

SCIENTIFIC NOTE

INSECTS AS SENTINELS OF CLIMATE CHANGE: IMPLICATIONS FOR CONSERVATION, AGRICULTURE AND PUBLIC HEALTH

Sajjad Reyhani Haghighi

Hawkesbury Institute for the Environment, Western Sydney University, Locked Bag 1797, Penrith, NSW, 2751
Email: s.reyhanihaghighi@westernsydney.edu.au

Summary

Global warming is reshaping insect populations and the ecosystem functions they support worldwide. Insects have persisted for ~480 million years, closely tracking regional climates and seasonal cycles, but rapid anthropogenic warming is now disrupting these long-standing relationships. Rising temperatures, more frequent extremes and altered rainfall patterns are shifting life cycles, distributions and species interactions, driving declines in habitat specialists while favouring generalist and invasive pests, including vectors of plant diseases. Climate-driven changes in pollinator phenology and mosquito populations further threaten crop pollination and increase public health risks from mosquito-borne diseases. Using Australian case studies of threatened native species and expanding pest and vector populations, this note argues that insect responses to climate change should be explicitly integrated into conservation, biosecurity and public health strategies worldwide.

Keywords: insect biodiversity; climate change; phenological mismatch; endangered species; pollinator decline; pest outbreaks; disease vectors.

GLOBAL WARMING: AN ANCIENT CHALLENGE FOR INSECTS, A NEW CRISIS FOR HUMANS

Global warming may seem like a recent challenge from a human perspective, but for insects it is part of a long evolutionary history of responding to climatic variation. Insects have been thriving on Earth for roughly 480 million years, long before *Homo habilis* appeared about 2.8 million years ago. By the time Australia's Aboriginal peoples arrived around 65,000 years ago, many Australian insect lineages were already well established. Groups such as the Bogong Moth and the Giant Burrowing Cockroach had spent tens of millions of years adapting to local climates and seasonal patterns.

For much of this time, temperature and seasonality provided reliable cues. The warmth of spring signalled development and emergence, while cooler autumn conditions triggered diapause, migration or dormancy. However, recent anthropogenic climate change is altering the baseline on which these evolutionary relationships were built. Since the beginning of national instrumental records in 1910, Australia's mean temperature has increased by about 1.5–1.6 °C, with marked increases in the frequency and intensity of heat extremes (Grose et al. 2023; CSIRO & Bureau of Meteorology 2024). At the same time, historical accounts such as Diego de Prado's 1606 report of "great quantities of flies" in the Torres Strait provide some of the earliest European observations of

abundant insect life in Australia. These descriptions were recorded under cooler Little Ice Age conditions. Seen against today's warming trends, this early account highlights that those insects that once flourished in a cooler, more stable climate now have to cope with environments that are significantly hotter and more variable.

For insects, even modest shifts in average temperature can substantially alter developmental rates, reproduction, survival and behaviour. Many species already experience summer temperatures close to their upper thermal limits, so further warming and more frequent heatwaves reduce their thermal safety margins and increase the likelihood of local population collapse. Experimental and theoretical work shows that short, intense heat events can be more damaging than equivalent changes in mean conditions. These brief extremes can push ectothermic insects beyond critical physiological thresholds and alter their interactions with host plants and natural enemies (Harvey et al. 2020; Ma et al. 2015).

In addition to gradual warming, recent years have brought record-breaking anomalies. For example, typical winter maximum temperatures in many parts of Australia have historically been around 18 °C. However, in August 2024, some regions recorded winter maxima of up to 29 °C, roughly 11 °C above the long-term average (The Guardian 2024). In addition, the 2024–25 financial year was Australia's warmest on

record, being with the nationally averaged mean temperature 1.68 °C above the 1961–1990 baseline (Bureau of Meteorology 2025). In winter 2025, national mean temperatures remained about 0.5 °C above the long-term average, even though it was the second coolest winter of the decade. Such anomalies

disrupt seasonal cues that insects use to time emergence, mating and migration, leading to mismatches with host plants, predators and mutualists. As climate variability increases, insects must cope with both a shifted mean climate and more frequent extremes (Figure 1).

