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MODELLING OF THE EUROPEAN CORN BORER CLIMATIC NICHE UNDER EXPECTED CLIMATE CONDITIONS

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Summary:

There are major gaps between the actual and attainable yields of crops, attributable largely to the pests, diseases and weeds. In global change research, estimates of crop yields using simulation models also suffer from major gaps between observed and predicted yields. Furthermore invertebrates and plant pathogen are highly adapted to change and so are prime targets for risk assessment in global climate change. Therefore predicting the potential distribution of all pests, both indigenous and introduced, plays a key role in determining the effects of global change effects on agricultural, horticultural and forestry ecosystems. Pest-host relationship can be affected by climate change in different ways. Pests that are currently of minor significance may become key species, thereby causing serious loses in European countries. The distribution and intensity of current key pest and diseases may be affected leading to changed effects on yield and on control measures such as pesticides and integrated pest management. It is also apparent that pests will migrate as crops will migrate in association with climate-induced changes in crop compositions in various regions. In the same time the pesticide usage will change thus leading in some cases to increase of the production costs.

European corn borer (ECB), *Ostrinia nubilalis* (Hübner) is a major pest of corn in many countries and has been studied by generations of entomologists since 19th century. Its development is known to be closely correlated with daily air temperature whilst the population density is to great extend dependent on other weather parameters. For these reason we have chosen it as one of the model organisms in order to widen the reach of the present assessments of the climate change impacts on crop growth and development. Based on the literature overview we derived a simple model indicating developmental stage and overall weather suitability in the given time during the season based on the meteorological parameters. In addition an extensive database containing records from multiple sources on the pest occurrence during period of 1961-2000 was collected and used to qualitatively evaluate this model. In the next step the potential climatic niche of ECB has been defined using GIS software and 1x1 km grid. Finally we present the ECB climate niche areas under expected environmental change that was determined with help of number of GCMs in combination with MIDDLE scenario (mean of A1 and B2 SRES green house emission scenarios) centered e.g. to years 2015, 2025 and 2050.

ABSTRAKT

Jednou z příčin rozdílných hodnot aktuálního a dosažitelného výnosu polních plodin je výskyt chorob, škůdců a plevelů. Uvedené faktory mohou být příčinou nepřesností např. v odhadech výnosů pomocí simulačních modelů jak v podmínkách současného tak i očekávaného klimatu. Protože většina škodlivých činitelů je i díky krátkému vývojovému cyklu vysoce adaptabilní ke změnám podmínek prostředí lze předpokládat že ve změněných klimatických podmínkách se právě oni mohou stát primárním rizikovým jevem. Předpověď potencionálního rozšíření škodlivých činitelů ať již stávajících nebo introdukovaných proto musí hrát klíčovou roli v posouzení dopadů změny klimatu na zemědělství, zahradnictví a lesnictví. Vztah mezi chorobou či škůdcem a jeho hostitelem může být změnou klimatu ovlivněn několika způsoby. V současnosti minoritně se vyskytující škodliví činitelé se mohou stát do-

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minantními, jejich infekční tlak vyvolá potřebu zvýšené chemické ochrany a tvorby nových systémů prognózy a signalizace s výrazným ekonomickým dopadem. S migrací rostlin do nových regionů je nutné počítat s výskyty chorob a škůdců v doposud nepostižených oblastech. Samostatnou kapitolou bude výskyt vyššího počtu generací u některých škůdců a tím intenzifikace jejich škodlivých projevů.

Zavíječ kukuřičný, *Ostrinia nubilalis* (Hübner) je hlavní škůdce kukuřice v mnoha zemích a byl studován generacemi entomologů od 19 století. Jeho vývoj je úzce spjat s teplotou vzduchu zatímco jeho populační hustota je vázána i na ostatní meteorologické prvky. Z těchto důvodů byl zvolen jako modelový organismus za účelem posouzení jeho vývoje v podmínkách změny klimatu. Na základě řady literárních zdrojů byl vyvinut jednoduchý model popisující jednotlivé fáze vývoje zavíječe, které jsou stanoveny na základě meteorologických údajů dané vegetační sezóny. K evaluaci modelu byla využita široká databáze obsahující záznamy výskytu zavíječe kukuřičného na území České republiky v období 1961-2000. Prvním výstupem bylo vymezení klimatického prostředí výskytu zavíječe pomocí Geografických informačních systémů a gridu o rozměru 1x1 km. Hlavním výsledkem příspěvku je popis možného výskytu škůdce založeného na řadě scénářů změny klimatu vycházejících z řady Globálních cirkulačních modelů (např. ECHAM, HadCM, NCAR) v kombinaci s několika scénáři vývoje emisí skleníkových plynů pro řadu časových obdoví včetně standardně definovaných časových period 2015, 2025 a 2050.

