Department for Environment Food & Rural Affairs

Rapid Pest Risk Analysis (PRA) for:

Hyphantria cunea

November 2015

Summary and conclusions of the rapid PRA

This rapid PRA shows that:

Hyphantria cunea, which has many common names including fall webworm and American white moth, is a polyphagous defoliator of many deciduous trees and shrubs, having between one and four generations every year. Native to North America, this moth was accidentally introduced to Hungary in 1940 and Japan in 1945. Since then, it has spread in both Europe and Asia, occasionally causing outbreaks and severe damage. In 2014, two adults were trapped in the UK. Hence, the 1991 PRA has been updated to re-assess the suitability of the UK for establishment, as well as the potential for high levels of damage.

Risk of entry

Hitchhiking was considered to be the riskiest pathway, as the pupae (which are the overwintering life stage) may be found concealed in cracks, on and in a range of materials and products, not necessarily of plant origin. Overall, hitchhiking was considered likely with medium confidence.

Transport with plants for planting was assessed as moderately likely with medium confidence. Though larvae (in webbed nests) and egg masses are both conspicuous, pupae are unlikely to be detected since they are buried just below the soil surface.

Entry by the two pathways of fruit and vegetables and cut branches was judged unlikely, with high and medium confidence respectively. Though there is some evidence of movement with harvested plant parts, it is mostly the larvae that have been associated with these products. These relatively non-mobile life stages are unlikely to find a new host to complete development, and, even if not eaten or processed, the commodities have too short a life span to enable development to be completed.

The pathways of soil and natural spread are both considered very unlikely. Soil may contain pupae, but are not likely to survive the physical disturbance of the pathway. This judgement is made with high confidence. While *H. cunea* is present in France, it has only been recorded from the south, and this is not known to be a migratory species. Thus, the assessment for the pathway of natural spread is made with high confidence.

Risk of establishment

Hyphantria cunea has one generation per year (univoltine) in southern Canada, increasing to three or four generations per year (multivoltine) in southern USA. All the non-native populations in Europe and Asia appear to have at least two generations per year, and no records of any univoltine populations have been found, other than those in the native range of North America.

The UK appears to be climatically suitable for the establishment of one generation per year, but too cool to allow multivoltine populations to develop. The European populations of *H. cunea* do not appear to have established in any location in northern Europe (such as Germany) where only one generation is predicted from the climate mapping carried out for this PRA. It is unclear why the European populations have not spread north and switched to a univoltine lifecycle, and it is also not known why population levels in the south-west of France have declined markedly since the early 1980s. As this has not happened to date, more than seventy years after the first introduction, the establishment of a multivoltine population in the UK is considered unlikely, but with low confidence as it is unclear what factor(s) may be preventing the northward expansion. However, establishment of a univoltine population in southern parts of the UK (for example, a population originating in Canada) is considered likely with high confidence.

As the larval nests are conspicuous, establishment in protected cultivation is considered very unlikely with high confidence, as it is assumed any infestation would be detected at an early stage.

Economic, environmental and social impact

Impacts in the native range of North America are all relatively small, with most being due to localised defoliation and public reaction to the webbed nests. Impacts in Europe can be much higher, though severe impacts appear to be sporadic, at least in western Europe. Higher, more sustained, levels of damage have been recorded in parts of eastern Europe and parts of Asia including China. Defoliation in outbreak years can be significant, and it is usually the second generation that causes higher levels of damage.

In the UK, it is expected that economic and environmental impacts would be small, in line with univoltine populations in Canada, these assessments have been made with medium confidence. While overall, social impacts are also small, due to the conspicuous webbed nests, occasional high local levels of damage, and the fact that urban trees are commonly infested, there is a potential for larger social impacts at a very localised level.

Endangered area

The south-east of the UK is most at risk of establishment, but no part of the UK is considered endangered, as the pest would be at the edge of its range, and significant damage would only be expected in the warmest years.

Risk management options

Continued exclusion would be difficult, as the pupae are very cryptic, and not necessarily associated with host plant material. This would make detection measures very challenging to design and implement. Spread of pupae out of an infested area would make eradication or containment measures similarly difficult. Chemical control options are available, and manually pruning and disposal of branches containing the highly visible nests would reduce populations at a local level. Unlike the processionary moths, *H. cunea* hairs are non-toxic.

Key uncertainties and topics that would benefit from further investigation

What factors might be responsible for the European (and Japanese) populations apparently failing to expand their range northward, including (but not limited to) whether the non-native European and Japanese populations are capable of developing a univoltine life-cycle.

Images of the pest

Figure 1. *Hyphantria cunea* nest © Clemson University - USDA Cooperative Extension Slide Series, Bugwood.org

Figure 2. *Hyphantria cunea* black-headed larva © Milan Zubrik, Forest Research Institute - Slovakia, Bugwood.org

Is there a need for a detailed PRA or for a more detailed analysis of particular sections of the PRA? If yes, select the PRA area (UK or EU) and the PRA scheme (UK or EPPO) to be used.

No	✓				
Yes		PRA area: UK or EU		PRA scheme: UK or EPPO	

The uncertainties remaining in this PRA are due to a lack of primary research and experimentation. Further literature searches at the current time for a more detailed PRA are considered unlikely to add significant new information, and appear unlikely to change any of the judgements made here.

Given the information assembled within the time scale required, is statutory action considered appropriate / justified?

Yes Statutory action		No Statutory action	✓

While it may be possible for univoltine populations of *H. cunea* to establish in the UK, they will be at the edge of their climatic range and little damage is expected, other than in very warm years. As all the measures to prevent entry or contain an outbreak at a national level would be very difficult to implement, non-statutory controls would seem the most appropriate action against this pest.

Stage 1: Initiation

1. What is the name of the pest?

Hyphantria cunea (Lepidoptera). There are many common names in use, including fall webworm and American white moth.

Traditionally, this species has been placed in the family Arctiidae, but the higher classification of the Noctuoidea has been revised, and more recent work may place this species in the family Erebidae, subfamily Arctiinae instead.

There are two forms of *H. cunea* in the USA, usually referred to as the red-headed and the black-headed races, referring to the colour of the larval head capsules. They have been described as separate species (*H. cunea* for the red-headed form, and *H. textor* for the black-headed form), but they were shown to be the same species by Morris (1963) and this is still the current taxonomic status. The colour of the larval head capsules and the behaviour of the late-instar larvae are the only consistent distinguishing features (Loewy *et al.*, 2013). There is some geographical separation of the races, though the distribution does overlap in parts of North America. Where they are sympatric, there appear to be some differences in the timing of the lifecycles (Takeda, 2005). Adults may show pheromone differences, but hybrid matings do occur and fertile eggs can be laid (McLellan *et al.*, 1991; Morris, 1963).

This rapid PRA has primarily been conducted on the black-headed form. This is the only type that is found outside North America, and thus it is the black-headed form that is present in Europe and hence is considered to pose the greatest risk to the UK.

2. What initiated this rapid PRA?

Two adult *H. cunea* were caught in light traps in the UK in 2014. In the same year, an article in the horticultural trade press warned importers about the risk of moving this species on plants from southern Europe. *Hyphantria cunea* was already on the UK Plant Health Risk Register[*], but these new pieces of information prompted a review of the Risk Register scores. As part of the discussions when the score was reviewed, it was decided to carry out a targeted survey around the sites at which the moths had been found, and to update the 1991 PRA, with particular focus on the climatic suitability of the UK for this species, both for establishment and for the potential to cause significant impacts.

