www.defra.gov.uk

Nuisance Insects and Climate Change

March 2009

Llywodraeth Cynulliad Cymru
Welsh Assembly Government

DOE
Department of the Environment
www.doeni.gov.uk

defra
Department for Environment Food and Rural Affairs

Department for Environment, Food and Rural Affairs
Nobel House
17 Smith Square
London SW1P 3JR

Tel: 020 7238 6000
Website: www.defra.gov.uk

© Queen's Printer and Controller of HMSO 2007

This publication is value added. If you wish to re-use this material, please apply for a Click-Use Licence for value added material at http://www.opsi.gov.uk/click-use/value-added-licence-information/index.htm.

Alternatively applications can be sent to Office of Public Sector Information, Information Policy Team, St Clements House, 2-16 Colegate, Norwich NR3 1BQ; Fax: +44 (0)1603 723000; email: hmsolicensing@cabinet-office.x.gsi.gov.uk

Information about this publication and further copies are available from:

Local Environment Protection
Defra
Nobel House
Area 2A
17 Smith Square
London
SW1P 3JR
Email: noise@defra.gsi.gov.uk

This document is also available on the Defra website and has been prepared by Centre of Ecology and Hydrology.

Published by the Department for Environment, Food and Rural Affairs

An Investigation into the Potential for New and Existing Species of Insect with the Potential to Cause Statutory Nuisance to Occur in the UK as a Result of Current and Predicted Climate Change

Roy, H.E.[1], Beckmann, B.C.[1], Comont, R.F.[1], Hails, R.S.[1], Harrington, R.[2], Medlock, J.[3], Purse, B.[1], Shortall, C.R.[2]

[1]Centre for Ecology and Hydrology, [2]Rothamsted Research, [3]Health Protection Agency

March 2009

Contents

Summary

Changes in ecology, climate and human behaviour over recent decades have favoured the development and increased prevalence of urban pests, including nuisance insects. The potential for nuisance insect species to increase in prevalence in the UK as a result of climate change is addressed in this report through two key objectives:

1: To complete a desk top study to determine the current level of knowledge in relation to new and existing species of insect with the potential to cause statutory nuisance in the UK as a result of current and predicted climate change

2: To investigate the potential for new and existing species of insect to cause statutory nuisance to occur in the UK as a result of current and predicted climate change

In the first section of this report we consider the first objective and present an inventory of nuisance insects and discuss the availability of information on these species to Environmental Health Officers (EHOs). We conclude from this section that defining an insect as a statutory nuisance should be on a case-by-case basis; an insect will be a statutory nuisance in some scenarios but not others (particularly in relation to the source and abundance of the insects). In addition, we focus on two subsidiary objectives:

3. To devise a programme or technique for monitoring trends in the insects of most concern

4 To devise a list of strategies that Environmental Health Officers can apply locally and disseminate to residents.

We comment on the wealth of literature and information on nuisance insect species but note the lack of a central information source for EHOs and other interested parties. We suggest that a central repository would be a valuable tool for EHO's particularly if it included fact sheets (providing relevant biological information for EHO's) and distribution maps. We advocate the use of the National Biodiversity Network (NBN) Gateway as a resource for providing distribution data but discuss the current limitations in terms of available data. We have appended example fact sheets for a number of species.

In the second section of this report we consider nuisance insects more broadly than encompassed in the statutory nuisance definition, and provide examples of species that have *already been recorded in Britain (native and non-native including residents and occasional immigrants) or are potential invaders (non-native new arrivals). The methods used to review the literature on nuisance insects species and the impacts of climate change on their distribution, in a systematic way, are described. We highlight the nuisance insect species that are unlikely to be affected by climate warming* Blattella germanica *(german cockroach)*, Cimex lectularius *(bed bug)*, Monomorium pharaonis *(Pharaoh's ant)*, Anobium punctatum *(woodworm)*, Ctenocephalides felis *(cat fleas)*, Lyctus brunneus *(powderpost beetle)*, Hylotrupes bajulus *(house longhorn)*, Tineola bisselliella *(common clothes moth)*, Dolichovespula media *(media wasp) and* Vespa crabro *(European hornet). The ten species most likely to increase with climate warming are* Tinearia alternata *(moth fly)*, Lasius neglectus *(invasive garden ant)*, Thaumetopoea processionea *(oak processionary moth)*, Linepithema humile *(Argentine ant)*, Reticulitermes grassei *(Mediterranean termite)*, Culex pipiens molestus *(urban mosquito)*, Culex pipiens pipiens *(mosquito)*, Aedes vexans *(mosquito – wetland)*, Ochlerotatus cantans *(mosquito – woodland) and* Musca domestica *(house fly). The ten species most likely to increase with changes in precipitation are the same as for increasing temperature with the exception of* Musca domestica *and inclusion of* Phlebotomus mascittii *(sand fly). We provide two detailed case studies illustrating potential modelling approaches: biting midges and mosquitoes. In addition, we highlight the potential for further studies which would enable detailed quantitative analysis, such as demonstrated in the case studies, to be undertaken across taxa.*

1.0 Background

Changes in ecology, climate and human behaviour over recent decades have favoured the development of urban pests, including nuisance insects (Bonnefoy *et al*., 2008). Numerous papers report the increase in abundance of nuisance insects (Brenner *et al.*, 2003). For example, cockroaches are one of the most common pests found in apartments, homes, food handling establishments, hospitals and health care facilities worldwide (Bonnefoy *et al*., 2008). Many people find cockroaches objectionable; indeed, in a London study 80 % of residents from uninfested apartments felt that cockroach infestations were worse than poor security, dampness, poor heating and poor repair (Majekodunmi *et al*., 2002). In addition, there are direct health problems associated with cockroaches, including allergic responses, transport of pathogenic organisms, and contamination of food. Nuisance insects not only cause problems through direct effects but are also problematic in terms of the use of pesticides directed at them, which can also have human health impacts: 90 % of pesticides applied in apartments in the United States are directed at cockroaches (Whyatt *et al.*, 2002). In this report we describe a number of insects that are, or have the potential to be, classified as nuisance insects. We examine the available sources of information and data on these species and make recommendations for improving these. We identify the traits that characterise nuisance insects as a group, and we begin to explore the role of predicted climate change on the potential for resident and potentially-invasive species of insect to cause statutory nuisance in the UK.

1.1 Consortium to perform the work

The partners are the Centre for Ecology and Hydrology (CEH, including Biological Records Centre - lead partner), Rothamsted Research (Centre for Bioenergy and Climate Change) and the Health Protection Agency.

1.2 Objectives

1: To complete a desk top study to determine the current level of knowledge in relation to new and existing species of insect with the potential to cause statutory nuisance in the UK as a result of current and predicted climate change

2: To investigate the potential for new and existing species of insect to cause statutory nuisance to occur in the UK as a result of current and predicted climate change

3: To, if necessary, devise a programme or technique for monitoring trends in the insects of most concern

4 To, if necessary, devise a list of strategies that Environmental Health Officers can apply locally and disseminate to residents.

2.0 Inventory of nuisance insects and associated information

2.1 What is a nuisance insect?

Insects can constitute a nuisance in law. For a nuisance to be found in law depends on the circumstances, notably on the effects that insects have on humans and property. Nuisance has been defined as *a condition or activity which unduly interferes with the use or enjoyment of land* (*Clerk & Lindsell on Torts* (2006), 19th ed, Sweet & Maxwell, ch. 20). So, where insects are harboured, allowed to remain, or cause an infestation, on land this may comprise a nuisance.

The above definition is relevant to private nuisance. This is a tort, or civil wrong, which provides a right to owners of property to use it free from *unreasonable* interferences from neighbouring property. This condition is often referred to an 'amenity' nuisance. The standard required to prove that the interference is unreasonable is a high one, so minor problems or mere annoyance would not be enough to amount to a nuisance in law. Because private nuisance is a civil action, the remedies available to a successful claimant include an injunction to prevent the nuisance from continuing and an award of damages to compensate for the harm.

Some nuisances are so widespread that they amount to public nuisances. In *A-G v PYA Quarries Ltd* [1957] 2 QB 169, at 190–1, Denning LJ defined public nuisance as a nuisance which is *so widespread in its range or so indiscriminate in its effect that it would not be reasonable to expect one person to take proceedings on his own responsibility to put a stop to it, but that it should be taken on the responsibility of the community at large.*
So if a class of people or a neighbourhood suffers to an unreasonable extent from insects emanating from a person's land, then a prosecution could be brought by the local authority or by a private individual against the person responsible. As with private nuisance, an injunction could be sought to prevent reoccurrence of the nuisance in the High Court or the County Court.

Insect nuisances can also be controlled under the statutory nuisance regime. Section 79(1)(fa) of the Environmental Protection Act 1990 (as amended) provides that: *any insects emanating from relevant industrial, trade or business premises and being prejudicial to health or a nuisance* shall constitute a statutory nuisance. This wording indicates that there is a two-limbed structure to the provision: either prejudicial to health *or* a nuisance.

This is a recent provision inserted into the Environmental Protection Act by section 101 of the Clean Neighbourhoods and Environment Act 2005. It requires a local authority to serve an abatement notice on the person or persons responsible where it is satisfied that a statutory nuisance exists, or is likely to occur or recur in its area [section 80(1) of the Environmental Protection Act]. Failure to conform to the requirements of the notice is a criminal offence. A private prosecution can also be brought by a *person aggrieved* by the statutory nuisance under section 82 of the Environmental Protection Act.

A prosecution brought under the Environmental Protection Act can only take place if the problem arises on relevant premises. The statute excludes residential or domestic premises. Also excluded by section 101(5) of the Clean Neighbourhoods and Environment Act 2005 is land used as arable, grazing, meadow and pasture land; land used as osier land, reed beds or woodland; land used as market gardens, nursery grounds or orchards; some other instances of agricultural land; and land included in a site of special scientific interest.

Section 79(1)(fa) is an important extension of the statutory nuisance regime because it brings into the regulatory system a number of situations where insect nuisance is problematic. Insects may constitute a statutory nuisance in two ways because section 79 of the Environmental Protection Act provides a two limbed structure. The nuisance limb includes both private and public forms of nuisance; both these are sometimes referred to as *common law* nuisance because they are creatures of case law. Under this limb, the victim of the nuisance is not required to have a proprietorial interest in neighbouring land (which would be a requirement for a civil action in private nuisance). The nuisance is required to *be one interfering materially with the personal comfort of the [person], in the sense that it materially affected their well-being* (*Wivenhoe Port v Colchester BC* [1985] JPL 175, at 178).

The prejudicial to health limb of section 79 would be triggered where there was a significant risk of injury to health arising from the insects. The House of Lords decided in *Birmingham CC v Oakley* [2001] 1 All ER 385, at 399 that prejudice to health: *covers what may be actually injurious as well as what may be likely to be injurious and [is] in either case something over and above what may be seen as a "nuisance".* Its significance in the context of insect statutory nuisance is that under the nuisance limb quite a substantial number of insects would usually be needed to cause a material interference in personal comfort. By contrast, a relatively small number of insects posing a risk to health could trigger the prejudicial to health limb.

Nuisance insects can emanate from a wide range of sources, but it is expected that most complaints of insect nuisance will be from the following sources: poultry and other animal houses, buildings on agricultural land including manure and silage storage areas, sewage treatment works, stagnant ditches and drains on relevant premises, landfill sites and refuse tips, waste transfer premises, commercial, trade or business premises, slaughterhouses and used car tyre recycling businesses.

The archetypal nuisance insect species will generally exhibit one or more of the following traits:

- **Synanthropy:** A life-history strategy which brings the species into constant/repetitive contact with humans, either directly, e.g. blood-feeding parasites, or indirectly as a result of other life-history strategy parameters (synanthropic/ hemisynanthropic/ eusynanthropic).
- **Overwintering Ability:** A relatively low thermal minimum, e.g. -5°C, allowing a good level of survival during outdoor overwintering, in turn allowing a population reservoir to build up which is capable of infesting buildings. Parasitic organisms may not need this capability if they can instead overwinter on an alternative host.
- **Resiliency:** Resilient populations capable of surviving unfavourable conditions, e.g. cold, application of pesticides, lack of food, etc. This can be either the result of a resistant life

stage (e.g. flea pupae, which, until triggered by specific mechanical or chemical stimuli, can remain dormant for several months), or by having a large amount of redundancy built into the population structure (e.g. the potential for parthenogenesis in cockroaches, or the polygynous, ephemeral-nesting nature of the Argentine & Pharaoh's ants).

- **Diet:** A generalist diet, particularly on human-created detritus, or alternatively a need to feed on humans, or on items precious to humans.
- **r-Selection:** A short generation time and high reproductive potential, allowing the species to take advantage of favourable conditions, particularly indoors, by producing large numbers of offspring quickly.
- **Anthropogenic Dispersal:** A high anthropogenic dispersive potential, giving the species a good chance of being transported between human settlements at a large scale, and between individual houses at a local scale.
- **Natural Dispersal:** A relatively low natural dispersal tendency. Species with a high natural dispersive ability will tend not to aggregate to nuisance numbers, but those with a low ability to disperse and a high reproductive potential will reach nuisance levels in a small area relatively quickly, while still allowing some element of dispersal, minimising the chances of the entire population being eradicated
- **Potential for Harm:** An ability to cause a nuisance event: the ability to cause human health issues, destroy or damage items held dear to people, e.g. furniture or pets, or creates severe annoyance by their mere presence, e.g. the incessant buzzing of a fly.

2.2 Lists of nuisance insect species for Great Britain

Lists of insects, constituting potential nuisance (statutory or otherwise), were derived from the following reports, web sources or spreadsheets:

- Public Health Significance of Urban Pests (Bonnefoy et al., 2008)
- Audit of non-native species in England (Hill et al., 2005)
- EPPO A1, A2 and Alert lists (http://www.eppo.org/QUARANTINE/quarantine.htm)
- British Pest Control Association (http://www.bpca.org.uk)
- Pest control companies and council pest control web pages
- Delivering Alien Invasive Species Inventories for Europe (http://www.europe-aliens.org/aboutDAISIE.do)

In total, 66 species from 7 orders were considered as nuisance insects. These species are given in the following tables, which are divided into taxonomic groupings (on the basis of insect order). Both the scientific name and common name (where one exists) are provided. In addition, the species status within the British Isles is stated: resident (the species is established within Britain) or potential invader (the species is established in temperate zones within Europe that are also represented within Britain). The term non-native is used here to correspond to species that have arrived since 1500 regardless of mechanism (Hill *et al*., 2005). The final column relates to the nuisance impact of the species. The problems associated with nuisance insects are varied ranging from human health (vectors of disease, allergens and irritants, pain through biting and stinging), annoyance when numerous (tendency to occur in large numbers results in intolerable annoyance), to household pest species (damaging or destroying the contents of houses including fabrics, structural timbers and stored products).

Table 2.1: Cockroaches (Dictyoptera) from the families Blattidae and Blattellidae (* in status indicates non-native)

Species	English name	Status	Nuisance impact
Blatta orientalis	Oriental cockroach	*Resident	Vector, causes allergies
Blattella germanica	German cockroach	*Resident	Vector, causes allergies
Periplaneta americana	American cockroach	*Resident	Vector, causes allergies
Periplaneta australasiae	Australian cockroach	*Resident	Vector, causes allergies
Supella longipalpa	A brown banded cockroach	*Resident	Vector, causes allergies

Table 2.2: Beetles (Coleoptera) from the families Anobiidae, Bostrichidae, Cerambycidae, Coccinellidae and Curculionidae (* in status indicates non-native)

Species	English name	Status	Nuisance impact
Anobium punctatum	Common furniture beetle or woodworm	Resident	Destroys household wood
Euophryum confine	New Zealand wood weevil	*Resident	Destroys structural timbers
Euophryum rufum	A wood boring weevil	*Resident	Destroys structural timbers
Harmonia axyridis	Harlequin ladybird	*Resident	Overwinters indoors in huge numbers
Hylotrupes bajulus	House longhorn	*Resident	Destroys structural timbers
Lyctus brunneus	Powderpost beetle	Resident	Destroys structural timbers
Pentarthrum huttoni	A woodboring weevil	Resident	Destroys structural timbers
Xestobium rufovillosum	Deathwatch beetle	Resident	Destroys structural timbers

Table 2.3: Flies (Diptera) from the families Anisopodidae, Calliphoridae, Ceratopogonidae, Chironomidae, Culicidae, Drosophilidae, Fanniidae, Muscidae, Phlebotomidae, Psychodidae, Simuliidae and Tabanidae (* in status indicates non-native)

Species	English name	Status	Nuisance impact
Aedes albopictus	Asian tiger mosquito	*Potential invader	Bites, potential vector
Aedes cinereus	A floodwater mosquito	Resident	Bites, potential vector
Aedes vexans	A floodwater mosquito	*Resident	Bites, potential vector
Anopheles claviger	A wetland mosquito	Resident	Bites, potential vector
Anopheles plumbeus	Tree-hole mosquito	Resident	Bites, potential vector
Calliphora vomitoria	Bluebottle	Resident	Vector, annoyance when numerous
Coquillettidia richiardii	A wetland mosquito	Resident	Bites, potential vector
Culex pipiens molestus	Urban mosquito	Resident	Bites, potential vector
Culicoides imicola	A midge	Resident	Bites, vector
Culicoides impunctatus	A midge	Resident	Bites
Culicoides obsoletus	A midge	Resident	Bites, vector
Culicoides pulicaris	A midge	Resident	Bites, vector
Culiseta annulata	A mosquito	Resident	Bites, potential vector
Drosophila spp.	Fruit flies	*Resident	Annoyance when numerous
Fannia canicularis	Lesser house fly	Resident	Vector
Metriocnemus spp.	Chironomid midges	Resident	Annoyance when numerous
Musca domestica	House fly	Resident	Vector
Ochlerotatus annulipes	A mosquito	Resident	Bites, potential vector
Ochlerotatus cantans	A woodland mosquito	Resident	Bites, potential vector
Ochlerotatus caspius	A saltmarsh mosquito	Resident	Bites, potential vector
Ochlerotatus detritus	A saltmarsh mosquito	Resident	Bites, potential vector
Ochlerotatus japonicus	A mosquito	*Potential invader	Bites, potential vector
Ochlerotatus punctor	A woodland mosquito	Resident	Bites, potential vector
Phlebotomus mascittii	A sand fly	*Potential invader	Potential vector of *Leishmania infantum* (Leishmaniasis)
Pollenia rudis	Cluster fly	Resident	Overwinters indoors in huge numbers
Psychoda albipennis	Sewage filter fly	Resident	Annoyance when numerous
Simulium equinum	Black fly	Resident	Bites
Simulium posticatum	Blandford fly	Resident	Bites
Sylvicola fenestralis	Window gnat	Resident	Annoyance when numerous
Tabanidae spp.	Horse flies	Resident	Bites
Tinearia alternata	Moth fly	Resident	Annoyance when numerous

