

Insect Migration and Changes in Venom Allergy due to Climate Change



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KEYWORDS

• Insect • Hymenoptera • Climate Change • Bee • Anaphylaxis • Venom
• Distribution

KEY POINTS

- Temperature increase, as related to climate change, impacts the range and distribution of stinging insects.
- Expansion of stinging and urticating insects expanding toward the poles will increase potential for human contact, increased risk of envenomation and potential increased frequency of allergic reactions.
- Allergist/Immunologists should be aware of the changing environment as a result of climate warming.

INTRODUCTION

The evidence that climate change is occurring is overwhelming. Recent work on climate change has helped advance our understanding of the influence environmental changes have on insect dynamics regarding population and redistribution. Insects are ectothermic animals, whose physiologies are strongly influenced by variations in the microclimate, particularly temperature.¹ There are only a few large-scale studies specifically addressing insects as a bellwether of our changing climate. This review highlights some changes in insect behaviors, particularly those that impact allergy, correlated with the direct and indirect effects of climate change and shifts in seasons.

Global, annually averaged surface air temperature has increased by approximately 1.8°F (1.0°C) over the past 115 years (1901–2016) with annual average near-surface air temperatures across Alaska and the Arctic increasing more than twice as fast as the global average temperature.² Globally, this period is now the warmest in the history of modern civilization. This past decade has seen record-breaking, climate-related weather extremes, and the warmest years on record for the globe.² These trends

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are expected to continue over climate timescales. There are many indicators of climate change, particularly physical responses, such as changes in surface temperature, atmospheric water vapor, precipitation, severe weather events, retreating glaciers, sea level rise, and diminishing sea and land ice.^{2,3}

Several factors can influence distribution of insects, climate change is but one of them. Species redistribution and biodiversity loss has been significantly impacted by urbanization. Other key elements of biodiversity include genetic diversity of species, the richness of local and global species, the spatial extent and the state of natural habitats, and the functioning of ecosystems.^{4,5} Because of the many variables, it is difficult to dissect out the effects of climate change versus habitat change. Therefore, modeling based on current trends, using best and worst case scenarios with regard to insect redistribution, may not reflect the many other factors of biodiversity and may not reflect real world interactions.⁶ Few studies have specifically addressed the direct impact of venomous insect redistribution on human health, instead focusing on recognized changes in patterns and projected response to changing climate variables.

HYMENOPTERA

Hymenoptera, the largest order of insects, account for more than 10 million stings in humans worldwide annually.⁷ It is estimated that potentially life-threatening systemic reactions to Hymenoptera stings occur in 0.4% to 0.8% of children and 3% of adults.⁸ Populations of Hymenoptera, such as *Vespula*, have extended their range in both the Northern and Southern Hemispheres. The adaptation skills of *Vespula vulgaris* enable it to live in a wide range of habitats, from very humid areas to artificial environments such as gardens and human structures.⁹ Although some Hymenoptera species appear to extend range, others will likely lose range and decline.

YELLOWJACKETS (*VESPULA* SP)

Vespula germanica and *V. vulgaris* are widespread in Europe and North America and have subsequently been introduced into the Southern Hemisphere. *V. germanica* became established in New Zealand in 1945 and Australia in 1959 and have continued to extend their range. It is projected that their range will continue to expand with the warming climate and as human populations and trade continues to increase.⁹ These species are scavengers and therefore flourish in urban environments, resulting in frequent human encounters.¹⁰

The first 2 reported deaths from insect-induced anaphylaxis in Alaska occurred 2006.¹¹ This was in a period in which organized outdoor sporting events were canceled because of high levels of stinging insects, predominantly yellowjackets, in Fairbanks, Alaska.^{11,12} Demain and colleagues¹³ undertook a retrospective study to assess increases in patients seeking medical care for sting reactions between 1999 and 2007, using the Alaska Medicaid database, which represents 132,000 lives. These data were applied to different climate variables. The results demonstrated increases in billings for insect reactions throughout each of the 6 epidemiologic regions of Alaska, with increasing incidence correlating with more northerly latitudes. The largest percentage increase was in the most northern region, with an increase of 626% from the average incidence of 16 per 100,000 per year during 1999 to 2001 to 119 per 100,000 per year during 2004 to 2006 (Table 1). In summary, there was a statistically significant increase in patients seeking medical care for sting-related events throughout the state, with 5 of the 6 regions experiencing at least a 6-degree Fahrenheit increase in winter temperature. It was surmised that milder winters provided greater survivability of overwintering queens. The expansion of northern range of

