen science projects on the early detection of this species could help reduce the costs of early detection and would allow the implementation of early detection programmes within a shorter period of time (Pocock *et al.*, 2014), although this might increase the probability of unintentional spread of propagules if weed hygiene protocols are not respected.

As this species can form extensive populations along roadways, which may also facilitate the dispersal of seeds or plant fragments (Gioria and Osborne, 2013), national road authorities or private contractors could contribute to early detection efforts, thus reducing their costs. The same applies to authorities with the responsibility for waterways or water bodies.

Costs include those for the acquisition of the necessary aeroplane, equipment, and staff to fully develop the remote sensing surveillance option, including the development of computer algorithms. For the New Zealand option, $25000 was needed to upgrade a small fixed-wing aircraft, the hire of a multispectral scanner, purchase a high-resolution camera, developing and testing of the computer algorithm and processing of multi-spectral data (Raal P., pers. comm.). Subsequent image processing costs are, however, expected to be significantly cheaper (Raal P., pers. comm.). While the use of drones might reduce these costs, they would have more limited coverage, although they may be more appropriate given the more restricted distribution of this species.

SIDE EFFECTS

Gunnera tinctoria is characterised by the rapid formation of vegetative and reproductive biomass early in the growing season particularly when mature. As the costs to control this species are high and extensive efforts would be required to manage this species over a long period of time, the benefits of early detection of sexually immature individual plants or small populations would be substantial. As this species forms a large persistent seed bank that rapidly accumulates over time (Gioria and Osborne, 2009; 2013), it is important that detection occurs before plants reach 2-5 years in age and start producing seeds. Also, the plants should be controlled before they produce a large rhizome system, which is the main cause for the failure of herbicide control programmes for this species (Gioria and Osborne, 2013). Once established and producing seed, this species also causes major changes in the seed bank of invaded communities, reducing their diversity, abundance, and altering their composition, with the resulting communities mainly comprised of seeds of weeds or other undesirable species (Gioria and Osborne, 2010). This is an issue especially in areas of medium/high conservation value, particularly coastal cliffs, which are a significant habitat for this species (Silva *et al.*, 1996; Williams *et al.*, 2005; Gioria and Osborne, 2013). Potential ecosystem effects have also been reported, including changes in biogeochemical cycles (Gioria and Osborne, 2013). As this is a nitrogen-fixing species, with a potential to increase the available nitrogen to plants, it could promote further invasions by other nitrophilous alien plants or undesirable native species (Gioria and Osborne, 2010; Gioria *et al.*, 2011). Early detection would minimize any long-term effects on native communities and ecosystems and thus reduce the costs necessary to restore previously invaded communities/ecosystems.

A further benefit of early detection is the knowledge acquired on the dispersal capacity and modes of dispersal of this species, the probability of establishment in different habitat/ecosystem types, and the duration of the lag-phase between the introduction, establishment, and spread (sensu Richardson *et al.*, 2000). Records from Ireland indicate that there is a long lag period between the introduction of this species and the invasion phase (Fennell , 2010; Gioria and Osborne, 2013). Potential negative effects of early detection programmes include the unintentional spread of seeds, whose small, rounded shape makes them easily transported by human activities. This, however, will only occur if staff treating sexually mature populations of Gunnera fail to adhere to an established weed hygiene protocol. Proper staff training in effective weed hygiene best practice should substantially mitigate this risk.

ACCEPTABILITY TO STAKEHOLDERS

This species often grows in abandoned land and in disturbed areas in its invasive range. Early detection programmes are thus not likely to interfere with any economic activity. The public perception of this species in areas where it is invasive is generally negative, largely due to its large size and conspicuous appearance and because it forms large areas covered by a thick layer of litter during the winter months, although most of this decomposes prior to the following growing season. As it is heavily invasive in abandoned farmland (Gioria and Osborne, 2013), its early detection would diminish the costs of reclaiming this land for agricultural purposes.

