



Research Note

The influence of climate change on forest insect pests in Britain

David Wainhouse and Daegan J.G. Inward

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Predicting future risks of damage by insect pests is an important aspect of forest management. Climate change has the potential to affect forest pests and their impact on trees through higher temperatures, altered precipitation patterns, and more frequent extreme weather events. Warmer temperatures are likely to have complex effects on insects, influencing, among other things, development rate and the seasonal timing of life-cycle events, while also affecting their host trees and natural enemies. It is not possible to predict the future impact of forest pests with any precision, but some generalisations can be made based on the ecological characteristics of different insect types. The damage caused by aphids and related insects is likely to increase as the climate warms. Higher temperatures will increase their reproductive rate, and drought stress of host trees may increase their susceptibility to aphid attack. The impact of bark beetles and related insects is also likely to increase, due to factors such as increased frequency of windblows, drought stress of host trees and, for some species, a shorter generation time. Effects upon defoliators are more difficult to predict, but the abundance and impact of some species is likely to be influenced by an increase in the number of generations per year and changes in their geographical distribution. Changes in forest management as a response to climate change, such as the introduction of new tree species, could additionally lead to the emergence of new pests.

Introduction

This Research Note outlines the main changes projected for the UK climate over the coming decades and how forest insects, grouped according to similarities in their ecology and life history, are likely to be affected by climate change. Within each insect group specific examples are discussed briefly. These examples were chosen in part to illustrate the range of factors with the potential to influence the likely responses of insect pests.

The prospect of climate change over the next several decades raises a number of questions about potential changes in the vulnerability of UK forests to attack by pests and pathogens. The most important questions in relation to the management of native or long-established forest insect pests are:

- How will the distribution of forest pests be affected by climate change and will they increase their range or the geographical area in which damage occurs?
- Will there be changes in the amount, frequency or duration of damage to trees?
- Will new pests arise as the climate changes?
- Will changes in silviculture implemented as an adaptive response to climate change increase the risk of pest damage?

Many factors influence the distribution and abundance of insects including the availability of food resources, natural enemies, competitors and climate, but it is the complex interaction between these factors that often determines insect population dynamics. As a consequence, it is usually not possible to predict outbreaks or damage to trees with any precision, especially when assessing likely responses to a projected future climate. Nevertheless, there are examples where only one or two factors have a dominant influence on pest abundance so making more specific predictions possible. Examples include the association between drought or windblow and bark beetle outbreaks, the effect of silvicultural operations on pest abundance and the link between particular site conditions and the occurrence of damage. Generalised predictions can also be based on the life-history characteristics of pests, such as where and when they feed, the number of generations per year (voltinism) and how they overwinter, because these characteristics can influence the likely nature and extent of the response to a warming and more unstable climate.

Temperature is the most significant climate variable directly affecting insect development but other factors linked to climate change could also be important (e.g. changes in precipitation patterns, an increase in the frequency of extreme weather events and perhaps even the increasing concentration of

atmospheric carbon dioxide). Climatic variables can also have an important influence on insect survival, and levels of mortality may be sufficiently high or frequent to maintain populations at a low level as can occur near the latitudinal or altitudinal limit of an insect's range. It will be more difficult to anticipate indirect effects on insect herbivores of climate-induced changes in the trees on which they feed, changes in the abundance or effectiveness of their natural enemies or changes in the community of insects, including competitors, of which they are part.

Exotic pests whose current distribution is constrained by low temperatures can increase their range if conditions become suitable in a wider geographical area. As a result, this might increase the probability of their establishment through natural dispersal or transportation in international trade in trees and timber. This aspect of climate change, which is addressed largely in relation to plant health regulations, is not discussed in this Note, coverage of which is restricted to likely effects on native or well-established exotic pests.