3. What is the PRA area?

The PRA area is the United Kingdom of Great Britain and Northern Ireland.

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[*] https://secure.fera.defra.gov.uk/phiw/riskRegister/

Stage 2: Risk Assessment

4. What is the pest's status in the EC Plant Health Directive (Council Directive 2000/29/EC[†]) and in the lists of EPPO[‡]?

This pest is not listed in the EC Plant Health Directive and is not recommended for regulation as a quarantine pest by EPPO, nor is it on the EPPO Alert List.

5. What is the pest's current geographical distribution?

Table 1: Distribution of *Hyphantria cunea.* Source: CABI CPC (2015), unless otherwise stated.	
North America:	Canada (southern states, from British Colombia in the west (Humphreys, 1982) to Nova Scotia in the east (Morris & Fulton, 1970)), USA (most states), Mexico
Central America:	No records
South America:	No records
Europe:	Albania (Paparisto *et al.*, 2010), Austria (Krehan & Steyrer, 2009), Bosnia and Herzegovina, Bulgaria, Croatia (Glavas *et al.*, 1997), Czech Republic, France (Moussion & Gravaud, 1987), Greece (Mouloudis *et al.*, 1980), Hungary (Szeoke, 2000), Italy (Mazzon & Martini, 2000), Moldova, Poland, Romania (Oltean, 2002), Russia, Serbia (Vajgand, 2009), Slovakia (Hrubik, 2007), Slovenia, Switzerland (Jermini *et al.*, 1995), Ukraine (Fedosov, 1992)
Africa:	No records
Asia:	Azerbaijan (Gaziev *et al.*, 1999), China (mainly provinces in the north-east), Georgia (Loladze *et al.*, 2003), Iran (Rezaei *et al.*, 2006), Japan (Honshu, Shikoku, Kyushu) (Yamanaka *et al.*, 2008), Kazakhstan (Isin *et al.*, 2008), Korea Democratic People's Republic, Republic of Korea (Choi & Park, 2012), Kyrgyzstan, Turkey (Firidin *et al.*, 2008)
Oceania:	Not currently present. New Zealand: there were isolated incursions in 2003 and 2005, but these were eradicated and the pest is no longer considered to be present (El-Sayed *et al.*, 2005; Kean & Kumarasinghe, 2007)

This species is native to North America. Its northern limit appears to be around 50-55°N in Canada, which includes Nova Scotia, New Brunswick and the extreme southern tip of Hudson Bay (Ontario). *Hyphantria cunea* is generally found in southern Canada, including

[†] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CONSLEG:2000L0029:20100113:EN:PDF
[‡] https://www.eppo.int/QUARANTINE/quarantine.htm

the southern parts of British Colombia. In the USA, it is widely distributed, and is found as far south as Florida and Louisiana, as well as Mexico.

Hyphantria cunea was introduced to parts of Europe and Asia during the Second World War, and has since increased its range within these regions. In Europe, it was first recorded in Hungary in 1940, and is now present in many countries in southern and eastern Europe, with isolated populations and records from more westerly regions. It has also spread east, into southern Russia and surrounding countries from Georgia to Kazakhstan, and south to Iran. In Eastern Asia, *H. cunea* was first found in Japan, around Tokyo, in 1945. It has now spread to the southern three main islands in Japan, and is also found in Korea, parts of north-eastern China and the Russian Far East.

6. Is the pest established or transient, or suspected to be established/transient in the UK/PRA Area?

There have been two findings of adult *H. cunea* in the UK, both in light traps in 2014. The first record was from Trumpington, Cambridgeshire in May (Dawson, 2015; Plant & Sale, 2015). The second record (which was published first) was of an adult male at the end of September, in Stevanage, Hertfordshire (Sale, 2014). The origins of neither specimen is known, and it is unclear if the 2014 specimens were accidentally imported, migrants, or from a breeding population in the UK. In response to these findings, the Forestry Commission organised trapping to survey for any potential breeding population in autumn 2015 in the area of the two findings. Pheromone lures were not available, and thus only light traps were used (S. Snape, pers. comm., June 2015). A request was also sent to county moth recorders in summer 2015, asking that Defra be notified of any reports they received of *H. cunea*. No specimens were found during the trapping (S. Snape, pers. comm., October 2015). No reports of this species in 2015 have been received from the county moth trappers to date, and both Kent and Devon specifically replied that there had been no findings of *H. cunea*.

7. What are the pest's natural and experimental host plants; of these, which are of economic and/or environmental importance in the UK/PRA area?

The larvae are highly polyphagous and feed on many deciduous trees, shrubs and low growing plants, with host records from a very wide range of plant families. Host lists can be found in many places, such as CABI CPC (2015), or Kim and Kil (2012) for hosts recorded in Korea. In years of high population density, larvae feed on many species, but in years where populations are lower, usually only more preferred hosts are attacked.

Fruit trees, such as *Malus* (apple), *Prunus* (stone fruit such as plums) and *Pyrus* (pears) are major hosts which are widely grown in the UK, as are ornamental trees such as *Juglans* (walnut), *Morus* (mulberry) and *Populus* (poplars).

8. What pathways provide opportunities for the pest to enter and transfer to a suitable host and what is the likelihood of entering the UK/PRA area?

Plants for planting

Eggs are laid in a conspicuous mass, and are only present for a short period of time. Larvae live in communal silken nests, or, by the time they disperse in the final instar, they are large and hairy, though solitary. Thus, both eggs and all sizes of larvae are likely to be detected on imported plants. Adults are unlikely to be associated with this (or any other) commodity, as they are likely to fly off when the plants are disturbed. Pupae, however, could also be associated with plants for planting as they are highly cryptic. Pre-pupal larvae actively seek out concealed places for pupation. It is unclear how far larvae might move in search of suitable pupation sites, but any tree with rough bark could potentially harbour pupae, though only larger trees will have rough bark, and fewer of these large trees are moved in trade. Any plant moved with soil may also harbour pupae, as they may also be found shallowly buried in soil and leaf litter, though it has not been possible to determine how frequently pupae are found in the soil. Additionally, pupae are the overwintering life stage, and many deciduous trees and shrubs will be moved in the winter, while the plants are dormant. Overall, entry on plants for planting is judged to be moderately likely, with medium confidence.

Fruit and vegetables

Between 1966 and 1975, data from Braasch (1976) show that the former East Germany intercepted *H. cunea* on 53 shipments of produce (namely apples, apricots, cherries, grapes, plums, paprika, potatoes and tomatoes), with all but one consignment originating in Hungary. Fifty nine out of the total of 67 specimens detected were larvae, with only a small number of adults and pupae found. While individual specimens have clearly travelled on this pathway in the past, only a small number of individuals have been recorded with each consignment, and there have not been any recorded interceptions in the UK (though produce from within the EU will be subject to a much lower rate of inspection than that from third countries). From the German data, most individuals intercepted were larvae, which have limited mobility. Due to the short shelf-life of fruit and vegetables, it is likely that larvae will need to locate another host to complete development, though it should be noted that larvae are able to withstand periods of starvation, with 30% of sixth instar larvae surviving 12 days without food (Ju *et al.*, 2008). Consignments of produce are also frequently dispersed rapidly, or processed. Thus, if an individual larva does survive to adulthood, the chances of it being able to locate another individual of the opposite sex in order to found a breeding population are not high. Overall, this pathway is considered unlikely, with high confidence.

