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Assessment of the suitability of the Finnish climate for *Popillia japonica*

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Abstract

Popillia japonica is a priority pest which all EU countries must survey annually. However, surveys are not required if the climate in the country is unsuitable for the pest. In previous research, it was unclear whether the climate in Finland was suitable for *P. japonica*.

Based on a literature review, we identified soil moisture and temperature as critical factors for the establishment of *P. japonica*. The suitability of soil moisture for *P. japonica* in Finland was assessed by comparing the summer rainfall across Finland to the corresponding rainfall within the known range of the pest. The suitability of the winter soil temperature was assessed by comparing the winter soil temperature across Finland with the minimum temperatures that *P. japonica* has been reported to endure. The suitability of summer soil temperatures was assessed by comparing the annual growing degree days (GDD) across Finland with a the annual GDD which *P. japonica* has, in previous assessments, been considered to require to complete its life cycle (i.e., 711 above 10 °C).

The results indicate that the soil moisture and winter soil temperature are suitable for *P. japonica* throughout Finland. However, the summers appear to be too cool for the pest throughout the country since the threshold GDD was not reached every year anywhere, and even in the warmest areas, it was reached only in 75% of the years.

The greatest sources of uncertainty in the assessment are the uncertainty of the annual GDD that *P. japonica* needs to complete its life cycle and the lack of research on the pest's cold tolerance.

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Tiivistelmä

Japaninturilas on prioriteettituhooja, jota kaikkien EU:n jäsenmaiden on kartoitettava vuosittain. Kartoituksia ei kuitenkaan tarvitse tehdä maissa, joiden ilmasto ei ole tuhoojalle sopiva. Aiempien tutkimusten perusteella ei ole selvää, onko Suomen ilmasto sopiva japaninturilaalle.

Kirjallisuuskatsauksemme mukaan japaninturilaan selviytyminen riippuu erityisesti maan kosteudesta sekä talvi- ja kesälämpötiloista. Sen vuoksi selvitimme, ovatko nämä tekijät Suomessa sellaiset, että japaninturilaan asettuminen meille olisi mahdollista.

Arvioimme Suomen maaperän kosteuden sopivuutta japaninturillaalle vertaamalla Suomen kesä-elokuun sademäriä vastaavan aikajakson sademääriin alueilla, joilla japaniturilasta esiintyy. Maaperän talvilämpötilojen sopivuutta puolestaan arvioimme vertaamalla julkaistuja havaintoja maaperän talvilämpötiloista Suomessa tietoihin tuhoojan kymänkestävyydestä. Kesälämpötilojen sopivuutta japaninturilaalle arvioimme vertaamalla vuotuisia lämpösummia eri puolilla Suomea vuotuiseen lämpösummaan, jonka japaninturilaan on arvioitu tarvitsevan elämänkiertoonsa
(eli 711 °Cvrk yli 10 °C).

Arviomme mukaan maan kosteus kesällä ja lämpötila talvella ovat sopivia japaniturilaalle koko Suomessa, mutta kesät vaikuttavat olevan liian viileitä japaninturilaalle koko maassa. Suomen lämpimimmissäkin osissa neljännes vuosista on niin viileitä, ettei japaninturilaan elikiertoon tarvittava lämpösumma täyty.

Eniten arvion varmuutta heikentää se, että tuhoojan kehittymiseen vaadittava lämpösumma on epävarma sekä se, että tuhoojan kylmänkestävyydestä on hyvin vähän tutkimustietoa.

Beskrivning

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Den japanska trädgårdsborren är en prioriterad karantänskadegörare som alla medlemsländer i EU ska kartlägga årligen. Kartläggningar behöver dock inte genomföras i länder vars klimat är olämpligt för skadegöraren. Det är på basis av tidigare undersökningar oklart om Finlands klimat lämpar sig för den japanska trädgårdsborren.

Enligt vår litteraturöversikt beror den japanska trädgårdsborrens överlevnad särskilt på markens fuktighet samt vinter- och sommartemperaturerna. På grund av detta utredde vi om dessa faktorer i Finland är sådana att den japanska trädgårdsborren kan etablera sig hos oss.

Vi bedömde om markfuktigheten i Finland lämpar sig för den japanska trädgårdsborren genom att jämföra mängden nederbörd i Finland i juni–augusti med mängden nederbörd under motsvarande tidsperiod i de områden där den japanska trädgårdsborren förekommer. Lämpligheten av temperaturerna i jorden under vintern bedömde vi genom att jämföra publicerade observationer av temperaturerna i jorden under vintern i Finland med uppgifter om skadegörarens köldtålighet. Vi bedömde sommartemperaturernas lämplighet för den japanska trädgårdsbaggen genom att jämföra de årliga temperatursummorna på olika håll i Finland med temperatursumman som den japanska trädgårdsbaggen bedöms behöva för att fullborda sin livscykel (nämligen 711 °C över 10 °C).