ADDITIONAL COST INFORMATION

There is no information on the costs of early detection for this species but these are likely to be similar to surveillance operations for other alien plants. If eradication is the objective, then the costs of surveillance will substantially increase because comprehensive surveys across the entire range of spread will need to be undertaken to ensure that all plants are found. These costs could be substantially reduced if an effective remote sensing system is developed that can locate individuals wherever they occur. The overall costs will depend on the presence of agencies and organizations

The Chilean rhubarb has been introduced to many parts of the world as an ornamental plant . © Stan Shebs CC BY-SA 3.0.

working on the early detection and rapid eradication of invasive alien plants within different Member States and the ability to utilise relevant existing networks, including the general public, concerned landowners, and other stakeholders interested in the general issue of invasive alien plants. In the absence of any existing organisation working on the early detection of invasive alien plants, the costs will involve those for the creation of teams within existing organisations or the creation of new organizations, the training of staff by experts in identification skills and in the ecology and biology of this species. Costs for developing citizen science projects for early detection should also be included. Reporting systems and databases should be created, as well as data collection standards; these will have a cost both for their establishment and maintenance.

LEVEL OF CONFIDENCE[1]

Medium.

No early detection programmes targeting this species are currently in place. Estimates of the efforts required to implement this measure are based on existing knowledge of the ecology and biology of this species. Information on the actual costs needed to implement effective early detection programmes will be strongly dependent on the availability of organisations and experts in dealing with invasions by alien plants and in the development of an effective remote sensing system. As this species is likely to spread in regions with a wet/humid climate, within a restricted number of habitats, we assume that the costs of early detection would only be associated with relatively low monitoring efforts, although limitations in the utilisation of this approach, due to frequent and persistent cloud cover, are likely. Major costs will likely involve the deployment of experts that understand the ecology of *Gunnera tinctoria* and can identify this species in the field. Additional costs may be incurred in training staff to be competent in the detection of the species.

Training will involve information on how to identify the species at different stages of its life cycle (from seeds, seedlings, juveniles, and adults), in the identification of sites where there is a high probability of detecting this species (this could be done by effective species distribution modelling – see Early Detection Section), and in the development of effective hygiene protocols aimed at minimising the risk of spreading propagules when conducting surveillance (and management) programmes.

1 See Appendix

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

Physical removal of juveniles.

MEASURE DESCRIPTION

This measure involves the physical removal of young plants and their rhizome system.

EFFECTIVENESS OF MEASURE

This measure is considered to be effective at preventing the establishment of self-sustaining populations if plants are removed before they become sexually mature. The age at which plants start producing significant numbers of seeds varies considerably depending on the environmental conditions (Osborne *et al.*, 1991), possibly after 2 years but generally after 5 years. To be effective, this measure requires that all below-ground parts of the rhizome/roots be removed as these can generate new plants (Armstrong, 2008; Gioria and Osborne, 2013; Cumming, 2015). Removal of young plants has been reported to be relatively easy because the rhizome is small and the rooting system undeveloped. However, even for relatively young individuals (<2 years old) it is uncertain whether all below ground material can be adequately removed.

EFFORT REQUIRED

This measure is most successfully applied during the growing season when the plants are recognisable, and would not need to be repeated if properly conducted (for instance removal of the rhizome system). Follow up surveillance may, however, be necessary because of the difficulty of removing all plant fragments, an inability to identify all juvenile plants, and a failure to remove all individuals that may become established from seed.

RESOURCES REQUIRED

There is no information on the cost of this measure. The cost of early removal of young plants is expected to be relatively low. Additional resources would be needed for the disposal of plant material in a way that the spread of this species is prevented.

SIDE EFFECTS

Negative side effects include the safe disposal of removed plant material. This problem has been addressed in County

Chilean rhubarb, County Kerry Ireland. © Kevin Smith.

Mayo, Ireland (Cunningham D, pers. comm.), and in the Planalto dos Graminhais, Azores, Portugal (Botelho and Peñil, 2013), by placing plant material in plastic bags until the material decomposes. However, no information has been provided on how long this material should be kept for, or on the costs of such a disposal method. Bringing plant material into recycling depots, such as that done in North Harris, Hebrides, UK, poses the risk that viable propagules are dispersed during the transport of this material (Cumming, 2015) or during its storage prior to recycling. Burial of plant material has also been used on São Miguel Island, Azores, Portugal (Botelho and Peñil, 2013), although there is no consensus on the depth at which vegetative material should be buried to prevent re-growth and establishment.

An alternative hygiene measure that could be considered is to soak the removed plant parts in a 20% triclopyr butoxyethyl ester (BEE) in oil solution (Raal P., pers. comm.). However, EU/national/local legislation on the use of plant protection products and biocides would need to be respected.

ACCEPTABILITY TO STAKEHOLDERS

Due to the habitat preferences of this species in its invasive range, this eradication measure is not likely to impact on any significant economic activity or on animal welfare. While seedlings and young plants are grazed by sheep, their removal should not have a major impact on the diet of these grazers.

