A REVIEW OF THE POTENTIAL CLIMATE CHANGE IMPACT ON INSECT POPULATIONS – GENERAL AND AGRICULTURAL ASPECTS

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Abstract. Considering insect populations, we can see that climate change affects in many ways: it can cause a shift in geographical spread (Porter et al., 1991; Ward and Masters, 2007), abundance (Ayres and Lombardero, 2000; Olfert and Weiss, 2006) or diversity (Conrad et al., 2002; Feehan et al., 2009; Sharon et al., 2001), it can change the location, the timing and the magnitude of outbreaks of pests (Volney and Fleming, 2000), and it can define the phenological or even the genetic properties of the species (Gordo and Sanz, 2006; Klok and Chown, 2001; Parmesan, 2007). Long-time investigations of special insect populations, simulation models and scenario studies give us very important information about the response of the insects far away and near to our century. Getting to know the potential responses of insect populations to climate change makes us possible to evaluate the adaptation of pest management alternatives as well as to formulate our future management policy.
Keywords: *climate change, insects, pest management, simulation, agriculture*

Introduction

In our century increasing societal, environmental, and economic pressures force us to develop new agricultural pest management strategies (Lima and Berryman, 2006; Lima et al., 2008; 2009). Interdisciplinary approaches have the aim to find the way, how the environmental degradation caused by the use of chemicals can be decreased, how the productivity can be increased by reducing insect and disease damage to cultivated plants, and how the competition with weeds can be reduced. Crop and forestry population system models are useful tools to examine the interrelationships among plants, pests and the environment. With simulation models we can find optimal strategies that meet individual and societal goals (Tang and Cheke, 2008).

Improved techniques for managing pests require weather and insect data from thoroughly maintained monitoring as well as climate information and forecast to determine their suitability. Climatic change, including global warming and increased variability require improved analyses that can be used to assess the risk of the existing and the newly developed pest management strategies and techniques, and to define the impact of these techniques on environment, productivity and profitability (Lee et al., 2009a; 2009b). Each technique has to be evaluated whether and how it is suitable in the farming system where they are to be applied.

Nowadays, several studies are investigating the impact of climatic change on insect populations. Some of the effects can be discovered in laboratories, only (eg. the effect of humidity (Buxton, 2004)), some of them need field observations maintenance (Andrew and Hughes, 2007). The impact of climate change, moreover, alters from region to region, from species to species. Quite a lot of new methods from different disciplines are used to detect the most important effects. Therefore, the studies of climate change effects are considering different aspects, such as palaeontological, agricultural (Spencer et al., 2009), medical (Kearney et al., 2009; Kiritani, 2006; Takken and Knolsm, 2007), geological (Uniyal and Uniyal, 2009), biological as well as the aspects of forestry management. This widespread research work requires interdisciplinary cooperation of researchers from several fields (Hilker and Westerhoff, 2007; Strand, 2000). We give a short review of the main approaches.

The most common methods

Palaeontology

One of the most important ways to find out what climate change can bring us is to look back into the very past. A few thousand years ago some regions were characterized by such kind of vegetations that existed within warming thermal conditions analogous to those today. For example, the transition from parkland vegetation and insects to the one of coniferous forest of south-western Ontario region indicates that the climate continued gradually warm through the mid-Holocene (Schwert et al., 1985).

The Lateglacial-Holocen transition is characterized by major changes in the insect fauna, too, reflecting an extremely rapid climate change in South-Sweden, as well as in Swiss-Alps. In these regions the cold-adapted species assemblage was immediately replaced by temperate species (Lemdahl, 1991; 2000). During the same time period most of temperate species of Chihuahuan Desert (Texas) were replaced either by desert species or more cosmopolitan taxa (Elias and Devender, 1990). The above studies pointed out the dependency of the changes in climate and fauna. The question of how these kinds of responses proceed was studied by (Ammann, 2000).