Table 2.4: Moths (Lepidoptera) from the families Lymantriidae, Thaumetopoeidae and Tineidae (* in status indicates non-native)

Species	English name	Status	Nuisance impact
Euproctis chrysorrhoea	Brown tail moth	*Resident	Larval hairs cause extreme irritation
Thaumetopoea processionea	Oak processionary moth	*Resident	Larvae defoliate trees, larval hairs cause extreme irritation
Tinea pallescentella	Large pale clothes moth	*Resident	Larvae feed on fabrics
Tinea pellionella	Case-bearing clothes moth	Resident	Larvae feed on fabrics
Trichophaga tapetzella	Carpet moth	Resident	Larvae feed on fabrics
Tineola bisselliella	Common clothes moth	Resident	Larvae feed on fabrics, leave unsightly webbing

Table 2.5: Wasps and ants (Hymenoptera) from the families Vespidae and Formicidae (* in status indicates non-native)

Species	English name	Status	Nuisance impact
Dolichovespula media	Media wasp	*Resident	Stings
Dolichovespula norvegica	Norwegian wasp	*Resident	Stings
Lasius neglectus	Invasive garden ant	*Potential invader	Swarms, potentially inside
Lasius niger	Black garden ant	Resident	Annoyance when swarming
Linepithema humile	Argentine ant	*Potential invader	Aggressive, can vector disease
Monomorium pharaonis	Pharaoh's ant	*Resident	Infest houses, vector
Solonopsis invicta	Red imported fire ant	*Potential invader	Stings
Tapinoma melanocephalum	Ghost ant	*Resident	Spoils carbohydrate-rich stores
Vespula germanica	German wasp	Resident	Stings
Vespula vulgaris	Common wasp	Resident	Stings
Vespa crabro	European hornet	Resident	Stings

Table 2.6: Miscellaneous: fleas (Siphonaptera); termites (Isoptera); aphids and bed bugs (Hemiptera) (* in status indicates non-native)

Species	English name	Status	Nuisance impact
Ctenocephalides canis	Dog flea	Resident	Bites
Ctenocephalides felis	Cat flea	Resident	Bites
Reticulitermes grassei	Mediterranean termiteΨ	*Resident	Destroys structural timbers
Reticulitermes santonensis	Saintonge termite	*Potential invader	Destroys structural timbers
Cimex lectularius	Bed bug	Resident	Vector, bites
Eucallipterus tiliae	Lime aphid	Resident	Drips honeydew onto paintwork

Ψ *Reticulitermes grassei* (Mediterranean termite) was last recorded in Devon (Saunton Colony) in 2000 but annual monitoring is scheduled for ten years from the last sighting. Currently this will be 2010 at which point this species will be declared eradicated from Britain.

It is clear that nuisance insects are taxonomically diverse, and their impacts reflect this. The distinction between statutory nuisance and non-statutory nuisance will vary on a case-by-case basis; an insect will be a statutory nuisance in some scenarios but not others (particularly in relation to the source and abundance of the insects). The need for reliable information on these species and their impacts is paramount to ensure appropriate measures are taken to address these nuisance insects.

2.3 Sources of general information on nuisance insects

There are many sources of general information, including description and identification, life cycle, nuisance impact (reasons for control), management and control, on nuisance insects from books (Robinson, 2005, Pinneger and Child, 1996), refereed publications, Chartered Institute of Environmental Health News (http://www.cieh.org/media/news.html) and many other websites. For this project we examined the sources of information available on the web for eight species of nuisance insect. The species selected provide examples of different vector types (mechanical vector – house fly, German cockroach, oriental cockroach, American cockroach; biological vector – asian tiger mosquito) and native status (non-native (potential invader) – asian tiger mosquito; native (resident) – house fly, cat flea, German cockroach, moth fly, black garden ant). The information available is variable both in quantity and quality, but it is relatively easy to find a fact sheet relating to a species of concern, from a reputable source. In some cases, almost identical fact sheets appear on a number of web sites and it is apparent that they have been derived from the same original source of information. Appendix 1 provides an overview of the sources of information from pest control companies and local authorities for the eight species mentioned above including the type of general information available on each site.

2.4 Sources of distribution data on nuisance insects

There are several of sources of data on nuisance insects available through organisations such as the Biological Records Centre (NERC Centre for Ecology and Hydrology), Rothamsted Insect Survey, Local Record Centres (LRCs), Natural History Museum (London) and other museums. The Biological Records Centre and the Rothamsted Insect Survey are currently two major sources of insect data and further details on these organisations are provided here.

The Biological Records Centre

The Biological Records Centre (BRC), established in 1964, is the national focus in the UK for terrestrial and freshwater species recording (other than birds). It works with the voluntary recording community throughout Britain and Ireland. The BRC database contains over 15 million records of more than 12000 species. BRC datasets are regularly uploaded to the National Biodiversity Network (NBN) Gateway (http://data.nbn.org.uk/) when permission is granted by the data provider.

A number of the entomology recording schemes (national schemes and societies) hosted by BRC (http://www.brc.ac.uk/recording_schemes.asp) either collate nuisance insect data or have the potential to do so. For example, the Dipterists' Forum (http://www.dipteristsforum.org.uk/) has a remit to promote the recording of all aspects of the natural history of Diptera. Recording of specific taxonomic families within the Diptera is coordinated by individual volunteers and many of these families include species that have nuisance status such as mosquitoes. Volunteer recorders provide considerable taxonomic expertise and their volunteer commitment to recording and coordinating the flow of data through to BRC and onto the NBN Gateway is invaluable. However, many volunteer recorders are less interested in household species in comparison to species in the wider countryside and so pest insects, and nuisance insects in particular, are poorly represented. The house fly is a widespread species and this is not evident from the distribution data that are currently available (Figure 2.1). There is considerable scope for encouraging and supporting the volunteer community in recording nuisance insects.

Rothamsted Research

Rothamsted Research is a BBSRC Institute. It is the largest agricultural research centre in the United Kingdom and almost certainly the oldest agricultural research station in the world. The Rothamsted Insect Survey is part of the Plant and Invertebrate Ecology Department, and holds standardised datasets on terrestrial invertebrates. These come from the national networks of suction traps and light traps which have been operating for more than 40 years.

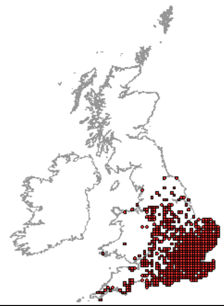
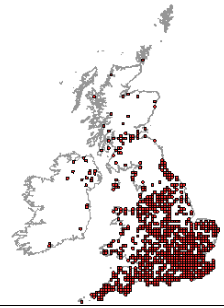
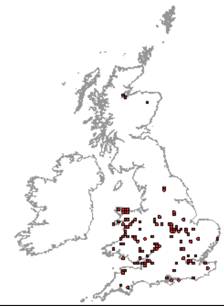
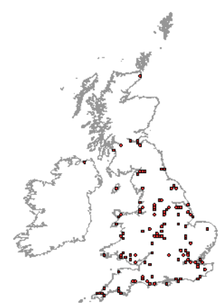
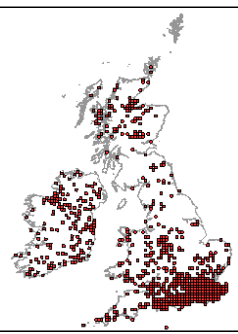
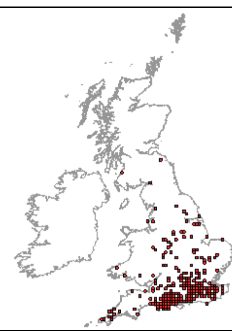
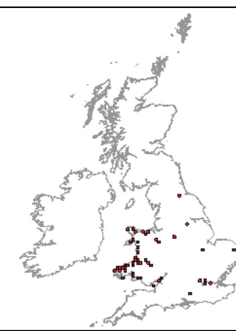
From the suction trap network aphids are identified to species where possible although, because of the need for rapid throughput and the subsequent use of low power binocular microscopes, some can only be identified to species group or genus. Although no other insect groups are identified routinely, all samples are kept, and there has been increasing use of the non-aphid fraction. A light trap network, run with the help of volunteers at about 100 sites in the UK, is used to monitor the larger (macro) moths. Daily samples are taken throughout the year, and altogether over 430 sites have been sampled. The data from both networks have a range of applications in fundamental and applied aspects of insect population dynamics and ecology and their potential value in assessing impacts of climate change on nuisance insects is being considered in the project.

Availability of data

The data on insects are fragmented and a system of strategic data flow between organisations to a central source is lacking. Flow of relevant nuisance insect data from LRCs to EHOs could be improved through reporting to the NBN Gateway; there is currently a Defra funding initiative to support LRCs in this. Data collected by EHOs could be validated, verified and collated through the National Entomological Schemes and Societies network although it is possible that expert volunteers would require payment. Data could also be captured through an on-line recording system such as that employed by the Harlequin Ladybird Survey (www.harlequin-survey.org). This single species (*Harmonia axyridis*) recording scheme has been extremely successful in terms of number of records captured (25000 records over five years). Members of the public and other interested parties are asked to report any sightings of this species through an on-line recording form which provides the option of uploading a photo for verification by an expert. This ensures that the data captured are reliable. Several National Entomological Schemes and Societies have websites and some offer the opportunity of on-line recording; these could be utilised by the EHOs.

Figure 2.1: Distribution data available on the NBN Gateway for a number of nuisance insect species across Britain with an indication of how accurately the data reflect the likely distribution

….. = Good (distribution data reflect the likely distribution of the species)
….. = Poor (distribution data under-represent the likely distribution of the species)

		
Harlequin ladybird	**Cat flea**	
		
		
		
Common wasp	**Media wasp**	
No Records	No Records	No Records

2.5 Recommendation on sources of information for Environmental Health Officers

There are many sources of information available; however, it would be useful to have a central repository on nuisance insect information and data. A central repository for nuisance insects could include fact sheets (examples in appendix 2), and dynamic links to distribution data (through the NBN Gateway). The fact sheet information could be reviewed by recognised experts to ensure reliability. Furthermore, the repository could link to the Defra funded non-native repository (commissioned with the Centre for Ecology and Hydrology and coordinated through the Non-Native Species Secretariat) where there is overlap in species information. Indeed, improving data flow and data acquisition on nuisance insect species could be achieved through a central repository that links with existing National Entomological Schemes and Societies' websites. In addition, a central repository could include a facility for on-line reporting of a species (perhaps through existing national entomological schemes and societies infrastructures); linking this with the opportunity for verification through a photograph (where species identification is possible from a photograph) or specimen. The central repository would provide:

1. techniques for monitoring trends in the insects of most concern;
2. strategies that Environmental Health Officers can apply locally and disseminate to residents; and
3. good practice and case studies in the control of nuisance insects

3.0 Key traits determining sensitivity of nuisance insect species to climate change

The increased temperatures associated with climate change coupled with anticipated extreme weather conditions (more and longer droughts, more frequent storms and increased rainfall) are predicted to impact on insect population dynamics. It has been recognised for many years that climate affects biochemical, physiological and behavioural processes in insects (Thomas and Blanford, 2003). Even modest changes to climate are expected to have a rapid impact on the distribution and abundance of pest insects because of their physiological sensitivity to temperature, short life cycles, high mobility and high reproductive potential (Ayres and Lombardero, 2000); (Roy *et al.*, in press-a). Many non-pest insects are already responding rapidly to climate change (Parmesan and Yohe, 2003) and expanding northwards (Asher *et al.*, 2001); (Hickling *et al.*, 2006). Milder and shorter winters will lengthen the breeding period of some insects. The disruption in synchrony of insects and their natural enemies is also likely (Roy *et al.*, in press-a).

We hypothesise that several key traits will govern sensitivity of nuisance insects to climate change impacts. Below is an explanation for each trait hypothesis and, in italics, the related characteristics scored for each species from the literature.

1. Persistence outside housing: The higher the proportion of a nuisance insect species' life cycle that is spent outside, the more likely it is that the species will be impacted by climate change. Nuisance insect species that have a dispersive phase outside houses/premises (e.g. dog fleas on their hosts, or clothes moths) are more likely to be impacted by climate changes than ones that live entirely inside houses and premises (e.g. bed bugs).

1a. What portion of the life cycle is spent outdoors?

1b. Is the species known to disperse in the natural environment?

2. Overwintering ability: Species that overwinter outside in the UK with a relatively low thermal minimum are more likely to increase in abundance as the climate warms. Species that do not diapause, where adults are produced and are active year-round, may be most likely to benefit from warmer environments.

2a. Does the species overwinter outside houses or premises?
2b. In which developmental stage does the species overwinter?
2c. Does the species diapause in the UK or Europe?

3. r-Selection: Provided that the species persists in the wider environment, a short generation time and high reproductive potential is likely to allow the species to take advantage of increasingly warm conditions by producing large numbers of offspring quickly. Here it was possible to distinguish between nuisance insect species that had <1, 1-2, 3-5 or many generations per year.

3a. How many generations does the species complete per year in UK and Europe?

4. Breeding sites: Species that breed outside are more likely to be impacted by climate change than species that breed exclusively indoors. Nuisance insect species with aquatic or semi-aquatic breeding sites are likely to be negatively impacted through drought and positively benefit impacted by increased precipitation future wetting.

4a. Does the species breed inside or outside houses or other premises?
4b. Does the species use aquatic or semi-aquatic breeding sites?
4c. What kinds of breeding sites does the species use?

5. Resource specialism: Nuisance insect species that are highly specialised in resource use (e.g. diet, hosts or habitat use) within a nuisance group are less likely to increase due to climate change than generalists.

5a. Is there evidence that the species is specialised as adults or larvae in its habitat use or *diet?*

5b. What habitat, host or diet is the species restricted to?

5c. Which trophic group does the species fall into?

6. Dispersal: Nuisance insect species that are dispersed by humans or on hosts may be better able to take advantage of climate change induced increases in habitat availability than species that undergo active dispersal.

6a. Does the species have an anthropogenic dispersal mechanism?

6b. What are the natural and anthropogenic dispersal mechanisms for the species?

7. Temperature or moisture dependence of life-history, habitat use, distribution or dynamics: Species whose development and survival rates, microhabitat use or abundance have been associated with temperature or moisture levels in the field or laboratory are likely to be sensitive to climate change impacts.

7a. Is there evidence that the species is sensitive to changing external temperature regimes?

7b. Is there evidence that the species is sensitive to changing precipitation regimes?

3.1 Literature review methods

The list of 66 nuisance insect species (Table 2.1 to 2.6) was selected for this project to comply with the following criteria:

- focus on species that primarily have the potential to cause nuisance in gardens, homes and other premises rather than amenity areas (e.g. horse flies are restricted to amenity areas)
- focus on species that currently cause nuisance or are likely to cause nuisance in the next 50 years (the list includes 6 potential invaders and 60 UK residents)
- exclude species that cause purely aesthetic nuisance (e.g. leaf-mining moths)
- consider the characteristics and impacts of fruit flies and Tabanid flies at genus level only.

The lack of specific information in the literature on the climate and habitat factors influencing the distribution, dynamics or life-history of nuisance insect species in the UK and Europe necessitated a qualitative approach to predicting the likely impacts of climate change on nuisance insect species. The climate data need to be viewed with caution because many of the studies have been conducted in the context of controlling the nuisance insect species using thermal methods (cooling or heating), for example, control of woodworm by either chilling or superheating infested wood (Pinneger and Child, 1996). Furthermore, there is a bias in publication numbers reflecting research emphasis on household pest species such as cockroaches and houseflies which are the most extensively covered taxa in the literature.

Species were scored (value from 0 to 2) as to whether they possessed key traits (see above) that might make them sensitive to environmental changes. For all 66 species, the ability to persist in the wider environment, type of dispersal and broad habitat preferences were scored. The remaining key traits were scored for a subset of 33 species, via in depth literature review of biological characteristics and impacts, spanning a broad range of taxa and types of nuisance impact. Where references on a nuisance insect species differed in the value of a biological characteristic, the modal value or value for UK or European populations was selected. Scores were summarised across subsets of traits to give indices of sensitivity to changing temperature and changing moisture levels (Traits 1a, 1b, 2a, 2b, 3a, 4a, 4b, 5a, 6a – as above). Species that do not spend any stage of their lifecycle outside (Trait 1a – see above) and do not disperse in the wider environment (Trait 1b see above) were given a value of 0 for these indices. Apart from this traits were given equal weighting.