ADDITIONAL COST INFORMATION

The cost of inaction would be high if young plants were allowed to reach sexual maturity and become established. Given the difficulties of controlling mature plants (see above-described issues) and the increased costs of disposal, control costs are expected to increase dramatically with time after establishment.

There is no evidence of negative socio-economic impacts for this measure.

LEVEL OF CONFIDENCE[1]

Medium.

This measure has been successful at eradicating sexually immature plants in the short-term (Armstrong, 2008; Cumming, 2015), although its overall effectiveness is dependent on the safe disposal of all plant parts after their removal.

1 See Appendix

Measures for the species' management.

Physical control.

MEASURE DESCRIPTION

This measure involves the manual of mechanical removal of both standing and below-ground biomass and propagules.

EFFECTIVENESS OF MEASURE

Eradication of mature individuals is effective only where the entire rhizome system can be removed together with standing biomass and all propagules (Williams *et al.*, 2005).

Removal of all the rhizome and root material and all viable propagules is the minimum prerequisite required to ensure the long-term effectiveness of this measure. However, this requirement poses major technical difficulties in most habitats where this species is typically invasive and this method is most effective at controlling small invasive populations, while the removal of large invasive populations would require extensive efforts, creating large-scale disturbances as well as posing issues associated with the disposal of large above- and below-ground biomass. The removal of this species is not suitable for the control of established or invasive populations near water because the disturbance created could exacerbate the dispersal of propagules, creating uncertainty about the efficacy of this approach under those conditions. There are also access and operational issues associated with the use of excavators and other machinery or with manual removal in inaccessible and waterlogged areas where this species is commonly found (Armstrong, 2008). Moreover, the effectiveness of this measure is hampered by the large persistent seed bank formed by mature individuals. If eradication is the objective, this measure should be combined with other measures aimed at detecting and treating (mainly removing) emerging seedlings arising, for instance, from missed propagules or ineffective treatments, to ensure its long-term effectiveness.

The Chilean rhubarb has cone-shaped inflorescences (to 1m) from spring to early summer, with small flowers. © Dick Culbert. CC BY 2.0.

EFFORT REQUIRED

The removal of established and invasive populations is generally too costly for the longer-term and sustainable control and management of this species (Jones and Osborne, in press). As this species is often invasive in inaccessible locations, such as coastal cliffs and wet areas, manual removal or excavation of large populations would be impractical and/or environmentally damaging.

Where the use of this method may be feasible but has been conducted by untrained operators, there is a high potential for overlooking rhizome/root/propagule material, resulting in control failure (Cumming, 2015).

A significant issue associated with the physical removal of *Gunnera tinctoria* is the disposal of large volumes of long-lived rhizome biomass. Disposal in plastic bags or burial in deep soils have been adopted in Ireland (Cunningham D., pers. comm.) and in the Azores (Botelho and Peñil, 2013). Such methods of disposal require the identification of suitable sites and, for the latter, the use of machinery to excavate the soil. Burning may be an option but, if incomplete, appears to be ineffective (Armstrong, 2008). Treating the entire surface of all removed plant parts with 20% triclopyr butoxyethyl ester (BEE) in oil before disposal will kill the material and may be a better option than burning (Raal P., pers. comm.). EU/national/local legislation on the use of plant protection products and biocides needs to be respected.

RESOURCES REQUIRED

This method is expensive, time- and labour-consuming, and the use of trained excavator operators would be required for the removal of large populations. Structures for containing/

impounding the material for long-term disposal would also need to be established. The costs of physical control measures have not been quantified.

SIDE EFFECTS

There are several potential side effects, including (1) the spread of viable propagules during removal and transport of plant material (2) soil erosion associated with the creation of areas with little vegetation cover, and (3) the recruitment of new individuals from the soil seed bank and the germination of seeds of undesirable native or alien species that are typically present in seed bank communities invaded by this species (Gioria and Osborne, 2009, 2010, 2013). The disturbance created by removal efforts would create ideal conditions for the re-establishment of *Gunnera tinctoria* and the germination of other alien species or weeds (Gioria and Osborne, 2010). Addressing this issue would require long-term efforts aimed at eradicating any emerged propagule of this species, as well as the implementation of restoration measures aimed at promoting the establishment of seeds of desirable native species, while suppressing the germination and establishment of seeds of this and other alien species.

