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Published in:
What makes an alien invasive? Risk and policy responses

Print publication: 01/01/2010

Document Version
Publisher's PDF, also known as Version of record

Citation for pulished version (APA):
Evans, KA., & Simpson, B. (2010). How climate change will make management of invasive species such as the Harlequin ladybird (Harmonia axyridis) a significant challenge. In A. Evans (Ed.), *What makes an alien invasive? Risk and policy responses: Aspects of Applied Biology* (Vol. 104, pp. 29-36). The Warwick Enterprise Park, Wellesbourne, Warwick CV35 9EF, UK: Association of Applied Biologists (AAB).

How climate change will make management of invasive species such as the Harlequin ladybird (*Harmonia axyridis*) a significant challenge

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Abstract

The Harlequin ladybird (*Harmonia axyridis*) is a biological control agent 'gone wrong' in that as well as being an effective predator of aphids, it will also feed on native coccinellid species in the UK, and is likely to out compete many native coccinellids, primarily through resource competition and intra-guild predation. It has already invaded the UK and its potential spread under current and future climates is predicted using CLIMEX models based on its response to climatic stress factors such as temperature, rainfall and induction of diapause. By 2050, whether using low or medium emissions climate change scenarios, *H. axyridis* has the potential to spread throughout most of Europe and the UK. Factors that can affect its establishment are discussed.

Key words: Harlequin ladybird, climate change, CLIMEX, invasive

Introduction

Harmonia axyridis (Pallas) (Coleoptera: Coccinellidae) is more commonly known as the multicoloured Asian lady beetle, or the Harlequin ladybird. Whilst originating in continental, temperate and subtropical regions of east and central Asia (Poutsma *et al*., 2008), its efficiency as a predator of aphids, coupled with its ability to inhabit a wide range of ecological niches and climatic conditions has led to numerous introductions as a biological control agent globally (Koch, 2003). This has led to population distributions ranging through much of northern Europe, North America, as well as its native range within Asia. In addition it has been discovered within South America, (Majerus *et al*., 2006). Within Europe its current range extends from Denmark in the north to France in the south and from the UK in the west to the Czech Republic in the east (Brown *et al*., 2007).

H. axyridis has spread significantly from release sites, and now poses a major problem upon the ecosystems it invades, outcompeting native cocceinellid's and affecting biodiversity (Majerus *et al*., 2006). *H. axyridis* has also become a problem within the wine industry where it clings to the grapes (Majerus *et al*., 2006; Koch, 2003), and as they are difficult to effectively remove on mass, many are crushed along with the grapes as they are turned into wine. Alkaloids contained within the organism significantly taint both the flavour and smell of any wine produced, having significant economic impacts (Pickering *et al*., 2006). There have also been recorded cases of allergic reactions to *H. axyridis*, usually in the form of conjunctivitis or dermatitis (Magnan *et al*., 2002). This is often either due to being bitten directly by *H. axyridis* or an allergic reaction to isopropyl methoxy pyrazine, which is released as a defensive mechanism.

Why is *Harmonia axyridis* so Successful?

H. axyridis has many key characteristics which allow it to be very invasive. Firstly, while it is a prolific predator of numerous aphid species, its diet is wide ranging, and has been recorded to consume egg, larval and pupal stages of Coleoptera, Lepidoptera and Neuroptera species (Sakuratani *et al*., 2000; Koch *et al*., 2003; Koch, 2003). As a consequence *H. axyridis* is liable to find suitable prey types in any environment it migrates too. In addition this also allows a greater availability of food sources much later into the year, giving greater survivability to larva (Majerus *et al*., 2006). *H. axyridis* also has a strong dispersal capability. With adults measuring between 5–8 mm in length, *H. axyridis* is significantly larger than most other coccinellid's. (Koch, 2003). As a consequence the distances it is able to fly are significantly greater. Within North America and Asia *H. axyridis* migrates long distances to dormancy sites where they aggregate and remain dormant over winter (Nalepa *et al*., 2000). This migratory behaviour enables *H. axyridis* to have a large geographical area within which it can forage for food (Majerus *et al*., 2006).

Originally thought to be a polyphagous arboreal species inhabiting only orchards, forest stands and old-field vegetation, *H. axyridis* has been shown to be equally successful in agricultural habitats such as forage crops, corn, wheat, as well as coniferous woodlands (Majerus *et al*., 2006). This is further emphasised by the wide ranging habitats found within its native range in Asia. In addition it has been shown that *H. axyridis* has an unusually high amount of phenotypic plasticity, enabling a higher degree of adaptation, and more successful colonisation (Grill *et al*., 2003). This also enables *H. axyridis* to inhabit numerous different climatic regions, surviving winter temperatures well below freezing and summer temperatures in excess of 30°C (Majerus *et al*., 2006).