3.2 Literature Review Results and Discussion

Availability of data on nuisance insect species

Most nuisance insect species (71%) were covered by at least 20 papers in the literature (median = 53 papers per species). However, papers very rarely reported explicitly UK status or ecology (34% of species covered by around one paper each) or covered the impacts of climate and climate change on nuisance insect species (53% of species covered by around two papers each). Literature on species causing human health problems was more extensive than for any other nuisance insect impact: indirect vectors (disease spread through food contamination for example) had the most extensive coverage in the literature, followed by direct vectors and species causing pain by biting or stinging (Figures 3.1 and 3.2). In addition to health-related species, those causing annoyance by abundance such as the harlequin ladybird were extensively covered by extant climate related references. Cockroaches and house flies are the most extensively covered taxa in the literature overall. House flies are the species with the highest number of publications with a UK context. Ants, termites and fleas have the most extensive coverage within the literature with respect to climate (Figures 3.3. and 3.4).

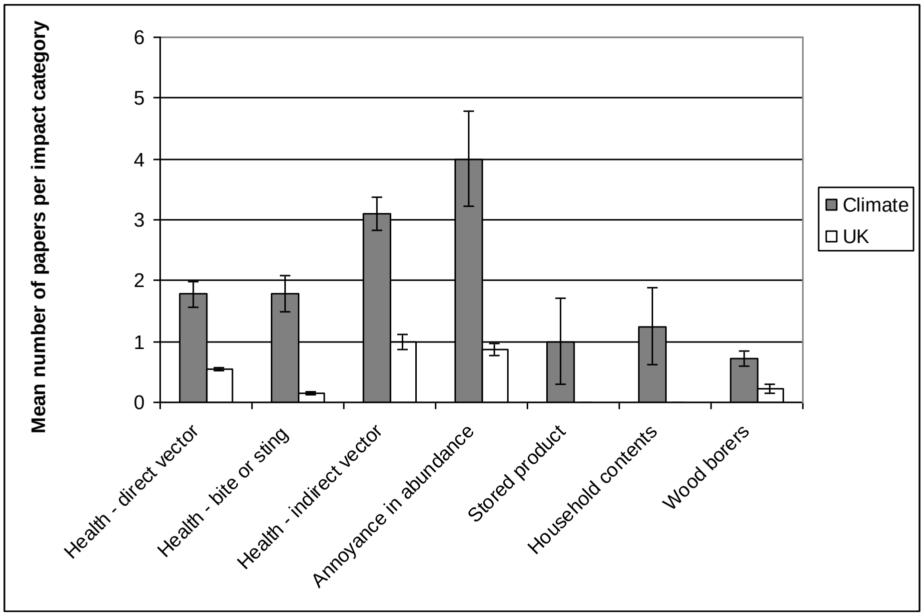


Figure 3.1: Mean number of refereed papers across species in each nuisance impact category (health – direct vector, health – bite or sting, health – indirect vector, annoyance in abundance, stored product, household contents, wood borers) separated those relating to climate (grey bars) and UK prevalence or ecology (white bars). Error bars = standard deviation.

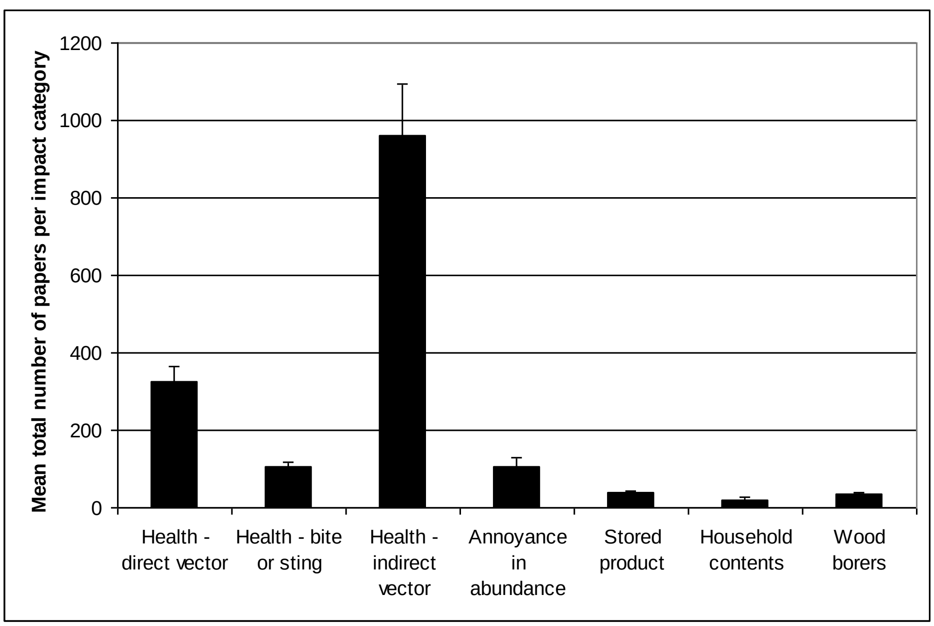


Figure 3.2: Mean total number of refereed papers across species in each nuisance impact category (health – direct vector, health – bite or sting, health – indirect vector, annoyance in abundance, stored product, household contents, wood borers). Error bars = standard deviation.

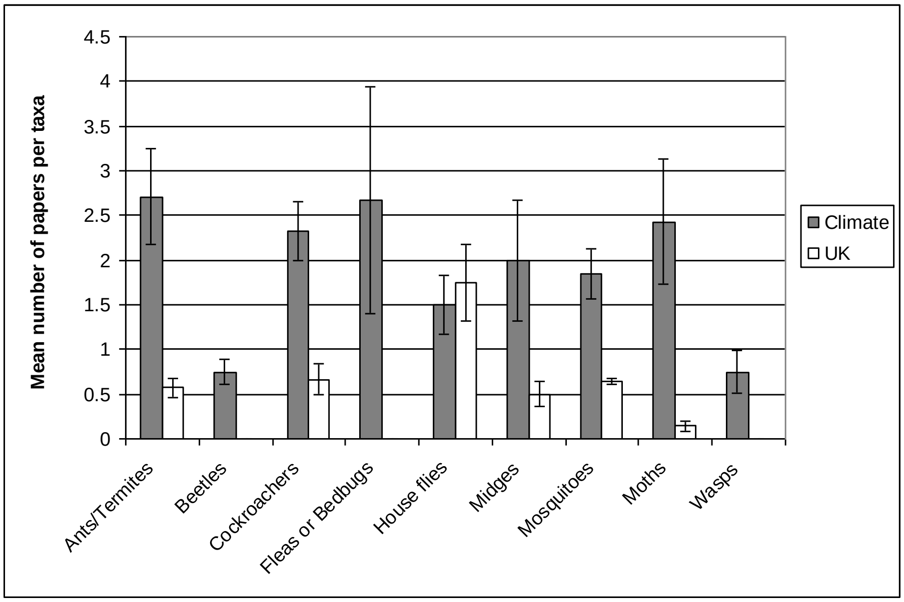


Figure 3.3: Mean number of refereed papers relating to climate (grey) and UK prevalence (white) within different categories of nuisance insect taxa (ants/termites, beetles, cockroaches, fleas or bed-bugs, house flies, midges, mosquitoes, moths, wasps). Error bars = standard deviation.

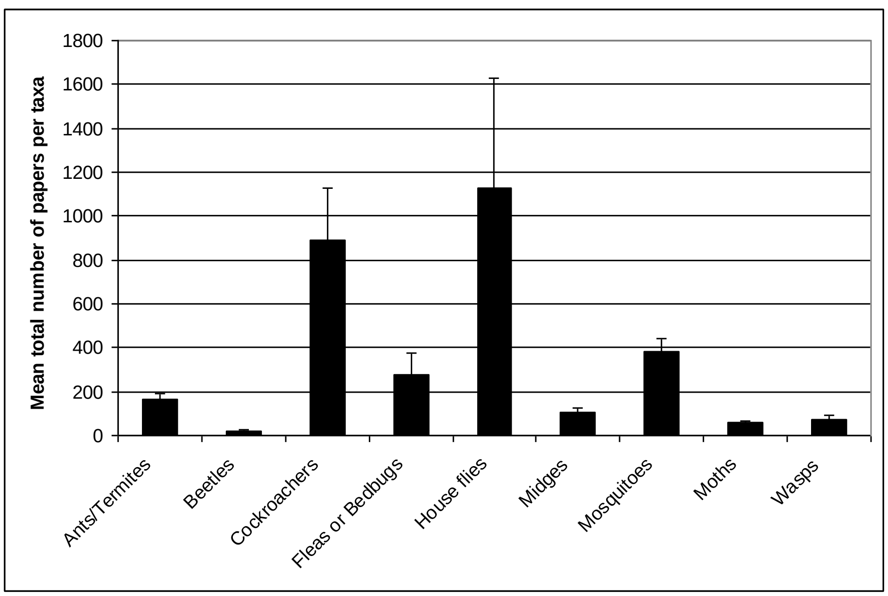


Figure 3.4: Mean number of refereed papers for different categories of nuisance insect taxa (ants/termites, beetles, cockroaches, fleas or bed-bugs, house flies, midges, mosquitoes, moths, wasps). Error bars = standard deviation.

3.3 Which nuisance insects are most likely to increase as a consequence of climate change?

A. Low risk nuisance groups which do not persist in the wider environment

Table 3.1 lists the ten nuisance insect species least likely to be sensitive to warming according to the index of sensitivity to changing temperature calculated from the literature review. The top three do not persist outside for any part of their life cycle and include the bed bug, the German cockroach and the Pharaoh's ant. These species are likely to be sensitive to changes in heating systems, cleanliness and control measures in domestic properties and almost entirely insensitive to external environmental changes. However, it is possible that a species that is currently restricted to permanently heated premises may be able to exploit external sites with sufficient climate warming (e.g. German cockroach). A second subset of species may be partially sensitive to external changes, such as the wood-boring insects that inhabit roof timbers (e.g. woodworm and powderpost beetle), fleas (e.g. cat flea) and cockroaches, through occasional dispersal outside (warming may increase the success of such dispersal events).

Two wasp species (media wasp and European hornet) had low scores for sensitivity to temperature changes but given the sensitivity of their congenerics we suspect this reflects lack of available information on these species. Sensitivity to allergic reactions to bee and wasp stings appears to increase with increased exposure which may, in turn, increase if warming enhances the daily activity rates of wasps and bees.

The long term population dynamics of many species will be dependent on both climate and habitat change and their corresponding interactions. There are a number of ways in which habitats will be altered anthropogenically as the climate changes. For example, trickling (pecolating) filter beds are being decommissioned in the UK. Therefore, the moth fly (*Tinearia alternata*) could decrease in abundance because of habitat loss even though on the basis of climate data alone it is anticipated to increase. In contrast, the asian tiger mosquito, (*Aedes albopictus*), has now been reported in 15 European countries following its global transportation through the international trade in used tyre casings and the wet-footed Lucky

Bamboo (*Dracaena* spp.). In south-east Asia, this mosquito is characteristically a tree-hole species. However, its ability to colonise urban areas, where the female lays drought-resistant eggs in water that collects in human-made containers (including discarded tyres and container plants), has facilitated its establishment elsewhere. It is predicted that container planting will increase in domestic gardens as the climate warms and, therefore, the establishment of this species in new countries could be enhanced by both climate change and an increase in suitable habitat (in part also driven by climate change effects). It is clear that the situation is complex and that at the very least both climate and habitat effects should be considered in predictive modelling approaches. Changes in human behaviour as a consequence of climate warming and development of new technologies should also be recognised. Indeed "*changes in biodiversity due to human behaviour were more rapid in the past 50 years than at any time in human history*" (Sarukhán *et al.*, 2005).

Table 3.1: Ten species least likely to be sensitive to warming (least sensitive species listed first)

Species	**English name**
Blattella germanica	German cockroach
Cimex lectularius	Bed bug
Monomorium pharaonis	Pharaoh's ant
Anobium punctatum	Woodworm
Ctenocephalides felis	Cat flea
Lyctus brunneus	Powderpost beetle
Hylotrupes bajulus	House longhorn beetle
Tineola bisselliella	Common clothes moth
Dolichovespula media	A wasp
Vespa crabro	European hornet

B. Nuisance insect species and groups likely to increase under a warming climate

There are a number of species whose traits make them likely to be sensitive to warming. Largely, the top ten species listed in Table 3.2 live outside through the year (including in their breeding and dispersal phases), have several to many adult generations and disperse as winged or walking adults. For many of these species, empirical relationships between temperature and development and survival rates, microhabitat use or abundance have been established in the field or laboratory (see Table 3.5 and references therein).

Table 3.2: Ten species most likely to increase with warming (most likely species listed first)

Species	English name
Tinearia alternate	Moth fly
Lasius neglectus	Invasive garden ant
Thaumetopoea processionea	Oak processionary moth
Linepithema humile	Argentine ant
Reticulitermes grassei	Mediterranean termite
Culex pipiens molestus	Urban mosquito
Aedes vexans	A floodwater mosquito
Culex pipiens pipiens	A mosquito
Ochlerotatus cantans	A woodland mosquito
Musca domestica	House fly

C. Nuisance insect species and groups likely to be sensitive to changes in precipitation (moisture levels)

There are a number of species whose characteristics are likely to make them sensitive to changes in precipitation and to anthropogenic changes in water levels. These species exploit external and moist or aquatic/semi-aquatic breeding sites. For mosquito vectors and sewage flies, the impacts of warming will depend on increased water availability. Resulting changes in nuisance impacts on humans will depend on the landscape surrounding particular premises in addition to climate change. Dermatitis associated with processionary moth larvae tends to be found when urban or amenity areas occur close to lime trees.

For vectors, proximity to non-human hosts may divert bites away from humans if mosquito species bite more than one host species. For example, in the late 18th century, malaria rates, due to transmission by the mosquito *Anopheles atroparvus* on marshland in southern England, dropped following the introduction of livestock hosts which this mosquito prefers to bite. Again for some of the species in Table 3.3 development and survival rates, microhabitat use or abundance have been associated with water availability in the field or laboratory, although impacts of changes in precipitation or moisture levels have been less well studied than impact of temperature changes (see Table 3.5).

Table 3.3: Ten species most likely to decrease with increasingly dry periods (drought) and increase with increasingly wet (precipitation) periods (most likely species listed first)

Species	English name
Tinearia alternata	Moth fly
Culex pipiens molestus	Urban mosquito
Aedes vexans	A floodwater mosquito
Culex pipiens pipiens	A mosquito
Ochlerotatus cantans	A woodland mosquito
Lasius neglectus	Invasive garden ant
Thaumetopoea processionea	Oak processionary moth
Linepithema humile	Argentine ant
Reticulitermes grassei	Mediterranean termite
Phlebotomus mascittii	Sand fly

D. Nuisance groups likely to be impacted by indirect factors (composting, recycling and sewage treatment).

Several nuisance groups are likely to be impacted by indirect anthropogenic factors, either because they are dispersed by an anthropogenic mechanism or because the availability of their breeding sites depends heavily on particular human behaviours. Mosquitoes are amongst the most sensitive of the nuisance groups to indirect factors. Container breeding mosquitoes (such as *Culiseta annulata*, asian tiger mosquito (potential invader) and

Ochlerotatus japonicus (potential invader)) are likely to be highly influenced by increases in the trade in used tyres and the maintenance of rain water butts and other water containers in gardens, whilst other mosquitoes, such as *Coquiellittidia richariadii* and *Anopheles claviger*, will be sensitive to the density of anthropogenically constructed ditches in gardens and arable land. *Culex pipiens pipiens,* urban mosquito, sewage fly and moth fly will all be affected by the location and management of sewage and water treatment works. All these indirect factors will govern the area and extent of nuisance impact when a warm summer leads to high insect numbers. With regards to household waste management, some wasp and fly species are likely to benefit from increases in composting in and around houses, with *Drosophila* fruit flies, media wasp, European hornet, German wasp and the common wasp all known to exploit compost as nest sites. Other species that are likely to be affected by disposal methods for household waste include cockroaches (that can be spread between households in rubbish) and house flies (that feed on and breed in carrion, faeces and food waste). Many of the wood-boring species, fleas and clothes moths are transported between houses in infested timber, furniture or fabric. Accidental colony transport, for example in cargo, has been reported in other countries as a mechanism by which the Argentine ant (invasive garden ant) and the Mediterranean termite enter new land areas.

3.4 Modelling the impacts of climate change on nuisance insects: approaches and case studies

3.4.1 Introduction

Nuisance insects, like all insects, are ectothermic (their body temperature is dependent on ambient conditions). Their small-size and large surface area compared to their volume, makes them vulnerable to water loss, particularly in hot, dry conditions. Impacts of future warming on the incidence of nuisance insects are therefore difficult to predict since warming may have contrasting impacts on the biological processes (e.g. survival, development and reproduction) governing insect populations. Although increased temperature is likely to greatly accelerate the development rates of most groups, when combined with drying, warming may increase rates of mortality by desiccation and reduce the availability of aquatic or semi-aquatic breeding sites. In addition, environmental changes may have indirect impacts on nuisance insects via impacts on their associated host animals (e.g. biting hosts of fleas or mosquitoes) or plants (tree hosts of processionary moths). It is important to (i) model the impacts of climate change on nuisance insects and their associated species and resources simultaneously; (ii) consider impacts of a range of climate and habitat drivers as well as temperature; (iii) consider changes in seasonal conditions (e.g. coldness of winter) and extreme weather events in addition to changes in mean levels of temperature and rainfall.

There are two main approaches to predicting the effects of climate change on the incidence of nuisance insects and their impacts on humans. This section describes the advantages and disadvantages of each, illustrated with some case studies of particular nuisance insects. The application of both approaches is restricted to species that persist in the wider environment outside houses, since these are the only nuisance insect species likely to be impacted by external environmental changes.