ACCEPTABILITY TO STAKEHOLDERS

Although no economic activities typically take place where this species is invasive, mainly in abandoned land and coastal cliffs, the removal of large invasive populations could be viewed negatively by the public, as large areas of unattractive bare soil would be created. The negative perception of disturbance created by removal could be mitigated by an effective communication plan, implemented before the control operations are conducted, that targets interested and affected parties as well as providing information on rehabilitation plans.

ADDITIONAL COST INFORMATION

This is the only measure that can be used to control this species in areas where the use of herbicides is prohibited. In these cases, this control option would need to be coupled with the management of seedlings establishing from the soil seed bank for it to be effective in the long-term.

Where their use is permitted, herbicides represent a most cost-effective measure to control this species (see below). Removal efforts are regarded as too costly for long-term, sustainable control and management.

LEVEL OF CONFIDENCE[1]

Low.

These considerations are based on the results of small-scale, short-term trials for this species (Williams *et al.*, 2005; Botelho and Peñil, 2013). The long-term effectiveness of this method has not been examined due to practical difficulties and its unsuitability for controlling mature populations in wet habitats, where this species is often invasive (Armstrong, 2008).

1 See Appendix

Chemical control.

MEASURE DESCRIPTION

This measure involves spraying whole plants (foliar spray) or rhizomes with herbicides.

Foliar herbicide applications can be undertaken under most circumstances. It can be highly effective if repeated over time and is the least labour intensive among herbicide application methods. This measure has proved to be effective at reducing the standing biomass of this species in the Azores, Ireland, Scotland, and New Zealand, particularly when treating large areas (Silva *et al.*, 1996; Williams *et al.*, 2005; Armstrong, 2008; Botelho and Peñil, 2013; Cumming, 2015; Raal P., pers. comm.).

EFFECTIVENESS OF MEASURE

Glyphosate

The use of glyphosate towards the end of the growing season has shown moderate efficacy for the control of *Gunnera tinctoria* in Ireland (Armstrong, 2008). Its effectiveness depends on several factors, including the age of the plants (Williams *et al.*, 2005) and the timing of the application (Williams *et al.*, 2005; Armstrong, 2008). Young plants can be readily killed by glyphosate but the control of mature plants requires the application of large amounts of the herbicide (Williams *et al.*, 2005). Contrasting results have been reported in the literature, with glyphosate applications being more effective when undertaken towards the end of the growing season in Ireland and the UK (Armstrong, 2008; Cumming, 2015), presumably due to the fact that the rhizome acts as a sink for assimilates that are translocated from senescing above-ground parts at the end of the growing season (Jones and Osborne, in press). However, in New Zealand, glyphosate application has been reported to be more effective at the beginning of the growing season (Williams *et al.*, 2005). To be effective, glyphosate-based products must be applied at product maximum label rate and repeated for multiple years (4-10 years), depending upon local growing conditions, stand age and level of establishment (Silva *et al.*, 1996; Armstrong, 2008; Jones and Osborne, in press).

While foliar sprays using glyphosate is useful for reducing the standing biomass, it does not kill the rhizomes and re-growth occurs from these parts if only one application is used.

There is a reluctance to apply herbicides such as glyphosate in sensitive areas, including those with special conservation status, although it might be prudent to do this (Gioria and Osborne, 2013). Glyphosate foliar sprays should not be applied where: (1) rain is forecast within six hours; (2) stand size is small (<100 m^2) and/or (3) desirable vegetation must be maintained (cut and inject application may be undertaken, see below). Jones and Osborne (in press) recommend that only one of the two glyphosate-based methods for control of mature *Gunnera* plants should be used: (1) mid- and late growing season foliar spray application at half the label application rate (2.16 kg AE ha-1) or (2) late growing season foliar spray application at full label application rate (3.60 kg AE ha1).

Precision Helicopters using specialized lance spray equipment to treat coastal cliff sites in New Zealand. © Jim Clarkson

Triclopyr butoxyethyl (Triclopyr BEE) in an aqueous solution (Raal P., pers. comm.)