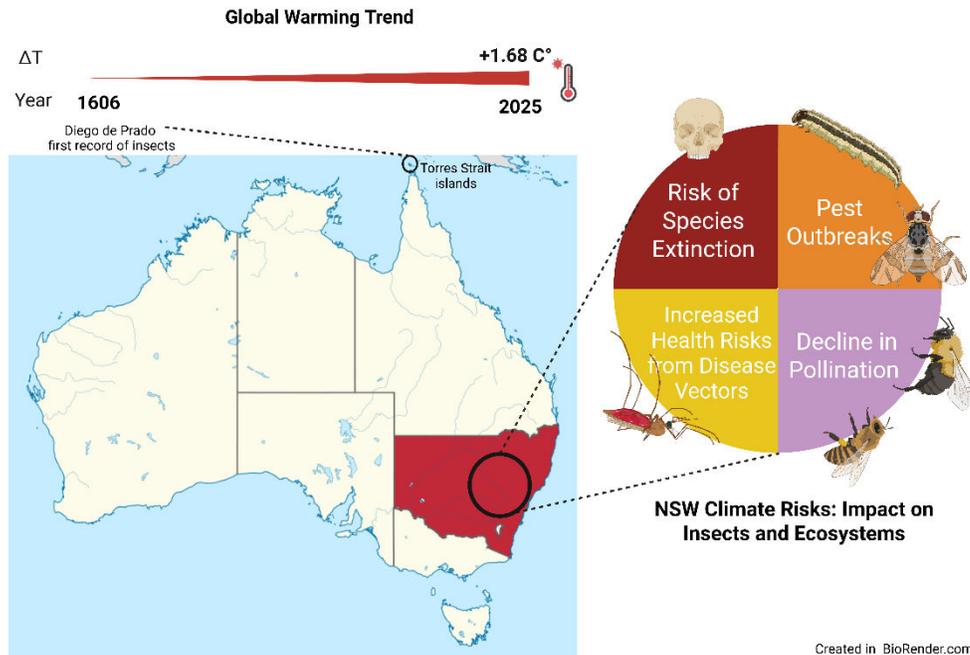


Figure 1. Global warming trends and their impacts on insect populations and ecosystems in New South Wales, Australia. Created in BioRender.com

FALLING OUT OF SYNC: CLIMATE CHANGE AND INSECT SURVIVAL

Extinction risk for plants and animals is escalating in many parts of the world as climate change and habitat loss intensify. In New South Wales (NSW), 1,043 plant and animal species and 115 ecological communities are listed as threatened, and 78 species are already presumed extinct (NSW Environment Protection Authority 2021). Among these, insects are both under-described and under-monitored, yet they are integral to the functioning of virtually all NSW ecosystems. Similar patterns are emerging globally, where climate change and land-use intensification interact to drive changes in insect abundance, richness and community composition across multiple biomes (Outhwaite et al. 2022; Harvey et al. 2023).

The Bogong Moth (*Agrotis infusa*) provides a well-known example of a climate-sensitive migratory insect. This temperate noctuid undertakes long-distance migrations exceeding 1,000 km to aestivate in cool caves and boulderfields of the Australian Alps during summer (Green et al. 2021). Historically, these migrations were so abundant that Aboriginal communities held large gatherings in the alpine region to harvest Bogong Moths as a seasonal resource. This practice is now documented archaeologically at Cloggs Cave in Victoria (Stephenson et al. 2020). Bogong Moth populations have declined markedly since the 1980s, with severe collapses recorded in 2017–2018 and 2018–2019 (Green et al. 2021). These declines are likely driven by a combination of drought and warming in lowland breeding areas and rising temperatures in alpine aestivation sites (Green et al. 2021). In addition, the 2019–2020 ‘Black Summer’

megafires burned large areas of south-eastern Australia, including parts of the Bogong Moth's range and the distributions of many other invertebrates (Hyman et al. 2020; Marsh et al. 2023). These fires added another pressure to populations already stressed by climate-driven changes in temperature and moisture regimes (Marsh et al. 2023; Dole et al. 2023). The resulting loss of moths has cascading consequences for alpine food webs (Green et al. 2021). The Mountain Pygmy Possum relies on Bogong Moths as a key spring food source after hibernation, and suffers reduced condition and litter survival when moth numbers are low (NSW DCCEEW 2025; Parrott 2024). In some caves once packed with aestivating moths, surveys now record few or no individuals, illustrating the vulnerability of cold-adapted migratory species to rapid warming (Green et al. 2021). As Bogong Moth numbers dwindle, the stability of the alpine food web is compromised, highlighting the fragile existence of cold-adapted species in a warming Australia.

