Climate Change and Its Possible Influence on the Occurrence and Importance of Insect Pests

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Abstract: Insect pests, as widely tolerant and adaptable organisms, may be less distinctly affected by climate change than other insect species. The changing climate may affect the occurrence and impact of the native pests both negatively and positively (increased importance of thermophilous and xerophilous species and decreased importance of psychrophilous ones, noxious abundances of several species also in higher altitudes, decrease of many pests by frost-free winters, low humidity, weather extremes, increased numbers of antagonists, and phenological discrepancy with the host plant). Expansions of new pests into the territory of the Czech Republic, caused by climate change, will be very limited. A small number of greenhouse pests may be expected to occur in outdoor conditions. Increased temperatures may cause a slight increase of non-indigenous invasive insect species and migratory pests. In Central Europe the climate change will intensify the effects of other factors. In the next 20–50 years, the changes in species composition and importance of insect pests of plants will be caused by factors in the following order: (l) introductions of non-indigenous species, (2) new approaches in pest control, (3–4) changes in crop cultivation and representation of crops, (3–4) climate change, (5) other causes (unexpected shifts of ranges, changes in food preferences of insect species, etc.).

Keywords: climate change; insect pests; Czech Republic

As indicated by the hitherto investigations, climate change will show mostly a negative influence on organisms and overall biodiversity (McLaughlin *et al.* 2002; Parmesan & Yohe 2003; Root *et al.* 2003; Thomas *et al*. 2004; Franco *et al.* 2006, etc.). It is interesting to note that research studies on insect pests of plants often bring contrary results: many of them should tend to disperse and their numbers and importance should increase (Porter *et al.* 1991; Cannon 1998; Parry 1998; Quarles 2007, etc.). Do insect pests really differ in some characteristics that could substantiate this difference? Within the class of insects, pests of plants actually are a specific group to a considerable extent. In general, compared to the remaining ("indifferent") species, they are much more adaptable to changed environmental conditions, which makes them capable of surviving in extreme conditions of agricultural ecosystems, dispersing over landscapes altered by man, rapidly occupying suitable habitats and new territories in which they are capable of attaining high levels of abundance. Such properties give them advantage against other species, and they suggest that most of these species may not be markedly affected by climate change. A small part of the insect pests may even be favoured by the change, increasing their impact. On the other hand, a comparable number of species may be handicapped and they may cause lower levels of damage. In the course of the 20^{th} century, about 460 species of insect pests causing damage to agriculture, forestry, cultures of ornamental plants and

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in various closed environments were registered in the Czech Republic, amounting to about 1.7% of total insect fauna. At the same time, the number of rather important insect pests increased by 15% (Šefrová & Laštůvka 2009).

What may be the response of insect pests to climate change in regard of the territory of the Czech Republic? Scientifically substantiated scenarios of the responses of particular species can only be compiled if sufficient data are available on their environmental requirements, and they have already been compiled for some of them (Turčáni *et al.* 2007; Kocmánková *et al.* 2008a, b; Hlásny & Turčáni 2009, etc.). Each species requires a separate analysis based on exact knowledge of temperature thresholds and ranges, effective temperature totals, etc. The situation is complicated by the fact that the results of numerous laboratory experiments are at variance with the responses of the insects in external conditions. In nature, the insect pests are affected by a number of natural as well as anthropogenic factors that are mutually combined and conditioned. A further factor is the capability of insects to compensate for, or become adapted to, the environmental changes in various ways (Bradshaw & Holzapfel 2001; Visser 2008). That is why long-term forecasts of the responses of particular insect pests to climate change are rather uncertain (Cannon 1998).

Probable responses of local insect pests

Species causing damage in warm and dry years (e.g. *Lobesia botrana, Neoglocianus maculaalba, Stenocarus ruficornis,* many aphid species), the same as those occurring only in the warm regions in this country (e.g. *Hyphantria cunea*) may increase in importance. On the other hand, psychrophilous species (such as *Contarinia nasturtii, Sitodiplosis mosellana, Delia radicum*) may become less destructive. In less humid conditions, moisture-loving species (such as *Contarinia medicaginis, Brevicoryne brassicae,* wireworms, nematodes, slugs) may become less important. The damage caused by some (e.g. *Leptinotarsa decemlineata*, Kocmánková *et al.* 2008a; Šmatas *et al.* 2008, or of forest pests e.g. *Lymantria dispar* and *L. monacha*, Hlásny & Turčáni 2009; Liška J. personal communication) species may increase at higher elevations and in more northern regions, or the regions of the most intensive damages done by, and frequent outbreaks of, a particular species may be shifted geographically (Williams & Liebhold 1995; Jepsen *et al.* 2007). At the same time, climate change may affect various properties and manifestations of insect pests.

