EUROPEAN AND MEDITERRANEAN PLANT PROTECTION ORGANIZATION
ORGANISATION EUROPEENNE ET MEDITERRANEENNE POUR LA PROTECTION DES PLANTES

18-23431 (17-22543)

Pest risk assessment for ***Lygodium japonicum*** **(Thunb.) Sw**

2018
EPPO
21 Boulevard Richard Lenoir, 75011 Paris
www.eppo.int
hq@eppo.int

This pest risk assessment scheme has been specifically amended from the EPPO Decision-Support Scheme for an Express Pest Risk Analysis document PM 5/5(1) to incorporate the minimum requirements for risk assessment when considering invasive alien plant species under the EU Regulation 1143/2014. Amendments and use are specific to the LIFE Project (LIFE15 PRE FR 001) 'Mitigating the threat of invasive alien plants to the EU through pest risk analysis to support the Regulation 1143/2014'.

Photo: Kimberly Bohn

EUROPEAN AND MEDITERRANEAN PLANT PROTECTION ORGANIZATION

Pest risk assessment for *Lygodium japonicum*

This PRA follows EPPO Standard PM5/5 Decision support scheme for an Express Pest Risk Analysis

PRA area: EPPO region

First draft prepared by: Kimberly Bohn

Location and date: Paris (FR), 2017-03-27/31

Composition of the Expert Working Group

BOHN Kimberly (Ms)	Penn State Extension, 17129 Rt. 6, 16749 Smethport, USA kkb29@psu.edu
BRUNDU Giuseppe (Mr)	University of Sassari, Department of Agriculture, Viale Italia 39, 07100 Sassari, Italy, gbrundu@tin.it
CHAPMAN Daniel (Mr)	Centre for Ecology and Hydrology Bush Estate, Penicuik, Edinburgh , UK dcha@ceh.ac.uk
DANCZA Istvan (Mr)	Syngenta Kft., Kotlan S. u. 3., 2100 GÖdÖllÖ, Hungary istvan.dancza@syngenta.com
FROHLICH Danielle (Ms)	c/o SWCA Environmental Consultants -Bishop Square: ASB Tower, 1001 Bishop Street, Suite 2800, 96813 Honolulu, Hawaii, USA dfrohlich@swca.com
HUTCHINSON Jeffrey (Mr)	The University of Texas at San Antonio, College of Science - Environmental Science Program, Flawn Science Building One UTSA Circle, 78249 San Antonio, USA jeffrey.hutchinson@utsa.edu
MILLER Steven R. (Mr)	Bureau of Land Resources St Johns River Water Management District, 4049 Reid St, 32178 Palatka, USA, srmiller@sjrwmd.com
VAN VALKENBURG Johan (Mr)	National Plant Protection Organization, Geertjesweg 15, P.O. Box 9102, 6700 HC Wageningen, Netherlands, j.l.c.h.vanvalkenburg@nvwa.nl
TANNER Rob (Mr)	OEPP/EPPO, 21 boulevard Richard Lenoir, 75011 Paris, France rt@eppo.int

The pest risk assessment for *Lygodium japonicum* has been performed under the LIFE funded project:

LIFE15 PRE FR 001

Mitigating the threat of invasive alien plants to the EU through pest risk analysis to support the Regulation 1143/2014

In partnership with

EUROPEAN AND MEDITERRANEAN PLANT PROTECTION ORGANIZATION

And

NERC CENTRE FOR ECOLOGY AND HYDROLOGY

Review Process

- This PRA on *Lygodium japonicum* was first drafted by Kimberly Bonn

- The PRA was evaluated under an expert working group at the EPPO headquarters between 2017-03-27/31

- Following the finalisation of the document by the expert working group the PRA was peer reviewed by the following:

  (1) The EPPO Panel on Invasive Alien Plants (April 2017)
  (2) The EPPO PRA Core members (2017)
  (3) The EU Scientific Forum

Approved by the IAS Scientific Forum on 26/10/2018

Contents

Summary 6
Stage 1. Initiation 10
Stage 2. Pest risk assessment 12
1.Taxonomy 12
2. Pest overview 13
3. Is the pest a vector? 16
4. Is a vector needed for pest entry or spread? 16
5. Regulatory status of the pest 16
6. Distribution 17
7. Habitats and where they occur in the PRA area 19
8. Pathways for entry 20
9. Likelihood of establishment in the natural environment in the PRA area 26
10. Likelihood of establishment in managed environment in the PRA area 27
11. Spread in the PRA area 27
12. Impact in the current area of distribution 28
13. Potential impact in the PRA area 31
14. Identification of the endangered area 32
15. Climate change 32
16. Overall assessment of risk 34
17. Uncertainty 36
18. Remarks 36
19. REFERENCES 37
Appendix 1: Projection of climatic suitability for *Lygodium japonicum* establishment 43
Appendix 2 Biogeographical regions 54
Appendix 3. Relevant illustrative pictures 55
Appendix 4: Distribution summary for EU Member States and Biogeographical regions 61
Appendix 5: Koppen-Geiger climate zones 62
Appendix 6: Distribution maps for Lygodium japonicum (World) 65

Summary[1] of the Express Pest risk assessment for *Lygodium japonicum*

PRA area: EPPO region

Describe the endangered area:

The Expert Working Group (EWG) predicts the endangered area is the Macaronesian (in particular the Azores) and Black Sea (eastern and southern areas) biogeographical regions. This prediction is based on the climatic suitability and other invasive fern species in Europe. For example, *Dicksonia antarctica* Labill. (Soft Tree Fern; Dicksoniaceae) is invasive in São Miguel Island (Azores archipelago - Portugal). This species is native to south-eastern Australia and Tasmania where it inhabits rain forests from sea level to 1,000 m a.s.l. (Arosa et al. 2012). Also, *Cyathea cooperi* Hook. ex F. Muell. (Domin tree fern: Dicksoniaceae) has been described as invasive in the Azores. In addition, Sanz-Elorza et al. (2005) included *L. japonicum* in a list of the potential invasive species for the Canary Islands. The species distribution model predicts suitability in part of the Atlantic biogeographical region (Portugal, northwest Spain south east of France). Although in these regions the model shows it has a lower suitability, the EWG consider that the presence of large plantation forestry and the humidity from the Atlantic will increase the suitability to establishment of *L. japonicum* so that part of the Atlantic biogeographical region deserves to be included in the endangered area. For example, areas like the Sierra de Buçaco forest might be suitable, as they already host plants of *Dicksonia antarctica* Labill.

The species distribution model (Appendix 1) predicts a high suitability along the Adriatic coast and the eastern Mediterranean biogeographical region (Italy, Croatia Albania (non-EU) and Greece), and a small part of the continental biogeographical region. However, the EWG consider these areas are less suitable for the establishment of a fern species due to the prevalence of agricultural land-use and high evaporation rates in the summer in combination with low rainfalls. For similar reasons, the Atlas Mountains in North Africa, the mountains on Crete island, and Mount Lebanon were not included by the EWG in the endangered area.

Main conclusions

Lygodium japonicum presents a moderate phytosanitary risk (including impacts of biodiversity and ecosystem services) for the endangered area within the EPPO region with a high uncertainty.

However, given this species' ability to spread via spores, the degree of invasiveness, and the difficulty of control experienced elsewhere, the EWG suggests special consideration be given to preventing its entry (and spread) into the EPPO region. In the current area of distribution, *L. japonicum* has a high negative impact on biodiversity and ecosystem, services

The overall likelihood of *L. japonicum* entering the EPPO region is moderate – based on evidence that the species is intercepted as a contaminant of bonsai plants from China and there is some evidence the species is traded.

Since *L. japonicum* is not yet documented within the PRA, likelihood of entry is mostly dependent on its introduction as an ornamental/landscape feature. If this happens, given the habitats and climate of the PRA area, this could readily be followed by escape and introduction into natural ecosystems, similarly as to its initial establishment in North America and Australia.

Entry and establishment

[1] The summary should be elaborated once the analysis is completed

Lygodium japonicum is absent from the natural environment in the EPPO region. Despite the fact that propagules are entering the PRA area, there are no records of the species in the natural environment.
Species distribution modelling (see Appendix 1) suggests the main biogeographical regions to be impacted include about a 30% of the Mediterranean and Black Sea regions, approximately 10% of the Atlantic region, and 5% of the Continental region. In addition, the Macaronesian biogeographical region is suitable (though not included quantitatively in the modelling appendix). Countries that would be affected under this projection include portions of Spain (Canary Islands), Portugal (Azores), France, Italy and coastlines of the Adriatic and Black Sea (Turkey Georgia and Russia). However, the EWG suggest caution when interpreting the model in view of the prolonged dry summer in the Mediterranean climate with the exception of local micro-climates. It is also important to consider that habitat is also a key component of the distribution of this species in its invaded range in the USA. *Lygodium japonicum* grows best in wet habitats such as along rivers and in wetland areas, and mesic forests under canopy. This should be considered in context to its potential distribution in the biogeographical regions described by the climate model. The risk of establishment in natural habitats is low with a high uncertainty.

Pathways for entry:

Plants for planting

This is the likely pathway of introduction into the PRA. In North America, *L. japonicum* was introduced as an ornamental plant for homeowners and landscapes. *Lygodium japonicum* is currently sold as an ornamental plant in the USA and there is some evidence the species is sold within the PRA area.

Contaminant of growing medium associated to other species of plants for planting
In the Netherlands, gametophytes have been detected in growing media of bonsai plants imported from China (Personal communication van Valkenburg, 2017).

Other pathways considered in the PRA are: contamination of machinery and equipment, contamination of tourists and contamination of timber and wood material.
Impacts

Current area of distribution

In the current area of distribution, *L. japonicum* has a high negative impact on biodiversity and ecosystem, services. The species has a moderate impact on socio-economy. In North America, *L. japonicum* alters the fire intensity, the extent burned, and the vertical development (serves as ladder fuels) of the fire even in communities where fire plays a natural role. These alterations to fire behaviour enhance the negative impact on native species biodiversity. This is due both to the chemical composition and the volume of *Lygodium* biomass (pers. comm., S. Miller, 2017).

The EWG consider that these impacts will be similar in the PRA area if the species can establish but the rating of uncertainty will rise to high. The high rating of uncertainty is associated with the current unknowns of how the biology of the species will be compatible with the climate within the EPPO region. The high rating for the magnitude of impact on biodiversity in the PRA area is based on the potential impacts of the species in the Azores (Macaronesian Region) and thus the geographical area for such impacts is restricted. This prediction is based on the climatic suitability and the invasiveness of other invasive fern species in Europe.

The EWG consider that in the PRA area, impacts on ecosystem services will be lower compared to the current area of distribution. If introduced into the PRA area, *L. japonicum* may establish in forest plantations, similar as has been observed in the Southeastern USA - including conifer and evergreen humid forests with a thick litter layer, or managed deciduous forests in mesic soils. A moderate rating is given for impacts on ecosystem services in the PRA area with a with high uncertainty, where the high uncertainty reflects the current unknowns – in particular if the species will exhbit the same invasive behaviour in the PRA area compared to other invasive regions.

The EWG consider that socio-economic impacts will be reduced in the PRA area as the species would not have the opportunity to gain a significant foothold compared to as seen in the areas of the USA, but this is accompanied with a high uncertainty.

There are no human health issues for the species in the PRA area.

Climate change

Under the climatic projection, RCP 8.5, the risk of establishment is likely to increase in the natural environment. The EWG predicts that under the natural environment, the likelihood of establishment will increase to a moderate score with high uncertainty. Climate conditions currently exist for its initial germinations but, the slight increases in temperature could initiate growth sooner allowing the plant to become established sooner. The rate of spread under future climate predictions is not likely to change. Light spores already disperse and spread readily by wind and water, and a significant change in the magnitude of spread is not likely. One potential impact of climate change would be on an increased likelihood of high intensity precipitation leading to flooding or rivers, which could then potentially move spores further downstream or up river bank sides then under normal stream water flows.

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, Netherlands, Belgium, Austria, Hungary, Czech Republic, Great Britain, Poland, Lithuania, Latvia, Italy, Croatia, Southern Sweden and Denmark).

Phytosanitary measures

The results of this PRA show that *L. japonicum* poses a moderate phytosanitary risk to the endangered area Macaronesian biogeographical region (the Azores), and Black Sea (southern areas) biogeographical region with a high uncertainty.

Phytosanitary risk (including ecosystem services and biodiversity) for the *endangered area* (current/future climate) **Pathways for entry** Plants for planting: Moderate/ Moderate Contamination of plants for planting: High/ High Contamination of machinery and equipment: Low/Low Contamination of tourists: Low/Low Contamination of timber and wood material: Low/Low Likelihood of establishment in natural areas: Low/ Moderate Likelihood of establishment in managed areas: Moderate/ moderate Spread: High/ High	High ☐	Moderate X	Low ☐

<table>
<tr><td>Impacts (potential: PRA area)
Biodiversity and environment: High/ High
Ecosystem services: Moderate/ Moderate
Socio-economic: Low/ Low</td><td></td><td></td><td></td></tr>
<tr><td>Level of uncertainty of assessment (current/future climate)
Pathways for entry
Plants for planting: High/ High
Contamination of plants for planting: Moderate/ Low
Contamination of machinery and equipment: High/High
Contamination of tourists: High/High
Contamination of timber and wood material: High/High
Likelihood of establishment in natural areas: High/high
Likelihood of establishment in managed areas: Moderate/ High
Spread: Moderate/Moderate
Impacts (potential: PRA area)
Biodiversity and environment: High/High
Ecosystem services: High/High
Socio-economic: High/High</td><td>High X</td><td>Moderate ☐</td><td>Low ☐</td></tr>
<tr><td colspan="4">Other recommendations:
Inform EPPO or IPPC or EU
Inform NPPOs that surveys should be conducted to monitor the endangered area for the presence of the species.
Inform industry, other stakeholders
Encourage industry to assist with public education campaigns associated with the risk of non-native plants. Encourage industry to sell native species as alternatives to non-natives.
Specify if surveys are recommended to confirm the pest status
Studies on the thermal tolerance of the spores.</td></tr>
</table>

Express Pest risk assessment:

…………..

Lygodium japonicum (Thunb.) Sw

First draft prepared by: BOHN Kimberly (Ms) Penn State Extension, 17129 Rt. 6, 16749 Smethport, USA

Date: 13th March 2017.

Stage 1. Initiation

Reason for performing the PRA:

Although *Lygodium japonicum* is currently absent from the natural environment in the EPPO region, a recent horizon scanning study identified the species as having a high risk of arrival, establishment, spread and threat to biodiversity and ecosystem services across the EU within the next ten years (Roy *et al*., 2015). In 2016, the species was prioritized (along with 36 additional species from the EPPO List of Invasive Alien Plants and a recent horizon scanning study[2]) for PRA within the LIFE funded project "Mitigating the threat of invasive alien plants to the EU through pest risk analysis to support the Regulation 1143/2014'. *Lygodium japonicum* was one of 16 species identified as having a high priority for PRA (Tanner *et al*., 2017). Climate modelling suggests that there are suitable areas for the establishment of *L. japonicum* under both current and future climatic scenarios. Within the invaded range, in particular the USA, *L. japonicum* has significant economic impacts to forests managed for a variety of products and services, in particular pine plantations managed for pine straw production. Furthermore, this vine can act as a ladder fuel, resulting in a significant loss of forest structure and timber revenue if crown fires develop. Ecologically, *L. japonicum* can smother groundcover and shrubs, resulting in the reduction of native plant species within a local ecosystem (Nauman 1993). The potential to spread is high due to its ability to spread by microscopic spores < 65 microns that are easily spread by wind and water.

PRA area: The EPPO Region (see https://www.eppo.int/ABOUT_EPPO/images/clickable_map.htm.)

The risk assessments were prepared according to EPPO Standard PM5/5 (slightly adapted) which has been approved by the 51 EPPO Member Countries, and which sets out a scheme for risk analysis of pests, including invasive alien plants (which may be pests according to the definitions in the International Plant Protection Convention). EPPO engages in projects only when this is in the interests of all its member countries, and it was made clear at the start of the LIFE project that the PRA area would be the whole of the EPPO region. Furthermore, we believe that since invasive alien species do not respect political boundaries, the risks to the EU are considerably reduced if neighbouring countries of the EPPO region take equivalent action on the basis of broader assessments and recommendations from EPPO.

All information relating to EU Member States is included in the Pest risk assessment and information from the wider EPPO region only acts to strengthen the information in the PRA document. The PRA defines the endangered area where it lists all relevant countries within the endangered area, including EU Member States. The distribution section lists all relevant countries

2 http://ec.europa.eu/environment/nature/invasivealien/docs/Prioritising%20prevention%20efforts%20through%20horizon%20scanning.pdf

in the EPPO region (including by default those of EU Member States and biogeographical regions which are specific to EU member States). Habitats and where they occur in the PRA are defined by the EUNIS categorization which is relevant to EU Member States. Pathways are defined and relevant to the EU Member States and the wider EPPO Member countries, and where the EWG consider they may differ between EU Member States and non-EU EPPO countries, this is stated. The establishment and spread sections specifically detail EU Member States. When impacts are relevant for both EU Member States and non-EU EPPO countries this is stated 'The text within this section relates equally to EU Member States and non-EU Member States in the EPPO region'. Where impacts are not considered equal to EU Member States and non-EU Member States this is stated and further information is included specifically for EU member States. For climate change, all countries (including EU Member States) are considered.

Stage 2. Pest risk assessment

1.Taxonomy

Lygodium japonicum (Thunb.) Sw, Kingdom: Plantae; Phylum: Pteridophyta; Class: Polypodiopsida(ITIS)/ Filicopsida (USDA); Order: Schizaeales; Family: Lygodiaceae).

Note that the genus was traditionally placed in the family Schizaceae, but recent molecular studies have supported the recognition of monospecific family the *Lygodiaceae*, containing only *Lygodium* (Garrison and Hanks, 1998).

Synonyms: *Ophioglossum japonicum* Thunb. (basionym) - *Adiantum scandens* Lour.

EPPO Code: LYFJA

Common name: Japanese climbing fern, French: fougère grimpante du Japon, German: Japanischer Kletterfarn, Japanaese: kani-kusa, Chinese: hǎi jīn shā, Russian: лигодий японский

Plant type: Broadleaved, herbaceous perennial climbing fern.

Related species in the EPPO region: None

2. Pest overview

INTRODUCTION

Lygodium japonicum (Japanese climbing fern) is a broadleaved, herbaceous perennial vine and true fern (see Appendix 3, Figure 1) which is native in much of south-eastern Asia through India and as far south as Papua New Guinea (Uddin et al., 1997, Flora of China Editorial Committee, 2014, Lindsay & Middleton, 2013 Garrison Hanks, 1998, Singh et al., 2012, Maideen et al., 2004 Wee & Chua, 1988). It was introduced outside of its native range on several continents. North American establishment was first recorded in the early 1900s in the State of Georgia (Clute 1903), where it was introduced as an ornamental plant (Pemberton and Ferriter, 1998; Ferriter, 2001; Clarke, 1936). *Lygodium 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). The species is primarily found in wetlands, mesic forests, along river edges, ditches and adjacent to other wet areas.

LIFE CYCLE AND ENVIRONMENTAL REQUIREMENTS

Lygodium japonicum is a true fern that reproduces by spores (homosporous fern), which then germinate and develop through gametophyte and sporophyte stages (Appendix 3, Figure 2). It reproduces sexually by intragametophytic selfing (Lott et al. 2003), meaning it is self-fertilizing. Spores develop only on frondlets (sorophores) of the new year's growth. In north Florida, spore development begins around late June to July, become mature in late August, and disperse throughout mid-September through late October. In controlled settings, spores have been observed to be viable for up to five years (Kimberly Bohn, personal observation). Spore germination is triggered by being exposed to temperatures of at least 15° C for at least two to three weeks, and may be enhanced by being protected by leaf litter rather than exposed to bare soil (Ulrich, 2012).

In its native range, the species mostly prefers warm climates with average year-round temperatures over 10 °C (CABI 2017), and with clearly defined wet and dry seasons. In the south-eastern USA, peak growth periods occur between mid-May through late July, and have been associated with average monthly temperatures ranging from lows of 22°C to highs of 32°C. Above-ground foliage of *L. japonicum* dies back after frost and temperatures at or near 0° C however belowground root and rhizomes will remain dormant through winter and resprout when temperatures reach at least 18 °C. Hutchinson and Langeland (2014) found that freezing temperatures do not affect spores. Gametophytes were sensitive to freezing temperatures, but could survive when exposed for several hours.