Predicted climate change in the UK

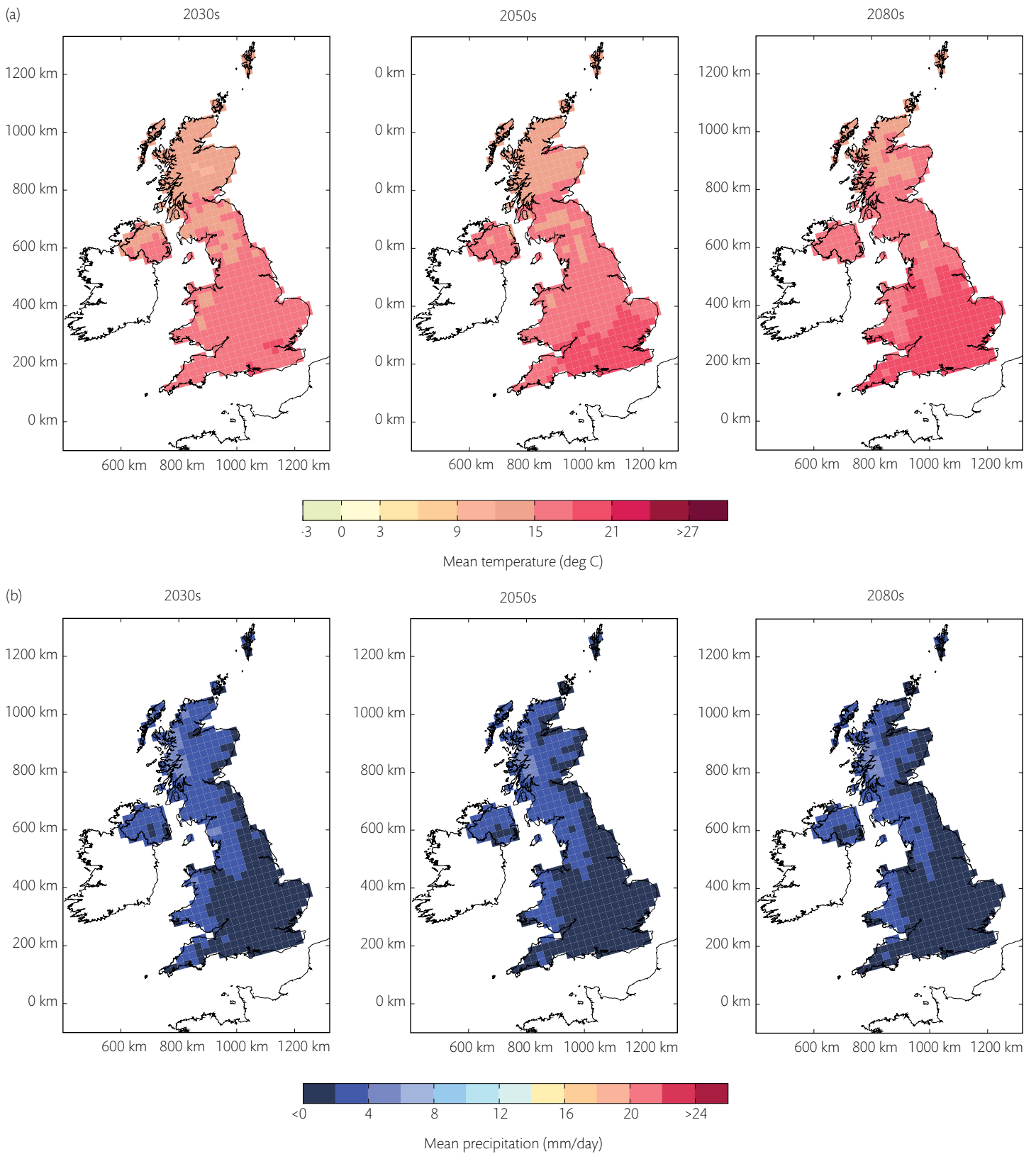
UK climate models show that under the medium emissions scenario parts of southern England may be up to 4°C warmer in summer by the 2080s, with parts of Scotland around 3.5°C warmer (Figure 1a). Winter temperatures are also projected to increase. Patterns of precipitation are expected to change so that in Wales and southeast England, for example, winter precipitation is projected to increase by about 20%, but decrease by around 21% in summer (Figure 1b). As these climatic trends progress over the next few decades forest pests are likely to be affected in a number of different ways as discussed in the following sections.