Cut branches

Hyphantria cunea feeds on deciduous plants, and deciduous cut branches will only be imported while in leaf. As noted under plants for planting, eggs and larvae are conspicuous and it is likely that they would be detected. Pupae are very unlikely to be associated with this commodity, as no reference to pupae in rolled leaves could be found, though it is possible they could be concealed in rough bark. Cut branches do not have a long lifespan, and in addition are likely to be dispersed very rapidly (e.g., for use in floristry). This will reduce the chances of any insect being able to complete its lifecycle, as well as the numbers of larvae in any one location, meaning that an emerged adult will have difficulty locating other adults to mate and establish a breeding population. Overall, entry on this commodity is thought to be unlikely (due to the likelihood of detection and the limited lifespan of the product), with medium confidence.

Hitchhiking on or in non-host commodities

The main life stage associated with non-host commodities are the pupae. Pre-pupal larvae seek out sheltered cracks and other concealed locations to pupate, and will do so in any substrate, not just those associated with their hosts. Shu and Yu (1984) stated that transportation of logs where the bark contains places for pupae to hide contributed to the spread of *H. cunea* in China. In south-east France, Moussion and Gravaud (1987) attributed the dispersal along roads of *H. cunea* to the movement of hitchhiking pupae. In Ukraine, decorative bricks were wrapped in cardboard for transport, and this provided an ideal site for *H. cunea* larvae to pupate, the infestation was noticed when the emerging adults created stains that affected the value of the bricks (Fokin, 2008). Larvae can cause a nuisance as they travel in search of sites to pupate (Giovanni *et al.*, 1986). Therefore, many non-host commodities, especially those moved in autumn, winter and early spring, may potentially be infested with *H. cunea* pupae, and by their nature, these will be hidden and cryptic. Non-host commodities are also less likely to be the target of plant health import inspections. Female moths emerging from the pupae are likely to be able to locate suitable hosts for egg-laying. The main limitation on this pathway for the pupae is the need for sufficient pupae to be transported together so the emerging adults can locate one another and mate.

Adults may be found inside containers or vehicles, and this is another potential hitchhiking pathway. Either a mated female or both sexes would need to be transported to enable a new population to be founded.

Overall, hitchhiking is assessed as likely, with medium confidence. This rating is higher than that for plants for planting due to the fact that so many commodities could potentially harbour pupae and the fact that the larvae and egg masses are more likely to be spotted in nurseries and removed, reducing chance of pupae being present.

Soil

While soil from outside the EU is a banned commodity, soil can be moved freely within the EU. Pupation may take place just under the soil surface, and thus there is a risk that pupae could be associated with soil transported into the UK. However, pupae are large, and thus seem likely to either be detected, or at risk of being damaged or crushed while the soil is collected and moved. Pupae are also only found in the top layer of the soil, and thus the chances of this life stage being associated with bulk imports of soil are considered to be very low as much of the soil will be collected from deeper layers. In addition, at least two pupae will need to survive transport, emerge and locate one another, in order to lay fertilised eggs. Overall, this pathway is considered very unlikely, and this judgement is made with high confidence.

Natural spread

Though both sexes of *Hyphantria cunea* are capable of flight, and the species is present in France, this pathway is rated very unlikely with high confidence. This moth is only found in southern France (and is absent from other countries bordering the North Sea, such as Belgium and the Netherlands), and, while occasional specimens have been found far outside their current range, this is not a known migratory species. The incidental specimens trapped (such as the UK findings in 2014) are more likely have been transported with trade. Even in an experimental flight mill, where flight is forced, maximum flight distances were around 23 km (Yamanaka *et al.*, 2001) and this is far less than the distance adults would need to travel from the nearest area of their current known distribution to the UK.

Plants for planting	Very unlikely ☐	Unlikely ☐	Moderately likely ☑	Likely ☐	Very likely ☐
Confidence	High Confidence ☐	Medium Confidence ☑	Low Confidence ☐		
Fruit and vegetables	Very unlikely ☐	Unlikely ☑	Moderately likely ☐	Likely ☐	Very likely ☐
Confidence	High Confidence ☑	Medium Confidence ☐	Low Confidence ☐		
Cut branches	Very unlikely ☐	Unlikely ☑	Moderately likely ☐	Likely ☐	Very likely ☐
Confidence	High Confidence ☐	Medium Confidence ☑	Low Confidence ☐		
Hitchhiking	Very unlikely ☐	Unlikely ☐	Moderately likely ☐	Likely ☑	Very likely ☐

Confidence	High Confidence	☐	Medium Confidence	☑	Low Confidence	☐				
Soil	Very unlikely	☑	Unlikely	☐	Moderately likely	☐	Likely	☐	Very likely	☐
Confidence	High Confidence	☑	Medium Confidence	☐	Low Confidence	☐				
Natural spread	Very unlikely	☑	Unlikely	☐	Moderately likely	☐	Likely	☐	Very likely	☐
Confidence	High Confidence	☑	Medium Confidence	☐	Low Confidence	☐				

9. If the pest needs a vector, is it present in the UK/PRA area?

This is a free living insect that does not require a vector.

10. How likely is the pest to establish outdoors or under protection in the UK/PRA area?

As this pest is polyphagous, and many of the preferred hosts are grown widely in the UK, host availability will not limit the potential for establishment. Climate is much more likely to be limiting, and the potential for the UK to be suitable for establishment of *H. cunea* is discussed in detail in Appendix 1. This pest has a complex lifecycle, and the judgements are not straightforward. In particular, it can have between one and four generations per year and overwinters as diapausing pupae. Univoltine populations have one generation per year, with adults emerging from overwintered, diapaused pupae in early summer. The ensuing larvae feed during the summer and the pupae then enter diapause to overwinter. Two generations per year (bivoltine populations) are possible if the first generation of larvae do not enter diapause as pupae, with the pupae instead continuing to develop rapidly into adults. The second generation of adults that emerges then gives rise to a second generation of larvae, which develop into pupae that enter diapause and overwinter. Three or even four generations are possible in a single year, determined by the environmental conditions not triggering diapause in the pupae. The induction of diapause is related to day length, as well as other factors, and the critical parameters apparently vary between populations. Univoltine populations of *H. cunea* from Canada, under experimental conditions, have been shown to switch to a multivoltine (no diapause) lifecycle (Morris, 1967); but bivoltine populations from Hungary, translocated to Germany in a field experiment, failed to switch to a univoltine lifecycle, instead dying out as the second generation of eggs or larvae failed to complete development in the autumn (Braasch, 1976). In Japan, Gomi (1996b) explicitly mentions mixed bi- and tri-voltine lifecycles, though mixed voltinism is likely to occur in many transitional areas. Therefore, the number of generations per year of *H. cunea* is clearly not fixed, and will change depending on the environment.

