Department for Environment Food & Rural Affairs

Rapid Pest Risk Analysis (PRA) for:

Ips typographus

April 2023

Summary and conclusions of the rapid PRA

This rapid PRA updates an earlier document and has been undertaken following confirmation of a breeding population of *Ips typographus* in Kent in December 2018 with wider additional findings in south-east (SE) England area since then. This version incorporates additional evidence from laboratory and field-based investigations conducted throughout 2021 and 2022. This PRA shows:

Ips typographus is a bark beetle from the subfamily Scolytinae, which has a very large Palaearctic distribution. Its primary host is spruce (*Picea*), but recorded hosts include other conifers such as pine (*Pinus*), fir (*Abies*) and larch (*Larix*). Breeding tends to be less successful in these secondary hosts and is generally only seen in continental outbreak situations when populations are very high and *Picea* host resources become limited.

Risk of entry

New evidence indicates that adult *Ips typographus* are capable of dispersing naturally across the English Channel from continental Europe; this is considered to be the pathway by which multiple localised incursions of the pest were initiated in SE England in 2021. Very large populations of *I. typographus* have built up across western and central Europe in recent years, including unprecedented population peaks in Belgium and France (Grégoire pers. comm. 2022). Risk from entry via this pathway to the southeast of the PRA area is assessed as **very likely** (with medium confidence), although the opportunities and scale of cross-channel dispersal will vary between years, depending on the suitability of

conditions during periods of adult dispersal, and the size of the source populations in continental Europe. No practical measures are available to mitigate the risk of natural dispersal across the channel.

As *I. typographus* broods feed and develop in conifer bark, and adult beetles also hibernate under the bark of host trees when conditions are unfavourable, pathways for entry for the pest additionally consist of conifer wood (mainly spruce) with bark present, as well as wood packaging material (WPM) and even isolated bark or woodchips of conifers, although the latter are likely to carry a lower risk. There is ample evidence that the pest has arrived in the UK on imported wood in the past (e.g. Winter 1985) and that emerging adult beetles have subsequently flown after arrival, so risk of entry without the current mitigation measures that are in place for each wood category is assessed as between **very likely** to **unlikely** (high confidence) depending on specific wood pathway. However, with the phytosanitary controls that are currently in place, the risk is reduced from **very likely** to **unlikely** (medium confidence).

Risk of establishment

Many parts of the PRA area (the UK) contain suitable host trees (primarily spruce) for *I. typographus*, but the likelihood of establishment is considered to be greatest in the south of England within the range of natural dispersal from continental European populations, and where higher temperatures are also likely to encourage greater flight activity and accelerate beetle development. Typically, two generations per year would be expected in southern England, with one in the cooler / upland regions of the north and west. Although numerous interceptions of adult *I. typographus* have been recorded associated with wood imports into the UK, there was no previous evidence of successful establishment until the finding in Kent in 2018. This suggests that relatively large numbers of beetles may be required to initiate a breeding population; indeed the incursion of multiple localised populations in 2021 appears to have involved the cross-channel dispersal of large numbers of beetles into SE England, although the number of breeding galleries found at individual sites was variable. The long term establishment of these populations can only be speculated upon, since eradication work is being undertaken for each detected incursion, but it is probable that at least some of these small localised populations would go extinct naturally. Since the beetles require suitable material for breeding after dispersal, sites without sufficient appropriate host material cannot host or maintain new *Ips* populations. However, in the light of recent evidence related to natural dispersal into southern England, the overall likelihood of initial establishment for the south east of the UK is assessed as **very likely**, lowering to **likely** for the rest of the PRA area (moderate level of confidence). Whether any individual initial localised establishment (incursion) would persist or go extinct is less certain however.

Economic, environmental, and social impact

Based on the distribution and number of potential host trees, timber losses and recreational use of forests, the potential economic impact of *I. typographus* is rated as

large (medium confidence), whilst environmental impacts are likely to be **medium** (medium confidence). Social impacts are rated as **large**, but with low confidence in the rating due to lack of data in relation to the potential impact upon the potentially major host, Sitka spruce.

Endangered area

The endangered area is assessed as **throughout the UK** due to the widespread distribution of suitable hosts and climatic conditions, but with the highest likelihood of establishment in southern England due to warmer temperatures and proximity to continental Europe.

Risk management options

As *Ips typographus* is a regulated quarantine pest in GB and a regulated protected zone quarantine pest in Northern Ireland (defined in ISPM 04), imported conifer wood should be bark-free or heat treated to 56ºC to the core of the wood for 30 minutes (analogous to ISPM 15 requirements), or sourced from an area known to be free from the pest. When the measures are applied fully, they have been shown to be effective at excluding the pest via wood related pathways, providing full compliance is in place. Widespread monitoring with a network of pheromone traps is carried out to determine the distribution of *I. typographus* adults annually. The Plant Health (*Ips typographus*) (England) Order 2019 introduced specific measures for the control of *I. typographus* infestations in England, including the provision of a demarcated area (DMA) subject to controls on the movement of susceptible host material. A DMA has been established in south-east England encompassing all incursion sites where evidence of breeding activity has been identified, and where surveillance traps have detected the beetle. The DMA is intended to contain the beetle from establishing or from spreading beyond it. An authorisation process applies inspections and approvals to felling activities or proposed movement of spruce trees within the DMA, to ensure that any infested trees are treated appropriately. The policy is being adjusted according to new information, for example recent changes now enable uninfested trees from an affected site to be harvested and utilised conventionally (in approved facilities). No practical measures are available to mitigate the risk of natural dispersal across the channel, but thorough surveillance and monitoring across the UK has enabled a rapid response and commencement of eradication measures against all identified local incursions to date. The risk of dispersing populations establishing can be mitigated by the careful management of spruce forests in high-risk areas, through sanitation felling and the removal of susceptible material before any dispersal flights in spring. This may become more difficult to achieve however if increasingly frequent and severe weather events (in particular drought and storms) intensify the susceptibility of many more trees to attack.

Evidence gaps recently addressed and topics currently under investigation

A range of investigations was initiated following the detection of the 2018 *I. typographus* incursion to address important evidence gaps around the risk to UK host trees. Some of the most significant questions addressed include:

- Is *I. typographus* dispersing by natural means to UK from endemic populations in northern France a significant pathway?
    - Evidence from the wider environment trapping network and field surveillance in 2019 & 2020 indicated that natural dispersal was a pathway for colonisation. This was followed by more extensive trapping in 2021 & 2022 as well as a coordinated trapping effort in southern England and northern France. This strongly indicates that adult beetles are capable of dispersing across the English Channel from continental European populations (Inward *et al.* in prep; Blake *et al.* in prep). A large-scale dispersal event across the channel evidently occurred in June 2021, driven by exceptionally large continental populations of *I. typographus*, which appears to have seeded most or all of the numerous localised incursions subsequently identified in Kent, East & West Sussex, and Surrey. Molecular evidence supports these conclusions (de Becquevort *et al.* in prep) with beetles found in the UK grouping consistently with populations from north western Europe. How many beetle generations per year are likely in different parts of the UK? Field-collected data from southern England indicates that *I. typographus* generally has two generations per year in the south (as observed in the climatically similar region of northern France & Belgium). We can confidently infer that one generation per year would be more likely in the cooler north & west (as observed in climatically similar areas of Scandinavia); ongoing modelling work should define better where this transition from multivoltine to univoltine development would typically be (Webb *et al*. in prep). Variation in local weather conditions (particularly temperature) from year to year can also influence the voltinism (number of generations each year) of *I. typographus* in different parts of its range, with cooler springs (as in 2021) delaying emergence and resulting in a single generation.
- What is the relative susceptibility of Norway and Sitka spruce to the bark beetle and associated fungi?
    - Norway spruce is the primary host of *I. typographus* in the west of its range, and is known to be susceptible to attack when trees are weakened or damaged, or when beetle populations are large enough to overwhelm tree defences. Investigations have demonstrated that cut logs of freshly-felled Sitka spruce are also susceptible to attack in both laboratory and field conditions (Inward *et al* in prep), but the capability of *I. typographus* to colonise live Sitka spruce trees has not yet been clarified. Sitka is rarely grown on the continent and although there are records of Sitka being

    - attacked, there is little experimental data to support it being more or less preferred as a host, or more or less well defended against *Ips typographus*.
- How is tree resistance affected by environmental stress factors related to the maritime climate of the UK and can risk indices be defined to identify susceptible stands?
    - This remains an evidence gap at present.
- What is the effectiveness of various controls to combat *I. typographus*?
    - An extensive range of control measures have been introduced since the initial detection of *I. typographus* in southern England, including wide-scale surveillance activities (such as a GB-wide network of wider environment pheromone traps and aerial surveillance), the introduction of the demarcated area and associated regulations around spruce felling, inspection and movement aimed at ensuring containment of the pest, and proactive eradication undertaken against all detected incursions. To date these measures appear to be proving effective at understanding the drivers and risk of further immigration of *I. typographus*, rapidly detecting new incursions and containing populations; however eradication may only be declared after 3 years of monitoring around each detected population.

Evidence gaps remaining

Many factors affect the population dynamics of the pest, and it is difficult to predict the influence of interactions between local climate, host resistance, environmental stress, and natural enemies on populations in the UK. Sitka spruce is a much more important component of forests here than elsewhere in Europe, and important knowledge gaps remain regarding the susceptibility of live trees compared to the primary host, Norway spruce. Spruce trees are also faster growing, more intensively managed and felled at an earlier age in Britain than in many other European countries, where older 'over-mature' trees are notably more susceptible to attack by *I. typographus*. They are however grown outside of their native range and climatic conditions may be exacerbating site-related stressors.

Important questions that still require additional consideration or investigation include:

- What is the relative susceptibility of live trees and forests of Sitka spruce to the bark beetle and associated fungi?
- How is tree resistance affected by environmental stress factors related to the maritime climate of the UK, and spruce site characteristics?
- What is the threshold number of beetles required to kill a tree (including a Sitka spruce) under a range of climatic and site conditions?
- What are the risk indices for susceptible stands and how is risk affected by the size and frequency of local windblow?
- What is the relative cost and effectiveness of forest hygiene operations?

- How will climate change and degraded host condition affect the risk of *Ips* establishing , and its potential spread across the UK?
- Is there validated evidence as to the effectiveness of chipping as a phytosanitary measure against *Ips typographus* and similar bark beetles?
- What is the effectiveness of fumigation (method to be determined) on wood, wood products and bark as a phytosanitary measure against *Ips typographus*.

Figure 1. Images of *Ips typographus* and symptoms of attack upon host trees

1a) Lateral view of adult *I. typographus*

1b) Dorsal view of adult *I. typographus*

1c) Breeding galleries excavated under the bark of infested tree (longer maternal galleries with smaller larval feeding galleries).