Climate variables and their direct and indirect effects on insects

Carbon dioxide

Much attention has been focused on the increasing concentration of atmospheric carbon dioxide as one of the main drivers of climate change. The concentration has risen from pre-industrial levels of around 280 ppm to the current concentration of around 395 ppm, but there is little evidence that these or likely future concentrations will directly affect insects. Indirect effects through the influence of carbon dioxide on tree growth and on a tree's nutritional and defensive status seem, on balance, unlikely to have a significant effect on the abundance of insect pests or the damage they cause (Zvereva and Kozlov, 2006).

Figure 1 Summer mean temperature (a) and precipitation (b) predicted for the 2030s, 2050s and 2080s using the medium emissions scenario central estimate in the UKCP09 climate model (Jenkins *et al.* 2009) © UK Climate Projections 2009.



Temperature

Temperature is the predominant abiotic factor that directly affects insect growth, development and reproduction. Over

most of the temperature range to which particular species are adapted, there is a positive linear relationship between growth rate and temperature. Development of the different stages of an insect's life cycle is usually quantified as the thermal sum above

a minimum developmental temperature that is required for completion of the life cycle. In a warmer climate this sum is accumulated earlier in the season, allowing some species to complete additional generations. This will result in additional periods of feeding damage during the season and may result in an overall increase in insect abundance.

Changes in seasonal temperatures are also likely to alter the phenology of trees, potentially resulting in a mismatch in phenological synchrony between insects and their host tree. For defoliating insects that feed on young, newly flushed leaves of broadleaved trees a mismatch in timing between leaf flush and egg hatch can result in high mortality of young larvae.

Insects have appropriate adaptations to survive normal daily and seasonal variation in temperature and other environmental factors. Nevertheless, unseasonably hot or cold weather can cause significant mortality, and temperature extremes can set ultimate limits to geographical range. Many insects have an obligatory dormant or diapause period during the winter, but in some insects dormancy is influenced by local temperatures. In warmer weather, therefore, insects that have a year-round food resource such as those that feed on wood or bark could develop throughout the year, benefitting from a projected increase in winter as well as spring and summer temperatures. In the maritime climate of the UK, which does not experience the climatic extremes found in continental areas of Europe, many forest pests are widely distributed. Exceptions include recently introduced pests which have not yet colonised all suitable areas. Nevertheless, some insects such as the two-spotted oak buprestid (*Agrilus biguttatus*), a beetle that exploits declining oak trees, have restricted ranges that may increase in a warmer climate. Where range extension increases the overlap between species attacking the same host, the risk of damage to trees may be increased.

Precipitation and drought

Changes in rainfall patterns, and the occurrence of extreme events such as storms or prolonged droughts can have both direct and indirect effects on insects. Insects feeding on the plant surface will be more exposed to environmental hazards whereas those in 'protected' microhabitats, below ground or in bark or woody stems, will be buffered to some extent from these environmental extremes. Intense and prolonged summer rainfall can dislodge aphids or the young larvae of defoliators, and can prevent larger ones from feeding and so increase mortality, and heavy winter rains can cause flooding and increased mortality of overwintering stages in the soil. On the other hand, tree water stress during prolonged periods of hot, dry weather may indirectly benefit insects through changes in the nutritional quality of the host tree, or a

reduction in the effectiveness of its defences. Prolonged dry weather also increases the risk of forest fires and subsequent insect attack on fire-damaged trees. In addition, winter storms can influence pest abundance indirectly by increasing resources for insects such as bark beetles that breed in moribund or windblown trees.