The main complication for assessing the likelihood of establishment arises from the fact that the introduced populations of *H. cunea* in Europe and Japan all appear to be multivoltine (having at least two generations per year). Seventy-five years after this pest was first recorded in Hungary, no records of it breeding in parts of Europe where only one generation is theoretically possible have been found. Though it is continuing to spread east into parts of Asia, it has not apparently been able to extend its range into northern Europe. Therefore, it is assumed that some factor is preventing the northward spread, and one suggestion is that the European populations are, for reasons unknown, not currently able to switch to a univoltine lifecycle, and that northern parts of Europe are not warm enough for the second generation of larvae to finish feeding before the onset of winter. Based on this, if a bi- or tri-voltine population were to enter the UK, establishment outdoors would be unlikely, as no part of the UK is suitable for more than one generation per year. This judgement is made with low confidence, as it is unclear what factors might prevent a multivoltine population switching to a univoltine lifecycle. There is also the possibility that some populations in Europe are, in fact, univoltine, and that the apparent lack of any expansion of range into places like Germany, the Baltic States or northern France is due to some other factor entirely, e.g. very low populations being overlooked. In the south-west of France, populations were high in the late 1970s and early 80s (Moussion & Gravaud, 1987), which suggests that conditions were suitable for the pest. However, *H. cunea* currently only seems to be present at very low population levels in France, including in the former outbreak area. The reasons for this aren't known, but could include parasitism, predation, or a combination of factors. As the factors behind the low populations in France aren't known, clearly it is also unknown which factors, if any, might serve to limit potential populations of *H. cunea* in the UK.

The maps in Appendix 1 show that southern England (particularly in the east) and an area around the Bristol Channel are theoretically suitable for one generation per year of *H. cunea*, though the rest of England is less favourable for establishment outdoors. Almost no part of Scotland or Northern Ireland, or Wales other than the south, have sufficient degree day accumulations to enable development of this pest, except in the warmest years. Establishment outdoors of a univoltine population is therefore rated likely in the southern part of England and Wales. While there are different thresholds for thermal development available in the literature, all show a similar pattern. Suitability at a local level, e.g., south-facing slopes or urban heat islands such as London, may also prove more or less favourable for the pest than is apparent from the maps here, but overall this judgement is made with high confidence as the data are reasonably consistent and three of the different thresholds available in the literature were analysed here in some detail.

Establishment in protected cultivation is rated very unlikely. While the polyphagy of the larvae means that some crops grown in such environments will be suitable hosts, the conspicuous nature of the larval nests mean that it is considered likely that infestations will be detected. This judgement is made with high confidence.

Outdoors: introduction of a multivoltine population	Very unlikely ☐	Unlikely ☑	Moderately likely ☐	Likely ☐	Very likely ☐
Confidence	High Confidence ☐	Medium Confidence ☐	Low Confidence ☑		

Outdoors: introduction of an univoltine population	Very unlikely ☐	Unlikely ☐	Moderately likely ☐	Likely ☑	Very likely ☐
Confidence	High Confidence ☑	Medium Confidence ☐	Low Confidence ☐		

Under protection	Very unlikely ☑	Unlikely ☐	Moderately likely ☐	Likely ☐	Very likely ☐
Confidence	High Confidence ☑	Medium Confidence ☐	Low Confidence ☐		

11. How quickly could the pest spread in the UK/PRA area?

Historically, data are available for the rate of spread within Europe, mostly at the country level. First recorded in Hungary (around the port of Csepel, south of Budapest) in 1940, by 1948 it was found through much of the country. The pest was detected in the former Yugoslavia (1948, though not reaching the Mediterranean coast until 1962), the former Czechoslovakia (1948), Austria (1951), the former USSR (1952, though not reaching the Ukraine east of the Carpathian Mountains until 1966), Romania (1963), Bulgaria (1963), Poland (1965), Moldova (1966) France (1976), Greece (1980), Italy (1983) and Switzerland (1991) (Railyan, 1974; Rezbanyai-Reser, 1991; Szalay-Marzso, 1971). It is unclear how much of this spread was human-aided, and how much spread was due to the pest's own dispersal capability. Additionally, *H. cunea* (like many forestry pests) has periodic outbreaks, and during these outbreaks, spread is likely to be more rapid due to the high populations.

Several types of data exist on the flight capacity of the males. In artificial flight mills, flights of over 23 km have been recorded, but when flight was not forced and capture-mark-recapture experiments were used, males were considered to fly less than 300 m per day (Yamanaka *et al.*, 2001). In a study which used pheromone traps to recapture males, 1 moth was recaptured after being released at a distance of 250 m from the traps (out of 10 released), while about a quarter of the 25 moths released 200 m away from the trap were recaptured (Zhang & Schlyter, 1996). The flight capacity of females is less well known, but one study was found. Female moths were infected with a nuclear polyhedrosis virus, which they were expected to transmit to the eggs and larvae (Suzuki & Kunimi, 1981). The field experiment took place in a mulberry field near Tokyo, Japan, in an area where no natural *H. cunea* larval colonies were found. Egg masses and colonial larval tents (originating from the released females) were subsequently located. The maximum distance from the release point was less than 200 m, though 90% were less than 40 m from the origin (Suzuki & Kunimi, 1981). There was also some evidence of host selection on the females' part, and, as the environment was not homogenous, this may also have affected the results, as it is suggested that if females left the field at the centre with a preferred host of mulberry, the females then flew actively, and for much longer distances (Suzuki & Kunimi, 1981).

Spread with trade could be much faster. Plants are widely traded, and though larval nests would be conspicuous, as are the egg masses, pupae would be less likely to be detected. Additionally, there is some evidence of local spread along roads, this presumably assisted by pupae hitchhiking on or in vehicles. In a map provided by Moussion and Gravaud (1987), showing the distribution of *H. cunea* around Bordeaux in France, the spread along roads is very apparent. Overall, spread in trade is considered to occur quickly, with medium confidence in the judgement.

Natural Spread	Very slowly	☐	Slowly	☐	Moderate pace	✓	Quickly	☐	Very quickly	☐
Confidence	High Confidence	☐	Medium Confidence	✓	Low Confidence	☐				

With trade	Very slowly	☐	Slowly	☐	Moderate pace	☐	Quickly	✓	Very quickly	☐
Confidence	High Confidence	☐	Medium Confidence	✓	Low Confidence	☐				

12. What is the pest's economic, environmental and social impact within its existing distribution?

There are a number of reports of damage from the current range of *H. cunea,* though it appears to have greater impacts in its introduced range of Europe and Asia than it does in its native North America. All known populations in Asia and Europe have a multivoltine lifecycle.

In western Europe, there appears to be a pattern of major damage soon after introduction to a new area, followed by a reduction in the harm seen in subsequent years. A localised outbreak (in a forest of 16 ha) was reported in 2009 from Burgenland in eastern Austria in 2009, but no larger outbreaks have been recorded in this country to date (Krehan & Steyrer, 2009). In France, the pest caused substantial damage soon after its introduction, but by 1985 very few moths were caught, this decrease in population was attributed to treatments with *Bacillus thuringiensis* (Moussion & Gravaud, 1987). Since the early 1980s, there haven't been any reliable records of outbreaks of *H. cunea* in any part of France (A. Roques, pers. comm., October 2014), though it is still present at low levels (www.lepinet.fr, 2015). In northern Italy, damage was reported in the years following its introduction (e.g. Deseo *et al.*, 1986), but populations appear to have declined since the 1990s (Allegro, 1997). It is unclear what has caused the reduction in numbers, but it is almost certain that there are several contributory factors (Allegro, 1997). The second generation causes higher percentage defoliation than the first, at least in poplar (Allegro, 1997). Another important factor is that, like many forest pests, outbreaks (when high numbers of the pest occur) only happen every few years, and there may be the potential for some population(s) in western Europe to reach outbreak levels again in future.