1d) standing dead Norway spruce trees in Kent killed by *I. typographus* infestation

1e) *Ips typographus* adult, Kent

Source ©: Images 1 (a-d) D. Inward, Forest Research; (1e) M. Blake, Forest Research

Is there a need for a detailed PRA or for a more detailed analysis of particular sections of the PRA? If yes, select the PRA area (UK or EU) and the PRA scheme (UK or EPPO) to be used.

No	✓				
Yes		PRA area: UK or EU		PRA scheme: UK or EPPO	

Given the information assembled within the time scale required, is statutory action considered appropriate / justified?

Ips typographus has caused considerable damage and mortality of spruce trees across Europe over many decades, and as such is a well-studied and well-understood pest. Until recently, the pest has not been known to have successfully established a breeding colony in the UK, and is a regulated quarantine organism for which specific surveillance has been routinely conducted. Given the high potential risk that it poses to UK spruce trees and the small and isolated nature of the breeding populations that have been detected, it is appropriate to undertake statutory action against this highly damaging insect.

[The text below is a recommendation by the risk analyst which requires approval by PHRG]

Yes Statutory action	✓	No Statutory action	

Stage 1: Initiation

1. What is the name of the pest?

Name:	*Ips typographus* Heer
Synonyms:	*Dermestes typographus* Linnaeus *Bostrichus octodentatus* Paykull *Ips japonicus* Niijima
Taxonomy:	Class: Insecta; Order: Coleoptera; Family: Curculionidae; Subfamily: Scolytinae
Common names:	Eight-toothed spruce bark beetle (English) Buchdrucker, grosser 8-zähniger Fichtenborkenkäfer (German) Typographe, grand scolyte de l'épicea (French) Granbarkbille (Norwegian)

The species is listed in the EPPO Global database under EPPO Code IPSXTY.

2. What initiated this PRA?

Ips typographus is a major pest of conifers in its native and invaded ranges, and a regulated quarantine pest in the UK. In 1998, a PRA of the pest was carried out prior to establishment of a UK Protected Zone (PZ), which has been maintained against this and other *Ips* species. The species is now designated as a 'priority pest' for the UK. As a quarantine species, restrictions are in place on imports of potentially infested material and regular monitoring is conducted to confirm the absence of the pest from the UK. A Contingency Plan for *I. typographus* was prepared for use in the event of any findings of the pest (Forestry Commission 2015), and this is currently being updated. In December 2018, PZ monitoring activities led to a confirmed finding of a breeding population of *I. typographus* in southern Kent. Since that time, an expanded monitoring programme using pheromone trapping and aerial surveillance has detected additional seasonal incursions of *I. typographus* into the south east of England (Inward *et al.* in prep). Additional breeding populations were found in 2021 and 2022 which are all believed to have been initiated by a significant dispersal event across the English channel in early summer of 2021. A total of 27 individual 'incursions' have been detected to date, and eradication measures are being taken. The term incursion is used to denote a small and geographically isolated population of the pest, which has recently initiated one or more breeding galleries. This updated PRA reflects new knowledge about the pest, and assesses the future potential for additional entry, as well as the potential for long term establishment and spread by the pest in the context of recent findings and research around the numerous localised incursions into southern England.

3. What is the PRA area?

The PRA area is the whole of the United Kingdom of Great Britain and Northern Ireland.

Stage 2: Risk Assessment

4. What is the pest's status in the plant health legislation, and in the lists of EPPO[1]?

Ips typographus is listed in Annex 2 Part of The Plant Health (Phytosanitary Conditions) (Amendment) (EU Exit) Regulations 2020[2] as a GB quarantine pest. It is also listed as a priority pest for Great Britain[3]. The legislation which applies to Northern Ireland is the EU Phytosanitary Conditions Regulation (2019/2072) and this pest is listed as in Annex III as a PZ pest for Northern Ireland[4].

The pest is not on EPPO A1 or A2 list or on the EPPO Alert List, since the species is widespread in the EPPO region.

5. What is the pest's current geographical distribution?

The native European range of *I. typographus* extends from Russia and Scandinavia in the north to Italy, Slovenia and Bosnia-Herzegovina in the south, and France, Belgium, and the Netherlands in the west (EFSA PLH Panel, 2017), but it has a very large Palaearctic distribution as far east as Korea and Japan. The most recent distribution map for the pest is provided by the EPPO Global Database (https://gd.eppo.int/taxon/IPSXTY/distribution) but the current worldwide distribution is summarised in Table 1.

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[1] https://www.eppo.int/ACTIVITIES/quarantine_activities

[2] https://www.legislation.gov.uk/eur/2019/2072

[3] https://www.legislation.gov.uk/uksi/2020/1482/schedule/1/made

[4] The latest consolidated versions can be accessed via a search on https://eur-lex.europa.eu/

Table 1: Distribution of *Ips typographus*	
North America:	USA and Canada (absent, interceptions only)
Central America:	Absent
South America:	Absent
Europe:	Austria; Belarus; Belgium; Bosnia and Herzegovina; Bulgaria; Croatia; Czech Republic; Denmark; Estonia; Finland; France; Georgia; Germany; Greece; Hungary; Italy; Latvia; Liechtenstein; Lithuania; Luxembourg; Moldova; Montenegro; Netherlands; Norway; Poland; Romania; Russia (including Central, Eastern, Far East, Northern Russia and Western Siberia); Serbia; Slovakia; Slovenia; Sweden; Switzerland; Turkey; Ukraine; United Kingdom: England (Present: Transient, under eradication)
Africa:	Algeria (present but no details)
Asia:	China (restricted distribution but including Heilongjiang, Henan, Jinlin, Inner Mongolia, Neimenggu, Qinghai, Shaanxi, Sichuan, Xinjiang); Iran; Japan (Hokkaido and Honshu); Kazakhstan; Korea Dem. People's Republic; Korea, Republic; Tajikistan
Oceania:	Absent

6. Is the pest established or transient, or suspected to be established/transient in the UK/PRA Area?

The pest *I. typographus* is considered a potential risk to spruce grown in the UK. As Northern Ireland is specified as a PZ for this pest and it is a priority quarantine pest (QP) for GB, annual monitoring is carried out to confirm absence of *Ips typographus.* Occasionally, adult beetles have been trapped in the UK during routine monitoring at sites where bark-associated insects are likely to arrive, such as sawmills and ports handling imported wood. However, no signs of an establishment (i.e. no breeding galleries detected within host material) have ever been found in follow-up surveys at or near such sites. A breeding population of the pest was found by a routine PZ survey in Kent, England in December 2018. Between June 2021 and autumn 2022, several additional incursion sites were confirmed in Kent, West and East Sussex, and Surrey. These were detected at a range of distances from the initial incursion site and are not believed to be connected to that population. Instead, all are presently believed to have resulted from natural dispersal from continental Europe. Most populations were very small (some just a single breeding gallery), and are believed to have been initiated during the same dispersal event in June 2021. Following these findings - and wider detections of flying adults in pheromone traps - a demarcated area has been established to incorporate the incursions, covering London and the south-east of England ([5]see *Ips typographus* demarcated area map). All localised populations of the pest are currently under eradication, and the presence of the beetle in the United Kingdom: England is therefore considered to be present: transient, under eradication.

7. What are the pest's natural and newly encountered host plants; of these, which are of economic and/or environmental importance in the UK/PRA area?

Ips typographus preferentially attacks spruce (*Picea* spp.) especially Norway spruce *P. abies* (the most widely distributed primary host), Serbian spruce *P. omorika,* and Oriental spruce *P. orientalis*, all of which are native to Europe (EFSA PLH Panel, 2017). Throughout its wide range, *Ips typographus* also feeds on other spruces including Qinghai spruce *P. crassifolia* and Siberian spruce *P. obovate*. In addition, a number of exotic spruce species, planted both for commercial forestry and ornamental use, may also be attacked. These include Sitka spruce *P. sitchensis*, White spruce *P. glauca*, Engelmann spruce *P. engelmannii*, Yezo spruce *P. jezoensis* and Blue spruce *P. pungens*. *Ips typographus* has also been recorded to attack *Pinus sylvestris* (Scots pine) and *Pseudotsuga menziesii* (Douglas fir). However, pines (and Douglas Fir) are attacked significantly less frequently than spruce, and breeding success in such hosts is reduced (e.g., Schroeder & Cocos 2018). No population of *Ips typographus* has yet been found on anything other than Norway spruce in the UK.

Various surveys in arboreta and experimental plantings suggest that when populations of the pest are high, attacks on a wider range of potential hosts are possible. Okland et al (2011) found that *I. typographus* attacked and bred in *Picea rubens*, *Picea engelmanii*, *Picea sitchensis* x *Picea glauca*, *Picea mariana* and *Picea glauca*. Kakatos & Kovacs[6] examined beetle attacks on a wide range of tree species at Budafapuszta Arboretum in Hungary. They categorized attacks as light, moderate or heavy and suggested that large populations of *I. typographus* arising from infested Norway spruce stands bordering the arboretum had invaded and attacked trees. Those in the light and medium attack category had entrance holes but no successful maternal galleries and all the trees survived. However, heavy attacks resulted in successful colonisation and tree death. Conifer species in the latter category included *Abies alba*, *Abies cephalonica, Abies nordmanniana, Abies numidica, Larix* x *eurolepis*, *Larix laricina*, *Larix leptolepis*, *Picea abies*, *Picea engelmanni*, *Picea glauca*, *Picea glauca* (Alberta), *Picea glauca* (Ontario), *Picea glauca* (Saskatchewan) *Picea glehnii*, *Picea mariana*, *Picea omorica*, *Picea polita*, *Picea rubens*, *Picea sitchensis*, *Pinus aristate*, *Pinus banksiana*, *Pinus contorta*, *Pinus contorta latifolia*, *Pinus flexilis*, *Pinus monticola*, *Pinus nigra* var. *pallasiana*, *Pinus pinaster*,

[5][Larger eight-toothed European spruce bark beetle (Ips typographus) - GOV.UK (www.gov.uk)]

[6]http://neespi.nbeeu.nyme.hu/system/files/Lakatos.F_Bark%20beetle%20outbreak%20in%20the%20arboretum%20of%20Budafa.pdf

Pinus ponderosa, *Pinus ponderosa scopulororn*, *Pinus resinosa*, *Pinus sylvestris*, *Pinus strobus*, *Pinus wallichiana*, *Pseudotsuga menziesi viridis*, *Taxodium distichum* and *Thujopsis dolobrata*. These lists however must be understood in the context of massive outbreaks (rather than incursions) of *Ips typographus* where food resource is the limiting factor in population growth, and competition for breeding resource forces adults to breed in sub-optimal hosts. It is unlikely that populations can persist long-term in non-spruce hosts.