Foliar spraying of mature *Gunnera tinctoria* plants growing outside of water using triclopyr BEE as an aqueous solution has been reported to be highly effective at killing the entire plant, including the rhizome (Coombes J., pers. comm.). Full foliar cover of triclopyr BEE in water with a methylated oil or non-ionic surfactant was reported to give best results when applied during the active growth stage of the plant. When using ground-based techniques (knapsack or gun and hose), the plant foliage and rhizomes needs to be sprayed from all sides to give complete and uniform coverage to ensure effectiveness. (Herbicide recipe: 60ml Triclopyr BEE 600 g/l active ingredient, emulsifiable concentrate and 10ml surfactant in 10 litres clean water). For dense, inaccessible populations growing outside of water, helicopter boom spraying is regarded as the most cost-effective option. For single inaccessible plants growing outside of water, a helicopter fixed lance or hand-held wand system can be used to accurately and precisely treat each plant.

Metsulfuron methyl in an aqueous solution (Raal P., pers. comm.)
Foliar spraying of mature *Gunnera tinctoria* plants or spraying the emerging shoots of dormant plants using metsulfuron methyl herbicide in water has been reported to be effective at killing the entire plant, including the rhizome (Belton T., pers. comm.). This herbicide can be used in and over water in New Zealand and could provide an effective herbicide control measure under these conditions. (Herbicde recipe: 7.5 grams of 600 grams per kilogram active ingredient metsulfuron methyl in 15 litres clean water).

Triclopyr BEE in oil (Raal P., pers. comm.)
For accessible *Gunnera tinctoria* plants growing out of water, the use of 20% triclopyr BEE in a penetrating oil applied to the lower section of the rhizome may also be effective in killing the entire plant. Triclopyr BEE in oil can also be used as a foliar spray to treat emerging seedlings and exposed propagules.

EFFORT REQUIRED

Glyphosate
Multiple applications (4-10 years; Armstrong, 2008) are likely to be required with mature individuals/populations to ensure complete control to zero density of both older plants and seedlings.

Triclopyr BEE in an aqueous solution (Raal P., pers. comm.)
If applied correctly and at the right time of the year, a single application is usually enough for effective control of mature plants. However, as for glyphosate, this herbicide will need to be used in subsequent years to control plants establishing from seed.

Metsulfuron methyl aqueous solution (Raal P., pers. comm.)
If applied correctly and at the right time of the year (winter for dormant basal buds), a single application is usually sufficient to achieve effective control of mature plants. However, the herbicide will need to be used in subsequent years to control seedling establishment.

Triclopyr BEE in oil (Raal P., pers. comm.)
If used properly, a single application will kill treated plants and seedlings. Ongoing herbicide applications will be required to control plants continually establishing from seed. As there is much uncertainty with regard to the age at which this species reaches sexual maturity (at least two years but typically five years, Osborne *et al.*, 1991), the seedlings should be treated as soon as possible to avoid any risk associated with the production of viable seeds.

RESOURCES REQUIRED

Foliar spray applications of herbicides can be delivered using a range of methods, including handheld, knapsack, and large volume sprayers (Williams *et al.*, 2005; Armstrong, 2008; Cunning, 2015). Specialised applicators such as the telescopic lance should be used where plant growth is above head height and/or at sites where herbicide operator access is limited (Williams *et al.*, 2005; Jones and Osborne, in press). Except for triclopyr BEE in oil, which needs to be applied to the lower rhizome or when using metsulfuron methyl on dormant shoots of accessible plants, these broadcast herbicide methods can be used for controlling large populations (Raal P., pers. comm.). Despite requiring the use of large amounts of herbicides and the need for repeat applications over multiple years, these are often the only methods that can be used. Trained staff and specialist equipment is required to correctly and efficiently apply the herbicides in order to minimise the impact of spray drift and risks to operators.

Gunnera tinctoria control work on the South Taranaki Coast, New Zealand. © Jim Clarkson.

SIDE EFFECTS

Large amounts of herbicides that are needed to control mature plants (Williams *et al.*, 2005; Armstrong, 2008; Cummins, 2015) might have negative effects on the environment, particularly the pollution of ground water and the destruction of native vegetation. Chemical control of large populations would require the exclusion of domestic animals and cattle from treated areas, according to label recommendations. This method may not be an attractive measure for widespread use in conservation areas, given the potential negative effects on non-target species. Many established or invasive populations, however, occur at sites of low conservation value where this may not be a significant issue.

ACCEPTABILITY TO STAKEHOLDERS

No economic activities would typically be impacted where this species is established or invasive. Animals would need to be excluded if herbicides other than glyphosate are used.