A. The statistical approach

Spatial models

In this approach, the current distributions of nuisance insects (or their human impacts) are matched statistically to patterns in climatic and landscape variables, from local to continental scales. The resulting understanding of the key drivers of nuisance insect species' distributions (i.e. the species-environment relationship) can then be applied to future climate and landscape scenarios to map future habitat suitability for individual nuisance insect species. For potential nuisance invaders, the potential for establishment in new regions can be evaluated by extrapolation of species-environment relationships derived in areas of current impact - provided the environmental conditions are sufficiently similar in the two regions. This approach can also be used to identify zones and conditions in which nuisance insects will overlap with key interacting species such as hosts that govern their incidence. Case study I illustrates how the statistical approach has been used to identify key limiting factors for *Culicoides* biting midge vectors and to map habitat suitability (at local and regional scales across Europe).

The statistical approach is particularly useful for nuisance insect species for which detailed biological knowledge is lacking. It requires fine scale species distribution data (preferably 1km resolution or finer) across a region (covering a range of environmental conditions found there) and concurrent environmental data that captures all the climate and habitat factors believed to govern habitat suitability for the species in question. Predictors could include remotely-sensed data on temperature, soil moisture levels and vegetation activity, land use data and human population or house-hold density or host density. Selection of variables based on biological understanding (*a priori*) is advisable rather than automatic variable selection because the latter can identify biologically spurious or irrelevant variables.

Temporal models

An understanding of how climatic conditions change nuisance insect impacts can also be gained from statistical pattern-matching of changes in population abundance to changes in climatic factors over time. For example, a model including humidity, precipitation and temperature accounted for 50-80% of the variation in weekly population changes of calyptrate flies over three years at six sites in southern UK (Goulson *et al.*, 2005). These models were useful for forecasting abundance in years that had not been used to define parameters for the models and further ahead in time by application to climate change scenarios. As well as predicting in which years nuisance insects will reach high abundance, this approach has the potential to predict the duration and peak of seasonal activity of nuisance insects in different locations and years. This approach requires seasonally rich abundance datasets for nuisance insect abundance, collected in a standardised way across several premises, preferably for several consecutive years.

This main draw back of these pattern-matching approaches is that they provide very little understanding of the biological processes underlying patterns in nuisance insects (Robinet *et al.*, 2007). Resulting predictions may be unreliable if future climate change brings new combinations of conditions (i.e. alters the covariance between temperature and rainfall patterns).

B. The biological approach

The biological approach involves the formulation of mathematical descriptions of nuisance insect life cycles and the additional processes governing their impact (e.g. contact rates between nuisance insects and humans or other hosts). This approach is dependent on the identification (in the field or laboratory) of precise quantitative relationships between environmental factors and demographic processes of birth and death. It therefore requires detailed ecological knowledge combined with seasonally rich survey data (as for Temporal models above) and is applicable only to well studied nuisance insects. For most species, only the temperature-dependence of important life cycle parameters, not the moisture dependence, has been established. A popular approach is the use of degree day summation models of developmental processes, where daily temperature differences from a developmental threshold are summed to describe the average suitability of conditions for development over a particular period. These models have been applied to predict the frequency with which pathogens can complete their incubation periods inside insect vectors in different locations and to associate this frequency with vector-borne disease impacts (Wilson *et al.*, 2007). It has been demonstrated for the oak and pine processionary moths in Europe that combining knowledge of the temperature requirements for larval feeding (night air temperature above 0° C and temperature inside the nest above 9°C on the preceding day) with spatial daily temperature datasets provides predictions of where this species is able to feed and survive under current and future climate conditions (Robinet *et al.*, 2007). This biological model outperformed a statistical temperature driven model of occurrence - predicting recent zones of expansion of the pine processionary moth very accurately. Case studies III illustrates the use of this approach to predict potential zones of establishment and survival for the asian tiger mosquito, a potential invader into the UK. Though climate-driven models may predict regional range limits successfully, fine scale impacts of nuisance insects within countries may only be predictable with the incorporation of information on host and food resources into models. For example the incidence of dermatitis caused by the oak processionary caterpillar in Austria was higher in households close to tree populations (Maier *et al.*, 2003, Maier *et al.*, 2004).

The main drawback of this approach is the level of detailed ecological knowledge required.

Often such biological models are driven only with temperature variables - making the outcome of interactions between temperature and moisture levels impossible to explore and predict. Many models focus on only one or two life history processes - not necessarily those processes that drive population dynamics. Nuisance insect taxa for which there are already substantial field and laboratory data on temperature and moisture dependencies that might facilitate the formulation of biological models of impacts in the short to medium term include the processionary moths, the house flies, some mosquito and ant species and the harlequin ladybird.

Case study I: Continental scale statistical models: Mapping habitat suitability and interations of *Culicoides* biting midge vectors of bluetongue virus across Europe

Background

Since 1998, the *Culicoides* biting midge-borne pathogen, bluetongue virus, has undergone a dramatic, climate-mediated colonisation in southern and northern Europe, with multiple strains entering from several different directions, devastating livestock trade (Purse et al., 2007). Early on in the emergence, bluetongue virus spread beyond the range of its traditional African vector, *Culicoides imicola*, implicating palearctic european species in transmission for the first time. Here, statistical models were used to identify the continental scale drivers of midge distributions and to evaluate the relative role of old and new vectors in disease transmission.

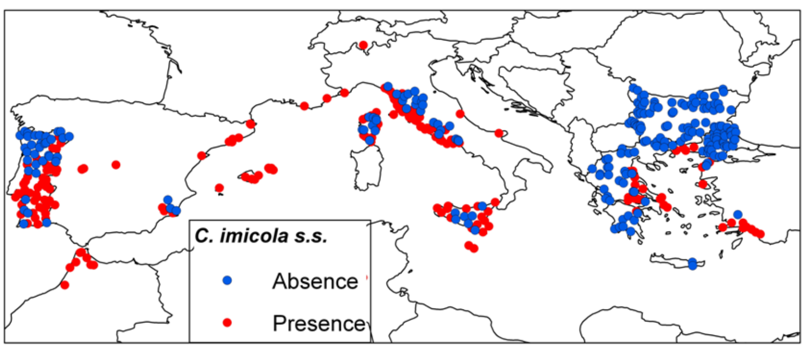


Figure 3.5: Distribution patterns of the African-asian midge vector *Culicoides imicola* used to define parameters for the environmental envelope model.

Approach

Current distribution patterns of the African asian vector *Culicoides imicola* (from European vector surveillance systems; Figure 3.5) were matched with patterns in average seasonal conditions of temperature and precipitation across Europe, to identify the seasonal drivers of this species' distribution and predict habitat suitability for this species across the region. The differential degree of overlap between the environmental envelopes for bluetongue (from outbreaks in Southern Europe) and its traditional (Afro-asian) and potential new (Palearctic) midge vectors was examined using multivariate distance measures.

Outcome

Culicoides imicola, was found to occur in warm (annual mean 12 to 20ºC), thermally stable locations that were dry in summer (< 400 mm precipitation). Favourable conditions for this species were not currently found to extend much further north than its known range margin (Figure 3.6). Palearctic *C. obsoletus* and *C. pulicaris* species complexes were both found to occur in cooler (down to 7ºC annual mean), thermally more variable and wetter (up to 700 mm summer precipitation) locations.

Almost half of the 501 recorded outbreaks from the 1998-2004 bluetongue epidemic in southern Europe (red symbols; Figure 3.7;) fall outside the climate envelope of *C. imicola* (black symbols; Figure 3.7), but within the species' envelopes of the *C. obsoletus* and *C. pulicaris* complexes (grey symbols; Figure 3.7). The distribution in multivariate environmental space of bluetongue virus is closer to that of the Palaearctic vectors than it is to that of *C. imicola*. This suggests that Palearctic vectors played a substantial role in transmission in Southern Europe and have facilitated the spread of bluetongue into cooler, wetter regions of this continent.

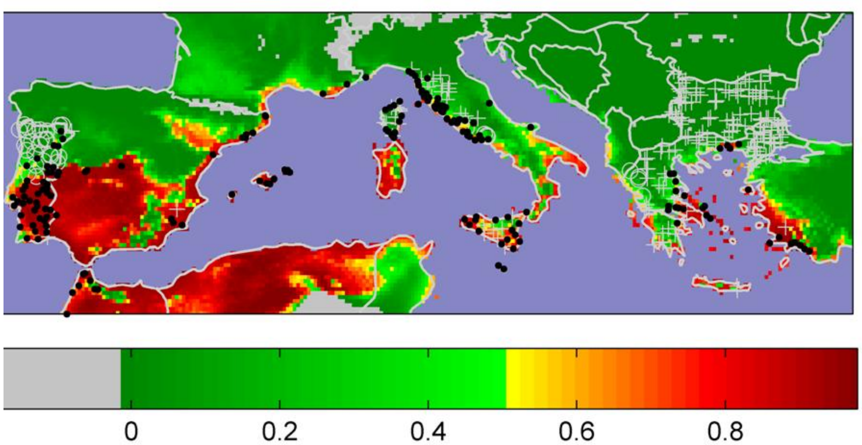


Figure 3.6: Predicted probability of the presence of *C. imicola* in Europe from a climate-driven model. Solid black circles are recorded presences and grey symbols are recorded absences.

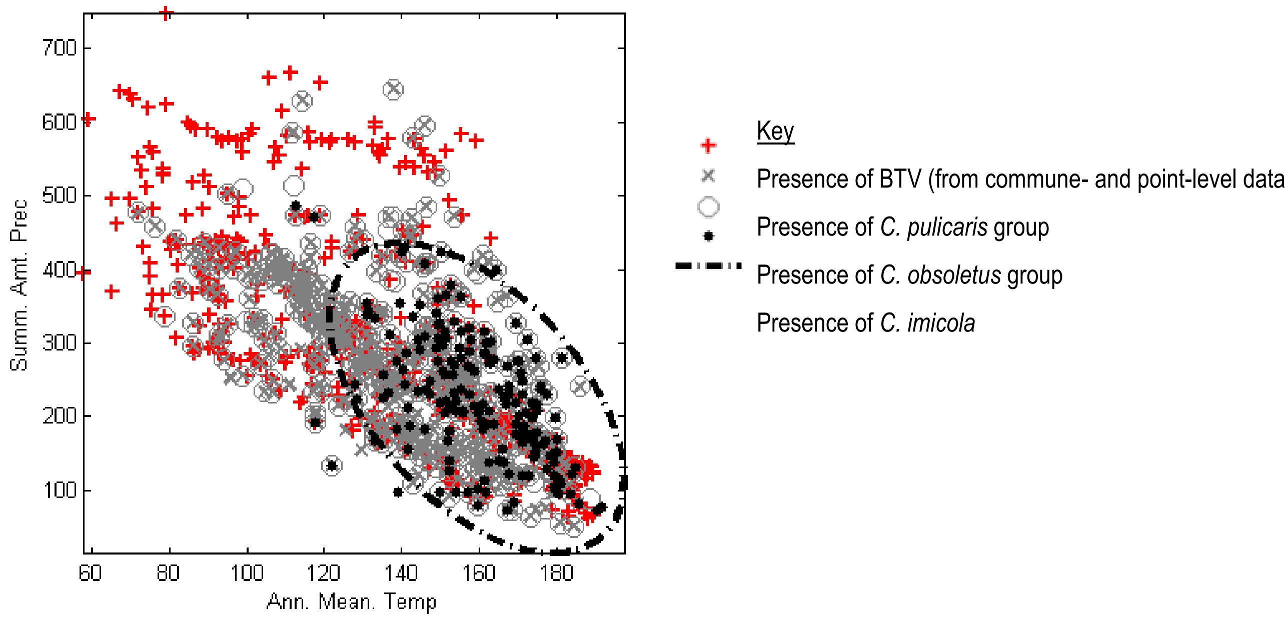


Figure 3.7: Climate space occupied by BTV and its vectors. The axes of bivariate climate space are defined by two of the key determinants of *C. imicola* distribution from the model – summer amount of precipitation (in mm) and annual mean temperature (in 0.1ºC). The overlap between the presence of BTV and the presence of *C. imicola* in environmental space is shown. In (b), (d) and (f), their overlap with the presence of other Palearctic *Culicoides* is also shown.

Case study II: Local scale statistical models: Which premises will support large midge vector populations, given their surrounding host, landscape and climatic factors?

Background

Following the arrival of bluetongue in Northern Europe and England in 2007, concern was raised over a potential incursion into Scotland. Scotland holds large populations of the farmland midge species from the *C. obsoletus* and *C. pulicaris* complexes that have widely involved in transmission in northern and southern Europe alongside both livestock and wild ruminant hosts for bluetongue virus. Taking advantage of country-wide seasonal vector surveillance data from a recently established Scottish Government funded project, statistical models were applied to determine the local scale drivers of farmland midge species in Scotland and to predict which premises are likely to support large midge populations.

Approach

Patterns in the mean spring abundance for each midge species were derived from vector surveillance data (collected by Advanced Pest Solutions Ltd; Figure 3.8) and matched to all environmental factors thought to drive midge populations at a local scale including remotely sensed correlates of temperature and moisture levels, soil pH, water content and carbon content, surrounding landscape type and sheep, deer and cattle densities. The same environmental factors were derived for every farm in Scotland to facilitate the application of the midge abundance model at the farm level – the scale at which midge control measures and vaccination against bluetongue would be applied.

Outcome

The *C. pulicaris s.s.* was found to dominate in abundance over the other species in the *C. obsoletus* and *C. pulicaris* complexes. The importance of particular climate, landscape, soil and host factors varied between midge species, with patterns in the highland human biting midge, *C. impunctatus* being driven by pH and soil moisture levels and patterns in *C. pulicaris s.s* being determined by livestock densities and temperature in addition to soil factors. Overall, a close correspondence was found between observed midge abundance levels and those predicted from the local scale model (Figure 3.9), enhancing our confidence in extending predictions to unsampled farms. When the local scale models were applied to individual farms, it is evident that even with a small region farms can vary considerably in their ability to support midge populations (Figure 3.10).

Note This is unpublished work arising from two Scottish Government contracts (*'Assessing the Economic Impact of Different Bluetongue Virus (BTV) Incursion Scenarios in Scotland'* Commission Number: CR/2007/56 and *'An Assessment of Presence, Distribution and Abundance in Scotland of Culicoides Midge Species and their Potential as Vectors of Animal Disease'* Commission Number: APS/846/07).

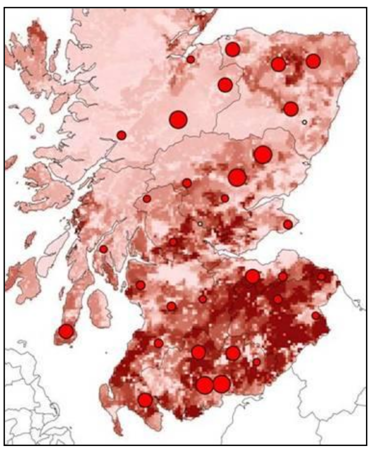


Figure 3.8: Mean spring abundance of *C. pulicaris s.s.*

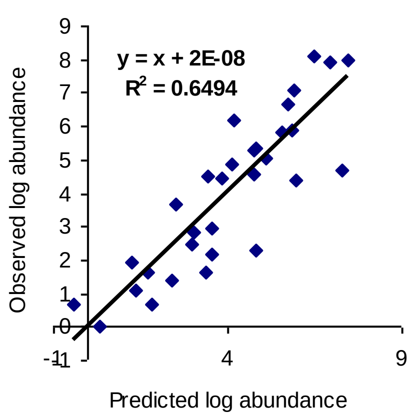


Figure 3.9: Correspondence between observed and across trap sites in Scotland, reproduced with predicted abundance levels of *C. pulicaris s.s.* permission of Advanced Pest Solutions Ltd.

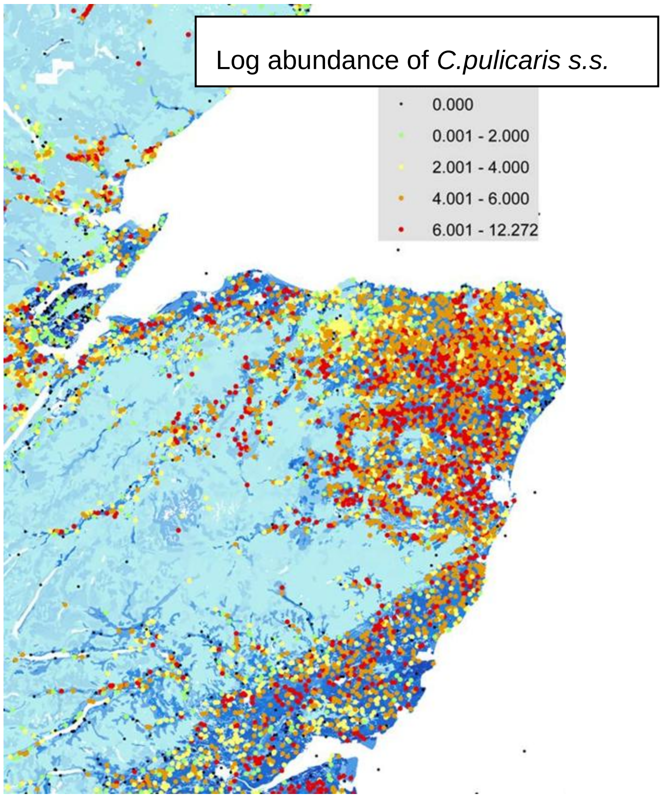


Figure 3.10: Predicted abundance levels of the dominant midge species, *C. pulicaris s.s.*, in farms across eastern Scotland

Case study III: Biological models: Potential for survival and seasonal activity of the Asian tiger mosquito, *Aedes albopictus* (Diptera: Culicidae) in the UK

This case study is paraphrased from the longer Appendix by Medlock et al. entitled 'Analysis of the potential for survival and seasonal activity of *Aedes albopictus* (Diptera: Culicidae) in the United Kingdom.