H. axyridis is multivoltine, producing up to four or five generations per year (Katsoyannos *et al*., 1997) in peak conditions, however it is much more commonly bivoltine with a period of dormancy over winter months (Koch & Hutchinson, 2003). Conversely in very hot regions *H. axyridis* requires a period of dormancy during the summer months.

Whilst introduced in many regions as a biological control agent, *H. axyridis* is now a major threat to biodiversity and particularly to native coccinellid's. The ability to disperse quickly, survive in numerous different habitat types and climatic conditions, as well as having a polyphagous diet mean *H. axyridis* is likely to out compete many native coccinellid's, primarily through resource competition and intra-guild predation (Koch, 2003). Indeed in regions where *H. axyridis* has been released, it has quickly become the dominant coccinellid (Hesler *et al*., 2001) with populations of native coccinellid's declining (Brown & Miller, 1998).

Identifying the Potential Distribution of *H. axyridis*

The potential distribution of *H. axyridis* under the current climate was modelled using CLIMEX 3.0 (Sutherst *et al*., 2007*b*); using species stress parameters developed by Poutsma *et al*. (2008). CLIMEX is a computer modelling programme that simulates the extent of annual extremes of conditions that allow persistence and those that support growth (Sutherst *et al*., 2007*a*). The software produces a variety of indices to represent the relative suitability of a given location for the species. An Ecoclimatic index (EI) value is produced, which is based on a combination of the annual growth index, stress values for cold, heat, dry and wet and their interactions e.g. cold-wet, as well as any limiting factors such as diapause (Sutherst *et al*., 2007*b*). CLIMEX was used to estimate the potential range of *H. axyridis* under current and future (2050) climatic conditions. For the climate change scenarios, low and a medium emissions scenarios were considered for the year 2050 based on IPCC projections. The low emissions scenario is based on the B1 projections, with the medium emissions scenario based on the A1B projection (see Table 1).

Table 1. *The climatic data for low and medium emission scenario's during summer and winter months for 2050 used in CLIMEX*

Scenario 2050		Summer		Winter	
		Temperature (ºC) increase	Temperature (ºC) increase	Temperature (ºC) increase	Temperature (ºC) increase
Low	Temperature (ºC) increase	1.1	1	1.4	1.15
	Precipitation (%) change	2.7	-7.7	4.4	-3.45
Medium	Temperature (ºC) increase	1.45	1.3	1.8	1.5
	Precipitation (%) change	3.5	-10	5.75	-4.5

Results

The CLIMEX model under current climatic conditions suggests that much of Europe is already climatically suited to *H. axyridis*. Much of Ukraine, Poland, as well as regions in Russia, Portugal, the Atlantic Coast of France and North East Italy exhibit EI values exceeding 30. Much of central Europe, including Germany, South England, Belgium, Holland and France exhibit EI values between 20 and 30, indicating potentially stable populations within this region. Literature shows *H. axyridis* is currently distributed across all of the above stated countries with the exception of Portugal and the Atlantic coast of France and Italy (Brown *et al*., 2008). Within the UK *H. axyridis* was first observed during 2004 in Sible Hedingham, Essex, England (Majerus *et al*., 2006). By 2010 *H. axyridis* had been found in northern Scotland (Fig. 1) and the potential UK distribution suggested by CLIMEX fits in well with the known distribution (Fig. 1).

The low emissions scenario causes significant increases in EI values across much of *H. axyridis* known range by 2050, with Belarus, Latvia, Lithuania, as well as regions of Germany, Northern France and Belgium all now exhibiting EI values over 30. Geographical range also expands further north to the northern tip of the Baltic Sea. Within the UK EI values do not exceed 30, but a wider area of the country now has higher EI values than under the current climate, with most of southern England being climatically suitable for establishment.

The medium emissions scenario essentially produces a similar outcome, but at a faster rate than the low emissions scenario in terms of UK climatic suitability for *H. axyridis* (Fig. 3). In addition the geographical range extends further northwards. By 2050 CLIMEX predicts climatic suitability across much of Europe, with Poland, Lithuania, Latvia, Belarus, Ukraine, Russia, Parts of Germany, France, Belgium, the Netherlands exhibiting EI values exceeding 30.