Table 1
Annual and winter temperature increases and changes in insect sting incidence among Medicaid-enrolled persons, Alaska

Region	Largest Community	Annual Temperature Increase ^a	Winter Temperature Increase ^a	1999–2001 Insect Sting Incidence ^b	2004–2006 Insect Sting Incidence ^b	Percent Change in Insect Sting Incidence (χ^2 for Trend, <i>P</i> -value) ^c
Northern	Barrow	3.8	6.1	16	119	626% (13, <i>P</i> <.001)
Southwest	Bethel	3.7	6.9	62	133	114% (8, <i>P</i> = .005)
Interior	Fairbanks	3.6	8.1	333	509	53% (28, <i>P</i> <.001)
Anchorage	Anchorage	3.4	7.2	276	405	47% (22, <i>P</i> <.001)
Southeast	Juneau	3.6	6.8	221	279	27% (22, <i>P</i> <.001)
Gulf	Kodiak	1.5	1.5	437	487	11% (0.1, <i>P</i> = .75)
Statewide		3.4	6.3	254	364	43% (54, <i>P</i> <.001)

^a Annual and winter average temperature increase (°F) from 1950 to 2006 based on data for largest community.

^b Incidence per 100,000 Medicaid-enrolled persons per year for entire region.

^c χ^2 for trend and *P*-value calculation based on individual years from 1999 to 2006.

From Demain JG, Gessner BD, McLaughlin JB, et al. Increasing Insect Reactions in Alaska: Is this Related to Climate Change? Allergy Asthma Proc. May-Jun 2009;30(3):238-43; with permission.

Vespula does not appear to be unique to Alaska, but rather has been observed in other circumpolar regions. In 2004, a Canadian entomologist and associate curator of the Natural History Museum in Los Angeles confirmed yellowjacket (*Vespula rufa*) in the village of Arctic Bay, Nunavut, Canada, at 73° latitude.¹⁴

Barnes and colleagues,¹⁵ working in Fairbanks, demonstrated that although freezing causes death in the common yellowjacket, *V vulgaris*, this species can “supercool” to temperatures below minus 16° Celsius without freezing. In their study, snow depths of as little as 60 cm provided enough insulation to allow the overwintering queens to survive in hibernacula, maintaining an average of minus 6.5° Celsius, while average air temperatures were minus 19.4° Celsius (with minima often below minus 30° Celsius). These data illustrate that snow depth could be an important factor in the annual population growth of yellowjackets and potentially other Hymenoptera. Lester and colleagues¹⁶ studied long-term population dynamics of *V vulgaris* over 39 years in 4 sites in the United Kingdom and over 23 years of data from 6 sites in New Zealand. They found that warmer winter temperatures and warmer spring temperatures were associated with increased *V vulgaris* abundance, although increased rainfall was associated with decreased abundance. They concluded that these data have broad implications that climate warming will have a direct impact on the yellowjacket population dynamic.¹⁶

PAPER WASPS (*POLLISTE* SP)

The most common Hymenoptera in North America is the paper wasp, with the European paper wasp, *Polliste dominula*, one of the most dominant of all social wasps. The specific epithet *dominula* is a noun meaning “little mistress.” Prominent in Europe and Asia, it has also been introduced to New Zealand, Australia, South Africa, South America, and North America. Since the mid-1980s, the population of *P. dominula* has expanded to historically cooler regions, especially toward northern Europe. Climate change, specifically climate warming, is speculated to have raised temperatures of certain areas enough to allow *P. dominula* to expand into more northern regions.^{10,17}

HORNETS (*VESPA* SP)

There are few data specifically addressing hornets regarding the impact of climate change. There are 22 species within the genus *Vespa*. Based on modeling, it is predicted that the Yellow-legged hornet, *Vespa velutina*, will expand its range into northern Europe and throughout the United States, except along the East coast.¹⁸ Nesting patterns are quite different from *Vespa crabo*, in that they are larger in size and can have much larger colonies, up to 15,000 to 30,000.¹⁹ These data suggest a significant increase regional predominance of these hornets, likely resulting in more frequent human encounters.

