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4
5 **Chapter 8 Climate change effects on agricultural insect pests in Europe**

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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**

31

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36

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; Hoyer 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 CO₂ and temperature can boost plant growth if necessary water, nutrients and pest
46 control is available (Ward 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; Bebbler 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, \pm standard error of mean) within the observed time period. The number of species is given in the
 133 brackets.
 134

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

135 1 Bebbber 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 Bebbler 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. Piironen 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 Bebbier 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 Bebbier 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
<i>Acanthoscelides obtectus</i> *	Chrysomelidae	Neotropical	A	N	G	Y?	Adult?	7.1	356
<i>Agrilus planipennis</i>	Buprestidae	Eastern Asia	H	Y	S	Y	Pre-pupa	127.8	236
<i>Anthonomus bisignifer</i>	Curculionidae	Japan	H	N	S	Y	Adult	28.4	0
<i>Anthonomus pomorum</i>	Curculionidae	Palaearctis	H	N	S	Y	Adult	35.5	35
<i>Callidiellum rufipenne</i>	Cerambycidae	Eastern Asia	H	Y	G	Y	Pupa	120.7	13
<i>Cylas formicarius</i>	Brentidae		A	N	S	N ^C	Adult	85.2	197
<i>Diabrotica virgifera</i>	Chrysomelidae	North America	A	N	S	Y	Egg	30	700
<i>Diocalandra frumenti</i>	Curculionidae	Australia	H	Y	S	N		78.1	1
<i>Gonipterus scutellatus</i>	Curculionidae	Australia	H	Y	S	Y	Adult	113.6	39
<i>Harmonia axyridis</i>	Coccinellidae	Central- and Eastern Asia	A	N	G	Y	Adult	120.7	850
<i>Hylobius abietis</i>	Curculionidae		H	Y	G	Y	Larva	127.8	310
<i>Hylotrupes bajulus</i>	Cerambycidae	Europe	H	Y	S	N ^C	Larva	127.8	90
<i>Hylurgus ligniperda</i>	Curculionidae	Europe	H	Y	S	Y	Adult	131.35	29
<i>Hypothenemus hampei</i>	Curculionidae	Central Africa	H	N	S	N		78.1	293
<i>Ips cembrae</i>	Curculionidae	Europe	H	Y	S	Y	Adult	134.9	24
<i>Ips sexdentatus</i>	Curculionidae		H	Y	S	Y	Adult	63.9	95
<i>Ips subelongatus</i>	Curculionidae		H	Y	S	Y	Adult	39.05	14