In relation to risk to the UK, there is an extremely wide presence of suitable hosts (Figs 2a and 2b), principally in the genus *Picea* as well as suboptimal *Pinus* and *Larix* hosts. However, the latter two genera are unlikely to be suitable for the early phases of establishment by the pest and field evidence has yet to show any evidence of establishments of *Ips typographus* feeding in such hosts. The three host genera occur in both commercial and non-commercial plantings of trees in forests and other locations, and this mix of conifers encompasses the known host ranges of all five species of *Ips* subject to Pest Free Area control (*I. typographus*, *I. amitinus*, *I. cembrae*, *I. duplicatus* and *I. sexdentatus*).

Figure 2a: Distribution of *Picea* species in Britain and Ireland on a 2 km tetrad basis (source Botanical Society of Britain and Ireland [https://bsbi.org/, extracted March 2023](https://bsbi.org/)). Note that this map illustrates tree presence (not density).

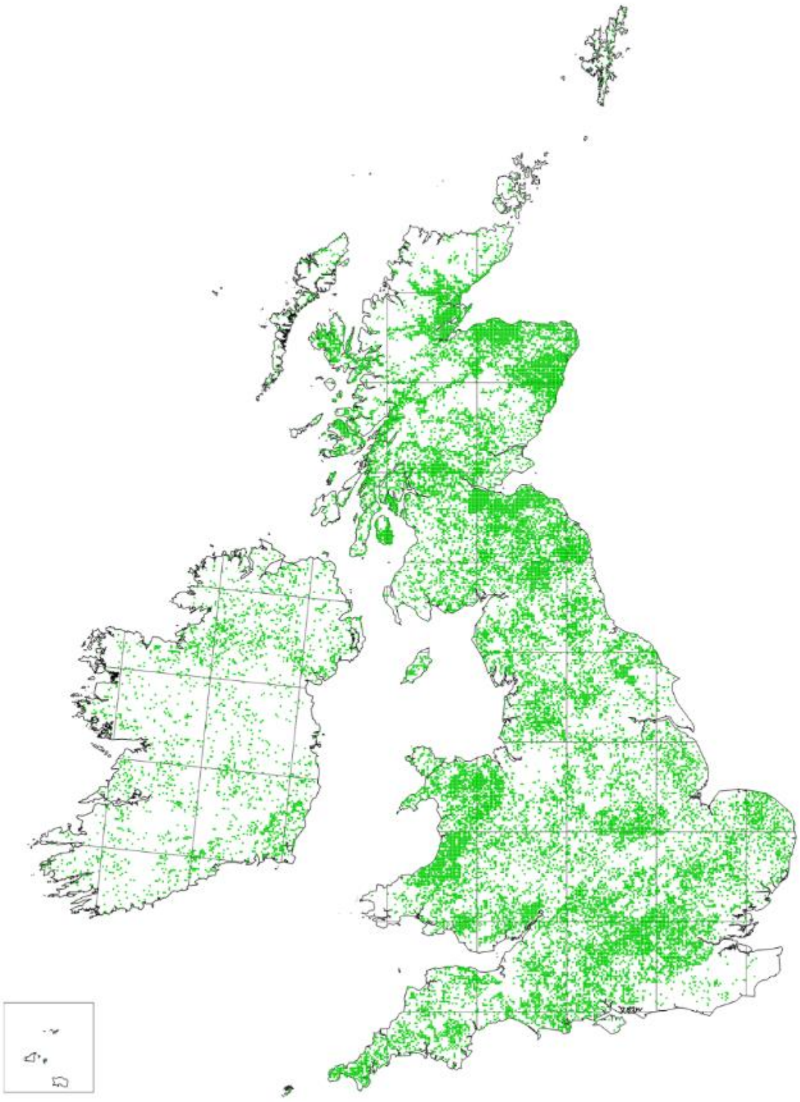
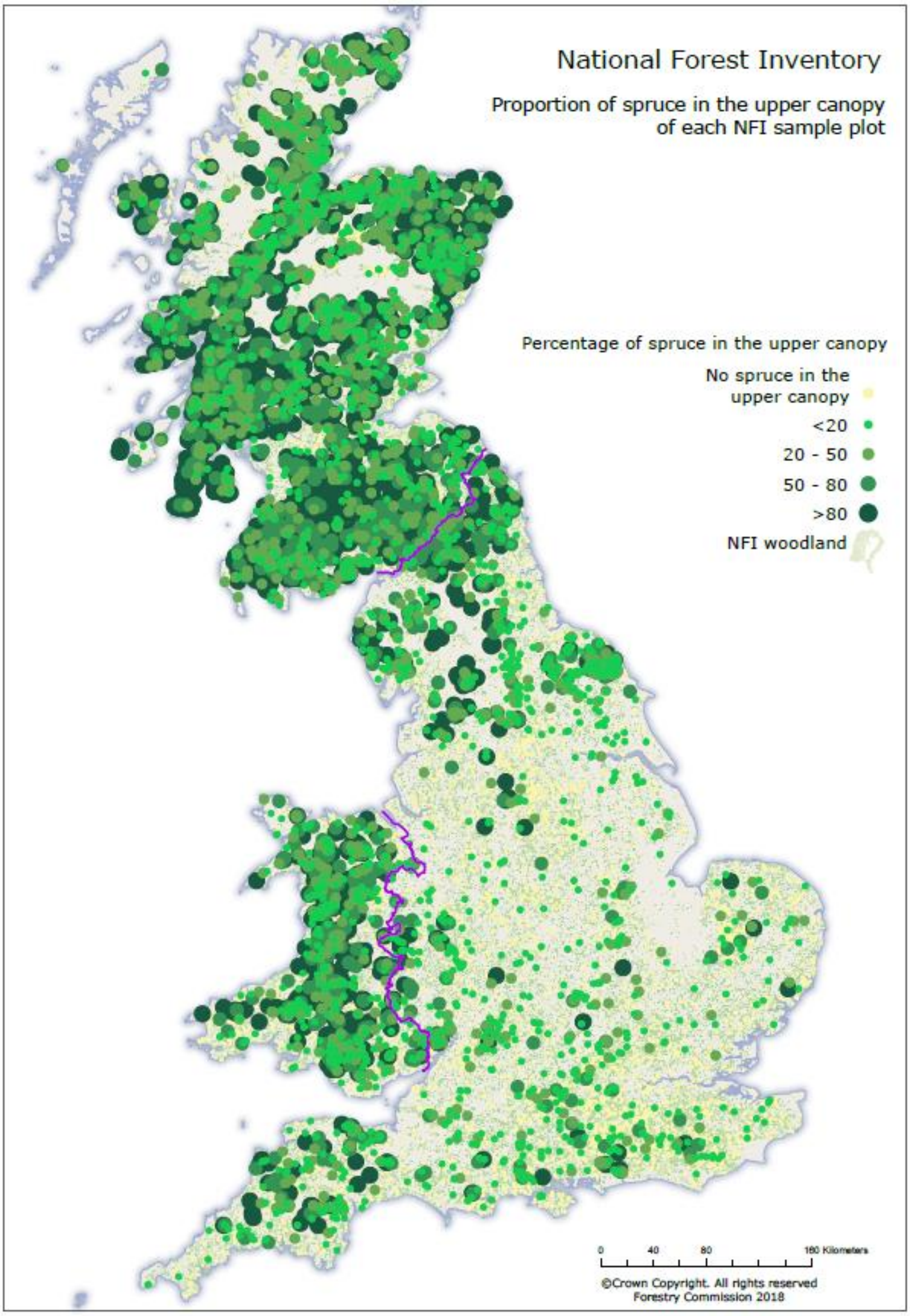


Figure 2b: Map showing the proportion of all spruce in the upper canopy of the National Forest Inventory sample plots in Great Britain (source, Forest Research NFI)



8. Summary of pest biology and/or lifecycle

Comprehensive accounts of the biology and ecology of *I. typographus* are available (e.g., reviews from Kausrud et al. (2011) and Wermelinger (2004)). Adult beetles of *I. typographus* are often associated with windblown, damaged and recently felled spruce trees, where they may build up numbers before moving on to attack adjacent live trees if the population is large enough to overwhelm the trees' defences. The major triggers for *I. typographus* outbreaks are the availability of storm-felled timber, summer rainfall deficits and warm temperatures (e.g. Grégoire et al. 2015; Marini et al. 2016); outbreaks take time to form, usually requiring at least two successive years of optimal conditions (for the beetle) to facilitate populations to build up .

Ips typographus can disperse over significant distances, sometimes tens of kilometres (Forsse & Solbreck 1985) and possibly further (Montano et al. 2016). Recent evidence suggests that the adults are capable of dispersal across the English Channel under suitable weather conditions (Inward et al. in prep; Blake *et al.* in prep). Suitable host trees are first located by male beetles, which attempt to bore into the phloem (inner bark layer) and release an aggregation pheromone to attract other individuals, both male and female. Where populations are large, mass attack may occur at this stage and overwhelm the defences of live trees. Females mate with the colonising males in nuptial chambers, and then begin to excavate a maternal gallery, laying eggs along it at regular intervals. Up to three females commonly mate with a single male, forming parallel maternal galleries originating from a single nuptial chamber. Once the larvae hatch, they feed and develop in individual larval galleries the phloem tissue before pupating and emerging; one (univoltine) to three (multivoltine) generations may be produced per year, depending on local climate. In central Europe there are normally two generations per year, and this appears to be the situation for southern England. Further north in Europe, including much of Scaninavia, cooler conditions lead to a single generation each year. Adult females initially stay with the developing larvae but then may re-emerge, create another gallery and lay more eggs (sister brood) without the need for a second mating (Wermelinger et al. 2011). *Ips typographus* commonly overwinters in the adult stage, either beneath the bark of host trees, or in the forest litter (Öhrn 2012). Though the adults seem to be better adapted to overwintering, suffering reduced mortality (Jönsson et al. 2011), immature life stages can also successfully overwinter (Štefková et al. 2017).

9. What pathways provide opportunities for the pest to enter and transfer to a suitable host and what is the likelihood of entering the UK/PRA area?

Previous risk assessments of *I. typographus* identified the main pathway of concern as wood of conifer hosts with bark present. Larvae of the pest develop in the phloem and cambium layers, thus any wood or wood product with residual bark present can harbour live stages of the pest. New evidence indicates that adult beetles are capable of dispersing across the English Channel from continental European populations, and that large numbers of beetles entered southern England in June 2021 by this means. This large-scale dispersal event appears to have initiated the multiple small and localised populations which established in Kent, East & West Sussex, and Surrey. Dispersal events were detected in 2019, 2020, 2021 & 2022 with by far the highest numbers caught in 2021 (many hundreds of beetles (Forest Research unpublished)), possibly due to spring swarming being delayed by unseasonably cool temperatures, followed by a strongly synchronised dispersal flight when the temperatures suddenly warmed in late May. There is some ongoing work into the effects of wind direction on this dispersal, but no evaluation as yet (Forest Research pers comm.)