HONEYBEES (*APIDAE* SP)

In the United States, there are more than 4000 species of native bees (Bee Pollination. US Department of Agriculture. Available at: <https://www.fs.fed.us/wildflowers/pollinators/animals/bees.shtml>. Accessed March 18,2020). Bee species have demonstrated a very mixed response to climate change and warming temperatures. Although some have expanded range, others have experienced a reduction in both range and population. The Africanized honeybee (*Apis mellifera scutellata*) was introduced to Brazil in the mid-1950s, quickly escaped, and ultimately hybridized with the domestic European honeybee (*Apis mellifera mellifera*), creating what is commonly termed the

“Africanized honeybee.”⁷ The venom from Africanized honeybees is essentially identical to their domestic cousins, as is the venom volume per sting.²⁰ However, unlike the single sting of a domestic honeybee, Africanized honeybees often swarm and sting in large numbers and pursue their victim for much longer distances. The domain of the Africanized honeybee in the United States was initially had limited distribution, predominantly Texas, New Mexico, Arizona, Nevada, and California.^{7,8,11} However, by 2009, the Africanized honeybee had almost doubled its range, now in 10 states⁸ (Fig. 1). Continued northward expansion of the Africanized honeybee is predicted, largely impacted by temperature warming. Considering their aggressive nature, increased human encounters and worsening envenomation events are likely.¹⁹

Counter to the Africanized honeybee, the domestic European honeybee is experiencing a withdrawal of range. *Apis mellifera* is a species that has demonstrated great adaptability to many climactic environments in that it can be found almost everywhere in the world.²¹ A *mellifera* is instrumental as insect pollinators. Approximately 35% of agricultural crops and 84% of cultivated plant species are reliant on honeybees for pollination.²¹ Since 1995, mortality of honeybees worldwide has been observed. The consensus is that this is related to a combination of factors. In addition to pesticides, which kill many colonies each year, there are factors linked to climate change leading to environmental stress, as well as new pathogens such as the brood parasite, *Varroa destructor*. Other factors, such as mismatches between phenology of honeybee colonies and flowering plants, have also had a significant impact on colony health and increased bee mortality.^{21–25} It is thought that these factors that might interfere with the honeybees’ capability to adapt to climate warming.^{25,26}

The mason bee, genus *Osmia* sp, order Hymenoptera, pose little to no threat of stinging because males do not have a stinger, and the females will only sting if threatened. Though not a significant direct health risk, such as anaphylaxis, they are very