Enligt vår bedömning är markens fuktighet på sommaren och temperaturen på vintern lämpliga för den japanska trädgårdsborren i hela Finland. Somrarna däremot verkar vara för svala för den japanska trädgårdsborren i hela Finland. Även i de varmaste delarna av landet är en fjärdedel av åren så svala att den mängd värme som behövs för den japanska trädgårdsborrens livscykel inte tillräcklig.

Det som påverkar uppskattningens osäkerhet mest är att temperatursumman som krävs för den japanska trädgårdsborrens livscykel är osäker och att det finns väldigt lite forskningsdata om skadegörarens köldtålighet.

Contents

1 Background and scope

The European Commission (EC) has established a list of 20 priority pests, whose economic, environmental, and social impact in the European Union (EU) is considered the most severe (EC, 2019a). In addition, the Commission has active emergency measures for several pests (e.g. EC, 2018; EC, 2019b).

According to the EU plant health regulation (EU, 2016), all Member States must conduct annual surveys for each priority pest. Annual surveys are also required for many emergency measure pests. However, surveys are not required for pests for which it is unequivocally concluded that they cannot establish or spread in the Member State due to unsuitable ecoclimatic conditions or the absence of host plants.

For some of the priority and emergency measure pests, the suitability of ecoclimatic conditions in Finland or parts of Finland is currently not known well enough. The Risk Assessment Unit of the Finnish Food Authority was therefore requested to assess the suitability of the present Finnish climate for the establishment of these pests.

The assessments are conducted based on non-systematic, yet thorough literature reviews. Literature is searched using the pest/diseases name(s) as search words in the Web of Science (Clarivate Analytics, 2023), the European and Mediterranean Plant Protection Organization's (EPPO) Global Database (EPPO, 2023a), and the European Food Safety Authority's (EFSA) publication database (EFSA, 2023a).

In some cases, the assessments may require modelling of the suitability of the climate. The need for modelling and the appropriate methods for it are evaluated based on the literature review.

By default, the assessments consider the present Finnish climate and do not consider the possible change of climate suitability due to future global warming. **Factors other than the suitability of the climate are not considered in the assessments.**

The following qualitative scale is used in the assessments.
- The climate is considered **suitable or unsuitable** for establishment.

This report presents the assessment of the suitability of the present Finnish climate for the establishment of the priority pest *Popillia japonica* Newman (Coleoptera: Scarabaeidae, EPPO code: POPIJA), commonly known as the Japanese beetle.

2 Overview of *Popillia japonica*

Popillia japonica is a widely distributed pest of a wide range of horticultural and agricultural crops and woody plants (Klein, 2020; EPPO 2023b). Its larval stages primarily consume roots, while adult beetles feed on foliage, flowers, and fruit. *Popillia japonica* is considered a significant threat to plant health worldwide (EPPO, 2023b). In addition to being a quarantine pest in the EU, it is also classified as such in many countries across Europe, Africa, Asia, and South and North America (EPPO, 2023b).

2.1 Known global distribution

Popillia japonica is native to Japan and the island of Kunashir in the far east of Russia. The pest is reported to be widespread throughout Japan (Fleming, 1972; EPPO, 2023b), yet according to Fox (1939), there are no definitive records of it occurring in the most northern and north-eastern parts of Hokkaido (Fox, 1939, referring to the scouting results of J. L. King, T. R. Gartner, and L. B. Parker). Currently, the northernmost records of *P. japonica* from Hokkaido are from the Monbetsu District and Nayoro City (JBIF, 2023), and from Wakkanai (iNaturalist, 2023), but it is uncertain whether these represent established or transient populations.

In the far east of Russia, *P. japonica* is restricted to the island of Kunashir, which is the southernmost island of the Kuril Islands in the Sakhalin Oblast (Chebanov, 1977). On Kunashir, the pest is established on the southern third of the island, up to Cape Stolbchaty on the west coast (Krivolutskaya, 1973; Kurbatov, 2013). It should be noted that there are two active volcanoes within the pest range on Kunashir, both with stable hydrothermal systems (Zharkov, 2020). This geothermal activity can create microclimates in the soils that are considerably warmer than what would be predicted based on air temperatures. Therefore, the occurrences of *P. japonica* on Kunashir should not been used for estimating the potential range of the pest without information on how geothermal activity affects soil temperatures in Kunashir. *P. japonica* has also been observed on other islands in the Sakhalin Oblast (Bezborodov & Lesik, 2023), but it is uncertain whether these represent established or transient populations.