The Giant Dragonfly (*Petalura gigantea*), one of the world's largest dragonflies with wingspans up to 12.5 cm, is another emblematic NSW species under pressure (NSW DCCEEW 2020; NSW EPA 2021). This species occurs in peat swamps, bogs and seepages along the coast and ranges of NSW and south-eastern Queensland (NSW DCCEEW 2020). It is listed as endangered under the NSW Biodiversity Conservation Act 2016 (NSW DCCEEW 2020; NSW TSSC 1998). Its larvae spend six to ten years in fossorial burrows that extend below the water table, feeding on small invertebrates and depending on stable groundwater levels and intact peatland hydrology (Baird 2012; Baird 2014). Urban development, longwall coal mining, altered fire regimes and climate-driven drying and warming threaten these upland swamps, compromising both larval habitat and adult emergence (NSW DCCEEW 2020; Baird 2014; Ware et al. 2014). Because *P. gigantea* belongs to the ancient dragonfly family Petaluridae, whose fossil record extends back to the Jurassic, it represents a "living relic" among modern dragonflies (Ware et al. 2014). Therefore, its decline signals the degradation of specialised wetland habitats that support this lineage (Ware et al. 2014).

The Golden Sun Moth (*Synemon plana*), once more widespread in south-eastern Australia, is now critically endangered (Kutt et al. 2015). This small diurnal moth is largely confined to native grasslands and grassy woodlands and depends on wallaby grasses

(*Austrodanthonia* spp.) as larval hosts (Kutt et al. 2015). Over 99.5% of temperate native grasslands in south-eastern Australia have been destroyed or heavily modified since European settlement, leaving *S. plana* populations highly fragmented (Kirkpatrick et al. 1995; Williams et al. 2015; NSW TSSC 2016). Adults are short-lived, with non-feeding females that rarely fly and rely on stored reserves and local dispersal (Kutt et al. 2015). This limited mobility, combined with habitat loss, invasive grasses, altered fire regimes and climate extremes, restricts recolonisation potential and reduces genetic diversity, further increasing extinction risk (Kutt et al. 2015; NSW TSSC 2016).

Together, these case studies, from alpine caves to upland peat swamps and lowland grasslands, illustrate how climate change compounds existing pressures such as habitat loss, hydrological alteration and invasive species. The result is a systematic erosion of insect diversity across NSW's major biomes.

CLIMATE CHANGE AND THE EXPANSION OF PEST INSECTS

While many specialist insects are declining, some generalist and invasive species are likely to benefit from warming climates and altered land use. This has direct implications for agriculture and horticulture in NSW. For key pests, species distribution models that combine physiological thresholds with climate projections are increasingly being used to map future risk, and these generally predict range expansions and increased voltinism in warmer southern and inland regions of Australia (Sultana et al. 2017, 2020; Simpson et al. 2020).

The fall armyworm (*Spodoptera frugiperda*) is a highly polyphagous lepidopteran pest native to the Americas that has spread across Africa, Asia and, more recently, Australia (CABI 2025; Maino et al. 2021). It was first detected in northern Australia in early 2020 and is now established in multiple states, including parts of NSW (Plant Health Australia 2020; Maino et al. 2021). Warmer conditions allow *S. frugiperda* to complete multiple generations per year and to overwinter in areas that were previously too cold, transforming a seasonal invader into a chronic, year-round threat in some regions (Maino et al. 2021). The species attacks a wide range of crops, including maize, sorghum and rice, and has the potential to cause substantial economic losses to Australian grain and horticultural industries (CABI 2025; Plant Health Australia 2020). National and international planning

efforts, including Australia's Fall Armyworm Industry Contingency Plan for grains and the FAO Global Action for Fall Armyworm Control, emphasise the importance of climate-aware surveillance and integrated pest management in limiting these impacts (Plant Health Australia 2020; FAO 2020).

The Queensland fruit fly (*Bactrocera tryoni*) provides another example of a pest whose distribution and impact are closely linked to climate. Historically, cooler winters limited *B. tryoni* survival and reproduction in temperate regions (Sultana et al. 2017). Rising temperatures and milder winters now enable higher overwintering survival and longer breeding seasons, increasing pressure on fruits such as peaches, plums and cherries (Sultana et al. 2017; Sultana et al. 2020). Infestations already cost Australian horticulture an estimated \$300 million annually (Plant Health Australia 2018). Modelling studies project that suitable habitat, and the number of generations per year for *B. tryoni*, will increase in many southern and inland horticultural regions under future climate scenarios, including parts of NSW (Sultana et al. 2017, 2020; Simpson et al. 2020). In addition, recent changes in distribution and quarantine boundaries show that climate-related shifts in *B. tryoni* range have influenced market access and management zones in eastern Australia (Dominiak & Mapson 2017).

