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5 **Chapter 8 Climate change effects on agricultural insect pests in Europe**

6

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11

12 **Abstract**

13

14 In this chapter we will discuss observations of climate change effects on agricultural pests in
15 Europe, the possible mechanisms behind these observed effects and finally delve into more
16 detail through some, relatively well studied model species (the Colorado potato beetle and the
17 rape beetle). Direct effects of climate change on agricultural pests in Europe are difficult to
18 dissect from all the human induced changes that have taken place in parallel with an
19 increased mean annual temperature. During the last decade agriculture has become more
20 professionalized in terms of land use, crop cultivation techniques and pest management
21 strategies. We review the effect of climate change on agricultural pest by comparing the
22 speed of range expansion of pest species to non-pest species. It seems that the poleward range
23 shift has been faster for pest than non-pest species. We partly attribute this to the
24 globalization of agriculture as human assisted movement has broken many natural dispersal
25 barriers. Since the biology of many pest species is relatively poorly studied, direct
26 conclusions on how climate change has affected biological processes of pests are challenging
27 to make.

28

29 Keywords: Coleoptera, range expansion, diapause

30   **Chapter 9 Climate change effects on agricultural insect pests in Europe**

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37   **1. Introduction**

38

39   While climate change scenarios for European agriculture suggest both positive and negative

40   effects, the net effects are calculated to be negative (Hyvönen 2011; Hoye et al. 2013;

41   Challinor et al. 2014). The effects depend on location and future scenarios vary largely for

42   different parts of Europe. In northern Europe mean temperatures are increasing (especially

43   during winter and spring) and thus the immediate effects of climate change could be positive

44   due to a prolonged growth season length (Myeni et al. 1997). Similarly the predicted increase

45   in air CO_2 and temperature can boost plant growth if necessary water, nutrients and pest

46   control is available (Wand et al. 1999). Indeed, in many countries, such as Finland,

47   increasingly shorter development times of various crops have been documented during the

48   last 50 years (Peltonen-Sainio and Hakala 2014). In southern Europe, in turn, temperatures

49   have been suggested to increase even more than the estimated average mean global

50   temperature increase (Carraro and Sgobbi 2008; IPCC 2013). When this is accompanied with

51   an increased frequency and severity of heat waves and decrease in precipitation, the end

52   result may be an increase of desertification rather than an increase of agricultural

53   productivity.

54

55   Similarly as for plants, growth season length and thermal stress are amongst the most

56   important factors limiting ranges also in many arthropods (Addo-Bediako et al. 2002).

57   Therefore we can ask: what are the major predictions of climate change responses of

58   European pests. A longer, warmer growth season is expected to affect pests through

59   increasing the time available for development and growth, provided that also hosts or prey

60   are available, or put another way, provided that the pests have been temporally restricted

61   previously (Bale et al. 2002). Depending on the life history strategies of the pest, signs of

62   climate change effects could be variable (see e.g. Musolin 2007; Kingsolver et al. 2011) and

63   expected for instance in development time (Boman et al. 2008), voltinism (the number of

64   annual generations) (Altermatt 2010) and the duration of the reproductive period (van Asch et

65   al. 2013). These changes in life history traits can have population consequences and lead to

66   increased population sizes or enlarging or alternatively, shifting, ranges (Gaston 2003;

67   Bebber et al. 2013; Bacon et al. 2014). On the other hand increased temperatures may also

68   allow host plants to be able to better protect themselves against herbivory (DeLucia et al.

69   2012), which again can reduce pest population sizes. Additionally most major agricultural

70   pest species are under continuous surveillance and actively controlled by humans when

71   needed and therefore might not be able to fully utilize the benefits of temperature increase

72   and climate change.

73

74   In the present chapter we aim to summarize observed effects of climate change on important

75   agricultural insect pests in Europe. Many pests exist in complex, often non-natural conditions

76   in agricultural systems. Climate change is expected to influence both the agricultural systems

77   as well as the pests in both indirect and direct ways. Therefore it can be challenging to show a

78   causal connection between climate change and pest species biology. For the purposes of

79   simplicity we will divide climate change into both climatic effects (e.g. temperature,

80   humidity), and anthropogenic effects, which mainly are responses to climate change (changes

81   in agricultural practices, land use, human population sizes, transport pressure). Of these,

82   direct climatic effects are more studied. In this chapter we will discuss: the basis of the

83   observation of climate effect, the possible mechanisms behind these observed changes and

84   finally delve into more detail through some, relatively well studied model species.

85

86   **2. Observed increase in pest introductions and range shifts towards the poles**

87

88   Due to the negative impact pest species generally have on agriculture there is an acute

89   interest to monitor and restrict the spread of pest species as well as to influence their

90   population dynamics. However, although many governmental and agricultural officials keep

91   records (e.g. Vänninen et al. 2011; Genovesi and Scalera 2011; Hyvönen 2011) of pest

92   species in a given country and EPPO (The European and Mediterranean Plant Protection

93   Organization) keeps a record of new introductions of many pests to Europe, systematic record

94   keeping is fairly recent. This makes it hard to estimate the effect of climate change on

95   European pests over long periods of time. Furthermore, the majority of existing literature on

96   climate change effects actually consists of predictions rather than observations (Cannon

97   1998; Dupin et al. 2011; Aragón and Lobo 2012; Kroschel et al. 2013; Maiorano et al. 2012;

98   Stöckli et al. 2012; Jönsson et al. 2013; Bacon et al. 2014).

99

100   At the same time as changes in climate have taken place during the last 100 years (IPCC

101   2013), agricultural practices have changed and become more professionalized. The

102   productivity of agriculture has increased due to the increase in plant breeding programs,

103   fertilizer use and organized pest management monitoring and control. In Europe there has

104   been an organized plant protection practice since the establishment of EPPO in 1951. This

105   means that there has been an early alert system as well as organized quarantine practices for

106   many pest species. This might have hindered pest species to respond to changes in climate

107   and invade new areas unnoticed. However, within the last 30 years, in parallel with

108   temperature increase, globalization and the associated large up-scaling in trade has broken the

109   natural dispersal barriers of many species (see e.g. Lebarbenchon et al. 2008). All these

110   changes have happened at the same time and disentangling effects due to changes in climate

111   from the other changes is extremely difficult.