Insect life history and the effects of climate change on abundance and damage

In a changing climate, variation in the location, extent, frequency and severity of damage will very much depend on the ecological characteristics of the different pests, the relative influence of climatic factors on population dynamics, and the methods and objectives of forest management. In the following sections insects are discussed in natural groupings that reflect not only differences in ecology but also the nature of the threat to forests – these groups are aphids, scale insects and related species; bark beetles, weevils and wood-boring beetles; and defoliators. Within these insect groups, a few important pests are discussed in more detail (Boxes 1 to 4). These examples are chosen in part to reflect the range of potential direct and indirect effects of climate change. At the end of this section, predicted effects of climate change on some of the most important UK forest pests are summarised in Table 1.

Aphids, scale insects and related species

These insects generally have sub-lethal effects on trees, typically causing growth loss, but some can cause cosmetic damage; by forming galls on high-value Christmas trees for example. Some species may contribute to a more general decline in tree health in association with other organisms. Insects in this group typically have close and sometimes highly specialised associations with their host tree, which can involve host alternation.

Aphids may disperse long distances on air currents and so are often widespread pests. They give birth to live young and have multiple generations each year (multi-voltine), and so are likely to respond strongly to increasing temperatures, resulting in a significant increase in abundance and damage. However, many are relatively small, sedentary for much of their life cycle, and exposed on the surface of the plant and are vulnerable to the effects of heavy rainfall and unseasonable cold weather. Climate change is therefore expected to have both direct and indirect effects on populations. Details of the green spruce aphid are shown in Box 1.

Box 1 The green spruce aphid (*Elatobium abietinum*)

A multi-voltine pest with the ability to respond strongly to rising temperatures



This aphid is an important pest of spruce throughout the UK. Norway spruce (*Picea abies*) is the likely natural host, but the host range extends to other spruces and Sitka spruce (*Picea sitchensis*) appears to be particularly susceptible. Aphids can be active throughout the year, so both summer and winter temperatures influence the life cycle. They feed on phloem sap causing needle loss at relatively low aphid densities resulting in significant loss of annual increment. Severe defoliation usually only occurs in a single year so that trees are rarely killed, but outbreaks can occur at intervals of 3–7 years.

In the maritime climate of the UK, aphids overwinter almost exclusively as females able to give birth to live young. Mild autumn weather can result in high overwintering populations

so outbreaks can occur in the spring and early summer. Aphid abundance in spring and autumn is also affected by seasonal changes in the nutritional quality of phloem sap, and drought 'stress' of trees can increase their susceptibility during the summer.

Low temperatures in autumn and winter can limit population growth and the sudden onset of freezing conditions can cause high mortality. In particularly wet climates with heavy rainfall, aphid mortality may also be high. Generalist predators can make a significant contribution to aphid mortality during the summer and may moderate population increase in response to a warmer climate and also hasten population collapse after outbreaks.

Warmer conditions in autumn and winter are likely to increase the frequency and severity of damage, with the risk that high populations will occur in successive years, resulting in tree mortality. Drier conditions are predicted for eastern Scotland and spruce currently in early rotation may experience an increase in the frequency of summer drought conditions, increasing their susceptibility to aphid attack. Changes in the species or provenance of spruce planted as an adaptation response to climate change has the potential to either increase or decrease aphid abundance and damage.

Key references: Carter (1972), Powell and Parry (1976), Parry (1979), Day (1984), Major (1990), Straw (1995), Day and Kidd (1998), Harding, Roulund and Wellendorf (2003), Day, Armour and Docherty (2004), Straw et al. (2005) and Day et al. (2006).

Overall, the abundance and damage caused by aphids and related insects is likely to increase under climate change.

In particular:

- higher temperatures will increase the reproductive rate and those species that have multiple generations or can remain active throughout the winter are likely to benefit most;
- moderate drought stress of host trees through changes in the spatial and seasonal distribution of rainfall will be favourable for some species;
- an increase in 'aphid load' on conifers may increase vulnerability to bark beetle attack.