Pathways of wood and bark

Long distance movement of the pest along human-assisted pathways of bark and wood has been confirmed by interceptions of *I. typographus* in several countries globally (Brockerhoff et al. 2006; Haack 2001, 2006). Any stage from egg to adult can be present within gallery systems in infested wood and bark in the absence of any mitigation measures, therefore wood with bark present represents a major pathway for pest movement. ince *Ips typographus* tends not to attack and breed in small trees or stem/branch material less than 8 cm diameter, and trees below this size are not imported for Forestry. There are imports of some larger trees for ornamental purposes, however these trees are likely to be healthy when sold and so unlikely to be infested with bark beetles. Therefore plants for planting represent a very low risk of pest movement and are not considered further.

The likelihood of pest presence, with capacity to emerge as adults at the end of the pathways, are evaluated below in the context of four wood/bark pathway categories. This evaluation takes account of current requirements when importing conifer wood which can include round wood, sawn timber, wood packaging material and timber in more processed form such as wood chips. The legislation that applies to conifer wood in relation to Northern Ireland is the EU legislation 2019/2072[4], and for the other countries within Great Britain the post-transition amended legislation for Great Britain applies (The Plant Health (Phytosanitary Conditions) (Amendment) (EU Exit) Regulations 2020[2]). The four categories are given in descending order of capacity to allow *I. typographus* to survive and emerge at the end of a pathway. This reflects the decreasing amount of bark available, either by volume or by capacity to support larval development and they are:

- Conifer wood packaging material and dunnage from countries where the pest occurs.
- Wood of *Abies, Larix*, *Pinus*, *Picea* and *Pseudotsuga* from countries where the pest occurs;
- Bark of conifers from countries where the pest occurs;
- Wood chips of conifers from countries where the pest occurs;

Each pathway is considered in the absence of any current controls or mitigation.

Pathway 1: Wood packaging material and dunnage

Wood packaging material (WPM) may be produced from lower quality wood and with little or no debarking, and on that basis can potentially present a high risk. In the past, WPM has been implicated in UK interceptions of *I. typographus* that have been made by Forestry Commission staff (including findings of infested material during port inspections). Additionally, a detailed review carried out by Haack (2001) which analysed various pathway components associated with entry of Scolytinae to the USA, reported that crating, dunnage and pallets were, in that order, the main types of wood packaging materials containing *I. typographus*. Other reports from Europe, through the Europhyt and Eurostat databases, indicated that wood packaging and conifer wood were imported in countries with protected zones from regions affected by the pest. The data indicate that large volumes were moved between 2011-2015 (countries with PZ status for the pest imported 41,000 tonnes from EU countries and 9,000 tonnes from third countries (EFSA PLH Panel, 2017)).

Based on this evidence and in the absence of any mitigation, the risk of entry by the pest in wood packaging material and dunnage would therefore be considered as very likely with a high level of confidence. However, all wood packaging material entering the UK, must be ISPM 15[7] compliant with limited exceptions applied to dunnage (Defra, 2021). In essence, all WPM must be made from debarked wood, with minimal bark remaining and have undergone either heat or fumigation treatment to render it low risk, which is then indicated by an identifying mark (see Forestry Commission (2017) for further details). However, there have been cases of poor compliance with ISPM 15, including fraudulent markings (Eyre et al. 2018), all of which can undermine its effectiveness in reducing risk around WPM pathways. Thus, while ISPM 15 will reduce the risk of WPM made of conifer timber acting as a pathway for *I. typographus*, some risk still remains, especially as this pest has a wide distribution in Europe and Asia (Table 1) and application of ISPM 15 may not be consistent across all regions. The last interception of live *Ips typographus* on imported wood was in 2018. The risk of entry on non-compliant wood packaging material (where treatment has failed or is absent) is therefore assessed as **unlikely** with **high confidence**.

Pathway 1 ***WPM ISPM15 non-compliant***	Very unlikely	☐	Unlikely	✓	Moderately likely	☐	Likely	☐	Very Likely	☐
Confidence	High Confidence	✓	Medium Confidence	☐	Low Confidence	☐				

Pathway 2: Wood of *Picea* (primary host), *Abies, Larix, Pinus* and *Pseudotsuga*

The UK is a major importer of timber with ca. 6.5 million cubic metres of sawn conifer wood imported each year, sourced primarily from Sweden, Finland, the Baltic States and Russia, but also from outside Europe (Table 2). Timber imports from Russia have been significantly impacted since the invasion of Ukraine however.

[7] https://www.ippc.int/en/core-activities/standards-setting/ispms/

Table 2: Trade in sawn softwood (all conifer) imports 2017-2021 in million m^3 (taken from Forestry Statistics 2022)							
Year	Sweden	Finland	Canada	Russia	Baltic States	Other countries	*Total*
2017	2.8	1.0	0.1	0.3	1.3	1.3	*6.8*
2018	2.7	0.9	0	0.4	1.4	1.1	*6.5*
2019	2.7	0.9	0	0.3	1.4	1.1	*6.4*
2020	2.7	0.8	0	0.4	1.5	1.2	*6.6*
2021	2.6	1	0.1	0.4	1.9	1.4	*7.5*
5 year total	13.5	4.6	0.2	1.8	7.5	6.1	*33.8*

Note: Totals reflect rounding

Wood of conifer host species can be a high-risk pathway even when sawn because some bark may be retained, creating the potential for Scolytinae beetle presence. A study reviewing timber imports into North America by Haack (2001) found that *I. typographus* was the fourth most commonly identified Scolytinae species from wood based on interception records compiled between 1985–2000. With specific reference to the UK, interceptions of *I. typographus* have a long history, including records dating back to the post-war period in the 1940s (Laidlaw 1947) and ongoing regular interceptions of the pest in pheromone traps at various UK ports which range from a few individuals to >100 individual beetles each year (Gibbs & Evans 2000). A spike of interceptions in the mid-1990s (Gibbs & Evans 2000) was associated with the new trade in sawn timber with the Baltic States and, at the time, poor standards of debarking. The first UK incursion/breeding population of *I. typographus* was only detected in 2018 however.

However, similar to WPM, any conifer wood to be imported into GB or Northern Ireland from EU or third countries must meet at least one of three phytosanitary requirements: (i) to be bark-free, (ii) to come from an area free from the specified bark beetle species (in this case the relevant pests are *Ips amitinus*, *I. duplicatus* and *I. typographus*) or (iii) to be kiln dried; (see Amendment of Annex 7)[8] and Forestry Commission 2017 for further details of the requirements). Without such measures in place, conifer wood (particularly spruce wood) is **very likely** to act as a pathway for the pest (**high confidence**), but with the mitigations in place the risk of entry via this pathway is reduced, and wood of conifers from EU countries must be accompanied by an official statement stating how it has been treated. Unfortunately, debarking processes do not necessarily produce truly bark-free wood. Conifer firewood is a potential pathway where wood is imported with bark. It is a requirement for all conifer imports from EU countries which retain any bark to be accompanied by phytosanitary export certificate, which should improve compliance and

[8] https://www.legislation.gov.uk/eur/2019/2072

additionally flag up such shipments for inspection. As Haack (2001) comments, "*complete debarking is difficult to achieve, and inspectors often examine only a small percentage of international cargo*". However, most imported spruce is square sawn or machine rounded for the fencing trade, treatments which are more likely to remove bark than previous de-barking treatments (Hazlitt *pers. comm.* 2023). However, due to the quantity of conifer timber imports and current high levels of *Ips* infestations in continental Europe, the risk of entry is maintained as **unlikely** (**high confidence**), as opposed to very unlikely.

Pathway 2 ***Wood with bark (non-compliant)***	Very Unlikely		Unlikely		Moderately likely		Likely		Very Likely	✓
Confidence	High Confidence	✓	Medium Confidence		Low Confidence					
Pathway 2 ***Debarked wood***	Very Unlikely		Unlikely	✓	Moderately likely		Likely		Very Likely	
Confidence	High Confidence	✓	Medium Confidence		Low Confidence					

Pathway 3: Bark of Conifers

In general isolated bark is considered to have reduced capacity to sustain larval development of Scolytinae beetles, due to the damage to life stages that is caused by the physical process of debarking, as well as desiccation in the bark fragments (Grousset et al. (2020). Survival will also depend upon the life stage involved, with eggs/young larvae unlikely to complete development in isolated bark before it desiccates and becomes unsuitable for feeding. In contrast, if late instar larvae, pupae, and new adults are undamaged by debarking, they may be able to complete development and emerge from isolated bark fragments. However, just as with conifer wood (see above) there are phytosanitary controls on movement of isolated conifer bark which, if it originates from non-European countries must have been subject to heat treatment (see Forestry Commission 2017 for further details of the requirements), and meet the phytosanitary requirements for *I. amitinus*, *I. duplicatus* and *I. typographus* (see above). With the mitigations required under GB and EU legislation, the limiting conditions that isolated conifer bark would place on the larval development of *I. typographus* is likely to reduce the risk of entry via this pathway from moderately likely to **very unlikely** but **with medium confidence** to account of the variable effect on different pest life stages and the lack of data on the extent of conifer bark trade.

Pathway 3 ***No mitigation***	Very Unlikely		Unlikely		Moderately likely	✓	Likely		Very likely	

Confidence	High Confidence	✓	Medium Confidence	☐	Low Confidence	☐				
Pathway 3 ***With mitigation***	Very Unlikely	✓	Unlikely	☐	Moderately likely	☐	Likely	☐	Very likely	☐
Confidence	High Confidence	☐	Medium Confidence	✓	Low Confidence	☐				

Pathway 4: Wood chips of conifers

There is no global standard for wood chips which sets out size limits but chipping of wood can be considered as a risk reduction measure in itself as the process destroys many insects. In particular, the process of making hogwood (a type of wood chip produced by crushing rather than cutting wood sections) is likely to be very destructive to insect life stages within the material (EPPO 2019). The potential for survival in woodchips will also depend on the dimensions of the end product. Smaller insects, such as bark beetles including *Ips* species, have been found to survive to some extent in wood chips (EPPO 2019), particularly those that retain small amounts of bark, although the combination of physical damage and desiccation will reduce the potential for larval development but not eliminate it entirely (Haack & Brockerhoff 2011). In addition, similar phytosanitary controls to those for isolated bark also apply to woodchips and further reduce the risk associated with this pathway.

