The vine-like fern is a vine like perennial that climbs over trees and other structures. © Eric Guinther. CC BY-SA 3.0

The management of vine-like fern (*Lygodium japonicum*)

Measures and associated costs

Scientific name(s)	*Lygodium japonicum* (Thunb.) Sw
Common names (in English)	Vine-like fern
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Date of completion	04/10/2018
Citation	Bohn, K.K. 2018. Information on measures and related costs in relation to species included on the Union list: *Lygodium japonicum*. Technical note prepared by IUCN for the European Commission.

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Common names

BG	–
HR	Japanska kovrđžava paprat
CZ	–
DA	Japansk klatrebregne
NL	Japanse klimvaren
EN	Vine-like fern
ET	Jaapani ronisõnajalg
FI	Kampakiipijäsaniainen
FR	Fougère grimpante du Japon
DE	Japanischer Kletterfarn
EL	Ιαπωνική αναρριχόμενη φτέρη
HU	–
IE	Raithneach dhreaptha Sheapánach
IT	Felce rampicante del Giappone
LV	Japānas ligodija
LT	Japoninis ligodis
MT	Il-felċi x-xeblieka tal-Ġappun
PL	Wężówka japońska
PT	–
RO	Feriga cățărătoare japoneza
SK	Popínavec japonský
SL	Japonska vzpenjava praprot
ES	Helecho trepador japonés
SV	Japansk klätterbräken

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

Lygodium japonicum (vine-like fern) is a broadleaved, herbaceous perennial vine and true fern which is native to much of south-eastern Asia, through India and as far south as Papua New Guinea (Uddin *et al*., 1997, – as cited in CABI, 2017; Maideen *et al*., 2004; Singh *et al*., 2012; Lindsay and Middleton, 2013; Chang *et al*., 2014; Flora of China Editorial Committee, 2014). It was introduced outside of its native range on several continents. North American establishment was first recorded in the early 1900's in the State of Georgia (Clute, 1903), where it was introduced as an ornamental plant (Clarke, 1936; Correll, 1938). *L. japonicum* has since spread throughout the south-eastern USA. In addition to North America, it has also been recognized as an introduced species in South Africa (Henderson, 2007), Singapore (Chong *et al*., 2009) and Australia, where it is classified as an environmental weed (Orchard and McCarthy, 1998; Hosking *et al*. 2011).

Where introduced in the USA, *L. japonicum* occupies a broad range of natural and disturbed habitats. While *L. japonicum* has a strong preference for moist soils it can sometimes occupy xeric sites (van Loan, 2006). It is invasive in diverse habitats throughout the southeastern USA ranging from floodplain forests, swamps, marshes, river and stream banks, to pine flatwoods, hardwood hammocks, and upland woodlands (Wunderlin and Hansen ,2003; van Loan, 2006; Miller *et al*., 2010). It commonly invades disturbed areas, including along roads and particularly ditches and culverts. *L. japonicum* can smother groundcover and shrubs, leading to a reduction in the abundance of native species within a local ecosystem (Bohn *et al*., 2011; Leichty *et al*., 2011). It has been documented to reduce native plant richness in both mesic and upland pine ecosystems of the U.S. (Ulrich, 2012). It also can climb trees, creating dense patches that limit photosynthesis of tree leaves or needles. In South Africa, it has been found in moist forest, scrub and road edges, and in Australia it has been documented outside of its cultivated area in wet forests and riparian areas (CABI, 2017). It is expected it would invade similar ecosystems in Europe, in areas with climate suitable to its development.

Across its native range, *L. japonicum* tolerates subtropical to tropical conditions with both wet and dry seasons (Koppen-Geiger climate codes Af, Am, and Aw; Kottek *et al*., 2006), and prefers warm temperate conditions that are fully humid with warm to hot summers. Predictive models of a risk assessment of *L. japonicum* (EPPO, 2017) currently show most suitable climates to be in Spain (Canary Islands), Portugal (the Azores), France, Italy and coastlines of the Adriatic and Black Sea (Turkey, Georgia and Russia). However, climate change models do suggest that much of central and northern Europe is predicted to become suitable, potentially allowing substantial establishment within the Atlantic, Continental, Black Sea, Mediterranean and Boreal biogeographical Regions (including: Portugal, France, Germany, the Netherlands, Belgium, Austria, Hungary, Czech Republic, Great Britain, Poland, Lithuania, Latvia, Italy, Croatia, southern Sweden and Denmark).

Prevention of primary pathway: The primary pathway for introduction of *L. japonicum* into the European Union is through the ornamental trade industry, either intentionally through direct breeding and selling of plants, or unintentionally as a contaminant in the soil or growing medium of other plants for planting. In fact, in the Netherlands gametophytes (small germinants) of *L. japonicum* have been detected in growing media of bonsai plants imported from China (J. van Valkenburg, pers. comm., 2017) on more than one occasion.

Therefore, the primary methods for preventing its intentional introduction would be a ban on keeping, importing, selling, breeding and growing this plant. Although a recent web search suggests some limited trade of this species, it is not very popular and a ban would likely not have a significant economic impact on the ornamental trade industry. Prevention of unintentional spread, through the importation and movement of gametophyte contaminants in soils of other plants for planting would require inspection of imported ornamental plants, particularly from facilities where ornamental *L. japonicum* is grown, or from outdoor nurseries in countries where *L. japonicum* is native (Asia) or invasive (southeastern United States, Australia). Inspections can be costly, though made cost-effective by incorporation into an overall inspection plan for Invasive Alien Species. Awareness campaigns to both the industry and buyers may also be a cost-effective method of prevention. Note also that the EPPO recognizes the introduction of *L. japonicum* via transport on imported equipment/machinery from invaded countries as a potential unintentional pathway into the E.U., though this has not been detected or documented thus far.

Prevention of secondary pathway: Prevention of the secondary spread of *L. japonicum*, if established in natural areas within the E.U., would include inspection and cleaning of clothing, equipment, and machinery used in invaded sites, particularly during periods where *L. japonicum* is reproducing. Spores adhere readily to soil, water, and clothing, and plant fragments have been noted to become lodged in equipment and machinery.

Early Detection: Scouting and monitoring of sentinel sites by natural resource professionals and/or in combination with citizen-scientists volunteers will be necessary for early detection. As *L. japonicum* is not currently found in the E.U. outside of a few known botanical and private gardens, initial monitoring could be limited to areas just outside those known locations or near large ornamental/nursery industries from where unintentionally introduced *L. japonicum* may spread. Monitoring in larger natural areas by resource professionals should focus on ecosystems most likely to be invaded within geographical regions that have climates suitable to its establishment now or with projected climate change (see areas listed above, as defined by projections in EPPO, 2017).

Rapid Eradication: Plant protection products (post-emergent herbicides) are one of the most effective and efficient ways to eradicate early stages of an infestation of *L. japonicum*. At early stages, chemicals can be applied as a directed foliar spray using hand pumps or backpack sprayers. Glyphosate applied at low rates of 2% v:v have been shown to be effective in several studies (van Loan, 2006; Minogue *et al.*, 2010; Bohn *et al.*, 2011) however it was also noted that metsulfuron methyl treatments at 0.75 g/l were least damaging to surrounding native vegetation, particularly graminoids (Zeller and Leslie, 2004). Herbicides must be applied according to manufacturer instructions and in accordance with EU and national regulations (particularly near waterways), and precautions must be applied to prevent non-target damage.