Bark beetles, weevils and wood-boring beetles

Bark and ambrosia beetles (*Scolytinae*) are among the most important pests of temperate conifer forests, with outbreaks typically killing trees in more mature stands, so the economic impact can be high. Bark beetles are also often associated with blue-stain fungi that can cause significant degrade of timber. Ambrosia beetles also degrade timber directly by boring into the sapwood, carrying symbiotic fungi that may be pathogenic. The abundance of many species in this group is determined by

environmental influences on the availability of a suitable breeding substrate and this is likely to increase under climate change. The most damaging species are 'primary' pests that have eruptive population dynamics that can be self-perpetuating over large areas through 'mass-attack' of individual trees. Mass-attack species are currently absent from the UK but the great spruce bark beetle (*Dendroctonus micans*), a non-native 'solitary' species introduced in the early 1970s, can successfully breed in and kill living trees. The large pine weevil (*Hylobius abietis*) is also a primary pest, feeding on and often killing young transplants (Box 2). All other UK bark beetles and most weevils of economic importance are 'secondary' pests, normally breeding in logs, root-stumps and windblown or defoliated trees. Details of the common pine shoot beetle are shown in Box 3. The most common risk factors are felled material stored in the forest during the period of insect activity and trees uprooted or damaged by windblow. Outbreaks may also occur in forests affected by a prolonged period of drought, defoliation by Lepidoptera or sawflies, and forests damaged by fire.

Damage by bark beetles and related species is likely to increase under climate change. The potential main influences are:

Box 2 Large pine weevil (*Hylobius abietis*)

A silvicultural pest where the duration of the life cycle determines the period of vulnerability of young transplants

The main economic impact of this weevil is through feeding damage, which can kill pine and spruce transplants in restock areas. Population levels are determined largely by the availability of root-stumps on clearfell sites and in intensively managed plantations populations can build up to high levels. The larval stages develop in the bark of root-stumps and adults emerge to attack seedling trees replanted on the site. Insecticides are used to minimise damage to plants in most years. The impact of this pest is increased by the long life cycle, which normally takes 1.5–3 years, so transplants are vulnerable for several years after felling. The length of the life cycle is determined by local temperatures, and geographical variation in voltinism determines the number of seasons over which emergence and damage occurs. In the north and west of Britain, where temperatures are lower, damage may occur for 4 or more years after clearfelling, but in the warmer south and east there is a shorter period of vulnerability.

Modelling the effects of climate change on the duration of development and timing of weevil activity shows that by the 2030s a shorter 2-year cycle becomes increasingly common in the north and west of Britain and this is likely to reduce the impact of this weevil by allowing either a shorter fallow period or an overall reduction in insecticide input. Since most of the UK conifer plantations occur in the north and west, there could be a significant reduction in economic impact of this pest as a

result of climate change. No such benefits are predicted for the south and east, where the duration of the life cycle is relatively little affected by the 2030s. Replacement of the relatively resistant Corsican pine by the more susceptible Scots pine as a response to dothistroma needle blight is likely to increase damage by this weevil.

Key references: Eidmann (1985), Örlander, Nilsson and Nordlander (1997), Långström and Day (2004), Wainhouse, Brough and Greenacre (2007), Inward, Wainhouse and Peace (2012) and Wainhouse, Inward and Morgan (2014).



Jean-Paul Grandjean, Office National des Forêts, Bugwood.org

Box 3 The common pine shoot beetle (*Tomicus piniperda*)

A bark beetle that causes sub-lethal damage in tree crowns and has the potential to attack and kill defoliated trees

One of the commonest 'secondary' bark beetles, this insect is an important pest of Scots pine (*Pinus sylvestris*) and to a lesser extent, Corsican pine (*Pinus nigra* ssp. *laricio*). It usually breeds in logs left in the forest after felling operations or in windblown trees but, unlike most other secondary species, it can develop in and kill trees heavily defoliated by, for example, the pine looper moth (*Bupalus piniaria*). Adult beetles also tunnel in shoots of living trees during 'maturation feeding', resulting in crown deformation and significant growth loss, especially where trees are close to timber storage areas.