(a) Accelerated development and increased number of generations

Increased temperatures and earlier onsets of the growing season (already documented by numerous authors) will lead to earlier and accelerated development of a number of species. As concluded by some authors, this should result in increased numbers and greater damage done by the pests (Parry 1998; Quarles 2007, etc.). An earlier or accelerated development of a pest in itself need not result in increased damage done. This depends on whether or not this acceleration will result in increased abundance of the pest and its relationship to its host plant. In most cases it is still uncertain whether the acceleration in development will be indifferent (probably in most cases), prosperous, or detrimental (Visser & Both 2005). For instance, accelerated development may decrease the effectiveness of predators. On the other hand, the accelerated individuals may be smaller in size and show decreased reproductive capacity. It is very difficult to predict the resulting abundance of the pest.

Over a half of the insect pests of agricultural crops produce one generation annually or their development lasts several years, which facts mostly remain unchanged by climate change, or the number of generations is limited by the photoperiod. About 30% of species produce two or three, and slightly over 10% even more generations a year. Insects may very rapidly adapt to new climatic situations by shifts in temperature thresholds, effective temperature totals, critical photoperiod lengths without showing any appreciable changes in their development (e.g. Pullin 1986). Some species will produce more generations annually in years with extreme temperatures, and this phenomenon may become regular with gradually warming. This is true of e.g. *Psammotettix alienus, Diaspidiotus perniciosus, Leptinotarsa decemlineata, Eupoecilia ambiguella, Pandemis heparana, Hedya nubiferana, Cydia pomonella, Grapholita molesta, Archips podana, Agrotis segetum* (Hrdý *et al.* 1979; Stará & Kocourek 2001, 2004; Kocourek & Stará 2005; Manurung *et al.* 2005; Malenovský I. personal communication, etc.); of forest pests, e.g. *Ips typographus* (Hlásny & Turčáni 2009). Southern populations with shorter critical photoperiods may spread with higher temperatures northwards where it will not inhibit them in producing more generations annually (e.g. Gomi 1997). In this connections intensive studies have been mainly focussed on aphids, yet the resulting effect on their abundance and further prosperity, nor the practical effect of this increase are insufficiently known, or the available results are often inconsistent (cf., e.g. Zhou *et al*. 1995; Davis *et al.* 2006; Quarles 2007). No data are available on the relationship between increased abundance and the effects of intrinsic factors inside the populations (such as decreased fertility and reproduction), the responses are unknown of host plants, and it is a question whether they may be available in sufficient quality at the later phase of a growing season. In extreme conditions, higher abundance of insect pests may partly be due to lower activity of parasitoids (Stireman *et al.* 2005; Hance *et al.* 2007) or to disturbed parasitoid-pest relationship and decreased controlling capability, yet other studies suggest that higher temperatures will favour parasitoids rather than their hosts (Kiritani 2006; cf. also Davis *et al*. 1998).

(b) Easier wintering during warm winters

The effect of climate change in temperate regions on wintering pests is considered one of the major effects (Bale *et al*. 2002). It is rather widely believed that warm winters may promote their increase. In Central Europe it is quite the contrary except in a few cases. A large majority of Central European insect pests winter in a diapause which they must undergo at sufficiently low temperatures, often below the freezing point, and lasting sufficiently long. Their successful development, therefore, requires long and frosty winters with snow blankets and moderate temperature oscillations. A warm, frost-free winter or a longish period with temperature above 10°C cause high mortality rates of various developmental stages of pests. This mortality is due not only to the temperature unfavourable for the diapause but also to high energy losses, development of pathogens, and greater availability to predators. If the climate change will mean the onset of frost-free winters it will negatively affect most Central European insect pests, and the importance of some of them may drop. Warm winters may positively affect just a small number of species for which the winter period of rest is not necessary a part of their development, as they only show decreased activity during dropping temperatures. For example, the aphid *Myzus persicae* could spend a markedly warmer winter period in the adult stage, which would slightly affect the time of its spring migration and the whole developmental cycle (Bale *et al.* 1988; cf. also Kocourek & Beránková 1989). Frost-free winters can positively affect even some of the migratory species which have only seasonally migrated into Central Europe (see below).

(c) Changed pest-host plant relationship

Parallel evolution gradually resulted in a close relationship between insect pest and its host plant, accompanied by the development of various adaptations of both. This relationship may be disturbed or changed by different climate. It may result e.g. in phenological asynchrony between insect and plant (Van Asch & Visser 2007), which may be in favour of the plant against the pest. This time discrepancy is often exemplified by the winter moth (*Operophtera brumata*), yet even in this case the scientific results are at variance (cf., e.g. Buse & Good 1996; Visser & Holleman 2001). Besides, that particular species will probably be more reduced by lack of summer moisture rather than by spring asynchrony, as a result of which the size of the area in danger of outbreaks will markedly decrease (Turčáni *et al*. 2007).