112

113   According to the latest assessment by the IPCC, mean annual temperatures have increased by

114   approximately 0.85°C during the last 100 years and will continue to increase under all

115   envisioned climate change scenarios (IPCC 2013). The observed increase in temperature has

116   resulted in range enlargements or shifting of the entire range towards higher latitudes or

117   altitudes in many non-pest species (Parmesan et al. 1999; Walther et al. 2002; Chen et al.

118   2011). The speed of climate change-dependent range shifts vary depending on the species

119   group as well as the time investigated (see Table 9.1; Hickling et al. 2006; Bebber et al.

120   2013). The first estimates of range shifts of several non-pest species suggested that the speed

121   has been on average 6.1 km per decade (Parmesan and Yoche 2003) whereas recent

122   estimates, at least for butterflies, suggest a 10 times faster speed (e.g. Pöyry et al. 2009). For

123   non-pest butterfly species in northern Europe, dispersal ability together with habitat

124   availability has been suggested to play major roles in the observed range expansions (Pöyry

125   et al. 2009). This and other studies highlight that species life-history traits are imperative to

126   consider when assessing their capacity to respond to climate change (Saikkonen et al. 2012;

127   Breed et al. 2014; Mair et al. 2014). While most studies on responses to climate change have

128   focused on non-pest species, these results may be used as tools to estimate effects also for the

129   numerous pest species (Bebber et al. 2013).

130

131 **Table 8.1** Average range shifts of both pest and non-pest insect species collected from various meta-analyses published during the last decade. The observation time (as
132 recorded in the given literature) and the rate of range shifts (kilometres/year, ± standard error of mean) within the observed time period. The number of species is given in the
133 brackets.
134

	Pest species		Non-pest species			
Observation time	ca.1920-2010	1960-2010	ca.1965-1990	1992-2000	ca.1920-2000	Variable
	Rate[1] km/a ± SE (sp)	Rate[1] km/a ± SE (sp)	Rate[2] km/a ± SE (sp)	Rate[3] km/a ± SE (sp)	Rate[4] km/a ± SE (sp)	Rate[5] km/a ± SE (sp)
Coleoptera	7.61 ± 1.87 (70)	12.21 ± 4.33 (70)	2.48 ± 0.43 (86)			
Diptera	3.11 ± 2.48 (24)	3.95 ± 6.08 (24)				
Hemiptera	6.13 ± 3.25 (47)	13.71 ± 5.32 (47)				
Hymenoptera	4.60 ± 9.48 (6)	8.11 ± 11.64 (6)				
Isoptera	19.62 ± 10.83 (1)	-7.51 ± 13.89 (1)				
Lepidoptera	8.00 ± 2.71 (36)	17.78 ± 8.58 (36)	1.76 ± 0.46 (29)	7.49 ± 1.75 (48)		
Neuroptera			1.76 ± 1.16 (6)			
Odonata			4.16 ± 0.68 (20)			
Orthoptera			1.36 ± 0.32 (22)			
Thysanoptera	7.68 ± 4.36 (3)	1.06 ± 9.31 (3)				
OVERALL		2.7 ± 0.8 (600)	1.74 ± 0.82 (329)		0.61± 0.24 (99)	1.76 ± 0.29 (764)

135 1 Bebber et al. 2013, Estimates based on CABI records
136 2 Hickling et al. 2006, Estimated from different UK species, times vary
137 3 Pöyry et al. 2009, Estimated from Finnish butterflies
138 4 Parmesan & Yoche 2003, Includes also birds, herbs and butterflies
139 5 Chen et al. 2011, Based on several published meta-analysis

140

141   The range shifts of pest species has been recently estimated from 612 species including fungi,

142   bacteria and viruses in addition to arthropods by Bebber et al. (2013). This study shows a

143   poleward shift of pests which is 27 km per decade since the 1960s and therefore it seems that

144   range shifting has been significantly faster in pest species than for non-pest natural

145   arthropods (Table 9.1). So can agricultural pests respond to climate change faster than non-

146   pest species? To dissect the effect of climate change on the range expansion of many pest

147   species from other anthropogenic effects, such as land use (Kalnay and Cai 2003) or human

148   assisted movement (Smith et al. 2007) is, like stated, challenging. During the last 100 years,

149   massive changes in agricultural policies and other anthropogenic factors have taken place.

150   These include, pesticide use together with quarantine regulations (see Bacon et al. 2014),

151   which should both hinder pest range shifts due to constant control of pest population size. On

152   the other hand, the transport of goods in turn has increased the interconnectivity of the globe

153   which should increase the rate of range expansion of many pathogens and pests

154   (Lebarbenchon et al. 2008) due to enhanced propagule pressure (Mack et al. 2000; Tatem &

155   Hay 2007). Indeed, it has been shown that the ornamental plant trade is one major contributor

156   to the introduction of new plant pest to European countries (Smith et al. 2007). This is

157   probably because an increase in trade elevates propagule pressure and makes introductions

158   more frequent. In Great Britain 70 % of pest species established since 1970 have been

159   estimated to be assisted by humans while only 30 % managed to establish on their own

160   (Smith et al. 2007). Similarly EPPO records show that there is actually an increase of new

161   pest records in Europe (Figure 9.1), although it is unknown whether this is related to the

162   changes in climate or changes in human transport (EPPO 2013a).

163

164   An additional problem is that the same pest species are imported from several places at the

165   same time. This can be illustrated with an example of a quarantine pest, the Silverleaf

166   whitefly, *Bemisia tabaci*. In 2013 alone, a significant number of *B. tabaci* individuals were

167   detected in imported vegetable and ornamentals shipments in the United Kingdom. These

168   individuals were brought to the UK from 14 countries from four continents (EPPO 2013a;

169   Figure 9.2) which could result in that the introduction site harbours higher genetic variability

170   than any of the original or native sites (Kolbe et al. 2004).This is part of the reason why for

171   instance tree nurseries in Europe can act as gateways for many plant pathogens in Europe

172   (Santini et al. 2013). Seedlings are brought to nurseries from various parts of the globe

173   together with their plant pathogens. In the nurseries it is therefore possible that different

174   disease strains meet and hybridize, resulting in high genetic variability of the plant pathogens.

