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Evaluation of the phenological synchrony between potato crop and Colorado potato beetle under future climate in Europe

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ABSTRACT

Europe is one of the world's largest food producers, and climate change may pose a serious threat to food security in the region. In the present study, we assess the potential impact of climate change on the Colorado Potato Beetle (CPB), *Leptinotarsa decemlineata* (Say)—a severe pest of potato (*Solanum tuberosum*, L.). We also investigate the possible impact of climate change on the phenological development of potato. The main focus is on factors that may limit the northward expansion of the CPB, and the number of generations per year in areas where the insect pest is already present. These factors include lack of temperature sum for completed development before winter, and lack of food (i.e. potato) due to mismatches in insect-host plant phenological synchrony.

We use a gridded observational dataset and an ensemble of bias corrected regional climate model data for the period of 1981–2099, representing RCP8.5, as input to a potato and CPB phenological model. The results show that in the future, CPB individuals with a low developmental threshold (+10 °C) can complete maturity of two generations per year before potato is harvested in most parts of Europe. A third generation of CPB may not be able to complete maturation due to lack of food in south and central Europe, while temperature becomes a limiting factor further north. In north-eastern Europe, the initiation of a first generation may be delayed due to lack of food in spring. CPBs with a high developmental threshold (+12 °C) will emerge later from winter hibernation, and food availability will therefore not be a problem in spring. However, individuals with a high developmental threshold face a greater risk of regeneration failure caused by harvesting of potato in autumn. The potential lack of food in autumn may also increase the strength of selection towards a low developmental threshold in northern populations. The combined analysis of CPB and potato phenology indicated that climate change can lead to increased pressure from the CPB in most potato growing areas.

1. Introduction

Climate change is one of the most serious problems facing the world today, and the recent IPCC report concludes that in northern Europe, >50°N, the climate will become warmer and wetter, while further south it will become warmer and drier (IPCC, 2013). This may have negative impacts on agriculture, due to increased severity of unfavorable weather and climate events (Porter et al., 2014). Insect pests can also cause damage to crops if left uncontrolled, thereby increasing the risk of crop losses (Oerke, 2006; Fand et al., 2012). Rising temperature may affect phytophagous insects, both directly via physiology, life cycle, and range shift, and indirectly via the availability of host plants (Bale et al., 2002). That is, climate change may cause mismatches in the timing of insects and their food sources, and periods with food shortage will lower the reproductive success of the insect pests (Porter et al., 1991).

The potato (*Solanum tuberosum*, L.) is the fourth most widely grown food crop in Europe and can be grown in a wide range of agro-climatic conditions (Haverkort, 1990; FAO, 2008). Temperature is one of the main factors that controls the development of potato (Kooman and Haverkort, 1995). In the future, in southern Europe, heat stress and scarcity of water will be the main limiting factors of potato growth, whereas in northern Europe a warmer climate is expected to enhance the crop yield (Supit et al., 2012).

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The Colorado potato beetle (CPB), *Leptinotarsa decemlineata* Say, is the most devastating insect pest of potato (Alyokhin et al., 2008) and both larvae and adults feed on potato leaves (Ferro et al., 1985). The development from egg to adult is temperature dependent, and the northern distribution limit of the CPB currently borders the Scandinavian countries (EPPO, 2014). Climate change could lead to range expansion of the CPB at high latitude and increases in voltinism across the range (Bebber et al., 2013; Jönsson et al., 2013; Pulatov et al., 2014).

Impact models can be a useful tool for assessing where and how changes in phenology of agricultural pests and crops are most likely to occur, in order to prepare timely management plans. Understanding how abiotic (e.g. temperature) and biotic (e.g. beetles) factors interact and influence potato production is essential to the decision on how to adapt to the effects of climate change (Hijmans, 2003; Oerke, 2006). In recent years, modelling studies have been carried out to assess the impact of a warming climate on the potential distribution of the CPB (Sutherst et al., 1991; Kocmankova et al., 2010; Jönsson et al., 2013; Pulatov et al., 2014), its host plant (Kooman and Haverkort, 1995; Wolf, 2002; Wolf and van Oijen, 2003; Streck et al., 2007; Supit et al., 2012), and the effectiveness of eradication measures (Valosaari et al., 2008; Ooperi and Jolma, 2009). However, climate change may lead to phenological mismatches between interacting organisms (Menzel et al., 2006; Cleland et al., 2007) rendering the simulations of species-specific impact models invalid. Host plant and insect pest phenological models can be combined to assess the joint effects of global warming (Maracchi et al., 2005; Soussana et al., 2010), but so far no study has linked the effect of climate change on the population dynamics of insects with potato crop models (Raymundo et al., 2014).