An additional, increasingly important issue for crop production is insect-vectored plant disease. In New South Wales (NSW), Tomato spotted wilt virus (TSWV) is one of the most widespread and damaging viruses of vegetable and ornamental crops and is endemic in the region (Persley et al. 2006; Plant Health Australia 2011; Agriculture Victoria 2021). It is transmitted by a complex of thrips species, including western flower thrips *Frankliniella occidentalis* and onion thrips *Thrips tabaci*, which acquire the virus as larvae and can transmit it throughout their adult lives (Persley et al. 2006; Agriculture Victoria 2021). Because TSWV replicates within its thrips vectors and persists in a wide range of crop and weed hosts, effective management requires simultaneous suppression of vector populations, removal of infected plants and control of alternative hosts; insecticides alone are seldom sufficient once virus–vector cycles are established (Plant Health Australia 2011; Agriculture Victoria 2021). Warmer conditions that favour rapid thrips population growth, together with documented insecticide resistance in some thrips

populations and resistance-breaking TSWV strains in capsicum and other crops, are likely to increase the frequency and severity of outbreaks under climate change (Sharman & Persley 2006; Chen et al. 2021).

These trends highlight a key duality of climate change for insects: while many native specialists are pushed towards the margins of their climatic niches, mobile, generalist and invasive species can exploit new opportunities, often at significant economic cost.

POLLINATION UNDER PRESSURE

Beyond their roles as pests or threatened species, insects underpin agricultural production through pollination services. Bees, including managed European honey bees and diverse native bee species, are critical pollinators of crops such as almonds, apples, blueberries and many other horticultural species in Australia (Cunningham et al. 2013; Rader et al. 2016). Native stingless bees such as *Tetragonula carbonaria* are increasingly managed as pollinators of macadamia, mango and other fruit crops in eastern Australia, highlighting the importance of native insects for crop production (Heard 2016; Cunningham et al. 2013). A substantial proportion of Australia's agricultural production is dependent, to varying degrees, on insect pollination (Aizen et al. 2009; Cunningham et al. 2013). Reviews of plant–pollinator interactions indicate that global warming is already generating spatial and temporal mismatches between flowering and pollinator activity, with likely consequences for seed set and crop yields (Gérard et al. 2020; Stoddard 2017).

Climate change can disrupt these services via phenological mismatches. Warmer springs may cause bees and other pollinators to emerge earlier, while flowering in crops and native plants may advance at a different rate. When pollinators and flowers are no longer synchronised, the effective window for pollination is shortened, reducing fruit set and yield. Heatwaves can directly impair pollinator performance and flower viability, further reducing pollination efficiency.

In addition, habitat loss and fragmentation, pesticide use and competition from managed honey bees interact with climatic stressors to reduce pollinator abundance and diversity. In Tasmania, the introduced large earth bumblebee *Bombus terrestris* now contributes to pollination of berries and greenhouse crops. However, it invades native vegetation and has the potential to

displace native pollinators and promote invasive weeds, illustrating the trade-offs involved when novel pollinators establish under changing climates (Hingston & McQuillan 1999; NSW Scientific Committee 2010). For Australian agriculture, maintaining resilient pollination networks under climate change will require integrated approaches that conserve nesting and floral resources, reduce chemical pressures and incorporate climate adaptation into orchard and crop management.

MOSQUITO-BORNE DISEASE IN A WARMING WORLD

Insects affect human wellbeing worldwide through their roles as vectors of disease. Across Australia, mosquitoes transmit pathogens such as Ross River virus (RRV) and Barmah Forest virus, which cause febrile illness with rash and often debilitating polyarthritis (Webb 2020; Hime et al. 2022). In New South Wales (NSW), these viruses are major causes of locally acquired arboviral disease, with roughly 700 notified cases of RRV each year and larger outbreaks in some years linked to climatic and environmental conditions (Webb 2020; Qian et al. 2020; Hime et al. 2022). Temperature strongly shapes RRV transmission potential, with risk peaking at intermediate temperatures typical of many temperate and subtropical regions (Shocket et al. 2018). In coastal and inland NSW, RRV and Barmah Forest virus are transmitted mainly by the saltmarsh mosquito *Aedes (Ochlerotatus) vigilax* and the common banded mosquito *Culex annulirostris*, with *Aedes (Ochlerotatus) camptorhynchus* contributing in southern estuarine habitats (Webb 2020; Shocket et al. 2018; Hime et al. 2022).

Warming temperatures and altered rainfall patterns are likely to extend the seasonal window of mosquito activity and increase the frequency of favourable breeding conditions, particularly in peri-urban wetlands, floodplains and container habitats. Warmer conditions can shorten mosquito development times and increase biting rates, while changes in rainfall and extreme events such as floods can create or expand larval habitats. Recent analyses of NSW and neighbouring jurisdictions show that RRV and Barmah Forest virus notifications often increase following periods of heavy rainfall and flooding, underscoring the importance of weather extremes for arboviral risk (Hime et al. 2022; Qian et al. 2020).