Risk of entry via conifer wood chip is lower than that for conifer bark (Pathway 3) and therefore rated as **unlikely** but **with a moderate level of confidence** without mitigation. This risk is reduced further with the additional phytosanitary measures to **very unlikely** but still with **medium confidence** due to uncertainties about the size and processing methods for woodchips.

Pathway 4 ***No mitigation***	Very Unlikely	☐	Unlikely	✓	Moderately likely	☐	Likely	☐	Very likely	☐
Confidence	High Confidence	☐	Medium Confidence	✓	Low Confidence	☐				
Pathway 4 ***With mitigation***	Very Unlikely	✓	Unlikely	☐	Moderately likely	☐	Likely	☐	Very likely	☐

Confidence	High Confidence	☐	Medium Confidence	☑	Low Confidence	☐

All four wood related pathways when unmitigated (apart from square sawn wood) can support live adults through to emergence, although it will depend on the stage of the life cycle reached before the pathway movement commences and, eventually, reaches its end point. In addition, there is no safe period during the year in relation to any of the pathways since life stages of the pest can be present at all times of year, including continuing development of immature stages that could eventually emerge as callow adults. Since *I. typographus* can have up to three generations per year, there could be several opportunities for adults to emerge, either as newly formed callow adults or as re-emergent adults attempting to establish sister broods in other host trees (Wermelinger 2004).

Natural dispersal

The 2018 finding of a breeding *I. typographus* colony in southern Kent (and subsequent follow up surveillance) emphasised the possibility that adult insects may have dispersed naturally across the channel from northern France/Belgium and encountered suitable host material in the form of windthrown Norway spruce trees which were present at the site. Following four years of wider environment beetle trapping in south-east England, and a complementary study involving pheromone traps placed along the coast of southern England and northern France, there is good evidence that *I. typographus* dispersed over the channel in 2019, 2020, 2022, and in particularly large numbers in 2021, assisted by southerly winds and the pest's ability for long-distance flight (Forsse & Solbreck 1985; Montano et al. 2016, Inward *et al* in prep). In addition, the very large populations of *I. typographus* which have built up across western and central Europe in recent years up to 2021 (Figure 3) are a likely source population, including historically large populations peaks in Belgium and France (Jean-Claude Grégoire, pers. comm; DFS 2019). Adult beetles appear to have dispersed *en masse* in 2021 following an unusually cool spring across Europe which had previously prevented flight from occurring (typically observed from late March onwards). As temperatures rose above the flight threshold temperature (a minimum of 16.5°C) at the end of May 2021, a large-scale dispersal event was detected just a few days later in early June (Inward *et al*. in prep; Blake *et al*. in prep). This event appears to have initiated the multiple small population incursions in the south-east of England, which were subsequently detected in 2021 and 2022. However, dispersing populations must find suitable stressed or dying spruce trees to breed in, and incursions have only been found in wind-snapped tops, thrown trees or standing material impacted by water stress. Sites without such material have not been subject to colonisation, despite regular propagule pressure.

Natural dispersal from pest infestations in mainland Europe is assessed as **very likely**, but **with medium confidence** in that rating because it will vary from year to year and depend on the proximity and size of pest infestations elsewhere in Europe, as well as the presence of suitable weather conditions during the adult dispersal phase. It should also be noted that this specifically refers to the South East of England rather than the UK in its entirety, but this entry is still seen as a risk to the whole UK as addressed further in the PRA.

Pathway 5 ***Natural dispersal***	Very Unlikely	☐	Unlikely	☐	Moderately likely	☐	Likely	☐	Very likely	✓
Confidence	High Confidence	☐	Medium Confidence	✓	Low Confidence	☐				

10. If the pest needs a vector, is it present in the UK/PRA area?

No vector is required for the spread of *I. typographus.*

11. How likely is the pest to establish outdoors or under protection in the UK/PRA area?

Establishment under protection

Establishment under protection is not relevant to this bark beetle pest as it does not attack host plants for planting at a stage which may be under protection, but instead attacks semi-mature or mature trees, so is assessed as **very unlikely** with **high confidence**.

Under Protection	Very unlikely	✓	Unlikely	☐	Moderately likely	☐	Likely	☐	Very Likely	☐
Confidence	High Confidence	✓	Medium Confidence	☐	Low Confidence	☐				

Establishment outdoors

Frequent outbreaks and extensive damage to spruce and other forests occurs in the Eurasian native range of the pest (e.g., Hlộsny et al., 2021), so the likelihood of establishment outdoors by *I. typographus* in the UK is considered below in the context of suitable hosts, climate and other variables.

Host plants and suitable habitats

Spruce (*Picea*) is the main host of the pest. In the UK, the principal conifer species planted is Sitka spruce (*P. sitchensis*) and there are also plantations and ornamental plantings of a range of spruce species, including the known main hosts of *I. typographus* - notably

Norway spruce (*P. abies*). The geographic distribution of suitable hosts is therefore wide in the PRA area (Figure 2). Both planted forests and smaller urban and rural plantings of host trees contribute to the pool of suitable hosts, with the main component consisting of commercial conifer plantations. The principal areas of conifer in Great Britain are summarised in Table 3. Similar data for each species are not available for Northern Ireland but total conifer area is estimated at 55,000 ha and mixed conifer and broadleaf woodlands at 14,500 ha[9].

Table 3: Principal conifer woodland areas (000 ha) I Great Britain by country, 2020

Principal Species	England	Wales	Scotland	Great Britain
Sitka spruce (*Picea sitchensis*)	80	77	507	665*
Scots pine (*Pinus sylvestris*)	61	3	154	218
Corsican pine (*Pinus laricicola*)	40	2	3	46*
Norway spruce (*Picea abies*)	27	8	25	61
Larches (*Larix* spp.)	40	22	66	128
Douglas fir (*Pseudotsuga menziesii*)	25	9	12	46
Lodgepole pine (*Pinus contorta*)	8	4	88	100
Other conifers	25	5	11	40*
Total	307	129	872	1308

Data from National Forest Inventory - Forest Research* Totals may reflect rounding

It should be noted that only *Picea abies* (Norway spruce) was attacked by the breeding population of the pest in the Kent, despite the presence of apparently suitable (i.e., recently dead or moribund) *Pinus sylvestris* and *Pinus nigra* within 20 m of *Picea abies* colonised by breeding *I. typographus.* It may therefore be incorrect to consider non-spruce conifers as likely hosts for an establishing population of *I. typographus* in the UK, although if the pest was fully established and environmental factors facilitated an outbreak, such sub-optimal hosts may be colonised. As of March 2023, numerous (27) localised incursion sites (with at least one breeding gallery present on host material) have been detected since June 2021 in SE England. All of these occurred on stressed (e.g., drought stressed), damaged or felled (typically wind-thrown) Norway spruce hosts, with most findings on storm-damaged trees, windthrown tops and harvesting residue.

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[9] Northern Ireland Woodland Register and Basemap https://www.daera-ni.gov.uk/publications/woodland-register

Climatic suitability

The distribution of *I. typographus* has a wide Palaearctic distribution (Table 1), and in this respect climatic suitability is illustrated by its presence in a number of different climate zones. As temperature has a critical influence upon the beetle's life cycle, driving development rate, generation time, flight activity, and ultimately population growth (Faccoli 2009), inevitably the UK climate will influence the voltinism (number of generations of an organism in a year) of *I. typographus*. Extensive European literature is available to inform predictions of the life cycle and development of *I. typographus* in the UK, with spring and summer temperatures driving generation time rather than cooler months when temperatures fall below the developmental thresholds. Using the FR climate matching tool (Broadmeadow et al. 2005; https://climatematch.org.uk/) for current mean average temperature and diurnal range, the mean April-September temperatures in southern England match those in northern France and Germany, Belgium and the Netherlands; for central England they match those in Denmark; and for northern England, Wales and southern Scotland they match those in southern Sweden (based on 30 year averages 1990-2020 using UKCP18 gridded climate data). This equivalence allows comparison with the pest life cycle data from these regions.

The thermal requirements for development from egg to emergent adult can be calculated for *I. typographus* using accumulated degree-days above a lower developmental temperature of 8.3°C (Wermelinger & Seifert 1998; Wermelinger et al. 2011). Spring emergence commences when air temperatures exceed ~16.0°C and around 140 degree-days (dd) have accumulated from early April (Baier et al. 2007), whilst mass beetle emergence is initiated at 20°C. The minimum temperature for flight is 16.5°C, but the optimum is 22-26°C (Wermelinger 2004). In southern Sweden, dispersal by flight of overwintering adults typically begins in late April, with colonisation of suitable host material occurring around a week later, in early May (Ohrn et al. 2014). Flight continues until mid-August in both southern Sweden and Denmark, continuing into September with the warmer conditions of central Europe. (Baier et al 2007).

Adults which colonise and breed earlier in the spring are more likely to re-emerge and successfully produce a sister-brood. This appears to be particularly important for the propagation of a population in cooler areas with a univoltine life cycle (single generation per year) (Wermelinger & Seifert 1999), but survival of the sister brood is also correlated with warmer conditions. The new generation of beetles usually emerges to fly around 8 weeks after colonization and breeding, typically beginning in July. These new adults then initiate breeding themselves. In southern Sweden this is only occasionally successful, in years with particularly warm summers (Ohrn et al. 2014), whereas in Denmark the successful production of a second generation each year appears to be the norm (Harding & Ravn 1985). Bivoltinism (two generations per year) is also typical in France and Belgium (Jean-Claude Grégoire, pers. comm) and most of central Europe, where the first generation tends to develop from May to July, and the second generation from August to October (Nageleisen 2018). Particularly hot summers occasionally generate a third generation in lowland central European forests, a situation expected to become more frequent under climate change. Similarly, bivoltinism is predicted to become predominant where populations are mainly univoltine at present. This would apply, for example, in southern Sweden (Jonsson et al 2011), as longer periods of optimal temperatures would drive earlier spring dispersal and faster development of the first generation. Based on these data, *I. typographus* is likely to follow a univoltine life cycle in the cooler areas of the UK (northern England, Wales and Scotland), except in unusually warm or prolonged summers, when a second generation might be successfully produced. In southern and central England however, typically a bivoltine life cycle could be expected. Data from the trapping work conducted over the last 4 years in southern England supports this hypothesis, with two peak periods of activity apparent in 2019, 2020 & 2022, with one in 2021 due to a cool and delayed spring.