Lygodium japonicum may have a preference for soils with a circumneutral pH (e.g. 6.5 to 7.5 pH) (Diggs and George, 2006; Langeland et al., 2008).

HABITATS

Where introduced in the USA, *L. japonicum* occupies a broad range of natural and disturbed habitats (Kimberly Bohn, personal observation). 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 et al., 2000; Diggs and George, 2006; van Loan, 2006; Langeland et al., 2008; Miller et al., 2010). Floodplain swamps are comparatively uninfested due to lower elevations and resultant regular flooding and inundation (Ferriter 2001). Infestations also occur in xeric sites, but do not appear to expand as rapidly as in more mesic sites, possibly due to the infrequency of appropriate conditions for gametophyte establishment or fertilization. It is a common invader of pine plantations (Ferriter, 2001; van Loan, 2006; Miller et al., 2010), and commonly invades disturbed areas, including along roads and particularly ditches and culverts.

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).

Within its natural range *L. japonicum* typically occupies moist habitats but favours regions with a defined dry season (Holttum, 1959; Garrison Hanks, 1998). It has weedy tendencies in its natural range and is primarily a pioneer and gap species. It is found from sea level to 2550 m (Holttum, 1959; Wardani and Jaenudin, 2014), primarily on southern slopes (Zheng *et al*., 2006). *L. japonicum* occupies secondary forests in China (Flora of China Editorial Committee, 2014), Indonesia (Wardani and Jaenudin, 2014) and Malaysia (Holttum, 1959) and forest edges and thickets in Japan (Ohwi *et al.,* 1965) and the Philippines (Barcelona *et al.,* 2006). In Bali, Indonesia *L. japonicum* was seen to occupy barren soil after a volcanic eruption (Dilmy, 1965).

IDENTIFICATION

Lygodium japonicum is a rhizomatous vine, with a twining rachis climbing to 30 m. Below-ground rhizomes are creeping, with black to reddish-brown hairs (Appendix 3, Figure 3). Stipes are spaced to 1 cm apart on rhizome. Stems remain underground, but send up long vine-like indeterminate fronds that have numerous compound pinnae. Pinnae on frondlets are triangular to deltoid-shaped, with short stalks, about 3-5 cm long (Appendix 3, Figure 4 and 5). The mid-ribs (costae) have scattered hairs, and veins and pinnae surfaces are typically glabrous. Each pinnule on the pinnae is pinnate to lobed and stalked often with dissected terminal lobes. Pinnules are pubescent below and margins are variously dentate. Spore diameters range in size from 64-80 µm, averaging 76 µm. Japanese climbing fern sporangia are borne on narrow, fingerlike segments of the pinnae (see Appendix 3, Figure 1).

The main differences between *L japonicum* and *L. microphyllum* (the closely related species which is invasive in North America) is the number of divisions of their pinnae. The sterile pinnae of L. microphyllum is pinnate where *L. japonicum* is bipinnate. The pinnae of *L. japonicum* is also slightly larger than that of *L. microphyllum* and have more of a matte green appearance than the glossier L. microphyllum.

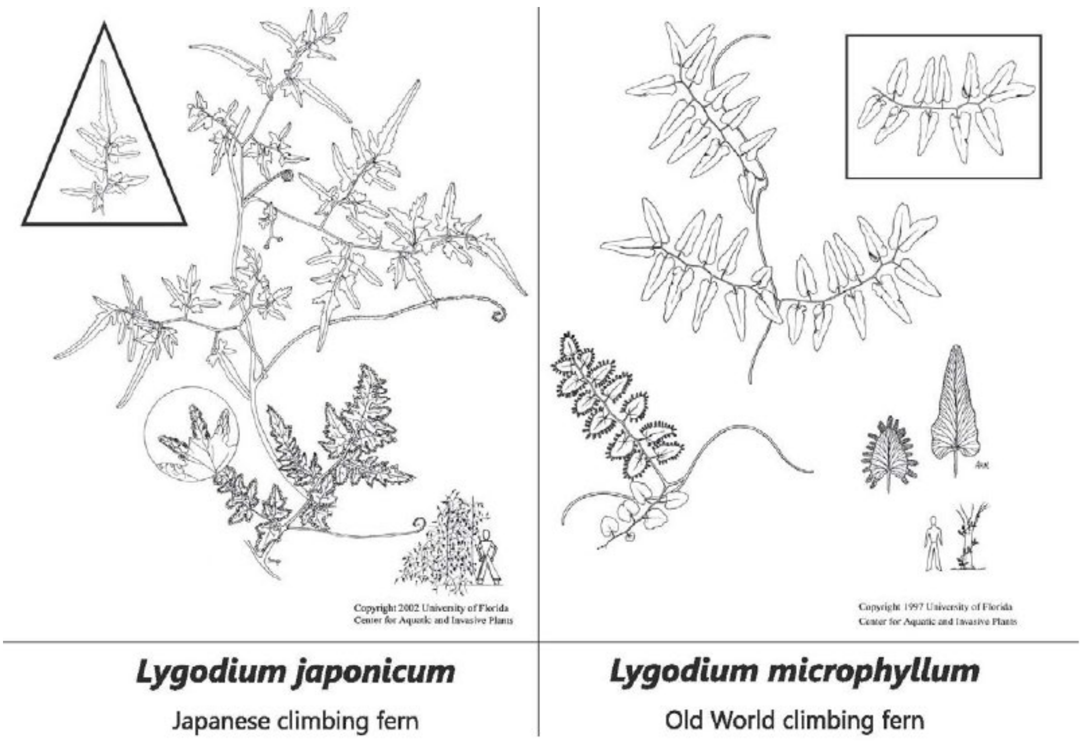


Fig. 1 Comparison of *Lygodium japonicum* and *Lygodium microphyllum*

SYMPTOMS/ IMPACT

In the USA, *L. japonicum* has significant economic impacts to forests managed for a variety of products and services, in particular pine plantations managed for pine straw production, which is an $80 million industry in Florida alone (Hodges et al 2005). Furthermore, this vine can act as a ladder fuel, resulting in a significant loss of timber revenue if crown fires develop.

Ecologically, *L. japonicum* can smother groundcover and shrubs, leading to a reduction in the abundance of native species within a local ecosystem (Nauman 1993) (see Appendix 2, Figure 5). For example, Leichty et al. (2011) found that *L. japonicum* is likely to compete with mesic pine savannah species in Louisiana. It has been demonstrated that herbaceous layers respond positively when *L. japonicum* is treated with herbicide (Minogue et al., 2010; Bohn et al., 2011).

Existing PRAs for *L. japonicum*

Risk assessments have been conducted for the USA and the Pacific Islands (Koop et al., 2011; PIER, 2014).

Florida (USA)- a risk assessment was evaluated using the Australian/New Zealand Risk Assessment, modified for Florida. *Lygodium japonicum* is rated as a high risk, with a score 25 out of a possible 28.

Hawaii (USA) and Pacific Islands- a risk assessment was evaluated using the Australian/New Zealand Risk Assessment, modified for Hawaii. *Lygodium japonicum* is rated as a high risk, score 23 out of a possible 28.

USA-the USDA also conducted a nationwide risk assessment, and rated this species as high risk. Nationwide it scored 17 out of a possible 28, and only ranked lower than the state-wide assessments because of its limited spread to northern states (USDA-APHIS 2009).

Socio-economic benefit

Lygodium japonicum is recorded as having medicinal value in its native range. CABI (2017) detail the following: In China it is used as a diuretic (Puri, 1970) and to treat colds, inflammation, kidney stones and renal ailments (Eisenberg et al., 2009). In India it is used as an expectorant and to treat snakebites (Reutter, 1923; Puri, 1970; Srivastava and Uniyal, 2013) and to treat diabetes, wounds and ulcers (Yumkham and Singh, 2011). In Nepal a paste is used to treat scabies, the juice is used to treat herpes and wounds (Manandhar, 1995) and its juice is applied for boils, wounds, whitlow and scabies (Mall et al., 2015). In Pakistan a powder is used on wounds to help healing and a root extract for reducing body aches and swelling (Khan et al., 2010). Spores are sold on the Internet for use in traditional Chinese medicine as "Spora Lygodii" (Ferriter, 2001). Formal studies have been conducted to determine medicinal benefits of *L. japonicum.* Duan et al. (2012) showed that this species has compounds with strong antioxidant properties. Cho et al. (2014) found it to be useful as a preventive and therapeutic agent against the formation of oxalate kidney stones, supporting one of the primary traditional uses. It has also been studied with potentially positive results for the regrowth of hair (Matsuda et al., 2002). None of the aforementioned socio-economic benefits are relevant for the EPPO region, including the EU.

Lygodium japonicum is currently sold as an ornamental plant in the USA (EWG observations). There is some recent indication (from plant exchange website forums, for example https://davesgarden.com/community/trading/search.php?search_text=PFPID:32029) the species is available in the PRA area but to a low extent. One supplier in Ireland has been highlighted as supplying the species in the past (http://www.shadyplants.net/photo_1509809.html). The species is also listed on the Royal Horticultural Society (GB) website, where one supplier is detailed.

3. Is the pest a vector?	**Yes** ☐	**No** X

If the pest is a vector, which organism(s) is (are) transmitted and does it (do they) occur in the PRA area?

4. Is a vector needed for pest entry or spread?	**Yes** ☐	**No** X

5. Regulatory status of the pest

USA: *Lygodium japonicum* does not have federal "noxious weed" status, but is listed as a Class B noxious weed in Alabama, and was added to the Florida Noxious Weed List in 1999 (USDA, 2017).

In Australia, it is "regarded" as an environmental weed in New South Wales and south-eastern Queensland and is a potential environmental weed in northern Australia; however, no laws or regulations exist to regulate its distribution and spread (Queensland Government 2014).

6. Distribution

Continent	*Distribution*	*Provide comments on the pest status in the different countries where it occurs*	*Reference*
Africa	South Africa	Introduced, casual	Macdonald et al., 2003; Henderson, 2007
America	USA- Alabama, Arkansas, Florida, Georgia, Hawaii, Kentucky, Louisiana, Mississippi, North Carolina, Oklahoma, South Carolina, Tennessee, Texas; Puerto Rico	Invasive, widespread through southeastern States Established but not invasive	EPPO, 2014 Diamond & Woods, 2007; Peck, 2011; Sundell, 1986 Loan van, 2006 Hutchinson & Langeland, 2010; Wunderlin et al., 2000 EDDMapS , 2015
Asia	Bangladesh, Bhutan, Cambodia, China, India, Indonesia, Japan, North and South Korea, Laos, Malaysia, Myanmar, Nepal, Pakistan, Philippines, Sri Lanka, Taiwan, Thailand, Vietnam	Native	Uddin et al., 1997 Flora of China Editorial Committee, 2014 Missouri Botanical Garden, 2015; Lindsay & Middleton, 2013 Garrison Hanks, 1998 Singh et al., 2012, Maideen et al., 2004 Flora of Japan, 2015; Chang et al., 2014; Khan et al., 2010
Asia	Singapore	Introduced	Chong et al., 2009; Wee & Chua, 1988
Europe	None, not present in the wild	Cultivated in Botanic Gardens and private collections (often within greenhouses)	EWG opinion and web search, https://www.biodiversitylibrary.org/page/40967000#page/14/mode/1up
Oceania	Australian- Northern Territory, New South Wales, Queensland	Invasive	Hosking et al., 2011; APNI, 2014; Garrison Hanks, 1998
Oceania	Papua New Guinea	Native	Garrison Hanks, 1998; Maideen et al., 2004

Asia

Lygodium japonicum is considered native in a number of Asian countries including Bangladesh, Bhutan, China, India, Indonesia, Japan, Laos, Myanmar, Nepal, Pakistan, Philippines, North and South Korea, Sri Lanka, Taiwan, Thailand and Vietnam (Garrison Hanks, 1998; Chang et al., 2014; Ferns of Thailand, 2014; Flora of China Editorial Committee, 2014; Flora of Japan, 2015). In China, it is primarily found south of the Yangtze River (Zheng et al., 2006). See appendix 5, Figure 1 and 2.

Africa

Lygodium japonicum is described as being sparingly established as a "casual alien" in South Africa (Macdonald et al., 2003; Henderson, 2007), and it is the only known, documented location for it on the African continent. The oldest confirmed naturalized record of *L. japonicum* is from 1985.

Australia and Oceania

Lygodium japonicum has been documented as escaped from cultivation in the Northern Territory from the early 1900s. It was suggested to be introduced as an ornamental, and as a specimen in botanical gardens during that period, from which it escaped. Most records of this species becoming naturalized have been reported in south-eastern Queensland since the mid-1990s (http://www.technigro.com.au/documents/Weed_Watch_Japanese_Climbing_Fern_Web.pdf). In Queensland, it is currently considered to be an environmental weed (Queensland Government, 2014). Hosking (2011) also reported *L. japonicum* to be naturalized in New South Wales. In particular, there are several records from the Sunshine Coast and Brisbane areas in the last ten years (pers comm. Bonn, 2017). In western Australia, Orchard and McCarthy (1998) considered previous reports of *L. japonicum* to be mistaken identities of the native *L. flexuosum*. See appendix 5, Figure 4.

Lygodium japonicum is considered native to Papua New Guinea.

North America

Introduced as an ornamental plant in the US (Pemberton and Ferriter, 1998; Ferriter, 2001; Clarke, 1936), *L. japonicum* individuals have been recorded near greenhouses (Anderson 1921, Diddell 1941) and in yards and gardens (Anderson 1921; Graves 1920). Regionally the species was sold commercially as trailing or running maidenhair (Brown and Correll 1942). The earliest record of *L. japonicum* as an escapee is from 1903 in Thomasville, GA where it was observed near the site of a greenhouse that had been destroyed in a fire (Harper 1905, Thomasville Times-Enterprise 1903). In the early 1920s it was recorded as escaped from cultivation in Alabama (Graves 1920) and South Carolina (Anderson 1921). In the late 1930s, *L. japonicum* was recorded in Florida; this record also indicated that the species was already known in Alabama, Georgia, and South Carolina and was expected to spread further in southern states (Correll 1938). Thorne (1949) reported the species as naturalized from Florida to Louisiana and North Carolina. It is currently found as far west as Texas and Arkansas, throughout Louisiana, Mississippi, Alabama, and Florida, as far north as North Carolina and Kentucky. In Florida, it is primarily found in the panhandle and through the central part of the peninsula, although a few observations have been noted as far south as the southern tip of the Peninsula. Its southern expansion may be limited by competition with its congener *Lygodium mycrophillum* or climatic conditions. It has also been introduced in Puerto Rico and Mexico but is not widely established or invasive. See appendix 5, Figure 5.

Europe

It is very-likely present in cultivation in private collections (often within confined greenhouses) and botanical gardens in Europe (often inside dedicated greenhouses). For example, Heinrich Friedrich Link *apud* G. Reimer (1827) had reported it under the synonym of *Ophioglossum japonicum* Thunb. as cultivated at the "Hortus regius botanicus berolinensis", and in the fern collection at Lipsia (Filices Horti Botanici Lipsiensis. Die Farne des botanischen Gartens zu Leipzig, by Mettenius, Georg Heinrich, 1823-1866, available at BHL - http://www.biodiversitylibrary.org/page/40967000#page/12/mode/1up). It was also introduced in the botanical garden of Coimbra, were it was also declared extinct since 2014, but also rarely cultivated in Portugal (Catálogo das Plantas do Jardim Botânico da Universidade de Coimbra by João Domingues de Almeida, 2014 – available at Research Gate). In 1889 it was introduced in Italy, in his garden at La Mortola (Liguria), by Thomas Hanbury who introduced many species of exotic ferns to experiment their acclimatization and their ornamental potential in Italy (Zappa et al. 2010 - Boll. Mus. Ist. Biol. Univ. Genova, 2010).

7. Habitats and where they occur in the PRA area

The following table represents potential habitats where *L. japonicum* could be found within the PRA area, based on its distribution in invaded ecosystems of the southeastern USA, which ranges from wet bottomland hardwoods to managed pine plantations.

Habitat (main)	**EUNIS habitat types**	**Status of habitat (e.g. threatened or protected)**	**Present in the habitat in the PRA area ?**	***major/minor habitats* in the PRA area?**	***Reference***
Inland water, riverbanks	C3: littoral zone of inland surface waterbodies	In part	No	Major	Ferriter, 2011,
Wetlands	D4: base-rich fens and calcareous spring mires	In part	No	Major	Ferriter, 2011,
Irrigation ditches	J: man-made drainage systems	None	No	Minor	Ferriter, 2011,
Grasslands	E2: Mesic grasslands E5: Woodland fringes and clearings	In part	No	Major	Wilson, 1996, Ferriter, 2011
Woodland	G1 – G4: From deciduous to conifer to mixed woodland G2 – G3: Humid evergreen larval forest of the Macaronesian Region Sub-tropical shrubland in Hawaii (not present in the PRA area)	In part	No	Major	Ferriter, 2011
Cultivated habitats	I2: Cultivated areas of gardens and parks	In part	No	Major	Ferriter, 2011

Where introduced in the USA, *L. japonicum* occupies a broad range of natural and disturbed habitats (Kimberly Bohn, personal observation). 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 et al., 2000; Diggs and George, 2006; van Loan, 2006; Langeland et al., 2008; Miller et al., 2010). Floodplain swamps are comparatively uninfested due to lower elevations and resultant regular flooding and inundation (Ferriter 2001). Infestations also occur in xeric sites, but do not appear to expand as rapidly as in more mesic sites, possibly due to the infrequency of appropriate conditions for gametophyte establishment or fertilization. It is a common invader of pine plantations (Ferriter, 2001; van Loan, 2006; Miller et al., 2010), and commonly invades disturbed areas, including along roads and particularly ditches and culverts.

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).

8. Pathways for entry (in order of importance)

Possible pathway	**Plants for planting** **(CBD pathway: Escape from confinement- horticulture)**
Short description explaining why it is considered as a pathway	This may be a likely method of introduction into the PRA area. In North America, *L. japonicum* was introduced as an ornamental plant for homeowners and landscapes and then it has escaped into the wild (Pemberton and Ferriter, 1998; Ferriter, 2001; Clarke, 1936). *L. japonicum* is currently sold as an ornamental plant in the USA and there is some evidence the species is sold within the PRA area (for example: http://www.shadyplants.net/photo_1509809.html). The plant can be purchased via the internet and thus imports into the EPPO region from outside are possible. The species has been listed on online sites, such as ebay.com (https://www.ebay.com/itm/LYGODIUM-JAPONICUM-Japanese-Climbing-Fern-Asian-tropical-fern-nice-large-plant-/191854106170). In Sweden: https://www.slu.se/centrumbildningar-och-projekt/skud/vaxtnamn/). The species is also available via the internet from horticulturalists: https://davesgarden.com/community/trading/search.php?search_text=PFPID:32029 The species is available from suppliers in India: https://plantslive.in/product-tag/buy-online-plants-lygodium-japonicum-plant/
Is the pathway prohibited in the PRA area?	No. The species nor the pathway are regulated within the PRA area.
Has the pest already intercepted on the pathway?	There is some recent indication (from plant exchange website forums) that the species is available in the PRA area but to a low

	extent. One supplier in Ireland has been shown as supplying the species in the past.
What is the most likely stage associated with the pathway?	Plants are likely to be imported as mature plants with growing medium. Spores would easily be spread into the PRA on fertile fronds for these pathways.
What are the important factors for association with the pathway?	The plant may still be widely available for mail order or through nurseries/landscape stores in the PRA.
Is the pest likely to survive transport and storage along this pathway?	Yes, spores also can remain viable for long periods of time.
Can the pest transfer from this pathway to a suitable habitat?	Yes, the extremely small and light spores easily disperse by wind and water into new areas beyond where it was introduced and find suitable habitats.
Will the volume of movement along the pathway support entry?	There is no evidence that the species is commonly imported as into the EPPO region for horticultural purposes. Therefore, it is unlikely that the volume of movement along this pathway will support entry.
Will the frequency of movement along the pathway support entry?	There is no evidence that the species is commonly imported into the EPPO region for horticultural purposes. Therefore, it is unlikely that the frequency of movement along this pathway will support entry. Frequency of trade is not critical for plants for planting as they are expected to be traded in such a way as to allow survival of the plants for a long time. Although the species has been sold within the EPPO region, the number of suppliers (online suppliers) is low.
Rating of the likelihood of entry	*Low* ☐ *Moderate* X *High*
Rating of uncertainty	*Low* *Moderate* ☐ *High* X

As the species is imported as a commodity, all European biogeographical regions will have the same likelihood of entry and uncertainty scores.