Extreme events interact with these dynamics. Flooding can generate extensive breeding sites, whereas bushfires can alter wildlife distributions and bring reservoir hosts and humans into closer contact. Following the 2019–2020 bushfires, for example, NSW experienced an unusual combination of fire, smoke, COVID-19 restrictions and increased RRV activity (Webb 2020). Such compound events complicate disease prediction and control, placing additional demands on public health systems.

As climates continue to warm, medical entomology will become increasingly important for surveillance, early warning and integrated mosquito management. Understanding how temperature, rainfall and land-use interact to shape mosquito populations will be critical for anticipating future disease risk in NSW.

A SHARED FUTURE IN A CHANGING WORLD

Insects perform a wide spectrum of functions—pollinating native plants and crops, decomposing organic matter, regulating pest populations and supporting the diets of birds, mammals and reptiles (Prather et al. 2013). Their responses to climate change—whether decline, range shift or population explosion—will reverberate across ecosystems, economies and public health.

From an entomological perspective, global warming is not only an environmental issue but also a complex biological and societal challenge. Conservation of threatened insect species, management of emerging and expanding pests, and surveillance of vector-borne diseases all depend on a clear understanding of how insects experience and respond to a rapidly changing climate.

Practical actions such as preserving and restoring native vegetation, reducing chemical inputs, managing water resources, and mitigating greenhouse gas emissions can help buffer insect communities and the services they provide. For entomologists, documenting insect responses, informing policy and fostering collaboration between conservation, agriculture and public health sectors will be essential to safeguard both insect biodiversity and human wellbeing in a warming world.

ACKNOWLEDGEMENTS

I thank the editor and the two anonymous reviewers for their constructive comments, which improved this manuscript. I also thank the Entomological Society of New South Wales for selecting an earlier version of this article, “Global Warming: Have You Ever Put Yourself in an Insect’s Shoes?”, as Runner-Up in the 2024 Ted Taylor Award and for their support.