At early stages, particularly in the first year of establishment, mechanically removing *L. japonicum* is also feasible but must include complete removal of the below-ground root and rhizome system. Below-ground biomass will need to be dug out, by hand in loose soil or with a small shovel. Roots and rhizomes should be separated from soil and disposed of properly to prevent further spread, either by burning or desiccating and killing plant material in plastic bags or under tarps. Above-ground plant material with spores present should be disposed of in a similar manner.

Management: Herbicide application is the primary method by which *L. japonicum* is managed in widespread and highly invaded areas. Glyphosate at a rate between 2–4% v:v solution is recommended for large scale infestations, though metsulfuron methyl at a rate of 0.038–0.75 g/l applied may at least provide short-term (1–2yr) control. A tank mix of the two chemicals has been found to be effective for controlling both adult plants and spore viability. Mechanical treatments alone are not effective for controlling *L. japonicum*, and in fact may be more detrimental. However, cutting of large climbing vines in combination with herbicide application to the lower portion of the vine as an Integrated Vegetation Management approach has been successful for controlling some *Lygodium* species. An integrated approach of utilizing prescribed fire and herbicides has also been effective in the southeastern United States, and would be appropriate in fire-dependent ecosystems of the E.U. where prescribed fire may be utilized, such as Mediterranean pine forests and shrublands in southern Portugal, France, and Italy (Fernandes *et al.*, 2013) which are also climatically suitable for *L. japonicum*.

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 *L. japonicum*.

MEASURE DESCRIPTION

The ornamental trade has been the main pathway of introductionof *L. japonicum* on other continents where it has become invasive. It was imported for use in home gardens and landscaping in the southern United States in the early 1930's (Clarke, 1936; Correll, 1938), and for planting in botanical gardens in Australia in the early 1900's (Orchard and McCarthy, 1998). A recent internet search suggests it is available for purchase and import into the European Union (EPPO, 2017), and indications from plant exchange website forums (such as: https://davesgarden.com/community/trading/search.php) suggest the species is currently available and already exists in the European Union but to a low extent. For example, one supplier in Ireland has been highlighted as supplying the species in the past, and another supplier is also listed on the Royal Horticultural Society (GB) website.

EFFECTIVENESS OF MEASURE

Effective.

In the United States, *L. japonicum* was listed as a noxious weed in two states, Florida and Alabama, in 1999. This measure has been effective at stopping the selling, growing, and importation of new plants into these states; however the listing occurred well after this species had spread aggressively throughout the southeastern U.S. Further, it is not listed as a federal noxious weed, and therefore may be purchased and grown in other nearby states.

A trade ban implemented across the European Union could be expected to be an effective measure because this species has not been widely detected or documented in the E.U. and would truly be a preventative measure. It currently only appears to be of limited interest to home gardeners. Preventing its trade and breeding as an ornamental now, before it has spread throughout the region, will be more effective than has been done on other continents. This measure will only be effective, however, if enforced across the entire E.U. region.

SIDE EFFECTS

Environmental: Neutral or mixed.

No side effects are anticipated, though preventing the intentional introduction of *L. japonicum* into the E.U. would be a key measure to limit the potential for it to establish in and impact natural areas.

Social: Neutral or mixed.

L. japonicum is recorded as having medicinal value in its native range. For example, it is used as a diuretic in China and for treatment of colds, inflammation, and renal ailments; and in India to treat snakebites, diabetes, and ulcers (Puri, 1970; Eisenberg *et al.*, 2009; Yumkham and Singh, 2011 – as cited in CABI, 2017). However, no conclusive evidence of its health benefits has been documented except for it having several antioxidants (Duan, 2012). In the E.U., it appears to be purchased primarily for ornamental use, and a ban on trade, breeding, and growing, would only have limited or neligible social impact.

Economic: Neutral or mixed.

Costs associated with enforcing a ban on trade, breeding, or growing would likely offset any cost associated with treatment of this species were it to escape and establish throughout the E.U. (see *Eradication* and *Management* sections for cost of *L. japonicum* treatment). Because *L. japonicum* is not widely sold or traded as an ornamental plant, a ban on this species would have little economic side effects on the ornamental/horticulture industries.

ACCEPTABILITY TO STAKEHOLDERS

The social and economic impact on the ornamental plant industry is expected to be low since a recent review of plant forums and websites suggest is has only been sought after and sold in small quantities. Additionally, nursery professionals have become more cognizant of selling plants that have been identified as invasive, and increasingly are willing to forego importation, breeding, and selling of those plants, (Burt *et al.*, 2007), particularly when those plants are not a major economic commodity such as is the case with *Lygodium japonicum*.

ADDITIONAL COST INFORMATION

As stated above, costs associated with enforcing a ban on trade, breeding, or growing would likely more than offset any cost associated with treatment of this species were it to escape and establish throughout the E.U. Exact costs for enforcement of a ban in the E.U. are unknown. Providing awareness of this species to the ornamental trade industry and emphasizing internal voluntary compliance could increase cost effectiveness in terms of insuring or enforcing compliance with the ban through monitoring and inspections.

LEVEL OF CONFIDENCE[1]

Well established.

It is expected that regulations to ban importing, selling, breeding and growing this plant would be effective as a means to prevent additional introductions into the E.U.

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.

Awareness campaigns targeted at both ornamental industries (growers and sellers) and to the general public or gardeners in particular (buyers), about the invasive potential of *L. japonicum*, is another measure that could help prevent new intentional and unintentional introductions and spread. Advising or providing training to industry professionals regarding best management practices to restrict trade *of L. japonicum* and to dispose of plant growing medium unintentionally contaminated with *L. japonicum* could be incorporated into this measure. Education and awareness campaigns to the general public could include fliers, announcements, or other educational materials specifically focusing on *L. japonicum* or incorporated into existing materials educating the public about invasive plants in general.

EFFECTIVENESS OF MEASURE

Effective.

Awareness of biosecurity issues has been identified as one of the top 20 priorities for invasive species awareness in the European Union (Caffrey *et al.*, 2014). Few studies have documented the impact and effectiveness of awareness campaigns at limiting intentional introductions of invasive species; though one recent study of the aquatics trade (Verbrugge *et al.*, 2014) suggests that retailers are more likely to be aware and act on the need to control potential impacts of invasive species than buyers. This suggests that additional education and outreach may be needed for the latter stakeholders.

It is more difficult to assess the effectiveness of awareness campaigns regarding limiting unintentional introductions through contaminants. Even with awareness and education, effectiveness would more likely be related to the frequency of inspections and ability to detect *L. japonicum* within other plants or in plant growing mediums.

SIDE EFFECTS

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

One potential positive side effect would be that those targeted by any awareness raising activities, may become more aware of invasive alien species in general, and therefore the measure may potentially reduce the risk of introductions of other species.

ACCEPTABILITY TO STAKEHOLDERS

Both the trade industry and general public are becoming more aware of the impact of invasive alien plants and are generally willing to learn more about non-native plants. As noted in the *Effectiveness* section above, consistent outreach and education through awareness campaigns may be needed to change behaviour.

LEVEL OF CONFIDENCE[1]

Established but incomplete.

While awareness campaigns are generally received positively, few studies have evaluated the degree to which such campaigns lead to the reduction in trade or unintended introductions in comparison to other efforts such as regulations or inspections.