Wind direction and the potential effects of drift on people and animals must be carefully examined before each application. Spraying significant amounts of herbicides

over large areas could encounter opposition from local communities. Such opposition could be addressed by the development of a communication plan on the control of this species that is customised to address the concerns of interested and affected parties.

ADDITIONAL COST INFORMATION

Broadcast herbicide control measures are the most cost-effective for the control of large populations occurring outside of water (Williams *et al.*, 2005; Armstrong, 2008; Cumming, 2015).

The cost of inaction will result in exponential increases in the size of established and invasive populations due to the spread of seeds by anthropogenic means, water, or birds, as well as by vegetative propagation, which seems to be the more likely means of population expansion after initial establishment by seeds (Gioria and Osborne, 2013). Hickey (2002) recorded a mean annual increase in rhizome length of 15 cm per year (range 2–24 cm) for an invasive population in Ireland, which means that the expansion of existing populations can occur very rapidly under suitable conditions. The rapid increase in the size and density of a population will cause a reduction in the diversity and composition of the native flora, including long-term changes in the soil seed bank (Gioria and Osborne, 2010) as well as ecosystem changes such as changes in biogeochemical cycles (Gioria and Osborne, 2013).

LEVEL OF CONFIDENCE[1]

High. This means that the information comes from published material, or current practices based on expert experience applied in one of the EU countries or third country with similar environmental, economic and social conditions.

Information on this measure is based on extensive herbicide control operations done annually in New Zealand (Raal P., pers. comm.). The effectiveness of triclopyr BEE and metsulfuron methyl aqueous solutions and triclopyr BEE in oil for control of mature plants has been established. However, due to the recruitment of new individuals from the persistent seed bank, it is uncertain how many herbicide applications will need to be carried out. As most populations in the invaded range occur in highly disturbed habitats, it is unlikely that there will be any significant negative impact of using this measure on resident communities and ecosystems.

EU/national/local legislation on the use of plant protection products and biocides needs to be respected. New restrictions on the use of glyphosate within the EU were recommended in June 2016, when the Commission granted an 18-month extension to glyphosate's authorisation in the EU until the European Chemical Agency issues its opinion. The Commission has presented to Member States three recommendations on the use of glyphosate: (1) a ban of a co-formulant (POEtallowamine) from glyphosate-based products; (2) minimise the pre-harvest use of glyphosate; and (3) minimise its use in specific areas, such as public parks, playgrounds and sports grounds (European Commission, 2016). Additional restrictions have been placed by some Member States, which bans its use in parks, gardens, along roadways and railways; in urban areas, sports fields and recreational areas; in playgrounds and green areas within school grounds; and in areas adjacent to health facilities. The use of this control method in the future will depend upon the approval of the use of glyphosate within the EU.

1 See Appendix

Combination of chemical and mechanical control.

MEASURE DESCRIPTION

This measure can only be used on accessible plants. It involves cutting petioles and inflorescences and either painting (Cut and Paint, C&P) or injecting (Cut and Injection, C&I) herbicides (glyphosate or triclopyr triethylamine salt) directly into the rhizome or via the cut surfaces (Williams *et al.*, 2005; Armstrong, 2008; Jones and Osborne, in press; Raal P., pers. comm.).

EFFECTIVENESS OF MEASURE

The effectiveness of C&P and C&I management measures using glyphosate-based products was tested in western Ireland (Armstrong, 2008) and in New Zealand (Williams *et al.*, 2005). Armstrong (2008) showed that both approaches resulted in the death of the standing biomass over the first year of application. However, the effectiveness of this measure is low if repeat applications are not made. Re-growth after C&P was more vigorous than C&I (Armstrong, 2008). Information on how long these measures would need to be repeated is unknown. The C&P technique was the most effective control method used to treat large invasive populations on coastal cliffs in New Zealand, although re-growth of large rhizomes was observed. This implies that, to be effective, follow-up treatments are required to prevent re-growth and seedling recruitment (Williams *et al.*, 2005; Armstrong, 2008). C&P cannot be applied if rainfall is forecast within 6 hours (Armstrong, 2008), but is cost-effective compared to C&I, requiring smaller quantities of dilute herbicide (Armstrong, 2008). In Ireland, Jones and Osborne (in press) recommended (1) late growing season C&P application at full label application rate (3.60 kg AE ha-1) or (2) late growing season C&I application at full label application rate (3.60 kg AE ha-1). In New Zealand, Williams *et al.* (2005) described a similar C&P method, with cut petioles and inflorescences being sprayed with 25 % v/v glyphosate solution. Reduction of above ground *Gunnera* growth using this method was highly effective (95 %) (Williams *et al.*, 2005).