In the 1910s, *P. japonica* was introduced to New Jersey in North America (Dickerson & Weiss, 1918). It has since spread almost throughout the USA and into Canada (Althoff & Rice, 2022; USDA, 2022; EPPO, 2023b; GBIF, 2023). The northernmost observations of the pest in North America are from Prince Edward Island, the province of Quebec, and Vancouver (EPPO, 2018; CFIA, 2022; GBIF, 2023).

In the 1970s, *P. japonica* was introduced to Europe, into the Portuguese Azores archipelago (Martins & Simoes, 1988; Jackson, 1992). In 2014, it was found near Milan in northern Italy (Pavesi, 201410), and by 2021, the infested zone covered 14 257 km2 (EPPO, 2022a). The pest was also found in Sardinia in Italy in 2021, in Switzerland in 2017, and in Germany in 2021 (EPPO, 2017; EPPO 2022a; EPPO, 2022b). Currently the pest is considered officially present in Portugal, Italy and Switzerland (EPPO, 2023b)

Furthermore, *P. japonica* has been detected in India in the Wayanad district of the Kerala region (Smitha et al., 2017) and in the Tamil Nadu and Karnataka regions (GBIF, 2023).

2.2 Host plants

Popillia japonica is a highly polyphagous pest that feeds on a wide range of crops and wild plants, both herbaceous and woody (Klein, 2020; EPPO, 2023b). Of the hosts listed by EPPO (2023b) and CABI (Klein 2020), several occur in Finland, either as field crops or native wild plants. Such hosts are e.g. *Acer platanoides*, *Aesculus hippocastanum*, *Alnus glutinosa*, *Corylus avellana*, *Fragaria* x *ananassa*, *Lolium perenne*, *Malus domestica*, *Medicago sativa*, *Ocimum basilicum*, *Phaseolus vulgaris*, *Prunus*, *Rosa*, *Tilia cordata*, *Trifolium pratense*, *Ulmus*, *Vaccinium*, and *Zea mays*.

2.3 Life cycle

Popillia japonica spends most of its life cycle underground as a larva feeding on roots. During the summer, adult beetles emerge from the soil to feed on aboveground plant parts and to mate. The timing of emergence and the subsequent mating and oviposition depend on the temperature and other environmental conditions, such as the type of the soil where the larvae have overwintered (Smith & Hadley, 1926; Fleming, 1972).

After mating, the female beetles burrow into the soil and begin laying eggs within the upper 10 cm of soil. During their adult lifespan, females undergo cyclical periods of feeding and oviposition, often re-entering the soil multiple times to lay an average of 40–60 eggs in total (Fleming, 1972).

The life cycle of *P. japonica* consists of three larval instars. Younger larvae typically reside within the upper 10 cm of soil, but older ones burrow more deeply to overwinter (Fleming, 1972; Potter & Held, 2002). Most larvae overwinter at a depth of 5–15 cm, although larvae have sometimes been observed to burrow as deep as 25 cm to overwinter (Fleming, 1972). The second and especially the third instar larvae are the overwintering stages of the pest, although in rare instances, the first instar larvae may also overwinter (Fleming, 1972; Potter & Held, 2002). When the soil temperature increases in the spring, the larvae continue their development or move towards the surface to pupate.

In most of its range, *P. japonica* is univoltine, but in some cooler areas in Japan and North America, two years are required for the life cycle to be completed (Clausen, 1927; Britton & Johnson, 1938; Fleming, 1972; Vittum, 1986).

2.4 Climatic requirements

This section provides an overview of the knowledge of the climatic requirements of *P. japonica* gained in laboratory and field studies. Further understanding of these requirements gained when modelling the pest's potential range are presented and discussed in sections 3.1 and 3.2

2.4.1 Soil moisture

The eggs and newly hatched larvae of *P. japonica* are particularly sensitive to desiccation, making sufficient soil moisture during summer especially important for its survival (Fox, 1939; Fleming, 1972). However, Régnière et al. (1981a) demonstrated that the eggs and newly hatched larvae can tolerate some level of drought, as they survived in soil with a moisture by weight of only 3%. Régnière et al. (1981a) also observed a delay in egg development in soils with a moisture by weight of over 24%, suggesting that excessive moisture might also hinder the pest's development.

As the larvae progress through the later stages, they become less vulnerable to desiccation. Moisture levels in the spring and autumn are therefore considered less critical for the pest's survival (Fox, 1939; Fleming, 1972).

Soil moisture also affects adult beetles. Allsopp et al. (1992) demonstrated that within a range of moisture by weight of 0 to 20%, adult beetles preferred to lay eggs in soils with moisture of 20% and did not lay eggs at all in soils with a moisture of 5% or less (Allsopp et al., 1992). Moreover, in completely dry soil (moisture by weight of 0–0.5%) egg-laying adults died within a few days.

2.4.2 Winter soil temperature

The successful overwintering of *P. japonica* requires sufficiently high soil temperatures during the winter. The minimum soil temperature that overwintering larvae can endure depends on various factors such as the duration of exposure to cold, and the maturity and overall condition of the larvae (Fleming, 1972).