1 See Appendix

Inspection of the growing medium of other species imported as plants for planting.

MEASURE DESCRIPTION

L. japonicum spores are small, ranging in size from 64–80 µm, and readily disperse by wind. In nurseries where *L. japonicum* is grown alongside other plants, or where plants are grown outdoors in the vicinity of naturally occurring *L. japonicum*, spores have been known to disperse and germinate in the growing medium of other plants. Spores may also remain viable for several years. In the Netherlands, gametophytes (known as young germinants) have been detected in growing media of bonsai plants imported from China (J. van Valkenburg, pers. comm., 2017) on more than one occasion. Contaminated soil of other plants for planting may therefore act as a pathway for its unintentional introduction and spread into natural areas within the E.U. In the United States, *L. japonicum* spores, as well as reproducing vegetative rhizomes, have also been known to be unintentionally spread in contaminated mulch products. While spores themselves may be undetectable, inspection of growing medium or mulch of other plants for *L. japonicum* gametophytes or sporophytes might be an effective method for limiting unintentional introductions and spread.

SCALE OF APPLICATION

To be effective inspection of plants for planting for possible *L. japonicum* contaminant would be required across.

EFFECTIVENESS OF MEASURE

Neutral.

The Florida Department of Agriculture and Consumer Affairs has effectively restricted and regulated the movement of *L. japonicum* plant parts from landscaping materials such as mulch that is transported into and throughout the state. The greatest efficacy has been in detecting root fragments or live fronds interspersed with other landscaping material. The ability to inspect all plants entering the E.U. and to detect small germinants of *L. japonicum* is likely challenging because of the small size of the germinants, and it is very likely spores will not have germinated during the shipment

L. japonicum *reproduces via spores and spreads vegetatively via underground rhizomes. © Keisotyo. CC BY-SA 3.0*

period and initial entry into the E.U. To be effective this measure would require thorough and continual inspection over at least 6–8 weeks (Ulrich, 2012).

EFFORT REQUIRED

Inspection of all plants for planting must be done indefinitely across the entire E.U. region for this measure to be effective.

RESOURCES REQUIRED

While the cost of initiating new inspections can often be high, where inspection of nursery stock is already occurring for other invasive plant propagules, little additional cost may be needed to also inspect for *L. japonicum*. Staff will need training on the identification of *L. japonicum* gametophytes and sporophytes.

SIDE EFFECTS

Environmental: Neutral or mixed.
Social: Neutral or mixed.
Economic: Neutral or mixed.
See information described in section above regarding *Preventing intentional spread* for similar considerations. Additionally, because of the relatively few cases in which *L. japonicum* has previously been identified as a contaminant in growing medium of other plants, the measure may have little economic impact to the ornamental and horticultural trades, in terms of disposing of contaminated product, unless regular inspections significantly increases the number of positive detections.

ADDITIONAL COSTS

The social and economic impact on the ornamental plant industry is expected to be low since a recent review of plant forums and websites suggest is has only been sought after and sold in small quantities. Additionally, nursery professionals have become more cognizant of selling plants that have been identified as invasive, and increasingly are willing to forego on importation, breeding, and selling of those plants, (Burt *et al.*, 2007), particularly when those plants are not a major economic commodity such as is the case with *Lygodium japonicum*.

ADDITIONAL COST INFORMATION

The cost effectiveness should be high assuming inspections for Invasive Alien Species in general are already occurring. Screening and plant-quarantines of incoming plant material that contain non-native plant contaminants has been estimated to save $1.67 billion over 50 years in Australia (Keller *et al.*, 2007), though it is unclear what the actual cost benefits would be in the E.U. for this particular species. The payoff could be high if potential unintentional introductions are prevented; however, it is difficult to know or quantify how many cases where unintentional introductions of *L. japonicum*, particularly as gametophytes, could be detected as a contaminant in growing medium on other plants imported into the E.U.

LEVEL OF CONFIDENCE[1]

Established but incomplete.
Inspection of plants for planting has been successful for detecting other known pests, but there has been no documentation of its efficacy for *L. japonicum*.

1 See Appendix

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

Inspection and cleaning of machinery, equipment and clothing.

MEASURE DESCRIPTION

L. japonicum plant parts, including fertile fronds or roots/rhizomes, have been detected on both clothing and equipment of workers treating invaded areas (Hutchinson and Langeland, 2006). Inspection and cleaning of machinery, equipment, and clothing may therefore limit secondary spread by humans from invaded to non-invaded areas. This measure could apply to both professional settings (for example where agriculture or forestry is practiced) as well as in recreational areas (for example hiking boots, bike or ATV tires). Cleaning of equipment and machinery is typically done by pressure washing to ensure that soil and plant parts are removed from any part of the equipment. This can be done on-site or at designated cleaning stations. Another common practice for both professionals and in recreation areas is the use of boot brushes to remove dirt and plant parts on-site.

SCALE OF MEASUREMENT

Guidelines for Best Management Practices (BMPs) and/or specific protocols for inspecting and cleaning equipment and clothing for invasive species typically occurs within an agency/industry, or at region (state-level) and national scales. The actual implementation of these BMPs would have the most environmental impact at local and possibly region scales, depending on the distance at which equipment and machinery is typically moved.

EFFECTIVENESS OF MEASURE

Effective.

Best management practices for various industries, including agriculture and forestry, are more commonly recommending sanitizing equipment and clothing for limiting the spread of many invasive plants, including *L. japonicum* (Ledoux and Martin, 2012). However, there has been very little research to evaluate or quantify the effectiveness and efficiency of cleaning equipment as a means of preventing the secondary spread of invasive plants by human. As *L. japonicum* spores can be transported naturally by wind and water over several kilometres (Ferriter, 2001) this measure would be most effective as a means of preventing spread to non-contiguous uninvaded areas at a greater distance.

Additionally, to be an effective measure in areas where *L. japonicum* is reproducing, any run-off from cleaned equipment/machinery must be contained on-site as spores will readily disperse in water.

EFFORT REQUIRED

Because *L. japonicum* is absent from natural areas in the E.U., these efforts are not an immediate need for *L. japonicum* but should be suggested in context to preventing the secondary spread of a large number of existing invasive plants in the region. Additionally, equipment and machinery that may be imported from countries/continents where *L. japonicum* is native (such as Asia) or invasive (southeastern United States, Australia, or South Africa) should be considered for inspection and/or sanitation before used in natural areas throughout the E.U., particularly in climates suitable to *L. japonicum* establishment (addressing unintentional introductions). It is only recently that an ISPM Standard, no. 41 (IPPC, 2017) has been drafted and adopted on 'International movement of used vehicles, machinery and equipment'. This focuses on reducing the risks of transporting contaminants (soil, seeds, plant debris, pests) associated with the international movement (either traded or for operational relocation) of vehicles, machinery and equipment (VME) that may have been used in agriculture, forestry, as well as for construction, industrial purposes, mining and waste management, and military.

In areas where *L. japonicum* has established, these measures must be applied indefinitely or up to 5 years after the plant has been removed from its introduced location since spores may remain viable under certain conditions for that length of time.

RESOURCES REQUIRED

Pressure washing equipment in a quarantined area and staff to conduct inspections would account for the greatest costs in implementing this measure. Boot brush stations and bike cleaning stations are more regularly being installed in many parks and recreation areas.

