Functional Ecology

British Ecological Society

Functional Ecology 2016, **30**, 1028–1029 doi: 10.1111/1365-2435.12678

FE SPOTLIGHT

Current and future challenges of predictive insect population modelling

Sharon Bewick*

Biology, University of Maryland, 20742 College Park, Maryland, USA

Like the plot of a one-star horror movie, bug swarms, bug invasions and bug outbreaks have dominated recent headlines. Last year alone, insects shut down a bridge in Pennsylvania (WorldNetDaily News, 2015), gathered in a 50-mile-wide swarm over Texas (Arciero 2015) and created such an infestation at Burning Man Festival that organizers suggested '[nuking] the city' (White 2015). From coast to coast, no one was spared – and everyone had a (different) explanation. Perhaps spring and summer rains stimulated an unprecedented bug hatch. Or maybe it was last year's mild winter that resulted in high bug survival. Increasing bug populations might be a sign of an improving environment. On the other hand, population explosions could be part of a natural boom/bust cycle. While these are all good guesses, the truth is that we do not always know what drives population dynamics. This not only makes it challenging to explain the sudden appearance of a hoard of Hemiptera at an outdoor arts festival, but also impedes our ability to predict how and when insect populations might respond to environmental perturbations, including global change.

Three of the most significant factors known to influence insect populations are temperature (including seasonal, day-to-day and multidecadal trends), intraspecific competition and interspecific interactions. Temperature alters the timing, duration and abundance of different insect life stages through its effect on development, fecundity and mortality (Bale *et al.* 2002). Intraspecific competition influences access to food or other limited resources and can lead to interesting density-dependent dynamics, including multiyear boom/bust cycles or even chaos (Klomp 1964). Interspecific interactions influence insect demography through a range of processes, including additional competition, plant–insect effects, predator–prey interactions, host–pathogen interactions and even parasitoid–host effects (Crawley 1983). Individually, the roles of temperature, competition and interspecific interactions have been studied both empirically and theoretically as determinants of insect population dynamics (Shelford 1927; Hassell 1975; Abbott & Dwyer 2007). Despite this, few studies have considered more than one of these factors simultaneously, limiting our understanding of how different drivers combine to create variation in abundance of insect populations in the field.

Recently, efforts to understand and predict insect population dynamics have taken on a new direction and a new urgency. Specifically, in the context of global change, we are now faced with a world where prediction of insect population dynamics is becoming necessary for everything from conservation (McLaughlin *et al.* 2002) to food security (Gregory *et al.* 2009) and protection against disease (Sutherst 2004). In response to the ongoing threat of climate warming, a number of studies have extended models of both insect temperature dependence (degree-day models) (Powell & Logan 2005) and species interactions (Abbott & Dwyer 2007) to forecast future trends in pest and endangered (Gregory *et al.* 2009) insect populations. Unfortunately, most of these approaches continue to focus on single drivers of population dynamics. Thus, while they are useful for understanding the independent contributions of altered species interactions (Fagan *et al.* 2014), altered competition (Bewick *et al.* 2016) or altered temperature regimes (Zipkin *et al.* 2012), they fail to be fully predictive because they do not consider combined effects. This is particularly problematic in the context of climate change, because many of the common drivers of insect population dynamics are likely to be perturbed independently and to different extents in response to global warming.

In a recent issue of *Functional Ecology*, Johnson *et al.* (2015) take an important step towards developing fully predictive models of insect population dynamics by combining degree-day models with sophisticated descriptions of intra- and interspecific interactions. They then use this approach to predict complex seasonal changes in a bordered plant bug population. Bordered plants bugs are an ideal system, because this species exhibits an unusual abundance pattern where adults are prevalent during summer and fall, but are nearly absent in late spring and late summer. Johnson *et al.* (2015) show that no single factor can independently predict these dynamics over the course of a year. Considering only density dependence, for example, bordered plant bugs are predicted to exhibit a steady-state population size. Considering density dependence and seasonal temperature variation, fluctuations are observed in the plant bug population; however, predicted adult density is greatest during the spring and early summer, which

*Correspondence author. E-mail: sharon_bewick@hotmail.com

does not match trends observed in the field. Considering density dependence and seasonal resource variation gives a closer match to field data, but greatly underestimates bug abundances, resulting in bug extinction over the course of several years. Only when density dependence, seasonal resource variation and seasonal temperature variation are considered simultaneously, do the authors accurately recapitulate observed seasonal changes in plant bug abundance. These results clearly demonstrate the need for considering multiple factors when attempting to predict insect population dynamics.