Hoshikawa et al. (1988) determined the supercooling point of overwintering larvae to be -7 °C. Fox (1939) concluded, based on several unspecified sources and his own observations, that -9.4 °C was the lowest soil temperature the larvae withstand in natural conditions. However, Smith & Hadley (1926) reported successful larval overwintering in ploughed soil where the minimum temperature reached as low as -13.3 °C. Neither Fox (1939) nor Smith & Hadley (1926) mention the duration of exposure to cold.

2.4.3 Summer soil temperature

During the summer, *P. japonica* requires specific soil temperatures to complete its life cycle. Ludwig (1928) conducted laboratory experiments to determine the suitable and optimal temperature ranges for the pest's life stages. Later, Régnière et al. (1981b) re-evaluated Ludwig's (1928) data and conducted laboratory experiments to quantify the impact of temperature on the developmental rates of overwintered 3rd instar larvae. Gilioli et al. (2021) developed a model for predicting the diapause termination and phenology of *P. japonica* using trap capture data from Lombardy, Italy, and Ludwig's (1928) data from the laboratory experiments. Table 1 summarises the results of these studies of the suitable and optimal temperatures for the development of the immature stages of *P. japonica*.

Table 1. *A summary of studies of the suitable and optimal temperatures for the development of the immature stages of P. japonica.*

Developmental stage	Suitable temperatures (°C)	Optimal temperatures (°C)	Study method	Reference
Egg	15–34	30	Laboratory	Ludwig, 1928
Egg	13–35	30	Modelling	Régnière et al., 1981b
1st instar	15–30	30	Laboratory	Ludwig, 1928
1st instar	13–31	30	Modelling	Régnière et al., 1981b
2nd instar	15–30	30	Laboratory	Ludwig, 1928
2nd instar	13–31	25	Modelling	Régnière et al., 1981b
3rd instar	10–34	30	Laboratory	Régnière et al., 1981b
Post-overwintering larvae	12.8–29.8	25.5	Modelling	Gilioli et al., 2022
Transformation from larvae to pupae	20–27.5	-	Laboratory	Régnière et al., 1981b
Pupa	13–35	30–32	Laboratory	Ludwig, 1928
Pupa	10–36	32–34	Laboratory	Régnière et al., 1981b
Pupa	11.4–39.1	32–33	Modelling	Gilioli et al., 2022

3 Suitability of the Finnish climate for *P. japonica*

3.1 Previous studies covering Finland

3.1.1 Early assessment based on the climate in the known range

Bourke (1961) assumed that the establishment of *P. japonica* in Europe was likely when the following conditions were met:

a) The mean rainfall combined over June, July, and August exceeds 250 mm.
b) The mean soil temperature in July at a depth of 5–10 cm is 20–28 °C, or the mean maximum air temperature in July is above 22 °C.
c) The mean soil temperature in January at the same depth is above -2 °C.

These conditions were determined based on the climate observed in the known range of the pest in Japan and the USA at that time. The results suggest that the climate in Finland is unsuitable for the establishment of *P. japonica*. However, since then, the distribution of *P. japonic*a has expanded to regions that would have been deemed unsuitable for it based on Bourke's (1961) criteria, suggesting that Bourke (1961) underestimated the potential range of the pest.

3.1.2 Assessments based on annual growing degree days

Korycinska et al. (2015) calculated, based on the data from Régnière et al. (1981b), that *P. japonica* needed 1 422 growing degree days (GDD) to complete its life cycle when a base temperature of 10 °C was used. Furthermore, they proposed that if the life cycle of *P. japonica* was completed in two years (instead of one), an annual accumulation of 711 GDD was required for establishment.

While Régnière et al. (1981b) explored the pest's soil temperature requirements, Korycinska et al. (2015) evaluated the suitability of the UK climate for *P. japonica* by assessing whether the 711 GDD threshold was met based on air temperatures. Their brief comparison of soil and air temperatures indicated good alignment, leading them to suggest that air temperatures could be used for preliminary analysis if soil temperature data were unavailable (Korycinska et al., 2015).

The European Food Safety Authority (EFSA) employed the degree days approach of Korycinska et al. (2015) to estimate the potential range of *P. japonica* in the EU (EFSA, 2018; EFSA, 2019; EFSA, 2023b). The results in EFSA (2018) and EFSA (2023b) indicate that the accumulated temperatures in Finland are insufficient for the development of the pest. However, EFSA (2019) suggests that the accumulated temperatures in certain parts of Southern Finland are sufficiently high for the development of the pest.