Trials are underway in New Zealand to test the stem injection method using a specialist tool and the triclopyr triethylamine salt as the herbicide (P. Raal, pers. comm.). This method appears to be promising, showing that the amine salt is readily translocated to the growing tips throughout the plant. It is unsure at this stage whether the entire rhizome will die. As with glyphosate, the removal and/or spraying of seedlings that might become established from the soil seed bank is still required.

EFFORT REQUIRED

Immediate control of treated plants can be expected. However, this measure should be followed by measures aimed at preventing regeneration from the rhizome and recruitment from the soil seed bank over an extended period of time (at least 4-10 years; Armstrong, 2008).

RESOURCES REQUIRED

This method is highly time and labour-consuming, thus high costs are expected for the control of large populations, although these costs have not been properly quantified.

SIDE EFFECTS

There are several potential side effects. Negative effects on non-target species are expected, although accurate and precise applications under conditions where runoff is unlikely to occur are likely to reduce the probability of occurrence of such effects. Glyphosate is immediately neutralised upon contact with inorganic material, which further minimises the impact on non-target plants. Triclopyr triethylamine salt is rapidly absorbed into the plant resulting in little, if any, spillage. Animals would need to be excluded where herbicides other than glyphosate are used. This measure could be problematic for the control of large populations, of if these are close to waterways, or in conservation areas, unless precisely applied.

ACCEPTABILITY TO STAKEHOLDERS

No economic activities are likely to be impacted and the largest established or invasive populations are reported from abandoned land and coastal cliffs. The risk that sheep and domestic animals may come into contact with the herbicides applied may be minimised by excluding them or, in the case of glyphosate, by covering the cut parts with the leaves that had been removed by cutting (Cumming, 2015).

ADDITIONAL COST INFORMATION

This method is significantly more expensive than the foliar spraying methods described above. Herbicide treatment of the rhizomes using triclopyr BEE in oil or the treatment of dormant shoots in winter would be more rapid than either the C&P or C&I methods. However, the costeffectiveness of this measure compared to other measures in areas where it can be carried out has not been quantified.

LEVEL OF CONFIDENCE[1]

Medium.

1 See Appendix

EU/national/local legislation on the use of plant protection products and biocides needs to be respected. As pointed out for foliar spray control methods, new restrictions on the use of glyphosate within the EU were recommended in June 2016, when the European Commission granted an 18-month extension to glyphosate's authorisation within the EU until the European Chemical Agency issues its opinion. The Commission has presented to Member States three recommendations on the use of glyphosate: (1) a ban of a co-formulant (POE-tallowamine) from glyphosate-based products; (2) minimise the pre-harvest use of glyphosate; and (3) minimise its use in specific areas, such as public parks, playgrounds and sports grounds (European Commission, 2016). The use of glyphosate in chemical or combined mechanical-chemical control in future will depend upon its approval within the EU.

Inflorescences in a Chilean rhubarb. © Archive of Institute Symbiosis.

Soil seed bank control by promoting seed germination.

MEASURE DESCRIPTION

Managing the soil seed bank requires the implementation of a range of measures aimed at promoting the recruitment of new individuals so that they can be destroyed. This can be achieved by promoting seed germination via soil disturbance and by bringing seeds close to the surface, so that they are exposed to light (seeds have a light requirement for germination; Gioria and Osborne, 2013). Once germinated, the resulting seedlings could be controlled by foliar spraying with herbicide or be physically removed. The aim is to exhaust the seed bank in the shortest possible time (Gioria *et al.*, 2017). The use of solarisation to effectively kill the seed bank of this species has not been tested, but it is possible that it might be successful if it is used to promote seed germination (rather than to kill seeds), thus contributing to the depletion of the seed bank. This measure can only be used in accessible sites.

EFFECTIVENESS OF MEASURE

The control of the seed bank is an essential requirement for the sustainable management of this species. The seed bank of this species can be classified as long-term persistent (*sensu* Thompson *et al.*, 1997) as seeds are capable of retaining their viability for over five years (Gioria and Osborne, 2009, 2013). Thus, recruitment from the seed bank will prevent the eradication of this species from established or invasive populations comprising sexually mature plants. A capacity to form long-term persistence seed banks composed of a large number of viable, long-lived seeds (10,000-100,000 seedlings m^{-2}) with an ability to germinate when conditions for the breaking of dormancy and germination are met (Gioria and Osborne, 2009, 2013), including human-associated disturbances, argues for a more holistic and longer-term management approach.