SIDE EFFECTS

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

The measure will address other potential invasive alien species that could also be introduced via the same pathway. There are likely no substantial negative side-effects of this measure, aside from the additional costs identified in the *Resources* section. Additionally, as stated in the *Effectiveness* section, care must be given to collect and dispose of any potentially contaminated run-off from cleaned equipment or clothing to prevent spread into nearby locations.

ACCEPTABILITY TO STAKEHOLDERS

Professional stakeholders may be hesitant to implementing such measures depending on the associated costs and location of cleaning facilities, which might introduce transportation costs. The general public or recreation users may also be ambivalent about the use of cleaning stations. However, both stakeholder groups may become more compliant with this measure through additional training, awareness and education.

LEVEL OF CONFIDENCE[1]

Unresolved.

Best management practices for invasive plants such as cleaning clothing and equipment are just gaining wider usage, but few studies have quantified their impact on reducing spread of invasive plants from introduced locations to new, uninfested areas and at what distances this measure is most effective.

1 See Appendix

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

Early detection monitoring of sentinel (high risk) sites by natural resource professionals.

MEASURE DESCRIPTION

Early detection is often a key measure in preventing the ecological and economic harm to ecosystems associated with larger infestations. Monitoring can be incorporated into day-to-day activities of natural resource professionals. Because *L. japonicum* is not established in natural areas in the E.U. yet, the most efficient implementation of this measure would be to limit monitoring to high risk ecosystems in areas with climates suitable to its establishment. In its invaded range, *L. japonicum* tends to be most problematic in wetter ecosystems such as floodplain forests, swamps, marshes, river and stream banks, but it can invade upland pine and hardwood forests as well (Wunderlin and Hansen, 2003; van Loan, 2006; Miller *et al.*, 2010). It commonly first invades disturbed areas, including along roads and particularly ditches and culverts.

Additionally, across its native range, *L. japonicum* tolerates subtropical to tropical conditions with both wet and dry seasons (Koppen-Geiger climate codes Af, Am, and Aw, Kottek *et al.*, 2006) and prefers warm temperate conditions that are fully humid with warm to hot summers. Predictive models of a risk assessment of *L. japonicum* (EPPO, 2017) currently show the most suitable climates across the European continent to be in Spain (the Canary Islands), Portugal (the Azores), France, Italy and coastlines of the Adriatic and Black Sea. However, climate change models do suggest that much of central and northern Europe is predicted to become suitable, potentially allowing substantial establishment within the Atlantic, Continental, Black Sea, Mediterranean and Boreal biogeographical Regions (including: Portugal, France, Germany, the Netherlands, Belgium, Austria, Hungary, Czech Republic, Great Britain, Poland, Lithuania, Latvia, Italy, Croatia, southern Sweden and Denmark).

SCALE OF APPLICATION

Early detection programs have been applied at a variety of scales from the local to regional, the latter particularly so when implemented as a collaboration between multiple organizations and incorporating citizen-science (see next section). For example, in the United States, "Cooperative Invasive Species Management Areas" can range in size from several hundred to tens of thousands of square kilometres, and often utilize web mapping tools to record observations across a large area. Individual organizations can also work at the scale of their individual land ownerships.

EFFECTIVENESS OF MEASURE

Effective.

Early detection has the potential to be highly effective. Though not evaluated for *Lygodium*, some case studies report that early detection of just small patches of invasive species and rapid response led to eradication in just 2 years, in contrast to a several year delay elsewhere that resulted in spread to thousands of hectares (Simberloff *et al.*, 2013). Effectiveness will depend on consistency of monitoring and ability to positively identify *L. japonicum* as it first establishes. Early detection is critical as this species can increase by 20–30% cover in one year, and fronds can have reproductive spore production rates of 5,900 spores per square cm within the first year (van Loan, 2006).

EFFORT REQUIRED

While it would be challenging and time consuming to identify gametophytes (new germinants) in a natural ecosystem, adult foliage of *L. japonicum* should be relatively easy to identify since no other fern species grow as a vine plant form. Additionally there are no other native *Lygodium* species in Europe with which it could be misidentified. Because above ground fronds of *L. japonicum* die back after multiple frosts, monitoring can be limited to once a year during the early part of the active growing season but preferably before spore production in order to initiate rapid eradication treatments. In the U.S., and in sub-temperate climates, the best period for monitoring would be between late May and early July.

As stated previously, because *L. japonicum* is not currently found in the E.U outside of a few known botanical and private gardens, monitoring in natural areas can be restricted to key ecosystems in geographical regions with climates suitable to its establishment now or with projected climate change (see areas listed above, as defined by projections in EPPO, 2017).

RESOURCES REQUIRED
No additional staff or equipment would be needed to carry out early detection monitoring, although it would require additional hours of labor. Monitoring for this species may be incorporated with monitoring of other invasive species or integrated into other environmental data collection that is done routinely.

SIDE EFFECTS
Environmental: Neutral or mixed.
Social: Neutral or mixed.
Economic: Neutral or mixed.
No side effects are expected for surveillance measures for early detection. Though a positive environmental *direct* effect will ensue if early detection AND rapid eradication occurs.

ACCEPTABILITY TO STAKEHOLDERS
Knowledge of invasive plant impacts have increased greatly in the last few decades, and most natural resource managers may already be monitoring for other species. The biggest limitation is manpower and time.

ADDITIONAL COST INFORMATION
Costs associated with scouting for a species can vary widely based on region, terrain, habitat, vegetation type and the number of species being scouted simultaneously. Often early detection surveillance by natural resource professionals is incorporated with other day-to-day activities, which can reduce the extra time and labor needed to accomplish that task. The cost of inaction may be high since the likelihood of successful eradication decreases the longer a new invasive species goes undetected. The costs of eradication also increase with time, often exponentially (Simberloff, 2003).

LEVEL OF CONFIDENCE[1]
Established but incomplete.
Early detection/rapid response programs have been evaluated for other species, and it is assumed would be effective for *L. japonicum* as well.

Early detection monitoring by citizen-scientists.

MEASURE DESCRIPTION
The use of citizen-science programs for monitoring invasive plants has gained in popularity in recent years, particularly as new technologies and use of "smart phone" apps has increased. In the context of monitoring for *L. japonicum* in Europe, citizen-scientists might best be utilized in areas not frequented by natural resource managers, or to assist resource managers in parks and recreational areas either casually or as targeted events to detect (and remove) invasive species.

Another key area where citizen-scientists could be effective would be near major nurseries or horticultural areas where *L. japonicum* may be unintentionally introduced and established, and near the few known locations where *L. japonicum* was introduced in the E.U. in private gardens and botanical gardens. Historical accounts suggest *L. japonicum* was cultivated in a number of private collections across the E.U. including in Germany, Portugal, and Italy (EPPO, 2017).

SCALE OF APPLICATION
A comprehensive review of citizen-science programs across multiple continents indicate that monitoring activities range in scale from local to region (Aceves-Bueno *et al.*, 2015). In this review, 41% of all identified projects were classified as local and 57% of projects were classified as regional.

EFFECTIVENESS OF MEASURE
Effective.
Several studies indicate that citizen-science monitoring can be effective and in many cases as accurate as professional monitoring (Crall *et al.*, 2011; Gardiner *et al*, 2012; Aceves-Bueno *et al.*, 2015). Effectiveness of monitoring programs using citizen-scientists is also improved in projects where data can be 'verified' by professionals (Gardiner *et al.*, 2012).