However, in eastern Europe, the damage can be more severe. Kiss *et al.* (1978) reported that the length of the outbreak cycle in Hungary was 5 years, using data from 1963 to 1976. More recent information suggests that after a period of low populations between 1990 and 1996, a population peak occurred in 1998 (Szeoke, 2000). In Romania, *H. cunea* defoliated 12 ha in Cluj in the north of the country, and 17 ha in Reghin (just to the east of Cluj) between 1999 and 2001, defoliation levels of 48 and 83% respectively (Oltean, 2002). In Slovakia, the first outbreak was noted in 1953, and more recently, in the southwest of the country, there have been repeated outbreaks in the 10 year period since 1992 (Hrubik, 2007).

In Asia, impacts have been recorded from a number of countries. In China, it was first detected in 1979 in Liaoning, and is now found from around 31°N to 42°N, and is considered a serious pest (Xu *et al.*, 2015). Kazakhstan first detected *H. cunea* in 2003. Three years later, it infested over 1300 ha, with up to 80% defoliation recorded at some infested sites (Isin *et al.*, 2008). South Korean populations were found mainly in the urban environment, with two thirds of street trees infested, but less than 20% of landscape trees and under 14% of forest trees affected (Kim & Kil, 2012).

Overall, where the species has more than one generation per year (although impacts can be variable and possibly cyclical), they are assessed as large with medium confidence.

Where the species is univoltine, much less information about damage is available. In British Colombia (Canada), the damage is regarded as generally only of aesthetic importance, though the larval tents and defoliation may be locally extensive (Humphreys, 1982). Morris (1964), discussing populations cycles in Canada, states that though the nests are more evident in some years, *H. cunea* is “not an outbreak species in its Canadian range”. Overall, impacts in Canada and the northern USA, where the pest is univoltine, are assessed as small with high confidence.

Impacts (multivoltine)	Very small	☐	Small	☐	Medium	☐	Large	☑	Very large	☐
Confidence	High Confidence	☐	Medium Confidence	☑	Low Confidence	☐				

Impacts (univoltine)	Very small	☐	Small	☑	Medium	☐	Large	☐	Very large	☐
Confidence	High Confidence	☑	Medium Confidence	☐	Low Confidence	☐				

13. What is the pest's potential to cause economic, environmental and social impacts in the UK/PRA area?

As the UK is only considered suitable for one generation per year, economic and environmental impacts are assessed as small, with high confidence. Univoltine populations in North America appear to cause little damage, and, with only one generation per year and a marginally favourable climate, it is not considered that the pest could reach damaging levels in the UK, except, perhaps, if the year was exceptionally warm. Social impacts, are overall assessed as small, with medium confidence. However, social impacts may be greater at a very local level. The larvae and the silken tents are conspicuous, and local levels of defoliation can be substantial. Though the effects will almost certainly be temporary, infestations on urban and amenity trees (which are apparently preferred by this species to forestry trees) could cause higher social impacts in the immediate area affected.

Economic Impacts	Very small ☐	Small ☑	Medium ☐	Large ☐	Very large ☐
Confidence	High Confidence ☑	Medium Confidence ☐	Low Confidence ☐		
Environ-mental Impacts	Very small ☐	Small ☑	Medium ☐	Large ☐	Very large ☐
Confidence	High Confidence ☑	Medium Confidence ☐	Low Confidence ☐		
Social Impacts	Very small ☐	Small ☑	Medium ☐	Large ☐	Very large ☐
Confidence	High Confidence ☐	Medium Confidence ☑	Low Confidence ☐		

14. What is the pest's potential as a vector of plant pathogens?

Hyphantria cunea is not known to vector any plant pathogens.

15. What is the area endangered by the pest?

The south-east of the UK is most at risk of the pest establishing, but significant damage is not expected, other than in the warmest years. Thus, no part of the UK is considered endangered by this pest.

Stage 3: Pest Risk Management

16. What are the risk management options for the UK/PRA area?

Exclusion

Hyphantria cunea currently appears to be absent from the UK. Measures against transport of the insect on the above-ground parts of plants and plant products moving in trade would be aided by the conspicuous nature of eggs, larvae and the larval nests, though within the EU, host plants are freely moved between member states, and are subject to a much lower level of inspection than imports from third countries. However, measures against pupae would be more difficult to design and implement. Pupae can be shallowly buried in soil, or hidden in cracks of many products, the latter not necessarily having any association with plants or plant products. Therefore, measures against pupae are unlikely to be wholly successful, and be very difficult and costly to implement.

Eradication or containment

Early detection might be problematic. While larval nests are highly conspicuous and the large number of amateur moth-trappers in the UK might suggest this species would be detected early, there are species in the UK which might be confused with *H. cunea*, both as adults and larvae. The adult has a superficial similarity to several other species of Arctiidae found in the UK (for example, species of *Spilosoma*), and Sale (2014) mentions some of the differences between *H. cunea* and the native species it could be confused with. Other larval Lepidoptera live in nests, and there is a guide to species which create conspicuous nests in Sterling and Parsons (2013). Overall, while a specialist would be able to identify both adults and larvae, others might not, and so any infestation in the wider environment might be able to spread and establish before it was detected. Pheromones have been identified for *H. cunea* (Hill *et al.*, 1982) but pheromone lures are not currently available commercially. Additionally, El-Sayed *et al.* (2005) identified differences between the composition of the pheromones extracted from the transient females trapped in New Zealand and the composition of the pheromone lure being sold in North America, suggesting that the imported lures might not be wholly effective against the specimens found.

As with any highly mobile pest in the wider environment, especially tree pests, once a population is established in the wider environment, eradication would be very difficult, if not impossible, to achieve. The wide host range also means that it would be necessary to target control measures at a wide range of crop and non-crop species. Containment may also be difficult. Final instar larvae seek out concealed locations to pupate, and there is some evidence that local spread within Europe has been due to the concealed pupae being transported in vehicles, etc.

Non-statutory controls

There are a number of chemical control options. However, it is difficult to target larvae with insecticides because the larvae are both protected by the silken nests, and the nests may be found in inaccessible locations in mature trees. Insecticides which are approved for use on amenity vegetation in the UK are *Bacillus thuringiensis* (BT) (DiPel DF), deltamethrin (e.g. Decis) and diflubenzuron (Dimilin Flo). These are highly effective against Lepidoptera larvae, if applied early enough in the life cycle, and to the whole tree canopy, though will only be practical for smaller trees or shrubs. However, once the larvae have passed the third instar, BT and diflubenzuron are less effective and better control is obtained using deltamethrin. It should be noted that this broad-spectrum insecticide is highly toxic to aquatic life (as is diflubenzuron) and cannot be used near water. It should also be noted that these products are only approved for use on amenity vegetation, none are approved for use in woodland, and only Dimilin is approved for use in forestry plantations.

At a local level, populations could be reduced by manual removal of the larval nests. The nests are highly visible, being constructed at the ends of the branches. Infested branches can be pruned to remove the nests, and either deep-frozen for a week before disposal, or some other phytosanitary secure method of destruction used, such as deep burial or immediate burning. Unlike some other nest-building caterpillars such as *Euproctis chrysorrhoea* (brown-tail) or *Thaumetopoea processionea* (oak processionary), the hairs of *H. cunea* larvae do not contain toxins (though, as with any hairy caterpillar, the structure of the hair may cause reactions on sensitive skin), making disposal of the nests less problematic.

17. References

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Name of Pest Risk Analysts(s)

Anastasia Korycinska

Appendix 1: Climate modelling to assess the potential for UK establishment and impacts of *Hyphantria cunea*

Background

There have been a number of studies on the thermal requirements of *H. cunea.* Many of the studies are from Japan, where this species is invasive, but thermal requirements for development have also been studied in North America (the native range) and also in Europe and Russia, where this is also a non-native pest.