Tomicus has only one generation per year (uni-voltine), but females can have additional 'sister broods' in warm conditions so with abundant breeding material populations can increase rapidly. At high population density, intraspecific competition can be an important limiting factor in the exploitation of the bark resource and together with host defences appears to be the most important cause of mortality.

Climatic factors can affect the population dynamics of *Tomicus* by influencing the availability of breeding material through windblow or the occurrence of defoliator outbreaks. The impact of this bark beetle is likely to increase significantly in a changing climate both from its ability to kill defoliated trees and to cause



Steve Passoa, USDA APHIS PPQ, Bugwood.org

extensive shoot damage to living trees during maturation feeding. While development is likely to remain uni-voltine in a warmer climate, newly emerged beetles can, under experimental conditions, successfully reproduce in pine logs without first overwintering and feeding in shoots in the spring. There is, therefore, at least the potential for a shift in feeding behaviour resulting in more than one generation per year.

Key references: Bevan (1974), Långström (1984), Saarenmaa (1985), Gibbs and Inman (1991), Långström and Hellqvist (1993) and Cedervind, Pettersson and Långström (2003).

- more frequent and possibly larger windblows;
- drought stress on trees resulting from changes in the spatial and seasonal distribution of rainfall;
- possible increase in defoliator outbreaks;
- increase in voltinism;
- an increase in fire frequency;
- changes in silviculture resulting in more mature trees in longer rotations.

Defoliators

Defoliators are a highly diverse group of insects, including Lepidoptera (butterflies and moths) and sawflies, some of which can cause extensive outbreaks in both broadleaved and conifer forests. Their abundance is often determined by complex interactions that may involve weather, natural enemies and site

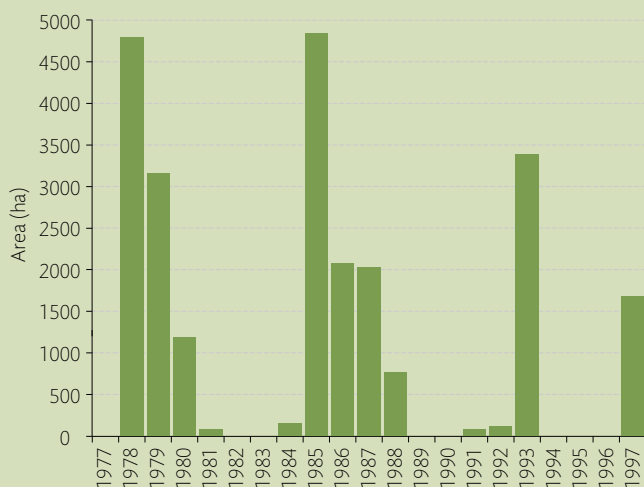
factors affecting both their survival and host tree suitability. Many species are uni-voltine, but some sawflies have the potential for two or more generations per year. Most defoliators feed externally on leaves but some, such as pine shoot moth (*Rhyacionia buoliana*), may mine within the leaves or shoots. Some species have more or less regular population cycles that are sometimes restricted to specific sites or areas. The main economic effect is through growth loss. In general, defoliated broadleaves are able to reflush after early season defoliation and significant damage usually only occurs when there are several successive years of defoliation. Conifers are particularly vulnerable to defoliators that can feed on more than one age class of needles and also those that feed late in the season so that trees are unable to reflush until the following year. Defoliated trees may be susceptible to attack by bark beetles. Details of an important defoliator, the pine beauty moth, are shown in Box 4.

Box 4 The pine beauty moth (*Panolis flammea*)

A native defoliator transformed to a serious pest following the introduction of an exotic pine



Bob Eade



Area of forest sprayed with insecticide against outbreaks of *Panolis flammea* on lodgepole pine in Scotland. Data from Hicks *et al.* (2001).