<i>Ips typographus</i>	Curculionidae	Europe	H	Y	S	Y	Adult	35	787
<i>Leptinotarsa decemlineata</i>	Chrysomelidae	Mexico	A	N	S	Y	Adult	71	1592
<i>Lilioceris lili</i>	Chrysomelidae		H	Y	S	Y	Adult	49.7	17
<i>Listroderes costirostris</i>	Curculionidae	South America	A	N	G	N ^C	Pre-pupa	110.05	6
<i>Megaplatypus mutatus</i>	Curculionidae	Neotropical	H	Y	G	Y?	Larva	99.4	12
<i>Meligethes aeneus</i>	Nitidulidae	Holarctic Region	A	N	G	Y	Adult	49.7	175
<i>Monochamus galloprovincialis</i>	Cerambycidae	Eurasia	H	Y	S	Y?	Larva	49.7	54
<i>Monochamus sutor</i>	Cerambycidae	Eurasia	H	Y	G	Y	Larva and pupa	49.7	11
<i>Phaedon brassicae*</i>	Chrysomelidae	East and South Asia	A	N	G	Y	Adult and larva?	35.5	12
<i>Phoracantha recurva</i>	Cerambycidae	Southeast Asia	H	Y	S	N?		106.5	20
<i>Phoracantha semipunctata</i>	Cerambycidae	Australia	H	Y	S	N?		127.8	88
<i>Pissodes castaneus</i>	Curculionidae	Europe	H	Y	G	Y	Larva, adult	49.7	22
<i>Rhynchophorus ferrugineus</i>	Curculionidae	Southeast Asia	H	Y	G	N?	Adult	78.1	131
<i>Saperda candida</i>	Cerambycidae	Costa Rica	H	Y	G	Y?	Larva	35.5	0
<i>Scolytus morawitzi</i>	Curculionidae	Asia	H	Y	S	Y	Larva	28.4	0
<i>Scolytus schevyrewi</i>	Curculionidae	Eastern Asia	H	Y	G	Y?	Larva, adult	35.5	13
<i>Scyphophorus acupunctatus</i>	Dryophthoridae	New World	H	N	S	N?		63.9	22
<i>Sinoxylon conigerum</i>	Bostrichidae		H	Y	G	Y	Adult	85.2	1
<i>Xylosandrus crassiusculus</i>	Curculionidae	Southeast Asia	H	Y	G	N?		78.1	26
<i>Xylosandrus germanus</i>	Curculionidae	East Asia	H	Y	G	Y	Adult	85.2	37
<i>Xylotrechus altaicus</i>	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 km² 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 Piironen 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; Piironen 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 (Piironen 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 19×10^6 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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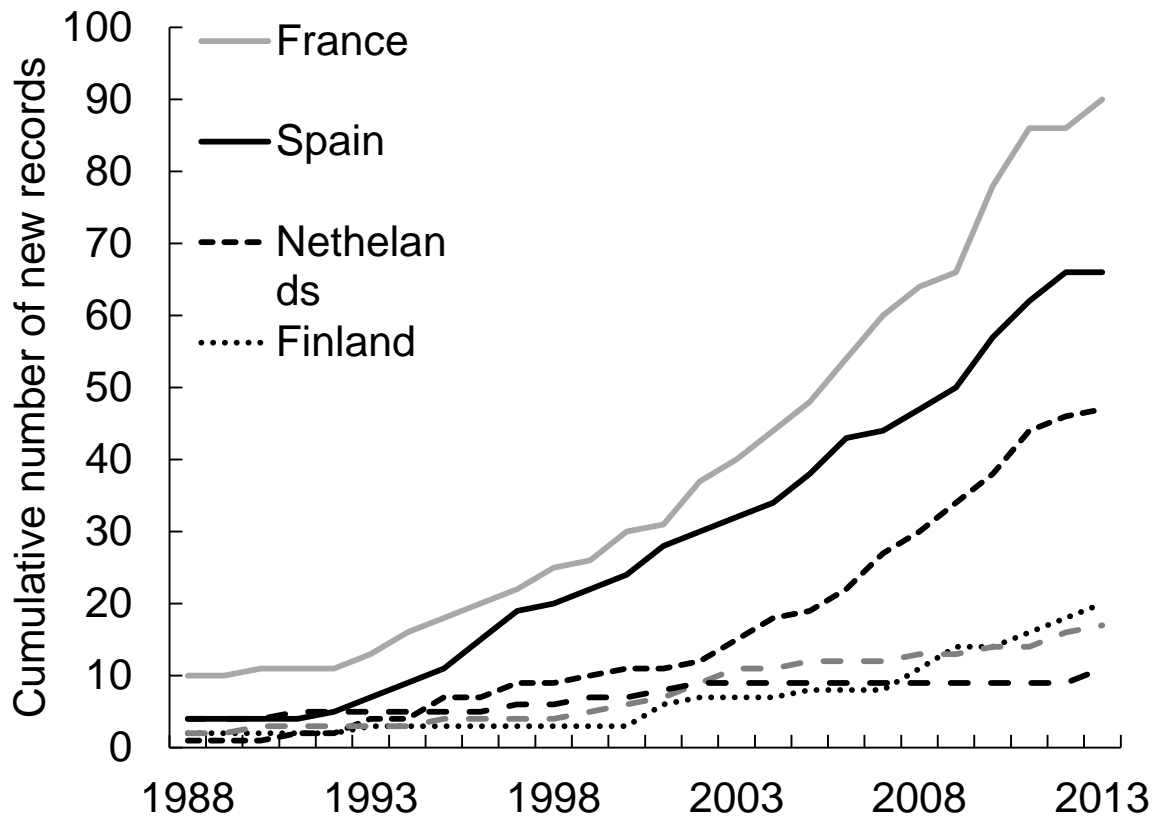
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827 Figure legends



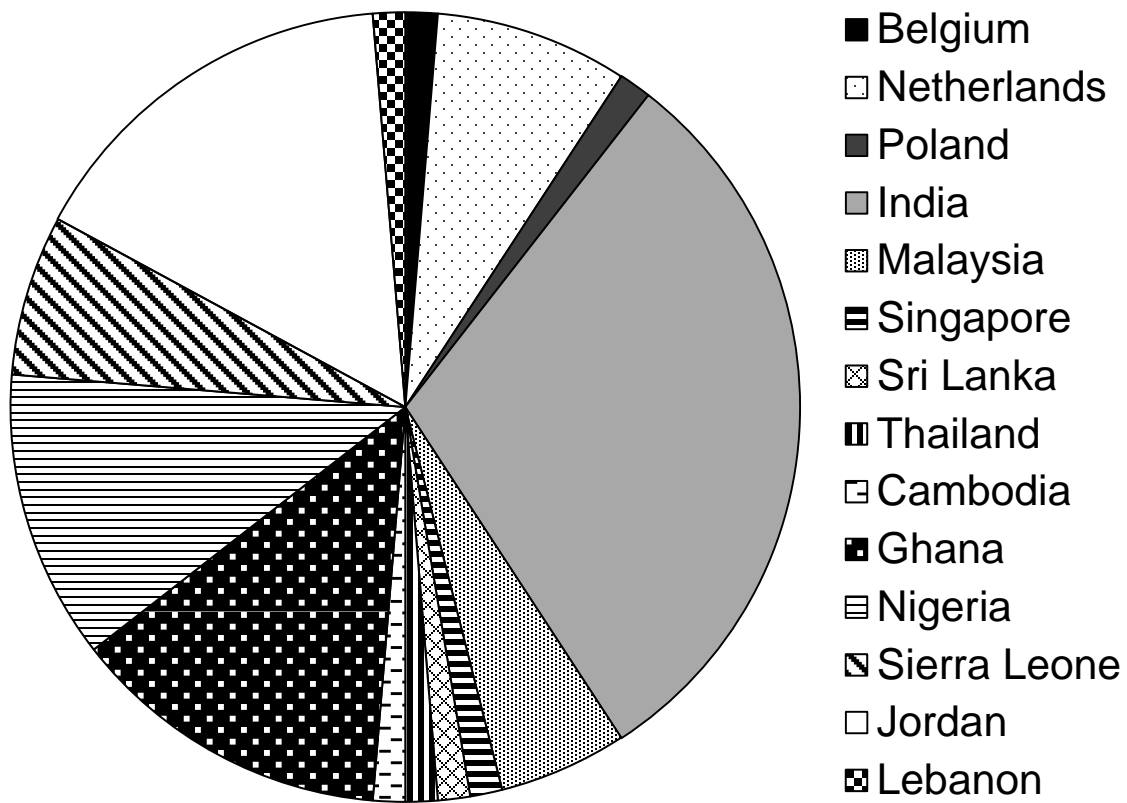
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829 Figure 8.1 Cumulative number of new records of pests in six western European countries
830 (data from EPPO website 2013b).