The phenology, voltinism and critical day length for diapause induction all apparently vary according to the origin of the population studied, and may also change over time in response to environmental conditions. Since its introduction into Japan, various biological characteristics of *H. cunea* have been studied in detail by several generations of Japanese researchers such as Itô in the 1960s and Gomi from the 1990s to the present day, and this body of research was a valuable resource for the analysis carried out here.

Data sources

Daily minimum and maximum temperatures between 2000 and 2014, interpolated to 25 km grid squares, were obtained for 42 countries in Europe (dataset from the EU Joint Research Centre (Ispra, Italy): MARS-AGRI4CAST, 2015). Countries from which data were obtained are as follows: Albania, Austria, Belarus, Belgium, Bosnia & Herzegovina, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Guernsey, Hungary, Ireland, Italy, Jersey, Latvia, Lithuania, Luxembourg, Macedonia, Malta, Moldova, Montenegro, Netherlands, Norway, Poland, Portugal, Romania, Russia (Kalingrad only), Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, UK and Ukraine. The data were manipulated and analysed in Microsoft Excel 2010®, with the relevant summary values mapped using ArcGIS 10.2.2®.

The literature was searched to obtain data on the thermal requirements of the insect, and the results are summarised in table 2. The accumulated degree day requirements of the diapausing and non-diapausing generations appear to differ, and for the analysis carried out here, only those studies where both values were given were used. Additionally, the values given for the Kobe population in Japan by Gomi and Takeda (1990) were excluded, as these results show that the diapausing generation need fewer day degrees than the non-diapausing generation, which is contrary to other sources.

Table 2. Development thresholds for *Hyphantria cunea*. The"1st generation" column gives degree day accumulations for populations with diapausing pupae; the "2nd generation" column accumulations for populations with non-diapausing pupae. The table is sorted according to the accumulated day-degree requirements of the non-diapausing generation, in descending order.

Country and region	Threshold temperature for development (°C)	Accumulated degree days above threshold		Source
		1st generation	2nd generation	
USA (Kentucky, red-headed larvae)	*11.3-12.1 (larvae)*	*1589*	*1022*	*Nordin and O'Canna (1985)*
Japan (Kobe)	10	686	870	Gomi and Takeda (1990)
USA (Kentucky, black-headed larvae)	10.7–10.9 (larvae)	1097	840	Nordin and O'Canna (1985)
Canada (New Brunswick and southern Nova Scotia)	10.5 (51°F)[§]	982	830	Morris and Fulton (1970)
Italy (Cadé, near Parma)	10		820-1060 (outdoor populations)	Deseo *et al.* (1986)
Japan (Nishigahara and Fuchu)	10.9 (larva + pupa)	–	780-800	Ito *et al.* (1968)
Japan (Gunma)	10	830	780	Shishida *et al.* (2004)
Japan (Fukui)	10.6	–	724.4	Gomi *et al.* (2007)
Japan (Kanazawa)	11.2	–	680.7	Gomi *et al.* (2009)
Germany	10.5	679.3 (generation unknown)		Braasch (1976)
Japan (Takaoka)	11.3	–	674.5	Gomi *et al.* (2009)
Japan (Akita)	10.09 (larvae)	–	596.68 (larva–pupa only)	Gomi (1996a)
Japan (Urawa)	10.07 (larvae)	–	567.39 (larva–pupa only)	Gomi (1996a)

[§] All data originally provided in Fahrenheit. The Celsius degree day values quoted here are taken from the conversion by Nordin and O'Canna (1985).

Analysis and interpretation

The thermal requirements of *H. cunea* found in the literature are in agreement to a large extent, though the precise thresholds do vary between populations and/or authors. The threshold temperature for development is often stated to be 10°C, and that was the value used in this work. However, values of up to 11.3°C have been recorded, and many of the experiments reported here do seem to set the threshold a little higher, though by less than 1°C. Likewise, the accumulated day degrees reported are somewhat variable. Most are around 800 day degrees, but these vary from 870 (or higher) to under 680.

Data on the number of generations of *H. cunea* are available for some European populations, though much of it is rather dated and does not refer to the same time period used in the maps generated here. Nevertheless, these reports were compared against the predicted number of generations for the climate mapping carried out here (Table 3) in an attempt to validate the maps produced, at least partially.

The maps provided here based on degree days for development (Figs. 3–5) are similar to the situation observed in the parts of Europe where *H. cunea* is present. According to these maps, parts of England and southern Wales would be suitable for the establishment of a univoltine population of *H. cunea.* However, although Germany has conditions suitable for one generation (but not two), and there have been repeated findings of the pest in imported fruit and vegetables (Braasch, 1976), it is not considered to be present in this country according to the NPPO (cited in EPPO global database, https://gd.eppo.int/taxon/HYPHCU/distribution/DE). Grosser (1980) calculated that one generation per year in the former East Germany was likely, but was unable to say if *H. cunea* would be capable of establishing in the country in the future. Over 30 years later (at the time of writing), this pest is not known to have established in any part of Germany. *Hyphantria cunea* is on the list of quarantine organisms for Belarus and Lithuania, both of which are countries where the maps generated here show that only one generation would be expected. In Switzerland, most of which is unsuitable for establishment according to the maps generated here, a single male *H. cunea* was found in 1991 (Rezbanyai-Reser, 1991), and currently it seems to be limited in distribution, apparently restricted to the southern part of Ticino canton (Wittenberg, 2005), on the border with northern Italy. This area, alone in Switzerland, is suitable for two generations every year according to the maps presented here. Of the remaining countries in northern Europe that are theoretically only suitable for one generation, Poland has a few records, mainly in the south-east (European Butterflies and Moths, 2015), but it is unclear if these are breeding populations or transient adults. Kosibowicz (2014) reported that the occurrence of *H. cunea* in Poland is sporadic, suggesting that these findings are due to repeated incursions and stating that it hasn't spread in Poland, perhaps because of unsuitable conditions. The Czech Republic also has a small number of records (AOPK ČR, 2015), but, once again, it isn't certain if these are transient adults or breeding populations. The species has been recorded from a national park near the southern border with Austria (Vitek, 2011) and Agromanual (2015) states that in exceptionally warm years, *H. cunea* is found as far north as Moravia, in the south of the Czech Republic. Both of these observations tie in with the southerly map locations of the previous reference.

Table 3. Comparison of observed and predicted number of annual generations of *Hyphantria cunea* in Europe.