Introduction

There are major gaps between the actual and attainable yields of crops, attributable largely to the pests, diseases and weeds. In global change research, estimates of crop yields using simulation models also suffer from major gaps between observed and predicted yields. Furthermore invertebrates and plant pathogens are highly adapted to change and so are prime targets for risk assessment in global climate change. Therefore predicting the potential distribution of all pests, both indigenous and introduced, plays a key role in determining the effects of global change effects on agricultural, horticultural and forestry ecosystems. Pest-host relationship can be affected by climate change in different ways. Pests that are currently of minor significance may become key species, thereby causing serious loses in European countries. The distribution and intensity of current key pest and diseases may be affected leading to changed effects on yield and on control measures such as pesticides and integrated pest management. It is also apparent that pests will migrate as crops will migrate in association with climate-induced changes in crop compositions in various regions. In the same time the pesticide usage will change thus leading in some cases to increase of the production costs.

European corn borer (ECB), *Ostrinia nubilalis* (Hübner) is a major pest of corn in many countries and has been studied by generations of entomologists since 19^{th} century. Its development is known to be closely correlated with daily air temperature whilst the population density is to great extend dependent on other weather parameters. For these reason we have chosen it as one of the model organisms in order to widen the reach of the present assessments of the climate change impacts on crop growth and development.

Material and methods

The initiation, 50 % development and termination dates of each stage were estimated using degree day model (DD) technique that has been found as rather effective compared to more sophisticated approaches (Got *et al.,* 1996). The base of the degree-day model was set at 10 °C as originally proposed by Apple (1952). The degree-day calculations were used the daily TMIN and TMAX values using method proposed by Arnold (1960) and recommended by Mason *et al.* (1996). The degree-day accumulation in given season starts only when there is no snow cover present and the TMIN at 2 m height is higher than 0.2 °C. The snow cover presence is simulated with the help of the Running and Couglan (1988) simple snow pack model. These changes to the degree day accumulation algorithm were found to perform in the climatic conditions of the Czech Republic better than the

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original approach starting degree day accumulation on the 1st January of the given year regardless of the weather conditions. As the rate of European corn borer development decreases significantly when the temperatures reach the upper threshold, we trimmed the TMAX values used for DD accumulation at 32°C. This value was set in the middle of the range reported by e.g. Anderson *et al.* (1982), Calvin *et al.* (1991), Got *et al.* (1994) or Got *et al.* (1996). As it was impossible to verify the rates of the pest development due to the scarcity of the experimental data we used the tables of temperature thresholds defined based on the Brown's degree-day model (Brown, 1982). The thresholds were partially modified based on the values given by Mason et al. (1996). Despite the fact that these thresholds were derived based on the populations from Kentucky, North Dakota, Missouri, Delaware and Pennsylvania we have found that they accommodate well values that have been used in the Central Europe (Cagáň et al., 1996; SPA, 1999) for the developmental stages that are routinely monitored in the field conditions.

The determination of the possibility of the second generation of the European corn borer in the Czech Republic is a critical part of the study. Until now the partial second generation has been proven only in Slovakia and Poland during 1994 (Cagáň *et al.,* 1998 and Cagáň *et al.* 2000) and the ratio of the pupae and the diapauzing 5th instar larvae was approximately 1: 2000. The economical effect of the partial second generation is negligible and its scarcity points out to the strong univoltine character of the population. As Cagáň noted, the partial second generation in the Central Europe can be encountered when larvae will reach the 4th instar under daylight (sunrise to sunset) of at least 15h 30 min. He showed that in both cases when the partial second generation was in fact proven in the field conditions of the Central Europe this condition was met. The approach suggested by Cagáň is advantageous due to its simplicity and the method successfully signaled the presence of the second generation when it actually occurred (during 1994 in Slovakia and Poland).

Spatial analysis of the European corn borer characteristics

One of the key aspects of the study was the effort to generalize results from the individual stations to the whole agricultural area of the Czech Republic. Therefore the Environmental Change Assessment Model of Ostrinia Nubilalis (ECAMON) integrating multiple modules (some of them described above) was run at each of the 45 weather stations over the given period (using the daily data set of 30 years at each site).