Verification of this comes from an analysis by Cambridge University[10], which utilised the findings of two phenological models for *I. typographus* development in Austria and southern Sweden (Baier et al. 2007; Jönsson et al. 2007) and applied them to weather data from East Malling weather station (located 36 km northwest of the 2018 Kent breeding site), to predict within-season emergence times for *I. typographus.* It was concluded that all variations of the models indicated that the climate in the initial 2018 Kent outbreak area was compatible with a bivoltine life cycle and at least one sister brood of *I. typographus*. However, subsequent work has shown that published models don't match all of the data collected from the trapping programme, likely due to the mild maritime climate of the UK (Webb *et al*. in prep). The models also suggest there is a high likelihood of pest establishment in more northern parts of Britain, but with probably with only one generation per year, although there is higher uncertainty in this prediction. The was some uncertainty around factors other than temperature (e.g., sunlight exposure (Štefková et al., 2017)), which could influence the ability of the pest to establish in the northern parts of the UK. These include effects of regional topography and stand conditions on local air temperature and the under-bark temperature of brood trees, all of which exert a strong influence on beetle development. Solar irradiation which affects under-bark temperature is affected by the extent of the forest canopy, decreasing exponentially with increasing canopy closure (Pennerstorfer, 2000). Once stands have a closed canopy, the influence of solar irradiation on bark temperatures is negligible, and the bark temperature remains equivalent to the air temperature inside the forest stand. In contrast, beetle development is significantly accelerated due to higher insolation on exposed sites, for example, after wind throw or at south-exposed stand edges (Baier et al. 2007).

It is worth noting that Baier et al. (2007) also comment that the multivoltine life cycle of *I. typographus,* with re-emerging parental beetles and photoperiodic thresholds influencing flight and reproduction activity, is much more complex and more challenging to model than the simpler life cycles of some other bark beetle pests that depend only on thermal

[10] Webb, C. & Gilligan, C. (2019). Ips typographus: application of two phenological models to predict within-season emergence times. Unpublished report: Epidemiology and Modelling Group, Department of Plant Sciences, University of Cambridge

conditions. Nevertheless, the broad patterns of voltinism in northern and central Europe are well understood and do correlate closely with local spring and summer temperatures.

Other abiotic factors

A key factor in initial infestation by *I. typographus* is the presence of weakened trees that enable pioneer beetles to attack and overcome tree defences and then breed successfully. Although this is a component of the biology of the host tree, the factors that can weaken the trees are mainly stochastic events such as drought, wind-storms, snow damage or physical damage from harvesting operations (Økland & Christiansen 2001). These factors are prevalent throughout the PRA area, with some regions more liable to high winds and other meteorological stochastic events.

Thus, the rapid removal of felled or damaged trees are important factors in limiting the build-up of bark beetles such as *I. typographus*. This is normal practice in the UK in commercial forests, and has probably contributed to reducing the availability of weakened trees that are key to enabling the beetle to establish in new locations. However, the very wide distribution of suitable host trees and the many abiotic factors that can produce local concentrations of weakened trees suggests that sufficient breeding material will be present at all times if the beetles are able to encounter them. This is evidenced by recent ground surveys in Kent and East Sussex which have revealed that, although there are many well-managed commercial spruce plantations in this region, there are also a small number of semi-managed PAWS (Plantations on Ancient Woodland Sites), as well many unmanaged commercial spruce stands where thinning or removal of weak/supressed and standing dead or fallen trees does not take place. The initial breeding pest population in Kent (2018) was on a site that had many of the triggers for weakened trees, including soils prone to summer droughts, winter waterlogging and windthrow, supporting the view that if the beetles are introduced they will occasionally encounter suitable host material. Winter storms appear to be responsible for creating some of the breeding material populations of *Ips* that were found in in 2021 & 2022, but for populations to persist long-term they will require continuous availability of susceptible trees, either through storm damage or drought stress, or weakened by disease, poor soil conditions, or other factors.

Competition and fungal symbionts

Although there are numerous competitors and natural enemies of *I. typographus* in its native range, they play a secondary role in relation to the boom and bust dynamics of this pest. Principal drivers of population increase are the presence of weakened trees which enable populations to build rapidly to the extent that they can overcome the defences of healthy trees. However, once populations have peaked, along with the exhaustion of their food resources, natural enemies play an important role in reducing pest numbers to endemic levels. Many of the natural enemies are generalists and have a delayed effect on the population dynamics of *I. typographus*. This has been well reviewed by Kenis et al. (2004). Overall, therefore, there is unlikely to be any influence of natural enemies or competition on the likelihood of establishment.

Endoconidiophora polonica, an early colonist of spruce sapwood following attack by *I. typographus*, is apparently the most pathogenic of the fungi associated with the beetle (Section 15), and therefore considered the most significant in aiding the beetle to overwhelm tree defences, contributing to tree death (Kirisits, 2004). However, comparisons following inoculation of *E. polonica* into Norway spruce (*P. abies*) and Sitka spruce (*P. sitchensis*) indicated that the fungus was more pathogenic to Norway spruce than Sitka spruce (Webber 1999; Flø et al. 2018). This difference could influence the ability of the pest to successfully colonise even weakened Sitka spruce trees and therefore the likelihood of establishment by the pest in the UK where Sitka spruce is the dominant conifer species (Table 2).

Overall conclusions on the likelihood of establishment

The presence of suitable host material throughout the PRA area, combined with climate variation that is well within the range for *I. typographus* in its Eurasian distribution, indicate that the whole of the PRA area is likely to be suitable for establishment of the pest in spruce and other forests. Where the expansion of *I. typographus* into new areas has been relatively slow in its Eurasian native range, this probably reflects a lack of suitable hosts rather than unsuitable climatic conditions. For example, the pest had still not fully colonised the western part of France by 2008 despite beetles being recorded there in pheromone traps (Jacquemin 2008), but spruce planted in Brittany has been attacked by *I. typographus* since 2014 as it has matured and become more suitable for colonisation (J-C Gregoire, pers comm.). The apparently slow spread is also likely to be related to the gradual build-up of large enough pest population densities to sustain attacks on trees (see below Section 12). Moreover, despite regular interceptions of the pest in Britain (particularly in port areas where spruce timber has been imported from mainland Europe (e.g.,Gibbs & Evans 2000)) no evidence of successful breeding has been detected over many years of surveys prior to the finding in Kent in 2018. This suggests that the circumstances for successful establishment may be achieved only infrequently. The significant outbreak of *Ips* in Belgium and France appears to have escalated from 2018 and will eventually subside as the beetles run out of suitable host material; this should reduce the propagule pressure of dispersing beetles, at least until a subsequent outbreak. However, the incursion of the initial Kent population detected in 2018 would predate this period, indicating that even without significant outbreak events in Belgium and France the UK remains at risk of colonisation by *Ips typographus*.

In addition, the dominant spruce host in the UK, Sitka spruce (*Picea sitchensis*), may not be optimal for attack and colonisation by *I. typographus* and its associated fungi, compared with Norway spruce (*Picea abies*) which is the most common host attacked in mainland Europe. Sitka spruce is not immune to attack however (Flø et al. 2018), and recent experimental work has demonstrated that freshly cut logs of Sitka spruce are as readily utilised for breeding by *I. typographus* as Norway spruce logs, both in the laboratory and field (Inward et al., in prep). Information on the susceptibility of live Sitka trees and forests to the pest is still outstanding, and it is prudent to assume that Sitka will be vulnerable to *Ips typographus*.

Climate change has long been predicted to alter the pest's voltinism and the vulnerability of host trees, leading to increased damage in the future (e.g.,EFSA PLH Panel, 2017). The combination of warming summers in the UK and close proximity to recent major pest outbreaks in Belgium and France is likely to have increased the likelihood of establishment, particularly in the southeast of England. Overall, therefore, the likelihood of establishment in the southeast of the PRA area is assessed as **very likely** with **moderate** confidence based on the numerous detected incursions in Kent and the southeast, but the uncertainty taking into account that the long-term survival of the numerous localised and small populations (some just a single breeding gallery) remains unknown. The likelihood of establishment elsewhere in the UK is likely to be lower but with low-medium confidence in the assessment. This also reflects the uncertainty over the suitability of Sitka spruce as a host for the beetle, as this is widely grown in the cooler and wetter areas of Britain.

Outdoors in southeast	Very Unlikely		Unlikely		Moderately likely		Likely		Very likely	✓
Confidence	High Confidence		Medium Confidence	✓	Low Confidence					

Outdoors in other parts of UK	Very Unlikely		Unlikely		Moderately likely		Likely	✓	Very likely	
Confidence	High Confidence		Medium Confidence	✓	Low Confidence					

12. How quickly could the pest spread in the UK/PRA area?

Spread by natural means through adult beetle flight has been regarded as a relatively slow process for *I. typographus*. Typically, dispersal by flight has been recorded as up to 100 m and often less, depending on the proximity of suitable host material from sources of beetles. However, these judgements are based on mainland European populations of the pest which are native to the region and occupy large areas of spruce where, in an outbreak setting, there is little requirement for long-distance dispersal due to the local availability of suitable trees. If *I. typographus* ever became permanently established in the UK, it is likely that it would primarily disperse via short-distance flights, but the same behaviour may not be typical of an establishing population.

Instances of long-distance flight over tens of kilometres have been recorded (Forsse & Solbreck, 1985) including wind-supported flight up to 43 km (Nilssen 1984), and more recently, evidence of dispersal across the English Channel. There is no reason to assume that that beetles will remain confined to sites if there is little or no spruce in a suitable condition for colonisation. Such activity could result in rapid dispersal, and may be more likely to occur from heavily infested locations. At the initial incursion site in Kent, the most isolated breeding activity was 350 m away from the main breeding colony, in a small block of very stressed Norway spruce, despite other suitable spruce being within 50 m. This suggests that under UK conditions, the pest is capable of flying up to 350 m (and probably beyond this range) to locate suitable spruce, and thereby establish satellite breeding populations. However, 99.9% of the overwintering beetles caught were within 100 m of infested trees and, following data from Europe, the overwhelming majority of beetles may be expected remain close to their natal trees (Blake *et al,* in prep). If the core population of the pest was able to build-up during the establishment phase, increasing numbers of beetles are also likely to disperse over longer distances to find uncolonized trees and avoid competition, thus undergoing stratified dispersal (Liebhold & Tobin 2010).

For local outbreaks arising from population growth to the point where mass attacks of trees occur, the expected period of maximum damage has been approximately 10 years. The estimated age of the breeding pest population discovered in Kent in 2018 was three to five years, but with considerable uncertainty around this estimate. The number of affected spruce trees was sufficient to be readily detectable during aerial surveys, but the outbreak was still limited and had not spread to other nearby woodlands. Other populations found in 2021 & 2022 were generally small (typically just a few breeding galleries detected) and were only found across a limited area of spruce. Though breeding had taken place, populations were still small enough to respond effectively and eradication efforts are expected to be successful.