Country	Reported	Predicted
France (Bordeaux)	Two generations per year in the south-east (Riom & Menassieu, 1979). Moussion and Gravaud (1987) also state there are two generations, and exceptionally a third in the autumn.	Two generations are expected most years in the south-east of France. A third generation is not predicted in this part of France.
Germany (Potsdam)	An experimental colony kept outdoors near Berlin during 1974-5 had one generation, but the second generation failed to complete development before winter (though the exact reasons aren't known) (Braasch, 1976).	No part of Germany is suitable for more than one generation, other than small areas in the south and east, and those only in the warmest years.
Hungary	Szalay-Marzso (1971) stated that there are two generations, though a partial third generation occurred in the first few years after introduction. Kiss *et al.* (1978) and Gaspar (1997) also reported that there are two generations per year.	Most parts of Hungary are suitable for two generations most years.
Italy (Cadé, Pavia)	There are two generations in northern Italy south of Parma, with no evidence of a partial third (Deseo *et al.*, 1986), and two generations just south of Milan (Camerini & Groppali, 1999).	Two generations would be expected every year in northern Italy.
Macedonia (Skopje)	Three annual generations in Skopje (Serifamovski, 1980), which is now in northern Macedonia.	Only two generations expected in the north, though southern parts of Macedonia may have three generations in warm years.
Moldova	Two complete generations, occasionally a partial third (Railyan, 1974).	Two generations are possible most years, in all but the extreme north of the country where only one generation would be expected.
Romania (Bucharest)	Two generations (Beratlief *et al.*, 1977).	Two generations around Bucharest in the southern part of the country.
Serbia (Sombor)	Two generations in northern Serbia (Vajgand, 2010).	Two generations are expected in northern areas, though in the south, bivoltine only during warmer years.
Slovakia	One author reported that the second generation failed to complete development in colder years, but another reported that 3 generations were possible in the extreme south of the country (both cited in Szalay-Marzso, 1971).	In the south of Slovakia, two generations are expected most years, but only one generation in the north. No part of Slovakia is expected to have three generations.
Ukraine (Odessa)	Two generations (Fedosov, 1992).	Two generations expected most years in this part of Ukraine.

Potential risk to the UK

It is not clear if *H. cunea* has any univoltine breeding populations in Europe. All the sources found state there are two or three generations per year and these all from more southerly (and warmer) parts of Europe. Unambiguous records of breeding populations (of any generation length) were not found for any part of Europe where only one generation is considered possible in the maps generated here. It has been a source of speculation to a number of authors as to whether *H. cunea* is capable of expanding its range further north in Europe, but the fact it has not done so at any time in the past 75 years, while expanding its range eastward into Asia, suggests that some factor is preventing this northward spread. One suggestion is that the European populations are unable to switch to a univoltine lifecycle, though the mechanisms for this lack of adaptability are all speculative at best. It must be noted that the number of generations per year are not known to be fixed in any population of *H. cunea* that has been studied to date. Univoltine Canadian populations kept under artificial conditions were able to avoid diapause, with many individuals switching to a multi-generation (no diapause) lifecycle (Morris, 1967). The introduced population in Japan has shown various changes in life-history traits in the years following its introduction to that country, including switching from bivoltine to trivoltine lifecycles in some areas, changes in critical day length required for diapause induction and differing rates of development, all of which have been studied intensively (for example, Gomi, 1997; Gomi, 2007; Gomi *et al.*, 2009; Gomi & Takeda, 1990). Research that involved rearing Ontario (Canada) and Ohio (USA) pupae in Ontario- and Ohio- like environments showed that each ecotype did better in conditions approximating to its native environment, for a number of overwintering metabolic measures (Williams *et al.*, 2015). The conclusion of Williams *et al.* (2015) was that different populations have different physiological adaptations to their local environments, and that many of these adaptive traits were heritable, though they do note further work will be necessary to distinguish between genetic local adaptation and other factors, such as the effects of the larval habitat (as late-instar larvae were collected from the field for this experiment).

Based on a review of the evidence gathered for this analysis, the UK is unlikely to be at risk of establishment by the current European populations of *H. cunea*, as no part of the country has sufficient thermal accumulations for two generations to develop in a single year, other than London, and that only in the very warmest years. However, it must be noted that the factors limiting the northern expansion of *H. cunea* in Europe are unknown.If the European population (or any part of it) was able to expand northwards, probably by means of switching to a univoltine lifecycle, large parts of England would appear thermally suitable for a univoltine population of *H. cunea* to establish. It should also be noted that univoltine populations may actually be present (undetected) in the northern part of the current European range, and the failure of *H. cunea* to expand its range northwards is due to some factor not analysed here. Additionally, *H. cunea* is already univoltine throughout its range in the southern parts of Canada. If a southern Canadian population were to be introduced to the UK, once again, parts of this country would be suitable for outdoor establishment.

Approximations, assumptions and limitations

Larvae live in webbed nests, and the presence of these nests in other lepidopteran species has been shown to raise the temperature experienced by the larvae within the nests significantly. However, the nests of *H. cunea* may be less effective than those of other species in increasing the temperature. Rehnberg (2002) showed that *H. cunea* nests did warm up quickly, but that the extra heat is quickly lost when there is wind. Further studies showed that it was sunlight warming the nests, as temperatures inside the nest at night or on cloudy days were close to ambient, though the temperature inside the nests did fluctuate a great deal (Rehnberg, 2006). Overall, there is the probability that these nest-living larvae will experience some temperatures higher than the ambient surroundings, and thus a greater day-degree accumulation, than the values calculated here.

Hyphantria cunea has a lifecycle that includes a period of diapause in some pupae. Diapause is triggered by day length below a certain value, though the critical period appears to differ depending on the source of the population being studied. If the day length is longer than the critical period, the pupae develop rapidly, and the next generation of adults emerge in the same year. However, if the day length is shorter than the critical length required by that population of larvae, the pupae go into diapause, only completing their development in the spring. Factors relating to termination of diapause have been less well studied, but a significant rise in temperature appears to re-start development, as long as there has been some time spent in cooler temperatures. Day-degree accumulation during diapause will not contribute to the development of the pupae. The degree-day accumulations given here were calculated for the whole year, the values will over-estimate the development possible, as they include the winter, during which the pupae will be in diapause. As the model of Kean and Kumarasinghe (2007) does include diapause (based on day length parameters only), this may be worth investigating if further modelling is considered necessary.

Figures 4–5 are based on the most precautionary set of thermal thresholds (those provided by Shishida *et al.* (2004)). Other versions of these figures (not shown here), using the thresholds provided by other authors, show slightly different risks and fewer grid squares in the UK are considered suitable for establishment.

In this work, “first generation” has been used for the first adults and larvae of the year, i.e. adults that emerged from the overwintering pupae and the larvae that result from the eggs laid by those adults. Terminology is not wholly consistent across the literature, and while all attempts have been made to determine exactly which generation is being studied in every instance, it is possible that some misattributions have occurred here when interpreting the literature.