Models, simulations and scenarios

Developing ecological and simulation models is a very useful tool to find out the response of a system to an event or a series of events (Estay et al., 2009; Gillman, 2009). Ecological or meteorological models describe biological or climate properties mathematically, while simulations make a computer based models system supplied with a great amount of empirical data (Musolin, 2007).

To reach his above mentioned palaeontological results in Swiss-Alps, (Lemdahl, 2000) applied a so-called climatic reconstruction (MCR) method that simulates realistic climate data in the past. Simulated weather data, however, are most commonly used to examine the potential future effects. These approaches are called scenario studies.

The main problems that have to precede scenario studies are, nevertheless, the evaluation, the validation and verification of the applied models. Though several models have been developed e.g. for the carbon budget of boreal forests, enormous problems remain in incorporating pest effects in these models. These problems have their origins, partly in scaling. The common problems of verification and validation of model results

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are particularly troublesome in projecting future productivity (Volney and Fleming, 2000).

A main point of scenario studies is, therefore, how the applied model should be scaled. Hanson and Weltzin (2000) noticed, that although early model predictions of climate change impacts suggested extensive forest dieback and species migration, more recent analyses suggest that catastrophic dieback will be a local phenomenon, and changes in forest composition will be a relatively gradual process. Better climate predictions at regional scales, with a higher temporal resolution (months to days), coupled with carefully designed, field-based experiments that incorporate multiple driving variables (e.g. temperature and CO_2), will advance our ability to predict the response to climate change.

Time-dependent models developed at fine spatial resolution of experimental studies are widely used to forecast how plant – insect populations will react over large spatial extents. Usually the best data available for constructing such models comes from intensive, detailed field studies. Models are then scaled-up to coarser resolution for management decision-making. Scaling-up, however, can affect model predictions and dynamical behaviour which can result misinterpretation of model output. The potential negative consequences of scaling-up deserve consideration whenever data measured at different spatial resolutions are integrated during model development, as often happens in climate change research (Fleming et al., 2002).

Chen et al. (2000) investigate the integrated effects of insect infections, management practices, carbon cycle and climatic factors both at regional and global scales.

To see that there can be great difference between the responses of even similar species, we refer to Conrad et al. (2002). They examined the garden tiger moth (*Arctia caja*) that was widespread and common in the UK in the last century, but its abundance fell rapidly and suddenly after 1984. The most UK butterflies are expected to increase under UK climate change scenarios of global warming. Contrary to them, garden tiger is predicted to decrease further because of warm wet winters and springs, to which it is very sensitive (Conrad et al., 2002).

Ecological models serving climate change studies

We give a short list of the most widely applied ecological models focused to insect populations.

The Forest Vegetation Simulator (FVS) is a distance-independent, geographic region dependent individual-tree forest growth model that has been widely used in the United States for about 30 years to support management decision making. It has been continuously extended, improved and adapted to further management tasks like prediction of climate change effects. Component models predict the growth and mortality of individual trees, and extensions to the base model represent disturbance agents including insects, pathogens, and fire. The geographic regions are represented by regionally specific model variants. The differences are due to data availability and the applicability of existing models. The model supports specification of management rules in the input (Crookston and Dixon, 2005; Dyck, 1999).

The Phenology and PopulatIoN SIM (INSIM) is an age – structured model that needs biological information on the insect species and gives calculations on the number of individuals and the development of the population. It involves a complex pest – natural enemies model, as well (Mols, 1990; 1992).

Agro – ECOsystem ManagemenT and OPtimization Model (ECOTOPE) is a typical simulation model, which describes processes of an agricultural ecosystem for crop growth, nitrogen dynamics in soil and pest population. It is used to derive optimum management strategies (Seppelt, 1999; 2000; 2001).

Boundary LAYER Model (BLAYER) simulates atmospheric flows and it has been adapted to forecast the timing and location of insect pest migrations into the United States corn belt. It is very useful to study the possible changes in pest populations like migration or dispersal patterns resulted by climate change (Paegle and McLawhorn, 1983).