Possible pathway	**Contaminant of growing medium associated to other species of plants for planting (CBD pathway: Transport contaminant – Contaminant nursery material)**
Short description explaining why it is considered as a pathway	In the Netherlands gametophytes have been detected in growing media of bonsai plants imported from China (Personal communication van Valkenburg, 2017). Following inspection, of the bonsai consignments, young plants were identified in the growing medium and subsequently identified.

Is the pathway prohibited in the PRA area?	No. The species nor the pathway are regulated within the PRA area.
Has the pest already been intercepted on the pathway?	Yes, in the Netherlands (Personal communication van Valkenburg, 2017). In the Netherlands gametophytes have been detected in growing media of bonsai plants imported from China.
What is the most likely stage associated with the pathway?	Spores, gametophytes and sporophytes.
What are the important factors for association with the pathway?	Import of plant material which will harbour (support) spores. Moisture conditions.
Is the pest likely to survive transport and storage along this pathway?	Yes, if the conditions are suitable. i.e. moist conditions.
Can the pest transfer from this pathway to a suitable habitat?	Yes. Within soil/growing media if the plant that is contaminated is planted out into the natural environment.
Will the volume of movement along the pathway support entry?	The EWG consider that the volume of movement is moderate. The species has been intercepted on two separate occasions where they were specifically looking for the species.
Will the frequency of movement along the pathway support entry?	The EWG consider that the frequency of movement is moderate. The species has been intercepted on two separate occasions where they were specifically looking for the species.
Rating of the likelihood of entry	*Low* ☐ *Moderate* ☐ *High* **X**
Rating of uncertainty	*Low* *Moderate* X *High* ☐

Possible pathway *(in order of importance)*	**Pathway: Contamination of machinery and equipment** **(CBD terminology: transport- stowaway – machinery/equipment)**
Short description explaining why it is considered as a pathway	Machinery and equipment entering the EPPO region could harbor spores shipped from contaminated areas to EU countries without proper decontamination. Spores of *L. microphyllum* have been shown to contaminate management equipment in the US (Hutchinson and Langeland, 2006).
Is the pathway prohibited in the PRA area?	No the pathway is not prohibited along this pathway. There is legislation on the cleaning of machinery in Israel and in Norway. In Norway, when used machinery and equipment intended to be used in agriculture, forestry or horticulture is imported, an official statement must accompany the consignment stating that it has been thoroughly cleaned and if necessary disinfected and that it is free from soil, plant

	remains and contamination from pests. The country exports plant inspection service, or an equivalent official agricultural authority shall issue this certification (Regulations of 1 December 2000 no. 1333 relating to plants and measures against pests). There is no other known compulsory management practice for cleaning agricultural machinery, vehicles or military equipment in the EPPO region. An ISPM 41 Standard (IPPC, 2017) has been adopted on 'International movement of used vehicles, machinery and equipment'.
Has the pest already been intercepted on the pathway?	No, not into the EPPO region but in Hawai'I the Department of Transportation has been responsible for the spread of this species via roadside maintenance.
What is the most likely stage associated with the pathway?	Spores are the most likely stage associated with this pathway Root and rhizome fragments may remain viable for several days if embedded in soil within machinery or equipment, but might likely desiccate and die otherwise.
What are the important factors for association with the pathway?	Spore longevity coupled with high spore production at the source.
Is the pest likely to survive transport and storage along this pathway?	The potential ability of the spores to survive prolonged periods highlight the species is may survive transport along this pathway. In addition, spores are small and can become attached in small crevices – for example tyres. It is only recently, that an ISPM Standard (IPPC, 2017, ISMP 41) has been drafted and adopted on 'International movement of used vehicles, machinery and equipment'. Previous to this, there are no specific biosecurity measures are required for the movement of used vehicles, machinery and equipment'.
Can the pest transfer from this pathway to a suitable habitat?	As much of the equipment or machinery is for potential use in the outdoors, spores would be able to transfer from this pathway to a suitable habitat.
Will the volume of movement along the pathway support entry?	It is unlikely that the volume of movement along this pathway will support entry. It is difficult to estimate the volume of machinery and equipment entering the EPPO region.
Will the frequency of movement along the pathway support entry?	Unknown, it is difficult to estimate the frequency of machinery and equipment entering the EPPO region. However, just one event could lead to the entry of the species and establishment in a region.
Rating of the likelihood of entry	Low X Moderate ☐ High ☐
Rating of uncertainty	Low ☐ Moderate High X

Possible pathway *(in order of importance)*	**Pathway: Contaminant of tourists** **(CBD terminology: Transport – stowaway – people and their luggage/equipment)**
Short description explaining why it is considered as a pathway	Material susceptible to be contaminated is: clothing, boot or shoe treads. Spores of *L. microphyllum* have been shown to contaminate clothing in the US (Hutchinson and Langeland, 2006).
Is the pathway prohibited in the PRA area?	No, currently this pathway is not prohibited in the PRA area and there are more importantly no biosecurity
Has the pest already been intercepted on the pathway?	No, *L. japonicum* has not been intercepted on this pathway.
What is the most likely stage associated with the pathway?	Spores are the most likely stage of the plant to be associated with this pathway
What are the important factors for association with the pathway?	Spore longevity coupled with high spore production at the source.
Is the pest likely to survive transport and storage along this pathway?	The potential ability of the spores to survive prolonged periods highlight the species is may survive transport along this pathway. In addition, spores are small and can become attached in small crevices – for example hiking boots or bags.
Can the pest transfer from this pathway to a suitable habitat?	As much of the clothing and equipment is for potential use in the outdoors, spores would be able to transfer from this pathway to a suitable habitat.
Will the volume of movement along the pathway support entry?	Though there is no data available, the volume of people travelling internationally is considered to be high. There is an estimated 700 million people crossing international borders as tourists each year (McNeely, 2006). Millions of people visit the EPPO region every year from the USA.
Will the frequency of movement along the pathway support entry?	Flights with travellers from all over the world arrive daily in the EPPO region
Rating of the likelihood of entry	Low X Moderate ☐ High ☐
Rating of uncertainty	Low ☐ Moderate High X

Possible pathway *(in order of importance)*	**Pathway: Contamination of timber and wood material** **(CBD terminology: transport- contaminant – timber trade)**
Short description explaining why it is considered as a pathway	Timber and wood material if not debarked could harbor spores if either are shipped from contaminated areas to EU countries without proper phytosanitary measures.

Is the pathway prohibited in the PRA area?	No the pathway is not prohibited There are however a number of phytosanitary requirements for timber and wood products entering the EU from third countries (Forestry Commission, 2018). There is also a ISPM Standard on the International Movement of wood (ISPM 39).
Has the pest already been intercepted on the pathway?	No, the pest has not been intercepted along this pathway.
What is the most likely stage associated with the pathway?	Spores are the most likely stage associated with this pathway.
What are the important factors for association with the pathway?	Spore longevity coupled with high spore production at the source.
Is the pest likely to survive transport and storage along this pathway?	The potential ability of the spores to survive prolonged periods highlight the species is may survive transport along this pathway. In addition, spores are small and can become attached in small crevices – for example bark. However, with phytosanitary measures adopted on wood at the source it is unlikely that any spores would survive this treatment.
Can the pest transfer from this pathway to a suitable habitat?	Timber and wood products may be stored outside following import and in the case of woodchips they would be directly applied to the ground in gardens and other amenity areas.
Will the volume of movement along the pathway support entry?	Timber is imported into the EU from the US https://apps.fas.usda.gov/gats/ExpressQuery1.aspx though the volume varies per year.
Will the frequency of movement along the pathway support entry?	Timber and wood products are frequently imported into the EU from third countries.
Rating of the likelihood of entry	Low X Moderate ☐ High ☐ It should be noted that a low rating of likelihood of entry has been given due to the phytosanitary measures applied to these commodities before export.
Rating of uncertainty	Low ☐ Moderate High X

All European biogeographical regions will have the same likelihood of entry and uncertainty scores.

Note: Pine straw bales can be a vector for the disbursement of viable plant parts and spores (Zeller and Leslie 2004). However, pine straw bales are not shipped from the US or the native range into the EPPO region and therefore this pathway is not considered.

9. Likelihood of establishment in the natural environment in the PRA area

Establishment of *L. japonicum* in its invaded range in the USA is a function of both habitat and climate. Moisture is a key requirement for germination. Warm temperatures stimulate the growth of adult plants (both fronds and vegetative regrowth from rhizomes), and above-ground growth is only limited by frost.

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) but prefers warm temperate conditions that are fully humid with warm to hot summers (code Cf and Cw; CABI 2017; Appendix 4, Figure 1). The invaded range in the southeastern USA has been more specifically classified as Cfa-warm temperate with hot summers having a T_{max} > 22° C (Kottek et al 2006; Appendix 4, Figure 2). Vegetative growth of the species has been observed to initiate after only a few days around 18-20 °C (K. Bohn, personal observation), though peak growth rates of newly established plants occurs in the USA when average monthly temperatures are higher. Germination requires minimum temperatures of 15 °C.

Under the revised Koppen-Geiger climate model by Kottek et al. (2006), several small, distinct areas within the PRA fall under the same Cfa code. A significant portion of the PRA (particularly western Europe) fall under code Cfb (Appendix 4, Figure 3), which is still considered a warm temperate climate though with 'warm' summers, and defined as having at least four months with T> 10° C. Though slightly different than the climate in its invaded range, it is likely that *L. japonicum* could germinate and become introduced in those PRA regions (particularly in moist habitats), though it may not fully establish. Hardiness zones for both the invaded range and most of Europe show strong agreement (Zones 7-9), and weed risk assessments in the US from USDA APHIS (2012) project the species to invade in Zone 6 as well. Using that framework, it suggests sufficient growing days before frost for this species to germinate and establish in the PRA.

Modelling (Appendix 1) suggests the main biogeographical regions where establishment may occur include about a third of the Mediterranean and Black Sea regions, approximately 10% of the Atlantic region, and 5% of the Continental region. In addition, the Macaronesian biogeographical region is suitable (though not included quantitatively in the modelling appendix). Countries that would be affected under this projection include portions of Spain and the Canary Islands, Portugal, and the Azores, France, Italy and coastlines of the Adriatic and Black Sea (Turkey, Georgia and Russia). However, the EWG suggest caution when interpreting the model in view of the prolonged dry summer in the Mediterranean climate with the exception of local micro-climates. It is also important to consider that habitat is also a key component of the distribution of this species in its invaded range in the USA. It grows best in wet habitats such as along rivers and in wetland areas, or in mesic forests when protected under canopy. This should be considered in context to its potential distribution in the biogeographical regions described by the climate model.

Despite the fact that propagules are entering the PRA area, there are no records of the species in the natural environment.

A significant difference exists between the potential risk and the current condition within the PRA area. The model, and the North American experience indicate a significant degree of risk from this species. The lack of current occurrence in the PRA area may encourage people to dismiss the risk. This dichotomy causes the EWG to place the risk as low with a high degree of uncertainty.

Rating of the likelihood of establishment in the natural environment	Low X	*Moderate*	High ☐
Rating of uncertainty	Low ☐	Moderate	High X

10. Likelihood of establishment in managed environment in the PRA area

Lygodium japonicum is unlikely to invade agricultural areas (particularly those treated annually with herbicides), although in part of its native range in the Philippines *L. japonicum* has been listed as a weed of upland rice (Moody, 1989; Galinato et al., 1999). The fast-vertical growth of the vine (Punetha 2000) could also favour growth on shrubs and other vine stocks grown for agricultural purposes. Fronds with support can grow 3.4-6.5 cm per day (Mueller 1983).

If introduced into the PRA, *L. japonicum* may establish in forest plantations, similar as has been observed in the Southeastern USA including conifer and evergreen humid forests with a thick litter layer, or managed deciduous forests in mesic soils.

In the EPPO region, the plant may be cultivated in private collections and botanical gardens (under protection) and has been documented as such (see section 6). Given the lack of any real detailed information in the EPPO region, a moderate level of uncertainty has been given for establishment in the PRA area with a moderate level of uncertainty.

Rating of the likelihood of establishment in the managed environment	*Low* ☐	*Moderate* X	*High* ☐
Rating of uncertainty	*Low*	*Moderate* X	*High* ☐

11. Spread in the PRA area

Natural spread

The ability to produce large numbers of very small, wind borne spores has given *L. japonicum* the capability to disperse over extremely long distances (Ferriter, 2001; Lott et al., 2003). Natural spread rates and distances have not been documented, but likely can be several kilometres or more. Nauman (1987) also suggested that the species appeared to follow rivers in its spread. This is plausible because of the hygroscopic nature of the spores – they will float on water but then adhere to riverbanks as they touch exposed soils or vegetation downstream. In fact, the dust-like spores of *L. japonicum* can adhere to a wide variety of surfaces, including animal fur which may be another natural vector for its spread between sites (Ferriter, 2001; van Loan, 2006; Langeland et al., 2008). Spores of the species are likely to survive via natural spread and transfer to suitable habitats within the vicinity of the parent plants. As the species reproduces by spores which are abundantly produced, the volume of movement will support natural spread.

Human assisted spread

In addition to intended spread of this plant through cultivation as an ornamental, unintended human assisted spread may occur if spores adhere to shoes, clothing or vehicles. In fact, roadways have been documented to be the primary mechanism of spread into natural areas such as state parks and forests (pers comm. Bonn, 2017).

Lygodium japonicum also regrows vegetatively from rhizomes, so human-assisted spread of the below-ground roots and rhizomes is also possible, for example if fragments are transported with soil, on tires of heavy machinery, etc.

None of these spread mechanisms have been documented in the PRA area but if the species does establish over time it could result in an intrinsic rate of spread - similar to that of the Southeastern USA.

Because of the tremendous propagule production and the ability for spores to be transported by both wind and water, if this species becomes established, the potential for rapid spread is significant; hence the high rating given for magnitude of spread in the PRA area. The moderate level of uncertainty reflects that the species is absent from the PRA area and information from the USA is used as a proxy.

Rating of the magnitude of spread in the PRA area	*Low* ☐	*Moderate* ☐	*High* X
Rating of uncertainty	*Low* ☐	*Moderate* X	*High* ☐

12. Impact in the current area of distribution

12.01. Impacts on biodiversity

At present negative impacts have only been reported from the USA. There are no known negative impacts reported in the introduced range. Therefore the uncertainty is moderate.

Lygodium japonicum can grow in sun or shade, damp, disturbed or undisturbed areas in the US. It can grow so dense that it forms a living ‘wall’, leading to the elimination of seedlings and other native vegetation. No long-term studies have been completed to assess the impact of *L. japonicum* on biodiversity. In upland and mesic pine forests of the southeastern USA, a statistically significant though relatively weak negative correlation (p=0.008l; r = -0.3021) was found between native plant richness and increasing fern percent cover (Ulrich 2012). Similar correlations were found with decreases in the Shannon diversity index and increasing fern cover ($p < 0.0001$; $r = -0.4603$). There may be less impact to species diversity on drier upland soils, where *L. japonicum* is more likely to co-mingle with native vegetation, at least during early periods of the infestation. Leichty et al. (2011) also found that *L. japonicum* is likely to compete with mesic pine savannah species in Louisiana, particularly with other native ferns or vines. On wetter sites, such as near rivers and wetlands, heavily infested areas have been observed to create dense mats over ground layer herbaceous vegetation. On those sites, both species abundance and richness will likely decrease more significantly over time. *Lygodium microphyllum* infests cypress swamps and other hydric sites, forming monocultures in the USA. The massive infestation displaces all native flora and fauna, completely changing the ecosystem of the area.

North American experience has shown that the presence of *Lygodium japonicum* alters the fire intensity, extent burned, and the vertical development (serves as ladder fuels) of the fire even in communities where fire plays a natural role. These alterations to fire behaviour enhance the negative impact on native species biodiversity. This is due both to the chemical composition and the volume of *Lygodium* biomass (pers. comm., S. Miller, 2017).

It has further been demonstrated that herbaceous layers in both upland pine and mesic bottomland hardwood forests respond positively when *L. japonicum* is treated with herbicide (Minogue et al., 2010; Bohn et al., 2011). Increases in native vegetation following fern reduction was primarily from expansion of pre-existing ruderal or generalist species, such as broomsedge *(Andropogon virginicus)* and blackberry or dewberry (*Rubus spp*). Two years after control of the fern, percent cover of native plants increased from 18% and 40%, while cover of native plants on non-treated plots continued to decrease at a rate of 20% over two years (Bohn and Minogue 2011).

Rating of magnitude of impact on biodiversity in the current area of distribution	*Low* ☐	*Moderate*	*High* X
Rating of uncertainty	*Low*	*Moderate* X	*High* ☐

12.02. Impact on ecosystem services

In the southeastern USA, the most important impact to the ecosystem is on Lygodium's ability to alter fire regimes in both natural areas and managed plantations. In both settings, surface fires with low flame lengths are used to limit wildfire fuels. In unmanaged longleaf pine ecosystems, surface fires as a result of lighting naturally occurred every 2-3 years. However, where the fern climbs vertically around shrubs and trees, fires can easily spread from into canopy trees from the ground. This has implications for commodity production of timber as well as primary productivity of mature trees in unmanaged ecosystems. The dense mats created by *L. japonicum* may also facilitate the movement of fires into wetland areas that might otherwise be barriers (Munger, 2005). Another important negative impact *L. japonicum* has on ecosystem services is the impact on cultural services by reducing access to forests for recreation and leisure. The aesthetic nature of an invaded habitat is also significantly reduced.

Ecosystem service	**Does the pest impact on this Ecosystem service?** Yes/No	**Short description of impact**	**Reference**
Provisioning	Yes	In North America, *L. japonicum* can impact on timber production and other products from forest plantations. It is also a major problem in pine plantations, causing contamination and harvesting problems for the pine straw industry.	Ferriter, 2001; Miller, 2003
Regulating	Yes	This species impacts a number of regulating services. It is a fire-adapted and fire promoting species that can dramatically increase fire frequency creating more intense crown fires which has the effect of influencing natural hazard regulation. Impacts on primary production of native ground cover species would occur as percent cover of natives is reduced, and particularly where mortality to overstory trees has occurred following altered fire regimes.	Ferriter, 2001, Langeland and Burks, 1998
Cultural	Yes	Impacts aesthetics for hiking and recreation in natural areas by reducing native groundcover. Because *L. japonicum* form impenetrable vine blankets that are unsightly and relatively useless to wildlife, they are	(Handley, 2008; Rowe, 2008).

Ecosystem service	Does the pest impact on this Ecosystem service? Yes/No	Short description of impact	Reference
		likely harming outdoor recreational activities such as wildlife viewing and hunting	

Rating of magnitude of impact on ecosystem services in the current area of distribution	*Low* ☐	*Moderate*	*High* X
Rating of uncertainty	*Low*	*Moderate* X	*High*

12.03. Socio-economic impact

The greatest economic impact *L. japonicum* has is on timber losses due to fire. In the USA, final harvest values for plantation forest range from about $1000-$1200/ac, so a crown fire that might be caused by climbing fern invasion could result in an economic loss of that scale (Georgia Forestry Commission, 2011).

In addition, the species negatively affects the pine straw industry in the southeastern USA. In Alabama and Florida, USA movement of *L. japonicum* spores through the distribution of pine straw for the landscaping industry is highly regulated. If caught, fines can be levied and regulatory action can be taken against such products (ADAI, 2008) and potentially lower product value. Some interest exists for developing a certification program for Lygodium-free pine-straw (FFWCC, 2005).

In the USA, *L. japonicum* has significant economic impacts to forests managed for a variety of products and services, in particular pine plantations managed for pine straw production, which is an $80 million industry in Florida alone (Hodges et al 2005). Furthermore, this vine can act as a ladder fuel, resulting in a significant loss of timber revenue if crown fires develop.

Recreational activities are a significant source of revenue. For example, in 2006 across the USA, hunters spent $740 million on hunting leases, while wildlife watchers spent $45.7 billion on travel and equipment (USFWS, 2006). *Lygodium* species can reduce the access into the forests for hunters and thus have an economic impact.