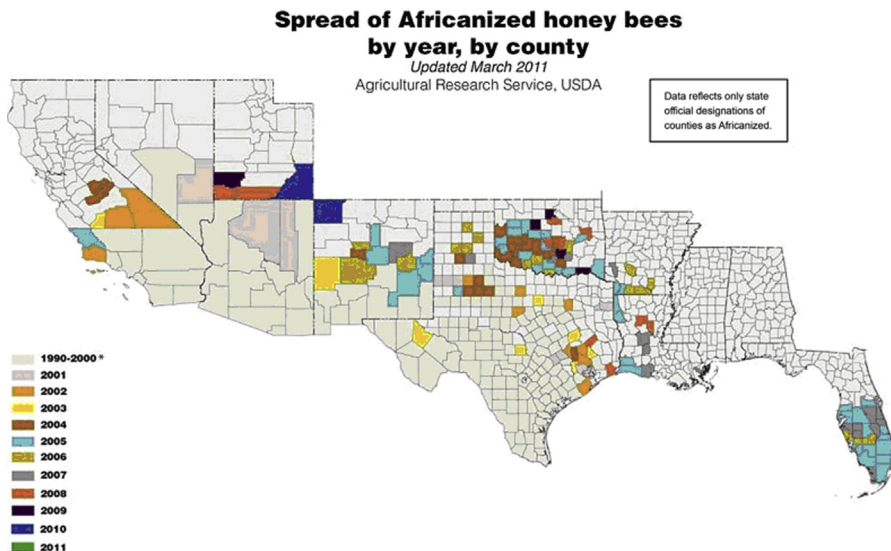


Fig. 1. Spread of Africanized honeybees. (From Agricultural Research Service. Spread of Africanized honey bees by year, by county. US Department of Agriculture. Available at: <https://www.ars.usda.gov/ARSUserFiles/20220500/New%20Bee%20Map09%20compressed.jpg> Accessed March 23, 2020; with permission.)

important pollinators. Using 17 climate chambers, Frund and colleagues²⁷ demonstrated that overwintering temperature did not influence mortality, which was uniformly low. They did demonstrate that overwintering temperature affected both weight loss after winter and the date of emergence. Weight loss reflects higher metabolic rates during overwintering at warmer temperatures and ultimately resulting in loss of energy, consequently increasing vulnerability and decreasing longevity of wild bees. These findings may further explain reduction of bee populations.

BUMBLEBEES (*BOMBUS* SP.)

There are more than 250 species within the genus *Bombus*, part of the family Apidae. Bumble bees are found in both the Northern and Southern Hemisphere, predominantly in cooler alpine climates.²⁸ Bumblebees are uncommon causes of sting reactions but have been reported to cause anaphylaxis, particularly with occupational exposure in greenhouse workers.^{8,29} Bumblebees have been in decline since the early 1900s. Early loss was initially attributed to loss of habitat for feeding and nesting resources.²⁸ Marshall and colleagues³⁰ studied 48 *Bombus* species common to Europe, using applied modeling with climate change scenarios. Analysis projected that by 2100 most of the bumblebee species will lose range, whereas some may experience a slight gain of range. A Belgium study³¹ looked at heat stress tolerance of bumblebees, 2 taxa with an arctic distribution, 3 mountainous taxa, and 1 widespread taxon. Relatively low tolerance to heat stress was seen in all groups, with least tolerance in arctic species. These data suggest that heatwaves could lead to fatal consequences for bumblebee species.³¹ In a recent study published in *Science*, Soroye and colleagues³² studied 66 species of bumblebees in North America and Europe, estimating the thermal and precipitation limits of each of the species. The data provided evidence of rapid and widespread declines of bumblebees across Europe and North America, with decreases of 46% in North America and 17% in Europe. They concluded that climate change has driven stronger and more widespread bumblebee declines than previously reported.³² Unlike many other taxa, bumblebees have failed to track warming, resulting in losses in their southern range and failure to expand in northern range in both Europe and North America, accumulating range compression in both continents.³³ Therefore, bumblebees are vulnerable to further and possible accelerated decline due to climate change, adding further concern to cultivated plant pollination.

Although not a high risk with regard to anaphylaxis, it is important to note that some Hymenoptera species, particularly bees, may not be able to expand range or adapt to the changing climate. Although this will likely decrease human encounters, it could have a significant impact on pollination.

ANTS (FORMICIDAE)

The family Formicidae is composed of more than 14,000 species. Within the genus *Solenopsis*, 2 species, *Solenopsis invicta* and *Solenopsis richteri* have become economically and medically important pests in the United States, with *S. invicta* responsible for 95% of sting reactions from ants in North America. Commonly referred to as imported fire ants or invasive fire ants (IFA), they build very large sub-terrarium nests with large mounds. Highly aggressive, they can sting multiple times in a circular pattern, producing sterile pseudo-pustules, and in some, potentially severe, life-threatening anaphylaxis.⁸ There are other species of stinging ants throughout most continents. In the United States, the distribution of *S. invicta* and *S. richteri* is predominantly in the Southeastern region (Fig. 2).