Boll Weevil DISPersal Model (BWDISP) is a stochastic simulation model that predicts the spread of boll weevil populations on cotton. Because the development and dispersal of this insect is sensitive to temperature, it is important to understand how this insect will potentially respond to climate change. In addition, without proper management of this pest, other secondary pests may attack the crop (McKibben et al., 1991).

Northern Corn ROOTWORM Model (ROOTWORM) is a process – oriented simulation model that examines the population dynamics of corn – rootworm in the northern United States. The rootworm attacks both the roots and tassels of corn, decreasing yields. The model examines how planting date affects the population dynamics of the insects. It gives information on phenology and the number of individuals in each growth state of corn. The model can analyse global change impact on the population levels and distribution of the insects, as well as the potential economic impacts (Norango and Sawyer, 1989).

Potential responses of insects to climate change

Climate and weather can substantially influence the development and distribution of insects. Current estimates of changes in climate indicate an increase in global mean annual temperatures of 1°C by 2025 and 3°C by the end of the next century. Such increases in temperature have a number of implications for temperature-dependent insects, especially in the region of Middle-Europe. Changes in climate may result changes in geographical distribution, increased overwintering, changes in population growth rates, increases in the number of generations, extension of the development season, changes in crop-pest synchrony of phenology, changes in interspecific interactions and increased risk of invasion by migrant pests (Memmott et al., 2007; Parmesan, 2007; Porter et al., 1991).

Under the climatic changes projected by the Goddard Institute for Space Studies general circulation model, northward shifts in the potential distribution of the European corn borer of up to 1220 km are estimated to occur, with an additional generation found in nearly all regions where it is currently known to occur (Porter et al., 1991).

Several results on the effect of climate change on insects were published in the field of forestry sciences, since insects cause considerable loss of wood that has an adverse effect on the balance of carbon sequestered by forests. Volney and Fleming (2000) state that pests are major, but consistently overlooked forest ecosystem components that have manifold consequences to the structure and functions of future forests. Global change will have demonstrable changes in the frequency and intensity of pest outbreaks, particularly at the margins of host ranges.

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Ayres and Lombardero (2000) have shown that climate change has direct effects on the development and survival of herbivores and pathogens; physiological changes in tree defences; and indirect effects from changes in the abundance of natural enemies (e.g. parasitoids of insect herbivores), mutualists (e.g. insect vectors of tree pathogens), and competitors.

Because of the short life cycles of insects, mobility, reproductive potential, and physiological sensitivity to temperature, even modest climate change will have rapid impacts on the distribution and abundance of many kinds of insects. To consider scenario studies, some of them predict negative, but many forecast positive effects on insects. E.g. global warming accelerates insect development rate and facilitate range expansions of pests, moreover, climate change tends to increase the vulnerability of plants to herbivores. One alarming scenario is that climate warming may increase insect outbreaks in boreal forests, which would tend to increase forest fires and exacerbate further climate warming by releasing carbon stores from boreal ecosystems (Ayres and Lombardero, 2000).

Hanson and Weltzin (2000) studied especially the drought disturbances caused by climate change. They showed that severe or prolonged drought may render trees more susceptible to insects.

Climate variability at decadal scales influences the timing and severity of insect outbreaks that may alter species distributions. Coops et al. (2005) have presented a spatial modelling technique to infer how a sustained change in climate might alter the geographic distribution of the species. Using simulations they produced a series of maps that display predicted shifts of zones where the species they examined might expand its range if modelled climatic conditions at annual and decadal intervals were sustained.

The connection between temperature tolerance and phenology of insects was investigated by Klok and Chown (2001). They defined how current climate change like increased temperature and decreased rainfall affect on physiological regulation and susceptibility.

Powell and Logan (2005) have reviewed the mathematical relationship between environmental temperatures and developmental timing and analysed circle maps from yearly oviposition dates and temperatures to oviposition dates for subsequent generations. Applying scenarios for global warming they proved that adaptive seasonality may break down with little warning with constantly increasing (and also decreasing) temperature.