REFERENCES

- Agriculture Victoria (2021). Tomato spotted wilt virus in potatoes. State of Victoria, Department of Jobs, Precincts and Regions, Melbourne. (accessed 8 Dec 2025) Available at: <https://agriculture.vic.gov.au/biosecurity/plant-diseases/vegetable-diseases/tomato-spotted-wilt-virus-in-potatoes>
- Aizen, M.A., Garibaldi, L.A., Cunningham, S.A. & Klein, A.M. (2009). How much does agriculture depend on pollinators? Lessons from long-term trends in crop production. *Annals of Botany* **103**: 1579–1588.
- Baird, I.R.C. (2012). The wetland habitats, biogeography and population dynamics of *Petalura gigantea* (Odonata: Petaluridae) in the Blue Mountains of New South Wales. PhD thesis, University of Western Sydney. <http://handle.uws.edu.au:8081/1959.7/509925>
- Baird, I.R.C. (2014). Larval burrow morphology and groundwater dependence in a mire-dwelling dragonfly, *Petalura gigantea* (Odonata: Petaluridae). *International Journal of Odonatology* **17**: 101–121. <https://doi.org/10.1080/13887890.2014.932312>
- Bureau of Meteorology (2025). Financial year climate and water statement 2024–25. Bureau of Meteorology, Canberra. (accessed 8 Dec 2025) Available at: <https://www.bom.gov.au/climate/current/financial-year/aus/summary.shtml>
- CABI (2025). *Spodoptera frugiperda* (fall armyworm) – Invasive Species Compendium datasheet. CABI, Wallingford, UK. (accessed 8 Dec 2025) Available at: <https://doi.org/10.1079/cabicompendium.29810>
- Chen, Y., Nguyen, D.T., Gupta, R. & Herron, G.A. (2021). Mutation (G275E) of nAChR subunit Foa6 associated with spinetoram resistance in Australian western flower thrips, *Frankliniella occidentalis* (Pergande). *Molecular Biology Reports* **48**(4): 3155–3163. <https://doi.org/10.1007/s11033-021-06372-3>
- CSIRO & Bureau of Meteorology (2024). State of the Climate 2024. CSIRO and BoM, Australia. (accessed 8 Dec 2025) Available at: <https://www.csiro.au/state-of-the-climate>
- Cunningham, S.A., FitzGibbon, F. & Heard, T.A. (2013). The future of pollinators for Australian agriculture. *Crop and Pasture Science* **64**: 489–499. <https://doi.org/10.1071/AR01186>
- Dole, H.E., Villamarín-Cortez, S. & Richards, L.A. (2023). Facing the flames: insect responses to megafires and changing fire regimes. *Current Opinion in Insect Science* **60**: 101129. <https://doi.org/10.1016/j.cois.2023.101129>
- Dominiak, B.C. & Mapson, R. (2017). Revised distribution of *Bactrocera tryoni* in eastern Australia and effect on possible incursions of Mediterranean fruit fly: Development of Australia’s Eastern Trading Block. *Journal of Economic Entomology* **110**: 2459–2465. <https://doi.org/10.1093/jee/tox237>
- Food and Agriculture Organization of the United Nations (FAO) (2020). Global action for fall armyworm control: 2020–2022. FAO, Rome. (accessed 8 Dec 2025) Available at: <https://doi.org/10.4060/ca9252en>
- Gérard, M., Vanderplanck, M., Wood, T.J. & Michez, D. (2020). Global warming and plant–pollinator mismatches. *Emerging Topics in Life Sciences* **4**(1): 77–86. <https://doi.org/10.1042/ETLS20190139>
- Green, K., Caley, P., Baker, M., Dreyer, D., Wallace, J. & Warrant, E. (2021). Australian Bogong moths *Agrotis infusa* (Lepidoptera: Noctuidae), 1951–2020: decline and crash. *Austral Entomology* **60**(1): 66–81. <https://doi.org/10.1111/aen.12517>
- Grose, M.R., Boschat, G., Trewin, B., Round, V., Ashcroft, L., King, A.D., Narsey, S. & Hawkins, E. (2023). Australian climate warming: Observed change from 1850 and global temperature targets. *Journal of Southern Hemisphere Earth Systems Science* **73**(1): 30–43. <https://doi.org/10.1071/ES22018>
- Harvey, J.A., Heinen, R., Gols, R. & Thakur, M.P. (2020). Climate change-mediated temperature extremes and insects: From outbreaks to breakdowns. *Global Change Biology* **26**(12): 6685–6701. <https://doi.org/10.1111/gcb.15377>
- Harvey, J.A., Heinen, R., Gols, R., Bezemer, T.M., de Boer, J.G. et al. (2023). Scientists’ warning on climate change and insects. *Ecological Monographs* **93**(1): e1575. <https://doi.org/10.1002/ecm.1553>
- Heard, T.A. (2016). *The Australian Native Bee Book: Keeping Stingless Bee Hives for Pollination and Honey*. Sugarbag Bees, Brisbane, Australia.
- Hime, N.J., Huete, A., Vardoulakis, S., McBride, J., Sisson, S.A., Codde, J., Makate, M., Hanigan, I.C. & Bi, P. (2022). Weather extremes associated with increased Ross River virus and Barmah Forest virus notifications in NSW: Learnings for public health response. *Australian and New Zealand Journal of Public Health* **46**(6): 654–661. <https://doi.org/10.1111/1753-6405.13283>
- Hingston, A.B. & McQuillan, P.B. (1999). Displacement of Tasmanian native megachilid bees by the recently introduced bumblebee *Bombus terrestris* (Linnaeus, 1758) (Hymenoptera: Apidae). *Australian Journal of Zoology* **47**: 59–65. <https://doi.org/10.1071/ZO98016>
- Hyman, I., Ah Yong, S.T., Köhler, F., McEvey, S.F., Milledge, G.A., Reid, C.A.M. & Rowley, J.J.L. (2020). Impacts of the 2019–2020 bushfires on New South Wales biodiversity: A rapid assessment of distribution data for selected invertebrate taxa. *Technical Reports of the Australian Museum* **32**: 1–17. <https://doi.org/10.3853/j.1835-4211.32.2020.1768>
- Kirkpatrick, J.B., McDougall, K. & Hyde, M. (1995). *Australia’s Most Threatened Ecosystem: The Southeastern Lowland Native Grasslands*. Surrey Beatty & Sons in association with the World Wide Fund for Nature Australia, Chipping Norton, NSW.
- Kutt, A.S., McKenzie, V.J., Wills, T.J., Retallick, R.W.R., Dalton, K., Kay, N. & Melero-Blanca, E. (2015). Spatial and temporal determinants of golden sun moth *Synemon plana* distribution. *Austral Ecology* **40**(1): 100–107. <https://doi.org/10.1111/aec.12181>
- Ma, G., Hoffmann, A.A. & Ma, C.-S. (2015). Daily temperature extremes play an important role in predicting thermal effects. *Journal of Experimental Biology* **218**(14): 2289–2296. <https://doi.org/10.1242/jeb.122127>
- Maino, J.L., Schouten, R., Overton, K., Day, R., Ekesi, S., Bett, B. & Kriticos, D.J. (2021). Regional and seasonal activity predictions for fall armyworm in Australia. *Pest Management Science* **77**: 2350–2363. <https://doi.org/10.1016/j.cris.2021.100010>
- Marsh, J.R., Bal, P., Fraser, H., Greenville, A., Latty, T., Moir, M.L., Rumpff, L., Umbers, K. & Woinarski, J.C.Z. (2023). Impacts of the 2019–20 wildfires on Australian invertebrates. In: van Leeuwen, S., Wintle, B.A., Woinarski, J.C.Z., Rumpff, L. &