175 When these seedlings are then sold to various parts of Europe the pathogens are exported to

176 large areas. Although we will observe a shift in ranges of these pathogens or pests, this is not

177 necessarily due to climate change but rather due to the human activities in the 21st century.

178 As an aside, forest pathologists have formulated "the Montesclaros Declaration", which states

179 that: "*We thus propose a phasing out of all trade in plants and plant products determined to*

180 *be of high risk to forested ecosystems but low overall economic benefit*"(see Santini et al.

181 2013).

182

183 **3. Can changes in winter biology explain changes in pest biology?**

184

185 Winter temperatures are predicted to be more strongly influenced by future climate change

186 than summer temperatures (IPCC 2013). Since winter abiotic and biotic conditions are major

187 factors governing arthropod biology in Europe, less severe and shorter winters in the future

188 could have a major impact on pest species population and range dynamics (Bale and

189 Hayward 2010). In a recent study the range shifts in non-pest butterflies in Finland were

190 found to relate to the stage in which the species overwinter (Pöyry et al. 2009). Species which

191 overwinter as adults were found to have expanded their ranges at a higher rate than those that

192 overwintered in other stages. This could be related to the fact that adults more easily can

193 prepare for winter, for instance through microhabitat selection, or it is easier for adults to

194 adapt to changes in the photoperiod (Lehmann et al. 2012; Saikkonen et al. 2012).

195

196 Although seasonal temperature averages and fluctuations are predicted to change in the

197 future, photoperiodic cycles will remain the same. As Europe is located in the temperate,

198 seasonal zone, any species invading to Europe or which can expand its range in Europe

199 should also be able to adapt to the changing relationship between photoperiod and season. In

200 temperate zones both the life-cycle of arthropods, as well as their hosts, are generally

201 governed by large seasonal fluctuations (Tauber et al. 1986). The season can be characterized

202 by a division into two phases, where summers constitute the active and winter the non-active

203 phase. This means that the species, which responds to changes in temperature by invading

204 northwards, have to be able to synchronize their life cycle with the new local seasonal cycle

205 (Bradshaw and Holzapfel, 2001; Bradshaw et al., 2004). For arthropods the observed range

206 shifts have been attributed to a release of thermal stress (Ammunét et al. 2012) as well as

207 seasonal re-synchronization of life-history (Gaston 2003; Bean et al. 2012; Saikkonen et al.

208   2012). This may require adaptive changes and ultimately the range shifts are then dependent
209   on the genetic variability within the species (e.g. Piiroinen et al. 2011).

210

211   To highlight some recent research and observations on insect pest species in Europe, we
212   chose to investigate beetles (Coleoptera) in more detail. Beetles are among the most diverse
213   insect taxa and several important pests are beetles, most notably in forestry, but also in agri-
214   and horticulture (Bebber et al. 2013). These include, for instance, the Colorado potato beetle
215   *Leptinotarsa decemlineata* (Alyokhin 2009) and the Western Corn rootworm *Diabrotica*
216   *virgifera* (Dupin et al. 2011). Table 2 lists some of the most important beetle pests found in
217   agri- and horticultural systems in Europe (Bebber et al. 2013). As can be seen the best
218   represented families are Curculionidae (true weevils or snout beetles), Cerambycidae
219   (longhorn beetles) and Chrysomelidae (leaf beetles). Of these insects, 26 feed primarily on
220   wood, 11 on soft plant tissue (including leaves, fruits, flowers, tubers) and 1 is carnivorous.
221   The majority (78 %) of these beetles have a dedicated overwintering stage, which in 72 % is
222   the adult stage. Interestingly, comparing ranges of beetle pests found in Europe with beetle
223   pests whose ranges do not include Europe (listed in Bebber et al. 2013) reveals that pests
224   whose range includes Europe are found over a larger latitudinal range (mean = 77.6°, SEM =
225   6.2) than those whose range excludes (mean = 55.0°, SEM = 4.5) Europe (two-tailed t-test:
226    $t_{66.2} = 2.43$, P = 0.018). This could indicate a sampling bias, since European (together with
227   North American) countries generally use more resources to track and report pest movements
228   (e.g. EPPO, NAPPO etc.), but the involvement of some biological mechanisms cannot be
229   ruled out.

230

231   While some species clearly have enlarged their ranges during the last 100 years, there are
232   several examples of beetle species which have not seemingly responded through range shifts
233   or changes in population dynamics (voltinism, population size). In fact, of the 37 beetle
234   species occurring in Europe which were studied by Bebber et al. (2013) only 2 showed a
235   significant range expansion or shift since 1960, while the absolute majority showed no
236   significant shift (Table 9.2). Since temperatures have increased, growth season become
237   longer and the winter shorter, the majority of species have likely not been restricted by
238   temperature previously, but more likely by other factors which are temperature-independent,
239   such as for instance pesticide use. Therefore it is important to consider the difference between
240   climatic unsuitability and invasion dynamics when trying to estimate whether species occur
241   where they do due to climate change. For example, as stated by Dupin et al. in their study

242   (2011): "*Only presence data* (ed. of *Diabrotica virgifera*) *were considered in Europe as the*

243   *range of the pest is still expanding and hence absences from this region may not be an*

244   *indication that the climate is unsuitable.*"

245

246 **Table 8.2** Major coleopteran pests found in Europe with some of their important biological traits. Data was gathered from EPPO and CABI. A generalist species is defined as
247 a beetle with over 5 host plant species. Latitudinal range was estimated based on Bebber et al. (2013). Some species are less well studied, and a question mark denotes that
248 uncertainty exists regarding that particular trait or that references are contradictory. Two species, (*Agrilus planipennis* and *Rhynchophorus ferrugineus*), have significantly
249 enlarged ranges due to climate change according to Bebber et al. (2013). All species occur in outdoor fields except for *Scyphophorus acupunctatus* which is limited to
250 greenhouses, and some species which occur both in outdoor fields and greenhouses (marked with a * after the species name).
251