Human assisted spread (see Section 9) could sustain rapid spread of the pest. Any wood that is infested by *I. typographus* could be moved and provide new foci of infestation, if the pathway end point was close to suitable host material. The strong evidence of international movement of the pest ‘in trade’ in the past indicates that human-assisted long-distance dispersal has been common, although more recently, effective phytosanitary measures have diminished this pathway. When infested timber is moved, both adult and juvenile stages can be carried long distances and, unlike adult flight, such movements do not depend on suitable air temperatures or favourable wind direction.

Precise estimates of the time needed for the pest to reach its maximum extent in the PRA area are likely to be influenced by local climate and environmental factors. Speed of spread is considered likely to occur **at a moderate pace** (**low confidence**) if based on beetle flight alone, but with human assistance, could occur **quickly** (**medium confidence**). In either case, spread would be influenced by the pest encountering suitable host species and triggering events. Should the optimum mix of triggering events and suitable weather conditions combine, then spread by natural means could occur quickly.

Natural Spread	Very Slowly	☐	Slowly	☐	Moderate pace	✓	Quickly	☐	Very quickly	☐
Confidence	High Confidence	☐	Medium Confidence	☐	Low Confidence	✓				

Human-assisted	Very Slowly	☐	Slowly	☐	Moderate pace	☐	Quickly	✓	Very Quickly	☐

Confidence	High Confidence	☐	Medium Confidence	✓	Low Confidence	☐

13. What is the pest’s economic, environmental, and social impact within its existing distribution?

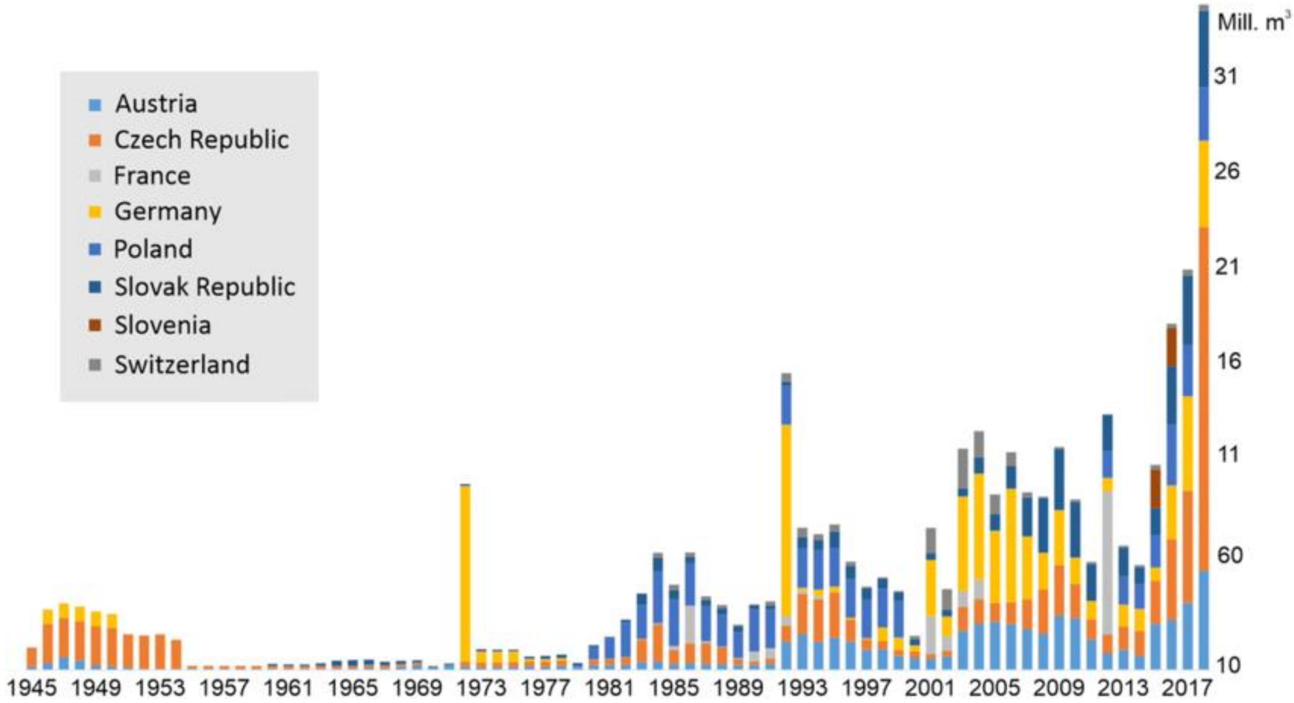
Timber losses and linked economic and environmental impacts have been extremely high for *I. typographus* in many countries across Europe. For example, Hlásny *et al* (2021) summarised damage arising in Norway spruce from bark beetles (primarily *I. typographus*) for a number of countries (Figure 3). These data are typical of some of the major outbreaks caused by the pest.

The large volumes and areas of damage in the data summaries shown in Figure 3 represent significant proportions of the available forest resources in some cases. For example, Schelhaas et al., (2003) estimated that around 8% of tree mortality in Europe between 1850 and 2000 was attributable to bark beetle activity, and principally from *I. typographus*.

Millions of trees can be killed in large outbreaks, for example in mainland Europe (Figure 3; Seidl et al. 2014) which are triggered following events such as windthrow, snow damage or extensive drought. These triggers are becoming more common in mainland Europe due to the increased frequency of severe storms and very dry summers. In the native/endemic ranges of the pest, and without the destabilising effect of such triggering events, the ‘return time’ between outbreaks when populations of the beetle gradually build up naturally is estimated to be as high as 75 years in Scandinavia, with each outbreak having a duration of about 10 years, whether triggered by stochastic events or natural increase (Okland & Bjornstad 2006). Although outbreaks have tended to be relatively local in relation to the triggering events, the large-scale outbreak seen across central Europe over the last 7 years or so (Figure 3) has been driven by multiple successive years of drought and high summer temperatures over a wide area. In addition a widely damaging ice storm in Slovenia triggered a large outbreak in forests there (Kolšek 2017). Overall, a significant population growth and unprecedented levels of damage have been recorded. The influence of climate change upon both host susceptibility and insect voltinism is therefore likely to play an important role in population build up and spread of *I. typographus* in the UK.

Apart from the economic and environmental impacts of *I. typographus*, the visual impacts of the pest’s attacks are highly evident and influence the social values that visitors attach to those environments. In Europe and North America, severe bark beetle outbreaks have been documented to cause hazardous falling tree conditions, aesthetic loss, ruined trail conditions and in some instances, property value loss, land use conflicts or loss of community identity.

Figure 3. Volume of Norway spruce killed by *Ips typographus* (and other bark beetles) in selected countries in Europe since 1945 (from Hlásny *et al* 2021)



Although the current understanding of the social aspects of forest disturbances is limited, there is an increasing need to address these aspects in relation to forest management and other activities (Hlásny et al. 2019). These include values which influence health and physical well-being, as well as contributions to social connections and cultural and spiritual significance (O'Brien et al. 2017). Additionally, the frequent and highly visible infestations of *I. typographus* in Europe have required forest managers to balance a range of requirements from their forests to take account of the perceptions of visitors to woodland parks, and to offset the impact of bark beetles. A study by Arnberger et al. (2018) indicated that visitors were most concerned by visual impacts such as clearfells or the effects of bark beetles near to the visitor trails.

In reviewing the economic, environmental, and social impacts within the existing distribution of *I. typographus*, in combination these are assessed as **large to very large** with a **high degree of confidence**.

Impacts	Very small	☐	Small	☐	Medium	☐	Large	✓	Very large	☐
Confidence	High Confidence	✓	Medium Confidence	☐	Low Confidence	☐				

14. What is the pest's potential to cause economic, environmental, and social impacts in the UK/PRA area?

Evidence presented in previous sections indicate that the pest could potentially build up to extremely damaging levels likely to affect the principal commercial conifer species in the UK. Successful breeding of *I. typographus* in the initial Kent incursion affirms the capacity of the beetle to establish and potentially increase in population size, and the view that very high levels of damage could be experienced if the beetle was allowed to reproduce without constraint.

Potential economic impacts in the PRA area

Economic impacts would include not only conifer timber losses (the value of which will depend on the stage in rotation when trees are attacked by the beetle), as well as other factors including reactive management, and harvesting and destruction costs of infested trees (Hlásny *et al* 2021). The only significant market likely to be affected is from Great Britain to the island of Ireland (both the Republic of Ireland and Northern Ireland), but existing regulations already require that any conifer wood being moved from Great Britain to Ireland has to comply with regulations in relation to the *Ips* Protected Zone of the island of Ireland. Thus, any localised infestation of *I. typographus* would not change the current export requirements and should have no additional costs other than potentially requiring greater surveillance. The presence of *I. typographus* in southern England has already been noted by the Irish authorities and only debarked or kiln-dried wood is now allowed from England. However, further spread of *Ips typographus* north into the West of Scotland Pest Free Area which is free of six regulated bark beetle species, including *I. typographus*, would impact trade from this region with the island of Ireland.

Overall, some of these negative effects could be mitigated by normal forest management and selective removal of infested trees or trees liable to be infested (e.g. wind-damaged material).

On that basis, economic impacts have the potential to be **large,** as spruce makes up half the commercial conifer crop in the UK (Table 3), although unlike mainland Europe where the dominant spruce species affected is Norway spruce, the majority of commercially grown spruce in the UK is Sitka spruce. The uncertainty about the susceptibility of Sitka spruce to attack by *I. typographus*, however, is reflected in the **medium level of confidence** in this assessment.

Economic Impacts	Very small	☐	Small	☐	Medium	☐	Large	☑	Very large	☐
Confidence	High Confidence	☐	Medium Confidence	☑	Low Confidence	☐				

Potential environmental impacts in the PRA area

Potential environmental impacts include consequences for a range of ecosystem services. For instance, large outbreaks could result in an increase in soil NH_4, NO_2 and cations and a decline in dissolved organic carbon. Large-scale mortality of trees through beetle attack or the clear-felling of a spruce forest resulting from an outbreak turns a conifer stand from a strong CO_2 sink to a strong source (Kurz et al. 2008, Xenakis et al. 2021). With regard to biodiversity, there would be a large loss of available canopy resources and a possible short-term increase in saproxylic invertebrates (likely followed by a severe population decline due to a lack of suitable breeding material) and ground flora (introduction of more light). An average monetary value estimate for biodiversity loss is £146 per ha, when estimated from Willis et al. (2003).

Taking this into account, environmental impacts are estimated as **medium,** but again with a **medium level of confidence**.