The medium emissions scenario has the greatest impact on *H. axyridis*, both in terms of geographical range changes and increases in climatic suitability. Given *H. axyridis* is already dispersing rapidly from a focus originating in Holland and Belgium, CLIMEX suggests that climate change will causes this to happen at an increased rate given improved climatic suitability.

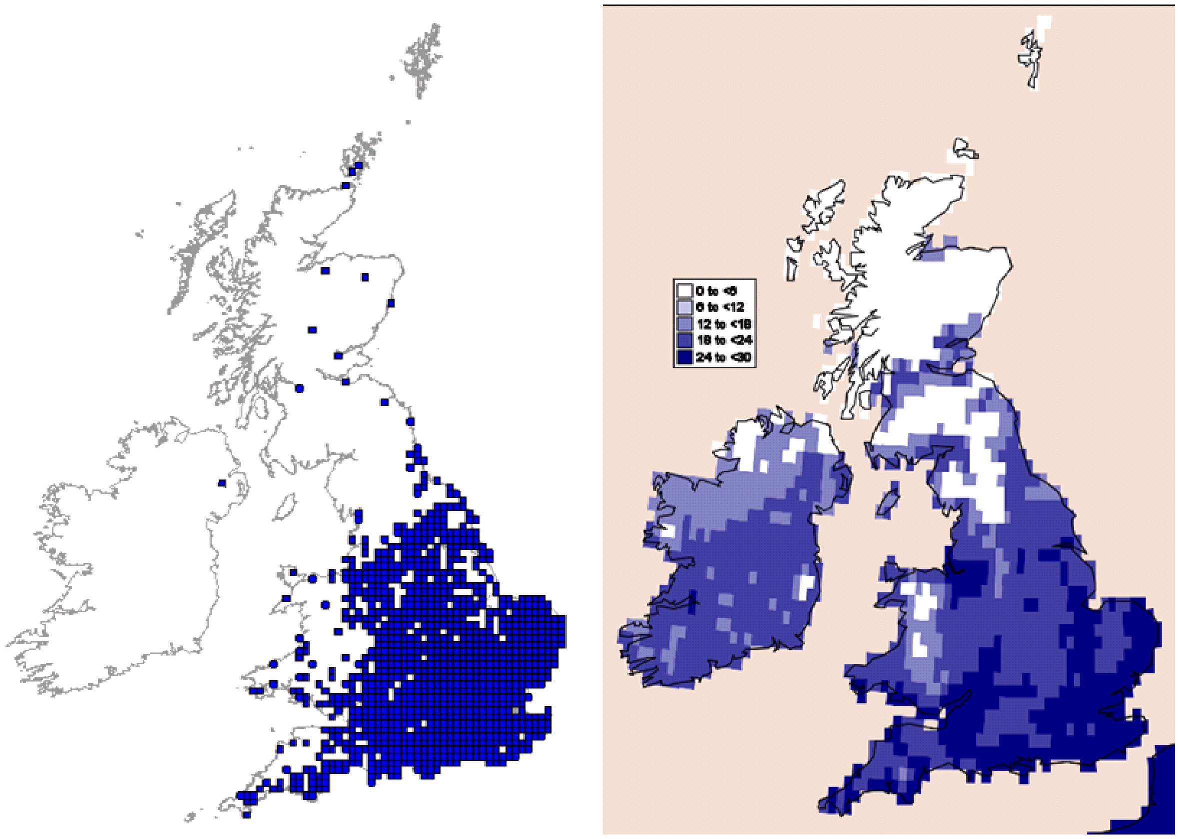

Fig. 1. Current (2010) UK distribution of *H. axyridis* based on recorded sightings (left) with predicted potential distribution from CLIMEX model (right).