The aim of our study is to identify and quantify the factors limiting the northward expansion of the CPB by assessing temperature restrictions for completed CPB development before winter and temporal lack of food due to asynchrony between insect and host plant phenology. This will provide a measure on how close an area is to a shift in voltinism, of relevance when planning agricultural monitoring activities and countermeasures.

2. Material and methods

In this study we use daily near-surface air temperature (tas) as input for an impact model simulating the phenology of CPB and potato and their temporal synchrony. The impact model consists of a Colorado potato beetle module (Section 2.2) and a potato module (Section 2.3). Both the plant and insect phenological development were expressed as growing degree days (DD) above a base temperature (D.T.). We use two gridded observational datasets of the recent past, one for bias correction and one for evaluation purposes (Section 2.1.1). To account for climate model uncertainties the impact model was driven by an ensemble of climate model data (Section 2.1.2).

2.1. Climate data

2.1.1. Reference data

European gridded observation data (Haylock et al., 2008), E-OBS version 10 interpolated onto a grid of approximately 50 km × 50 km, was used as reference input data for the impact model. The period 1981–2010 was selected to represent the baseline conditions, as recommended by the World Meteorological Organisation (WMO, 2014).

For the bias adjustment of the regional climate model data, a recently published European gridded observation data set, Mesan-EURO4 M (Bärring et al., 2014; Landelius et al., 2015) was used. The data set includes, among other variables, daily mean temperature covering the period 1989–2010 at a spatial resolution of about 5 km. For use with the lower resolution datasets (50 km), this high-resolution dataset (5 km) is re-gridded using first-order conservative remapping to the same grid as E-OBS and the regional climate model data.

E-OBS has the advantage of covering a longer period (1951–2010), than Mesan-EURO4M which covers 22 years, while the latter makes use of a more advanced approach towards interpolation. We therefore choose to use E-OBS in our modelling of CPB and potato for the past few decades, and Mesan-EURO4 M as reference dataset for the bias correction.

Table 1
GCM-RCM combinations from EUR O-CORDEX RCP8.5 on 0.44°_ grid (Jones et al., 2011). Five ensemble members were selected for use in this study (bold letters) based on a statistical analysis (Fig. S1).

GCM	RCM	Abbreviation
CanESM2	**SMHI-RCA4**	**CanESM2-RCA4**
CERFACS CNRM CM5	**SMHI-RCA4**	**CERFACS-RCA4**
IPSL CM5A MR	**SMHI-RCA4**	**IPSL-RCA4**
MIROC5	SMHI-RCA4	MIROC5-RCA4
HadGEM2-ES	SMHI-RCA4	HadGEM2-RCA4
M-MPI-ESM-LR	SMHI-RCA4	MPI-RCA4
NorESM1-M	**SMHI-RCA4**	**NorESM1-RCA4**
GFDL-GFDL ESM2M	**SMHI-RCA4**	**GFDL-RCA4**
EC-EARTH	SMHI-RCA4	EC-RCA4
EC-EARTH	DMI HIRHAM5	E C—HIRHAM5
EC-EARTH	KNMI RACMO22E	EC-RACMO22E

2.1.2. Regional climate model data

Regional climate model data from the EUR O-CORDEX project used in the present study were downloaded from the federated web service ESGF[1] in February 2015 (see Table 1). The data covers all of Europe and a 149−year period, 1951−2099. The period 1951−2005 comprises historical runs where the global climate models (GCM) were forced with observed concentrations of greenhouse gases and other radiative forcing agents. For the remaining period, 2006–2099, we decided to focus on simulations driven by the high-end scenario RCP 8.5 (Riahi et al., 2011), representing strong radiative forcing due to large greenhouse gas emissions. The motivation for focussing on RCP8.5 is two-fold. Firstly, during the short period since 2006, when there is overlap between observed and projected emissions there are indications that the current CO_2 emissions are tracking close to the RCP8.5 path (Sanford et al., 2014). Secondly, we wish to analyse a scenario that has potential to show a distinct climate change response in the Colorado potato beetle and potato development.

2.1.3. Bias adjustment of climate model output

Direct output from climate models commonly shows systematic biases compared to observations (Christensen et al., 2008; Vautard et al., 2012). In the present study, empirical quantile mapping was used to adjust for climate model output biases. For each grid-cell, empirical cumulative distribution functions (ECDFs) of simulated model output were mapped onto the corresponding ECDFs of a reference data set extracted from Mesan-EURO4M-based observations (cf. Themeßl et al., 2011; Wilcke, 2014).

2.1.4. Climate model selection

The EUR O-CORDEX data set contains several ensemble members (Table 1) to quantify the spread and uncertainty of future climate projections. The spread and uncertainty should be taken into account also in impact studies, however, using the full ensemble is commonly not feasible due to time restrictions and

[1] ESGF: Earth System Grid Federation, e.g. http://esg-dn1.nsc.liu.se/.