On the region scale, citizen-science monitoring can be most efficient and effective when citizens have training and access to a web database where pictures, locations, and other descriptors can be uploaded and available across the region.

In Europe, there are a few such apps already developed, including those by the JRC European Alien Species Information Network (EASIN) as well as the UK Plant Tracker app.

1 See Appendix

EFFORT REQUIRED

L. japonicum is currently not a highly visible or recognized species so effort would be needed in terms of engaging citizens through awareness campaigns and training. If and when the species is detected in greater numbers (either as plantings or escaped) then increased effort would be needed to monitor larger areas. In this case, monitoring would need to occur consistently and in perpetuity.

RESOURCES REQUIRED

Few resources are needed by citizen-scientists themselves except smartphones, internet access, etc. where monitoring is used in conjunction with apps or web-based databases. Most mobile apps likely do not currently contain *L. japonicum*, and would need to be updated should significant monitoring on a region level be warranted. Additional staff resources and time would be needed by organizations to oversee training and coordination of volunteers as well as data verification. This could be incorporated into an overall invasive species program.

SIDE EFFECTS

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

Citizen-science can have positive effects on society by increasing engagement of the community with important issues. Awareness of the potential impacts of the species through education and training are all suggested to increase the motivation and intent of the public to engage in invasive species monitoring efforts (Crall *et al.*, 2012). A listing of current citizen-science projects can be found at European Alien Species Information Network's website at https://easin.jrc.ec.europa.eu/CitizenScience/Projects. Total costs of training and oversight of citizen-science projects can be minimized by monitoring several invasive species jointly.

ACCEPTABILITY TO STAKEHOLDERS

Generally both natural resource agencies and the public view citizen-science projects positively.

ADDITIONAL COST INFORMATION

Data collection by citizen-scientists has been documented to save money for researchers and natural resource agencies. Some estimates suggest that verified citizen-science data reduced data collection costs from $126/hour to $40/hour (Gardiner *et al.*, 2012), and another study of a forest monitoring project estimated monitoring costs were four times less using citizen-scientists (Holck, 2008).

LEVEL OF CONFIDENCE[1]

Well established.

Citizen-science programs have gained wide popularity and usage in the last few decades, and their effectiveness has also been well studied and documented.

1 See Appendix

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

Chemical control.

MEASURE DESCRIPTION

Post-emergent herbicides are one of the most effective and efficient ways to eradicate early stages of an infestation of *L. japonicum*. At early stages, chemicals can be applied as a directed foliar spray using hand pumps, backpack sprayers, or other mounted tanks and sprayers that direct application from atop an ATV or small vehicle. Directed sprayer wands can be fitted with an adjustable cone nozzle set to produce a relatively narrow (approximately 20°) cone pattern to direct the spray to very small areas. Herbicides should be applied according to manufacturer instructions and in accordance with EU and national regulations. It is important to note that EU/national/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. Some chemicals described below may be restricted in certain nations and/or certain ecosystems (particularly near water).

Herbicide treatment of *L. japonicum* fern has been investigated in multiple studies in its invaded range in the southeastern United States (Valenta *et al.*, 2001; van Loan, 2006; Minogue *et al.*, 2010; Bohn *et al.*, 2011). The effectiveness of glyphosate treatments was observed in these studies, however it was also noted that metsulfuron treatments were least damaging to surrounding native vegetation, particularly graminoids (Zeller and Leslie, 2004). Minogue *et al.* (2010) and Bohn *et al.* (2011) examined a range of herbicide types and rates for efficacy in controlling *L. japonicum* and their impact on associated vegetation in both bottomland (wet) hardwood forests and upland (xeric) pine forests. Early control of vine-like fern improved linearly as the glyphosate product rate was increased from 1 percent to 4 percent of the spray solution, though at 2 years after treatment, effectiveness of different glyphosate rates did not differ. Given that re-treatment was needed to control re-sprouting plants and new germinates, use of a 2% glyphosate solution was recommended to reduce costs and potentially avoid adverse effects to associated vegetation. Combinations of glyphosate (2% v:v) and metsulfuron methyl (at 0.375–0.75 g/l) were also effective. A non-ionic surfactant should also be used if not already incorporated into the herbicide product, except in areas near waterways, streams, and wetlands.

From operational experience, best results are obtained with application of foliar herbicides in the later stages of the growing season, from July through early October. However, studies evaluating the timing of treatments to better control spore maturation found reduced spore viability from spores collected off of adult fronds treated between July and no later than early September. Metsulfuron methyl was shown to be more effective than glyphosate for reducing spore viability on individually treated plants (Bohn and Thetford, 2014), though both herbicides applied individually or in combination similarly reduced spore viability when applied at a larger patch and stand scale (Bohn *et al.*, 2015).

SCALE OF APPLICATION

Directed foliar application by hand pump or backpack sprayer is most efficient for treating individual plants or patches at small scales of tens to hundreds of hectares. The number of hectares treated is a function of number of personnel and hours available for treatment. ATV/small vehicle mounted tanks and directed spray wands can cover larger swaths of land but require existing trails and easy access.

EFFECTIVENESS OF MEASURE

Effective.

Several studies have shown that low rates of glyphosate have resulted in 90% or greater control of *L. japonicum* up to 2 years after treatment on large infestations (van Loan, 2006; Minogue *et al.*, 2010; Bohn *et al.*, 2011). Successful (complete) eradication is possible on smaller, early stage infestations. Individual plants that were germinated from spores and grown for 2 years in contained pots were treated with glyphosate, which resulted in complete dieback of above-ground fronds with no observed resprouting from rhizome biomass 2 years after the treatment (Bohn and Thetford, 2013).

EFFORT REQUIRED

The level of effort required in early eradication would be determined primarily by the terrain and accessibility to the site and the density and distribution of *L. japonicum* patches, since directed herbicide applications are generally easy to apply on small populations. Additional effort should be made for follow-up monitoring and treatments to control vegetative resprouts or new gametophytes (germinants).

RESOURCES REQUIRED

Depending on EU and national regulations, trained (and often certified or licensed) professionals will be required to mix and apply herbicides either on public or private land. For early infestations, costs in the United States have generally ranged from $200–300/hectare (ca. €170 to €260) (Millerpers, S. pers. comm.).

SIDE EFFECTS

Environmental: Neutral or mixed.

Early eradication efforts should mostly be positive, particularly in contrast to the 'environmental cost' of doing nothing which can over time lead to reduced native plant cover. Care must be given to preventing non-target exposure to broad-spectrum herbicides vegetation as a result of drift or mis-application. However, Bohn *et al*., (2011) found that when herbicides were directed to *L. japonicum*, even when intermingling with other native vegetation, effects to non-target native vegetation was minimal. In fact, control of *L. japonicum* resulted in an increase of 20 to 35 % cover of native plants two years after 90–95% *L. japonicum* control using glyphosate, compared to an almost 25% loss in native plant cover on untreated plots.

Care must also be used when herbicides are applied near water such as in wetlands, near streambanks, or in ditches, if allowed at all under national regulation. Some formulations of glyphosate (and other chemicals) are known to cause harm to aquatic organisms, primarily from the surfactants and additives in the products (Tsui and Chu, 2003), so only herbicide formulations approved for aquatic use (as indicated on the manufacturer's label and by national regulation) should be used.