The differences in these results are presumably due to the difference in the climate data used. According to Boberg & Björklund (2020), citing personal communication with EFSA, climate data from 1998 to 2008 was used by EFSA (2023b), and as the results appear identical to those in EFSA (2018), we assume the same dataset was used in both assessments. In contrast, EFSA (2019) used climate data from 1998 to 2017. The assessments do not specify whether the climate data are air or soil temperatures.

Notably, the assessments by EFSA (2018, 2019, 2023b) are based on the long-term mean annual GDD in Europe. This approach would be appropriate if the used threshold GDD was based on the long-term mean annual GDD observed in areas where the pest is present. However, when the threshold GDD is based on experiments on the time the pest needs to complete its life cycle in a given temperature, using long-term mean annual GDD is likely to overestimate the potential range of the pest. This is because in areas close to the limits of a range predicted like this, GDD in some individual years is inevitably below the threshold. (In fact, at the limit, it is below the threshold in 50% of individual years, assuming that the annual GDD values are normally distributed.) Since Finland appears to be close to the northern limit of the potential range of *P. japonica*, we considered comparing the threshold GDD of 711 with the long-term mean annual GDD inappropriate for our purpose.

3.1.3 Correlative species distribution models

Zhu et al. (2017) used a Maxent model to predict the potential global range of *P. japonica* by incorporating bioclimatic variables and anthropogenic factors such as human footprint and human population density. The results suggest that the climate in certain regions of southern Finland is suitable for *P. japonica*.

Della Rocca & Milanesi (2022) predicted the potential global range of *P. japonica* based on climatic and land-use factors. Their analysis considered only areas where the annual GDD was at least 711 when a base temperature of 10 °C was applied. The results suggest that the climate in certain regions of southern Finland is suitable for *P. japonica*.

Borner et al. (2023) predicted the suitability of areas for *P. japonica* based on various factors related to the climate, soil characteristics, land use, and other human activities. Their findings suggest that almost all of Scandinavia is unsuitable for the pest. However, the results also indicate that Oregon, Washington, and British Columbia are unsuitable for *P. japonica*, although it is known to occur in these areas. This suggests that the model by Borner et al. (2023) is not suitable for estimating the potential range of *P. japonica*.

3.1.4 CLIMEX analyses

Allsopp (1996) used the modified match climate mode in CLIMEX software (Kriticos et al., 2015) to estimate the potential global range of *P. japonica* based on the climate similarity to Philadelphia, the centre of its North American distribution at that time. The results suggest that the climate in Finland is unsuitable for the pest. However, this analysis underestimated the potential range of *P. japonica* because it ignored all other distribution areas of the pest except Philadelphia. The distribution of the pest has since expanded to regions that Allsopp (1996) predicted would be unsuitable (Klein, 2020).

Kistner-Thomas (2019) predicted the potential global range of *P. japonica* using the Compare Location mode of CLIMEX software (Kriticos et al., 2015). The results suggest that the climate in certain regions of southern Finland is suitable for the pest. However, we consider the model by Kistner-Thomas (2019) debatable, since its threshold for the degree days needed per generation (PDD) was defined such that it allows the inclusion of the southern half of Kunashir Island in the potential range of *P. japonica*. This may underestimate the GDD needed per generation since CLIMEX uses data on air temperature, and due to geothermal activity, soil temperature in the Kunashir Island cannot be predicted by air temperature. Indeed, the threshold PDD in the model (525, using 10 °C as the base temperature) is clearly lower than the 711 GDD suggested by Korycinska et al. (2015).

3.2 Analyses made in this study

Based on previous studies, the key climatic factors that restrict the establishment potential of *P. japonica* are soil moisture during the summer, and soil temperature during the winter and summer (see 2.4 and 3.1). To further assess the suitability of the Finnish climate for the establishment of *P. japonica*, we conducted the following analyses based on these factors.

3.2.1 Suitability of soil moisture in Finland during the summer

Sufficient soil moisture during the summer is required for the survival of the immature stages of *P. japonica* (see section 2.4.1) However, data on soil moisture are seldom available. Several researchers have therefore used the amount of summer rainfall to predict if the soil moisture is sufficiently high for the pest (Fox, 1939; Bourke, 1961; Fleming, 1972).

Fox (1939) and Bourke (1961) suggested that at least 250 mm of rainfall during the summer was required for the establishment of *P. japonica*. Fox (1939) observed that the populations of the pest declined significantly when precipitation fell below this threshold, while Bourke (1961) noted that this was the approximate minimum summer rainfall within the range of the pest known at the time.

To further explore how much summer rainfall is required for the establishment of *P. japonica*, we calculated the total rainfall from June to August within the areas where *P. japonica* has been observed (GBIF, 2023) using 2.5-arc minute spatial resolution average monthly precipitation data from 1970 to 2000 (Fick & Hijmans, 2017). The analysis revealed that in almost a third of the areas where *P. japonica* had been observed, the average total rainfall during the summer months was below 250 mm. Indeed, in some regions within the known range of *P. japonica*, e.g. in Colorado, the USA, and the Azores in Portugal, it was below 150 mm. It should be noted that irrigation might in some cases explain the occurrence of the pest in naturally dry areas.