Treatment to control this species in these and other areas can cost in the range of $100-$150/ac. Based on the experience in Florida, from six years of data and 147 treatment records, the cost per acre ranges from $97 to $247/acre (pers. Comm. S. Miller, 2017).

The economic impacts resulting from *Lygodium japonicum* is rated moderate. This rating is based on primary impacts to other economic activities such as timber production.

Control methods

The species can be controlled using mechanical and chemical methods (see section 3. Risk management).

Rating of magnitude of socio-economic impact in the current area of distribution	*Low* ☐	*Moderate* **X**	*High* ☐
Rating of uncertainty	*Low*	*Moderate* X	*High* ☐

13. Potential impact in the PRA area

Will impacts be largely the same as in the current area of distribution? **In part**

In the current area of distribution, *L. japonicum* has a high negative impact on biodiversity and ecosystem, services. The species has a moderate impact on socio-economy. In North America, *L. japonicum* alters the fire intensity, the extent burned, and the vertical development (serves as ladder fuels) of the fire even in communities where fire plays a natural role. These alterations to fire behaviour enhance the negative impact on native species biodiversity. This is due both to the chemical composition and the volume of *Lygodium* biomass (pers. comm., S. Miller, 2017).

The EWG consider that these impacts will be similar in the PRA if the species can establish but the rating of uncertainty will rise to high. The high rating of uncertainty is associated with the current unknowns of how the biology of the species will be compatible with the climate within the EPPO region. The high rating for the magnitude of impact on biodiversity in the PRA area is based on the potential impacts of the species in the Azores (Macaronesian Region) and thus the geographical area for such impacts is restricted. This prediction is based on the climatic suitability and the invasiveness of other invasive fern species in Europe. For example, *Dicksonia antarctica* Labill. (Soft Tree Fern; Dicksoniaceae) is recorded as invasive in São Miguel Island (Azores archipelago—Portugal). This species is native to south-eastern Australia and Tasmania, where it inhabits high rainfall forests from sea level to 1,000 m a.s.l. (Arosa et al. 2012). Also, *Cyathea cooperi* (Hook. ex F. Muell.) Domin tree fern has been described as invasive in the Azores. In addition, Sanz-Elorza et al. (2005) included *L. japonicum* in the list of the potential invasive species for the Canary Islands.

The EWG consider that in the PRA area, impacts on ecosystem services will be lower compared to the current area of distribution. If introduced into the PRA, *L. japonicum* may establish in forest plantations, similar as has been observed in the Southeastern USA including conifer and evergreen humid forests with a thick litter layer, or managed deciduous forests in mesic soils. A moderate rating is given for impacts on ecosystem services in the PRA area with a with high uncertainty, where the high uncertainty reflects the current unknowns – in particular if the species will exhbit the same invasive behaviour in the PRA area compared to other invasive regions.

The EWG consider that socio-economic impacts will be reduced in the PRA area as the species would not have the opportunity to gain a significant foothold compared to as seen in the areas of the USA, but this is accompanied with a high uncertainty.

There are no human health issues for the species in the PRA area.

13.01. Potential impacts on biodiversity in the PRA area

Rating of magnitude of impact on biodiversity in the PRA area	*Low* ☐	*Moderate*	*High* **X**
Rating of uncertainty	*Low* ☐	*Moderate*	*High* **X**

13.02. Potential impact on ecosystem services in the PRA area

Rating of magnitude of impact on ecosystem services in the PRA area	*Low* ☐	*Moderate* **X**	*High* ☐
Rating of uncertainty	*Low* ☐	*Moderate*	*High* **X**

13.03 Potential socio-economic impact in the PRA area

Rating of magnitude of socio-economic impact in the PRA area	*Low* **X**	*Moderate*	*High* ☐
Rating of uncertainty	*Low* ☐	*Moderate*	*High* **X**

14. Identification of the endangered area

The Expert Working Group (EWG) predicts the endangered area is the Macaronesian (in particular the Azores) and Black Sea (eastern and southern areas) biogeographical regions. This prediction is based on the climatic suitability and other invasive fern species in Europe. For example, *Dicksonia antarctica* Labill. (Soft Tree Fern; Dicksoniaceae) is invasive in São Miguel Island (Azores archipelago - Portugal). This species is native to south-eastern Australia and Tasmania where it inhabits rain forests from sea level to 1,000 m a.s.l. (Arosa et al. 2012). Also, *Cyathea cooperi* Hook. ex F. Muell. (Domin tree fern: Dicksoniaceae) has been described as invasive in the Azores. In addition, Sanz-Elorza et al. (2005) included *L. japonicum* in a list of the potential invasive species for the Canary Islands. The species distribution model predicts suitability in part of the Atlantic biogeographical region (Portugal, northwest Spain south east of France). Although in these regions the model shows it has a lower suitability, the EWG consider that the presence of large plantation forestry and the humidity from the Atlantic will increase the suitability to establishment of *L. japonicum* so that part of the Atlantic biogeographical region deserves to be included in the endangered area. For example, areas like the Sierra de Buçaco forest might be suitable, as they already host plants of *Dicksonia antarctica* Labill.

The species distribution model (Appendix 1) predicts a high suitability along the Adriatic coast and the eastern Mediterranean biogeographical region (Italy, Croatia Albania (non-EU) and Greece), and a small part of the continental biogeographical region. However, the EWG consider these areas are less suitable for the establishment of a fern species due to the prevalence of agricultural land-use and high evaporation rates in the summer in combination with low rainfalls. For similar reasons, the Atlas Mountains in North Africa, the mountains on Crete island, and Mount Lebanon were not included by the EWG in the endangered area.

15. Climate change

15.01. Define which climate projection you are using from 2050 to 2100*

Climate projection: RCP8.5 is the most extreme of the RCP scenarios, and may therefore represent the worst-case scenario for reasonably anticipated climate change. It assumes an increase in atmospheric CO2 concentrations to approximately 850 ppm by the 2070s. Climate models suggest this would result in an increase in global mean temperatures of 3.7 °C by the end of the 21st century.

15.02. Which component of climate change do you think is the most relevant for this organism?

Temperature ***(yes)***	*Precipitation* ***(yes)***	*C0$_2$ levels* ***(no)***
Sea level rise ***(no)***	*Salinity* ***(no)***	*Nitrogen deposition* ***(no)***
Acidification ***(no)***	*Land use change* ***(yes)***	

15.03. Consider the influence of projected climate change scenarios on the invasive alien species.

The influence of projected climate change scenarios has not been taken into account in the overall scoring of the risk assessment based on the high levels of uncertainty with future projections.

Are the **pathways** likely to change due to climate change? **(If yes, provide a new rating for likelihood and uncertainty)**	**Reference**
The main pathway for entry INTO the PRA would not change, as this would mostly be due to movement via the ornamental or landscaping trade. Plants for planting: Moderate with a high uncertainty Contamination of plants for planting: High with low uncertainty	Appendix 1 and EWG opinion
Is the **likelihood of establishment** likely to change due to climate change? **(If yes, provide a new rating for likelihood and uncertainty)**	**Reference**
Yes. Climate conditions currently exist for its initial germination but, the slight increases in temperature could initiate growth sooner allowing the plant to become established sooner. In addition, the area of establishment increases in the PRA area (see Appendix 1, Fig. 7). Natural environment: increases from low to moderate with high uncertainty Managed environment: remains moderate with uncertainty increased from moderate to high.	Appendix 1 and EWG opinion
Is the magnitude of **spread** likely to change due to climate change? **(If yes, provide a new rating for the magnitude of spread and uncertainty)**	**Reference**
No. Light spores already disperse and spread readily by wind and water, and a significant change in the magnitude of spread is not likely. One potential impact of climate change would be on an increased likelihood of high intensity precipitation leading to flooding or rivers, which could then potentially move spores further downstream or up river bank sides then under normal stream water flows. Spread remains High with Moderate uncertainty	Appendix 1 and EWG opinion
Will **impacts** in the PRA area change due to climate change? **(If yes, provide a new rating of magnitude of impact and uncertainty for biodiversity, ecosystem services and socio-economic impacts separately)**	**Reference**
No. If there is an increase in the number of growing degree days before frost, then increased growth of the vine could smother/ impact more native species. Impact remains the same: Biodiversity and the environment: High with high uncertainty Ecosystem services: Moderate with high uncertainty Socio-economic impacts: Low with high uncertainty.	Appendix 1 and EWG opinion

16. Overall assessment of risk

Lygodium japonicum presents a moderate phytosanitary risk for the endangered area within the EPPO region with a high uncertainty.

The overall likelihood of *L. japonicum* entering the EPPO region is moderate – based on evidence that the species is intercepted as a contaminant of bonsai plants from China and there is some evidence the species is traded.

Since *L. japonicum* is not yet documented within the PRA, likelihood of entry is most dependent on its introduction as an ornamental/landscape feature. If so, given the habitats and climate of the PRA, this could readily be followed by escape and introduction into natural ecosystems, similarly as to its initial establishment in North America and Australia.

Pathways for entry:

Plants for planting

Rating of the likelihood of entry for the pathway, plants for planting	*Low* ☐	*Moderate* **X**	*High* ☐
Rating of uncertainty	*Low*	*Moderate* ☐	*High* X

Contaminant of plants for planting

Rating of the likelihood of entry for the pathway, plants for plating	*Low* ☐	*Moderate*	*High* X
Rating of uncertainty	*Low*	*Moderate* X	*High* ☐

Contaminant of machinery and equipment

Rating of the likelihood of entry for the pathway Contaminant of machinery and equipment	*Low* X	*Moderate*	*High* ☐
Rating of uncertainty	*Low*	*Moderate* ☐	*High* X

Contaminant of tourists

Rating of the likelihood of entry for the pathway: Contaminant of tourists	*Low* X	*Moderate*	*High* ☐
Rating of uncertainty	*Low*	*Moderate* ☐	*High* X

Contaminant of timber and wood material

Rating of the likelihood of entry for the pathway: Contaminant of timber and wood material	*Low* X	*Moderate*	*High* ☐
Rating of uncertainty	*Low*	*Moderate* ☐	*High* X

Likelihood of establishment in the natural environment in the PRA area

Rating of the likelihood of establishment in the natural environment	*Low* X	*Moderate* ☐	*High*
Rating of uncertainty	*Low*	*Moderate* ☐	*High* X

Likelihood of establishment in managed environment in the PRA area

Rating of the likelihood of establishment in the managed environment	*Low* ☐	*Moderate* X	*High*
Rating of uncertainty	*Low*	*Moderate* X	*High* ☐

Magnitude of Spread

Rating of the magnitude of spread	*Low* ☐	*Moderate* ☐	*High* X
Rating of uncertainty	*Low* ☐	*Moderate* X	*High* ☐

Impacts in the current area of distribution

Biodiversity

Rating of the magnitude of impact on biodiversity in the current area of distribution	*Low* ☐	*Moderate* ☐	*High* X
Rating of uncertainty	*Low*	*Moderate* X	*High* ☐

Ecosystem services

Rating of the magnitude of impact on ecosystem services in the current area of distribution	*Low* ☐	*Moderate*	*High* X
Rating of uncertainty	*Low* ☐	*Moderate* X	*High* ☐

Socio-economic impacts

Rating of the magnitude of socio-economic impact in the current area of distribution	*Low* ☐	*Moderate* X	*High* ☐
Rating of uncertainty	*Low*	*Moderate* X	*High* ☐

Potential impact in the PRA area

Will impacts be largely the same as in the current area of distribution **In part**

Rating of magnitude of impact on biodiversity in the PRA area	*Low* ☐	*Moderate*	*High* X
Rating of uncertainty	*Low* ☐	*Moderate*	*High* X

13.02. Potential impact on ecosystem services in the PRA area

Rating of magnitude of impact on ecosystem services in the PRA area	*Low* ☐	*Moderate* X	*High* ☐
Rating of uncertainty	*Low* ☐	*Moderate*	*High* X

13.03 Potential socio-economic impact in the PRA area

Rating of magnitude of socio-economic impact in the PRA area	*Low* **X**	*Moderate*	*High* ☐
Rating of uncertainty	*Low* ☐	*Moderate*	*High* X

17. Uncertainty

There is a high level of uncertainty detailed in this PRA given the fact the species is not currently established in the PRA area. A significant difference exists between the potential risk and the current condition within the PRA area. Because of the tremendous propagule production and the ability for spores to be transported by both wind and water, if this species becomes established, the potential for rapid spread is significant but the moderate level of uncertainty given for spread reflects that the species is absent (from the natural environment) from the PRA area and information from the US is used as a proxy.

The model, and the North American experience indicate a significant degree of risk from this species. The lack of current occurrence in the PRA area may encourage people to dismiss the risk. This dichotomy causes the team to place the risk as low with a high degree of uncertainty. In the EPPO region, the plant may be cultivated in private and botanical gardens (under protection) and has been documented as such (see section 6). Again, given the lack of any real detailed information in the EPPO region, a moderate level of uncertainty has been given for establishment in the PRA area with a moderate level of uncertainty.

While this is preferable to not accounting for recording bias at all, a number of factors mean this may not be the perfect null model for species occurrence:

- The GBIF API query used to did not appear to give completely accurate results. For example, in a small number of cases, GBIF indicated no Tracheophyte records in grid cells in which it also yielded records of the focal species.
- We used additional data sources to GBIF, which may have different biases to the GBIF records.

Other variables potentially affecting the distribution of the species, such as soil nutrients and land use, were not explicitly included in the model.
The climate change scenario used is the most extreme of the four RCPs. However, it is also the most consistent with recent emissions trends and could be seen as worst case scenario for informing risk assessment.

18. Remarks

Inform EPPO or IPPC or EU

- Inform NPPOs that surveys should be conducted to monitor the endangered area for the presence of the species.

Inform industry, other stakeholders

- Encourage industry to assist with public education campaigns associated with the risk of non-native plants. Encourage industry to sell native species as alternatives to non-natives.

Specify if surveys are recommended to confirm the pest status

- Studies on the thermal tolerance of the spores.

19. REFERENCES

Anderson, M.L. 1921. Lygodium japonicum in South Carolina. American Fern Journal 11(3): 90-91.

APNI, 2014. Australia plant names index. Australian National Botanic Gardens, Canberra, Australia. http://www.anbg.gov.au/cgi-bin/apni?taxon_id=46576

Arosa, M.L., R.S. Ceia, L.G. Quintanilla, and J.A. Ramos. 2012. The tree fern Dicksonia antarctica invades two habitats of European conservation priority in Sao Miguel Island, Azores. Biological Invasions 14(7): 1317-1323.

Barcelona JF; Dolotina NE; Madroñero GS; Granert WG; Sopot DD, 2006. The ferns and fern allies of the karst forests of Bohol Island, Philippines. American Fern Journal, 96(1):1-20.

Bennett CA, Pemberton RW, 2008. Neomusotima fuscolinealis (Lepidoptera: Pryalidae) is an unsuitable biological control agent of Lygodium japonicum. Florida Entomologist, 91(1):26-29

Bohn, K.K., P.J. Minogue, and E.C. Pieterson. 2011. Control of invasive Japanese climbing fern (Lygodium japonicum) and response of native ground cover during restoration of a disturbed longleaf pine ecosystem. Ecological Restoration 29:346-356.

Bohn, K.K. and M. Thetford. 2014. Effect of herbicide type, application timing, and lightintensity on Japanese climbing fern reproduction. Florida Fish and Wildlife Conservation Commission, Bureau of Invasive Species Management Final Report. 13 pp.

Brown, C.A. and D.S. Correll. 1942. Ferns and fern allies of Louisiana. Baton Rouge: Louisiana Stat University Press. 186pp.

CABI. 2017. Lygodium japonicum. www.cabi.org/isc/datasheet/31783. Accessed February 2017

Chang C-S, Kim H, Chang K, 2014. Provisional checklist of vascular plants for the Korea peninsula flora (KPF). Seoul, South Korea: DesignPost, 561 pp

Cho HJ, Bae WJ, Kim SJ, Hong SH, Lee JY, Hwang TK, Choi YJ, Hwang SY, Kim SW, 2014. The inhibitory effect of an ethanol extract of the spores of Lygodium japonicum on ethylene glycol-induced kidney calculi in rats. Urolithiasis, 42(4):309-315

Chong KY, Tan HT, Corlett RT, 2009. A checklist of the total vascular plant flora of Singapore: native, naturalised and cultivated species. Singapore: Raffles Museum of Biodiversity Research, National University of Singapore, 273 pp

Correll, D.S. 1938. A county check-list of Florida ferns and fern allies. American Fern Journal 28(2): 46-54.

Clute WN, 1903. Fernwort notes - IV. Fern Bulletin, 11:105-107

Diamond Jr AR, Woods M, 2007. Pteridophytes of southeast Alabama. Journal of the Alabama Academy of Science, 78(1):21-28.

Diddell, M.W. 1941. New stations for Florida pteridophytes. American Fern Jl 31(2): 48-52.

Diggs GM, George R, 2006. Illustrated flora of east Texas, volume 1. Fort Worth, Texas, USA: Botanical Research Institute of Texas.

Dilmy A, 1965. Pioneer plants found one year after the 1963 eruption of Agung in Bali. Pacific Science, 19(4):498-501.

Duan YingHui, Dai Yi, He RongRong, Kurihara H, Li YaoLan, Yao XinSheng, 2012. A new phenylpropanoid glucoside from the aerial parts of Lygodium japonicum. Journal of Asian Natural Products Research, 14(3):286-292.

Eisenberg A, Amato PJ, Tao D, 2009. Kam Guilzhouh nyim Guangxxih di Benxtux Wenchual nyim Zihyuanc dih Gonxliix: Kam local indigenous knowledge and sustainable resource management in Guizhou and Guangxi provinces, China. Ethnobotany Research and Applications, 7:67-113.

EPPO, 2014. PQR database. Paris, France: European and Mediterranean Plant Protection Organization. http://www.eppo.int/DATABASES/pqr/pqr.htm

Ferriter, A., Ed. 2001. Lygodium management plan for Florida. 1st Ed. Florida Exotic Pest Plant Council, Lygodium Task Force.

Ferns of Thailand, 2014. http://rbg-web2.rbge.org.uk/thaiferns/index.htm

Flora of China Editorial Committee, 2014. Flora of China. St. Louis, Missouri and Cambridge, Massachusetts, USA: Missouri Botanical Garden and Harvard University Herbaria.http://www.efloras.org/flora_page.aspx?flora_id=2

Flora of Japan, 2015. Flora of Japan database. http://foj.c.u-tokyo.ac.jp/gbif/foj/

Forestry Commission. 2014. *Importing woodchip: Requirements for landing regulated material into Great Britain* 2014. www.forestry.gov.uk/pdf/FCPH006.pdf/$FILE/FCPH006.pdf. [accessed 14 Auguts 2018]

Galinato MI, Moody K, Piggin CM, 1999. Upland rice weeds of South and Southeast Asia. Manila, Philippines: International Rice Research Institute.

Garrison H J, 1998. A monographic study of Lygodium Swartz (Pteridophyta: Lygodiaceae). Doctor of Philosophy Dissertation. New York, USA: The City University of New York.

Georgia Forestry Commission. 2011. Does reforestation pay? Loblolly pine for traditional products. http://www.gfc.state.ga.us/utilization/economic-impacts/DoesReforestationPayLoblollyPineforTraditionalProducts-Mar2011rev.pdf accessed 3/2017.

Graves, E.W. 1920. The fern flora of Alabama. American Fern Journal 10(3): 65-82.

Harper, R.M. 1905. The fern flora of Georgia. The Fern Bulletin 13(1): 1-17.

Henderson L, 2007. Invasive, naturalized and casual alien plants in southern Africa: a summary based on the Southern African Plant Invaders Atlas (SAPIA). Bothalia, 37(2):215-248.

Hodges, A.W., W. D. Mulkey, J. R. Alavalapati, D. R. Carter, and C. F. Kiker. 2005. Economic impacts of the forest industry in Florida, 2003. The University of Florida, Institute of Food and Agricultural Sciences. Final Report to the Florida Forestry Association. 3 pp

Hosking JR, Conn BJ, Lepschi BJ, Barker CH, 2011. Plant species first recognised as naturalised or naturalising for New South Wales in 2004 and 2005. Cunninghamia: A Journal of Plant Ecology for Eastern Australia, 12(1):85-114

Holttum RE, 1959. Flora Malesiana. Series II. Pteridophyta (Ferns and Fern Allies) Vol. Part I. Gleicheniaceae, Schizaeaceae and Isoetaceae. Leyden, The Netherlands: Noordhoff International Publishing, 64 pp.