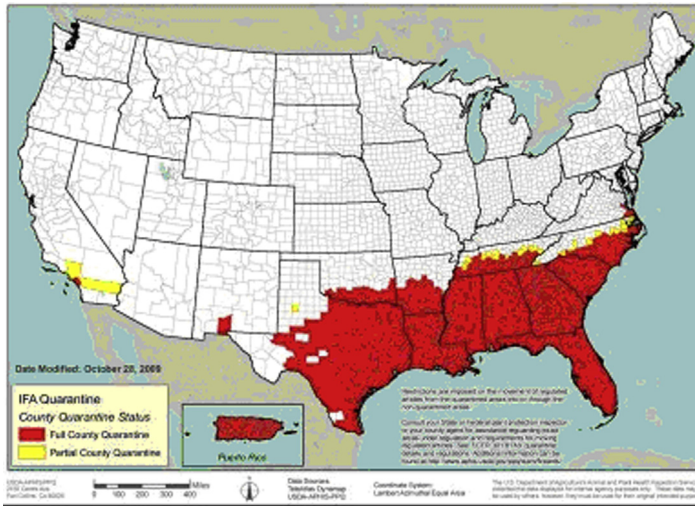


Fig. 2. Imported fire ant quarantine, as of June 9, 2017. (From Agricultural Research Service. Imported Fire Ant Quarantine. US Department of Agriculture. Available at: https://www.aphis.usda.gov/aphis/ourfocus/planthealth/plant-pest-and-disease-programs/pests-and-diseases/imported-fire-ants/ct_imported_fire_ants Accessed March 23, 2020; with permission.)

IFAs are invasive species in the United States. Native to South America, *S. invicta* was accidentally introduced to the Southern United States in the 1930s and again in 1945 and has successfully increased its range to include the Southeastern Region and Southern California, as depicted in Fig. 2.^{34,35} *S. richteri* was introduced into the United States in the 1950s, although with a much small footprint.

Using scientific modeling, it is predicted that changing climate will create favorable conditions for further northern expansion. Morrison and colleagues³⁵ predicted northern range expansion of *S. invicta* of 80 to 150 km, with acceleration of expansion by the second half of the twenty-first century. This was modeled using Vegetation-Ecosystem Modeling and Analysis Project (VEMAP) along with historical data from the North American Oceanic and Atmospheric Administration. VEMAP is a multi-institutional, international effort whose goal is to evaluate the sensitivity of terrestrial ecosystem and vegetation processes to altered climate forcing and elevated atmospheric CO₂ (Vegetation-Ecosystem Modeling and Analysis Project [VEMAP] Available at: DAAC Home > Get Data > NASA Projects > Vegetation-Ecosystem Modeling and Analysis Project [VEMAP]. Accessed March 18, 2020) Findings revealed that in some areas, expansion range of IFA would be limited by drier conditions, while range increased in higher elevations where temperatures are cooler.³⁵

It is projected that *S. invicta* will continue to expand its range within the United States, at least in part due to climate warming. This will undoubtedly increase insect-human contact. Based on a prospective study, sting rate with exposure is more than 50% and the potential development of allergic sensitivity is 7%.³⁶ Thus, in addition to economic impact, the continued spread of imported fire ants will almost certainly result in increased morbidity and mortality risk.

Pachycondyla chinensis, or the Asian needle ant, is native to areas of Japan and Asia. Like the imported fire ant, it is in the order Hymenoptera and family Formicidae. The Asian needle ant is another invasive species in the United States. It was first introduced

in North Carolina early in the twentieth century and is rapidly spreading along the Eastern United States and throughout a wide range of habitats.^{37,38} Stings from the Asian needle ant are an important cause of anaphylaxis in East Asia. A 23-kDa protein homologous to antigen 5 is the major allergen produced by these ants.³⁹ Using species distribution models, Bertelsmeier and colleagues,³⁸ demonstrated that climate change will greatly increase the risk of *P. chinensis* invasion by increasing suitable landmass by 64.9% worldwide. Climate change is a crucial factor in extending the habitat of this invasive ant. There is concern over anaphylaxis risk to this stinging insect that we lack the ability to perform venom testing and are unable to offer immunotherapy.