Species	Family	Origin	Horti- (H) or Agricultural (A)	Feeds on wood	Generalist (G) or specialist (S)	Overwinters in diapause	Overwintering stage	Latitudinal range (°) [A]	Number of references in WoS [B]
*Acanthoscelides obtectus**	Chrysomelidae	Neotropical	A	N	G	Y?	Adult?	7.1	356
Agrilus planipennis	Buprestidae	Eastern Asia	H	Y	S	Y	Pre-pupa	127.8	236
Anthonomus bisignifer	Curculionidae	Japan	H	N	S	Y	Adult	28.4	0
Anthonomus pomorum	Curculionidae	Palearctis	H	N	S	Y	Adult	35.5	35
Callidiellum rufipenne	Cerambycidae	Eastern Asia	H	Y	G	Y	Pupa	120.7	13
Cylas formicarius	Brentidae		A	N	S	N[C]	Adult	85.2	197
Diabrotica virgifera	Chrysomelidae	North America	A	N	S	Y	Egg	30	700
Diocalandra frumenti	Curculionidae	Australia	H	Y	S	N		78.1	1
Gonipterus scutellatus	Curculionidae	Australia	H	Y	S	Y	Adult	113.6	39
Harmonia axyridis	Coccinellidae	Central- and Eastern Asia	A	N	G	Y	Adult	120.7	850
Hylobius abietis	Curculionidae		H	Y	G	Y	Larva	127.8	310
Hylotrupes bajulus	Cerambycidae	Europe	H	Y	S	N[C]	Larva	127.8	90
Hylurgus ligniperda	Curculionidae	Europe	H	Y	S	Y	Adult	131.35	29
Hypothenemus hampei	Curculionidae	Central Africa	H	N	S	N		78.1	293
Ips cembrae	Curculionidae	Europe	H	Y	S	Y	Adult	134.9	24
Ips sexdentatus	Curculionidae		H	Y	S	Y	Adult	63.9	95
Ips subelongatus	Curculionidae		H	Y	S	Y	Adult	39.05	14

Species	Family	Origin					Stage		
Ips typographus	Curculionidae	Europe	H	Y	S	Y	Adult	35	787
Leptinotarsa decemlineata	Chrysomelidae	Mexico	A	N	S	Y	Adult	71	1592
Lilioceris lilii	Chrysomelidae		H	Y	S	Y	Adult	49.7	17
Listroderes costirostris	Curculionidae	South America	A	N	G	N[C]	Pre-pupa	110.05	6
Megaplatypus mutatus	Curculionidae	Neotropical	H	Y	G	Y?	Larva	99.4	12
Meligethes aeneus	Nitidulidae	Holarctic Region	A	N	G	Y	Adult	49.7	175
Monochamus galloprovincialis	Cerambycidae	Eurasia	H	Y	S	Y?	Larva	49.7	54
Monochamus sutor	Cerambycidae	Eurasia	H	Y	G	Y	Larva and pupa	49.7	11
*Phaedon brassicae**	Chrysomelidae	East and South Asia	A	N	G	Y	Adult and larva?	35.5	12
Phoracantha recurva	Cerambycidae	Southeast Asia	H	Y	S	N?		106.5	20
Phoracantha semipunctata	Cerambycidae	Australia	H	Y	S	N?		127.8	88
Pissodes castaneus	Curculionidae	Europe	H	Y	G	Y	Larva, adult	49.7	22
Rhynchophorus ferrugineus	Curculionidae	Southeast Asia	H	Y	G	N?	Adult	78.1	131
Saperda candida	Cerambycidae	Costa Rica	H	Y	G	Y?	Larva	35.5	0
Scolytus morawitzi	Curculionidae	Asia	H	Y	S	Y	Larva	28.4	0
Scolytus schevyrewi	Curculionidae	Eastern Asia	H	Y	G	Y?	Larva, adult	35.5	13
Scyphophorus acupunctatus	Dryophthoridae	New World	H	N	S	N?		63.9	22
Sinoxylon conigerum	Bostrichidae		H	Y	G	Y	Adult	85.2	1
Xylosandrus crassiusculus	Curculionidae	Southeast Asia	H	Y	G	N?		78.1	26
Xylosandrus germanus	Curculionidae	East Asia	H	Y	G	Y	Adult	85.2	37
Xylotrechus altaicus	Curculionidae	Asia	H	Y	S	Y	Larva	21.3	0

252   *Notes* [A] Resolution was 7.1°. [B] Web of Science (WoS): "http://apps.webofknowledge.com/" was accessed 24.4.2014. [C] Non-diapause dormancy.

253

254   Although the poleward range shift for Coleoptera was estimated to be 12.2 km/year in the
255   data collected by Bebber et al. (2013), only two species showed significant, climate-change
256   driven, enlargements of their range. These were the Emerald ash borer, *Agrilus planipennis*,
257   and the Red palm weevil, *Rhynchophorus ferrugineus*, both serious wood-feeding forest pests
258   (Bebber et al. 2013). *Agrilus planipennis* feeds on various *Fraxinus* species and has a
259   distribution covering most of northern Asia including European Russia (Baranchikov et al.
260   2008) and North America, where it was introduced in the beginning of the 21st century
261   (EPPO 2005). Larvae feed in the cambium of trees or in the stems of smaller woody plants
262   and will ultimately kill attacked trees. While still absent from the EU, despite several
263   interceptions, the likelihood the species could establish itself is considered very high (EPPO
264   2005; Baranchikov et al. 2008). While *A. planipennis* is native to Far East Russia and thus
265   adapted to seasonal environments, *R. ferrugineus* is native to the tropics and has expanded its
266   range into seasonal environments only relatively recently (EPPO 2008). As can be deduced
267   from its common name, *R. ferrugineus* feeds on various Palm trees. Currently it is found in
268   most of southern Europe, where palm trees are cultivated both commercially and for
269   ornamental purposes. While a serious pest in the tropics it is less of a problem in Europe,
270   primarily due to the relatively small scale of palm cultivation.