Background

The ability to lay drought-resistant eggs in water that collects in human-made containers coupled with the international trade in used tyres, has enabled *Aedes albopictus* (Skuse) (Diptera: Culicidae) to travel and establish on new continents, including North, Central, and South America, the Caribbean, Australasia, Africa, and Europe (Medlock *et al.*, 2006). Concerns have been raised over its potential role in the transmission of arboviruses and *Dirofilaria* nematodes. It is now established in large parts of Italy, and small pockets of Mediterranean France and Spain and along the Adriatic coast. Following importation into northerly latitudes, photoperiodically induced egg diapause enables establishment of *Ae. albopictus*, and a number of abiotic factors determine the subsequent seasonal activity

Approach

Medlock *et al.* (2006) combined synoptic temperature, rainfall and photoperiod data for the UK with field derived temperature and photoperiod thresholds for diapause, egg hatching and development to adulthood and developed a biological model to predicted the likely duration of adult activity of *Aedes albopictus* and the locations suitable for establishment in the UK. In the low risk scenario below, the upper thresholds for temperature and photoperiod were used from the empirically observed range and in the high risk scenario, the lower thresholds were employed.

Outcome

Conditions in the south east of the UK are particularly suitable for establishment and activity of *Aedes albopictus.* For scenario 1 (low risk; Figure 3.11), 16 weeks would be expected to elapse between egg hatching of overwintering eggs in spring (weeks 17-19: April/May) and the production of diapausing eggs in autumn (wks 36-37: September). More prolonged activity would occur throughout SE England, Severn and Mersey basins, with 18 weeks in London and south coast ports.

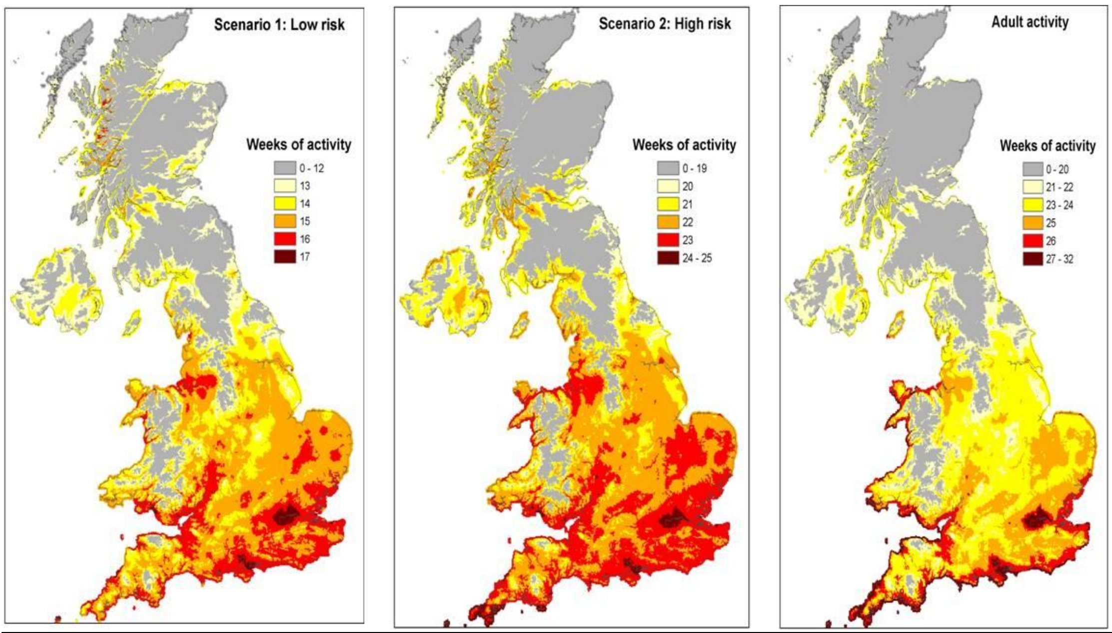


Figure 3.11: Locations suitable for establishment in the UK of *Ae. Albopictus* for three risk scenarios based on modelling synoptic temperature, rainfall and photoperiod data for the UK with field derived temperature and photoperiod thresholds for diapause, egg hatching and development to adulthood to predict the likely duration of adult activity of *Ae. albopictus*. In the low risk scenario the upper thresholds for temperature and photoperiod were used from the empirically observed range and in the high risk scenario the lower thresholds were employed.

For scenario 2 (Figure 3.11), this period would extend to 20-22 weeks. Assuming adult mosquitoes succumb to winter temperatures <9.5°C, biting adults could be on the wing for up to 5-6 months. Given the recent outbreak of chikungunya virus in Italy, and the vector competence of *Ae. albopictus* for dengue, *Dirofilaria* and many other arboviruses, the UK must be vigilant to ensure that it is not added to the list of infested regions. Targeted surveillance should be in place in prolonged activity zones, with particular attention at ports and neighbouring urban areas.

3.5 Summary of review of impacts of changing temperature and moisture levels on life-history, habitat use, distribution and dynamics of selected nuisance insect species

The impacts of temperature and moisture levels detected for 17 selected nuisance insect species (for which information was sufficient to draw conclusions) from a review of 38 climate related references (Table 3.5) indicates that:

- Investigation of climate impacts on nuisance insects have rarely considered interaction with non-climatic factors such as land use and microhabitat and host availability (only four species in Table 3.5)
- Impacts of climatic factors were most common on life history parameters such as survival, reproduction and development rather than habitat use, reflecting the fact that nuisance insect species as a whole are relatively extensive in their habitat preferences.
- For eight species, studies have covered impacts of UK climate or climate changes (underlined in reference numbers)
- Positive impacts of warmer summers and winters were noted for most nuisance insect species analysed but will only significantly increase abundance and distribution of species that live outside buildings
- External changes in precipitation and moisture levels were found to be important for seven of the focal species. Their importance was most marked for species with aquatic breeding sites such as *Ochlerotatus cantans* that inhabits seasonally wet, woodland pools and the container breeding asian tiger mosquito. Some species with terrestrial breeding sites were also impacted by changing moisture levels, namely Argentine ant and the house fly.

Table 3.5: Impacts of temperature and moisture levels on life-history, habitat use, distribution and dynamics of selected nuisance insect species
* = study considering climate change impacts, reference numbers for UK studies are underlined

Species and Common name	Reference nos for studies	Type of studies	Climate change aspects considered in studies	Non-climatic factors considered in studies	Temperature				Precipitation or moisture levels			
					Life history	Habitat use	Distribution	Dynamics	Life history	Habitat use	Distribution	Dynamics
Aedes albopictus Asian tiger mosquito	512*, 455, 448*	review	warmer winters and summers, wetting	human population density	y		y	y	y		y	y
Anobium punctatum Woodworm	497*, 499	field			y		y	y	y		y	y
Blatta orientalis German cockroach	144, 403	lab			y		y	y	y		y	y
Eucallipterus tiliae Lime aphid	729*, 730, 731	field and lab	warmer winters and summers, increase in the number of hot days		y			y				
Euproctis chrysorrhoea Brown tail moth	737*, 736*	field	warmer winters and summers, increase in the number of hot days	agricultural land use, flood plain management, planting of host plants, microhabitat availability	y	y	y	y				
Harmonia axyridis Harlequin ladybird	620*, 619*	field and lab	warmer winters, decrease in number of frost days	microhabitat availability	y		y	y				
Hylotrupes bajulus House longhorn beetle	745*	field and lab	warmer winters and summers			y						
Lasius neglectus Invasive garden ant	739	field and lab			y		y	y				
Lasius niger Black garden Ant	743*	lab	warmer winters and summers		y	y	y	y				
Linepithema humile Argentine ant	71*, 601*, 604*, 602*	field and lab	warmer winters, wetting and drying decrease in number of frost days,	microhabitat availability, disturbed ground, agriculural land use, planting of host plants	y		y	y	y		y	y
Musca domestica House fly	350*, 617*, 102*, 615	field and lab	warmer winters, decrease in number of frost days		y		y	y	y		y	y
Ochlerotatus cantans A woodland mosquito	728*	field and lab	wetting, increases in flooding frequency								y	
Phlebotomus mascittii Sand fly	746*	field	warmer winters and summers		y	y	y	y				
Reticulitermes flavipes / virginicus Subterranean termites	608*	lab	wetting, increases in flooding frequency		y		y	y	y	y	y	y
Tinearia alternata Moth fly	618*, 474	field and lab	warmer winters and summers	human population density	y		y	y				
Tineola bisselliella Common clothes moth	750	lab	decrease in number of frost days		y	y	y	y				
Vespula germanica German wasp	748	lab	warmer winters		Y	y	y	y				

Further work beyond this project

There are three main areas of future work that have been identified through this project:

Central data repository: The paucity of available data for key nuisance insect species hinders the potential for predicting nuisance insect population dynamics in a changing climate. In addition there is no centralised source of information available for EHOs. A web-based repository could enhance data flow and exchange of information on nuisance insects. Furthermore, a nuisance insect repository could be linked to the forthcoming Defra funded Non-native Species Data repository. Public participation and outreach could be coordinated through a central data repository.

Indirect effects of climate change: Climate change is predicted to impact on humans in many (diverse) ways. Changes in human behaviour to cope with a climate change will impact on the distribution and abundance of nuisance insects species (through container planting, more time spent outside etc). Furthermore, the drive to generate a low carbon economy could also impact on nuisance insects species through changes in building technology, agricultural changes (shift from livestock production), changes in waste technology (sewage and other waste) including increased recycling. These aspects could be considered in more detail and more systematically than delivered through this report. This, coupled with quantitative climate and habitat models, would allow predictions to be made with more certainty than is currently possible.

Multi-species interactions: Understanding nuisance insects from a community ecology perspective would also enable detailed predictions to be made. Nuisance insects do not live in isolation but will interact with a multitude of other species such as humans but also including predators and parasites. Indeed, predators and parasites (natural enemies) could be important in regulating populations of nuisance insects and increasingly important in the future; it is predicted that pathogens of insects will have an increasingly important role to play as the climate changes because pathogens will benefit from warmer, wetter periods (Roy *et al.*, In press-b).

It would be feasible and pertinent to assess the impacts of climate change on the natural enemies of nuisance insects and to make predictions as to whether they will exert more or less control on the nuisance insects.

Modelling the dynamics of processionary moths: The oak processionary moth recently invaded the UK and has been found in several locations in London through 2006. This species is a major defoliator of oaks in Europe and also has human health impacts because the toxic, irritant hairs covering the larvae can cause severe skin irritation and allergic reactions in humans following contact or inhalation.

The development and survival of this phytophagous insect is likely to be highly sensitive to climatic changes (especially temperature) but the availability of suitable habitat (tree species) and presence of natural enemies are likely to determine the extent of expansion and impacts of this species in the UK. Characterisation of natural enemies and local and regional scale maps of potential areas for oak processionary moth establishment are likely to add significantly to the armoury of current control methods for this moth in the UK. We would propose that this nuisance insect is the ideal focus for a research project with the following objectives:

- Work with European researchers in ecology and human health and UK stakeholders to collate existing spatial datasets of oak processionary moth occurrence, impacts and suitable habitat across the UK and Northern Europe
- Match current patterns of occurrence of oak processionary moths and their impacts (including dermatitis and defoliation rates) with concurrent climate and landscape data to identify key drivers of (i) the occurrence and abundance of processionary moths within the distribution of their habitat; (ii) the focal nature of dermatitis or defoliation caused by processionary moths; (iii) the seasonality of large outbreaks of processionary moths within their distributions
- Identify key natural enemies of oak processionary moths in UK compared to field populations in continental Europe

- Perform field and laboratory experiments to examine threshold temperatures for survival and feeding activity of larval oak processionary moths from British populations
- Investigate the host preferences and differential survival between hosts of the oak processionary moths from British populations in the laboratory
- Examine the relative role of natural enemies compared to habitat availability and landscape factors in determining the abundance and impacts of oak processionary moths in field sites across the UK (using statistical models)
- Develop mechanistic models (combining empirical temperature relationships with UK climatic data and scenarios) for survival and feeding activity of oak processionary to map areas of current and future establishment
- Undertake parallel studies on pine processionary moths

Traits analysis: There are several hypotheses in this report concerning traits that are likely to determine responses to change. These hypotheses are currently not strongly supported in the literature and it may be possible to devise experimental approaches or climate analogue approaches to testing them. It would be useful to expand studies to encompass traits analyses to determine functional groups that respond to changes in a particular way.

Acknowledgements

The study was funded by Defra. We would like to thank the Temple Group for their expert advice throughout the project and particularly for refining the definition of nuisance insect. We are also grateful to the Health Protection Agency.

Glossary

Abundance - number of individual specimens of an animal or plant seen over a certain period of time in a certain place

Alien (= non-native) species – species brought to the study area by humans, intentionally or unintentionally, even if native to the source area *or* one which has come into the area without human intervention, but from an area in which it is alien

Anthropogenic – processes or materials derived from human activities rather than natural environments or sources without human influence

Biological vector – microbial pathogens propagate within the vector before transmission to the primary host. In contrast, microbial pathogens do not multiply within mechanical vectors (the mechanical vectors physically transport microbes from host to host)

Bluetongue – is a non-contagious, biological (insect) vectored viral (bluetongue virus) disease of ruminants (mainly sheep and less frequently cattle, goats, buffalo, deer etc). There are no reports of transmission to humans

Cestode - parasitic flatworms of the class Cestoda, including the tapeworms, which have a long flat body with a specialised organ of attachment at one end

Coleoptera – an order of insects, beetles, which have hardened fore-wings called elytra

Community ecology – study of the distribution, abundance, demography and interactions between coexisting populations

Diapause – physiological state of dormancy which enables an insect to survive predictable but unfavourable environmental conditions, such as temperature extremes, drought or reduced food availability

Dictyoptera – an order of insects that includes three groups of insects: cockroaches, termites and mantids

Diptera – an order of insects, flies, that have one pair of membranous wings and modified hind wings that form specialised structures called halteres

Dispersal - species movement away from an existing population or away from the parent organism

Distribution – pattern in which groups of species are spread out

Ectotherm - species that control body temperature through external means and are consequently dependent on environmental heat sources

Environmental envelopes – range of environmental (temperature, moisture etc) requirements of a species. Environmental envelope models are used to predict the distribution of species under current, past and future environmental conditions by inferring a species' environmental requirements from localities where it is currently known to occur

Hemiptera – an order of insects, bugs, that have sucking mouthparts

Hymenoptera – an order of insects, wasps, ants and bees, that have constricted abdominal segments (usually constriction between the first and second abdominal segments)

Insect growth regulator - compound, either natural or synthetic, which influences insect growth and development usually through the disruption of insect hormones

Isoptera – an order of insects, termites, that are social. Recent DNA evidence suggests that termites are most closely related to the wood-eating cockroaches and placed within the order Dictyoptera.

Lepidoptera – an order of insects, butterflies and moths, that have wings with scales

Life history - traits of a species such as survival, age at first reproduction, fecundity (reproductive output and frequency) that cumulatively describe the species existence

Mechanical vector - microbial pathogens do not multiply within the mechanical vector (the mechanical vector physically transports the microbial pathogen from host before transmission to the primary host).

Microhabitat – small, specialised habitat described by small scale changes in habitat parameters such as temperature, moisture levels etc

Midge – ill-defined taxonomic group that includes a number of small two-winged flies

Monomorphic – one form as opposed to polymorphic in which a species exhibits many different forms

Multivariate - observation and analysis of more than one variable (such as size, generation time etc)

Myiasis - an animal or human disease caused by parasitic fly larvae feeding on necrotic or living tissue of the host

Native species – a species which has arrived in the study area without human intervention, having come from an area in which it is native *or* one which has arisen *de novo* in the study area.

Natural enemies – parasites and predators of an organism

Nuisance Insect Species – Insect species with the potential to cause nuisance.

Non-native (= alien) species - brought to the study area by humans, intentionally or unintentionally, even if native to the source area *or* one which has come into the area without human intervention, but from an area in which it is alien

Parthenogenesis - asexual form of reproduction found in females where growth and development of embryos occurs without fertilisation by a male

Pathogen – disease causing agent such as a virus, bacterium, fungus or protist

Photoperiodicity – physiological reaction of a species to light

Polygynous – males mate with multiple females

Population ecology – study of the dynamics of species populations and how they interact with the environment

Potential invader – non-native species absent in the country but with the potential to arrive in the near future

Remote sensing - acquisition of information through the use of either recording or real-time sensing device(s) that are not in physical or intimate contact with the object (such as by satellite, spacecraft or ship)

Resident – species (native or non-native) that is established (reproducing) in a country

Resource specialisation – the degree to which a species is dependent on a resource such as food, habitat or environment. Some species are generalist and can thrive in a variety of habitats and others have highly specialised requirements

r-selection – life history strategy for species living in unstable and unpredictable environments. Traits that are characteristic of r-selection species include: high fecundity, small body size, early maturity onset, short generation time, and the ability to disperse offspring widely

Siphonaptera – order of insects, fleas, that are wingless with mouthparts adapted for piercing skin and sucking blood

Stored product – products such as grain, flour, cheese, chocolate

Synanthropic species – species which live near, and benefit from, an association with humans and artificial habitats that humans create such as houses, gardens, farms, roadsides etc. Eusynanthropic species are those that have an intimate association with humans and hemisynanthropic species have more diffuse or opportunistic association with humans perhaps just in one life cycle stage

Traits – characteristics of a species

Trickling (percolating) filter bed – sewage treatment system consisting of a fixed bed of rocks, gravel, slag, sphagnum peat moss, polyurethane foam or plastic media over which wastewater flows downward and causes a layer or film of microbial slime to grow, covering the bed of media

Vector – an organism that does not cause disease but transmits disease (infection) by transmitting pathogens from one host to another

Vector surveillance data – information gathered through surveillance on insect vectors

Wood borer – an insect that feeds on wood by channelling through the wood producing tunnels and galleries

Appendix 1: Sources of information available on-line for eight selected species

Aedes albopictus Asian tiger mosquito (gov.uk google hits, on 2nd March 2009, from search term "*Aedes albopictus* advice" = 8)

Pest Control Companies

Not applicable because this species is a potential invader.