In the beginning of each run we assumed that European corn borer can eventually occur at each of the stations. Then we evaluated outputs of the ECAMON model for all years and stations and discarded those where the given developmental stage of the pest was not found. Multiple linear regression models were consequently fitted to each data set containing altitude, northing and easting (as well as their first order interactions and squares) as independent variables, with the various ECAMON outputs as the dependent variable. Each climate data set was considered to be independent of the previous ones. The Pearson correlation coefficient values of the regression line forced through the origin between the independent and dependent variables were found to be within 0.85-0.97 depending on the mapped characteristics.

Results

Evaluation of the ECAMON model

The temperature sums marking onset of the stage and its completion by 50% and 100% of the population were the key input parameters of the model and thus special care was taken regarding their values. Despite the fact that the key input parameters were derived from various literature sources we have found that the ECAMON is capable to reasonably well estimate the dates of the first generation flight initiation and the flight completion by 50% of the population. The flight initiation was estimated by the ECAMON model with mean bias errors smaller than 2 days whereas the date in which 50% of the population finished the flight stage was estimated with mean error of 4 days. Limited data from the experiments in the Czech or Slovak

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Republic showed that the ovipossition beginning was simulated with the same mean bias as the flight initiation.

The diapauze modules were tested using datasets published by Cagáň (1998), Cagáň et al. (2000) and Tancik and Cagáň (2004) from Central European sites where the partial second generation occurrence has been verified under field conditions. Out of the datasets we selected years 1994-1996 for which daily weather data are available for both locations. At both sites in 1994 the possibility of partial second generation (i.e. some non-diapauze larvae were recorded) while in the remaining two seasons the diapauze module did not indicated the possibility of the partial second generation.

In general we have found the degree of uncertainty in the ECAMON model outputs to be acceptable for the studies of the climatic niche of the pest and the ECAMON precision is comparable with the methods recommended by the Czech State Phytosanitary Authority.