Social: Neutral or mixed.

There are few if any scientifically rigorous studies indicating side effects of small-scale herbicide applications on public health, particularly at the rates required to control early infestations of *L. japonicum*. However, herbicide applicators do need to wear appropriate personal protective equipment (PPE) such as safety glasses, gloves, and other outerwear to prevent accidental exposure to chemicals. Attention must also be paid to apply herbicides in low wind conditions to avoid accidental exposure.

Economic: Neutral or mixed.

Though there is a cost associated with eradication at early stages of establishment, it is likely far less than the cost of control efforts for widespread and heavy infestations, particularly in regard to the cost of purchasing herbicides needed for small versus large applications. Herbicide applications of small-scale infestations are quite low compared to treatment costs of large-scale infestations; often reducing costs by as much as $300/ hectare (ca. €260) (S. Miller, pers. comm., 2017).

ACCEPTABILITY TO STAKEHOLDERS

Given the efficiency and efficacy of herbicides for eradication of *L. japonicum*, most natural resource professionals, at least in countries where *L. japonicum* is already well-established and invasive, approve of the use of chemical methods. Public stakeholders maybe more wary of herbicide use, unless educated about the limited side effects with proper application.

ADDITIONAL COST INFORMATION

See comments on side-effects above for information on cost of inaction.

LEVEL OF CONFIDENCE[1]

Well established.

As noted above, there is clear evidence of the application of herbicides, particularly glyphosate and/or metsulfuron methyl.

Manual removal of the plant and its root/rhizome system.

MEASURE DESCRIPTION

For small infestations, particularly in the first year of establishment, mechanically removing *L. japonicum* may be possible but must include complete removal of the belowground root and rhizome system, since it readily spreads and resprouts by rhizomes. For plants detected in its first year of establishment, the aboveground vines can be gently pulled out or can be cut near the base if intertwined with other vegetation. Below-ground biomass will need to be dug out, by hand in loose soil or with a small shovel or trowel. Roots and rhizomes should be separated from soil and disposed of properly, either by burning or desiccating and killing plant material in plastic bags or under tarps. Above-ground plant material with spores present should be disposed of in a similar manner. This method of rapid eradication may be an alternative approach where chemical use is restricted or undesirable.

SCALE OF APPLICATION

This method of eradication is best applied at very small scale, from individual plants to small scattered patches (less than a few m^2). However total area (ha) of individual plants

1 See Appendix

that can be treated in this manner would be a function of number of personnel or volunteers available. This measure would not be effective or efficient for large-scale or heavy infestations.

EFFECTIVENESS OF MEASURE

Effective.

It is very likely that such mechanical treatments can be effective at very small scales, particularly for individual plants or very small patches. It would be appropriate for homeowners, gardeners, recreationists, and volunteers in small areas. Manual treatments would likely be less effective and efficient in larger natural areas where *L. japonicum* may be more intertwined with native vegetation and separation of *L. japonicum* roots from roots of native vegetation would be difficult. Manual treatments have typically not been used in other countries where *L. japonicum* has invaded, so there is little documentation of the effectiveness and efficiency of this treatment method, even at small scales.

EFFORT REQUIRED

As with chemical treatments, the level of effort required in early eradication would be determined primarily by the time and effort to detect small-scale patches across a site, since hand pulling, clipping, and digging out of roots is relatively easy. Additional effort would be needed for follow-up monitoring and treatments to control vegetative resprouts or new gametophytes.

RESOURCES REQUIRED

The main resource and cost will be in the personnel needed to conduct treatments (or oversee volunteers).

Other resources needed include simple tools for cutting and digging as well as bags, tarps, etc. for proper disposal of dead plant material.

SIDE EFFECTS

Environmental: Neutral or mixed.

While eradication of *L. japonicum* in the early stages of infestation will have beneficial long-term effects on native vegetation by preventing the vine from creating dense mats and smothering vegetation, there are some potential negative effects of the soil disturbance created by digging out roots as well as potential damage to native plants due to inadvertent clipping of foliage or roots where *L. japonicum* is intertwined. This negative impact would be minimal however, in very early stages where the plant is small and isolated.

Social: Neutral or mixed.

Volunteers tend to prefer mechanical treatments and derive satisfaction from removing invasive plants.

Economic: Neutral or mixed.

As with chemical treatments, there is a cost associated with eradication at early stages of establishment, but it is likely far less than the cost of control efforts for wide-spread and heavy infestations. Exact costs for small scale manual treatments are not available.

ACCEPTABILITY TO STAKEHOLDERS

Manual treatments tend to be more acceptable to the general public than herbicides and may be more appropriate for use near waterways or other sensitive areas.

ADDITIONAL COST INFORMATION

As stated in other sections, the cost of inaction in terms of potential detriment to native vegetation and habitat far exceeds the cost and effort of early eradication. There are trade-offs in cost and cost-effectiveness between manual and chemical treatments. While there is an additional cost associated with purchasing herbicides, chemical applications are also quite effective for eradication, and more so as infestations grow in size as compared to manual treatments. However, manual treatments require little training and/or licensing to implement in contrast to chemical applications.

LEVEL OF CONFIDENCE[1]

Established but incomplete.

Mechanical removal of invasive plants has been documented to be effective, though more so for shallow-rooted species (Flory and Lewis, 2009). It is assumed that as long as entire root systems are removed this will be effective for *L. japonicum* at early stages of establishment as well, but effectiveness of manual treatments has not been studied or documented.

1 See Appendix

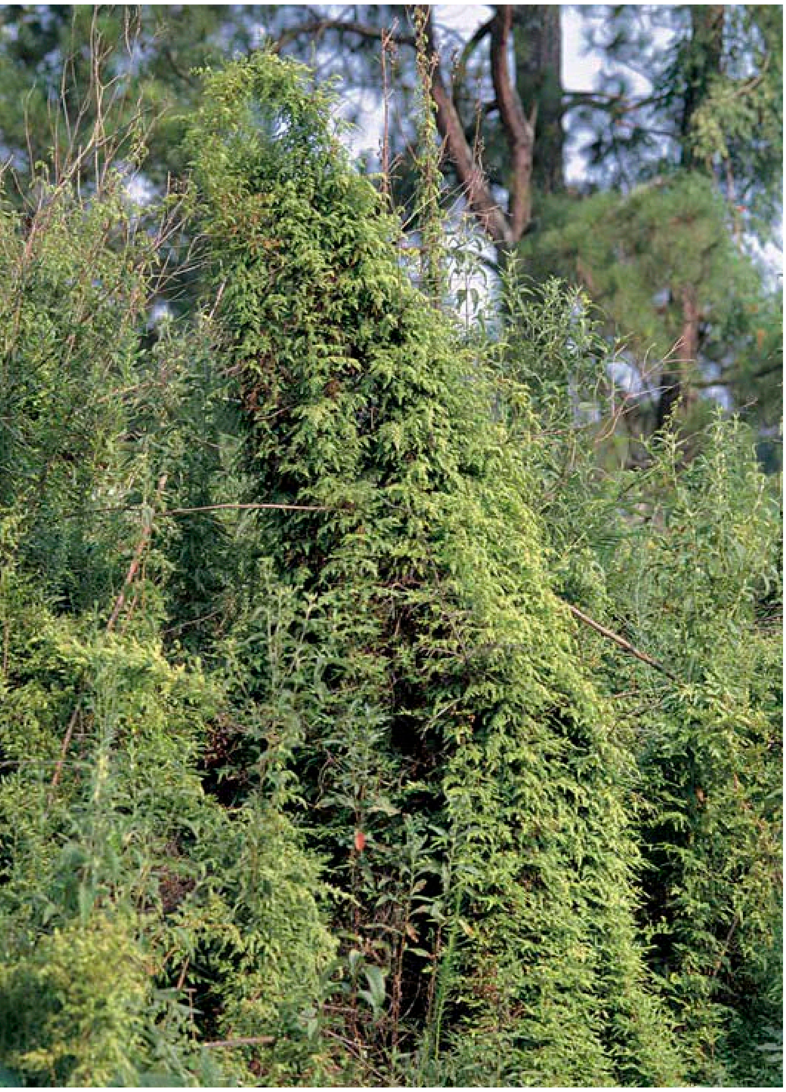
Measures for the species' management.