Hutchinson JT, Langeland KA, 2006. Potential spread of Lygodium microphyllum spores by herbicide applicators. Wildland Weeds, Spring 2006.

Hutchinson JT, Langeland KA, 2014. Tolerance of Lygodium microphyllum and L. japonicum spores and gametophytes to freezing temperature. Invasive Plant Science and Management, 7(2):328-335.

Hutchinson JT, Langeland KA, 2010. Review of two non-native, invasive climbing ferns (*Lygodium japonicum* and *L. microphyllum*), sympatric records and additional distribution records from Florida. American Fern Journal, 100(1):57-66.

Hutchinson, JT, Langeland KA. 2006. Survey of control measures on old world climbing fern (*Lygodium microphyllyum*) in southern Florida. Florida Scientist 69(4): 217-223.

ISPM 39. 2017. International movement of wood. Rome, IPPC, FAO.

Khan MA, Khan MA, Mazar Hussain, Ghulam Mujtaba, 2010. An ethnobotanical inventory of Himalayan region Poonch Valley Azad Kashmir (Pakistan). Ethnobotany Research and Applications, 8:107-124.

Koop AL, Fowler L, Newton LP, Caton BP, 2011. Development and validation of a weed screening tool for the USA. Biological Invasions, 14(2):273-294

Kotek, M. J. Grieser, C. Beck, B. Rudolf, and F. Rubel. 2006. World map of the Koppen-Geiger climate classification updated. Meteorologische Zeitschrift 15(3): 259-263.

Langeland, K.A. and Burks, K.C., 1998. Identification and Biology of Non-native Plants in Florida's Natural Areas University of Florida Gainesville.

Langeland KA, Cherry HM, McCormick CM, Craddock Burks KA, 2008. Identification and biology of non-native plants in Florida's natural areas, 2nd edition. Gainesville, Florida, USA: University of Florida, 210 pp.

Langeland KA, Hutchinson J, 2013. Natural area weeds: old world climbing fern (Lygodium microphyllum). IFAS Extension, SS-AGR-21. Florida, USA: University of Florida.

Leichty, E. R., B. J. Carmichael, and W. J. Platt. 2011. Invasion of a southeastern pine savanna by Japanese climbing fern. Castanea 76:293-299.

Lindsay S, Middleton D, 2013. Ferns of Thailand, Laos and Cambodia.http://rbg-web2.rbge.org.uk/thaiferns

Lott, M.S., Volin, J.C., Pemberton, R.W., and D.F. Austin. 2003. The reproductive biology of the invasive ferns Lygodium microphyllum and L. japonicum (Schizaceae): Implications for invasive potential. American Journal of Botany 90(8): 1144-1151.

Macdonald IAW, Reaser JK, Bright C, Neville LE, Howard GW, Murphy SJ, Preston G]. Cape Town, South Africa: Global Invasive Species Programme, 125 pp. http://www.gisp.org

Maideen H, Latiff A, Bidin A, Damanhuri A, Jaman R, 2004. Notes on the genus Lygodium Sw. (Schizaeaceae) in Malaysia. Fern Gazette, 17(2):53-57

Mall B, Gauchan DP, Chhetri RB, 2015. An ethnobotanical study of medicinal plants used by ethnic people in Parbat district of western Nepal. http://www.ncbi. Journal of Ethnopharmacology. http://www.ncbi.nlm.nih.gov/pubmed/25571849

Manandhar NP, 1995. An inventory of some herbal drugs of Myagdi District, Nepal. Economic Botany, 49(4):371-379

Matsuda H, Yamazaki M, Naruto S, Asanuma Y, Kubo M, 2002. Anti-androgenic and hair growth promoting activities of Lygodii Spora (spore of Lygodium japonicum) I. Active constituents inhibiting testosterone 5alpha-reductase. Biological & Pharmaceutical Bulletin, 25(5):622-626.

Miller JH, Manning ST, Enloe SF, United U, Forest F, Southern RR, 2010. A management guide for invasive plants in southern forests. General Technical Report - Southern Research Station, USDA Forest Service, No.SRS-13: 120 pp.

Minogue, P.M., Jones, S., Bohn, K.K., and R.L. Williams. 2009a. Biology and control of Japanese climbing fern (Lygodium japonicum). EDIS Publication #FOR 218. Gainesville, FL: Institute of Food and Agricultural Sciences, University of Florida.

Minogue, P.J., K.K. Bohn, A. Osiecka, and D.K. Lauer. 2010. Japanese climbing fern (Lygodium japonicum) management in Florida's bottomland hardwood forests. Invasive Plant Science and Management 3:246-252.

Missouri Botanical Garden, 2015. Tropicos database. St. Louis, Missouri, USA: Missouri Botanical Garden. http://www.tropicos.org/

Moody K, 1989. Weeds reported in rice in South and Southeast Asia. Los Banos, Philippines: IRRI, 442.

Munger GT, 2005. Lygodium spp. Fire Effects Information System. USA: USDA Forest Service. http://www.fs.fed.us/database/feis/plants/fern/lygspp/all.html

Mueller, R.J. 1983. Indeterminate growth and ramification of the climbing leaves of Lygodium japonicum (Schizaeceae). American Journal of Botany 70(5): 682-690.

Nauman. C.E. 1993. Lygodium C. Presl. In, Flora of North America Editorial Committee, Eds., Flora of North America: Volume 2, Pteridophytes and Gymnosperms. Oxford University Press, New York.

Nauman CE, 1987. Schizaeaceae in Florida. Sida, 12(1):69-74.

Ohwi J, 1965. Flora of Japan [in English] [ed. by Meyer, F. G. \Walker, E. H.]. Washington D.C, USA: Smithsonian Institution.

Orchard AE, McCarthy PM, 1998. Flora of Australia. Volume 48. Ferns, Gymnosperms and allied groups. Melbourne, Australia: CSIRO

Peck JH, 2011. New and noteworthy additions to the Arkansas fern flora. Phytoneuron, 30:1-33

PIER, 2014. Pacific Islands Ecosystems at Risk. Honolulu, USA: HEAR, University of Hawaii. http://www.hear.org/pier/index.html

Punetha, N. 2000. Phenology of the climbing leaf of Lygodium japonicum (Thunb.) SW. (Schizaeaceae). Phytomorphylogy 50(1): 75-85.

Puri HS, 1970. Indian Pteridophytes used in folk remedies. American Fern Journal, 60(4): 137-143.

Queensland Government, 2015. Fact Sheet: Lygodium japonicum., Australia: QLD Government. http://keyserver.lucidcentral.org/weeds/data/03030800-0b07-490a-8d04-0605030c0f01/media/Html/Lygodium_japonicum.htm

Reutter L, 1923. Traite de matiere medicale: drogues vegetales, drogues animales et de chimie vegetale. [english title not available]. Paris, France: J.B. Baillière.

Roy, H.E., Adriaens, T., Aldridge, D.C., Bacher, S., Bishop, J.D.D., Blackburn, T.M., Branquart, E., Brodie, J., Carboneras, C., Cook, E.J., Copp, G.H., Dean, H.J., Eilenberg, J., Essl, F., Gallardo, B., Garcia, M., García-Berthou, E., Genovesi, P., Hulme, P.E., Kenis, M., Kerckhof, F., Kettunen, M., Minchin, D., Nentwig, W., Nieto, A., Pergl, J., Pescott, O., Peyton, J., Preda, C., Rabitsch, W., Roques, A., Rorke, S., Scalera, R., Schindler, S., Schönrogge, K., Sewell, J., Solarz, W., Stewart, A., Tricarico, E., Vanderhoeven, S., van der Velde, G., Vilà, M., Wood, C.A., Zenetos, A. (2015) Invasive Alien Species - Prioritising prevention efforts through horizon scanning ENV.B.2/ETU/2014/0016. European Commission.

Singh S, Panigrahi G, 1984. Systematics of genus Lygodium Sw. (Lygodiaceae) in India. Plant Sciences, 93(2):119-133.

Sundell E, 1986. Noteworthy vascular plants from Arkansas. Castanea, 51(3):211-215.
Srivastava R, Uniyal PL, 2013. Developmental study of two species of a homosporous climbing fern, Lygodium. In: Climate change and Himalayas: natural hazards and mountain resources [ed. by Sundaresan, J. \Gupta, P. \Santosh, K. M. \Bhoojh, R.]. Jodhpur, India: Scientific Publishers, 86-93.

Tanner, R., Branquart, E., Brundu, G., Buholzer, S., Chapman, D., Ehret, P., Fried, G., Starfinger, U. and van Valkenburg, J. (2017). The prioritisation of a short list of alien plants for risk analysis within the framework of the Regulation (EU) No. 1143/2014. NeoBiota, 35, p.87.

Thorne, R.F. 1949. The flora of southwestern Georgia. Dissertation. Cornell University.

Uddin MG, Mahal M, Pasha MK, 1997. Taxonomic account of genus Lygodium Sw. (Lygodiaceae) in Bangladesh. Indian Fern Journal, 14(1-2):33-37.

Ulrich, J. 2012. Japanese climbing fern (lygodium japonicum) propagation and invasion: effect of environmental variables on spore germination and consequences of establishment for understory plant communities and habitat quality. Master's Thesis, University of Florida. 70 pp.

USDA, 2009. Lygodium microphyllum (Old world climbing fern), Lygodium japonicum inspection (Japanese climbing fern), and Lygodium flexuosum: weed risk assessment. Raleigh, North Carolina, USA: USDA Animal and Plant Health Inspection Service

USDA Plant Database. 2017. https://plants.usda.gov/core/profile?symbol=LYJA. Accessed 2/2017.

Van Loan, A.N. 2006b. Aspects of the invasion and management of Japanese climbing fern (Lygodium japonicum) in Southeastern forests. Masters thesis. University of Florida.

Wardani W; Jaenudin J, 2014. Proceedings of the 4th International Conference on Global Resource Conservation & 10th Indonesian Society for Plant Taxonomy Congress. 173-184.

Wee YC, Chua LL, 1988. Lygodium japonicum in Singapore. Fern Gazette, 13(4):246-247.

Wilson KA, 1996. Alien ferns in Hawaii. Pacific Science, 50(2):127-141.

Wunderlin RP, Hansen BF, Edwin LB, Fischer JB, 2000. Flora of Florida. Volume 1: Pteridophytes and Gymnosperms. Gainesville, Florida, USA: University Press of Florida, 384 pp.

Wunderlin, R.P. 2001. Guide to the vascular plants of Florida. Gainesville: University Press of Florida. 806pp.

Yumkham SD, Singh PK, 2011. Less known ferns and fern-allies of Manipur with ethnobotanic uses. Indian Journal of Traditional Knowledge, 10(2):287-291.

Zeller, M., and D. Leslie. 2004. Japanese climbing fern controls in planted pine. Wildland Weeds 7: 6-9.

Zheng H, Wu Y, Ding J, Binion D, Fu W, Reardon R, 2006. Invasive plants established in the United States that are found in Asia and their associated natural enemies. General Technical Report Number FHTET 2005-15, 1. Beijing, China: Chinese Academy of Sciences.

Appendix 1: Projection of climatic suitability for *Lygodium japonicum* establishment

Aim

To project the suitability for potential establishment of *Lygodium japonicum* in the EPPO region, under current and predicted future climatic conditions.

Data for modelling

Climate data were taken from 'Bioclim' variables contained within the WorldClim database (Hijmans *et al.*, 2005) originally at 5 arcminute resolution (0.083 x 0.083 degrees of longitude/latitude) and aggregated to a 0.25 x 0.25 degree grid for use in the model. We used three climate variables commonly limiting plant distributions at global scale:

- Mean temperature of the warmest quarter (Bio10 °C) reflecting the growing season thermal regime.
- Mean minimum temperature of the coldest month (Bio6 °C) reflecting exposure to frost.
- Climatic moisture index (ratio of annual precipitation Bio12 to potential evapotranspiration) (ln + 1 transformed). Monthly potential evapotranspirations were estimated from the WorldClim monthly temperature data and solar radiation using the simple method of Zomer *et al.* (2008), based on the Hargreaves evapotranspiration equation (Hargreaves, 1994).

To estimate the effect of climate change on the potential distribution, equivalent modelled future climate conditions for the 2070s under the Representative Concentration Pathway (RCP) 8.5 were also obtained. RCP8.5 is the most extreme of the RCP scenarios, and may therefore represent the worst case scenario for reasonably anticipated climate change. It assumes an increase in atmospheric CO_2 concentrations to approximately 850 ppm by the 2070s. Climate models suggest this would result in an increase in global mean temperatures of 3.7 °C by the end of the 21st century. The above variables were obtained as averages of outputs of eight Global Climate Models (BCC-CSM1-1, CCSM4, GISS-E2-R, HadGEM2-AO, IPSL-CM5A-LR, MIROC-ESM, MRI-CGCM3, NorESM1-M), downscaled and calibrated against the WorldClim baseline (see http://www.worldclim.org/cmip5_5m).

In addition, the following habitat variables were obtained and ln+1 transformed for modelling:

- Tree % cover was estimated from the MODerate-resolution Imaging Spectroradiometer (MODIS) satellite continuous tree cover raster product, produced by the Global Land Cover Facility (http://glcf.umd.edu/data/vcf/). The raw product contains the percentage cover by trees in each 0.002083 x 0.002083 degree grid cell. We aggregated this to the mean percent cover in our 0.25 x 0.25 degree grid cells and applied a ln+1 transformation for modelling. As a vine, *L. japonicum* colonises trees and is reported to occur in a range of forest types (CABI, 2015).
- Lake and wetlands % cover estimated from the Global Lakes and Wetlands Database: Lakes and Wetlands Grid (Level 3), which was originally in a 0.008333 x 0.008333, aggregated to the 0.25 x 0.25 grid as the percentage of constituent pixels classified as wetlands and ln+1 transformed for modelling. Wetlands include lakes, reservoirs, rivers, marshes and floodplains, swamp forest, flooded forest, coastal wetlands, bogs, fens and mires, intermittent wetlands and mixed pixels with wetlands and other land cover types.
- Human Influence Index (ln+1 transformed) estimates the relative anthropogenic influence based on nine global data layers covering human population pressure (population density), human land use and infrastructure (built-up areas, nighttime lights, land use/land cover), and human access (coastlines, roads, railroads, navigable rivers) (Wildlife Conservation Society - WCS & Center for International Earth Science Information Network - CIESIN - Columbia University, 2005). *L. japonicum* is associated with human-disturbed habitats in both the native and invaded ranges (CABI, 2015).

Species occurrences were obtained from the Global Biodiversity Information Facility (www.gbif.org), USGS Biodiversity Information Serving Our Nation (BISON), the Integrated Digitized Biocollections (iDigBio), iNaturalist and EDDMaps. We scrutinised occurrence records from regions where the species is not known to be well established and removed any that appear to be casual or planted specimens or where the georeferencing was too imprecise (e.g. records referenced to a country or island centroid). The remaining records were gridded at a 0.25 x 0.25 degree resolution for modelling (Figure 1).

In total, there were 974 grid cells with recorded occurrence of *L. japonicum* available for the modelling (Figure 1).

Figure 1. Occurrence records obtained for *Lygodium japonicum* used in the model.

Species distribution model

A presence-background (presence-only) ensemble modelling strategy was implemented using the BIOMOD2 R package v3.3-7 (Thuiller *et al.*, 2014, Thuiller *et al.*, 2009). These models contrast the environment at the species' occurrence locations against a random sample of the global background environmental conditions (often termed 'pseudo-absences') in order to characterise and project suitability for occurrence. This approach has been developed for distributions that are in equilibrium with the environment. Because invasive species' distributions are not at equilibrium and subject to dispersal constraints at a global scale, we took care to minimise the inclusion of locations suitable for the species but where it has not been able to disperse to. Therefore the background sampling region included:

- The native distribution of *L. japonicum* was assumed to be Asia and Papua New Guinea, excluding Singapore where the species is introduced (CABI, 2015). Countries where *L. japonicum* is native (CABI, 2015) but which returned no distribution records were also omitted (Bangladesh, India, Bhutan, North Korea, Pakistan and Sri Lanka); AND
- A relatively small 50 km buffer around all non-native occurrences, encompassing regions likely to have had high propagule pressure for introduction by humans and/or dispersal of the species; AND
- Regions where we have an *a priori* expectation of high unsuitability for the species (see Fig. 3). Absence from these regions is considered to be irrespective of dispersal constraints. We specified the following rules for defining unsuitability:
    - Mean minimum temperature of the coldest month (Bio6) < -10 °C, reflecting exposure to extreme frost. *L. japonicum* foliage exhibits necrosis after hard frosts but re-sprouting occurs from rhizomes below the soil, indicating a level of frost tolerance

(Hutchinson & Langeland, 2010). However, the coldest location with a presence in our dataset has Bio6 = -9.4 °C.

- Mean temperature of the warmest quarter (Bio10 °C) < 12 °C, which we assume would be too cold to sustain growth. A recent study indicates spore germination does not occur at 10 °C (Ulrich *et al.*, in review). The coldest occurrence in our data has Bio10 = 12.9 °C.
- Climatic moisture index < 0.4, reflecting extreme drought and a lack of preferred moist habitats. The driest occurrence in the data has climatic moisture index = 0.427.

Within this sampling region there will be substantial spatial biases in recording effort, which may interfere with the characterisation of habitat suitability. Specifically, areas with a large amount of recording effort will appear more suitable than those without much recording, regardless of the underlying suitability for occurrence. Therefore, a measure of vascular plant recording effort was made by querying the Global Biodiversity Information Facility application programming interface (API) for the number of phylum Tracheophyta records in each 0.25 x 0.25 degree grid cell (Figure 2). The sampling of background grid cells was then weighted in proportion to the Tracheophyte recording density. Assuming Tracheophyte recording density is proportional to recording effort for the focal species, this is an appropriate null model for the species' occurrence.

To sample as much of the background environment as possible, without overloading the models with too many pseudo-absences, 10 background samples of 10,000 randomly chosen grid cells were obtained (Figure 3).

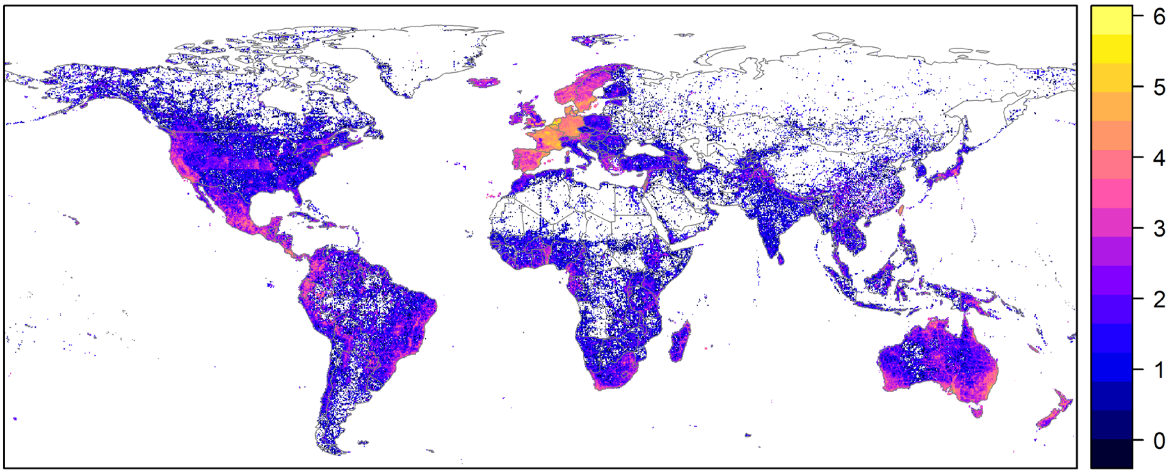


Figure 2. The density of Tracheophyta records per 0.25 x 0.25 degree grid cell held by GBIF, $\log_{10}$ transformed. These densities were used to weight the sampling of background locations for modelling to account for recording effort biases.