271

272   **4. Model systems in more detail**

273

274   **4.1 The Colorado potato beetle and the Rape beetle**

275

276   What is evident from the literature search on pest species we list in Table 9.2, is that we know
277   very little of the basic biology on many of them. Therefore it is difficult to actually document
278   changes that might have taken place due to climate change. We have therefore chosen two
279   pest species that are relatively well studied and ask how climate change has affected their
280   range expansion dynamics or general biology within ranges. The Colorado potato beetle,
281   *Leptinotarsa decemlineata* (Say) (Coleoptera:Chrysomelidae), is chosen as its range
282   expansion is well documented over the past and it originates from low latitudes in North
283   America and whose high latitude range expansion thus potentially has been restricted by
284   temperature. The Rape or Pollen beetle, *Meligethes aeneus* (Fabricius)
285   (Coleoptera:Nitidulidae), in turn is native to Europe and its expansion potential might be
286   related to indirect effects of climate change.

287

288   **4.2 The range expansion of the Colorado potato beetle across the northern hemisphere**

289

290   The rapid range expansion of *L. decemlineata* across most of the northern hemisphere has

291   been very well documented (Johnson 1967; EPPO 2014). *Leptinotarsa decemlineata*

292   originally stems from northern Mexico, and has in around 200 years transformed from a low-

293   density, low-latitude, non-pest species, to a high-density, high-latitude commercially

294   significant pest species (Alyokhin 2009). In this section we will briefly outline the life- and

295   expansion history of *L. decemlineata* and attempt to answer whether its range expansion has

296   been driven or influenced by ongoing climate change, and how climate change is expected to

297   affect established populations at different latitudes.

298

299   *Leptinotarsa decemlineata* was discovered and named by Thomas Say in the early 19th

300   century (Say 1824). The then described leaf beetle was just one of a group of 30-odd closely

301   related chrysomelids living in rather low density populations in Central America and the

302   southwestern part of the United States of America. This changed dramatically when potato,

303   *Solanum tuberosum*, was introduced into the southern states of the USA as a crop between

304   1840 and 1850. Soon afterwards some of the native *L. decemlineata* shifted host plants from

305   the local potato relative Buffalo bur, *Solanum rostratum*, to potato and became invasive. The

306   first American state where a major outbreak occurred was Colorado, which is the origin of

307   the beetles' common name (Casagrande 1987). Today *L. decemlineata* is the most important

308   insect pest of potato found in an area covering 16 million km^2 from Mexico, through North

309   America, to most of Europe and deep into Asia (Johnson 1967, EPPO 2014, Alyokhin 2009).

310

311   The capacity of *L. decemlineata* adults to burrow into the soil for overwintering in diapause

312   (e.g. Hsiao 1985) is probably among the most important features which has assisted its range

313   expansion into high latitude habitats (EPPO 2014). Diapause is a deep resting stage which

314   normally lasts one winter season, but can also be prolonged and last up to 9 years (Tauber

315   and Tauber 2002). Another interesting characteristic is that around 20 % of all newly eclosed

316   adults in every thus far studied population enter diapause regardless of environmental

317   conditions (Danilevski 1965; Hsiao 1985; Tauber et al. 1986; de Kort 1990). As *L.*

318   *decemlineata* is a major pest of potato, quarantine inspections and regulations has hindered its

319   spread (first notification in Europe 1875, permanent populations 1922). It is likely that de-

320   regulation of concerted pest management during the First World War was pivotal in allowing

321   the beetle to establish in France. The beetle has further been heavily selected by pesticides as

322   chemical control of population densities has been forcefully employed throughout its range.
323   The species is very capable of resisting pesticides, which probably is partly due to the natural
324   toxicity of the alkaloids of the host plant, potato (see discussion in Piiroinen et al. 2013), and
325   also rapid evolution of resistance against new pesticides (Alyokhin 2009). Indeed *L.*
326   *decemlineata* is justifiably called a super-pest due to the many features (fecundity, dispersal,
327   overwintering, and pesticide resistance) which have made containment and management very
328   challenging (Hsiao 1985; Alyokhin 2009).

329

330   The annual expansion distance of *L. decemlineata* has been estimated to be between 80 - 130
331   km in North America and Europe (Walsh 1865; Tower 1906; Johnson 1967; EPPO 2014).
332   The original historic spread of *L. decemlineata* across North America from relatively low
333   latitudes in Nebraska (41°N) where the first major outbreak took place in 1859 (Tower 1906)
334   to 50 °N in Canada 1901-1911, occurred took place during a time when little change in
335   ambient temperature occurred (IPCC 2013). Consequently, it is likely that this spread was
336   facilitated by habitat availability, dispersal ability, plastic life-history strategies and local
337   adaptation to pronounced seasonality at higher latitudes (Hsiao 1985) rather than changes in
338   climate. In Europe, in turn, the beetle has invaded northwards at a rate of approximately 28.6
339   km/year since the 1920s when the population was considered established in Europe in France
340   (44 °N) to its current northernmost latitude of around 61 °N in 1970. Thus it has expanded its
341   range at a much faster rate than non-pest species responding to climate change (Table 9.1)
342   which suggests that human involvement has been important.

343

344   Several studies on European and North American *L. decemlineata* populations suggest rapid
345   divergence of adaptive variation in life-history and physiological traits (e.g. Danilevskij
346   1965; Hsiao 1985; Boman et al. 2008; Lyytinen et al. 2012; Lehmann et al. 2012; 2014a; Izzo
347   et al. 2014). The question is whether these changes are driving range expansion, or whether
348   local adaptations arise secondarily after successful establishment (see Urbanski et al. 2012),
349   which primarily occurs without adaptation, through for instance plasticity or broad general
350   stress tolerance (Lehmann et al. 2014b). The range expansion of *L. decemlineata* in northern
351   Europe has slowed down during the last 30 years (EPPO 2014). This could be due to many
352   factors, including a shorter growth season, and a longer and harsher winter or due to a low
353   genetic variability (Grapputo et al. 2005). It is unlikely that a short and cold growth season is
354   strongly limiting expansion, since genetic variability still exists in growth related traits
355   (Boman et al. 2008; Lyytinen et al. 2008). At northern latitudes the progressively harsher

356   winter is a likely expansion barrier (Valosaari et al. 2008; Piiroinen et al, 2011). It is possible
357   that plasticity in avoidance behavior, which might have assisted in expansion in more benign
358   environments, fails to provide enough thermal buffering at high latitudes, thus requiring local
359   adaptation (Lehmann et al. 2014b). The retardation of expansion is therefore probably due to
360   an inability to respond to selection as high-latitude populations show low amount of heritable
361   variation in physiological traits important for winter survival (Piiroinen et al. 2011).