Application of chemicals.

MEASURE DESCRIPTION

Herbicide application is the primary method by which *L. japonicum* is managed in widespread and highly invaded areas. Glyphosate at a rate between 2–4% v:v solution is recommended for large scale infestations, though metsulfuron methyl at a rate of 0.75 g/l applied may at least provide short-term (1–2yr) control.

Broadcast applications of herbicides in wide-spread areas can be made using backpack sprayer, mist blowers mounted on ATV's or other vehicles, and even by aerial application for extensive monocultures. Herbicides should be applied according to manufacturer instructions and in accordance with EU and national regulations. It is important to note that EU/national/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. Some chemicals may be restricted in certain nations and/or certain ecosystems (particularly near water). Most critical with broadcast applications is the prevention of drift into non-target areas or onto non-target plants.



The stems of the climbing fern can grow up to 90 feet long.

SCALE OF APPLICATION

Broadcast foliar herbicide treatments can be applied at scales ranging anywhere from tens to hundreds of hectares, and the scale of application depends primarily on the amount of personnel and hours available for treatment, equipment or vehicles available, as well as terrain and accessibility to the site.

EFFECTIVENESS OF MEASURE

Effective.

Several studies have documented the effectiveness of controlling (though not eradicating) *L. japonicum* with glyphosate, or a combination glyphosate and metsulfuron methyl, at least as small plot and stand levels. In both bottomland (wet) hardwood forests and upland (xeric) pine forests where *L. japonicum* cover ranged from 40–60% prior to treatment, Minogue *et al*. (2010) and Bohn *et al*. (2011) found 90–95% reduction in cover of fern two years after treatment. However, the degree to which small-scale control studies translate to large-scale invasive plant management programs has not been well studied (Kettenring and Adams, 2011). Successful *L. japonicum* control at large scales will depend on the effectiveness of the broadcast application in making complete contact with target foliage across a wide area.

EFFORT REQUIRED

Monitoring and repeated treatments will be necessary as it often takes several treatments to kill the entire root system. Additionally, because spores may travel by wind for several kilometres, repeated treatments of new gametophytes and growth will likely be needed if *L. japonicum* is still present off-site.

RESOURCES REQUIRED

Depending on EU and national regulations, trained (and often certified or licensed) professionals will be required to mix and apply herbicides either on public or private land. Costs based on experience in the southeastern United States, from six years of data and 147 treatment records, indicate that to effectively treat and control *L. japonicum* ranges from $200 to as much as $500/hectacre (ca. €173 to €433) (S. Miller, pers. comm., 2017).

SIDE EFFECTS

Environmental: Neutral or mixed.
Social: Neutral or mixed.
Economic: Neutral or mixed.
Side effects are generally the same as those noted in the section on *Rapid eradication using chemicals*. The positive environmental effects of managing *L. japonicum* are thought to outweigh any potential non-target impacts. However, with widespread infestations and application of broad spectrum chemicals, increased diligence must be given to avoid non-target damage and/or human exposure from drift. This can be avoided with proper application rates under appropriate environmental conditions (for example – low wind) using appropriate personal protective equipment.

ACCEPTABILITY TO STAKEHOLDERS

See comments in section on *Rapid eradication by chemical application*.

ADDITIONAL COST INFORMATION

See comments in section on *Rapid eradication by chemical application*.

LEVEL OF CONFIDENCE[1]

Well established.
As noted above, there is clear evidence of the effectiveness of herbicides, particularly glyphosate and/or metsulfuron methyl.

Combination of chemical and mechanical application.

MEASURE DESCRIPTION

For widespread and heavily invaded sites, mechanical treatments such as pulling or cutting are ineffectual as stand-alone treatments for controlling *L. japonicum* because of the inability of these methods to control resprouting from rhizomes; however mechanical treatments may be used in conjunction with chemical treatments as an integrated vegetation management approach. For example, for large infestations where *L. japonicum* is climbing trees or tall vegetation, the vines may be clipped at about 0.5–1m from the ground and herbicide only applied to the foliage on just the lower part of the cut vines. This approach has been used more extensively in the southeastern United States on *Lygodium microphyllum* and is known as a "poodle cut". This integrated approach thus limits the volume of herbicide applied in the landscape. However, this approach may not work where *L. japonicum* forms a dense low-lying mat over low-lying vegetation as it would be difficult to distinguish the cut fronds unless raked away.

SCALE OF APPLICATION

Integrated vegetation management programs can be implemented at the same large scales as chemical-only programs.

EFFECTIVENESS OF MEASURE

Effective.
Several studies have documented the effectiveness of integrated vegetation management of *L. japonicum*, so long as herbicides are included as one of the treatments. Hutchinson and Langeland (2007) found the greatest translocation of herbicides, especially glyphosate, to the root system of *Lygodium* was when applying herbicides only to the base foliage of cut vines rather than a complete foliar application, resulting in 85–90% control.

EFFORT REQUIRED

Even with integrated approaches, monitoring and repeated treatments will be necessary as it often takes several treatments to kill the entire root system and suppress spore germination over time.

RESOURCES REQUIRED

Incorporating mechanical cutting treatments into control methods can reduce the amount and therefore costs of herbicides, but it does require more personnel and labor, which might offset those savings. In the southeastern United States, estimates for manual cutting and herbicide

1 See Appendix

treatments can be as high as $800/ha (ca. €695) in large-scale infestations (Hutchinson and Langeland, 2007).

SIDE EFFECTS

Environmental: Positive.
Social: Positive.
Economic: Neutral or mixed.
As noted previously, management and control of widespread infestations will have beneficial long-term effects on sites where native vegetation can recover or be restored. Further, a reduction in the volume of herbicides being applied using integrated vegetation management may limit potential impacts of broad spectrum herbicides to non-target, desirable species as well as decrease potential human exposure. Economic effects remain neutral or mixed because of the increased costs of implementing the combination of mechanical and chemical applications, though this may offset potential negative impacts of *L. japonicum* to agricultural products or timber.

ACCEPTABILITY TO STAKEHOLDERS

Natural resource managers likely will find the integrated approach acceptable, and both professionals and the public typically support efforts to reduce herbicide use.

ADDITIONAL COST INFORMATION

Integrated vegetation management approaches are not necessarily more effective than herbicide-only treatments in widespread and heavy infestations, and the costs are often similar if not greater. The trade-off and advantages are mostly environmental and social in regards to the reduction in herbicide use.