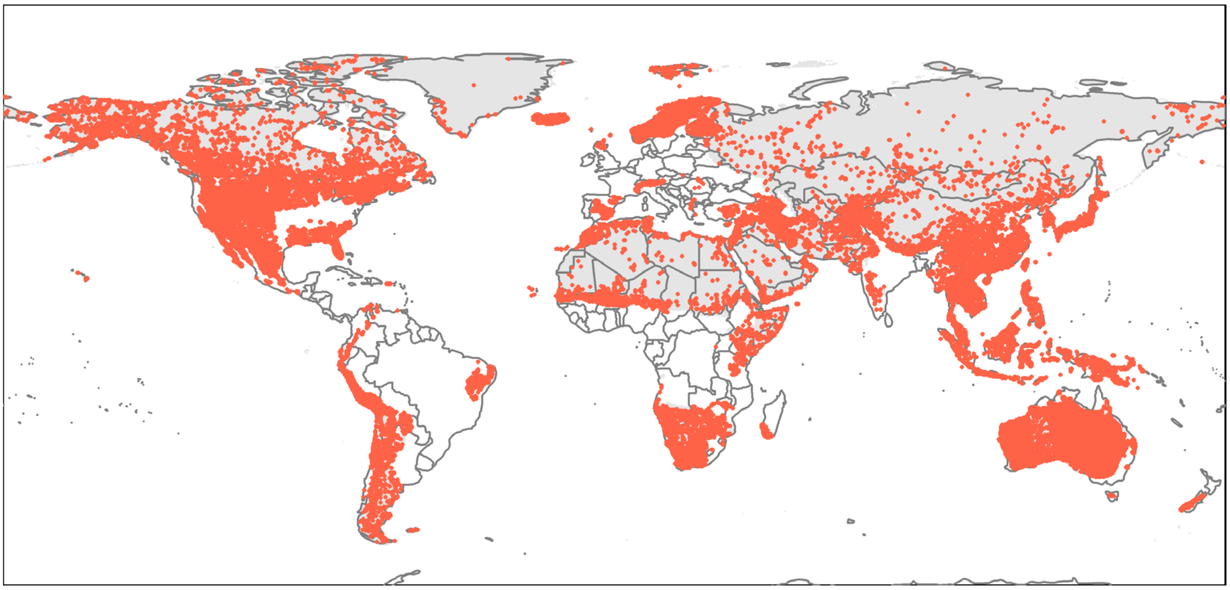


Figure 3. Randomly selected background grid cells used in the modelling of *Lygodium japonicum*, mapped as red points. Ten sets 10,000 points were sampled from across the native range (Asia and Papua New Guinea, excluding Singapore and countries in the native range without records of the species), a small buffer around non-native occurrences and from areas expected to be highly unsuitable for the species (grey background region), and weighted by a proxy for plant recording effort (see Figure 2).

Each of the 10 datasets (combinations of the presences and the individual background samples) was randomly split into 80% for model training and 20% for model evaluation. With each training dataset, ten statistical algorithms were fitted with the default BIOMOD2 settings, except where specified below:

- Generalised linear model (GLM)
- Generalised boosting model (GBM)

- Generalised additive model (GAM) with a maximum of four degrees of freedom per smoothing spline.
- Classification tree algorithm (CTA)
- Artificial neural network (ANN)
- Flexible discriminant analysis (FDA)
- Multivariate adaptive regression splines (MARS)
- Random forest (RF)
- MaxEnt
- Maximum entropy multinomial logistic regression (MEMLR)

Since the background sample was much larger than the number of occurrences, prevalence fitting weights were applied to give equal overall importance to the occurrences and the background. Variable importances were assessed and variable response functions were produced using BIOMOD2's default procedure. Model predictive performance was assessed by calculating the Area Under the receiver-operator characteristic Curve (AUC) for model predictions on the evaluation data, that were reserved from model fitting. AUC can be interpreted as the probability that a randomly selected presence has a higher model-predicted suitability than a randomly selected absence. This information was used to combine the predictions of the different algorithms to produce ensemble projections of the model. For this, the three algorithms with the lowest AUC were first rejected and then predictions of the remaining seven algorithms were averaged, weighted by their AUC. Ensemble projections were made for each dataset and then averaged to give an overall suitability.

The optimal threshold for partitioning the ensemble predictions into suitable and unsuitable regions was determined using the 'minimum ROC distance' method. This finds the threshold where the Receiver-Operator Curve (ROC) is closest to its top left corner, i.e. the point where the false positive rate (one minus specificity) is zero and true positive rate (sensitivity) is one.

Results

The ensemble model had a better predictive ability (AUC) than any individual algorithm and suggested that suitability for *L. japonicum* was most strongly by the climatic moisture index, mean temperature of the warmest quarter and minimum temperature of the coldest month (Table 1). As shown in Figure 4 and allowing for variation among the model algorithms, the estimated optimum conditions for occurrence were approximately:

- Climatic moisture index = 0.86 (> 50% suitability with CMI > 0.57).
- Mean temperature of the warmest quarter = 27.1 °C (>50% suitability with > 18.2 °C).
- Minimum temperature of the coldest month = 2.6 °C (>50% suitability with -8.5 to 18.2 °C).

A weaker preference for anthropogenic habitats were modelled, but tree and wetlands cover had very little effect (Figure 4).

These optima and ranges of high suitability described above are conditional on the other predictors being at their median value at the occurrence locations, which may explain some of the variation in responses among algorithms (Figure 4). The variation in the modelled responses among algorithms will also reflect their different treatment of interactions among variables. Since partial plots are made with other variables held at their median, there may be values of a particular variable at which this does not provide a realistic combination of variables to predict from. It also demonstrates the value of an ensemble modelling approach in averaging out the uncertainty between algorithms.

Global projection of the model in current climatic conditions (Figure 5) indicates that the major native distribution area with records in China, Japan, and southeast Asia was well defined and predicted to be climatically suitable. Despite a lack of sampling through much of the western part of the native range, the model predicted suitable regions of high suitability that are consistent with the most comprehensive description of the species' distribution at regional scales (CABI, 2015). The major clusters of non-native records in North America and eastern Australia also virtually all fell within regions of high climatic suitability (Figure 5). The model predicts that the climate may permit some further expansion of the species' distributions in both regions, notably predicting possible northwards spread in the USA and spread around the coast of eastern Australia. Other non-native regions without records of the species, but that are projected to be climatically suitable include most Caribbean islands, Uruguay, Paraguay and the neighbouring parts of Brazil and Argentina. In sub-Saharan Africa, small pockets of climate suitability are predicted to occur through much the region, notably in countries such as Madagascar, Guinnea-Bissau, Guinea and Sierra Leone and Nigeria (Figure 5).

The projection of suitability in Europe and the Mediterranean region (Figure 6) suggests that *L. japonicum* may be capable of establishing in many parts of southern Europe. The Biogeographical Regions (Bundesamt fur Naturschutz (BfN), 2003) currently most suitable for *L. japonicum* establishment are predicted to be the Mediterranean, Black Sea and Atlantic regions (Figure 8). The main limiting factor for the species across Europe appeared to be low growing season temperatures (warmest quarter) in northern Europe, drought stress (low CMI) in southern Europe and cold winter temperatures in eastern Europe.

By the 2070s, under climate change scenario RCP8.5, the suitability for *L. japonicum* is predicted to increase substantially across Europe (Figure 7). 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 (Figure 8).

Table 1. Summary of the cross-validation predictive performance (AUC) and variable importances of the fitted model algorithms and the ensemble (AUC-weighted average of the best performing seven algorithms). Results are the average from models fitted to 10 different background samples of the data.

Algorithm	**Predictive AUC**	**Variable importance**					
		Minimum temperature of coldest month	**Mean temperature of warmest quarter**	**Climatic moisture index**	**Human influence index**	**Tree cover**	**Wetland cover**
GBM	0.9686	15.3%	22.6%	59.4%	1.1%	1.6%	0.0%
MARS	0.9673	15.9%	23.1%	58.9%	1.8%	0.1%	0.2%
ANN	0.9672	22.0%	22.1%	45.5%	3.4%	6.2%	0.9%
GAM	0.966	19.1%	25.1%	52.7%	2.2%	0.3%	0.6%
MaxEnt	0.9654	19.7%	21.2%	48.6%	3.2%	4.3%	3.0%
GLM	0.962	14.9%	28.0%	50.4%	4.3%	1.5%	0.9%
FDA	0.9543	14.8%	42.1%	38.0%	1.5%	0.0%	3.5%
RF	0.9517	11.4%	33.7%	38.1%	6.1%	6.6%	4.0%
CTA	0.9389	14.1%	29.8%	54.0%	0.0%	2.1%	0.0%
MEMLR	0.6542	39.1%	18.3%	7.8%	0.1%	12.0%	22.6%
Ensemble	0.9698	17.4%	26.3%	50.5%	2.5%	2.0%	1.3%

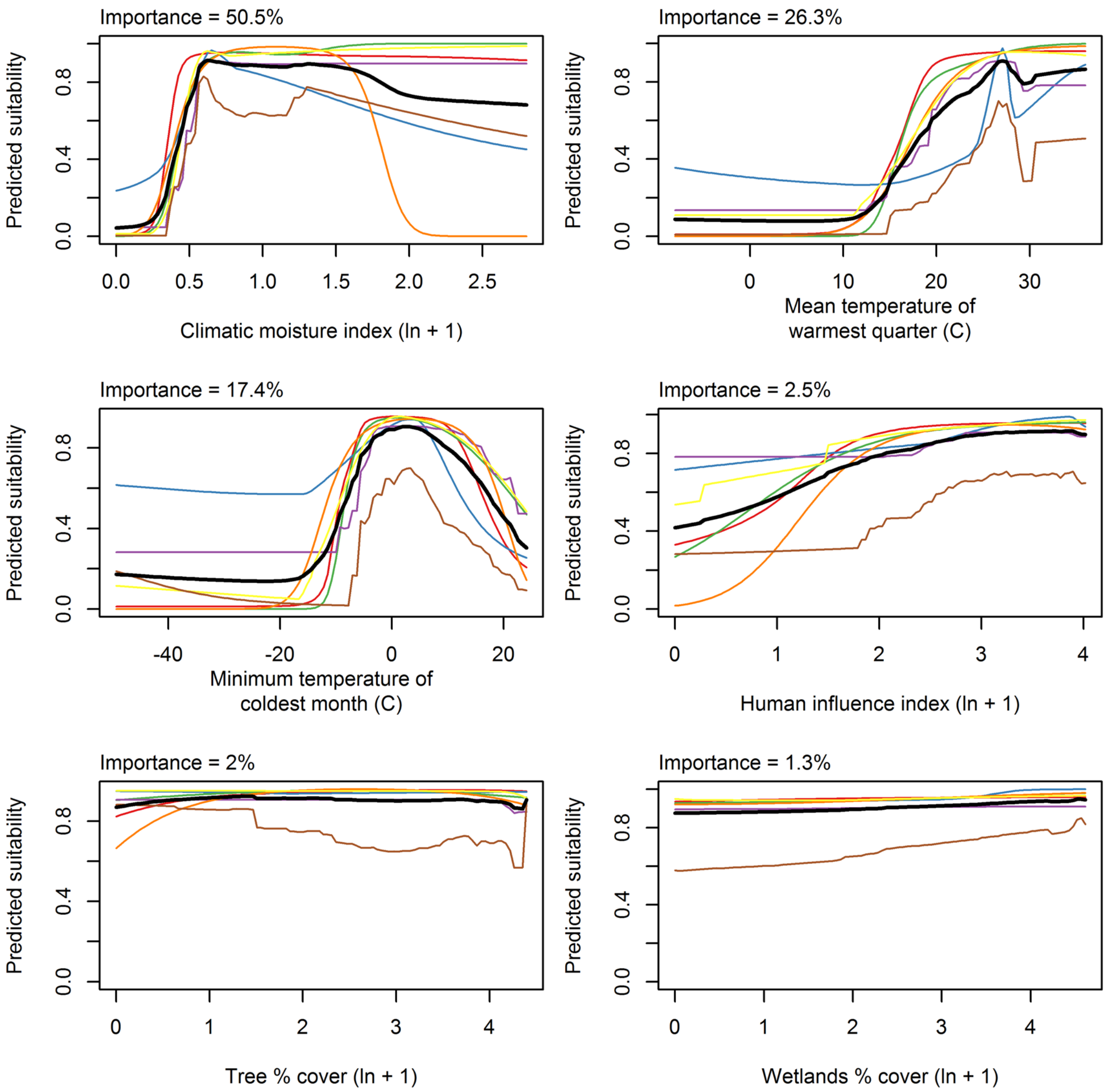


Figure 4. Partial response plots from the fitted models, ordered from most to least important. Thin coloured lines show responses from the seven algorithms, while the thick black line is their ensemble. In each plot, other model variables are held at their median value in the training data. Some of the divergence among algorithms is because of their different treatment of interactions among variables.

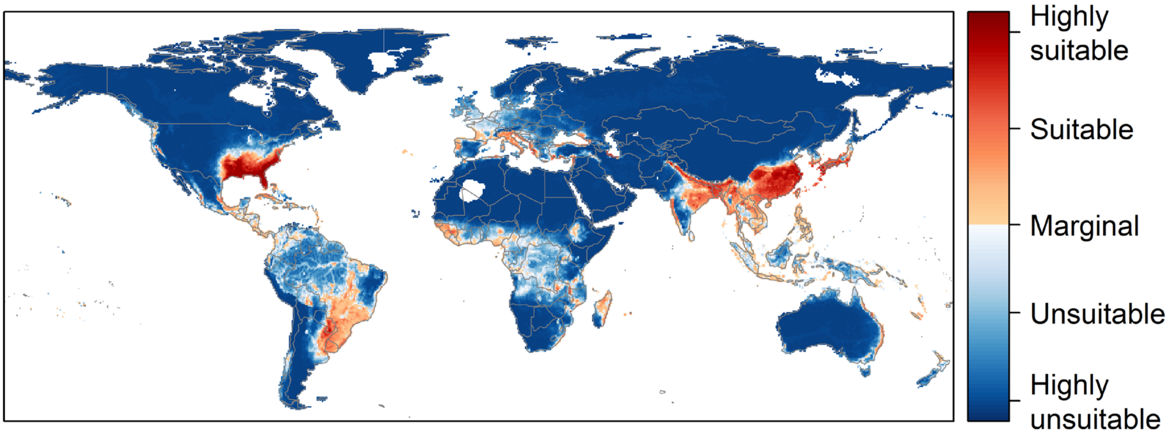


Figure 5. Projected global suitability for *Lygodium japonicum* establishment in the current climate. For visualisation, the projection has been aggregated to a 0.5 x 0.5 degree resolution, by taking the maximum suitability of constituent higher resolution grid cells. The threshold for marginal suitability was determined by the 'minimum ROC distance' method. Any white areas on land have climatic conditions outside the range of the training data so were excluded from the projection.

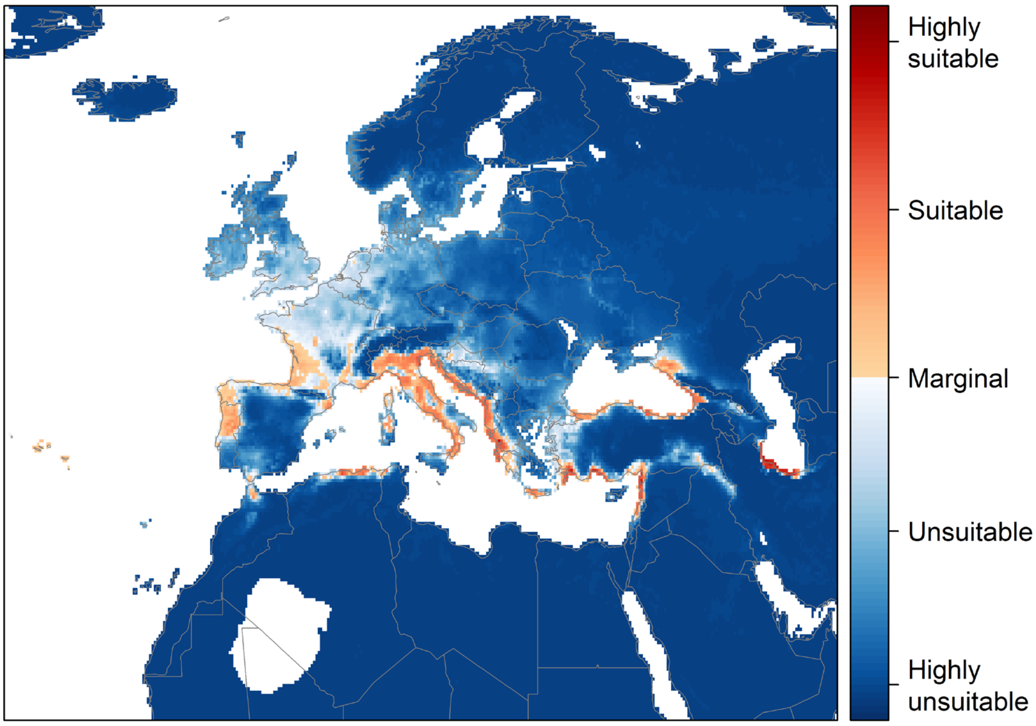


Figure 6. Projected current suitability for *Lygodium japonicum* establishment in Europe and the Mediterranean region. Any white areas on land have climatic conditions outside the range of the training data so were excluded from the projection.

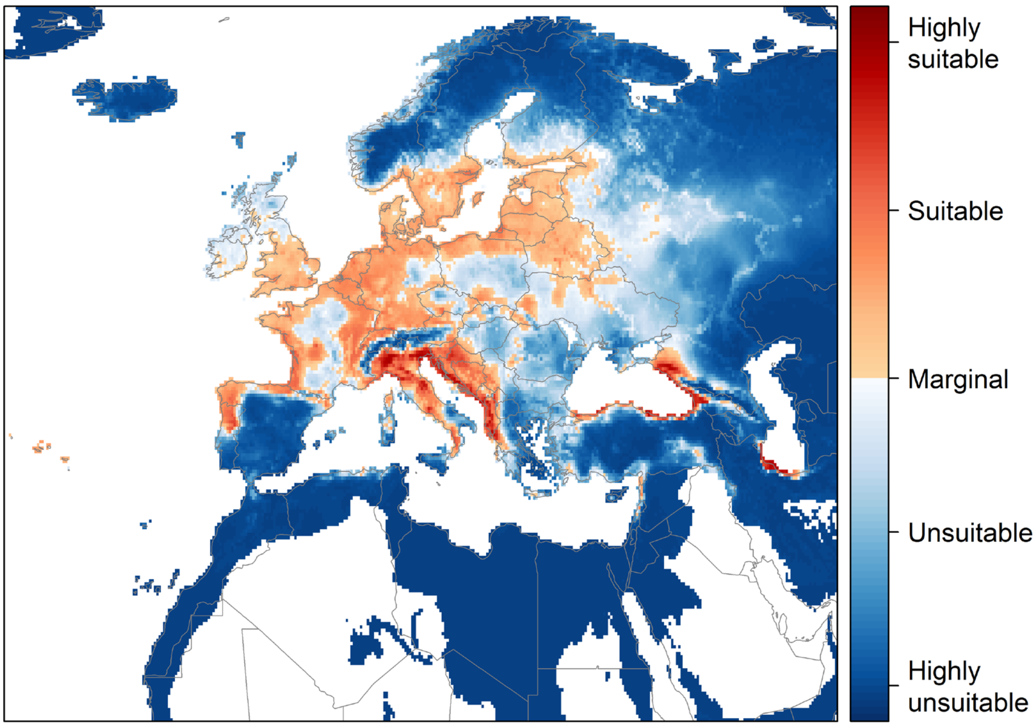


Figure 7. Projected suitability for *Lygodium japonicum* establishment in Europe and the Mediterranean region in the 2070s under climate change scenario RCP8.5, equivalent to Fig. 6.