Higher temperatures and higher CO_2 content may change the quality of vegetable food. Insect pests may respond in a different way than they do at present, positively or negatively, their numbers may increase or decrease, and as a result they may consume the same, greater or smaller amounts of food (Caulfield & Bunce 1994; Buse *et al.* 1998; Kerslake *et al*. 1998; Parry 1998), and a change in their practical importance is unpredictable on a general level. Likewise, assumptions that climatic extremes may cause more frequent outbreaks of insect pests (e.g. Quarles 2007; Farrow 2008) are hardly probable in general, as the climatic extremes will negatively affect insect pests the same as other organisms, yet a higher abundance of some pest species may be conditioned by dry and hot periods (Mattson & Haack 1987; Rouault *et al*. 2006). Besides, the gradations of important insect pests are not induced by weather conditions as a rule (e.g. Turčáni *et al.* 2007). New conditions (higher temperatures, moisture defficiency) may stress host plants (which may become apparent in forest stands). The stressed host plants may insufficiently resist the infestation by insect pests. Again, the responses of particular insect pests and their antagonists are hardly predictable in this point.

(d) Changed structure and geographic distribution of crops

This problem cannot be examined solely in view of the climate change but in view of a whole complex of changes that took place in European agriculture in the course of the 21st century (e.g. Parry 1998). The composition and geographic dislocation of agricultural crops is of decisive influence on the species spectrum and abundance of specialised pests, regardless of whether it will be primarily due to climate change, economic impacts, social situation, or other factors. The importance of a pest will proportionally decrease with the decreased extent of "his" crop (smaller areas and their discontinuity), and *vice versa.* Increasing the extent of crops and varieties requiring higher temperatures and less moisture will lead to increasing importance of their insect pests. With the shift of some crops to higher altitudes, their respective pests will also shift or disperse. In such cases, additional factors such as landscape structure and soil conditions will be of importance besides climatic conditions suitable for the cultivation of a particular crop.

Considering the present ecological knowledge of local insect pests, their occurrence in other parts of Europe and in years of extreme weather conditions, one may presume that the change in their importance due to climate change should not exceed 10% at a more or less unchanged species number.

New insect pests spreading into the Czech Republic

The ranges of insect species are not static but show various shifts. At any time it is possible to give examples of species spreading into or retreating from the Czech Republic. As regards actual or at least potential insect pests, in the past two decades e.g the noctuid moth, *Noctua interjecta,* spread from the west, the bark beetle, *Ips duplicatus,* from the north, and the aphid, *Diuraphis noxia,* from the east (Beránková & Novák 1986; Mrkva 1994; Starý *et al.* 2003). Recently, the sudden range shifts of insects have often been thought to be connected to climate change, yet in most cases they have had nothing in common with it. Dispersion due to climate change is slow and has to be correlated with it (and is limited by additional biotic and abiotic factors, see e.g. Davis *et al.* 1998), and has also been documented, mostly in higher latitudes (e.g. Parmesan *et al.* 1999; Hill *et al.* 2002; Ryrholm 2003) or predicted (Settele *et al.* 2008) for different insect groups. Parmesan and Yohe (2003) state that due to climate change, insect species spread at a mean rate of 6.1 km per decade. The shift of range boundaries may be more rapid in some cases, yet it cannot overtake the climate change. The Czech Republic (Central Europe) lies within a more extensive region with similar macroclimate, character of vegetation, composition of agricultural crops, and spectrum of insect pests. A more distinct spread of noxious and other insect species in the northward direction can be expected at the southern and northern limits of this territory (e.g. Parmesan *et al.* 1999; Ryrholm 2003; Jepsen *et al.* 2007). If quite new kinds of crops would be introduced as a result of climate change or other reasons, they will be rapidly accompanied by their insect pests, both local non-specialised and new species that will be introduced together with the crops.

In particular cases of south European insect pests, increased temperatures may possibly be expected to spread in the northward direction. For instance, the carnation tortrix moth, *Cacaecimorpha pronubana,* is widely distributed over Southern and Western Europe as a pest of decorative plants. It is occasionally introduced into Central Europe (Bártová & Marek 2009), yet it is not known to occur in free nature. Due to increased temperatures, it could become established in climatically most suitable regions. An expansion of the pine processionary, *Thaumatopoea pityocampa,* a pest of pine trees has already been recorded in several southern European countries (Krehan & Steyrer 2006; Buffo *et al.* 2007). It is difficult to estimate how far north the boundary of its range may shift.

Thus, the danger of possible expansion of new insect pests into the territory of the Czech Republic due to climate change is altogether negligible. Compared to the present number of important insect pests, it may not exceed 1% in both number and importance.