LEVEL OF CONFIDENCE[1]

Well established.
As noted above, there is documented evidence of the effectiveness of integrated vegetation management for *L. japonicum*.

Combination of cultural and mechanical approach.

MEASURE DESCRIPTION

Prescribed fire alone tends to promote resprouting of *L. japonicum* from rhizomes; however when implemented in conjunction with chemical treatments, it can be effective as an integrated vegetation management approach. In heavily infested areas, prescribed burns can reduce thick mats of *L. japonicum*, and chemicals would be applied to resprouting vegetation. This approach could reduce the volume of chemicals applied to an area. Bohn and Minogue (2011) found that a period of six weeks of growth post-fire was sufficient for herbicide absorption and translocation, applied at similar rates as mentioned in the *Chemical application* section above. Chemicals can also be applied before prescribed fire application, but should be done at least a month after the active growing season begins and at least 6 weeks prior to burning to allow time for translocation of herbicides throughout the entire plant.

This integrated approach would be most appropriate in fire-dependent ecosystems. It should only be considered where *L. japonicum* has formed dense mats over groundcover or low lying shrubs. It should not be used where *L. japonicum* has climbed up and around trees, as this could lead to severe crown fires.

SCALE OF APPLICATION

Integrated vegetation management programs can be implemented at the same large scales as chemical-only programs.

EFFECTIVENESS OF MEASURE

Effective.
Use of chemicals in conjunction with prescribed fire has been used effectively for control of *L. japonicum* in the southeastern United States. In a replicated study of timing of herbicides with prescribed fire, Bohn and Minogue (2010) found that plots treated either in July before burning, or in August or September six weeks after burning, resulted in between 85–100% reductions in fern cover. Greater reductions were observed with hotter burns.

EFFORT REQUIRED

Even with integrated approaches, monitoring and repeated treatments will be necessary as it often takes several treatments to kill the entire root system and suppress spore germination over time.

RESOURCES REQUIRED

This integrated approach can reduce the amount and therefore costs of chemical control but it does require more personnel and labor, which might offset those cost savings. Use of prescribed fire has been shown to reduce the amount of herbicide by half (Stocker *et al.*, 2008). Costs for implementing prescribed fire can add an additional $50 to $500 per hectare (ca. €43 to €434) to the cost of chemical application for invasive plant control (Cleaves *et al.*, 1999).

1 See Appendix

SIDE EFFECTS

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

As noted previously, management and control of widespread infestations will have beneficial long-term effects on sites where native vegetation can recover or be restored. Further, a reduction in the volume of herbicides being applied using integrated vegetation management may limit potential impacts of broad spectrum herbicides to non-target, desirable species, but there are still limited risks. There are also certain risks associated with using prescribed fire (example where fire might escape due to unpredicted weather or other circumstances). Additionally, while this integrated approach can also reduce the volume of chemicals used and potential exposure of herbicides to people, prescribed fire can create smoke management issues that must be addressed. Economic effects remain neutral or mixed because of the increased costs of implementing an Integrated Vegetation Management system; though this may offset potential negative impacts of *L. japonicum* to agricultural products or timber.

ACCEPTABILITY TO STAKEHOLDERS

Natural resource managers likely will find the integrated approach acceptable, and both professionals and the public typically support efforts to reduce herbicide use. However, the general public may not favour the use of prescribed fire unless this cultural treatment has been a long-standing practice in the community (Fernandes, 2013). High wildfire seasons may also contribute to concern over the use of prescribed fire.

ADDITIONAL COST INFORMATION

Integrated vegetation management approaches are not necessarily more effective than herbicide-only treatments in widespread and heavy infestations, and the costs are often similar if not greater. The trade-off and advantage is mostly environmental and social in regards to the reduction in herbicide use.

LEVEL OF CONFIDENCE[1]

Well established.

As noted above, there is documented evidence of the effectiveness of integrated vegetation management for *L. japonicum*.

Biological control.

MEASURE DESCRIPTION

At the present time, biological control agents have not been sufficiently tested for *L. japonicum* as a viable control option. A rust-forming organism (*Puccina lygodii*) is currently being evaluated in central Florida, USA as a potential biological control.

Neomusotima conspurcatalis (a *Lygodium* defoliator moth) was released in peninsular Florida as a biocontrol of *L. microphyllum* (Smith *et al.*, 2014). This moth is genus specific and also will feed on *L. japonicum*, however, it is sensitive to cold temperatures. A second species in the genus, *N. fuscolinealis*, may also be a potential biocontrol agent (Bennett and Pemberton, 2008). It feeds on *L. japonicum* in its native range but was not released and tested in the southeastern USA, because it was found to also impact a sympatric species, *L. palmatum*, which is native to the U.S. However, *L. palmatum* is not native to Europe, so *N. fuscolinalis* may have potential for trial in the European Union. It is important to note that the release of macro- (or micro- in this case) organisms as biological control agents is currently not regulated at EU level. Nevertheless national/region laws are to be respected. Before any release of an alien species as a biological control agent an appropriate risk assessment should be made.

SCALE OF APPLICATION

In initial phases of the release of a biological control agent, it is suggested that release of large populations in a few locations across a broad landscape may be most effective to establish populations of the control agent in the ecosystem (Shea and Possingham, 2001). Following establishment, smaller populations can be released at multiple sites within a region.

EFFECTIVENESS OF MEASURE

Neutral.

Effectiveness is rated as neutral because it is unknown at this time whether biocontrol agents who have been found to be effective for *L. microphyllum,* such as *Neomusotima conspurcatalis* and *N. fuscolinealis,* will also be effective for *L. japonicum*. It is suggested that these agents feed on all species in the *Lygodium* genus, but this has not been thoroughly tested or documented, nor is it known how these agents would adapt to the climate and ecosystems of Europe.

EFFORT REQUIRED

Multiple releases over multiple years are needed to establish populations of biological control agents in the wild. Additionally, host specific biological control agents require

1 See Appendix

L. Japonicum *prefers a neutral to slightly acid soil for growth.*
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a constant supply of its host for populations to survive, so multiple release events would be necessary if *L. japonicum* were not widespread across a region.

RESOURCES REQUIRED

Testing and release of biological control agents in new areas can require significant upfront resources and costs. Worldwide estimates of establishing biological control programs, which includes breeding, lab testing, and field trials, range from $160,000 to $460,000 US$ per year (ca. €139,000 to €400,000) for several years (Paynter *et al.*, 2015).

SIDE EFFECTS

Environmental: Neutral or mixed.
Social: Neutral or mixed.
Economic: Neutral or mixed.
Because there are currently no evaluations of potential biocontrol agents for *L. japonicum*, the potential side effects are also not known.

ACCEPTABILITY TO STAKEHOLDERS

Public perception of the use of biological control agents can be mixed. While there is much interest in reducing the use of chemical plant protection products, biological controls have not been widely used in the E.U. for invasive plants. Education and awareness campaigns could aid in the acceptability of this control method.

LEVEL OF CONFIDENCE[1]

Inconclusive.

The scientific literature (Bennett and Pemberton, 2008; Smith *et al.*, 2014) suggests that the brown *Lygodium* moths including *Neomusotima conspurcatalis* and *N. fuscolinealis* will feed on *L. japonicum*, but they have only been tested for control with *L. microphyllum*. Sensitivity to cold may limit their use in the full range of *L. japonicum*'s possible distribution.

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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