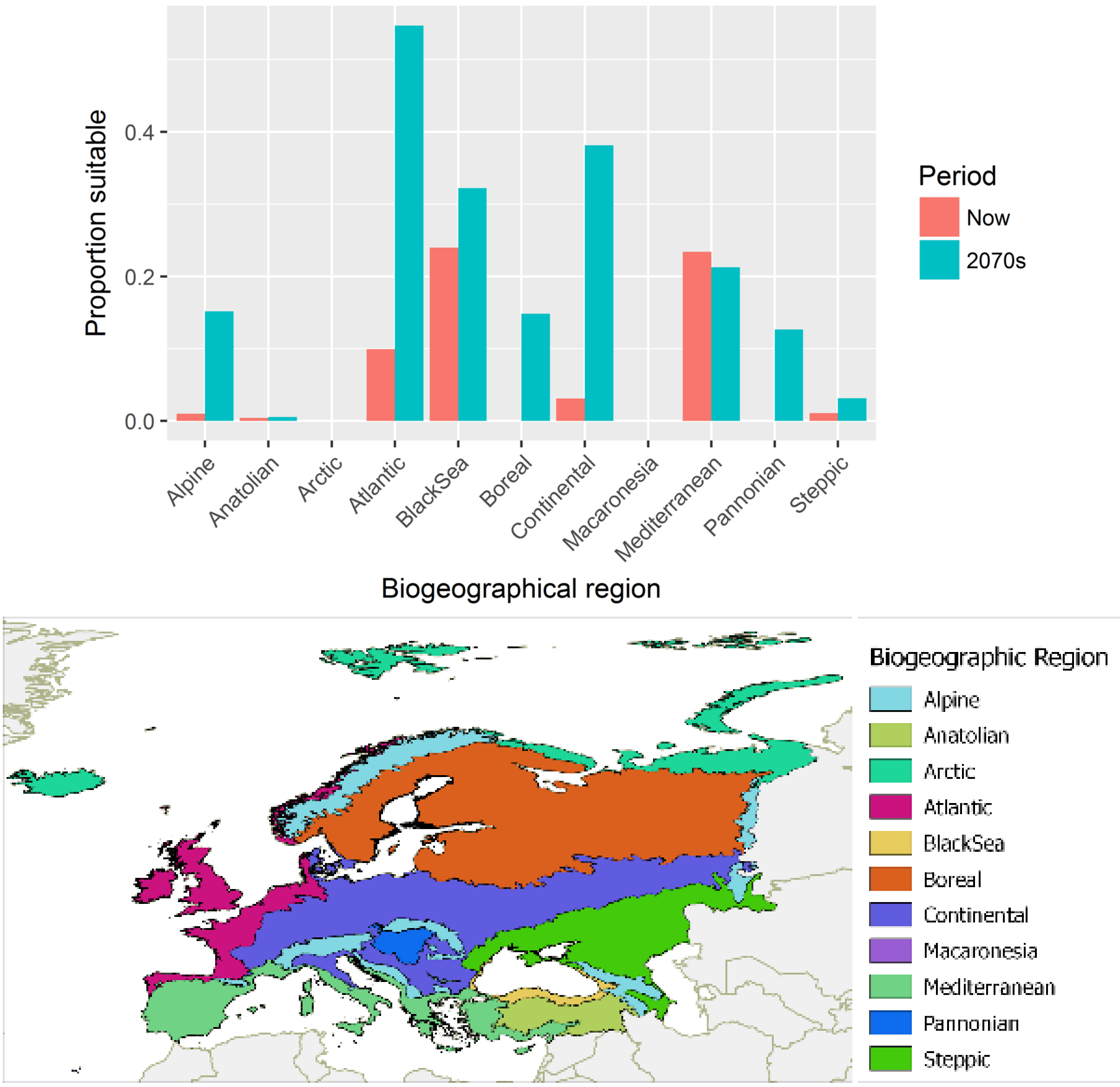


Figure 8. Variation in projected suitability among Biogeographical regions of Europe (Bundesamt fur Naturschutz (BfN), 2003). The bar plots show the proportion of grid cells in each region classified as suitable for the *Lygodium japonicum* in the current climate and projected climate for the 2070s under emissions scenario RCP8.5. The coverage of each region is shown in the map below.

Caveats to the modelling

To remove spatial recording biases, the selection of the background sample was weighted by the density of Tracheophyte records on the Global Biodiversity Information Facility (GBIF) (Figure 3).

While this is preferable to not accounting for recording bias at all, a number of factors mean this may not be the perfect null model for species occurrence:

- The GBIF API query used to did not appear to give completely accurate results. For example, in a small number of cases, GBIF indicated no Tracheophyte records in grid cells in which it also yielded records of the focal species.
- We used additional data sources to GBIF, which may have different biases to the GBIF records.

Other variables potentially affecting the distribution of the species, such as soil nutrients and land use, were not explicitly included in the model.
The climate change scenario used is the most extreme of the four RCPs. However, it is also the most consistent with recent emissions trends and could be seen as worst case scenario for informing risk assessment.

References

R. J. Hijmans, S. E. Cameron, J. L. Parra, P. G. Jones & A. Jarvis (2005) Very high resolution interpolated climate surfaces for global land areas. *International Journal of Climatology* **25**, 1965-1978.

R. J. Zomer, A. Trabucco, D. A. Bossio & L. V. Verchot (2008) Climate change mitigation: A spatial analysis of global land suitability for clean development mechanism afforestation and reforestation. *Agriculture, Ecosystems & Environment* **126**, 67-80.

G. H. Hargreaves (1994) Defining and Using Reference Evapotranspiration. *Journal of Irrigation and Drainage Engineering* **120**.

CABI (2015) *Lygodium japonicum* (Japanese climbing fern). In *Invasive Species Compendium*, Wallingford, UK.

Wildlife Conservation Society - WCS & Center for International Earth Science Information Network - CIESIN - Columbia University (2005) Last of the Wild Project, Version 2, 2005 (LWP-2): Global Human Influence Index (HII) Dataset (Geographic). NASA Socioeconomic Data and Applications Center (SEDAC), Palisades, NY.

W. Thuiller, D. Georges & R. Engler (2014) biomod2: Ensemble platform for species distribution modeling. R package version 3.3-7 *Available at:* https://cran.r-project.org/web/packages/biomod2/index.html.

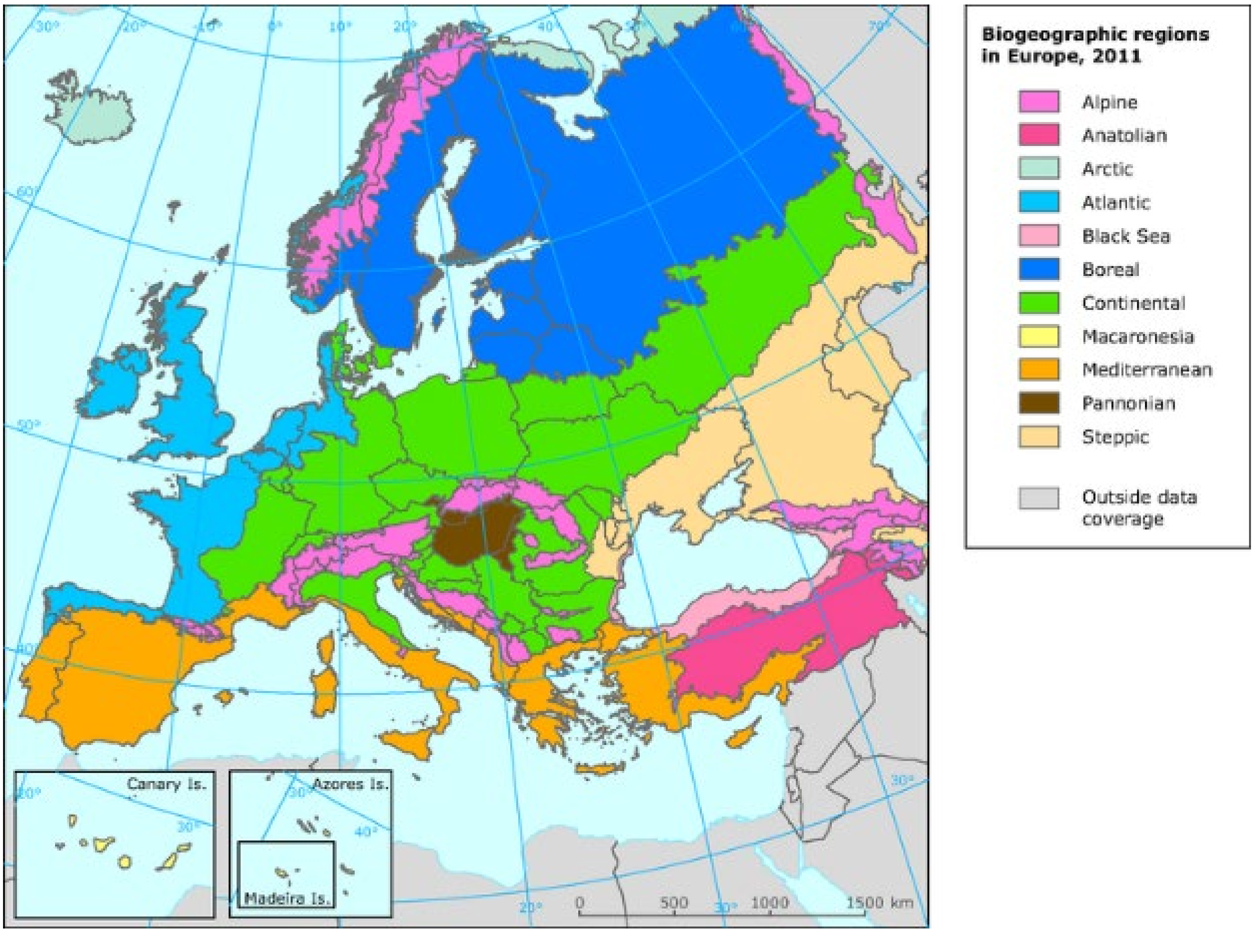
W. Thuiller, B. Lafourcade, R. Engler & M. B. Araújo (2009) BIOMOD–a platform for ensemble forecasting of species distributions. *Ecography* **32**, 369-373.

J. T. Hutchinson & K. A. Langeland (2010) Review of Two Non-Native, Invasive Climbing Ferns (*Lygodium japonicum* and *L. microphyllum*), Sympatric Records and Additional Distribution Records from Florida. *American Fern Journal* **100**, 57-66.

J. Ulrich, K. K. Bohn & P. Minogue (in review) Effect of temperature and litter on Japanese climbing fern germination. *Invasive Plant Science and Management*.

Bundesamt fur Naturschutz (BfN) (2003) Map of natural vegetation of Europe. Web site: http://www.bfn.de/. National data included.

Appendix 2 Biogeographical regions



Appendix 3. Relevant illustrative pictures

Figure 1. Japanese climbing fern (*L. japonicum*). Photo: Kimberly Bohn

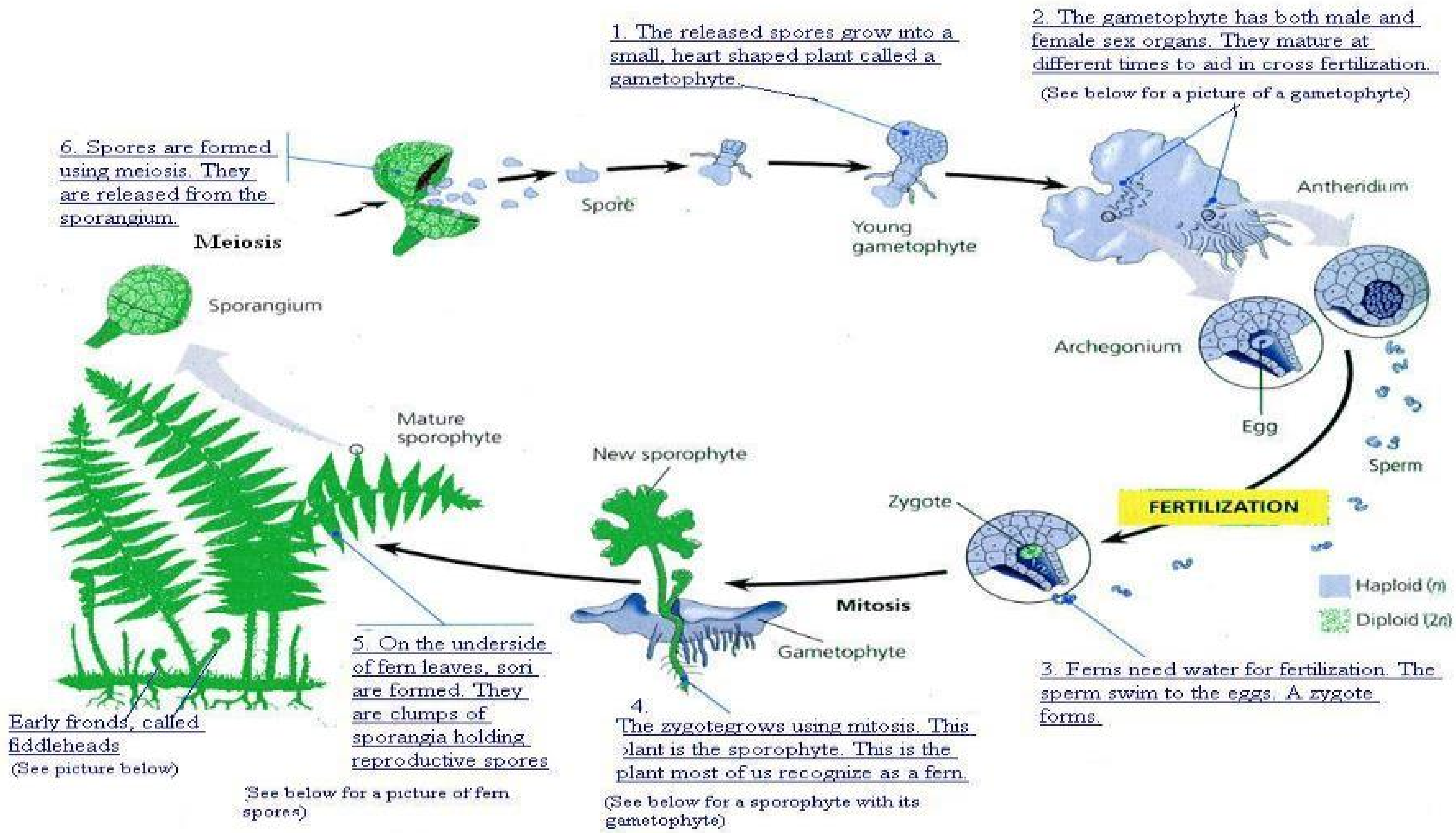


Figure 2. Life cycle of ferns.

Source: http://www.sas.upenn.edu/~joyellen/bioweb.html

Figure 3. Root and rhizomes of *L. japonicum.*

Figure 4. *L. japonicum.*

Figure 5. Frondlet of *L. japonicum*, in the unfertile stage.

Figure 6. Smothering habit of *Lygodium japonicum*

Appendix 4: Distribution summary for EU Member States and Biogeographical regions

Member States:

	Recorded	Established (currently)	Established (future)	Invasive (currently)
Austria	–	–	YES	–
Belgium	–	–	YES	–
Bulgaria	–	–	–	–
Croatia	–	–	YES	–
Cyprus	–	–	–	–
Czech Republic	–	–	YES	–
Denmark	–	–	YES	–
Estonia	–	–	YES	–
Finland	–	–	YES	–
France	–	–	YES	–
Germany	–	–	YES	–
Greece	–	–	YES	–
Hungary	–	–	YES	–
Ireland	–	–	YES	–
Italy	–	–	YES	–
Latvia	–	–	YES	–
Lithuania	–	–	YES	–
Luxembourg	–	–	YES	–
Malta	–	–	–	–
Netherlands	–	–	YES	–
Poland	–	–	YES	–
Portugal	–	–	YES	–
Romania	–	–	YES	–
Slovakia	–	–	YES	–
Slovenia	–	–	YES	–
Spain	–	–	YES	–
Sweden	–	–	YES	–
United Kingdom	–	–	YES	–

Biogeographical regions

	Recorded	Established (currently)	Established (future)	Invasive (currently)
Alpine	–	–	YES	–
Atlantic	–	–	YES	–
Black Sea	–	–	YES	–
Boreal	–	–	YES	–
Continental	–	–	YES	–
Mediterranean	–	–	YES	–
Pannonian	–	–	YES	–
Steppic	–	–	YES	–

YES: if recorded in natural environment, established or invasive or can occur under future climate; **–** if not recorded, established or invasive; **?** Unknown