No attempts have been made at controlling the soil seed bank of this species. What is known is that recruitment from the seed bank is a major source of recruitment of new individuals at sites where physical and chemical control methods have been applied. It must be expected that the management of sites where a seed bank has been accumulated over time will require long-term investment. This measure will only be effective if all sexually mature plants that are contributing to the seed bank are destroyed before employing this technique.

EFFORT REQUIRED

No reliable information is available on the time required to successfully exhaust the seed bank of this species or how long the seeds are viable. Available information from experiments carried out under greenhouse conditions suggests that a large number of seeds still germinate two years after seed collection (Gioria and Osborne, 2009). This, combined with the long-term persistence of seeds in the soil, make the management of the seed bank and the removal of new seedlings for several years a major requirement of any successful control strategy (seeds remain viable in the soil for at least five years but probably much longer; Gioria and Osborne, 2013) in areas where this species has been controlled as well as in areas where seeds could have been dispersed. Gioria and Osborne (2009) have shown that uninvaded areas adjacent to those with established populations of *G. tinctoria* supported a relatively small but persistent soil seed bank (on average, 600 seeds per square metre).

Understanding the conditions that prevent seeds in the seed bank from germinating (for example, depth profile information) would be beneficial for the effective management of this species. Such knowledge would provide guidelines for management purposes, including how recruitment from the seed bank may vary at specific localities and for different habitats, how long seeds retain their viability, and how this is influenced by climatic, environmental, and habitat-related factors.

To promote the recruitment of native species, seeds of desirable species should be sown and germination timing should be manipulated to occur before germination of the seeds of this species. This this would allow seeds of desirable species to germinate when competition for resources is low, so that their early growth might promote asymmetric competition and suppress the establishment of seeds of *G. tinctoria* (Gioria *et al.*, 2017). Also, highly disturbed sites are often invaded by other undesirable species, which will also need to be managed.

RESOURCES REQUIRED

There is no information on the potential costs of this measure, but it would require soil disturbances to be applied a few times during the growing season, as well as in autumn for 2 or more years (for instance before they can become sexually mature) after they germinate.

SIDE EFFECTS

This measure would require regular disturbance and the maintenance of bare ground until seeds of *Gunnera tinctoria* are considered to have emerged or to be no longer viable. There are potential negative consequences of this approach due to the likely visual impact and the increased risks of erosion and nutrient leaching particularly in unstable locations or in areas subjected to high rainfall.

ACCEPTABILITY TO STAKEHOLDERS

This measure is not likely to negatively affect any economic

activity, as this species grows largely in abandoned land or in disturbed areas. Measures that specifically target the seed bank after the removal of standing vegetation would also reduce/eliminate any additional post-treatment costs and/or the costs associated with the removal of soil prior to building or other developments.

ADDITIONAL COST INFORMATION

There is no information on the feasibility of this approach or on its costs. Costs are expected to be high, as this approach would require frequent disturbances throughout the growing season, for multiple growing seasons.

Using the alternative approach of removing large quantities of contaminated soil would, in most cases, be impractical, and the costs prohibitive. There would also be significant negative impacts on native biodiversity, the environment, and aesthetics.

The cost of inaction is associated with the risk of juvenile plants reaching sexual maturity and further contributing to the seed bank. If this is allowed to occur, the success of any measure aimed at the long-term control of established or invasive populations would be compromised. As seeds persist in the soil for several years and are present in the order of thousands per square metre in invaded sites, this would mean that long term monitoring programmes aimed at controlling newly recruited plants would need to be carried out.

LEVEL OF CONFIDENCE[1]

Low.

This approach has been recommended at the theoretical level, but has never been tested.

EU/national/local legislation on the use of plant protection products and biocides would also need to be respected.

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.

- **High:** Information comes from published material, or current practices based on expert experience applied in one of the EU countries or third country with similar environmental, economic and social conditions.
- **Medium:** Information comes from published data or expert opinion, but it is not commonly applied, or it is applied in regions that may be too different from Europe (for example tropical regions) to guarantee that the results will be transposable.
- **Low:** data are not published in reliable information sources and methods are not commonly practiced or are based solely on opinion. This is for example the case of a novel situation where there is little evidence on which to base an assessment.

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