Local Authorities

Not applicable because this species is a potential invader.

Anobium punctatum Common furniture beetle **(gov.uk google hits, on 2nd March 2009, from search term "*Anobium punctatum* advice" = 70)**

Pest Control Companies

Property Repair Systems

http://www.woodworm-info.co.uk/boron_google_Boraxtreatment.htm?gclid=CJGjuq_0kJoCFQJ2xgoduh8Y-A

Type of information: Identification, Distribution, Life Cycle, Nuisance potential (Significance), Management/Control

Timberwise

http://www.timberwise.co.uk/pages/woodworm.php?gclid=CMHMj730kJoCFRFMagodTgaVFA

Type of information: Identification, Distribution, Life Cycle, Nuisance potential (Significance), Management/Control

Local Authorities

Leeds City Council

http://www.leeds.gov.uk/templenewsam/house/prev_pest.html

Document relates to one historic property

New Forest District Council

http://www.newforestnpa.gov.uk/damp_rot_and_insect_attack.pdf

Fact sheet on damp, rot and insect attack of historic buildings. Limited specific information.

Salford City Council

http://www.salford.gov.uk/insect13spiderbeetle.pdf

Includes spider beetles and biscuit beetles (very limited information on common furniture beetle)

Blattella germanica **German cockroach,** ***Blatta orientalis*** **Oriental cockroach,** ***Periplaneta americana*** **American cockroach (gov.uk google hits, on 2nd March 2009, from search terms: "*Blatta germanica* advice" = 109; "*Blatta orientalis* advice" = 107)**

Pest Control Companies

Ultrasonic Pest Control

http://ultrasonicpestcontrol.co.uk/cockroaches.htm

Type of information: Identification, Nuisance potential, Management/Control

No More Pests

http://www.nomorepests.co.uk/BeetlesAndCockroaches.html

Type of information: Identification, Nuisance potential

Pest Control Solutions

http://www.pestcontrol-uk.biz/cockroaches.pdf

(This is the same pdf as presented by Stafford Borough)

Type of information: Identification, Distribution, Life Cycle, Nuisance potential (Significance), Management/Control

Provincial Pest Control

http://www.ppc-ni.co.uk/roach.html

(This is exactly the same information as presented by Stafford Borough)

Type of information: Identification, Distribution, Life Cycle, Nuisance potential (Significance), Management/Control

Universal Pest Control

http://www.universalpestcontrol.co.uk/serv_bugs.html

Type of information: Nuisance potential, Management/Control

Comet Pest Control

http://www.cometpc.btinternet.co.uk/btpage9.htm

Type of information: Identification, Life cycle, Nuisance potential (Reasons for Control), Management/Contol

Local Authorities

Fareham Borough Council

http://www.fareham.gov.uk/council/departments/healthcommunity/cockroac.asp

Type of information: Identification, Nuisance potential (Infestation/Significance), Management/Control

Salford City Council

http://www.salford.gov.uk/insect5cockroaches.pdf

(Includes Australian cockroach)

Type of information: Identification, Distribution, Life Cycle, Nuisance potential (Significance), Management/Control

Stafford Borough Council

http://www.staffordbc.gov.uk/static/static/eh/Cockroaches.pdf

(pdf created by Aventis Environmental Science) (Includes Australian cockroach)

(This is the same information as on the Salford City Council Website)

Type of information: Identification, Distribution, Life Cycle, Nuisance potential (Significance), Management/Control

Wolverhampton City Council

http://www.wolverhampton.gov.uk/environment/environmentalhealth/pests/cockroaches/

Type of information: Management/Control

Babergh District Council

http://www.babergh-south-suffolk.gov.uk/NR/rdonlyres/FE9B114B-24E0-4D01-AA5A-5F441F548690/0/CockroachControlLeaflet.pdf

Type of information: Identification, Life cycle, Nuisance potential (Significance), Management/Control

Charnwood Borough Council

http://www.charnwood.gov.uk/files/documents/cockroach/cockroach.doc

Type of information: Identification, Life cycle, Management/Control

Ctenocephalides felis Cat Flea **(gov.uk google hits, on 2nd March 2009, from search term "*Ctenocephalides felis* advice" = 133)**

Pest Control Agencies

Pied Piper Pest Control

http://www.the-piedpiper.co.uk/th5b.htm

(Includes dog flea)

Type of information: Identification, Management/Control

Agropharm

http://www.agropharm.co.uk/uk/bug_view.asp?bug_id=5

(includes dog flea)

Type of information: Life cycle, Nuisance potential, Management/Control

Countrywide Pest Control

http://www.countrywide-pestcontrol.co.uk/Phils%20files/Fleas.htm

(Includes dog flea)

Type of information: Identification, Life cycle, Nuisance potential, Management/Control

Petfleas.co.uk

http://www.petfleas.co.uk/acatalog/Fleas_Advice.html

(Includes dog flea)

Type of information: Identification, Nuisance potential (infestation), Management/Control

Local Authorities

Macclesfield Borough Council

http://www.macclesfield.gov.uk/pdfs/fleas.pdf

(Includes dog & human fleas)

Type of information: Identification, Life cycle, Management/Control

State of Guernsey Council

http://www.gov.gg/ccm/navigation/health---social-services/public-health-and-strategy/environmental-health---pollution-regulation/pest-control/?page=4

(Includes dog & human fleas)

Type of information: Identification, Management/Control

Horsham District Council

http://www.horsham.gov.uk/council_services/council_services_9336.asp

Type of information: Distribution, Identification, Life cycle

Rushmore Borough Council

http://www.rushmoor.gov.uk/index.cfm?articleid=6238

(Includes dog flea)

Type of information: Identification, 'Other facts'

Harrow Council

http://www.harrow.gov.uk/downloads/factsheet_fleas.pdf

(Includes dog flea)

Type of information: Identification, Life Cycle, Nuisance potential (Habits), Management/Control, 'Other facts'

Lasius niger **Common Black Ant (gov.uk google hits, on 2nd March 2009, from search term "*Lasius niger* advice" = 138)**

Pest Control Agencies -

Agropharm Ltd.

http://www.agropharm.co.uk/uk/bug_view.asp?bug_id=18

Type of information: Identification, 'Other Facts', Management/Control

Ehrlich Pest Control

http://www.jcehrlich.com/pest-guides/insects-and-spiders/ants/garden-ant/

Type of information: Identification, Life cycle, 'Other facts'

Rentokil

http://www.rentokil.co.uk/pest-guides/insects-and-spiders/ants/garden-ant/

(This page is identical to the Ehrlich pest control site)

Type of information: Identification, Life cycle, 'Other facts'

Pesticide Action Network

http://www.pan-uk.org/pestnews/Homepest/ants.htm

Type of information: Nuisance potential (Biology), Management/Control

Protec

http://www.protecpestcontrol.co.uk/ants.htm

(Includes all ants)

Type of information: Identification, Nuisance potential, Management/Control

Local Authorities

Chelmsford Borough Council

http://www.chelmsford.gov.uk/index.cfm?articleid=10516

Type of information: Distribution, Identification, Life cycle, Nuisance potential (Public Health Significance), Management/Control,

Cherwell District Council

http://www.cherwell.gov.uk/media/pdf/7/k/Pests_Info_and_Advice.pdf

Type of information: Distribution, Life cycle, Management/Control

North Shropshire District Council

http://www.northshropshiredc.gov.uk/Environment/PestsAndNuisance16

Type of information: Identification, Nuisance potential, Management/Control

Salford City Council

http://www.salford.gov.uk/insect2blackants.pdf

Type of information: Distribution, Identification, life cycle, Nuisance potential (Significance), Management/Control

Stafford Borough Council

http://www.staffordbc.gov.uk/static/static/eh/Black%20Ants.pdf

Type of information: Distribution, Life cycle, Nuisance potential (Significance), Management/Control

Linepithema humile Argentine Ant (gov.uk google hits, on 2nd March 2009, from search term "_Linepithema humile_ advice" = 2)

Both hits refer to PDF documents:

http://209.85.229.132/search?q=cache:VNBr2nRgPcsJ:www.forestresearch.gov.uk/pdf/IUFRO_Shepherdstown_Okabe_Potential_pest_in_Japan.pdf/%24FILE/IUFRO_Shepherdstown_Okabe_Potential_pest_in_Japan.pdf+Linepithema+humile+site:gov.uk&cd=1&hl=en&ct=clnk (Japan case study)

http://darwin.defra.gov.uk/documents/14054/5521/14-054%20FR%20-%20edited.pdf (Darwin Initiative)

Musca domestica **Common House Fly (gov.uk google hits, on 2nd March 2009, from search term "*Musca domestica* advice" = 97)**

Pest Control Companies

Arkay Hygiene*

http://www.arkayltd.co.uk/pages/info_about_flying_insects/detailed_fly_info_files/house_fly_detailed_info.htm

Type of information: Distribution, Life cycle, Identification, Nuisance potential (Damage), Management/Control

Agropharm Ltd.

http://www.agropharm.co.uk/uk/bug_view.asp?bug_id=4

Type of information: Identification, Life cycle (brief), Nuisance Potential, Management/Control

Pied Piper Pest Control

http://www.the-piedpiper.co.uk/th6a.htm

Type of information: Life cycle, Identification, Nuisance potential (Damage/Economic Injury Level), Management/Control

AG Pest Management

http://www.agpestmanagement.co.uk/House_Fly.html

Type of information: Distribution, 'Other facts', Control

Local Authorities

Chichester District Council

http://www.chichester.gov.uk/index.cfm?articleid=8205

(Includes common & lesser houseflies, autumn fly & cluster fly)

Type of information: Life Cycle, Management/Control

Torfaen County Borough

http://www.torfaen.gov.uk/EnvironmentAndPlanning/AnimalAndPestControl/PublicProtectionPestControl/Publications/FlyLifeCycle.pdf

Type of information: Life cycle, Identification,

Salford City Council

http://www.salford.gov.uk/insect9houseflies.pdf

(Includes common & lesser houseflies)

Type of information: Distribution, Life cycle, Identification, Nuisance potential (Significance), Management/Control

Winchester City Council

http://www.winchester.gov.uk/General.asp?id=SX9452-A781AFA5

(Includes common & lesser houseflies, autumn fly & cluster fly)

Type of information: Life Cycle, Management/Control

(similar information to Chichester District Council and information is replicated on other council sites (e.g. Kennet District Council)

Lisburn City Council

http://www.lisburncity.gov.uk/your-city-council/council-departments/environmental-services/environmental-health/pest-control/flies/

(Includes common housefly, bluebottle & cluster fly)

Type of information: Identification, Nuisance potential, Management/Control

Tinearia alternata Moth-Fly **(gov.uk google hits from search term "*Tinearia alternata* advice" = 3)**

Appendix 2: Example fact sheets for seven species

Asian Tiger Mosquito - *Aedes albopictus* Skuse

What are they?

Blood-feeding ectoparasite.

Adult males feed only on nectar, while the female requires a blood meal to provide the protein necessary to lay each batch of eggs. The aquatic larvae feed on organic matter in the water. Adults generally fly and bite during the day.

What do they look like?

The adult is black, with an 8mm leg length and wing span and a 5mm body length. The legs and abdomen are both banded with white stripes on a black base. The thorax is predominantly black, with a distinctive single white stripe down the centre of the back. The non-biting males have conspicuous feathery antennae; biting females do not.

How do they move about?

Asian tiger mosquito adults do not usually disperse more than about 200 metres. However, this mosquito is a container-breeding species, and consequently immature stages, particularly larvae and the cold- and desiccation-resistant ova are often transferred in or on containers, particularly used tyres. Notably, transfer in Lucky Bamboo (*Dracaena* spp.) packaged in water for greater moisture retention during transport was responsible for the temporary establishment of the species in California in 2001 and the Netherlands in 2006-7.

Where do they live?

The species is thought to have originated in southeast Asia and India, extending to Mauritius, Madagascar and the Seychelles but is known to have colonised virtually every continent, including Europe (Albania, France, Italy, etc); Africa (Nigeria); North America (USA, Mexico); South America (Argentina, Brazil, Guatemala, etc), and Pacific islands, while it has also been intercepted in shipments bound for New Zealand.

The trend for this species is for increasing spread, facilitated and largely mediated by the international used tyre trade. This mosquito has never been reported within the UK, but on the continent colonies (since exterminated) have been recorded as far north as Normandy, and there appears to be no climatic barrier to colonisation of the UK.

Why are they considered to be nuisance insects?

The asian tiger mosquito is a persistent biting nuisance and a competent biological vector for at least twenty-two arboviruses, numerous alphaviruses, and two nematodes, causing canine heartworm in dogs and Dengue, West Nile Virus, Chikungunya, Ross River, LaCrosse Encephalitis, Eastern Equine Encephalitis amongst others in humans and other animals.

What can be done to manage this insect?

Prevention - Removal of potential larval development sites, especially around houses, either by the physical removal of containers, prevention of water accumulation (e.g. by slicing used tyres in half and stacking so that rainwater does not collect), or by adding vegetable oil to likely waterbodies, decreasing the surface tension and so drowning the larvae. Surveillance and monitoring of likely sites of first colonisation are necessary to enable timely action to be taken to prevent the establishment of the species. Possible sightings of this species should be reported to the Mosquito Recording Scheme (http://www.brc.ac.uk/scheme_details.asp?schemeChoice=23) or the Non-native Species Secretariat (http://www.nonnativespecies.org/) or the Biological Records Centre (www.brc.ac.uk).

Chemical - adults and larvae can be controlled chemically but larval control is critical to reduce populations effectively. Larvae can be controlled by the application of either Insect Growth Regulators (such as methoprene) or chemical insecticides to waterbodies.

Biological – biological control agents such as *Bacillus thuringensis* and *B. sphaericus* are effective when applied to larval sites.

Woodworm / Common Furniture Beetle - *Anobium punctatum* De Geer

What are they?

Wood-boring beetles

What do they look like?

The larvae ('woodworms') are off-white, up to 7mm long, with developed legs. The adults are 2-3mm long, brown with clear longitudinal striations on the wing cases and a large thoracic covering (pronotum) extending forward so that the downwards-pointing head cannot be seen from directly above. When emerging from the wood, which they do between April and August, adult beetles gnaw a characteristic circular hole, 1.5-2mm in diameter.

How do they move about?

Adult beetles can fly and are attracted to light but their flight range is relatively short, minimising their threat to urban areas, although it is possible for adults to be blown a long way with the wind. Movement of infested wood is the main method of long-distance spread. It is almost impossible to accurately identify infested timber until the first adults emerge and frequently the beetles may have completed several generations before the infestation becomes noticeable.

Where do they live?

The species is native to the UK and continental Europe.

The most favourable conditions for the larvae are moderate temperature (20-25°C), and fairly high relative humidity (70-75% RH). Larvae cannot establish and develop completely in timber with a moisture content below 15% RH, which equates to 65% RH ambient humidity. In modern, centrally-heated houses, RH tends to be below 65%, and consequently timber indoors usually dries out, reducing the moisture content to below that necessary to support populations of this beetle.

Why are they considered to be nuisance insects?

Woodworm is capable of causing structural damage to a property by tunnelling in roof timbers and floorboards. Most infestations are detected and eradicated, or die out naturally, before this stage is reached. Structural and aesthetic damage to furniture is more common.

What can be done to manage this insect?

Prevention - examination of wood brought into the house, particularly furniture, which has the potential for hidden infestations. Fumigation to kill larvae should be carried out on suspect wooden articles before they enter a dwelling. Alternatively, timber can be pre-treated against woodborers, or timber from tree species which are not attacked by this beetle can be used. It is possible to determine whether or not an infestation is current or old; current infestations will produce frass with a characteristic 'gritty' feel as a result of the lemon-shaped pellets (visible under a microscope): old holes will not actively produce frass. Additionally, current infestations produce new adult exit holes over the summer and these can be detected by filling old holes (by painting or varnishing), or by marking holes over the winter prior to emergence. Inspection in the autumn will allow any new holes to be identified and appropriate action can be taken.

Physical - possibly the most effective mechanical measure is central heating of homes which tends to reduce wood moisture content to below that necessary for successful larval development. In addition, adult insects are attracted to light, and it has been suggested that a 'bug zapper' light trap may be effective in helping to reduce a population, particularly in roof spaces. A pheromone trap which mimics the female beetle's attraction pheromone is available.

Chemical - fumigation with insecticides or atmospheric gases such as nitrogen or CO_2 can be used, although the latter may take a considerable amount of time due to larval adaptations to the low oxygen concentration in their tunnels.

German Cockroach - *Blattella germanica* Linnaeus

What are they?

Omnivorous scavenger

What do they look like?

The adult is 10-15 mm long, mid- to dark brown in colour, with two distinct dark stripes on the back of the thorax. The egg case is approximately 8 mm long, 3 mm wide and 2 mm high and is carried in the genital chamber of the female until shortly before the eggs hatch, visibly protruding beyond the end of the insect. Nymphs closely resemble adults but are smaller and wingless.

How do they move about?

German cockroaches can disperse short distances through flight (gliding from high to low) but are incapable of prolonged flight. They can walk considerable distances and their small size allows movement through tiny gaps such as airbricks resulting in dispersal between connected buildings. German cockroaches can be moved accidentally in packaging, or similar items, left in an infested area, particularly overnight. Colonies have been found on ships, particularly in mess halls, creating the risk of infestation of port facilities.