This insect is an important defoliator of pine with a long history of outbreaks in continental Europe. In the UK, however, there are no records of outbreaks on the native host Scots pine. Extensive outbreaks from the mid-1970s followed the widespread planting of the North American lodgepole pine (*Pinus contorta*) in Scotland in the 1950s and 1960s during afforestation of infertile acidic soils. A single complete defoliation can kill young trees without subsequent attack by secondary bark beetles, largely because of the relatively small size of the trees and the very long dormant season before they could reflush in spring.

The life cycle is uni-voltine and newly hatched larvae feed predominantly on current needles but in later instars may feed on needles from previous years so that defoliation can be extensive. The difference in population dynamics between Scots and lodgepole pine may be influenced by insect predators and parasitoids, which are more abundant and diverse in Scots than in lodgepole pine forests. Cycles of abundance, with a periodicity of about 7 years (as shown in the bar chart), are an interesting feature of the population dynamics of this insect in which the delayed action of natural enemies is likely to have played a role.

This insect has proved so damaging over a period of 20 years that lodgepole pine is not now considered a first choice commercial species. The relevance to climate change, however, is that while the influence of climatic factors appears limited in the population dynamics and impact of this pest, its rapid elevation from innocuous endemic on Scots pine to serious defoliator of an introduced pine is important in the context of adaptation measures in UK forestry. As a response to climate change the introduction and widespread planting of new species better adapted to a warmer climate could result in the emergence of new pests.

Key references: Stoakley (1977), Barbour (1987), Lines (1987), Watt and Leather (1988), Watt and Hicks (2000) and Hicks *et al.* (2001).

Table 1 Risk of increased damage by UK forest insect pests under climate change.

Forest insect pest	Host	Risk of increased damage	Likely effects on populations and damage in a warmer, more unstable climate
Aphids, scale insects and related species			
<i>Elatobium abietinum</i> Green spruce aphid	Spruce	Very high	Multiple generations in warm weather result in rapid population increase, exacerbated by increased winter survival. Drought stress of host trees favourable to population growth.
<i>Cryptococcus fagisuga</i> Beech scale	Beech	Low	Reduced importance of beech in a warmer, more drought prone climate likely to reduce importance of beech scale.
Bark beetles, weevils and wood boring beetles			
<i>Dendroctonus micans</i> Great spruce bark beetle	Spruce	High	Reduced generation time may increase abundance. Drought stress of host trees decreases resistance to attack. Range extension resulting in more widespread damage.
	Pine	Low	
<i>Hylobius abietis</i> Large pine weevil	Spruce	Moderate	Reduced generation time increasing population size but reducing period of risk, especially in northern forests.
	Pine	Moderate	
<i>Tomicus piniperda</i> Common pine shoot beetle	Pine	High	Windblow in stormy weather increases breeding material. Sister broods increase abundance. Host stress through drought or defoliation reduces resistance of living trees to attack.
<i>Agrilus biguttatus</i> Two-spotted oak buprestid	Oak	Moderate	Availability of declining oaks and warmer weather likely to increase both abundance and geographical range.
<i>Platypus cylindrus</i> Oak pinhole borer	Oak	Moderate	Availability of declining oaks and warmer weather likely to increase abundance and damage to timber.
<i>Ips cembrae</i> Larch bark beetle	Larch	Moderate	Windblow in stormy weather increases breeding material. Sister broods increase abundance. Host stress through drought or defoliation by sawflies reduces resistance of living trees to attack. Range extension likely to increase area of damage.
Lepidoptera			
<i>Thaumetopoea processionea</i> Oak processionary moth	Oak	High	Range extension likely to increase significance of this pest.
<i>Bupalus piniaria</i> Pine looper moth	Pine	Moderate	Reduced rainfall on vulnerable sites has potential to trigger outbreaks.
<i>Operophtera brumata</i> Winter moth	Spruce	Moderate	Phenological synchrony with oak may be disrupted as the climate warms, reducing likelihood of outbreaks in the short to medium term. Exposure to novel hosts during afforestation can result in local outbreaks.
	Oak	Moderate	
<i>Lymantria dispar</i> Gypsy moth	Oak	Low	A newly established pest may increase its range as the climate warms resulting in localised defoliation.
<i>Panolis flammea</i> Pine beauty moth	Pine	Low	Has potential to cause outbreaks on exotic pines introduced as an adaptation to climate change.
<i>Zeiraphera diniana</i> Larch budmoth	Spruce	Low	Disruption of phenological synchrony with host tree likely to reduce risk of outbreaks in short to medium term.
	Pine	Low	
	Larch	Low	
Sawflies			
<i>Gilpinia hercyniae</i> European spruce sawfly	Spruce	Moderate	Increased number of generations extends seasonal occurrence of damage and may increase abundance. Range extension may result in local damage.
<i>Neodiprion sertifer</i> European pine sawfly	Pine	Low	Possible increased risk of damage on dry nutrient-poor sites.
<i>Cephalcia lariciphila</i> Web-spinning larch sawfly	Larch	Low	Range extension may result in localised defoliation, depending on the future importance of larch.