Increase in numbers and invasions of non-indigenous species

Non-indigenous species are accidentally or intentionally introduced by man from other geographic regions. Those non-indigenous species that are capable of surviving and spreading in external conditions (invasive species), i.e. they can find suitable climatic conditions, habitat types and food in a new territory, may become pests of plants. The territory of the Czech Republic is known to harbour about 400 non-indigenous insect species; of which number 70 species are invasive and 30 among them are pests of plants (Šefrová 2005; Šefrová & Laštůvka 2005). Important insect pests of crops include e.g. *Diaspidiotus perniciosus, Eriosoma lanigerum, Bruchus pisorum, Leptinotarsa decemlineata, Grapholita molesta, Hyphantria cunea* and *Contarinia pisi;* of ornamental plants, e.g. *Psylla buxi, Thrips simplex, Cameraria ohridella* and *Monarthropalpus flavus.*

The introduction of non-indigenous species is an anthropogenic issue, not connected with climate change. The number of newly introduced species is on a distinct increase, obviously connected with the permanently increased business exchange and transport of diverse material (cf., e.g. Roques *et al*. 2008 and in press). In the territory of the Czech Republic in particular, a new non-indigenous insect pest was registered every four years on average by 1980, every two years in 1980–2000 and every year after 2000. Approximately 250 invasive insect species are known in Europe. Most of them, around 120, are distributed over the western part of the Mediterranean. In western and Central European countries, this number decreases to about 60%, their numbers showing no appreciable differences in those countries. Only about 40% of the initial number occurs in the north and north east of Central Europe, and about 15% in northern Europe. Most of the non-indigenous species occurring in the Mediterranean are pests of thermophilous plants (citrus and cedar trees, palms, etc.) that cannot grow in Central Europe. Only a very limited number of the Mediterranean invasive species could expand northwards after climate warming. As regards insect pests, these might be 3–5 in number in the next 30–50 years, which is negligible, compared to the increasing trend of introducing additional non-indigenous species.

An expansion may be expected of pests of crops and ornamental plants cultivated from the Mediterranean up to the far north. These could include e.g. planthoppers *Scaphoideus titanus* and *Metcalfa pruinosa,* the bug *Nezara viridula,* the aphid *Aphis illinoisensis*, gelechiid moths *Tuta absoluta* and *Phthorimaea operculella,* mining moths *Phyllocnistis vitegenella* and *Antispila ampelopsifoliella* (for particulars see e.g. Elsner *et al*. 1999; Lauterer 2002; Rédei & Torma 2003; Seljak 2008; Baldessari *et al*. 2009; Ramel 2009 and personal communication Malenovský I., van Nieukerken E.J., and Starý P.). Some of the thermophilous invasive species that occupied a part of our territory in the past may expand towards the north and to higher elevations, e.g. *Hyphantria cunea* and *Grapholita molesta* (cf. Miller 1952; Hrdý *et al*. 1993). They will respond to the climate change in a similar way as the thermophilous native insect pests.

In future, non-indigenous insect pests may present an increasing problem of plant protection, in Central Europe just slightly affected by the climate change. Due to the latter, their number may increase in the next 50 years by 5–10% against the present trend of introduction of non-indigenous species.

More frequent occurrence and greater damage done by migratory species

Of migratory insect species, greater damage is occasionally done by *Plutella xylostella, Agrotis ipsilon, Autographa gamma, Heliothis armigera, H. maritima, Loxostege sticticalis,* and *Nomophila noctuella.* Their arrival in Central Europe varies considerably in successive years and longer periods, cases of their outbreaks are very irregular and unpredictable (see e.g. Rambousek 1921 or Novák 1966). The intensity of their arrival is probably affected by the abundance of the species in its permanent range (north of Africa, the Mediterranean) and perhaps even by the actual weather situation in those regions, less so or not at all by that in Central Europe. Yet in warm and dry weather these species may migrate farther northwards and attain greater abundance in the subsequent generation(s), thereby increasing their noxious effects. Some of them, e.g. *Autographa gamma*, may go through a mild winter and thus survive even over a longer period in Central Europe. The pupa of *Heliothis armigera* can even survive a frosty winter but its larvae will not complete their development as a rule in cold autumn weather. They may succeed in prolonged growing season, however.

Thus, one may presume that in the next decades the abundance of migratory species may increase slightly and cause irregular damage. Since they are non-specialised insect pests, such increase will probably cause no major problems in plant protection.

Possible shift of greenhouse pests to outdoor conditions

Most of the insect species that cause damage to plants grown in greenhouses, flats and other closed environments are native to the tropics and subtropics. As a rule, they do not tolerate frost, often not even long periods with temperatures below 10°C. In the Czech Republic about 70 species of greenhouse insect pests have been registered, 25 of which cause permanent and important damage. Most of them belong to such groups as scale insects, thrips, aphids, whiteflies and flies (Zahradník 1990; Šefrová & Laštůvka 2005, here next references). Aquatic plants grown in greenhouses are locally damaged by four species of tropical pyralid moths (Marek & Bártová 1998; Marek J. and Vrabec V. personal communication). Further insect pests may be individually imported into greenhouses with their host plants from abroad (e.g. Bártová & Marek 2000, 2009). Many greenhouse insect pests occur in free nature in Southern Europe. In our conditions, the survival of longer-lasting outdoor populations could only be possible in a series of frost-free winters, and they would be liquidated by the first next frosts. If the outdoor weather conditions were favourable for some of the greenhouse pests then such species would also expand from Southern Europe and would behave like other thermophilous native as well as introduced insect pests. Even so, their outdoor occurrence is probable in only a very limited number of species. Outdoor populations have been observed in the thrips, *Frankliniella occidentalis,* and may also be considered to occur in thrips, *Gynaikothrips ficorum* and *Echinothrips americanus,* as well as in 2–3 species of scale insects, e.g. *Planococcus citri* or *Aspidiotus nerii* (Fedor P. and Hlavjenková I. personal communication). Some of the aphids detrimental preferably in greenhouses (e.g. *Macrosiphum euphorbiae* and *Aphis gossypii*) may be of more importance even in outdoor conditions in warmed climate.

