

# Forest Pests and Climate Change

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## Part 1: Overview of Climate-Pest Interactions

Among the many potential impacts of climate change, changes in insect and disease populations rise to the top as the most immediate and possibly significant impact on our forests. This is because of the destructive potential of forest pests and the direct link between climate and pest survival or spread. In particular, climate influences:

- Frequency and intensity of outbreaks
- Spatial patterns, size, and geographical range of outbreaks
- Life cycles, range shifts, range expansions or contractions

Being ectothermic, insects are particularly sensitive to temperature, as it directly influences their metabolic rate, consumption, development, and the timing of life history stages. Water availability is also an important factor determining the interaction between plants and insects. Forest pathogens are similarly sensitive to temperature and moisture conditions. As a result of this sensitivity, these organisms will be *directly* affected by changing climate, in addition to being *indirectly* influenced via climate change impacts on other organisms, such as their host species.

Forest insects and pathogens have a number of characteristics that will allow them to rapidly respond to climate change, including: (1) physiological sensitivity to temperature, (2) high mobility, (3) short generation times, and (4) high reproductive potential.

### Direct Climate Impacts

A number of climate change-related variables will have direct impacts on the population dynamics of forest insects and pathogens:

- **High overall temperatures, especially milder winters**
  - Greater over-winter survival
  - Increased spore production and infectiousness
  - Decreases in insect populations at a certain level of warming, as most insects are susceptible to heat stress between 82 and 90°F

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*“In general, it is thought that “warmer is better” for nuisance species. In the absence of water stress, warmer temperatures increase metabolism, reproductive rates, and survival.” (Dukes et al 2009)*

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- **Longer and warmer growing season**
  - Lengthening of reproductive season
  - Accelerated life cycles; increase in number of generations per year
  - Earlier appearance in spring
- **Changing snow pack**
  - Affecting overwinter survival
- **Climate variability**
  - Affecting performance and survival

## Indirect Climate Impacts

Pests will experience the indirect effects of climate change through the following avenues:

- **Host plants**
  - *Distribution of primary (or alternate) host plants*
    - Reduced/shifting habitat suitability may result in the loss of suitable host plants for some pest species within their preferred climate niche
    - Changing habitat suitability may also cause tree stress and increased susceptibility to attack
  - *Nutritional quality*
    - Elevated CO<sub>2</sub> and temperature typically increases the concentration of leaf carbohydrates and decreases nitrogen content, lowering nutritional value
      - This can lead to increased herbivory from “compensatory feeding” – herbivores consume more low-quality food to meet their nutrient needs
  - *Plant resistance*
    - Little is known about the mechanisms by which increased CO<sub>2</sub> and temperature affect plant production of secondary metabolites (defense chemicals), which deter feeding – at this time, we only have observational data that indicates climate-induced changes vary by species and context
    - Conditions that promote increased plant growth may be a double-edged sword because they are often associated with declines in plant production of defense compounds, which is a benefit for certain insects
  - *Phenology*
    - Accelerating phenology due to warming temperatures can lead to a mismatch between plants and associated organisms, which can be positive or negative for plant life – negative when it leads to a misalignment between plants and their pollinators (this is especially an issue for specialist plant-pollinator interactions) and positive when it reduces the frequency or severity of insect/pathogen attacks
  - *Rate of plant development*
    - When the rate of plant development shifts relative to insect development, it can amplify or minimize consequences of herbivory

- **Community interactions** with:
  - Natural enemies (predators, parasitoids, pathogens), e.g. shifting bird populations may increase predation on arthropods in some areas, increasing the strength of top-down control on those pest populations
  - Competitors
  - Mutualists
- **Abiotic damage** that increases tree stress and makes hosts more susceptible to attack\*, such as: (1) Storm Damage, (2) Drought, and (3) Extreme heat events.

*\*Note:* Pests can generally be divided into two categories: primary pests that can typically attack healthy trees and secondary pests that tend to attack trees that are already weakened by a predisposing factor like drought, water-logging, or injury (e.g. ambrosia or ips engraver beetles). It is likely that the biggest impacts from abiotic damage will come from these secondary pests.

