Final Report

Project title (Acronym)
Range Expansion of bark beetles in the genus *Ips* (**ECLIPSE** – **E**cological **C**o-factors **L**ead **IPS** **E**xpansion)

Project duration:

Start date:	2021-09-01
End date:	2024-03-31

Contents

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2. Short project report

2.1. Short executive summary

Bark beetle pests of conifer trees represent the most serious damaging agents and threats to both natural and commercial forestry in Europe. There have been frequent and highly destructive outbreaks of several bark beetle species in the genus *Ips*, the most serious of which, *Ips typographus*, has killed millions of spruce trees particularly from the beginning of the 20th Century. Concurrently with these large outbreaks there have been expansions in the ranges of the main European *Ips* species with both northward and westward infestations being recorded.

The ECLIPSE project has analysed the recent history of *Ips* infestations in Europe, using country narratives as exemplars of the appearance and frequency of attacks by the beetles. These analyses have enabled close examination of potential factors driving geographic distributions of the beetles. Both insect-driven spread by flight and longer-distance spread through human movement of infested wood have been recorded for all the European *Ips* species, exemplified by records of world-wide interceptions. Analysis of infestations across Europe has indicated that presence of suitable host trees is, not surprisingly, an essential factor in whether movements of *Ips* species result in infestations both in known infested areas and in newly invaded areas. Expansion of afforestation, particularly in the west of Europe, using various conifer genera through the last 120 years has been significant; for example, Belgium, The Netherlands, Ireland and the United Kingdom have gone from virtually no conifers to extensive plantations of these host trees.

We have been able to map the chronology of changes in host tree distribution and abundance and the parallel expansion in ranges of *Ips* species in Europe. From a pest management perspective, provision of extensive conifer plantations has resulted in increases in both severity and distribution of attacks by *Ips* species. In parallel to this primary driver, aspects such as climate suitability, particularly extreme weather events such as high winds and droughts, have provided increased availability of weakened trees which are essential to initiate new infestations. Within this increased total availability of host trees, the proportion of conifers within a mixed woodland is important, with attacks increasing with higher host: non-host ratios.

While long distance dispersal of beetles with trade is a well-established mechanism for potential range expansion, it is also apparent that relatively long-distance flights by adult beetles can be important contributors to spread. This is well demonstrated by the cross-channel dispersal of *Ips typographus* into Kent which correlates with periods of large-scale infestations in the proximal spruce forest areas of Belgium and France. In this respect, the persistent pressure from flying clouds of beetles provides a more sustained presence of the pests among host trees compared with more short-term invasive populations likely to arrive with movements of infested wood.
This study has highlighted the important primary role of host tree availability, correlated with environmental and human-driven factors, in driving historical infestations by *Ips* bark beetles in Europe. It has also raised questions about why some areas and countries, such as Ireland, have had invasions but not establishment of these important pests. While it is not possible to provide a precise numerical value, it appears that a combination of host tree availability and sustained beetle pressure is needed for an invasive population to become established. From a management perspective it is, therefore, important to both monitor for beetle arrivals but also to be aware of the status of beetle source populations to account particularly for long-distance flight to previously uninfested areas.

2.2. Project aims

First evidence of breeding by *Ips typographus* in the UK and expansion of *Ips amitinus* in Scandinavia, *Ips duplicatus* in central Europe and *Ips cembrae* in Great Britain and western/northern Europe suggest that factors that previously limited or moderated range expansion may be changing. This project assesses the biotic, abiotic, climatic and anthropogenic factors that could be driving these changes in ecology and distribution of this important group of forest pests.

There is accumulating evidence that bark beetles are expanding into new areas with associated potential for greatly increased damage and tree mortality. While there are clearly some factors that are species-specific, it is also pertinent to explore whether there are more generic factors underpinning the range expansion and which could be influential in predicting and reacting to future changes in beetle distributions. This is the main goal of the project. Results will be disseminated through a major review of the history of *Ips* species attacks in Europe, with assessment of the range of factors that have driven the attacks during the past 120 years. This paper will provide an evidence-based document of value to national and regional plant protection organisations and to those concerned with tree health and management of woodlands and forests.