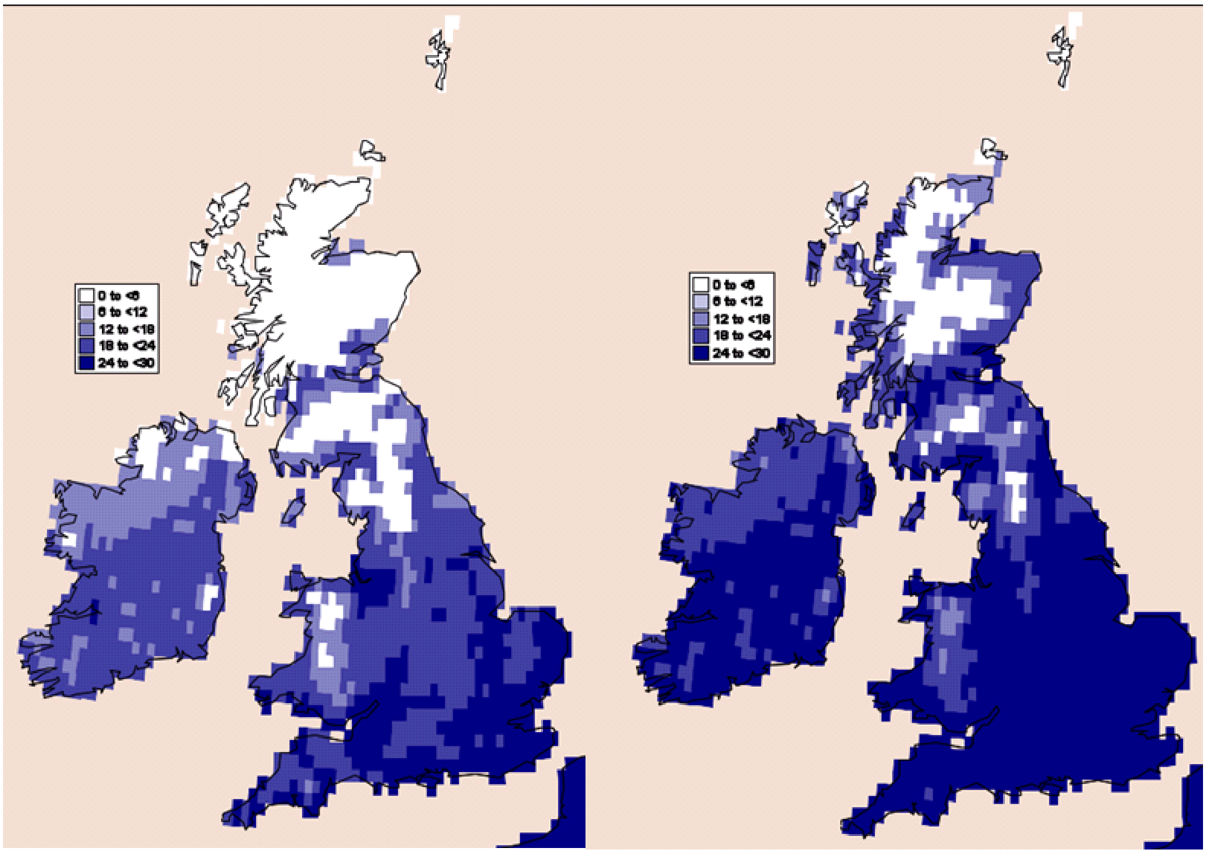

Fig. 2. Predicted current potential distribution of Harmonia (left) with predicted potential distribution in 2050 (right): Low emissions scenario.