Environ-mental Impacts	Very small	☐	Small	☐	Medium	☑	Large	☐	Very large	☐
Confidence	High Confidence	☐	Medium Confidence	☑	Low Confidence	☐				

Potential social impacts in the PRA area

It is likely that social responses to damage caused by *I. typographus* would be similar to those described for woodland visitors in areas where widespread attacks by bark beetles are already experienced (e.g. Prentice *et al*. 2018). Social values have been found to be particularly affected, when the visual amenity of recreational visits to the forest is reduced. Successful acceptance of management around affected woodland, especially where eradication activities are being undertaken, will certainly include good stakeholder engagement and collaboration from the outset. This will be particularly important for private woodland owners/managers affected by the prohibitions and restrictions in place in the demarcated area, or whose trees may have been infested. New clear guidance[13] has been produced to aid this process, and experience from other tree health campaigns should be considered (e.g. Porth *et al*. 2015).

Overall social impacts are therefore judged as likely to be **large** but with a **low level of confidence** due to the lack of data.

Social Impacts	Very small	☐	Small	☐	Medium	☐	Large	☑	Very large	☐
Confidence	High Confidence	☐	Medium Confidence	☐	Low Confidence	☑				

15. What is the pest's potential as a vector of plant pathogens?

Various Ophiostomatoid species are common fungal associates of *I. typographus,* and the combination of beetle and fungi has been hypothesized to exhaust host tree defences during attack and allow successful beetle breeding. More than 30 fungal species have been detected in the assemblages associated with *I. typographus* beetles, although many are not within the Ophiostomatales. Although the combination of fungal associates carried by *I. typographus* varies to some extent with season and geographical region, the dominant species are *Endoconidiophora polonica*, *Ophiostoma bicolor*, *Ophiostoma ainoae* and *Grosmannia piceiperda* (Linnakoski et al. 2016).

Probably the most damaging associate of *I. typographus* to spruce is the fungus *Endoconidiophora* (formerly *Ceratocystis*) *polonica*. As adult beetles attack trees, *E. polonica* (and other fungal associates) are introduced into phloem tissue and underlying sapwood which they then colonise, with the more pathogenic fungal species contributing to the weakening of tree defences and even death (Kirisits 2004). A new real-time PCR assay has been developed by Forest Research to detect the presence of *E. polonica* in environmental samples.

16. What is the area endangered by the pest?

Ips typographus could potentially become established and cause impacts throughout the ranges of its known hosts in UK (principally *Picea* species) which are found in woodlands, forests, parklands, and gardens (Figure 1). The presence of suitable host material, combined with a suitable climate, suggests that the whole of the PRA area could be suitable for establishment of the pest, but with the highest likelihood of establishment in southern England.

Stage 3: Pest Risk Management

17. What are the risk management options for the UK/PRA area?

Exclusion

Tested and validated measures are already in place which aim to prevent *I. typographus* entering the United Kingdom with imported wood products. Northern Ireland is specified as a Protected Zone for this pest (it is now a priority quarantine pest for GB having been a PZ pest for many years while the UK was part of the EU) meaning that any imported wood must be free from bark, or heat treated to 56^{o}C to the core of the wood for 30 minutes (analogous with ISPM 15 requirements), or sourced from an area known to be free from the pest. In all cases, phytosanitary documentation is required to indicate compliance with the specified measures. In addition, annual widespread monitoring is carried out to confirm absence of *I. typographus* from the UK.

Before PZ status, interceptions of *I. typographus* in the UK had a long history, with records dating back to the 1940s (Laidlaw 1947). Regular but low-level interceptions of adult beetles in pheromone traps were made at high risk locations (ports or timber yards) handling imported conifer timber. A spike of interceptions at ports in the mid-1990s was associated with the new trade in sawn timber with the Baltic States, and poor standards of debarking, but no signs of an outbreak were ever found in follow-up surveys at or near these sites. The source of the initial *I. typographus* population detected in 2018 in southern Kent is still a matter of some speculation, but recent evidence suggests that natural dispersal of beetles across the channel from outbreak areas in mainland Europe is a likely cause. Large-scale natural dispersal event of beetles from European populations is considered to have initiated the numerous isolated populations of *I. typographus* detected in 2021 and 2022.

Overall, strict application of the mitigation measures to exclude *I. typographus* applied to the wood/bark related pathways appear to be effective at preventing introduction of the pest along such pathways. However, the interceptions of the pest in the UK (and other countries which maintain pest free status) suggests that compliance may vary, although the measures are realistic and, when applied correctly, effective (Gibbs & Evans 2000; Haack 2001). Preventing entry through natural dispersal from mainland Europe is not possible, but the rapid detection of new incursions is being addressed by the additional monitoring activities listed below.

- Improved efficiency of QP measures/PZ by inclusion of pheromone traps, including additional sites in high-risk forests, and a review of the use of billet trapping against other trapping methods.
- Deployment of pheromone traps at major timber yards and at sawmills handling UK spruce.
- Visual and pheromone trap surveys conducted in high-risk forests.
- Helicopter surveillance of spruce forests combined with year-on-year analysis of stand quality and declines.
- Targeted publicity to increase the level of awareness in key stakeholder groups (e.g., landowners and forest managers).

Eradication, containment, and controls

During routine UK-wide PZ surveys, *I. typographus* was detected and confirmed present in Kent, England in December 2018. Follow up surveys found a breeding population in weakened individual trees of Norway spruce (*P. abies*). Following this finding, and further detections in the same area, a demarcated area (DMA) covering parts of Kent and East Sussex, was established. Extensive surveillance in 2021 and 2022 detected numerous additional incursions in south-east England, and a new enlarged DMA was introduced accordingly. The pest is currently under eradication at all incursion sites.

Containment is an important function of the DMA, to prevent any subsequent spread beyond the incursion sites, and to support the eradication efforts of the beetle. Restrictions on felling or moving spruce trees within the area are now in place/imposed via The Plant Health (Ips typographus) (Demarcated Area No. 5) Notice. Authorisation to fell or move susceptible material (spruce) within the DMA must be sought through the Authorisation process. This ensures that any trees or woodland can be inspected prior to harvesting and any timber stacks containing spruce material may be inspected by the Forestry Commission before it is moved within or out of the DMA. The movement of any material is prohibited until it has been inspected and approved and may only be moved to an authorised processor. Material that has been inspected and designated as low risk may be transported to an authorised processor either as chipped material or as roundwood. Material designated as high risk or infested material must be felled, and all material over 8 cm diameter must be burnt or chipped on-site. Chipped material may then be moved to and utilised by an authorised processor only. All activities must be carried out in a timely manner, and before the potential emergence of a new generation of adult beetles in the spring.

Surveillance of the demarcated area and more widely has included the use of traps baited with *I. typographus* aggregation pheromone which has been shown to be a reliable method for detecting adult flight activity. Surveys within the demarcated area were initially on-the-ground inspections to check for dead and dying conifers. Suspect trees were felled and subject to close inspection (6-12 trees selected at most sites showing stand decline) to give confidence in assessments which judged that breeding colonies of the pest were absent from each site under suspicion. Aerial surveillance was then deployed to detect groups of trees with evidence of dieback or mortality, again followed up by on-the-ground inspection for presence of the pest in the form of larval gallery systems under the bark and exit holes made by emergent adults. Pheromone traps were also installed in most private and publicly owned spruce forests and woodlands with conifers in the area, to detect any breeding populations which might have been missed during surveillance activities.

Eradication has involved removal and destruction of all affected trees; these have all consisted of weakened Norway spruce trees. No infested trees were detected during 2020 surveys, but 27 localised infestations were subsequently detected in the second half of 2021 and in 2022. Where breeding colonies of the pest have been discovered, during the original finding in 2018 and the surveys of 2021, the spruce was destroyed (both healthy and infested, within a minimum of 300m of the finding, depending on the site). Follow-up surveillance continues on those sites, but no evidence of residual breeding insects has been found to date. Eradication action is underway at the sites discovered during the 2022 season at the time of writing.

Changes in policy and in the practice of dealing with infested sites have developed through recent experience. All infested trees must be treated to destroy the beetles, for example by chipping on site and then burning chipped material in an approved facility, or covering securely with a tarpaulin in the case of small sites with individual or very small numbers of infested trees. Uninfested trees from the same site can be harvested and utilised conventionally in approved facilities (subject to conditions). This approach significantly changes the economics of addressing outbreaks in the DMA.

The treatment of felled trees with insecticide to prevent attack by adult *I. typographus* beetles would be uneconomic except on a very limited scale, would raise environmental concerns, and potentially breach The UK Woodland Assurance Standard (UKWAS) for certified woodlands[11]. For individual (or very small numbers) of felled trees, such as those felled during inspections on potential outbreak sites, the risk of colonisation can be eliminated by securely covering the resulting timber with a high-quality tarpaulin, weighed down around the edges and secured with tacks. The tarpaulin can be removed once the timber has sufficiently dried (at least one year later), rendering it unfit for colonisation, and the landowner can leave it in situ or utilise it for firewood (as is often the case in private gardens/small holdings). The attack of standing living/stressed trees cannot be prevented other than through the selective felling of weakened trees to remove suitable breeding material and reduce the rate of population increase. In forests with highly stressed trees, especially where mortality is occurring due to a variety of causes, an accelerated programme of thinning - or clear felling of vulnerable areas - as well as increased forest hygiene measures could be part of a comprehensive action plan to control the risk of infestation by the pest. In general, good management practices are encouraged throughout the southeast, to reduce vulnerability of holdings to windthrow, and to clear up damaged material following storms.

During normal forest operations, when trees are felled, they are at risk of attack during the adult flight period from April to August (under UK conditions). To reduce this risk, time limits on the utilisation of felled timber apply within the demarcated area. For low-risk material moving within the demarcated area (i.e., healthy material, inspected prior to felling and movement and deemed free of the pest), material initially harvested between 1st April to end of August, this material, once seasoned, must be inspected, and utilised in an approved manner prior to the end of February the following year at the latest. For low-risk material harvested after August, seasoned wood must be inspected and utilised in an approved manner prior to the end of February two calendar years later, at the latest. In cases where low risk material originating within the DMA is moved beyond the DMA boundary to an Authorised Processor, an 8-week time limit will apply from the date of felling to date of processing during the flight period of the pest (1st April to 31st August). Material moved outside of the flight season must be processed by the end of February at the latest.

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[11] http://ukwas.org.uk/

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This PRA has been undertaken following IPPC International Standards for Phytosanitary Measures (ISPMs 2 and 11) and it provides technical evidence relating to the risk assessment and risk management of this pest.

This PRA has been undertaken taking into account the environmental principles laid out in the Environment Act 2021. Of particular relevance are:

The prevention principle, which means that any policy on action taken, or not taken should aim to prevent environmental harm.

The precautionary principle, which assists the decision-making process where there is a lack of scientific certainty.

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