362

363   During the last 100 years, in parallel with the range expansion of *L. decemlineata*, climate has
364   warmed by approximately 0.85°C (IPPC 2013). Has this increase in temperature had a
365   meaningful impact on the range expansion propensity of the beetle? Many life-history traits
366   have been shown to depend on temperature in *L. decemlineata*, such as development time
367   (Boman et al. 2008), dispersal capacity (Caprio and Grafius 1990), and the decision to enter
368   diapause (Danilevskij 1965). While most of these traits are affected positively by increased
369   temperature, the decision to enter diapause is more complex since increased temperature
370   decreases diapause propensity (Danilevskij 1965) thus potentially increasing the ovipositing
371   period of beetles. Since late summers are associated with higher climatic variability,
372   especially at high latitude, under current climate change scenarios the decision to prolong the
373   reproductive period can have negative consequences for beetles. Furthermore, warmer
374   winters mean less snow cover, which, combined with wetter conditions, means that low
375   temperatures can more easily penetrate deep into the soil, potentially increasing
376   overwintering mortality of diapausing beetles (Boiteau and Coleman 1996; Constanzo et al.
377   1997; 1998; Groffman et al. 2001).

378

379   Taken together, we think it is unlikely that *L. decemlineata* has been significantly affected by
380   climate change related ambient temperature increase in its expansion thus far (see supplement
381   in Bebber et al. 2013). Future expansion and population dynamics in established populations
382   might show both positive and negative associations with increased temperature (see e.g.
383   Milner et al. 1992). In case winters become more benign (shorter, warmer) a major potential
384   obstacle for spread to higher latitudes in Europe may disappear (Jönsson et al. 2013).
385   Furthermore, many models predict fairly rapid responses in increased voltinism in European
386   *L. decemlineata* populations, in case growth season, and importantly, potato growing season,
387   increases in length significantly (Valosaari et al. 2008; Jönsson et al. 2013). Therefore we
388   stress that care must be taken when partitioning out the effect of climate change in driving
389   historical, current or future range expansion in pest species.

390

391   **4.3 Population dynamics of the Rape beetle, *Meligethes aeneus*, at high latitudes in**
392   **Europe**

393

394   The rape beetle, *Meligethes aeneus* is a common beetle occurring in most of the holarctic
395   region (Alford 2003). It feeds on a range of naturally occurring plants, especially Brassica
396   and Sinapis species and is not considered particularly harmful when on natural plants.
397   However, since it also uses commercially grown Rape crops as hosts, it has the potential to
398   become a serious pest with a large economic impact. Populations of *M. aeneus* are generally
399   univoltine, and adults overwinter as adults in woodlands. Due to their high protein content,
400   Rape crops (*Brassica napus*, *B. rapa*) have increasingly been appreciated as animal feed, and
401   an increasing interest in biofuel applications (Tiilikainen and Hokkanen 2008) have further
402   increased the attractiveness of growing Rape. Indeed, Rape is one of the most important crop
403   plants in Europe with a total production volume of 19 x 10^6 tonnes grown during 2010-2011
404   in the EU (Eurostat Pocketbooks 2012). At high latitude in Europe, such as Finland, *B. rapa*,
405   has traditionally been favored over *B. napus*, due to shorter growth season requirements
406   (Peltonen-Sainio et al. 2009). The increasing utilization potential of Rape has led to the
407   development of more cold-tolerant and hardy high-latitude variants which can be found in
408   northern Europe (Mäkelä et al. 2011). This has led to shifts in the prevalent or preferred
409   variant of Rape in northern growing regions (*B. rapa* spp. *oleifera* becoming more common
410   while the more traditional *B. napus* spp. *oleifera* has become less common). Shifting to a
411   hardier variant has allowed Rape crops rearing at higher latitude and at higher areals
412   (Peltonen-Sainio et al. 2009). Indeed, the total cultivated area of different Rape species has
413   increased by several orders of magnitude in Finland during the last 50 years (Figure 3). The
414   increased growing areals of Rape crops has had positive effects on *M. aeneus*, which also has
415   increased in abundance in concert with its host plant (Tiilikainen and Hokkanen 2008)
416   (Figure 3).

417

418   Both adult and larval *M. aeneus* can damage Rape crops. The adults can eat the flowers and
419   supporting structures while larvae eat pollen within buds and flowers. In case populations are
420   not controlled, yield losses in commercial rape crops can be up to 70 % (Nilsson 1987).
421   *Meligethes aeneus* is widely controlled both through biological (Veromann et al. 2006), and
422   more commonly, chemical means (Smatas et al. 2012). Chemical management is complicated
423   by high levels of pesticide resistance (Tiilikainen and Hokkainen 2008; Smatas et al. 2012)

424   which is exacerbated by host shifts of *M. aeneus* individuals from commercially grown Rape

425   crops to wild relatives (Hokkanen 2000). This shifting of host plants can increase spatial

426   heterogeneity and contribute to the maintenance of large potential genetic variation in the

427   populations.

428

429   The effect of climate change is difficult to estimate in *M. aeneus* since this univoltine species

430   already has a more northern distribution than its crop host plants. Therefore climate change

431   effects appear to be indirect as warming affects the range of its host plant range, Rape being

432   cultured at higher latitudes and at larger areas. According to Bebber et al. (2013) *M. aeneus*

433   has not shifted or enlarged its range during the last 60 years, however its severity has

434   increased, primarily through an enlargement host plant planting areas and increasing pesticide

435   resistance (Tiilikainen and Hokkainen 2008; Smatas et al. 2012). According to Hakala et al.

436   (2011) climate change might make cultivation of different Rape variants possible as far north

437   as Lapland by 2085. If this is the case, *M. aeneus* most likely will transition along with its

438   host, and increase in severity as pest.