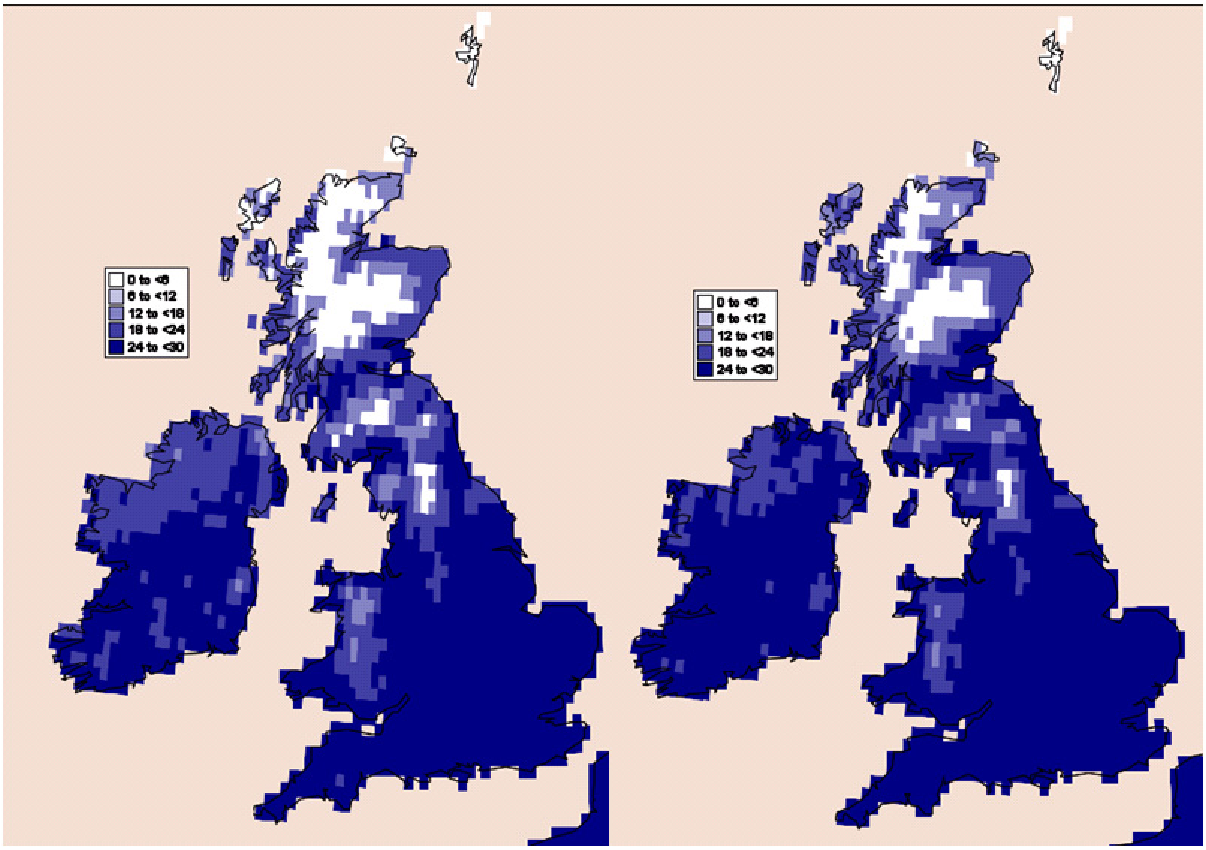

Fig. 3. Predicted distribution of Harmonia in 2050: Low emissions scenario (left) and medium emissions scenario (right).

Further analysis of the outputs of the CLIMEX model indicate that the main limiting factor for the establishment of *H. axyridis* in the UK is temperature; specifically the day degrees required for *H. axyridis* to complete a generation (Fig. 4). *H. axyridis* requires 330º day degrees to complete a generation (Poutsma *et al*., 2008), and under the current climate the maximum number of generations a year (taking into account the induction of a winter diapause) is 3, focused in south east England (Fig. 4). By 2050 3–4 generations are possible in south east England (Fig. 4), with most of the country being able to have at least one generation a year.