Thus, following a marked climate warming, up to 5–7% of greenhouse insect pests might shift to outdoor environments. There they would exist at the limits of their environmental requirements, and as pests they would probably become unimportant.

CONCLUSIONS

The degree to which various species of insect pests will be affected by climate change will be proportional to the degree of the change, and inversely correlated with the width of environmental requirements of each species. Most insect pests are widely tolerant and adaptable organisms, and their occurrence in an environment depends upon the presence of their particular host plants. Therefore, they may be less distinctly affected by climate change than other species. The Czech Republic lies in the middle of a more extensive region with much the same macroclimate, character of vegetation, field crop composition, and spectrum of insect pests. Countries lying at the margins of this region (especially the southern and northern ones) will be affected by climate change earlier and more markedly than the Czech Republic, and it may also be of principal influence in those countries. In Central Europe the climate change will intensify the effects of other factors. The climate change may result in partially changed occurrence and importance of native insect pests (up to 10% at more or less unchanged species number) (increased importance of thermophilous and xerophilous species and decreased importance of psychrophilous ones, noxious abundances of several species also in higher altitudes). The abundance of a number of native insect pests may be influenced in a negative way (thereby decreasing their harmfulness) by frost-free winters, low humidity, weather extremes, increased numbers of antagonists, and phenological discrepancy with the host plant. Changes may occur in the mutual host plant-insect pest relationships, and they may become apparent, in particular cases, in increased or decreased levels of damage done. The dispersal of quite new species over the territory of the Czech Republic, caused by the climate change, may not exceed 1% of the present number of insect pests. In future, some 5–7% of greenhouse insect pests may shift to outdoor conditions, probably without any appreciable importance. Increased temperatures may cause a small increase of non-indigenous invasive insect species (roughly by 3–5% against the present trend) as well as a slight increase in the importance of migratory species.

In the next 20–50 years, the changes in species composition and importance of insect pests of plants will be caused by factors in the following order: (1) introductions of non-indigenous species,

(2) new approaches in pest control, (3–4) changes in crop cultivation and representation of crops, (3–4) climate change, (5) other causes (unexpected shifts of ranges, changes in food preferences of insect species, etc.).

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References

Asch van M., Visser M.E. (2007): Phenology of forest caterpillars and their host trees: the importance of synchrony. Annual Review of Entomology, **52**: 37–55.

Baldessari M., Angeli G., Girolami V., Mazzon L., Nieukerken van E.J., Duso C. (2009): *Antispila* sp. minatore fogliare segnalato in Italia su vite. L'Informatore Agrario, **15**: 68–72.

Bale J.S., Harrington R., Clough M.S. (1988): Low temperature mortality of the peach-potato aphid *Myzus persicae*. Ecological Entomology, **13**: 121–129.

Bale J.S., Masters G.J., Hodkinson I.D., Awmack, C., Bezemer T.M., Brown V.K., Butterfield J., Buse A., Coulson J.C., Farrar J., Good J.E.G., Harrington R., Hartley Z., Jones T.H., Lindroth R.L., Press M.C., Symrnioudis I., Watt A.D., Whittaker J.B. (2002): Herbivory in global climate change research: direct effects of rising temperature on insect herbivores. Global Change Biology, **8**: 1–16.

Bártová E., Marek J. (2000): Kovolesklec jižní – nový škůdce (*Chrysodeixis chalcites*). Zahradnictví, **74**(2): 1, 4.

Bártová E., Marek J. (2009): Další jihoevropský škůdce v našich sklenících. Zahradnictví, **83**(7): 29.

Beránková J., Novák I. (1986): Faunistic records from Czechoslovakia. Lepidoptera: Noctuidae. Acta Entomologica Bohemoslovaca, **83**: 474.

Bradshaw W.E., Holzapfel C.M. (2001): Genetic shift in photoperiodic response correlated with global warming. Proceedings of the National Academy of Sciences USA, **98**: 14509–14511.

Buffo E., Battisti A., Stastny M., Larsson S. (2007): Temperature as a predictor of survival of the pine processionary moth in the Italian Alps. Agricultural and Forest Entomology, **9**: 65–72.