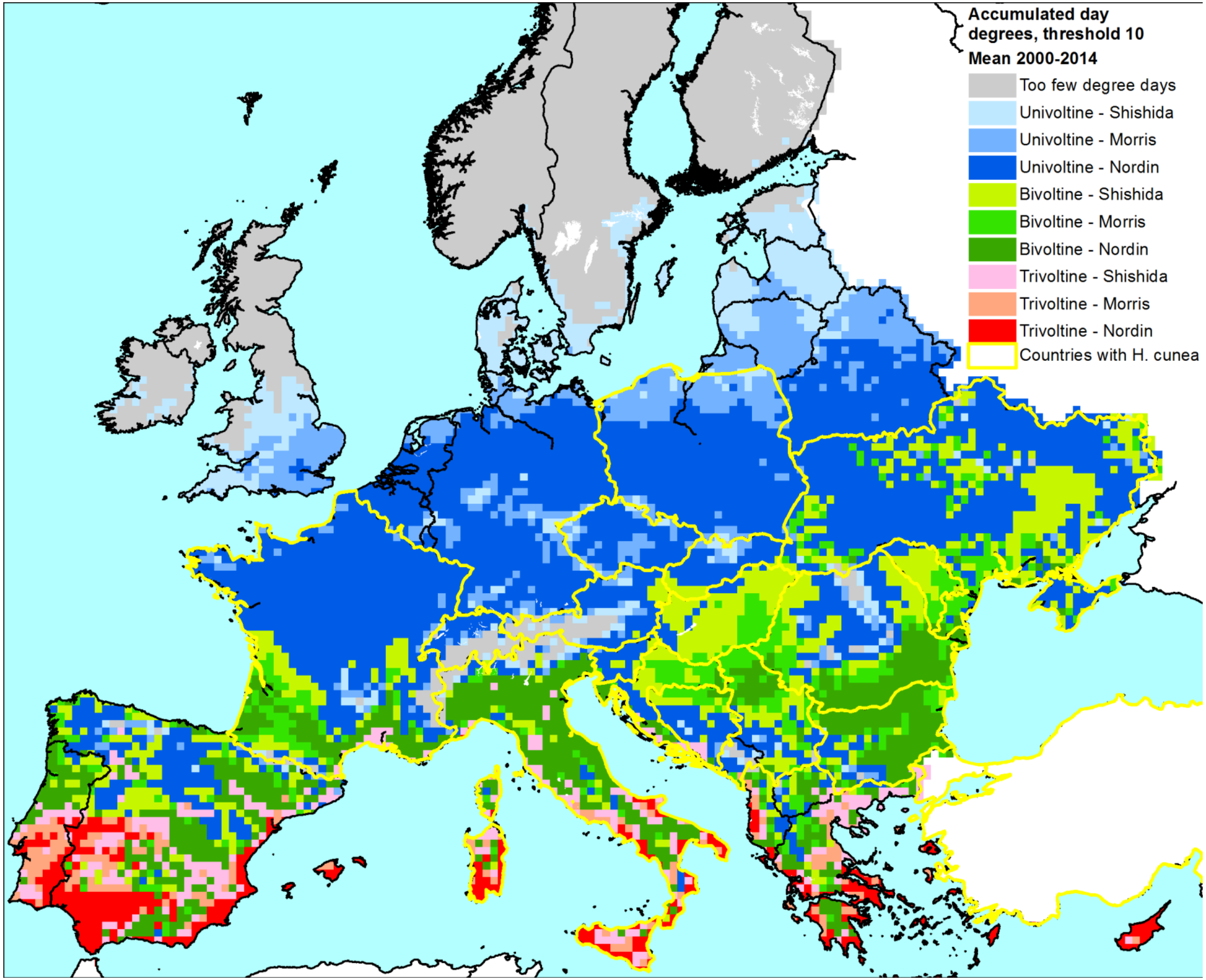
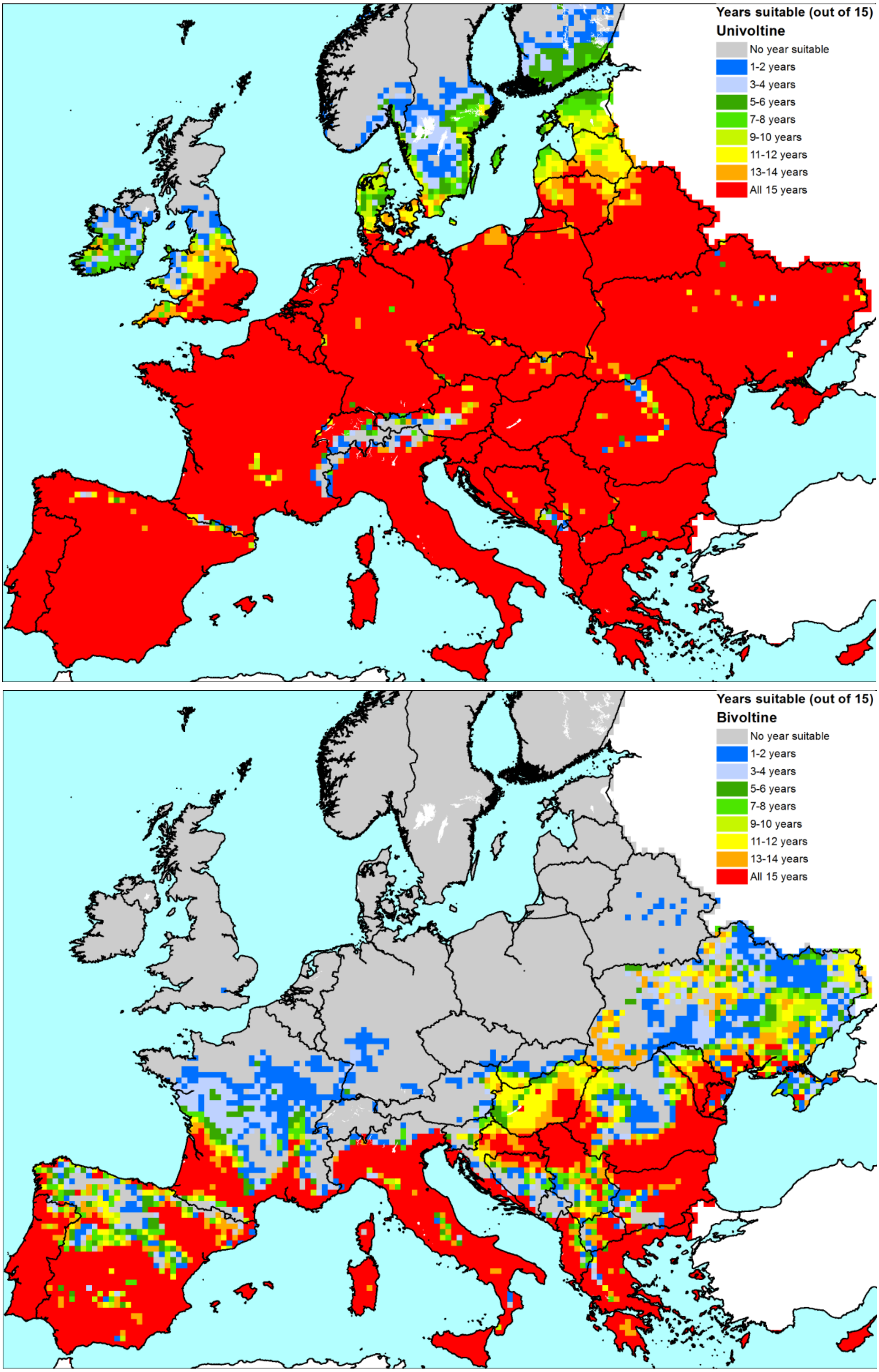


Figure 3. Map showing the mean theoretical number of generations of *Hyphantria cunea* in Europe over a fifteen year time period, using a threshold temperature for development of 10°C, and total accumulated day degree values from three different sources. Shishida *et al.* (2004): univoltine, 830 day degrees; bivoltine, 1610 (=830+780); trivoltine, 2390 (=830+780+780). Morris and Fulton (1970): 982, 1812 and 2642 day degrees. Nordin and O'Canna (1985), for black-headed larvae: 1097, 1937 and 2777 day degrees. Climate data are from MARS-AGRI4CAST (2015), from 2000 to 2014 inclusive. It should be noted that it has not been possible to ascertain if there are breeding populations of *H. cunea* in all countries where it is marked as “present”.



Figures 4–5. Maps showing the number of years 2000-2014 where each grid square is suitable for one generation (top) or two generations (bottom) of *Hyphantria cunea.* Thermal requirements are based those from Shishida *et al.* (2004), which give the most precautionary output, and climate data are from MARS-AGRI4CAST (2015).

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