2.3. Description of the main activities

- To analyse and identify factors that are **common** to the main species of *Ips* and those that may be **unique** to each species. The information will form a knowledge base of biotic and abiotic factors for further investigation to determine which are most important in determining geographical spread and likelihood of success or failure when *Ips* spp. encounter host trees.
- Arising from the factor analysis, to assess the key local factors influencing whether a pioneer beetle population can successfully establish in a new location.
- To investigate historic and ongoing changes in forest structure to assess the roles of tree species mix and relative density in determining beetle establishment success and, particularly, in population expansion.
- To investigate the potential role of climate change as a co-factor in enabling the beetles to gain a foothold in new locations that were previously considered to be climatically limiting. Important known drivers are temperature (affecting both the insect and its host tree), moisture and prevalence of storms (wind and snow).
- To consolidate the range of factors within a major review to identify those that are primary and those that are linked, but secondary, to determining beetle breeding success in a given area. The conclusions of the review will provide surveillance and management options for the various species of *Ips*, both for general usage and for tailoring phytosanitary measures for those pests invading new areas.
- To use the major review to disseminate the results in a timely and effective manner so that improved prediction and management options can be implemented quickly.

2.4. Main results (knowledge, tools, etc.)

The project has assessed, through in-depth literature review and input from partner projects, the biology and ecology, including pest status, of the six European species of bark beetle in the genus *Ips*. Through a range of detailed country narratives and assessments of biological and ecological factors, the principal and subsidiary factors in determining beetle range and breeding success have been assessed.

Particular attention has been paid to changes in the areas infested by the beetles since the beginning of the twentieth century. This approach has enabled the consortium to identify the

key drivers behind the changes in distributions of the six European *Ips* species. Principal among these drivers is the very large change in the availability and distribution of host tree species which has resulted from sustained afforestation across Western Europe, with emphasis on the planting of conifers. Occurrence data on *Ips* species from the Global Biodiversity Information Facility (GBIF) have been mapped along with distribution data on their host tree genera. Expansion of the areas attacked by all *Ips* species mirror, to a considerable extent, the increased availability of host trees in Europe. Even though host availability increased rapidly in the 20th century, not all areas of afforestation were infested by *Ips*. For example, Great Britain has expanded its conifer tree cover from an extremely low base in 1900, with a large surge in planting from the 1950s. Both *I. sexdentatus* on pine and *I. cembrae* on larch established as new invasive species by the mid-1950s, whereas *I. typographus* only established in 2018, despite regular interceptions in plant health inspections. In Northern Europe, *Ips amitinus* has increased its northward range which has been attributed mainly to increasing availability of suitable host trees as well as pre-adaptation to low winter temperatures and potential for increased wind storms providing damaged and weakened trees, which are important for early colonisation when relatively low numbers of pioneer beetles are present.

From our analysis we, therefore, distinguish the necessary condition of presence of host trees as the primary factor determining beetle attack success but with the likelihood of this occurring being influenced by various constitutive drivers. These drivers include flight capacity with increasing evidence that *Ips* adults can fly many kilometres. This is supported by recent strong evidence from flights of *I. typographus* from the Ardennes to SE England over the English Channel and probably exceeding 250 km. At a local scale, adult flight behaviour and the linked response to pheromones are important in determining host location. Factors that affect breeding success include voltinism (number of generations per year), fecundity and pre-dispersal mating which, by removing to need for mate-finding, would result in cohorts of dispersing viable females capable of successful egg laying without the need to locate males.

Underpinning these insect-specific biological characteristics several extrinsic factors affect both the insect and its host trees. Climatic events are known to influence the number of beetle generations per year and the vulnerability of host trees that might be affected by summer rainfall deficit, increased storms and high temperatures. These are trigger points that enable pioneer beetle populations, in particular, to establish a foothold in a new area.

Central to the hypothesis that increased host tree availability has been the main driver of *Ips* expansion in Europe is the question of how a dispersing population of beetles can find and exploit this resource. Interceptions of various *Ips* species, especially *I. typographus*, confirm that adult beetles move both nationally and internationally, but there is relatively low establishment considering the frequency with which the pests move. We assessed the concept of propagule pressure in examining how a small arriving population of beetles can breed and grow to pest status. We conclude that beetles arriving in trade generally exhibit a decline in numbers per unit area as they disperse from an arriving point source. Unless this declining population finds suitable weakened trees to breed and expand, there is a low likelihood of establishment as evidenced by the disparity between interceptions and establishments. New evidence on long-range flights indicate that a more sustained population of beetles can arrive in a given area with ‘reinforcement’ from further cohorts of beetles during the flight season. It appears that this scenario is the likely explanation for establishment of *I. typographus* in Kent. An interesting contrast is provided by establishments of *I. cembrae* (Denmark, Great Britain and Sweden), *I. duplicatus* (Austria, Germany and Switzerland) and *I. sexdentatus* (Great Britain) where the primary pathway for arrival in new locations is through trade in infested wood.