Appendix 5: Koppen-Geiger climate zones

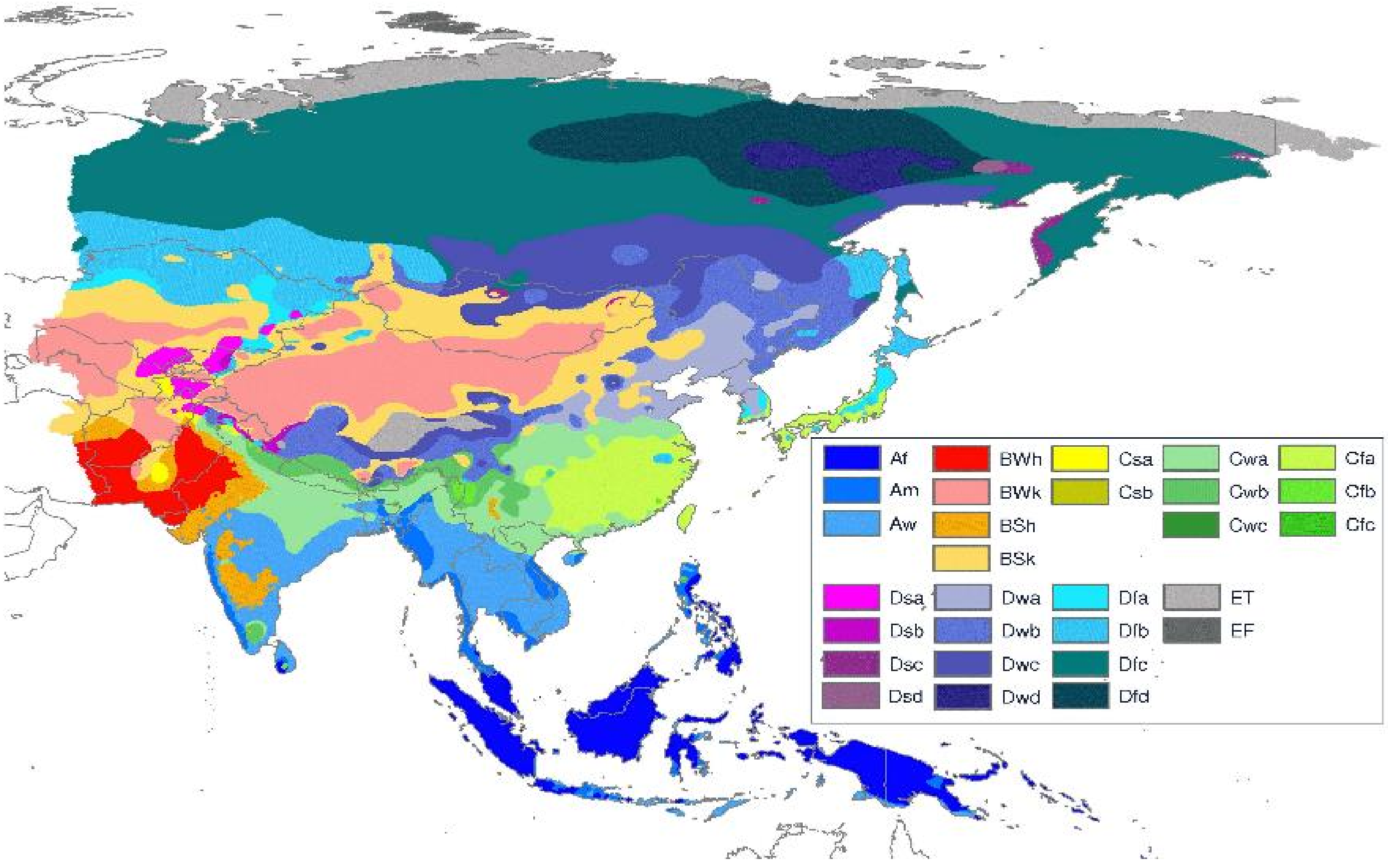


Figure 1. Koppen-Geiger climate zones for Asia

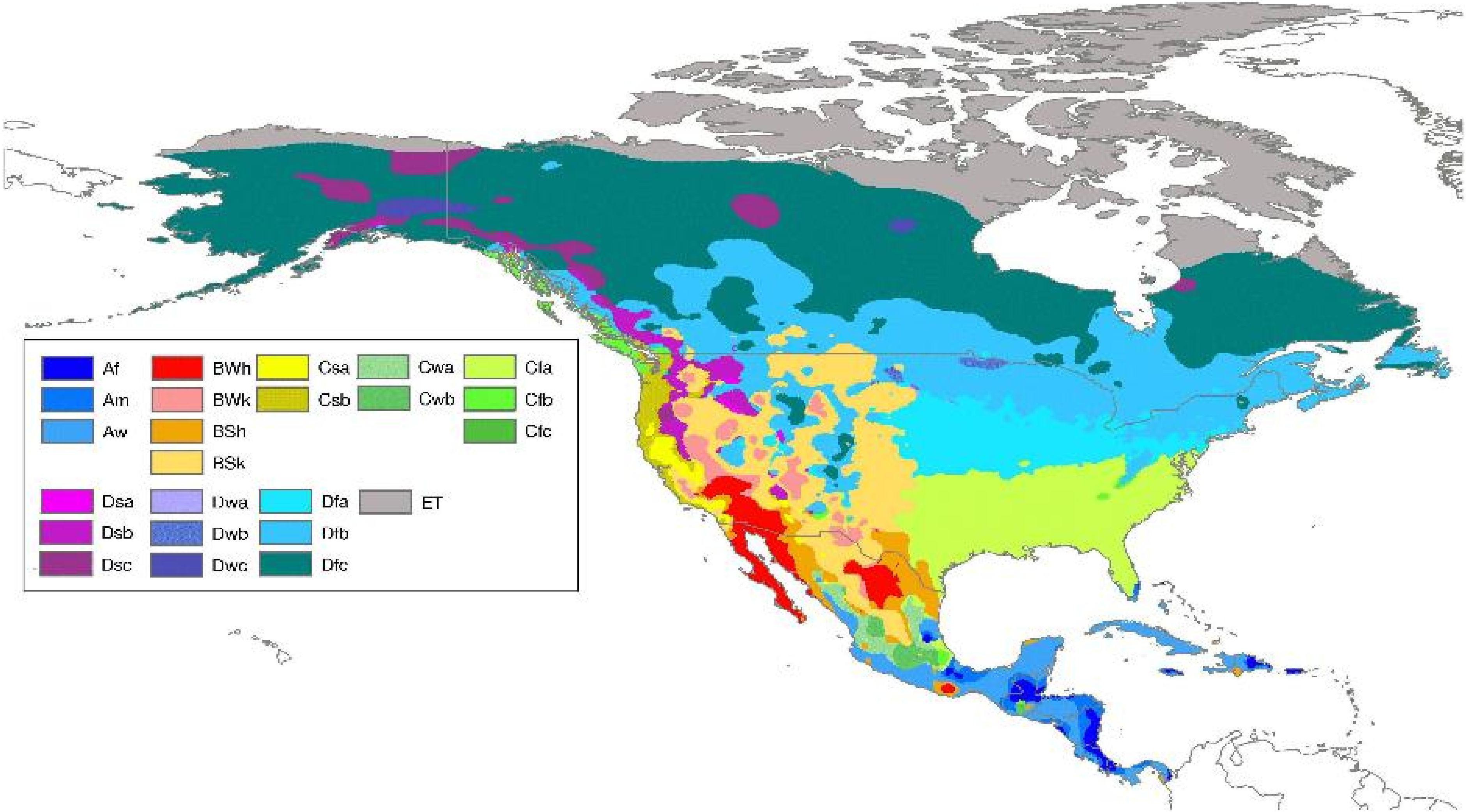


Figure 2. Koppen-Geiger climate zones for North America

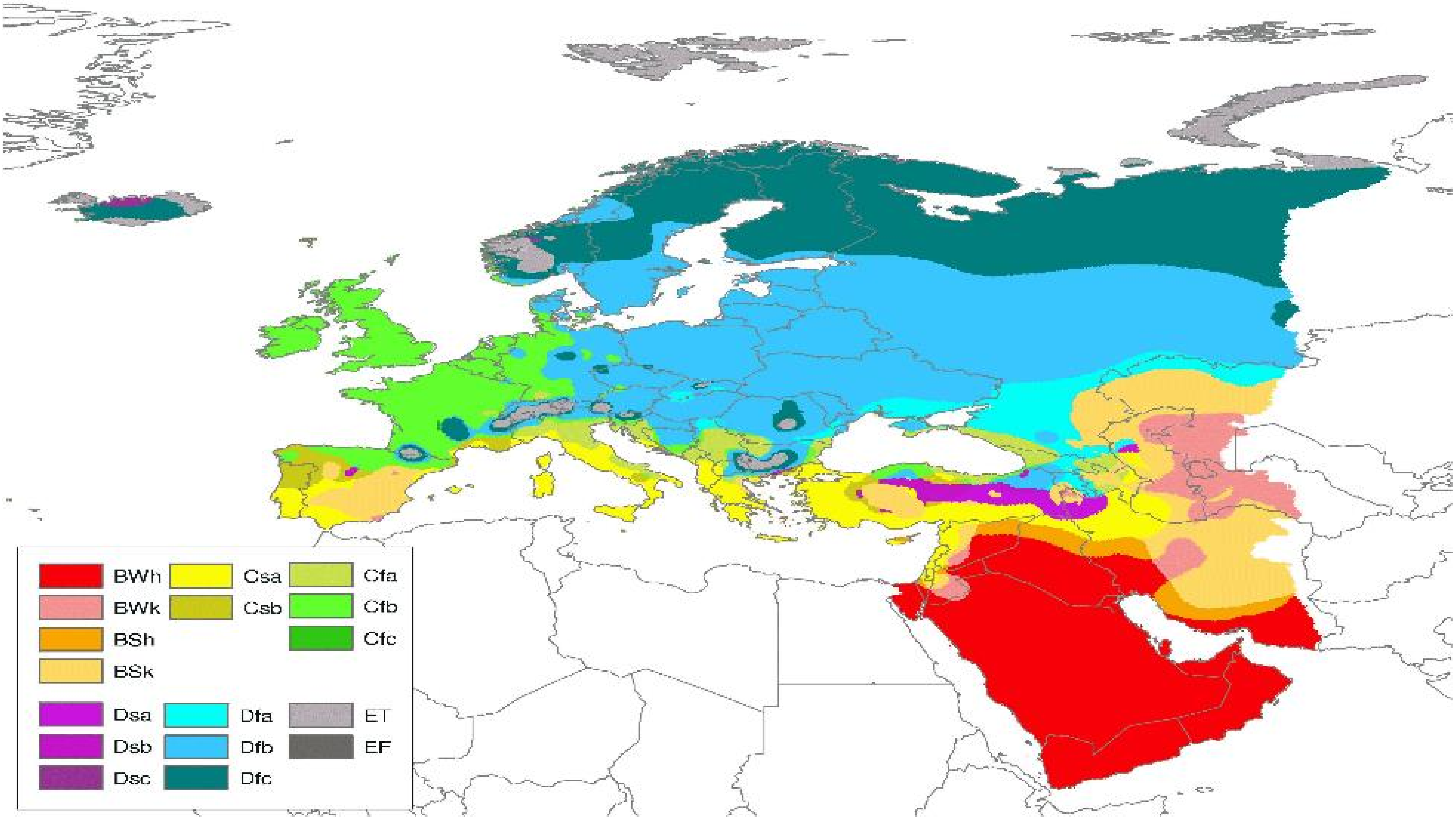
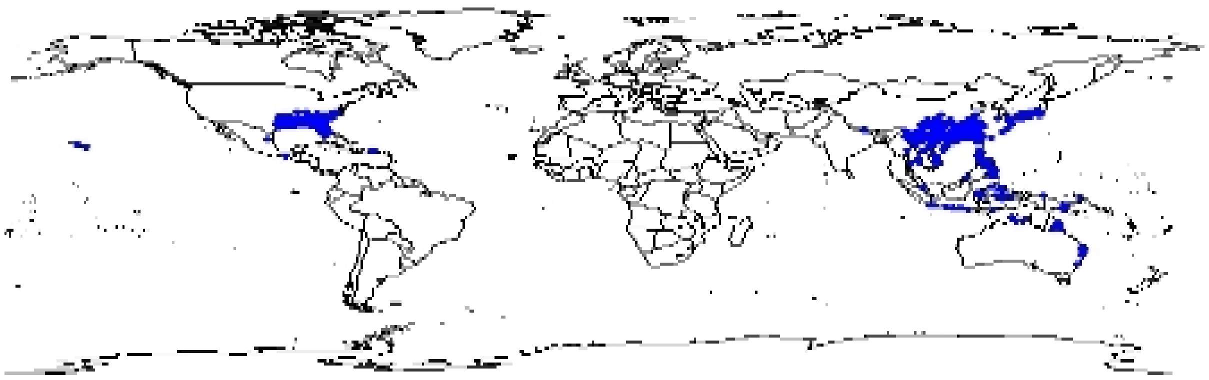


Figure 3. Koppen-Geiger climate zones for Europe /

Appendix 6: Distribution maps for Lygodium japonicum (World) [3]

`



[3] Note Maps in appendix 6 may contain records, e.g. herbarium records, that were not considered during the climate modelling stage. Data sources are from literature, GBIF and expert opinion.

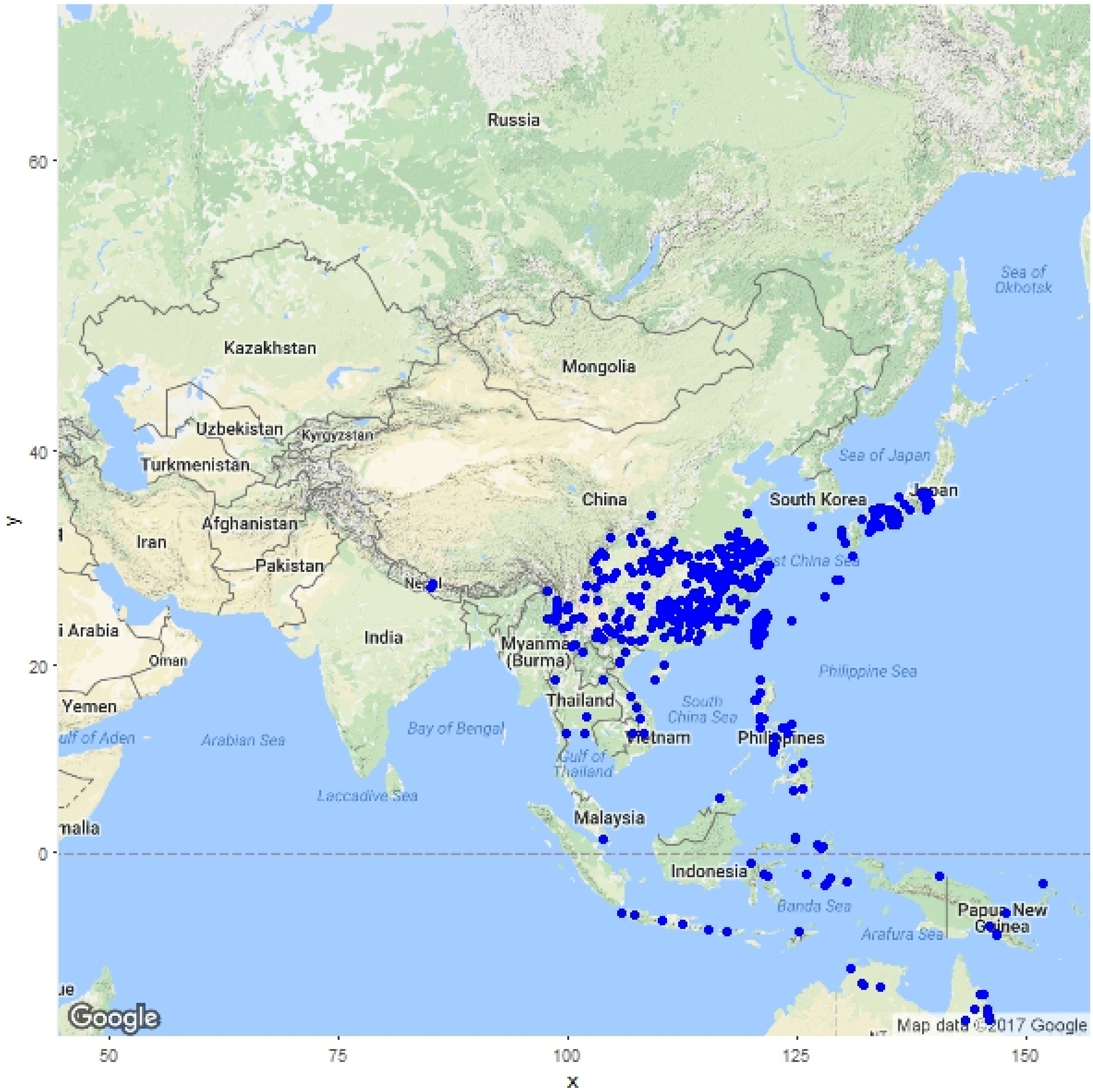


Figure 2 (Asia)

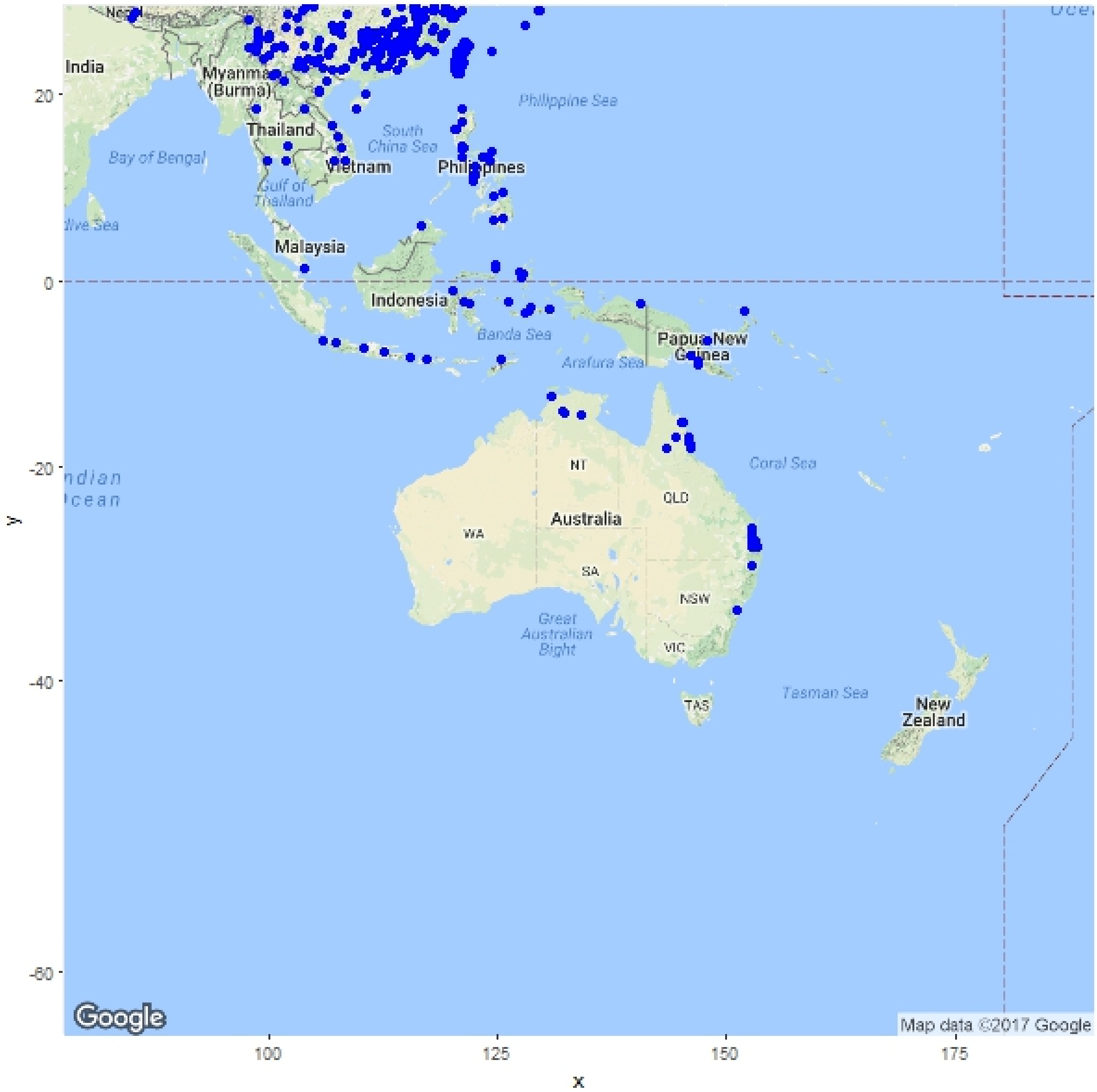


Figure 3 (Australia)

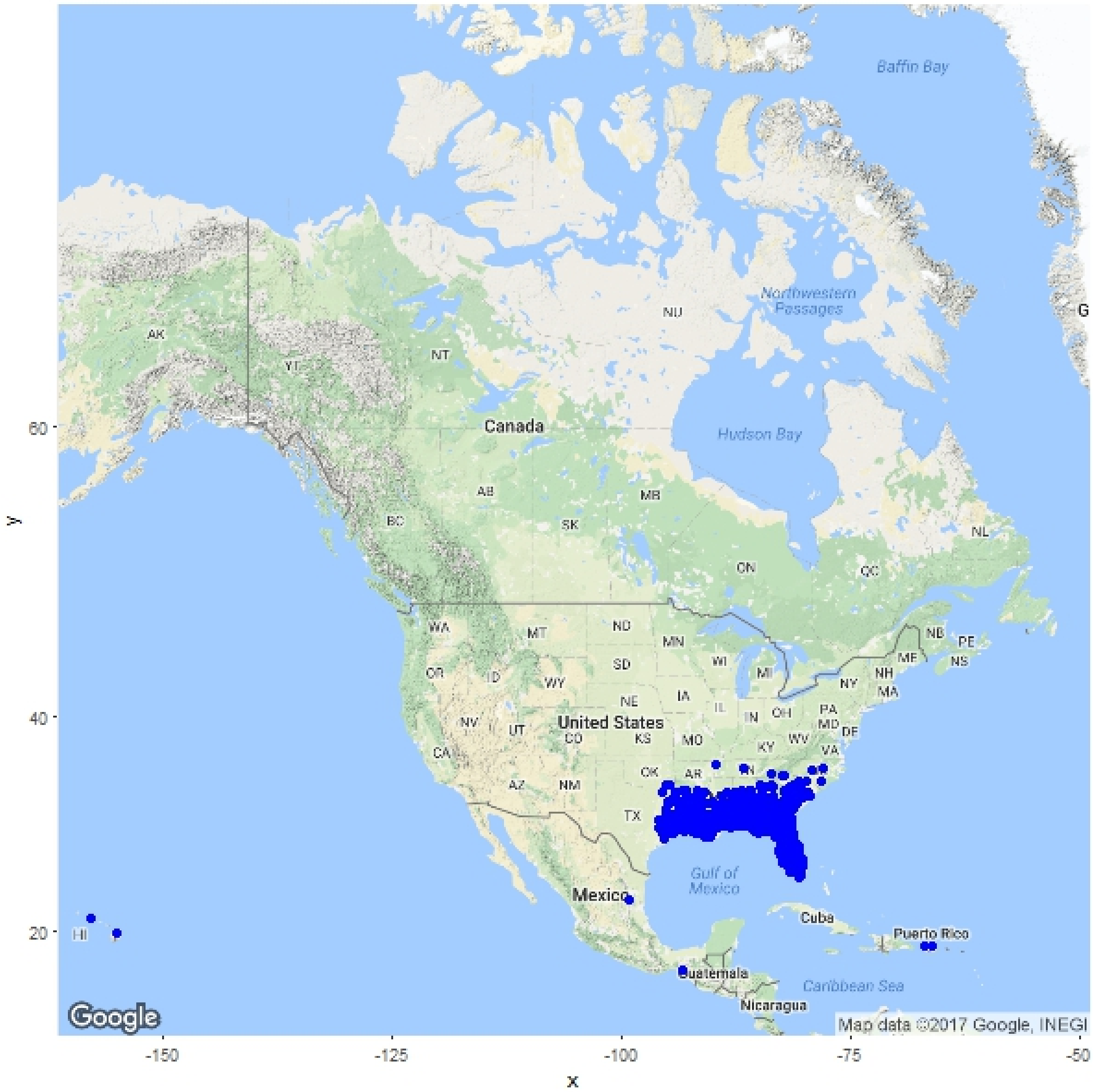


Figure 4 (North America)