Buse A., Good J.E.G. (1996): Synchronization of larval emergence in winter moth (*Operophtera brumata* L.) and budburst in pedunculate oak (*Quercus robur* L.) under simulated climate change. Ecological Entomology, **21**: 335–343.

Buse A., Good J.E.G., Dury S., Perrins C.M. (1998): Effects of elevated temperature and carbon dioxide on the nutritional quality of leaves of oak (*Quercus robur* L.) as food for the Winter Moth (*Operophtera brumata* L.). Functional Ecology, **12**: 742–749.

Cannon R.J.C. (1998): The implications of predicted climate change for insect pests in the UK, with emphasis on non-indigenous species. Global Change Biology, **4**: 785–796.

Caulfield F., Bunce J.A. (1994): Elevated atmospheric carbon dioxide concentration affects interactions between *Spodoptera exigua* (Lepidoptera: Noctuidae) larvae and two host plant species outdoors. Environmental Entomology, **23**: 999–1005.

Davis J.A., Radcliffe E.B., Ragsdale D.W. (2006): Effects of high and fluctuating temperatures on *Myzus persicae* (Hemiptera: Aphididae). Environmental Entomology, **35**: 1461–1468.

Davis A.J., Jenkinson L.S., Lawton J.H., Shorrocks B., Wood S. (1998): Making mistakes when predicting shifts in species range in response to global warming. Nature, **391**: 783–786.

Elsner G., Huemer P., Tokár Z. (1999): Die Palpenmotten (Lepidoptera, Gelechiidae) Mitteleuropas. Bestimmung, Verbreitung, Flugstandort, Lebensweise der Raupen. F. Slamka, Bratislava.

Farrow R.A. (2008): Implications of potential global warming on agricultural pests in Australia. EPPO Bulletin, **21**: 683–696.

Franco A.M.A., Hill J.K., Kitschke C., Collingham Y.C., Roy D.B., Fox R., Huntley B., Thomas C.D. (2006): Impacts of climate warming and habitat loss on extinctions at species' low-latitude range boundaries. Global Change Biology, **12**: 1545–1553.

Gomi T. (1997): Geographic variation in critical photoperiod for diapause induction and its temperature dependence in *Hyphantria cunea* Drury (Lepidoptera: Arctiidae). Oecologia, **111**: 160–165.

Hance T., Baaren J. van, Vernon P., Boivin G. (2007): Impact of extreme temperatures on parasitoids in a climate change perspective. Annual Review of Entomology, **52**: 107–126.

Hill J.K., Thomas C.D., Fox R., Telfer M.G., Willis S.G., Asher J., Huntley B. (2002): Responses of butterflies to twentieth century climate warming implications for future ranges. Proceedings of the Royal Society of London, Series B, Biological Sciences, **269**: 2163–2171.

Hlásny T., Turčáni M. (2009): Insect pests as climate change driven disturbances in forest ecosystems. In: Střelcová K. *et al.* (ed.): Bioclimatology and Natural Hazards. Springer, Dordrecht: 165–176.

Hrdý I., Krampl F., Kuldová J., Marek J., Šimko K. (1979): Mapování obaleče východního (*Cydia molesta*) feromonovými lapáky. Ochrana rostlin, **15**: 259–269.

Hrdý I., Marek J., Krampl F., Kuldová J., Barabás L. (1993): Distribution of the fruit tree pests *Cydia molesta, Cydia funebrana* and *Anarsia lineatella* (Lepidoptera: Tortricidae, Gelechiidae) in former Czechoslovakia as recorded by pheromone traps. Acta Societatis Zoologicae Bohemicae, **58**: 53–60.

Jepsen J.U., Hagen S.B., Ims R.A., Yoccoz N.G. (2007): Climate change and outbreaks of the geometrids *Operophtera brumata* and *Epirrita autumnata* in subarctic birch forest: evidence of a recent outbreak range expansion. Journal of Animal Ecology, **77**: 257–264.

Kerslake J.E., Woodin S.J., Hartley S.E. (1998): Effects of carbon dioxide and nitrogen enrichment on a plant-insect interaction: the quality of *Calluna vulgaris* as host for *Operophtera brumata*. New Phytologist, **140**: 43–53.

Kiritani K. (2006): Predicting impacts of global warming on population dynamics and distribution of arthropods in Japan. Population Ecology, **48**: 5–12.

Kocmánková E., Trnka M., Semerádová D., Žalud Z., Dubrovský M., Možný M., Juroch J., Šefrová H. (2008a): The change of the potential occurrence of Colorado potato beetle (*Leptinotarsa decemlineata*, Say 1824) in the Czech Republic till 2050. Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis, **56**(2): 87–94.

Kocmánková E., Trnka M., Žalud Z., Semerádová D., Dubrovský M., Muška F., Možný M. (2008b): Comparison of two mapping methods of potential distribution of pests under present and changed climate. Plant Protection Science, **44**: 49–56.