In Finland, the average total rainfall from June to August, based on 10 x 10 km resolution average monthly climate data from 2003 to 2022 (Aalto et al., 2016), is between 200 and 250 mm in almost the entire country (Figure 1). Notable, in cooler regions, such as Finland, the soils retain more moisture than in warmer regions, due to lower evapotranspiration rates. Furthermore, soils in Finland typically become saturated with water in the spring due to snowmelt. Therefore, at a large geographical scale, we do not consider that soil moisture limits *P. japonica* establishment in Finland. However, because soil moisture is also influenced by other factors such as topography and soil structure, not all areas in Finland are necessarily suitable for *P. japonica* due to inadequate or excessive soil moisture.

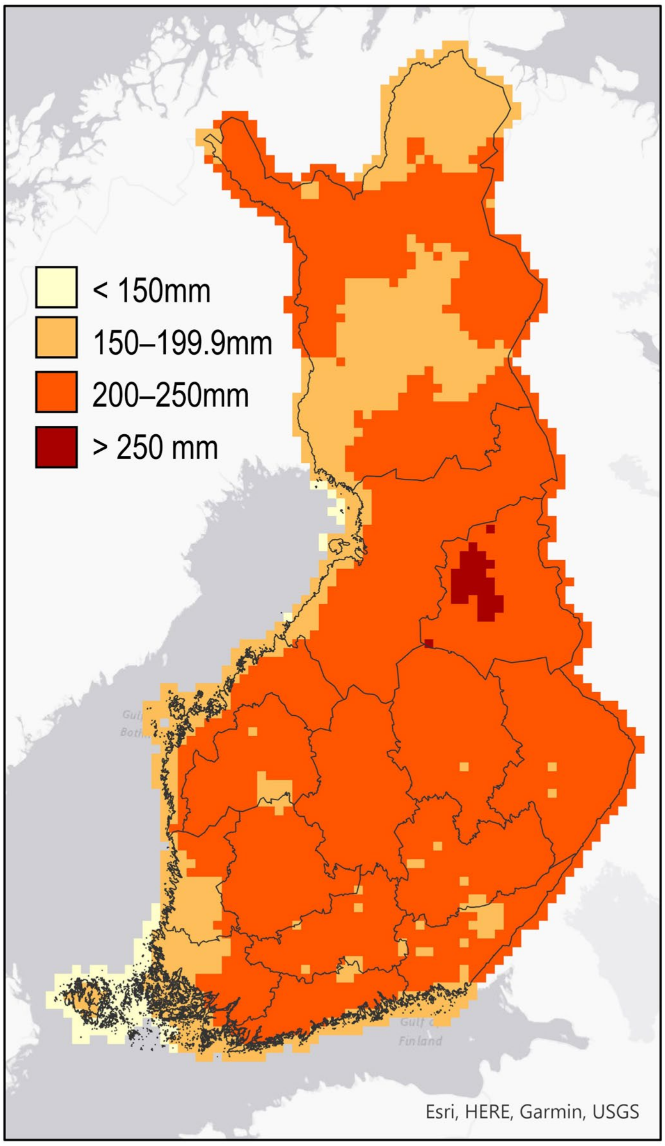

Figure 1. *The two-decade average total rainfall (mm) from June to August in Finland, calculated based on monthly climate data from 2003 to 2022 at a resolution of 10 x 10 km. The borders of the Centres for Economic Development, Transport and the Environment (ELY) were sourced from Statistics Finland (2022).*

3.2.2 Suitability of soil temperature in Finland during winter

Bourke (1961) suggested that a mean soil temperature above -2 °C in January was necessary for the successful establishment of *P. japonica*. He considered this threshold appropriate because according to his investigations soil temperatures in January within the known range of the pest typically did not fall below -2 °C, and severe mortality occurred when soil temperatures dropped below this threshold (Bourke, 1961). However, Bourke (1961) also noted that the high mortality during cold winters might have resulted from direct contact with ice and restricted ventilation. Other studies have suggested that *P. japonica* can tolerate soil temperatures as low as -7 °C (Hoshikawa et al., 1988) or even -13.3 °C (Smith & Hadley, 1926), at least for short periods.

Measured soil temperatures from 1971 to 1990 from eight sites in Finland (Heikinheimo & Fougstedt, 1992), which varied in terms of soil type, hydraulic conductivity, and density, show that the mean soil temperatures in the coldest month at a depth of 20 cm remain above -2 °C in some areas in southern Finland, and above -7 °C throughout the country.