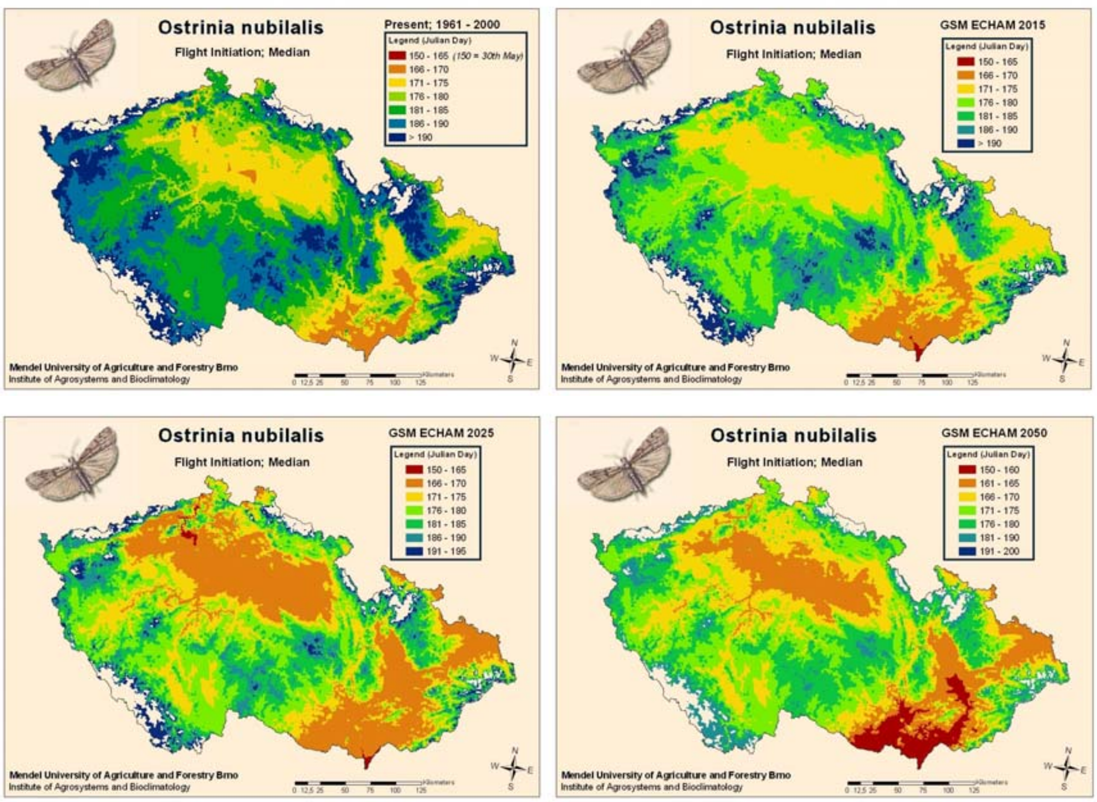

Figure 1: Estimated date (in Julian days) of the flight initiation calculated as median of 40 (for the present climatic conditions) and 30 years (for changed climate conditions) series. The 2015, 2025 and 2050 time horizons are given in comparison with the present climatic conditions (1961-2000). In this case ECHAM GCM model in combination with MIDDLE scenario (mean of A1 and B2 SRES green house emission scenarios) and average climatic sensitivity were considered.

Climate change impact on the selected characteristics of European corn borer

The evaluation of the effect of the climatic change included extensive simulation exercise using range of Global Circulation Models - from now on GCMs - (with focus on the ECHAM, NCAR and HadCM) and four SRES emission scenarios in combination with three levels of sensitivity of the climatic system. For details on the construction of the scenarios

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please refer to the Dubrovský *et al.* (2005). In this study we opted for three various combination of the climate system sensitivity and greenhouse gases emission scenarios. So called LOW set of scenarios assumes green house gasses emission development according to B1-SRES in combination with low sensitivity of climatic system to their increased concentration. On the contrary the HIGH scenario assumes high sensitivity of the climatic system to the increased greenhouse gases emissions and emissions according to the A2-SRES scenario. Finally the MIDDLE scenarios assumes the greenhouse gasses increase according to the average of A1 – SRES and B2-SRES scenarios and medium sensitivity of the climatic system.

After construction of the climatic scenarios the daily data for the period 1961-1990 at the 45 stations were directly modified by the monthly increments of temperature and by a relative change of precipitation in the time horizons of 2010, 2015, 2020, 2025, 2030, 2040, 2050 and 2075. The ECAMON was then run for all combinations of the HIGH, MIDDLE, LOW and GCM for each time horizon and the selected output parameters were mapped as described in the methodology section.

As it is apparent from the Fig. 1, marked shifts in the date of the first generation flight initiation are going to become apparent by 2015. (Such changes have been already taking place during 1991-2000 period compared to 1961-1990 baseline – not shown). By 2050 the flight would in general start 10 days earlier compared to the 1961-2000 period (14 days earlier compared to 1961-1990 baseline). As Fig. 2 shows the area with potential partial second generation will increase significantly by 2015 (assuming ECHAM GCM predictions in combination with MIDDLE emission scenario will be realized). By 2050 all maize growing regions will be faced with the prospect of partial second generation in at least 25 years out 30 with possible complete second generation in 15-22 seasons out of 30.

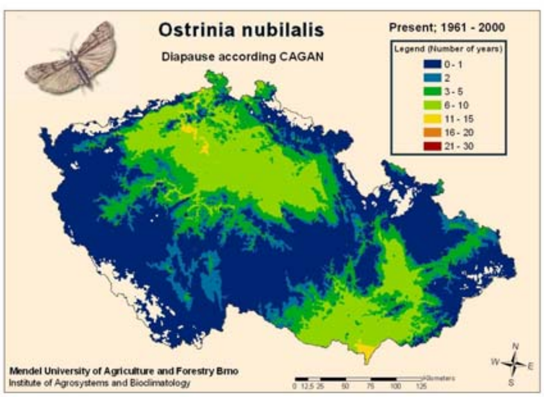

Figure 2: Estimated number of years during which part of the ECB population will not likely enter diapauze i.e. the second generation will be possible at the territory. Whereas the present climate includes 40 year long series 1961-2000 (thus including the warmest decade of the 20th century) the changed climate runs are based on direct modification of 30 year long series of 1961-1990 baseline. ECHAM GCM model in combination with MIDDLE scenario (mean of A1 and B2 SRES green house emission scenarios) and average climatic sensitivity were considered.

Conclusions

Initial analysis of the climate change impact on the European corn borer climatic niche uncovered that significant changes of the pest distribution are to be expected in the foreseeable future. Even despite the degree of high uncertainty caused both by the wide range of possible development of the climatic system and uncertainties in the pest response to the climatic conditions the bivoltine population will likely occur

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at part of the territory by 2025-2050 depending on the actual climatic conditions. Even though the impact of such shift would be economically significant one should bear in mind that the presented study shows worrying effect of climate change on other species of the insect in the ecosystems with consequences that we are not currently able to estimate with reasonable precision.

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