439

440   **5. Conclusions**

441

442   The fifth IPCC report (IPCC 2013) presents, clearer than any time before, evidence

443   supporting the dynamics of ongoing climate change. Therefore the general emphasis has

444   already shifted from merely predicting climate change, into discussing means to mitigate

445   damage due to already occurred or currently occurring climate change (see e,g. Carraro and

446   Sgobbi 2008). For agriculture this means that across the globe, both governmental and non-

447   governmental groups are calling for more information for more strongly integrated pest

448   management and discuss various adaptation strategies since climate change already is

449   apparent in many European agricultural systems (Genovesi and Scalera 2011; Vänninen et al.

450   2011).

451

452   The observed climate change effect include both direct (loss of thermal constraints) or

453   indirect (changes in habitat, species interactions, host plant ranges etc.) effects, which are

454   often hard to dissect from other, anthropogenic, effects (pesticide usage, assisted dispersal).

455   There is also very little systematic information on population sizes of a given pest over large

456   areas for long periods of time, which makes it difficult to observe the changes in the first

457   place. What is needed is a more systematic record keeping or a unifying Europe-wide

458   database, similar to what already is available for non-pest species (see e.g. Atlas of Finnish

459   Macrolepidoptera, Huldén et al. 2000). The citizen science application used for instance to

460   detect and monitor the invasion of *Harmonia axyridis* (Coleoptera:Coccinellidae) in UK

461   (http://www.ladybird-survey.org/default.aspx) might be a possible application beneficial also

462   for agricultural professionals. Finally, effective utilization of the internet with rigorous data

463   selection criteria also allows us to utilize available databases (EPPO, NAPPO, CABI) more

464   thoroughly, as recently seen in Bebber et al. (2013). Taken together, these various systematic

465   approaches should provide the necessary tools to better predict likely responses of pest

466   species to climate change. The goal should be to develop means for horti- and agricultural

467   stake-holders to more effectively mitigate the negative impact which current and future

468   climate change might have through changes in pest species biology.

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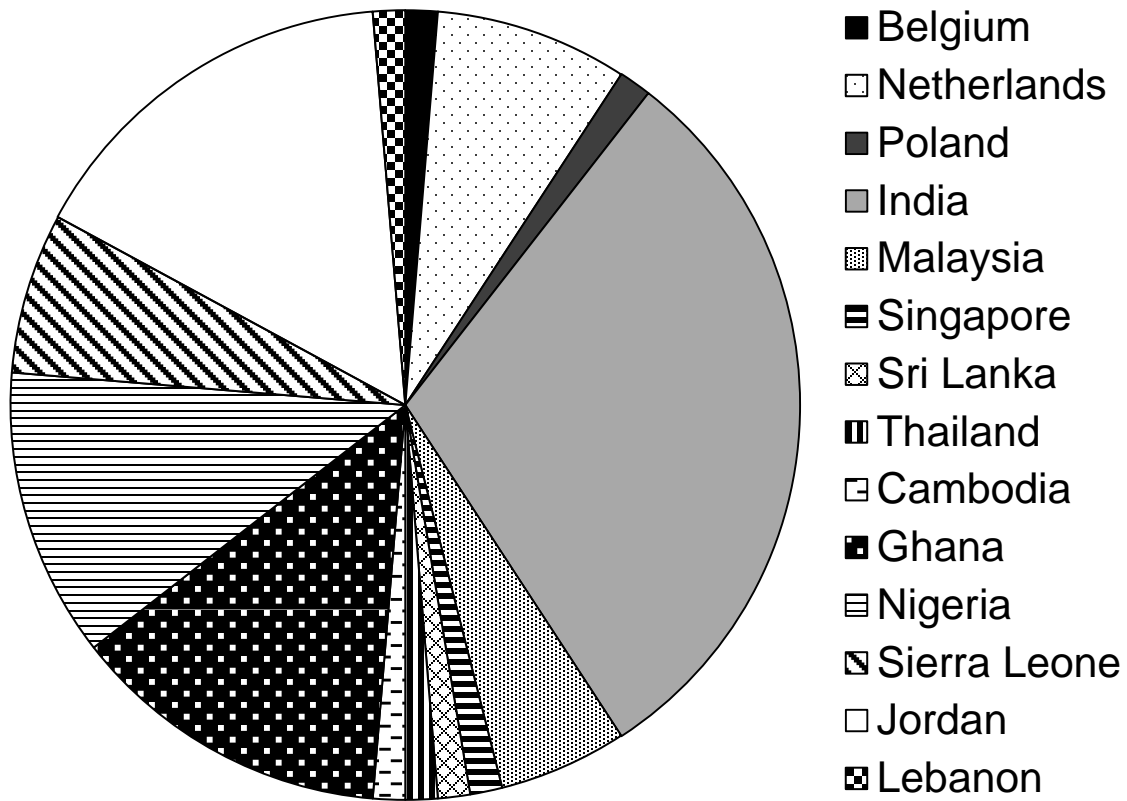826