Kocourek F., Beránková J. (1989): Temperature requirements for development and population growth of the Green peach apid *Myzus persicae* on sugar beet. Acta Entomologica Bohemoslovaca, **86**: 349–355.

Kocourek F., Stará J. (2005): Monitoring of San Jose scale (*Quadraspidiotus perniciosus* Comst.) by pheromone traps and timing of control on crawlers. IOBC WPRS Bulletin, **28**: 183–187.

Krehan H., Steyrer G. (2006): Klimaveränderung – Schadorganismen bedrohen unsere Wälder. BFW-Praxisinformation, **10**: 15–17.

Lauterer P. (2002): Citrus flatid planthopper – *Metcalfa pruinosa* (Hemiptera: Flatidae), a new pest of ornamental horticulture in the Czech Republic. Plant Protection Science, **38**: 145–148.

Manurung B., Witsack W., Mehner S., Grüntzig M., Fuchs E. (2005): Studies on biology and population dynamics of the leaf hopper *Psammotettix alienus* Dahlb. (Homoptera: Auchenorrhyncha) as vector of Wheat dwarf virus (WDV) in Saxony-Anhalt, Germany. Zeitschrift für Pflanzenkrankheiten und Pflanzenschutz, **112**: 497–507.

Marek J., Bártová E. (1998): *Duponchelia fovealis* Zeller, 1847, nový škůdce skleníkových rostlin v České republice (Lepidoptera, Pyralidae, Pyraustinae). Plant Protection Science, **34**: 151–152.

Mattson W.J., Haack R.A. (1987): The role of drought in outbreaks of plant-eating insects. BioScience, **37**: 110–118.

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 USA, **99**: 6070–6074.

Miller F. (1952): Přástevníček americký – *Hyphantria cunea* Drury náš nejvážnější škůdce. Folia Zoologica Entomologica, **15**: 16–23.

Mrkva R. (1994): Lýkožrout severský (*Ips duplicatus* Sahlberg), nový významný škůdce na smrku. Lesnická práce, **73**: 35–37.

Novák I. (1966): Výskyt šedavky *Chloridea maritima* Grasl. (Lepidoptera, Noctuidae) jako škůdce vojtěšky v Československu. Ochrana rostlin, **2**: 275–282.

Parmesan C., Yohe G. (2003): A globally coherent fingerprint of climate change impacts across natural systems. Nature, **421**: 37–42.

Parmesan C., Ryrholm N., Stefanescu C., Hill J.K., Thomas C.D., Descimon H., Huntley B., Kaila L., Kullberg J., Tammaru T., Tennent W.J., Thomas J.A., Warren M. (1999): Poleward shifts in geographical ranges of butterfly species associated with regional warming. Nature, **399**: 579–583.

Parry M.L. (1998): The impact of climate change on European agriculture. In: Proceedings of the British Crop Protection International Conference: Pests and Diseases, Brighton, 16–19 November 1998: 325–341.

Porter J.H., Parry M.L., Carter R. (1991): The potential effects of climatic change on agricultural insect pests. Agricultural and Forest Meteorology, **57**: 221–240.

Pullin A.S. (1986): Effects of photoperiod and temperature on the life-cycle of different populations of the peacock butterfly *Inachis io*. Entomologia Experimentalis et Applicata, **41**: 237–242.

Quarles W. (2007): Global warming means more pests. The IPM Practitioner, **29**: 1–8.

Rambousek F. (1921): Letošní kalamita způsobená zavíječem řepovým. Ochrana rostlin, **1**: 1–5.

Ramel J.-M. (2009): French's situation of *Tuta absoluta* (Meyrick, 1917) (Lepidoptera: Gelechiidae). In: Proceedings of the 16th European Congress of Lepidopterology, 25–31 May 2009, Cluj, Romania: 36–37.

Rédei D., Torma A. (2003): Bug, *Nezara viridula* (Heteroptera: Pentatomidae) in Hungary. Acta Phytopathologica et Entomologica Hungarica, **38**: 365–367.

Root T.L., Price J.T., Hall K.R., Schneider S.H., Rosenzweig C., Pounds J.A. (2003): Fingerprints of global warming on wild animals and plants. Nature, **421**: 57–60.

Roques A., Rabitsch W., Rasplus J.-Y., Lopez-Vaamonde C., Nentwig W., Kenis M. (2008): Chapter 5. Alien terrestrial invertebrates of Europe. In: DAISIE, Handbook of Alien Species in Europe. Springer, Dordrecht: 63–79.

Roques A., Rasplus J.-Y., Rabitsch W., Lopez-Vaamonde C., Kenis M., Nentwig W. (eds) (2009): Terrestrial invertebrate invasions in Europe. Pensoft, Sofia (in press).

Rouault G., Candau J.-N., Lieutier F., Nageleisen L.-M., Martin J.-C., Warzée N. (2006): Effect of drought and heat on forest insect populations in relation to the 2003 drought in Western Europe. Annals of Forest Science, **63**: 613–624.