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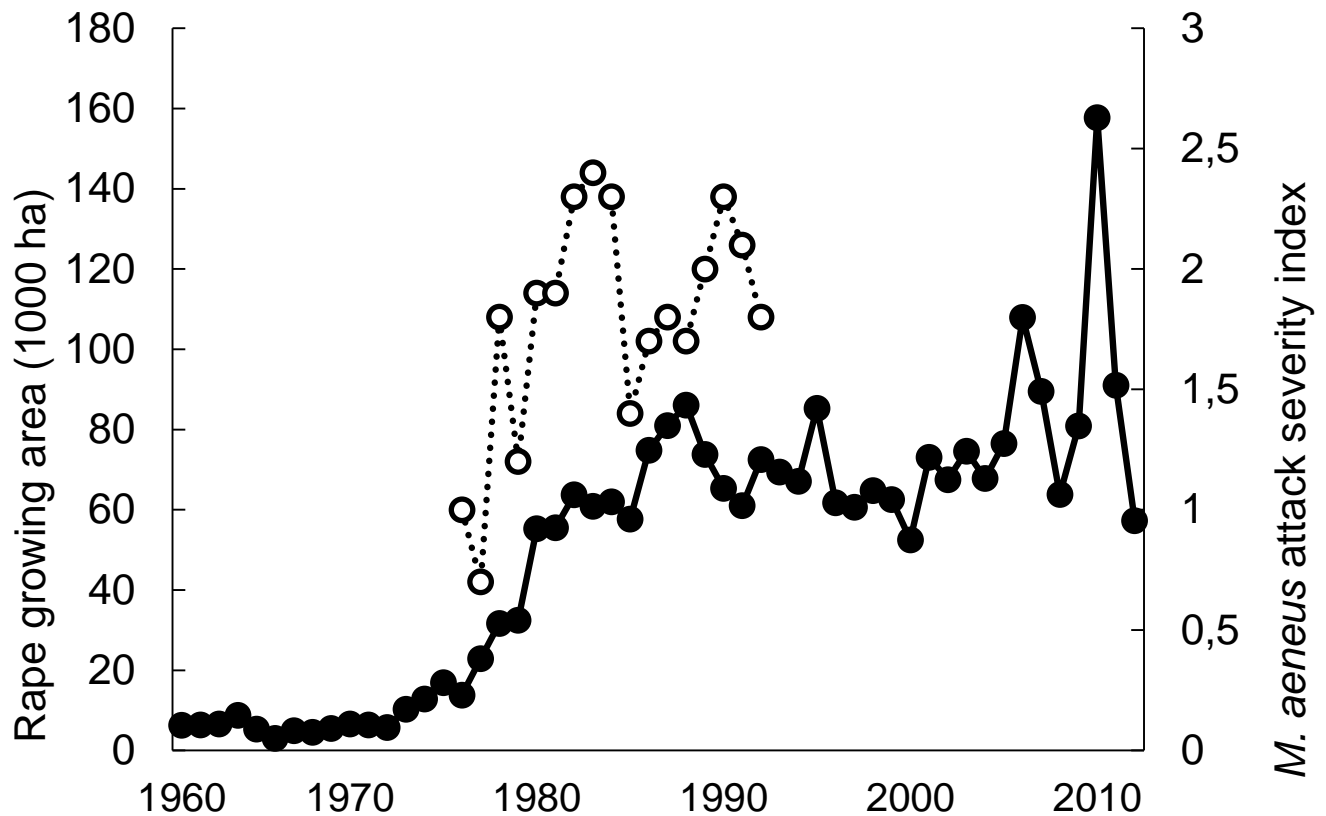
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836 Figure 8.2 Proportion of *Bemisia tabaci* individuals found on ornamentals and vegetables
837 from the UK divided according to country of origin (EPPO 2013a, NO 11, N = 76).

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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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