827   Figure legends
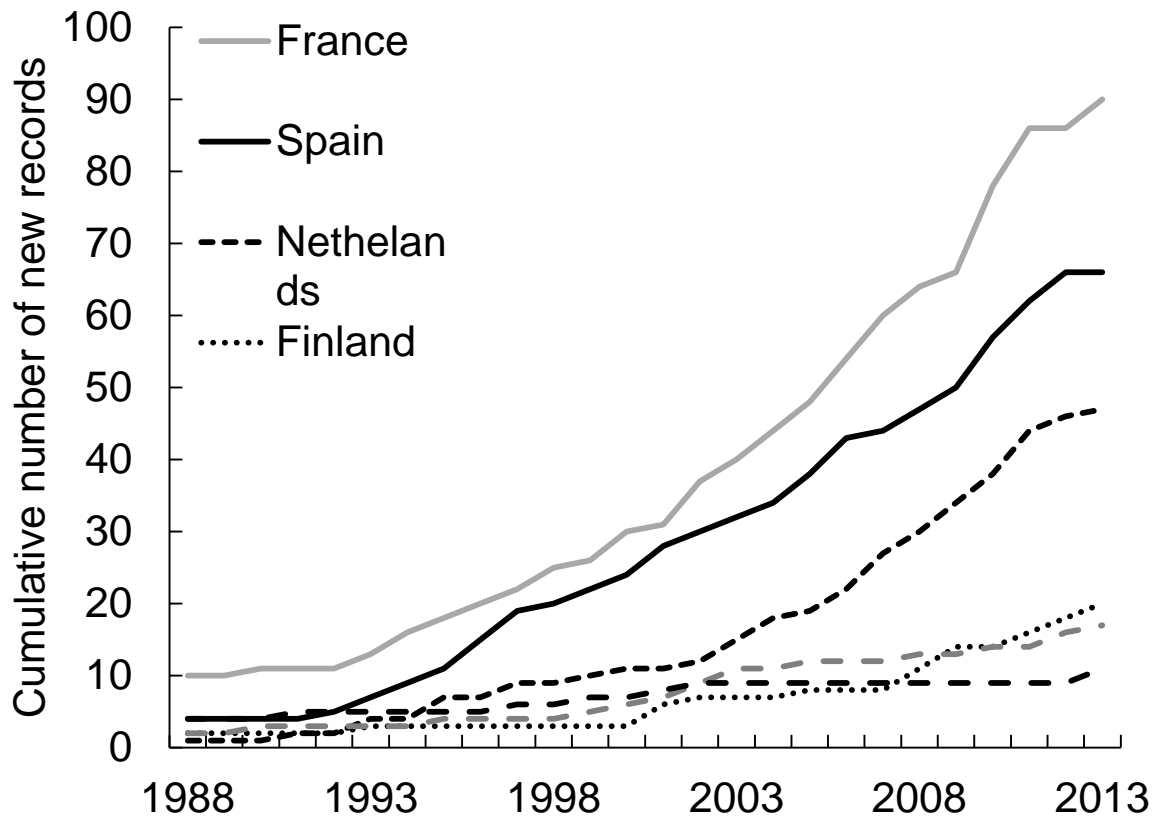
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829   Figure 8.1 Cumulative number of new records of pests in six western European countries
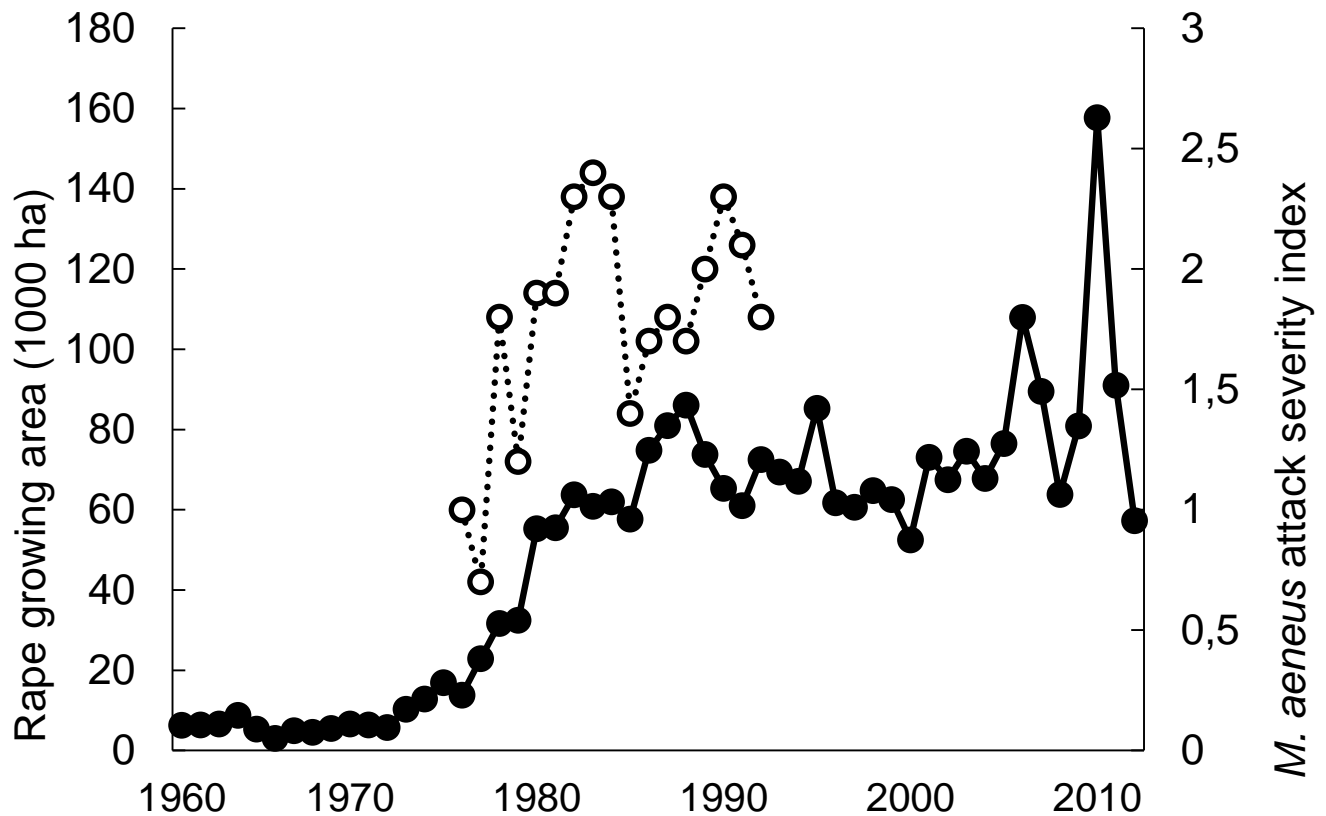830   (data from EPPO website 2013b).

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Figure 8.2 Proportion of *Bemicia tabaci* individuals found on ornamentals and vegetables from the UK divided according to country of origin (EPPO 2013a, NO 11, N = 76).

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842 Figure 8.3 The solid line shows areas of rape grown in Finland, 1950-2010. During 1950-
843 1970 the predominant rape variant was Winter turnip rape (*Brassica napus* spp. *oleifera*),
844 while the increase after 1970 up till present day primarily constitutes Spring turnip rape
845 (*Brassica rapa* spp. *oleifera*) substituting Winter turnip rape. The dashed line shows the
846 severity index of *Meligethes aeneus* attacks estimated in southwestern Finland between 1977
847 and 1992. Data is from Mäkelä et al. 2011 and Hokkanen 2000.
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