Knowledge on range of drivers for range expansion also provides a basis for explaining the slow rate of establishment or even non-establishment of *Ips* species at the edges of their known ranges. The island of Ireland (the Irish Republic and Northern Ireland) remains free of any *Ips* species, despite evidence of frequent arrivals in trade. It seems likely that a number of factors have contributed to slow or zero establishments in these peripheral zones; slow accumulation of suitable host trees, relatively low numbers of beetles arriving which have not been able to establish a viable breeding population, perhaps by Allee effects arising from small local pioneer populations. It does not appear that climate would be a limiting factor, although in many areas at risk there is likely to be only a single generation per year.

2.5. Conclusions and recommendations to policy makers

Along with most insect populations on trees, bark beetles in the genus *Ips* only thrive when there is an abundance of suitable breeding material. Although this might seem an obvious conclusion, our research has shown that it is the expansion of forestry in the 20th century that has resulted in a parallel increase in the ranges and impacts of *Ips* bark beetles in Europe. In particular, the presence of large tracts of conifers with relatively little broadleaved components or open spaces has provided ideal conditions for beetles to establish and increase their populations. All species of *Ips* share a common initial attack strategy of targeting weakened trees which may lead to population increases sufficient to enable healthy living trees to be mass-attacked and killed. From these initial population centres, beetles can spread naturally or through trade, the former being exemplified by *Ips typographus* flying across to England from Belgium.

From a policy perspective, the key lessons are that longer-term management of bark beetle populations needs to consider the increased risks from large scale afforestation with, essentially, monocultures of conifers. The move to large-scale afforestation across Europe in the 20th century demonstrates that areas with no previous records of damaging *Ips* attacks became infested, while those areas with long histories of attacks suffered from increased frequencies and scales of attacks. While some of these can be attributed to aspects such as changing climate increasing the primary trigger of tree stress, the necessary condition for *Ips* population growth and spread is host tree availability.

We also show that, within pest risk assessment, pathway analysis for bark beetles should take greater account of natural dispersal in addition to the current strong emphasis on human movement of infested wood in trade. Clearly, this approach does not enable measures, such as debarking for traded timber, to be put in place. However, it suggests that greater focus on potential source populations of beetles, along with climatic conditions that could encourage flight (higher temperatures, wind direction, etc), should be a core component of active risk management. Early warning of a potential incoming flight of beetles would enable surveillance to be increased and early action taken if incursions of adults are detected. These trigger conditions should be included in pest risk assessment, especially for those regions and countries that have remained free from *Ips* attacks. Close collaboration and sharing of knowledge on outbreak situations is, therefore, an essential component for management of bark beetle threats.

2.6. Benefits from trans-national cooperation

ECLIPSE has included countries at the core and limits of known *Ips* infestations, particularly for the most damaging species *I. typographus*. Expertise has included research into the biology and ecology of bark beetles through to policy and management at government levels. Sharing

of knowledge and experience has been essential to the project, with excellent collaboration through email, online and face-to-face meetings of the consortium.

Despite the relatively small budgets allocated specifically to the project, the consortium members have been generous in sharing results from related projects so that up-to-date information has been included in the major review paper.

Presentation of results from the project and a description of the project itself featured at the Forest Protection Colloquium held in Vienna in March 2023. This was also a key opportunity for the ECLIPSE team to get together and finalise plans for the main output from the project.

3. Outreach

3.1. Article(s) for publication in journals

The main output from the project will be a major review paper entitled 'Territorial expansion of the European Ips species in the 20th century – a review'. This is in very late draft stage and will be submitted to the journal *Entomologia Generalis*.

3.2. Grey literature

None.

3.3. Events

- Presentations at the Forest Protection Colloquium held at BFW in Vienna 21-22 March, 2023.
- Hugh Evans: Range expansion of *Ips* bark beetles: the Euphresco ECLIPSE project.
- Daegan Inward: Investigating the natural dispersal of *Ips typographus* into Britain, and the susceptibility of Sitka spruce to attack.

4. Open Euphresco data

None.