Where do they live?

German cockroaches have a worldwide distribution and overseas can be found outside where conditions are suitable, but in the British Isles they are primarily encountered indoors.

Why are they considered to be nuisance insects?

German cockroaches are a potential threat to human health. The species acts as a mechanical vector of human pathogens, as a source of allergens causing cockroach allergy, as a psychological stressor, and it occasionally bites humans, usually in the process of feeding on food residues on the skin, leading to dermatitis and necrosis. German cockroaches have been recorded carrying a range of pathogenic bacteria (including *Salmonella*), fungi, helminths, protozoa and viruses (infectious hepatitis) externally on the exoskeleton. These pathogens can be transferred to food and food preparation areas through contact with the cockroach.

What can be done to manage this insect?

Prevention - sanitation is the most effective method of prevention by removing accessible food, minimising free water sources (by repairing dripping taps and leaks) and removing potential shelters by filling in cracks, gaps under kitchen units etc. Limiting access between the garden and inside dwellings, by sealing cracks around windows and doors, can also be effective.

Mechanical - removal of food sources, moisture sources and shelter followed by thorough cleaning to remove cockroach remains, particularly in dust, as these will still be allergenic.

Physical - physical barriers (sealing cracks) can be used to prevent infestation at source. Also trimming vegetation around airbricks and eaves, and sprawling ground plants near the house which could potentially harbour cockroaches.

Chemical - a wide range of insecticides and Insect Growth Regulators (such as hydroprene and methoprene) are available for the control of cockroaches in spray, bait and pellet form, and this has been the traditional method of dealing with infestation. However, German cockroaches are increasingly resistant to chemical insecticides.

Cat flea - *Ctenocephalides felis* Bouché

What are they?

Ectoparasite.

Adult diet consists almost exclusively of mammalian blood (although there are occasional reports of feeding on birds), while the larvae feed almost exclusively on the faeces of the adult fleas.

What do they look like?

Adults are mid-brown, laterally-flattened fleas, reaching a maximum length of approximately 2.5 mm. Eggs are white, oval, smooth and approximately 0.5 mm long, usually laid off host or falling off the host rather than developing *in situ*. The larvae are whitish, translucent and wormlike in appearance, with the dark gut contents clearly visible. Sparsely haired, they reach approximately 5 mm in length before pupating in a silken cocoon covered with debris. The pupal stage can last for months (until the presence of a host is detected by means of mechanical or chemical stimuli).

How do they move about?

The primary method of dispersal is through larval and pupal infestation of material shared by several potential host individuals; particularly pet bedding, where the presence of a host triggers the hatching of dormant pupae to infest the new host individual.

Where do they live?

Worldwide distribution on a range of domestic and wild species. Moderate temperature and relatively high humidity requirements: 20-30°C and 70% or higher relative humidity (RH) for optimal larval development.

Why are they considered to be nuisance insects?

Cat fleas achieve nuisance status simply through biting but they are also biological vectors (to humans) of Cat Flea Rickettsiosis (via transfer of *Rickettsia felis*), Cat Scratch Disease (*Bartonella henselae*) and Murine Typhus (*Rickettsia typhi*) and are secondary biological vectors of the plague bacteria *Yersinia pestis*. They have also been associated with *Bartonella claridgeiae, Bartonella koehlerae, Bartonella quintana* (Trench fever) and *Francisella tularensis* (tularemia). In pets, particularly cats and dogs, cat fleas can vector the first three of the above, as well as causing flea allergy dermatitis (FAD), and are the primary intermediate host of the intestinal cestode *Dipylidium caninum*. Heavy flea infestations on young or weak animals can cause anaemia or even death.

What can be done to manage this insect?

Prevention -Insect Growth Regulators (such as pyriproxyfen) applied to likely breeding sites such as carpets and animal bedding provide varying levels of protection (75-100% larvae killed or prevented from developing for 2-18 months), while insecticides applied likewise provide good short-term protection. Where fleas can develop outside in turf, nematode preparations containing *Steinernema carpocapsae* are available to provide biological control. A range of on-host flea control products are available, either using Insect Growth Regulators or residual insecticides, administered orally, as a spot-on treatment, or by the fitting of the animal with a flea collar. Research is also taking place to develop an anti-flea vaccine, although results have been conflicting.

Mechanical - vacuuming carpets can provide effective flea control by removing 32-90% ova, 15-50% larvae and 95% adults present in the carpet.

Physical - animal self-grooming and combing by humans are effective mechanisms for the removal of adult fleas from their host; adult female fleas die within days of removal from a host once the cycle of feeding and ovipositing had begun.

Chemical - see prevention. Cat fleas are recorded as having developed resistance to at least five categories of insecticide (organophosphates, organochlorines, pyrethroids, pyrethrins, and carbamates).

Argentine ant - *Linepithema humile* Mayr

What are they?

Omnivorous ant

Argentine ants will eat virtually anything, but in the main their diet includes nectar, honeydew, carrion, and other insects. They have a particular liking for sweet things, in common with most other ants.

What do they look like?

Workers are monomorphic, approximately 3 mm long, mid- to dark brown, with relatively large eyes set low on the teardrop-shaped head, a long first antennal segment, and smooth, hairless dorsal surfaces. Queens are similar to workers, but 2-3 times larger; colonies contain several queens simultaneously, and there may be as many as 16.3 queens per thousand workers, so it is not unusual to see queens foraging with workers. They have no sting.

How do they move about?

Argentine ant colonies spread by budding, where small satellite colonies are set up on the periphery of the range with one of the queens from the main colony. A Mediterranean supercolony of Argentine ants has dispersed to cover 6000 kilometres. This species of ant is usually found near water, and can form rafts, particularly during flood events, which disperses the species downstream. Human-mediated dispersal is responsible for the long-range movement, as well as much of the regional dispersal of this species; it can easily be spread with the movement of small propagules, and as peripheral, ephemeral colonies are often established in potted plants, refuse, compost heaps etc, the potential for the dispersal of propagules suitable for establishment is high.

Where do they live?

The Argentine ant is native to the River Paraná watershed in Brazil, and has recently spread, either naturally or anthropogenically, to surrounding areas in Brazil, Argentina, Chile, Columbia, Ecuador, and Peru. Introduced colonies are present on every continent except Antarctica, wherever suitable Mediterranean habitat occurs, including southern Europe, Japan, USA, Australia, and many oceanic islands. Occasionally recorded as an adventive, casual immigrant to the British Isles, there is no record of a colony surviving the British winter.

The species establishes outdoors in areas of Mediterranean climate, with a midwinter mean temperature of 7-14°C, and a midsummer mean of 19-30°C. This species tends to establish in wet habitats; an annual rainfall of around 500 mm is necessary for colonisation and rainfall, especially during the summer, has been found to increase their spread in introduced areas. In colder climates, the species is able to establish in protected environments such as greenhouses or homes, their small size and ephemeral colonisation habits ideally suiting them for living in cavity walls, drop ceilings etc, and raiding kitchens for food.

Why are they considered to be nuisance insects?

The Argentine ant is regarded as more of an ecosystem pest than a human nuisance; however, large numbers in a home can be considered a nuisance, and the species rapidly reaches very high numbers. This species cannot sting but individuals do bite, and foraging parties will disperse into foodstuffs in the kitchen, rendering them inedible.

What can be done to manage this insect?

Prevention – Inception through inspection of imports, particularly of high-risk items such as plants from infested areas, such as eastern Spain. Possible sightings of this species should be reported to the Non-native Species Secretariat (http://www.nonnativespecies.org/) or the Biological Records Centre (www.brc.ac.uk).

Mechanical - minimise access to nesting sites and food through the use of insect-proof containers.

Chemical – many kinds of toxicant, including insecticides and Insect Growth Regulators (such as methoprene) have been trialled however, unless alternative food sources can be removed across the range of the colony, the effect of the toxicant is likely to be too dilute to have any noticeable effect.

House fly - *Musca domestica* Linnaeus

What are they?

Omnivorous opportunist

Larvae feed on decomposing organic matter, particularly cadavers and faeces. Adults have a similar food range to the larvae.

What do they look like?

Eggs are approximately 1 mm long, cylindrical and are laid in small batches. Larvae are white, legless maggots, reaching 12 mm when fully grown and are usually in large numbers where present. Puparia are chestnut-coloured, barrel shaped, approximately 8 mm long and can be located up to 5 km from the larval development sites. The adult fly is dark grey in colour with reddish eyes, four dark stripes on the upperside of the thorax, irregular dark markings on the abdomen, and clear, colourless wings. It is 6-7 mm long, with a 13-15 mm wingspan, and a hairy body. The female is usually slightly larger than the male.

How do they move about?

House flies are highly dispersive in the adult stage, moving up to 32 km. Adults have been translocated by road transport, shipping, and aircraft, and the larvae are frequently transported in refuse at a local scale.

Where do they live?

House flies are thought to have originated from the southern Palaearctic, but are now widespread and naturalised globally. They are a thermally-tolerant species which breeds throughout the winter (surviving at sites with a -5°C thermal minimum and sufficient time above 10°C to allow development). Huge populations can often be found around poultry farms, landfill sites and similar locations.

Why are they considered to be nuisance insects?

House flies are considered a public health threat because of their feeding habits, which include consumption of decaying cadavers and faeces alongside human foodstuffs. The combination of a hairy-bodied species which occurs with humans, coupled with a propensity to feed on, and oviposit in, faeces, makes the house fly an effective mechanical vector for a wide range of pathogens and parasites, especially as it feeds by regurgitation. In addition, the species is relatively large, produces a loud buzzing noise in flight, and frequently aggregates, particularly near breeding sites where huge numbers can build up, often becoming a major domestic nuisance.

What can be done to manage this insect?

Prevention - largely impossible because house flies are widespread and common.

Mechanical - Removal of larval feeding material, such as refuge, may solve local problems and may well reduce populations, but is unlikely to eradicate them to below pest proportions.

Physical - biosecurity barrier methods such as filling gaps and fitting mesh screens will minimise adult incursion, particularly to food preparation areas, and good food hygiene will also minimise the risk.

Chemical - house flies are becoming increasingly resistant to insecticides, but careful use of a range of adulticides or larvicides allows control.

Sewage Filter Fly - *Tinearia alternata* (Say)

What are they?

Swarming non-biting midge.

Huge clouds of sewage filter flies can form over the larval breeding beds, often intermixed with other midge species. Although they do not bite, the sheer numbers can be a nuisance to those in the vicinity.

What do they look like?

Minute (2-3 mm) fly, usually black, with pointed, hairy wings held roofwise over the very hairy body when at rest. The tiny off-white larvae have a distinct head capsule, and look more like a legless water beetle larva than the familiar house fly maggot.

How do they move about?

The sewage filter fly is minute, and has a correspondingly short flight range, although individuals can potentially be blown long distances by the wind. However, this species is only a nuisance when present in large numbers, and wind-mediated accidental dispersal seems unlikely to allow a swarm to remain cohesive enough to present a nuisance at any distance from the origin. Nuisance from this species is therefore usually closely associated with sewage treatment works.

Where do they live?

The species is native to Europe, including the British Isles, and also occurs in the USA and Japan, the Subantarctic Islands, China, Ethiopia, and probably many others. The optimum water temperature for the survival and development of the larvae and pupae is 13-27°C, with complete mortality at 4 and 35°C.

Why are they considered to be nuisance insects?

Generally the sewage filter fly is only a nuisance when present in large numbers. It is strongly attracted to light, and can accumulate in large numbers at windows. It does not appear to act as a vector, although there are occasional reports of myiasis in humans associated with this midge. There are scattered reports of sensitisation to the sewage filter fly causing or exacerbating asthma.

What can be done to manage this insect?

Prevention - only necessary where potential sources are within 1.5 km of houses or industrial premises. Hatching of adult flies should be monitored at likely sources, such as Sewage Treatment Works (STW), and action taken to reduce populations or minimise translocation when population size appears about to cross the threshold into the nuisance category.

Mechanical - mechanical control may be possible for occasional individuals, but it becomes infeasible when outbreaks occur at a statutory nuisance level, due to the sheer numbers involved.

Physical - where sources are known, physical barriers to development and adult dispersal can be utilised. For example, at STW, where the midge develops in filter beds, fine mesh can be used on the filters themselves to prevent adult dispersal.

Chemical - application of larvicides to the filter beds of STWs is generally accepted to decrease the efficiency of sewage processing, and so is to be avoided and consequently chemical control has focussed largely on the larval flies.

Biological – none confirmed although the bacterium *Clostridium bifermentans* has been shown to be a suitable agent for biocontrol of nematocerous flies and preparations of *Bacillus thuringiensis* have proved effective against other closely related species

Appendix 3: List of references used for the review and stored in endnote file (nuisance insects)

Endnote no. Reference

4 Labrie, G. and Lucas E. (2008). Overwintering strategy of multicolored Asian Lady Beetle (Coleoptera: Coccinellidae): Cold-free space as a factor of invasive success. *Annals of the Entomological Society of America* 101(5): 860-866.

69 Ugelvig, L.V., et al. (2008) The introduction history of invasive garden ants in Europe: Integrating genetic, chemical and behavioural approaches. *BMC Biology*: 6.

71 Jumbam, K.R., Jackson, S., Terblanche, J.S., McGeoch, M.A. and Chown, S.L. (2008) Acclimation effects on critical and lethal thermal limits of workers of the Argentine ant, *Linepithema humile*. *Journal of Insect Physiology* 54: 1008-14

76 Maronna, A., Stache, H. and Sticherling, M. (2008) Lepidopterism - oak processionary caterpillar dermatitis: Appearance after indirect out-of-season contact. *Journal Der Deutschen Dermatologischen Gesellschaft* 6: 747-50

91 Hartley, S., Harris, R. and Lester, P.J. (2006) Quantifying uncertainty in the potential distribution of an invasive species: climate and the Argentine ant. *Ecology Letters* 9: 1068-79

102 Goulson, D., Derwent, L.C., Hanley, M.E., Dunn, D.W. and Abolins, S.R. (2005) Predicting calyptrate fly populations from the weather, and probable consequences of climate change. *Journal of Applied Ecology* 42: 795-804

128 Learner, M. A. (2000). Egression of flies from sewage filter-beds. *Water Research* 34(3): 877-889.

144 Lepatourel, G. (1995) Effect of environmental conditions on progeny production by the Oriental cockroach *Blatta orientalis*. *Entomologia Experimentalis Et Applicata* 74: 1-6

350 Rosales, A.L., Krafsur, E.S. and Kim, Y. (1994) Cryobiology of the face fly and house fly (Diptera: Muscidae). *Journal of Medical Entomology* 31 (5): 671-80

372 Rust, M.K., Dryden, M.W. (1997) Biology, ecology, and management of the cat flea. *Annual Review of Entomology* 42: 451-73

399 Alexander, J.B., Newton, J. and Crowe, G.A. (1991) Distribution of Oriental and German cockroaches, *Blatta orientalis* and *Blattella germanica* (Dictyoptera), in the United Kingdom. *Medical and Veterinary Entomology* 5: 395-402

403 Lepatourel, G.N.J. (1993) Cold-tolerance of the Oriental Cockroach *Blatta orientalis*. *Entomologia Experimentalis et Applicata* 68: 257-63

410 Bonnefoy, X., Kampen, H. and Sweeney, K. (2008) Public Health Significance of Urban Pests: World Health Organisation

411 Brenner, B.L., Markowitz, S., Rivera, M., Romero, H., Weeks, M., *et al.* (2003) Integrated pest management in an urban community: A successful partnership for prevention. *Environmental Health Perspectives* 111: 1649-53

415 Baumholtz, M.A., Parish, L.C., Witkowski, J.A., Nutting, W.B. (1997) The medical importance of cockroaches. *International Journal of Dermatology* 36: 90-6

448 Eritja, R., Escosa, R., Lucientes, J., Marques, E., Molina, R., *et al.* (2005) Worldwide invasion of vector mosquitoes: present European distribution and challenges for Spain. *Biological Invasions* 7: 87-97

449 Gratz, N.G. (2004) Critical review of the vector status of *Aedes albopictus*. *Medical and Veterinary Entomology* 18: 215-27

455 Hawley, W.A. (1988) The biology of *Aedes albopictus*. *J Am Mosq Control Assoc Suppl* 1: 1-39

468 Gold, B.L., Mathews, K.P. and Burge, H.A. (1985) Occupational asthma caused by sewer flies. *American Review of Respiratory Disease* 131: 949-52

474 Biever, K.D., Mulla, M.S. (1966) Effects of temperature on the developmental stages of *Psychoda alternata* (Diptera - Psychodidae). *Mosquito News* 26: 416-9

487 Pinniger, D.B., Child, R.E. (1996) Woodworm - a necessary case for treatment? New techniques for the detection and control of Furniture Beetle. *Proceedings of the Second International Conference on Urban Pests*

499 French, J.R.J. (1968) The distribution of the Furniture Beetle, *Anobium punctatum* (De Geer) (Coleoptera: Anobiidae), in New South Wales. *Australian Journal of Entomology* 7: 115-22

506 Silverman, J. and Brightwell, R.J. (2008) The Argentine ant: Challenges in managing an invasive unicolonial pest. *Annual Review of Entomology* 53: 231-52

510 Holway, D. A., L. Lach, et al. (2002) The causes and consequences of ant invasions. *Annual Review of Ecology and Systematics* 33(1): 181-233

512 Mitchell, C.J. (1995) Geographic spread of Aedes albopictus and potential for involvement in arbovirus cycles in the Mediterranean basin. *Journal of Vector Ecology* 20: 44-58