LEPIDOPTERA

Caterpillars/Butterflies/Moths

Lepidoptera are “scaly, winged insects,” comprising butterflies and moths in all stages of development. There are an estimated 140,000 species in this class. They have a very complex life cycle: however, a general understanding is important. After the male and female mate, the fertilized eggs are deposited onto foliage, where they hatch, and the larval form (caterpillar) emerges. The caterpillar undergoes 5 or 6 developmental molts and transformations known as instars. It is during these early developmental stages that they are a threat to humans. The most mature instar pupates into a cocoon, ultimately emerging as an adult.^{40,41} Lepidopterism and erucism are interchangeable terms that refers to the ill effects of larval and adult butterflies and moths resulting from inhalation, ingestion, direct contact, or envenomation. The stinging or urticating caterpillars excrete their venom through hollow hairs or spines, which can result in hypersensitivity reactions, including local and/or systemic reactions. Caterpillars excrete their venom through hollow hairs or spines. As an example, during the final instar of *Euproctis similis*, there are an estimated 2,000,000 urticating setae per caterpillar.^{40,42,43}

There are an estimated 50 to 150 species that have been implicated in lepidopterism, representing only 0.1% of the known species of moths and butterflies. Four species of caterpillar frequently encountered in the United States pose a potentially serious threat for the sensitized victim: (1) the io moth caterpillar (*Automeris io*); (2) the saddleback caterpillar (*Sibine stimulea*); (3) the Douglas fir tussock moth caterpillar (*Orgyia pseudotsugata*); and (4) the puss caterpillar or “asp” (*Megalopyge opercularis*). These have all been reported as causing serious occupational and public health problems, related to lepidoterism.^{40,41} Because of their quick response to climactic factors, butterflies are good indicators of climate change in Europe. The Butterfly Monitoring Scheme has accurate data sets dating back to the 1970s. As of 2005, the average temperature in Europe had increased 0.8° C. With that change, 63% of butterfly species expanded their range northward.^{44,45}

Expansion of range of Lepidoptera in response to climate change provides information that is helpful in assessing redistribution of other insects, which in turn is an important demonstration of potential impacts on human health. This is demonstrated in a meta-analysis, Battisti and colleagues⁴⁶ reported that over the past 20 years there has been an increase in reporting of setae-related health problems associated with expansion of the processionary moth. The processionary moth, subfamily Thaumetopoea, consists of approximately 100 species, occurring across Africa, Asia, Europe, Australia, and the Middle East.⁴⁶

SUMMARY

Frazier and colleagues⁴⁷ reported on the relationship between increasing temperatures and population growth of 65 insect species. Insects that adapt well to warmer

environments experienced an increase in population growth rates. Deutsch and colleagues⁴⁸ in turn demonstrated that with a warming climate, the fitness of ectothermic organisms is expected to generally increase with their latitude. Based on these data, faster population growth for insects at mid to high latitudes, and negative consequences with increased extinction rates for ectothermic species near the equator has been forecast.

Anticipating how climate change will affect cyclic and seasonal patterns across latitudes as temperatures increase will be determined by the thermal sensitivities and tolerance of insect species. Expansion of range toward the poles has been demonstrated in many species. As discussed in this review, most insects known to cause anaphylaxis are predicted to expand their range, thereby almost certainly increasing the frequency of human encounters.

Some species may be less adaptable or less tolerant and move toward extinction. This has been demonstrated in both honeybees and bumblebees.^{21–25,32,33} As discussed, the expansion of range for social wasps has been documented through modeling, predicting a continuation of this trend of expansion of range. There are other studies that suggest there could be a decrease in social wasp expansion, in part due to reduced ability to defend against parasitoids, bacteria, and viruses, and to intolerance of greater rainfall as a result of climactic changes.⁴⁹

Although beyond the scope of this review, synchrony between the insect and its environment is of great importance. Insects are key to pollination of many plants, with almost 88% of angiosperms relying on insects for pollination services (entomophilous). Much work has been focused on shifts in flowering time and insect emergence and potential temporal mismatches between the two.^{25,26}

It is likely that climate change will continue to alter the distribution and population of Hymenoptera and other insects. As temperatures warm and regions become suitable for nesting and establishment of colonies, many insects will expand their territory. It is the job of the allergist/immunologist to recognize these changing patterns and to educate and manage the human impact of our changing climate.

DISCLOSURE

The author has nothing to disclose.

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