## Part 2: Summary of Anticipated Impacts

As with projections of tree response to climate change, we expect the response of insects and pathogens to be species-specific, or at least vary depending on host type and feeding guild (e.g. defoliators, gall makers, wood borers, etc.). However, there are some general predictions that can be made:

### Asynchrony/Ecological Mismatches

It is likely that projected changes in seasonality will lead to instances where the life cycle or developmental stages of host species and pests are no longer aligned, which could exacerbate or alleviate pest impacts, depending on the species involved. For example, insects that typically feed on young, nutrient rich foliage may be negatively impacted if the growing season begins earlier and causes faster leaf maturation after budbreak, especially if the timing of their spring emergence does not change. Likewise, the timing of spore release by pathogens can be an important determinant of disease incidence and severity, but changing climate conditions are likely to change those interactions. These issues of synchronicity are at the heart of many complex species interactions that may be disrupted by climate change because pests, hosts, and predators may all have different sensitivities to changing climate and varying levels of tolerance and/or plasticity to deal with those changes. Therefore, it is likely that in the future the rate or timing of development may no longer be in alignment among species that have historically been tightly linked.

### Range Shifts/Redistribution

In addition to being misaligned in time (as described above), hosts and pests may become misaligned geographically due to climatically-driven changes in species ranges. Generalist pest species tolerate a wide range of climate conditions, are highly mobile, and use a variety of host species, so they will likely fare better as their ranges expand into northern regions. Whereas, more specialized species,

such as those commonly found in tropical areas, are likely to see their ranges shift entirely, or contract in instances where migrating populations encounter hard (e.g. continental edges) or soft (e.g. soil moisture) range boundaries. These shifts may be good or bad for forest ecosystems, depending on the species and region in question.

In a general sense, we expect to see the following trends in pest distribution:

- Expanded northern ranges
- Invasion of new habitat and forest types
- Range shifts toward poles and higher elevations (most shifts in temperate regions)
- Better survival and increased impact from poleward populations

*Note:* In some cases, poleward populations may be locally adapted to colder temperatures, so there may not be as much of an advantage conferred by warmer temperatures in those regions.

### Changing Pest Populations and Outbreak Frequency

Some research suggests that a warmer world doesn't necessarily mean more forest pest impacts because we may mostly see distribution shifts toward higher latitudes and altitudes, rather than an increase in the overall incidence of pest outbreaks. However, climate change is also likely to amplify abiotic stressors, such as drought, extreme heat, and increased storm strength, which creates conditions that are favorable to more frequent and intense outbreaks.

Herbivorous insects will generally fare well because warmer temperatures will increase winter survival, promote faster development rates, and sometimes allow their populations to grow faster than normal because they can complete more life cycles in a season. That last characteristic (increased voltinism, i.e. number of generations per year) is particularly troubling because it will lead to more herbivory. Multiple generations of herbivores can do significant damage in a single season, especially for long-lived plants (increased likelihood of mortality and impacts on future growth and reproduction) and conifers (they don't typically releaf and their resin defenses can be over-ridden by large numbers of attackers). In fact, there is evidence that a similar increase in herbivory happened in North America during a past period of global warming known as the Paleocene-Eocene Thermal Maximum approximately 55.8 million years ago.

### Increased Pathogen Infectiousness

Evidence suggests that pathogens, including those that affect tree species, are likely to increase their infection rate under increased humidity and temperature conditions associated with climate change. These organisms are also generally able to evolve, adapt, and migrate more quickly than their long-lived hosts, so their role in forest disturbance regimes will probably increase. An increase in pathogen development and survival rates, disease transmission, and host susceptibility will have deleterious effects on forest ecosystems, but there will also be some subset of pathogens that actually decline with warming and lead to improved conditions for their host species.

## Increased Vulnerability in Water-Stressed Regions

Some of the most obvious and immediate pest-related impacts will occur in regions with reduced precipitation and more frequent or severe drought conditions. This is particularly true for insect groups and pathogens that typically affect water-stressed hosts – the increased bark beetle activity coincident with drought in the western U.S. is a prime example. Drought conditions create physiological stress for trees that increases their susceptibility to attack and reduces their ability to survive and/or recover. A recent meta-analysis (Jactel et al 2012) of drought effects on damage by forest insects and pathogens found that primary damaging agents (i.e. insect or fungal species that can develop on healthy trees) living in wood caused lower damage than those living on foliage, indicating that the type of feeding substrate was very important for the level of pest damage.

## Part 3: Regional Pest Highlights

The following section contains several regional examples of forest pests and pathogens that are likely to be influenced by climate change, including a brief, high-level overview of how climate is anticipated to impact each species.

### Northeast

#### **Spruce Budworm**

Current research on the effects of climate change on eastern spruce budworm (SBW) suggests that there will be an increase in its range at higher latitudes and higher altitudes. This is because SBW is limited primarily by cool summer temperatures, which prevents the eggs from hatching before winter and does not give the larvae sufficient time to find winter shelter. Warmer summer temperatures will allow the pest to move into new territory and that has already been seen at unusually high latitudes on the north shore of the Saint Lawrence River in Quebec (c. 2009).