Forecasted increases in atmospheric CO_2 and global mean temperature are likely to influence insect – plant interactions. Plant traits important to insect herbivores, such as nitrogen content, may be directly affected by elevated CO_2 and temperature, while insect herbivores are likely to be directly affected only by temperature. Flynn et al. (2005) stated that insect populations did not change significantly under elevated CO_2, but tended to increase slightly. Average weight decreased at high temperatures. Plant height and biomass were not significantly affected by the CO_2 treatment, but growth rates before infestation were enhanced by elevated CO_2. These results indicate that the combined effects of both elevated CO_2 and temperature may exacerbate pest damage to certain plants, particularly to plants which respond weakly to increases in atmospheric CO_2.

Up to this time, as we have seen, mainly two climatic factors – temperature and humidity have been investigated. Though, it is possible that some parts of solar radiation have at least the same importance in controlling insect populations (Buxton, 2004).

Last, but not least, changes in climate increases the likelihood of insect transport from regions to regions, as well Whinam et al. (2005).

Special agricultural aspects of climate change effect on insects

Global climate change impact on plant - pest populations depends on the combined effects of climate (temperature, precipitation, humidity) and other components like soil moisture, atmospheric CO_2 and tropospheric ozone (O_3). Changes in agricultural productivity can be the result of direct effects of these factors at the plant level, or indirect effects at the system level, for instance, through shifts in insect pest occurrence. With respect to crops, the data suggest that elevated CO_2 may have many positive effects, including yield stimulation, improved resource - use efficiency, more successful competition with weeds, reduced O_3 toxicity, and in some cases better pest and disease resistance. However, many of these beneficial effects may be lost — at least to some extent — in a warmer climate. Warming accelerates plant development and reduces grain-fill, reduces nutrient-use efficiency, increases crop water consumption, and favours weeds over crops. Also, the rate of development of insects may be increased. A major effect of climate warming in the temperate zone could be a change in winter survival of insect pests, whereas at more northern latitudes shifts in phenology in terms of growth and reproduction, may be of special importance. However, climate warming disturbs the synchrony between temperature and photoperiod; because insect and host plant species show individualistic responses to temperature, CO_2 and photoperiod, it is expected that climate change will affect the temporal and spatial association between species interacting at different trophic levels. Although predictions are difficult, it seems reasonable to assume that agro – ecosystem responses will be dominated by those caused directly or indirectly by shifts in climate, associated with altered weather patterns, and not by elevated CO_2 per se. Overall, intensive agriculture may have the potential to adapt to changing conditions, in contrast to extensive agricultural systems or low - input systems which may be affected more seriously (Fuhrer, 2003).

Crop protection in Europe became strongly chemically oriented in the middle of the last century. An excellent climate for fast reproduction of pests and diseases demanded high spray frequencies and, thus, resulted in quick development of resistance against pesticides. This initiated a search for alternatives of chemical pesticides, like natural enemies for control of pests. A change from chemical control to very advanced integrated pest management programs (IPM) in European greenhouses took place at the end of the last century (Kogan and Jepson, 2007; Lenteren, 2000). For the main greenhouse vegetable crops in northern Europe, most insect problems can now be solved without the use of insecticides. IPM without conventional chemical pesticides is a goal that will be realised for most of the important vegetables in Europe, not limited to greenhouse vegetables. At the same time, however, climate change affects the distribution, the phenology, the susceptibility and the interrelationship of insects drastically, which emphasize the risk of sustainable crop protection by loosing the control on pests – natural enemies populations.

Summary

Based on results of factorial experiments under a range of experimental conditions, it is difficult to draw generalized conclusions. Climate change on insect populations, however, forces us to assess the ecological, economical, and social risk of biotic disturbances (Merrill et al., 2008). There are a number of priorities for future research such as examination of the influence of climatic variables, long-term monitoring and modelling of insect population levels and insect behaviour, identification of potential migrants and consideration of possible changes in pest management systems in agriculture and forestry.

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