The novel and comprehensive approach taken by Johnson *et al*. (2015) should serve as a template for future studies of insect populations, both under current conditions and in the context of global change. Attempts to predict future population dynamics of pest or endangered species should not, for example, rely on degree-day models alone. Instead, models should incorporate phenology information for insect food resources and insect predators/parasitoids. This could involve use of data from phenology databases, or webcam or satellite NDVI green-up data. Likewise, it could involve multilevel degree-day models where insect prey/predators/parasitoids are, themselves, subject to changing seasonal abundances in response to changing seasonal temperatures. Regardless of the approach, transitioning from single factor analyses to multifactor analyses is a necessary next step in predictive insect population dynamics modelling. Although we are currently just beginning this fruitful avenue of research, the likely benefits are great. Increased ability to predict insect population dynamics will allow us to better define regional differences in vector-borne disease risk, predict years where certain crop pests may be problematic and identify species at risk of population decline or extinction. Indeed, improved prediction of insect population dynamics could even benefit the organizers of Burning Man, who are no doubt wondering whether or not to prepare for an onslaught of uninvited, six-legged guests at their 2016 festival.

References

Abbott, K.C. & Dwyer, G. (2007) Food limitation and insect outbreaks: complex dynamics in plant–herbivore models. *Journal of Animal Ecology*, **76**, 1004–1014.

Arciero, R. (2015) 50 mile bug swarm: Texas nightmare? examiner.com. Available from: http://www.examiner.com/article/50-mile-bug-swarm-texas-nightmare-huge-swarm-of-grasshoppers-located-by-radar.

Bale, J.S., Masters, G.J., Hodkinson, I.D., Awmack, C., Bezemer, T.M., Brown, V.K. *et al*. (2002) Herbivory in global climate change research: direct effects of rising temperature on insect herbivores. *Global Change Biology*, **8**, 1–16.

Bewick, S., Cantrell, R.S., Cosner, C., Fagan, W.F., Gross, K. & Day, T. (2016) How resource phenology affects consumer population dynamics. *The American Naturalist*, **187**, 151–166.

Crawley, M.J. (1983) *Herbivory. The Dynamics of Animal–Plant Interactions*. Blackwell Scientific Publications, Oxford, UK.

Fagan, W.F., Bewick, S., Cantrell, S., Cosner, C., Varassin, I.G. & Inouye, D.W. (2014) Phenologically explicit models for studying plant–pollinator interactions under climate change. *Theoretical Ecology*, **7**, 289–297.

Gregory, P.J., Johnson, S.N., Newton, A.C. & Ingram, J.S. (2009) Integrating pests and pathogens into the climate change/food security debate. *Journal of Experimental Botany*, **60**, 2827–2838.

Hassell, M.P. (1975) Density-dependence in single-species populations. *The Journal of Animal Ecology*, **44**, 283–295.

Johnson, C.A., Coutinho, R.M., Berlin, E., Dolphin, K.E., Heyer, J., Kim, B. *et al*. (2015) Effects of temperature and resource variation on insect population dynamics: the bordered plant bug as a case study. *Functional Ecology*, **30**, 1122–1131.

Klomp, H. (1964) Intraspecific competition and the regulation of insect numbers. *Annual Review of Entomology*, **9**, 17–40.

McLaughlin, J.F., Hellmann, J.J., Boggs, C.L. & Ehrlich, P.R. (2002) Climate change hastens population extinctions. *Proceedings of the National Academy of Sciences of the United States of America*, **99**, 6070–6074.

Powell, J.A. & Logan, J.A. (2005) Insect seasonality: circle map analysis of temperature-driven life cycles. *Theoretical Population Biology*, **67**, 161–179.

Shelford, V.E. (1927) An experimental investigation of the relations of the codling moth to weather and climate. *Illinois Natural History Survey Bulletin*, **016**, 311–437.

Sutherst, R.W. (2004) Global change and human vulnerability to vector-borne diseases. *Clinical Microbiology Reviews*, **17**, 136–173.

White, D. (2015) Swarms of Giant Bugs Infest Burning Man Festival TIME. Available from: http://time.com/4004824/burning-man-bugs/.

WorldNetDaily News (2015) Swarms of bugs close Pennsylvania bridge. Available from: http://www.wnd.com/2015/06/swarms-of-bugs-close-pennsylvania-bridge/.

Zipkin, E.F., Ries, L., Reeves, R., Regetz, J. & Oberhauser, K.S. (2012) Tracking climate impacts on the migratory monarch butterfly. *Global Change Biology*, **18**, 3039–3049.