#### **Hemlock Woolly Adelgid**

The Hemlock Woolly Adelgid (HWA) is vulnerable to low temperatures and its continued spread is primarily limited by minimum winter temperatures, rather than hemlock abundance. In particular, studies have found that an average winter temperature of 23°F (-5°C) is limiting, which historically meant that about half of the Northeast region was too cold for HWA (including upstate New York and most of Vermont, New Hampshire, and Maine). However, warming temperatures will allow for HWA range expansion – by mid-century half of the area that is currently temperature-limited will become suitable and by the end of the century (under the higher emissions scenario) the entire Northeast will have average winter temperatures above 23°F. HWA is an example of a pest that will be directly influenced by climate change, with temperature conditions becoming progressively more suitable for its migration northward and into higher elevation areas.

## **Gypsy moth**

Gypsy moth is another example of an insect that is limited by cold in the northern portions of its range. A number of studies indicate that increasing temperatures will lead to an increase in defoliated area and an expansion of gypsy moth populations into new regions. However, precipitation changes are also important, as evidence suggests that a warmer *and drier* climate will actually decrease defoliated area. Drier conditions can also reduce the buildup of *Entomophaga maimaiga*, a lethal fungus that thrives during wet spring weather and was introduced from the gypsy moth's native range in Japan in the early 1900's as a way to control its population in the U.S.

## **Southeast**

### **Southern Pine Beetle**

Model projections and observed changes of Southern Pine Beetle (SPB) populations generally indicate that rising temperatures lead to more outbreaks. Winter minimum temperatures below 6.8°F (-14°C) cause population declines, but in recent years warming temperatures have allowed these insects to move north into areas where cold was once limiting, including the New Jersey pinelands, Long Island, and, most recently, Connecticut. Although, seasonal changes in temperature are also relevant because increases in winter and spring temperature are projected to increase outbreaks, while increases in fall temperatures will tend to ease outbreaks. The intensity and area of outbreak is also related to precipitation levels, with more precipitation being beneficial for the insects, although it is a less important factor than temperature.

On a positive note, there is evidence that extremely hot summer temperatures are lethal for SPB, leading to increased mortality, reduced activity, and hindered flight. Therefore, it is possible that future increases in extreme heat events in the southeastern U.S. will provide a benefit in terms of SPB population control. Whereas, pine stands in the northern stretches of the beetles' range will likely see the greatest increase in beetle activity and impact.

### **Ips Engraver Beetles**

Ips engraver species can be cold-limited in the sense that low temperatures disrupt egg development and synchronized flight activities. These species can also see a reduction in the number of generations per year when cold temperatures persist over a long winter. In this way, climate warming may directly benefit ips by increasing their reproductive rates. In fact, several studies of *Ips* species in Scandinavia have indicated that higher temperatures will lead to an increase in the frequency and length of late summer swarming events in those regions, as well as an increase in the number of generations per year.

Ips rarely attack healthy trees and instead tend to target trees that are under stress, a condition that is likely to increase in prevalence as various climate stressors interact to increase physiological stress on trees. Drought stress is one example of a condition

that increases the risk of ips attack and there is some evidence that decreased precipitation, and the consequent reduction in host tree resistance, contributed to ips outbreaks in the southwest U.S. in the early 2000's. Projections of increased drought stress under future precipitation patterns may contribute to an increased risk of ips attack.

### **Fusiform Rust**

A number of climate-related factors influence the extent and severity of fusiform rust infection, including temperature, humidity, and late winter/early spring weather. However, the disease is already widely distributed throughout the host range, so it is likely that climate change will not directly cause an expansion of the affected area. Instead, experts expect this disease to experience indirect climate impacts via changes in the distribution of its host species as a result of rising temperatures, e.g. increased planting of loblolly pine in northern regions or migration of pine (and alternatively, oak) hosts from coastal areas into the Appalachian Mountains.

## **West/Northwest**

### **Mountain Pine Beetle**

As with many other North American forest pests, the latitudinal and elevational limits of the Mountain Pine Beetle (MPB) range are delineated by climatic conditions related to average annual minimum temperature. The beetles generally cannot survive to complete successful brood development in places where this average minimum is less than -40°F (-40°C). Given that the range of potential hosts is far more extensive, there is significant potential for MPB to expand under the right climate conditions. Warmer winters in British Columbia with an absence of cold snaps sufficient to kill MPB (a week or more of temperatures at or below -31°F) have already allowed the insect to have outbreaks in more northerly areas. Studies conducted to date generally predict MPB will continue to expand northward, eastward, and toward higher elevations, with the potential for a reduction at lower elevations in the northwestern region of the U.S. due to future climate-related losses of suitable host species in those areas.