According to the same data (Heikinheimo & Fougstedt, 1992), the annual minimum soil temperature was above -7 °C on three sites (Anjalankoski, Ruukki, and Ylistaro) and above -13.3 °C on additional four sites (Jokioinen, Maaninka, Sodankylä, and Vuotso). Although soil temperatures were generally higher in southern than in northern Finland, the results showed variation independent of geographic location, presumably due to differences in soil characteristics and potentially due to differences in snow cover.

It therefore appears that soil temperatures in Finland during the winter are unlikely to limit the establishment of *P. japonica* at a large geographical scale. However, at a local scale, not all soils in Finland are necessarily suitable for the establishment of *P. japonica* due to soil temperatures being too cold in the winter.

3.2.3 Suitability of soil temperature in Finland during summer

During the summer, *P. japonica* requires high enough soil temperatures to complete its life cycle (see section 2.4.3). However, data on soil temperatures are seldom available. Several researchers have therefore used the air temperature data to predict if the soil temperature is sufficiently high for the pest during the summer. Similarly, our analysis presented in this chapter have been conducted using air temperature data.

We assessed the suitability of summer soil temperatures for the establishment of *P. japonica* by comparing the annual GDD values across Finland with a the annual GDD that *P. japonica* is considered to require to complete its life cycle. As a threshold GDD we used 711, which was proposed by Korycinska et al. (2015) and used by EFSA (2018, 2019, 2023) (see section 3.1.2).

To study if and where in Finland GDD exceeds the threshold of 711, we calculated annual GDDs from 2003 to 2022 using daily air temperature data at a resolution of 10 x 10 km (Aalto et al., 2016). The annual GDDs were calculated using the method 1 by McMaster & Wilhelm (1997), with 10 °C as the base temperature.

The threshold GDD (711) was not reached every year anywhere in Finland, and even in the warmest areas, it was reached only in 75% of the years (Figure 2). The proportion of years above the threshold was 50% or more only in parts of southern Finland. If the used threshold GDD of 711 is indeed a valid estimate of the annual GDD needed by *P. japonica* to complete its life cycle, these results indicate that the pest would not be able to establish anywhere in Finland, although it might be able to form transient populations in most of southern and central Finland.

To study how sensitive the above conclusion is to the used threshold, we reran the assessment with a 5, 10 and 15% lower GDD thresholds. These percentages were chosen arbitrarily because neither the epistemic nor aleatoric uncertainty of the GDD of 711 has been quantified.

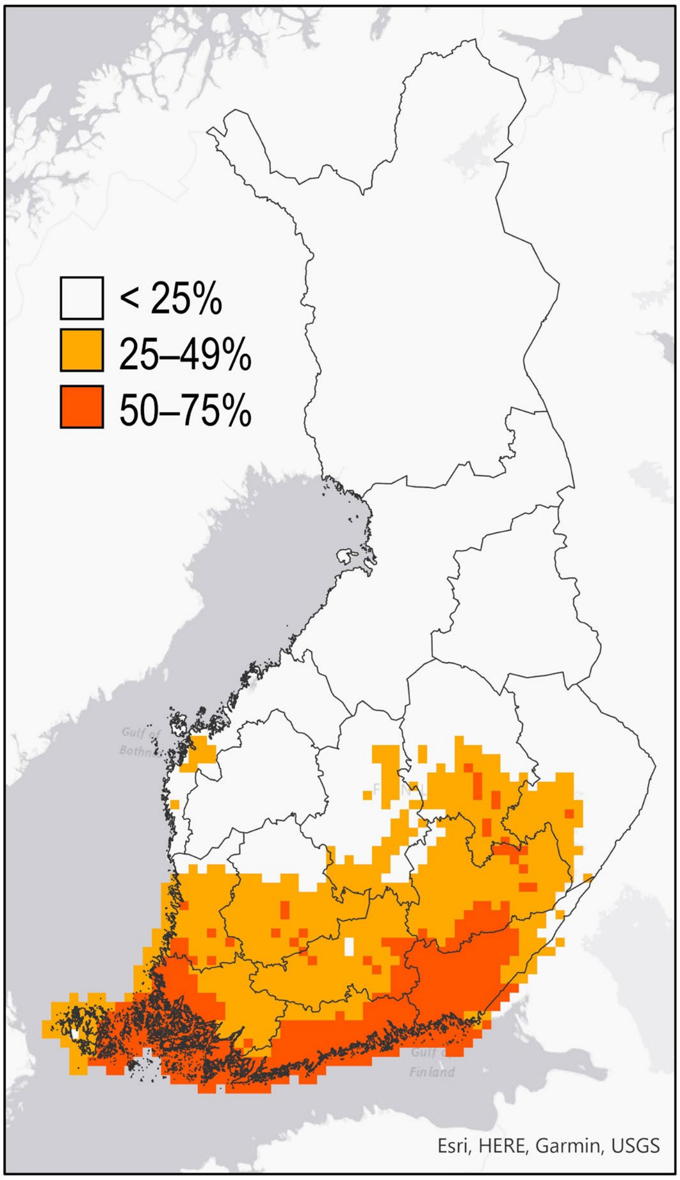

Figure 2. *The proportion of years between 2003 and 2022 when the annual GDD was at least 711. The borders of the Centres for Economic Development, Transport and the Environment (ELY) were sourced from Statistics Finland (2022).*