Ryrholm N. (2003): Global warming and the change of butterfly distributions: a new opportunity for species diversity or a severe threat (Lepidoptera)? In: Proceedings 13th International Colloquium European Invertebrate Survey, Leiden, 2–5 September 2001: 7–11.

Šefrová H. (2005): Introduced and invasive insect species in the Czech Republic. Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis, **53**(5): 151–158.

Šefrová H., Laštůvka Z. (2005): Catalogue of alien animal species in the Czech Republic. Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis, **53**(4): 151–170.

Šefrová H., Laštůvka Z. (2009): How many insect species are real plant pests and which insect orders are the most important? In: Šafránková I., Šefrová H. (eds): XVIII. Česká a slovenská konference o ochraně rostlin. Sborník abstraktů. MZLU v Brně, 2.–4. září 2009: 173.

Seljak G. (2008): Distribution of *Scaphoideus titanus* in Slovenia: its new significance after the first occurrence of grapevine "flavescente dorée". Bulletin of Insectology, **61**: 201–202.

Settele J., Kudrna O., Harpke A., Kühn I., Swaay van C., Verovnik R., Warren M., Wiemers M., Hanspach J., Hickler T., Kühn E., van Halder I., Veling K., Vliegenthart A., Wynhoff I., Schweiger O. (2008): Climatic Risk Atlas of European Butterflies. Pensoft, Sofia.

Šmatas R., Semaškiene R., Lazauskas S. (2008): The impact of the changing climate conditions on the occurrence of the colorado potato beetle (*Leptinotarsa decemlineata*). Zemdirbyste-Agriculture, **95**: 235–241.

Stará J., Kocourek F. (2001): Flight patterns of *Hedya dimidioalba, Spilonota ocellana* and *Pandemis heparana* (Lep.: Tortricidae) based on data from pheromone traps. Plant Protection Science, **37**: 129–137.

Stará J., Kocourek F. (2004): Flight pattern of *Archips podana* (Lep.: Tortricidae) based on data from pheromone traps. Plant Protection Science, **40**: 75–81.

Starý P., Basky Z., Tanigoshi L.K., Tomanović Z. (2003): Distribution and history of Russian wheat aphid, *Diuraphis noxia* (Kurdj.) in the Carpathian basin (Hom., Aphididae). Anzeiger für Schädlingskunde, **76**: 17–21.

Stireman J.O., Dyer L.A., Janzen D.H., Singer M.S., Lill J.T., Marquis R.J., Ricklefs R.E., Gentry G.L., Hallwachs W., Coley P.D., Barone J.A., Greeney H.F., Connahs H., Barbosa P., Morais H.C., Diniz I.R. (2005): Climatic unpredictability and parasitism of caterpillars: implications of global warming. Proceedings of the National Academy of Sciences, USA, **102**: 17384–17387.

Thomas C.D., Cameron A., Green R.E., Bakkenes M., Beaumont L.J., Collingham Y.C., Erasmus B.F.N., Fereira de Sigueira M., Grainger A., Hannah L., Hughes L., Huntley B., Jaarsveld van A.S., Midgley G.F., Miles L., Ortega-Huerta M.A., Townsend Peterson A., Phillips O.L., Williams S.E. (2004): Extinction risk from climate change. Nature, **427**: 145–148.

Turčáni M., Hlásny T., Kalina V., Vach M. (2007): Modelování gradačního areálu píďalky podzimní (*Operophtera brumata* L. 1758) při předpokládaných změnách klimatu na Slovensku. Zprávy lesnického výzkumu, Speciál 2007, **52**: 8–13.

Visser M.E. (2008): Keeping up with a warming world; assessing the rate of adaptation to climate change. Proceedings of the Royal Society of London, Series B, Biological Sciences, **275**: 649–659.

Visser M.E., Both Ch. (2005): Shifts in phenology due to global climate change: the need for a yardstick. Proceedings of the Royal Society of London, Series B, Biological Sciences, **272**: 2561–2569.

Visser M.E., Holleman L.J.M. (2001): Warmer springs disrupt the synchrony of oak and winter moth phenology. Proceedings of the Royal Society of London, Series B, Biological Sciences, **268**: 289–294.

Williams D.W., Liebhold A.M. (1995): Herbivorous insects and global change: potentional changes in the spatial distribution of forest defoliator outbreaks. Journal of Biogeography, **22**: 665–671.

Zahradník J. (1990): Die Schildläuse (Coccinea) auf Gewächshaus- und Zimmerpflanzen in den Tschechischen Ländern. Acta Universitatis Carolinae, Biologica, **34**: 1–160.

Zhou X., Harrington R., Woiwod I.P., Perry J.N., Bale J.S., Clark S.J. (1995): Effects of temperature on aphid phenology. Global Change Biology, **1**: 303–313.

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