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From species distributions to climate change adaptation: Knowledge gaps in managing invertebrate pests in broad-acre grain crops

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ABSTRACT

Extensive research has shown that climate change will impact the distribution and outbreak potential of invertebrate pests in broad-acre crops. However, much less attention has been placed on translating these likely changes in pest outbreak frequency into practical management options for growers. Dryland grain production systems are generally predicted to be vulnerable to the effects of climate change. An initial step in understanding changes to outbreak potential of different pests is to describe the spatial distribution of different species and communities. Using a bioclimatic modelling approach, we demonstrate how general patterns of distribution for four major invertebrate pests of Australian dryland grain production systems are likely to be altered by climate change. While such models are useful for predicting the direct impacts of climate change on potential species distributions, they are less useful for assessing pest outbreak frequency from direct or indirect changes. In light of this, we explore different tools that can be used to support adaptive management by farmers to limit the impact of induced pest outbreaks. Primarily, research to increase available information of indirect impacts on the pest species and the communities they interact with, including their natural enemies, is required to extend models of pest outbreak potential. Further, incorporation of pests into global crop models combined with monitoring for existing pests and surveillance for new pests is critical for future pest management decision-making. For natural enemies, generalizations around the impact of climate change and flow on effects for pest control services need to be attempted now. The knowledge of potential management interventions is needed by farmers to support improved management decisions in the short-term, but in some cases will also facilitate adaption to climate change in the long-term.

1. Introduction

Pest outbreaks in agricultural landscapes are driven by a combination of factors including seasonal pest biology, synchrony of host plant resources in the landscape, asynchrony of natural enemy species that otherwise limit population growth, and management actions that inadvertently facilitate population growth and movement (Letourneau, 2012). These factors are all influenced by climate to some extent. Increases in temperature, greenhouse gases (especially CO_2), and rainfall patterns as a result of global climate change will undoubtedly continue to exacerbate some pest problems in grain crops, and alleviate others. However, the development of management options for farmers to mitigate or adapt to these risks appears slow.

Invertebrates are especially sensitive to climate conditions, and parameters such as temperature, rainfall, relative humidity and soil moisture have proved useful for predicting important events in the growth of pest populations (e.g. Chen et al., 2014; Klapwijk et al., 2012). Changing pest profiles in southern Australia (Hoffmann et al., 2008), earlier spring flights in aphids across Europe (Hulle et al., 2010), destabilization of the outbreak cycles of the multivoltine tea tortrix moth in Japan (*Adoxophyes honmai*) (Nelson et al., 2013), and earlier arrival across the United States of America (USA) of the potato leafhopper, (*Empoasca fabae*) (advanced by 10 days over the last 62 years) especially in warmer years (Baker et al., 2015) have all been attributed to climate change. In practice, determining whether such changes are solely driven by climate is challenging, and examples with unequivocal evidence of changes to agricultural pest outbreaks driven solely by climate change are rare. This is because pest outbreaks are typically due to interactions between biotic and abiotic factors (including climate) and management choices (Ali et al., 2014; Li et al., 2015). For

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example, pesticide applications are often applied prophylactically across large areas, so climate induced shifts in abundance and distribution may be obscured (Hoffmann et al., 2008). Ewald et al. (2015) used a 42-year data set to examine historical changes in abundances of a range of invertebrate groups in cereal fields. Whilst some long-term trends in abundance were correlated with temperature and rainfall, pesticide-use was more important in explaining patterns in abundance. We expect that if climate changes lead to an increase in pest outbreaks, farmers may respond by applying more pesticides to minimize the potential of pest damage (Ziska, 2014). It is especially hard to predict the consequences of changes in multiple factors at once (Rosenblatt and Schmitz, 2014).

Determining the likely impacts of climate change on pest invertebrates, and quantifying the consequences of these impacts, is required to provide advice to farmers regarding adaptive responses. Such responses may include changes to pesticide use, improved pest monitoring technologies, better timing and management of insecticide inputs, changes to crop rotation sequences, changes to tillage and stubble retention practices, through to enterprise-wide alterations to land-use. Some of these responses are inexpensive and represent a shift toward more sustainable pest management practices. Others are costly to implement and have implications for a myriad of other farm business decisions. For example, shifting from one crop type to a different crop type that has a lower susceptibility to pest damage may involve changes to seeding and harvesting equipment, changes to crop rotation practices and changes to buyers and marketing of the grain. Conversely, changing to a different crop variety that allows for earlier or later sowing may require only minimal alterations. It is important to build our capacity to predict the impact of climate change on the likelihood of pest outbreaks as the knowledge-gained through such exercises will aid adaptive management strategies in the future (Sutherst et al., 2011).

