American fall webworm in China: A new case of global biological invasions

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Season of mists and mellow fruitfulness—a wonderful autumn scene was described by the poet John Keats. Unfortunately, in multiple locations in China, this picturesque scenery has been nibbled away by an invasive moth, fall webworm, *Hyphantria cunea* (Lepidoptera: Arctiidae). By the end of September in 2021, outbreaks were detected in 607 counties in 14 provinces, resulting in cumulative damage of 10,427,300 acres and increasing the amount of infested area by 6.15% (Data from Biological Disaster Prevention and Control Center, China).

Fall webworm is native to North America, but during the past 80 years, it has become highly invasive throughout the Northern Hemisphere (Figure 1A). In China, the pest was introduced to Liaoning province in 1979, after which it has expanded its range rapidly and caused unprecedented economic losses.[1,2]

HIGH FOOD CONSUMPTION AND BROAD DIET BREADTH CONTRIBUTES TO THE PREVALENCE OF THE FALL WEBWORM POPULATION

The robust adaptability of fall webworm results from its high polyphagy and reproductive capability. It can feed on about 600 species of deciduous trees worldwide. The preferred host plants include multiple globally important tree species, such as mulberry, oak, hickory, pecan, walnut, elm, alder, and poplar.[1–3] Genetic diversity and genome structure have played major roles in fall webworm's ability for high polyphagy. Genes and pathways associated with carbohydrate metabolism, gustatory and olfactory receptors are substantially expanded in the webworm's genome and show strong signatures of functional polymorphisms in the invasive populations.[1] These findings suggest that fall webworm's ability to colonize novel hosts and adapt to new environments is mediated by the plasticity in the gustatory capabilities, along with the increased ability to utilize novel nutrition sources and detoxify harmful compounds.

This insect has a multivoltine life cycle, typically having two to three generations per year.[3] An adult female can lay up to 900 eggs during each oviposition period, and due to the generation overlap, her total number of offspring may reach up to 400,000 per year.[1] Damage is mainly caused by the larvae, which have seven instars. After entering the fourth instar, the food intake of the larvae increases sharply: a group of larvae can defoliate an entire tree within 3 to 4 days. The gregarious smaller larvae construct a massive silk web tent as a protection against competitors and natural enemies, whereas mature larvae rely on the long bristles or hairs on their bodies for defense.

FACTORS BEHIND THE OUTBREAKS OF THE CHINESE FALL WEBWORM POPULATIONS IN 2021

Suitable temperature range is an important environmental factor limiting survival and distribution of species. However, fall webworm is highly tolerant to extreme temperatures, withstanding temperatures ranging from $-16^\circ C$ to $40^\circ C$. This wide thermal tolerance provides the basis for the survival of the moth in a wide range of environments. Fall webworm also adjusts the number of generations per year depending on the ambient temperature: during colder years, bivoltine populations often occur, whereas trivoltine populations are more common during warmer years.[3] The preference of moth for high-humidity environments is supported by facts that its optimal relative humidity range is in between 70% and 80% and that the outbreaks are often correlated with high frequency of rainfall.

During September in 2021, fall webworm had extensive three-generation outbreaks. Firstly, the abnormally fluctuating temperatures resulted in an irregular and extended (from mid-April until late June) emergence pattern of the first adult generation. Such pattern may have prolonged the oviposition period, resulting in wider generation overlaps and higher larval abundance (Figure 1D). Secondly, the 15 rainy days more than doubled September's average precipitation, which promoted the growth and development of the third larva generation (Figures 1B, 1C, and 1E). In brief, the stronger weather fluctuation caused the third generation of fall webworm to break out in a short period of time.

CLIMATE CHANGE AND POTENTIAL GLOBAL EXPANSION OF INVASIVE SPECIES IN THE FUTURE

Climate change and invasive species influence ecosystem functions and may enhance each other's negative impacts. Global warming is expected to increase the frequency of extreme weather events, which may facilitate the propagation and spread of invasive species,[3–5] which generally are highly adaptable to various environments. Climate change may also reduce habitats' resilience against biological invasions by reducing biodiversity. Invasive species, in turn, can reduce the resilience of natural habitats, agricultural systems, and urban areas against climate change by interfering with ecosystem functions.

The costs of invasive alien species and their management are high, with the total reported costs reaching minimum US $1.288 trillion over the past decades (1970–2017), up to US $26.8 billion per year.[4,5] Therefore, interdisciplinary subjects, such as bioclimate and biometeorology, have become new research hotspots that will hopefully aid our understanding of the role of climate change in species invasion.