### **Sudden Oak Death**

Sudden Oak Death (SOD) is caused by a fungus-like water mold called *Phytophthora ramorum*, which produces spores that spread easily in warm, wet conditions, e.g. it is often transmitted when rainwater splashes the spores onto susceptible plants. Extreme weather events contribute to mortality from SOD – heavy rains and extended wet weather create optimal conditions for infection and mortality results when this is followed by extended dry periods, because infected trees are not able to manage water as effectively. Unfortunately, researchers expect climate change, particularly increases in temperature and coastal fog, to exacerbate the effects of this pathogen and shift the at-risk area northward. Alternate hosts include a variety of woody species, especially bay laurel in California. Notably, several studies have highlighted the potential for this

pathogen to colonize the southeastern U.S., given the climatic conditions and distribution of potential host species in that region.

## Midwest

### **Emerald Ash Borer**

Emerald Ash Borer (EAB) have very low supercooling points (the temperature far below freezing that insects can survive through physical and chemical changes in their bodies), but exposure to temperatures at or below 32°F (-30°C) can cause overwintering mortality and help keep their populations in-check. In this sense, warming temperatures are likely to increase the rate of overwinter survival and potentially allow EAB to colonize previously unsuitable areas.

However, these insect do express some phenotypic plasticity in terms of their cold tolerance – while they can successfully acclimate after being exposed to colder temperatures over several months, they will lose that cold tolerance (i.e. deacclimate) if they experience warm mid-winter temperature fluctuations, and it is not reversible. This means that a mid-winter warm spell may cause EAB to deacclimate and then suffer mortality during the next cold snap because they have lost their cold tolerance. A potential opportunity, in terms of EAB population control, is the projected increase in the likelihood of extreme warm winter events associated with climate change.

## Conclusion

There are hundreds of pests and pathogens, both native and introduced, which interact with the forest ecosystems we manage. A challenge is that there are widely varying levels of knowledge about the physiology, life cycle, and climate niche from one organism to the next. The list of species for which researchers have specifically addressed the question of climate impacts is fewer still. The pests and pathogens highlighted in Part 3 are some examples of higher-profile biotic threats for which we have some of this information. Although, there are many others where there is a weak climate link (especially in cases where climate is not the dominant limiting factor) or there is a lack of literature discussing the pest specifically in the context of climate change. Examples include: Asian Longhorned Beetle, Oak Wilt Disease, Dogwood Anthracnose, Pear Thrip, and many others. There is also the practically inevitable reality that new species will continue to be introduced from abroad for which we will have very little initial information.

Given the lack of complete information about climate change impacts on the catalogue of forest pests and diseases, it is useful to take a general, high-level view of pest-climate interactions, such as that presented in Part 1 and 2 of this bulletin. The best strategy is often to identify the life cycle characteristics or physiological limits of a particular pest that are most likely to be impacted by changing climate; for example, a need for synchronicity with budbreak of a particular species, level of cold tolerance, vulnerability to mortality from climate variability and temperature extremes, or a high degree of host specificity. This is where **local knowledge** and personal experience with a particular



pest and forest type becomes really valuable for anticipating how climate, pest, and host may interact in novel ways in the future. Additionally, the importance of **monitoring** for detecting early changes in pest behavior or abundance cannot be overstated, so it is beneficial to proactively have those monitoring systems in place on your land. However, **staying alert to new information** is also key, especially in terms of looking beyond your ownership and being aware of pests that may potentially move into your area from other regions as a result of climatic shifts. This bulletin will act as a foundational document on the subject of forest pest-climate interactions and, going forward, the Climate Smart Land Network will continue to monitor and highlight newly documented links between changes in regional climate and important forest pests and pathogens.

### So what can land managers do now?

Insects and disease have always been recognized as serious threats to forests and as a result they have received significant research and communication funding. This includes town tree wardens, university, state, and federal funding and support. The whole wood product transport quarantine system is designed to address these issues.

But things are changing rapidly and we need all the eyes and ears we can get. Foresters and arborists, are ideal data gatherers, question askers and teachers in this situation. Stay connected with state insect and disease departments as well as arborist information sources. Watch for new conditions in the woods and report them to these same organizations. If there are any research or education efforts existing, explore becoming part of those efforts. Spread your knowledge to others.

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