Here, we summarise the evidence-base for the potential direct and indirect impacts of climate change on outbreaks of pest species on grain production systems. We use examples from the published literature and models developed for some common pest species in Australia to improve our understanding of the threats posed by existing pest species under future climate change scenarios. The Australian context provides an ideal case study because grain production there is already vulnerable to seasonal rainfall variability along with the added effects of climate change, and the crops are attacked by a range of polyphagous pest species that

Table 1
Examples of studies showing three potential responses of pests to changing climate. Examples from studies of invasive species have been included as a surrogate for climate change impacts as these species may experience new climates in their invasive ranges. Also see Table 7.4 in Reddy, (2015); and Table 2 in Juroszek and von Tiedemann, (2013).

Response group	Species	Details	Citation
Shifting distributions	*Penthaleus* spp. (blue oat mites)	Distributions of the three *Penthaleus* species in Australia are correlated with different climatic variables, suitable climate space likely to decrease in the future. Cryptic species respond differently.	Hill et al. (2012)
	Leptinotarsa decemlineata, Colorado potato beetle, *Ostrinia nubilalis*, European corn borer	The models suggest a widening of the area of suitable habitat for both pests in central Europe.	Kocmankova et al. (2011)
	Diabrotica virgifera virgifera, western corn rootworm	The models showed a northward advancement of the upper physiological limit in the Northern hemisphere, which might lead to increased outbreaks at higher latitudes.	Aragón and Lobo, (2012)
	12 pest fruit fly species (Tephritidae)	Results from distribution models revealed general patterns of poleward movement for the group. For individual species, distribution shifts appear to also be eastward, and at finer scales, varying amounts of species turnover was apparent. These changes in response across different scales present regional management challenges for these species under climate change.	Hill et al. (2016)
Altering phenology	*Leptinotarsa decemlineata*, Colorado potato beetle, *Ostrinia nubilalis*, European corn borer	Models suggest an increase in the number of generations per year. Area of arable land affected by a third generation per season of *L. decemlineata* in 2050 is c. 45% higher, and by a second generation of *O. nubilalis* is nearly 61% higher, compared to present levels.	Kocmankova et al. (2011)
	Cydia pomonella, Codling Moth	Under future conditions of increased temperatures (2045–2074) in Switzerland, the risk of an additional third generation will increase from 0–2% to 100% and there will be a two-week shift in earlier overwintering adult flight. The shifts in phenology and voltinism will require change to plant protection strategies.	Stoeckli et al. (2012)
	13 agriculturally important pest insect species.	Degree-day models were used predict the voltinism of 13 agronomically important pests in California, USA. Under future climate change all species are likely to see an increase in voltinism per year, with different climate change models contributing variance across results.	Ziter et al. (2012)
	Halotydeus destructor (redlegged earth mite)	Models suggest that the temperature cues for post-diapause egg hatch have evolved markedly between the western Australian “Mediterranean” environment (20.5 °C) and the south-eastern Australian (16 °C) more temperate environment.	McDonald et al. (2015)
Adjusting to persist *in situ* (phenotypic plasticity or adaptation)	*Halotydeus destructor* (redlegged earth mite)	Species distribution models indicate that invasive populations of *H. destructor* in Australia have undergone a recent range shift into hotter and drier inland environments since establishing a stable distribution in the 1960s. Experiments measuring physiological traits reported greater thermal tolerance in Australian populations than South African (native).	Hill et al. (2013)
	Zaprionus indianus (African fig fly)	Invasive populations in India display latitudinal clines indicative of rapid adaptive shifts. Traits included in studies were desiccation and starvation tolerance of adults, body weight, wing length and thorax length, and number of ovarioles.	Case study in Gibert et al. (2016)
	Aedes albopictus (Asian tiger mosquito)	Invasive populations in USA from Japan demonstrated rapid adaptive evolution (in 20 years) of the photoperiodic response during invasion and range expansion into higher latitudes. Change in photoperiodism has been an important adaptation to climatic variation across the invasive range.	Urbanski et al. (2012)

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