In China, climate change will likely increase habitat suitability for fall webworm in middle and high latitude regions. Human mobility and logistics also increase the risk of spread of the pest to new areas. The eastern farmland and man-made vegetation regions are high risk areas mainly in Liaoning, Beijing, Tianjin, Shanghai, Hebei, Shandong, Henan, Anhui, Hubei, Jiangsu, and Shanxi. Fall webworm is also threating to spread to Jilin, Inner Mongolia, Hunan, Jiangxi, Xinjiang, Ningxia, and other provinces.

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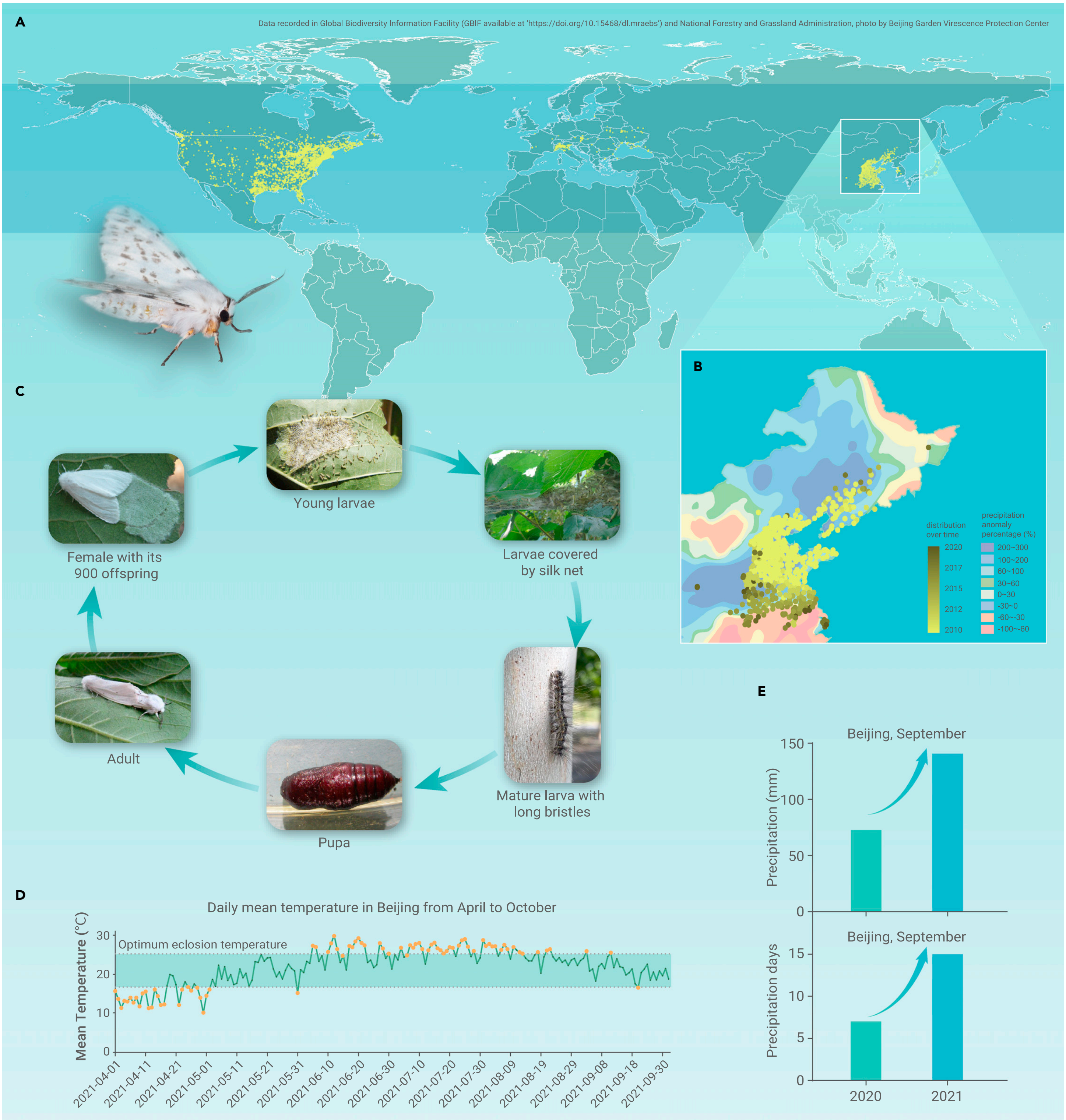

Figure 1. Global distribution, climatic factors involved in outbreaks, and an example of typical fall webworm infestation (A) Known global distribution of fall webworm. (B) Precipitation anomaly percentage in the invaded areas in September 2021 in China. (C) Life cycle of fall webworm. (D) Daily mean temperature in Beijing from April to September. (E) Precipitation in Beijing in September 2020 and 2021.

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DECLARATION OF INTERESTS

The authors declare no competing interests.