The 5% lower threshold was not reached annually anywhere, and the 10–15% lower thresholds were reached annually only in a narrow zone in the southwestern coast and archipelago (Figure 3). The area where the lower thresholds were reached in over 75% of the years ranged from a narrow zone in the southwestern coast (the 5% lower threshold) to most of southwestern and southeastern Finland (the 15% lower threshold) (Figure 3). These results indicate that even if *P. japonica* were to require somewhat less GDD for completing its life cycle than previously estimated, it would still be unable to establish in Finland, except in the very southernmost part of the country.

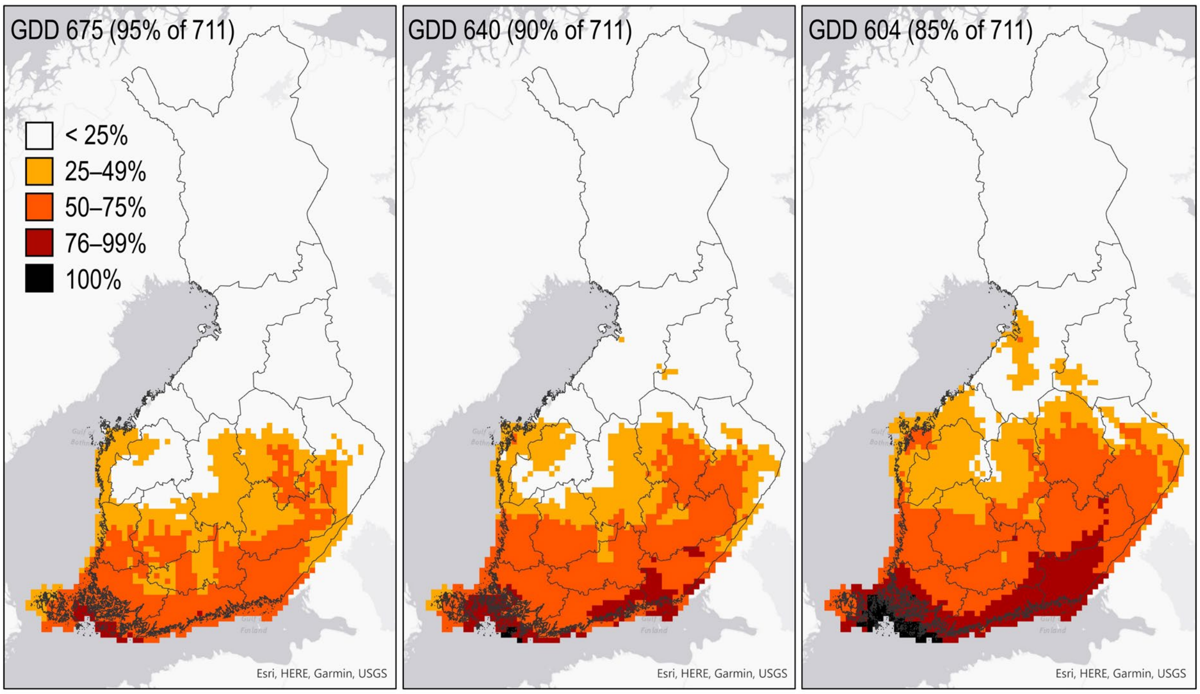

Figure 3. *The proportion of years between 2003 and 2022 when the annual GDD was 5, 10 and 15% lower than 711. The borders of the Centres for Economic Development, Transport and the Environment (ELY) were sourced from Statistics Finland (2022).*

3.3 Conclusions

We rated the present Finnish climate unsuitable for the establishment of *P. japonica*. This is because the annual growing degree days (GDD) was below the threshold, which the pest was considered to need to complete its life cycle, everywhere in the country in at least 25% of the considered years. For the southwestern coast and archipelago, the assessment was considered highly uncertain since in those areas, the results depend strongly on the accuracy of the used GDD threshold.

Our analysis showed that soil moisture and soil temperature during the winter do not appear to limit the potential establishment of *P. japonica* in Finland at a large geographical scale. However, at a local scale, these factors may limit the establishment of the pest.

The greatest sources of uncertainty in the assessment are uncertainty of the annual GDD that *P. japonica* needs to complete its life cycle, and the lack of research on the pest’s cold tolerance and of data on winter soil temperatures in Finland.

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