Note: risk is rated as low, moderate, high or very high based on an assessment of life-history characteristics, population dynamics, historical patterns of damage and likely changes in planting.

Climate change is likely to influence the abundance and impact of some defoliators by:

- an increase in the number of generations per year in some species;
- effects on tree susceptibility through changes in the seasonal timing and amount of rainfall on some sites;
- range extension of species with a predominantly southern distribution;
- phenological asynchrony with host trees.

Forest management and climate change

Changes in forest management to minimise the impact of climate change on tree growth and productivity, such as increasing forest area, extending rotation length, increasing stocking density or altering age structure, have the potential to either increase or decrease insect abundance and damage. Afforestation and the introduction of new provenances and species better adapted to a warmer climate may lead to the emergence of new native pests. A number of insects have exploited the opportunities for host range expansion provided by afforestation of upland Britain in previous decades. Host shifting moths are most likely to be polyphagous on a wide range of woody trees and shrubs, to occur in habitats associated with afforestation, and to overwinter as eggs. A recent example is the winter moth (*Operophtera brumata*). This defoliator is normally found on oak but also occurs on heather and bilberry in upland areas and has defoliated Sitka spruce in some parts of northern Britain, sometimes at outbreak densities. The gradual introduction of new tree species or provenances, rather than initial widespread planting, is likely to minimise the risk of pest damage in forests during a period of adaptation to climate change.

Conclusions

Climate-related variables such as temperature, precipitation or weather extremes can affect insects directly by influencing development or survival, or indirectly through the action of natural enemies or by altering the nutritional or defensive status of their host tree. The relative importance of direct and indirect effects will depend on the ecological and life-history characteristics of different kinds of forest pest. These characteristics include the number of generations per year, overwintering strategy, seasonal food availability and population dynamics. The impact of a changing climate on insect abundance, feeding damage and outbreaks is difficult to predict, but some generalisations are possible for different kinds of pest

and more specific predictions can be made for those pests whose abundance is determined by one or two dominating factors that can be readily quantified. Overall, the abundance and damage caused by aphids and related insects is likely to increase under climate change through the effect of higher temperatures on reproductive rate and the impact of changes in the spatial and seasonal distribution of rainfall on host trees. Bark beetles and related species are likely to benefit from more frequent and possibly larger windblow events, drought stress on trees and changes in silviculture that result in more mature trees in longer rotations. For defoliators, an increase in the number of generations per year, effects on tree susceptibility through changes in rainfall patterns and, for some species, phenological asynchrony with host trees are likely to have significant effects on damage levels. Finally, afforestation and the introduction of new provenances and species better adapted to a warmer climate may lead to the emergence of new native pests.

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Enquiries relating to this publication should be addressed to:

Dr Daegan J.G. Inward
Forest Research
Alice Holt Lodge
Farnham
Surrey GU10 4LH
+44 (0)300 067 5600

daegan.inward@forestry.gsi.gov.uk
www.forestry.gov.uk/forestresearch

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