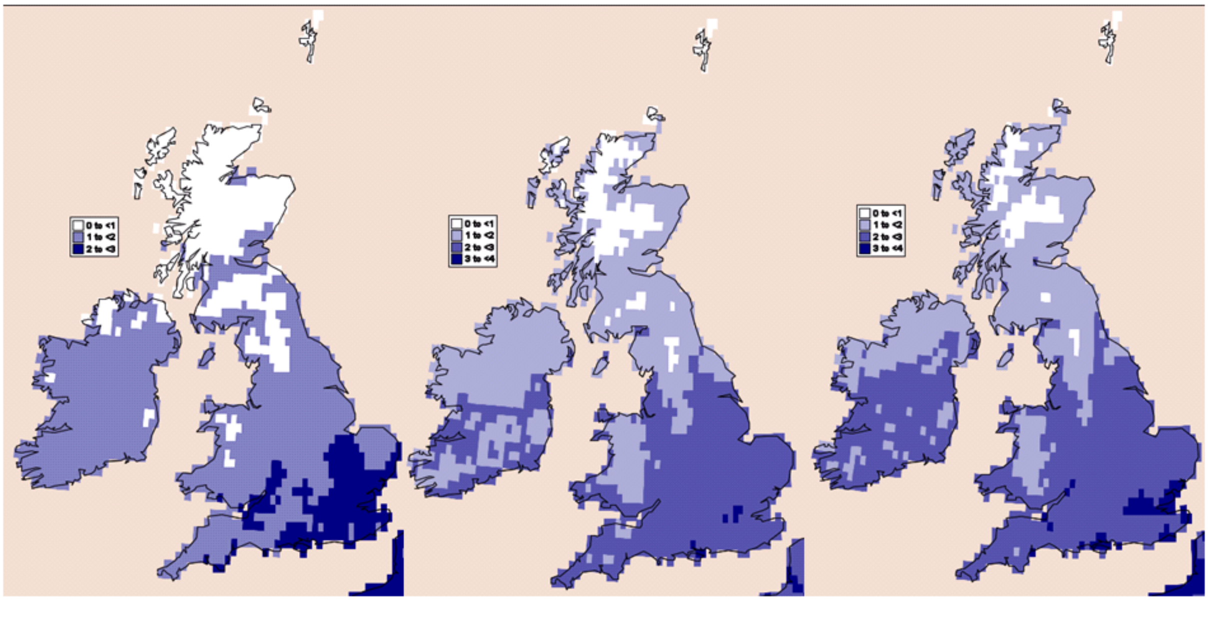

Fig. 4. Potential No. of generations of *H. axyridis* a year: Current climate (left), 2050 low emissions scenario (middle) and 2050 medium emissions scenario (right).

Discussion

CLIMEX suggests that *H. axyridis* is going to become significantly more prevalent as climate change takes effect. It is likely that *H. axyridis* will experience an increase in abundance but also in species geographical range.

However, a few caveats need to be taken into account with the outputs of the CLIMEX model. The climatic datasets used comprise of monthly data which has been averaged to give general trends in climatic variability. This causes a smoothing of data (Sutherst, 2007*b*) which therefore minimises the effect of possible extremes of weather. *H. axyridis* for example has a threshold minimum temperature of -5°C (Poutsma *et al*., 2008). Below this temperature there is a significant decrease in survival. As a result it is conceivable for CLIMEX to indicate a region is climatically suitable, which may be, due to extremes in climatic variables, actually unsuitable. This especially needs to be taken in context against projections that climate change will cause an increase in frequency of extreme weather events over the course of the 21st century (Alley *et al*., 2007).

CLIMEX also assumes that a species range is determined solely by climatic factors (Sutherst, 20007*b*). However, in reality this is never the case, with many ecological factors such as habitat availability, aggregation site availability (in the case of *H. axyridis*), soil type, food availability, predation, competition, parasitism and dispersal ability all contributing to the likely establishment of a species. In the case of *H. axyridis* for example, CLIMEX predicts high suitability for north United States of America and Canada. However in practice populations have struggled in these countries, predominantly because the large expanses of agricultural land leave few sites for aggregation during overwintering (Poustma *et al*., 2008).

CLIMEX also predicts under current climatic conditions that the Mediterranean basin should have a large population of *H. axyridis*. However populations have been limited within this region. This is likely to be due to a lack of aphids year round due to less favourable climatic conditions and fewer suitable vegetation types for the aphids (Poutsma *et al*., 2008).

Whilst there are limitations to the CLIMEX model, this is true of any climatic model. However, if used as a guide, this method can be useful in aiding future pest risk analysis, providing valuable insight into how a given species may respond to alterations in climate. In addition one must assess numerous ecological factors as well as anthropogenic factors such as dispersal facilitation and land usage, to establish how the CLIMEX results may translate outside of a modelled situation.

H. axyridis is already prevalent throughout Europe (Poutsma *et al*., 2008; Koch; 2003; Majerus *et al*., 2006). Due to being larger than many other ladybirds, *H. axyridis* is able to fly further distances, and indeed in America and Asia undertakes long migratory flights (Koch, 2003; Majerus, 2006). As a result it is therefore very likely to continue to disperse without anthropogenic involvement. Further evidence to support this comes from the rapid colonisation of North America. Within 2 years of establishment in Georgia, *H. axyridis* had spread state wide, entering Florida and South Carolina (Majerus *et al*., 2006). CLIMEX predicts that *H. axyridis* could spread to the north Baltic, with viable populations as far north as Finland and Sweden. Given this previously exhibited dispersal capability; *H. axyridis* should be able to reach regions highlighted in the CLIMEX models.

Geographical barriers can place considerable constraints on the dispersal of a species. CLIMEX assumes climate as the only limiting factor in species range (Sutherst, 2007*b*). Within Europe particular geographical barriers could be the English Channel, or the Alps. *H. axyridis* has already been found within the UK meaning the English Channel will not be a barrier, however, dispersal seems to originate from a central focus within Holland and Belgium. Whilst northern Italy and much of the rest of Europe has been shown by CLIMEX to be climatically suited, the Alps themselves could pose a significant barrier to the dispersal of *H. axyridis*.

Acknowledgements

The UK Harlequin Survey (http://www.harlequin-survey.org) provided much of the UK distribution data on *H. axyridis* and a great deal of the background information.

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