- Legge, S.M. (eds), *Australia's Megafires: Biodiversity Impacts and Lessons from 2019–2020*, pp. 141–153. CSIRO Publishing, Collingwood.
- NSW Department of Climate Change, Energy, the Environment and Water (NSW DCCEEW) (2020). Giant dragonfly (*Petalura gigantea*) – Saving our Species fact sheet. NSW Government, Sydney. (accessed 8 Dec 2025). Available at: <https://www.environment.nsw.gov.au/publications/giant-dragonfly-petalura-gigantea>
- NSW Department of Climate Change, Energy, the Environment and Water (NSW DCCEEW) (2025). Mountain Pygmy-possum (*Burrhamys parvus*) – threatened species profile. NSW Government, Sydney. (accessed 8 Dec 2025) Available at: <https://threatenedspecies.bionet.nsw.gov.au/profile?id=10114>
- NSW Environment Protection Authority (NSW EPA) (2021). New South Wales State of the Environment 2021. Environment Protection Authority, Sydney. (accessed 8 Dec 2025) Available at: https://www.soe.epa.nsw.gov.au/sites/default/files/2022-02/21p3448-nsw-state-of-the-environment-2021_0.pdf
- NSW Scientific Committee (2010). Invasion of native plant communities by the large earth bumblebee (*Bombus terrestris*) – Key Threatening Process listing. NSW Office of Environment and Heritage, Sydney. (accessed 8 Dec 2025) Available at: <https://www.environment.nsw.gov.au/topics/animals-and-plants/threatened-species/nsw-threatened-species-scientific-committee/determinations/final-determinations/2004-2007/introduction-of-the-large-earth-bumblebee-bombus-terrestris-key-threatening-process-listing>
- NSW Threatened Species Scientific Committee (NSW TSSC) (1998). Giant Dragonfly (*Petalura gigantea*) – endangered species listing. Final Determination. NSW National Parks and Wildlife Service, Hurstville. (accessed 8 Dec 2025) Available at: <https://www.environment.nsw.gov.au/topics/animals-and-plants/threatened-species/nsw-threatened-species-scientific-committee/determinations/final-determinations/1996-1999/giant-dragonfly-petalura-gigantea-endangered-species-listing>
- NSW Threatened Species Scientific Committee (NSW TSSC) (2016). *Synemon plana* – A Review of the Conservation Status of the Golden Sun Moth. Final Determination. NSW Office of Environment and Heritage, Sydney. (accessed 8 Dec 2025) Available at: <https://www.environment.nsw.gov.au/topics/animals-and-plants/threatened-species/nsw-threatened-species-scientific-committee/determinations/final-determinations/2022/synemon-plana>
- Outhwaite, C.L., McCann, P. & Newbold, T. (2022). Agriculture and climate change are reshaping insect biodiversity worldwide. *Nature* **605**: 97–102. <https://doi.org/10.1038/s41586-022-04644-x>
- Parrott, M.L. (2024). Moth Tracker: citizen science to help the Bogong Moth and Mountain Pygmy-possum. Science Victoria (Royal Society of Victoria). (accessed 8 Dec 2025) Available at: <https://www.rsv.org.au/articles/moth-tracker>
- Persley, D.M., Thomas, J.E. & Sharman, M. (2006). Tospoviruses – an Australian perspective. *Australasian Plant Pathology* **35**(2): 161–180. <https://doi.org/10.1071/AP06015>
- Plant Health Australia & Nursery & Garden Industry Australia (2011). Industry Biosecurity Plan for the Nursery and Garden Industry: Threat-specific Contingency Plan – Thrips Transmitted Viruses. Plant Health Australia, Canberra. (accessed 8 Dec 2025) Available at: <https://nurseryproductionfms.com.au/wp-content/uploads/download-manager-files/Pest-Contingency-Plan-Thrips-transmitted-viruses-2011.pdf>
- Plant Health Australia (2018). *The Australian Handbook for the Identification of Fruit Flies*. Version 3.1. Plant Health Australia, Canberra. (accessed 8 Dec 2025) Available at: <https://www.fruitflyidentification.org.au/wp-content/uploads/2018/10/The-Australian-Handbook-for-the-Identification-of-Fruit-Flies-v3.1.pdf>
- Plant Health Australia (2020). Fall Armyworm Continuity Plan for the Australian Grains Industry. Version 1 (November 2020). Plant Health Australia, Canberra. (accessed 8 Dec 2025) Available at: <https://www.planthealthaustralia.com.au/wp-content/uploads/2024/01/Fall-Armworm-Continuity-Plan-2-1.pdf>
- Prather, C.M., Pelini, S.L., Laws, A., Rivest, E., Woltz, M., Bloch, C.P., Del Toro, I., Ho, C.-K., Kominoski, J., Scott Newbold, T., Parsons, S. & Joern, A. (2013). Invertebrates, ecosystem services and climate change. *Biological Reviews* **88**(2): 327–348. <https://doi.org/10.1111/brv.12002>
- Qian, W., Viennet, E., Glass, K. & Harley, D. (2020). Epidemiological models for predicting Ross River virus in Australia: A systematic review. *PLoS Neglected Tropical Diseases* **14**(9): e0008621. <https://doi.org/10.1371/journal.pntd.0008621>
- Rader, R., Howlett, B.G., Cunningham, S.A., Westcott, D.A., Newstrom-Lloyd, L., Walker, M., Teulon, D.A.J. & Edwards, W. (2016). Non-bee insects are important contributors to global crop pollination. *Proceedings of the National Academy of Sciences USA* **113**: 146–151. <https://doi.org/10.1073/pnas.1517092112>
- Sharman, M. & Persley, D.M. (2006). Field isolates of Tomato spotted wilt virus overcoming resistance in capsicum in Australia. *Australasian Plant Pathology* **35**(2): 123–128. <https://doi.org/10.1071/AP06014>
- Shocket, M.S., Ryan, S.J. & Mordecai, E.A. (2018). Temperature explains broad patterns of Ross River virus transmission potential. *eLife* **7**: e37762. <https://doi.org/10.7554/eLife.37762>
- Simpson, M., Reynolds, O.L., McGowen, M.R., Rice, S.J. & Dominiak, B.C. (2020). Bioclimatic niche modelling projects a potential shift in the distribution of Queensland fruit fly, *Bactrocera tryoni* (Froggatt), in response to climate change. *General and Applied Entomology* **48**: 61–74.
- Stephenson, B., Garvey, J., Delannoy, J.-J., Fairbairn, A. & Marshall, L. (2020). 2000 year-old Bogong moth (*Agrotis infusa*) Aboriginal food remains, Australia. *Scientific Reports* **10**: 21746. <https://doi.org/10.1038/s41598-020-79307-w>
- Stoddard, F.L. (2017). Climate change can affect crop pollination in unexpected ways. *Journal of Experimental Botany* **68**: 1819–1821. <https://doi.org/10.1093/jxb/erx075>
- Sultana, S., Baumgartner, J.B., Dominiak, B.C., Royer, J.E. & Beaumont, L.J. (2017). Potential impacts of climate change on habitat suitability for the Queensland fruit fly. *Scientific Reports* **7**: 13025. <https://doi.org/10.1038/s41598-017-13307-1>
- Sultana, S., Baumgartner, J.B., Dominiak, B.C., Royer, J.E. & Beaumont, L.J. (2020). Impacts of climate change on high priority fruit fly species in Australia. *PLoS ONE* **15**(2): e0213820. <https://doi.org/10.1371/journal.pone.0213820>
- The Guardian (2024, 26 August). Winter heat records broken as Australia set for more temperatures over 10°C above average. (accessed 8 Dec 2025) Available at: <https://www.theguardian.com/australia-news/article/2024/aug/26/winter-heat-records-broken-as-australia-set-for-more-temperatures-over-10c-above-average>
- Ware, J.L., Beatty, C.D., Sánchez Herrera, M., Valley, S., Johnson, J., Kerst, C. et al. (2014). The petaltail dragonflies (Odonata: Petaluridae): Mesozoic habitat specialists that survive to the

- modern day. *Journal of Biogeography* **41**: 1291–1300.
<https://doi.org/10.1111/jbi.12273>
- Webb, C.E. (2020). Reflections on a highly unusual summer: Bushfires, COVID-19 and mosquito-borne disease in NSW, Australia. *Public Health Research & Practice* 30(4): 3042027.
<https://doi.org/10.17061/phrp3042027>
- Williams, N.S.G., Marshall, A. & Morgan, J.W. (eds) (2015). *Land of Sweeping Plains: Managing and Restoring the Native Grasslands of South-Eastern Australia*. CSIRO Publishing, Clayton South, Victoria.

*Submitted 28/11/2025. Accepted
, 8/12/2025.*