532 Roura-Pascual, N., Suarez, A.V., Gomez, C., Pons, P., Touyama, Y., *et al.* 2004. Geographical potential of Argentine ants (*Linepithema humile* Mayr) in

the face of global climate change. *Proceedings of the Royal Society of London Series B-Biological Sciences* 271: 2527-34
575 Hesler, L.S., Logan, T.M., Benenson, M.W. and Moser, C. (1999) Acute dermatitis from oak processionary caterpillars in a US military community in Germany. *Military Medicine* 164: 767-70
582 Mabbett, T. (2004) Keeping track of cockroach control. *International Pest Control* 46: 189-93
583 Mackie, R.A. (1969) Biology and control of cockroaches in the San Diego city sewer system. *California Vector Views* 16: 57-66
584 Tree Health Division FR. (2008) Survey and intervention in relation to different phases of the oak processionary moth life cycle, Forest Research
585 Evans, H.F. (2007) Pest Risk Analysis record for *Thaumetopoea processionea*, Forest Research
588 Diaz, J.H. (2005) The evolving global epidemiology, syndromic classification, management, and prevention of caterpillar envenoming. *American Journal of Tropical Medicine and Hygiene* 72: 347-57
590 Verkerk, R.H.J. and Bravery, A.F. (2004) A case study from the UK of possible successful eradication of *Reticulitermes grassei*. Final workshop COST Action E22 'Environmental Optimisation of Wood Protection' Lisboa - Portugal, 22nd-23rd March 2004
595 Nunes, L. and Nobre, T. (2001) Strategies of subterranean termite control in buildings. In: Wood Protection 2006, ed. HM Barnes. New Orleans, Louisana, USA: Forest Products Society
596 ISSG, I.S. (2007) Ant Management: Argentine Ant (*Linepithema humile*), IUCN
597 Harris, R.J. (2002) Potential impact of the Argentine Ant (*Linepithema humile*) in New Zealand and options for its control. *Science for Conservation* 196: 36p
598 Laine, L.V., Wright, D.J. (2003) The life cycle of *Reticulitermes* spp. (Isoptera: Rhinotermitidae): what do we know? *Bulletin of Entomological Research* 93: 267-78
599 Majekodunmi, A., Howard, M.T.V.S. (2002) The perceived importance of cockroach (*Blatta orientalis* (L.) and *Blattella germanica* (L.)) infestation to social housing residents. *Journal of Environmental Health Research* 1
601 Menke, S. B., Fisher, R. N. *et al.* (2007) Biotic and abiotic controls of argentine ant invasion success at local and landscape scales. *Ecology* 88(12): 3164-3173
602 Menke, S. B. and D. A. Holway (2006) Abiotic factors control invasion by Argentine ants at the community scale. *Journal of Animal Ecology* 75(2): 368-

376
604 Holway, D. A., Suarez, A. V. *et al.* (2002) Role of abiotic factors in governing susceptibility to invasion: A test with Argentine ants. *Ecology* 83(6): 1610-1619
607 Touyama, Y., Ogata, K. *et al.* (2003). The Argentine ant, *Linepithema humile*, in Japan: Assessment of impact on species diversity of ant communities in urban environments. *Entomological Science* 6(1): 57-62
608 Forschler, B.T. and Henderson, G. (1995) Subterranean termite behavioral reaction to water and survival of inundation: Implications for field populations. *Environmental Entomology* 24: 1592-7
615 Keiding, J. (1976) 7. The House Fly: Biology and Control, WHO.
617 Strong-Gunderson, J. M. and R. A. Leopold (1989) Cryobiology of *Musca domestica*: Supercooling capacity and low-temperature tolerance. *Environmental Entomology* 18(5): 756-62.
619 Watanabe, M. (2002) Cold tolerance and myo-inositol accumulation in overwintering adults of a lady beetle, *Harmonia axyridis* (Coleoptera: Coccinellidae). European Journal of Entomology 99(1): 5-10
620 Koch, R.L., Carrillo, M.A. *et al.* (2004) Cold Hardiness of the Multicolored Asian Lady Beetle (Coleoptera: Coccinellidae). *Environmental Entomology* 33(4): 815-822
717 Turell, M.J., O'Guinn, M. and Oliver, J. (2000) Potential for New York mosquitoes to transmit West Nile virus. *Am J Trop Med Hyg*. 62(3): 413-414
718 Halouzka, P.H. (1998) Isolation of the spirochaete Borrelia afzelii from the mosquito Aedes vexans in the Czech Republic. *Medical and Veterinary Entomology* 12(1): 103-105
719 Burkot, T.R. and DeFollart, G.R. (1982) Bloodmeal Sources of *Aedes Triseriatus* and *Aedes Vexans* in a Southern Wisconsin Forest Endemic for La Crosse Encephalitis Virus. *Am J Trop Med Hyg*. 31(2): 376-381
720 Becker, N. and Ludwig, M. (1993) Investigations on possible resistance in *Aedes vexans* field populations after a 10-year application of *Bacillus thuringiensis israelensis*. *Journal of the American Mosquito Control Association* 9(2): 221-224
721 Molaei, G. and Andreadis, T.G. (2006) Identification of avian- and mammalian-derived bloodmeals in *Aedes vexans* and *Culiseta melanura* (Diptera: Culicidae) and its implication for West Nile Virus transmission in Connecticut, U.S.A. *Journal of Medical Entomology* 43(5): 1088-1093
722 Halouzka, J. *et al.* (1999) Isolation of Borrelia afzelii from Overwintering *Culex pipiens Biotype molestus* Mosquitoes. *Infection* 27(4): 275-277

723 Roiz, D. *et al.* (2007) A survey of mosquitoes breeding in used tires in Spain for the detection of imported potential vector species. *Journal of Vector Ecology* 32(1): 10-15

725 Mikov, O.D. (2008) Determination of the season of possible malaria transmission by Anopheline mosquitoes in South-Western Bulgaria. *Med Parazitol* (Mosk) 2008(1): 31-3

727 Zamburlini, R. (1998) Classification of Anopheles claviger (Diptera, Culicidae) in north-eastern Italy. *Parassitologia* 40(3): 347-51

728 Service, M.W. (1977) Ecological and biological studies on *Aedes cantans* (Meig.) (Diptera: Culicidae) in Southern England. *Journal of Applied Ecology* 14(1): 159-196

729 Zuparko, R. (1983) Biological control of *Eucallipterus tiliae* (Hom.: Aphidae) in San-Jose, California, through establishment of *Trioxys curvicaudus* (Hym.: Aphiidae). *Entomophaga* 28(4): 325-330.

730 Dixon, A.F.G. (1973) Metabolic acclimitization to seasonal changes in temperature in sycamore aphid, *Drepanosiphum platanoides* (Schr), and lime aphid, *Eucallipterus tiliae* L. *Oecologia* 13(3): 205-210

731 Llewellyn, M., (1972) The effects of the lime aphid, *Eucallipterus tiliae* L. (Aphididae) on the growth of the lime *Tilia* x *Vulgaris Hayne*. I. Energy requirements of the aphid population. *Journal of Applied Ecology* 9(1): 261-282

733 Llewellyn, M. (1972) The effects of the lime aphid (*Eucallipterus tiliae* L.) (Aphididae) on the Growth of the Lime (*Tilia* X *Vulgaris* Hayne). II. The primary production of saplings and mature trees, the energy drain imposed by the aphid populations and revised standard deviations of aphid population energy budgets. *Journal of Applied Ecology* 12(1): 15-23

734 Barlow, N.D. (1982) The lime aphid in New Zealand (Hemiptera: Aphididae): a first record. *New Zealand Entomologist* 7(3): 314-5

736 Elkinton, J.S., et al. (2008) Factors influencing larval survival of the invasive browntail moth (Lepidoptera: Lymantriidae) in relict North American populations. *Environmental Entomology* 37(6): 1429-1437

737 Csoka, G. (1995) Increased insect damage in Hungarian forests under drought impact. In: Conference on Insects and Environment. Zvolen, Slovakia: Slovak Academic Press Ltd.

739 Cremer, S. et al., (2008) The evolution of invasiveness in garden ants. *PLoS ONE* 3(12): 1-9

740 Espadaler, X. et al. (2007) Regional trends and preliminary results on the local expansion rate in the invasive garden ant, *Lasius neglectus* (Hymenoptera,

Formicidae). *Insectes Sociaux* 54(3): 293-301
741 Rey, S. and Espadaler, X. (2004) Area-wide management of the invasive garden ant *Lasius neglectus* (Hymenoptera: Formicidae) in Northeast Spain. *Journal of Agricultural and Urban Entomology* 21(2): 99-113.
742 Servigne, P. and Detrain, C. (2008) Ant-seed interactions: combined effects of ant and plant species on seed removal patterns. *Insectes Sociaux* 55(3): 220-230.
743 Kipyatkov, V.E. *et al*. (2004) Effect of temperature on rearing of the first brood by the founder females of the ant *Lasius niger* (Hymenoptera, Formicidae): Latitude-dependent variability of the response norm. *Journal of Evolutionary Biochemistry and Physiology* 40(2): 165-175.
744 Cannon, K.F. and Robinson, W.H. (1982) Notes on the biology and distribution of *Hylotrupes bajulus* (L) (Coleoptera, Cerambycidae) in Virginia. *Entomological News* 93(5): 173-176.
745 Ebeling, W. (1978) Urban Entomology. Division of Agricultural Sciences, University of California. 695.
746 Naucke, T.J. *et al.* (2008) Sandflies and leishmaniasis in Germany. *Parasitol Res* 103 Suppl 1: 65-8.
747 Stohr, S. (1995) Oxygen consumption of the eggs of four non-diapausing blackfly species (Diptera, Simuliidae). *Entomologia Generalis* 20(1-2): 59-72
748 Ward, D., Honan, P. and Lefoe, G. (2002) Colony structure and nest characteristics of European wasps, *Vespula germanica* (F.) (Hymenoptera: Vespidae), in Victoria, Australia. *Australian Journal of Entomology* 41: 306-309
749 Rose, E.A.F., Harris, R.J. and Glare, T.R. (1999) Possible pathogens of social wasps (Hymenoptera : Vespidae) and their potential as biological control agents. *New Zealand Journal of Zoology* 26(3): 179-190
750 Chauvin, G. and Vannier, G. (1997) Supercooling capacity of *Tineola bisselliella* (Hummel) (Lepidoptera: Tineidae): Its implication for disinfestation. *Journal of Stored Products Research* 33(4): 283-287
751 Cox, P.D. and. Pinniger, D.B (2007) Biology, behaviour and environmentally sustainable control of *Tineola bisselliella* (Hummel) (Lepidoptera: Tineidae). *Journal of Stored Products Research* 43(1): 2-32

Appendix 4: Analysis of the Potential for Survival and Seasonal Activity of *Aedes albopictus* (Diptera: Culicidae) in the United Kingdom

J.M. Medlock, D. Avenell, I. Barrass & S. Leach

Health Protection Agency, Centre for Emergency Preparedness & Response, Porton Down, Salisbury, UK

ABSTRACT

The international trade in used tyres, coupled with the ability to lay non-desiccating eggs, has enabled *Aedes albopictus* (Skuse) (Diptera: Culicidae) to travel and establish on new continents, including North, Central, and South America, the Caribbean, Australasia, Africa, and Europe. Concerns have been raised over its potential role in the transmission of arboviruses and *Dirofilaria* nematodes. Following importation into northerly latitudes, photoperiodically induced egg diapause enables establishment of *Ae. albopictus*, and a number of abiotic factors determine the subsequent seasonal activity. The UK imports over 5 million used tyres annually, and this seems the most likely route by which *Ae. albopictus* would be imported. The anthropophilic and container-breeding nature of *Ae. albopictus* could cause an urban human biting nuisance with the potential for involvement in (human and veterinary) disease transmission cycles, which needs to be assessed. This paper addresses the likelihood for importation of *Ae. albopictus* into the UK and assesses, using a Geographic Information Systems (GIS)-based model, the ability for *Ae. albopictus* to establish, and its likely seasonal activity. It also reviews its possible role as a potential disease vector in the UK. The model predicts that abiotic risk factors would permit establishment of *Ae. albopictus* throughout large parts of lowland UK, with at

least four to five months of adult activity (May-September), being more prolonged in the urban centres around London and the southern coastal ports. Pre-emptive surveillance of possible imported *Ae. albopictus*, through a targeted approach, could prevent the establishment of this exotic mosquito and mitigate any subsequent human and animal health implications for the UK, either now or in the future.

Introduction

The asian tiger mosquito, *Aedes albopictus*, has now been reported in 15 European countries following its global transportation through the international trade in used tyre casings and the wet-footed Lucky Bamboo (*Dracaena* sp.). It is now established in large parts of Italy, and small pockets of Mediterranean France and Spain and along the Adriatic coast. Elsewhere it is established in >25 US states and parts of Africa, in addition to its historical endemic regions in Asia. In south-east Asia, the mosquito was historically a tree-hole species. However, the ability to colonise urban and peri-urban areas, where the female lays drought-resistant eggs in water that collects in human-made containers (including discarded tyres), facilitated its establishment elsewhere. The production of non-desiccating eggs coupled with the trade in tyres, led to its global movement and establishment on new continents.

Temperate strains of *Ae. albopictus* are also able to lay eggs that enter winter diapause, facilitating their survival in more northerly latitudes. The aim of this paper is to assess the potential for survival and seasonal activity of the mosquito in the United Kingdom by understanding the impact of known critical thresholds for survival, and by developing models that incorporate seasonal cues related to climate and photoperiod.

Methods

A GIS model was developed to simulate the factors crucial to life cycle of *Ae. albopictus* to identify the areas for potential establishment (incorporating annual rainfall and cold-month isotherms) and numbers of weeks elapsing between first egg hatching in spring, and the production of diapausing eggs in autumn (incorporating weekly temperature and photoperiod).

GIS model development

The model was developed using ESRI ArcGIS, Spatial Analyst and ArcObjects (ESRI, Redlands, CA) and incorporated datasets for photoperiod (generated using astronomical equations of sunrise and sunset) and climate average data for mean monthly temperature (UK Meteorological Office) for the UK on a 1 km resolution. The mean monthly climate data for temperature was converted to mean weekly temperature using a continuous piecewise quadratic function, preserving the mean maximum temperature over each monthly period. The model was also validated using daily temperature data for 1995-2000.

Model outputs

The model calculates firstly the predicted number of weeks elapsing between the first hatching of overwintered eggs in spring and the production of diapausing eggs in response to a critical photoperiod in late summer. Secondly, it calculates the predicted number of weeks elapsing between first egg hatching and possible adult die-off in early winter.

Entomological rationale

Unlike tropical strains, only temperate strains of *Ae. albopictus* overwinter as eggs; an evolved feature that has facilitated their spread to more northerly latitudes. During the shortening daylight hours in late summer/early autumn the reducing photoperiod stimulate the females to produce eggs that enter facultative diapause (Estrada-Franco and Craig, 1995). These eggs, able to resist hatching stimuli until the following spring, remain in a state of reduced morphogenesis as fully formed 1st instar larvae, exhibiting increased resistance to environmental extremes. Although the diapause is expressed in the egg stage, it is the adults and pupae that are the photoperiodically sensitive stages (Wang, 1966, Imai and Maeda, 1976, Mori and Wada, 1981). As the onset of diapause in autumn and egg hatching in spring are dictated by environmental variables of climate and photoperiod, a model can be developed that predicts the number of weeks of activity of *Aedes albopictus*. This can then be used to determine whether (a) the mosquito would be active long enough to establish in a new location and (b) where there might be prolonged activity, thereby acting as a surrogate for mosquito abundance.

Input parameters

Autumn diapause

The actual timing of the onset of diapause in newly produced eggs appears to be correlated with specific critical photoperiod thresholds. Given the mosquito's ability to evolve and adapt to their surroundings, the actual threshold photoperiod appears to vary geographically. A critical daylight threshold of 13-14h has been reported in strains of *Ae. albopictus* from Shanghai and Nagasaki (Mori and Wada, 1981, Wang, 1966), North America (Pumpuni et al., 1992) and Italy (Toma et al., 2003). In other studies in Nagasaki, a critical photoperiod of 11-12h has been reported (Kobayashi et al., 2002). Indeed in Italy some eggs continued to hatch until a daylength of 10 hours (Toma et al., 2003). For the purpose of this model the more common critical photoperiod of 13.5hrs of daylight has been incorporated.

Overwintering criteria

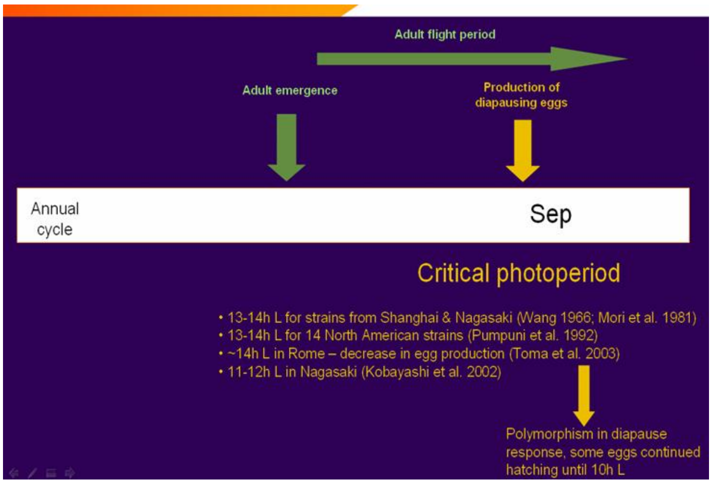
It is generally accepted that a winter isotherm of between -3 and 0^{o}C is a limiting factor for establishment (Nawrocki and Hawley, 1987, Mitchell, 1995, Kobayashi *et al.*, 2002).

Spring egg hatching

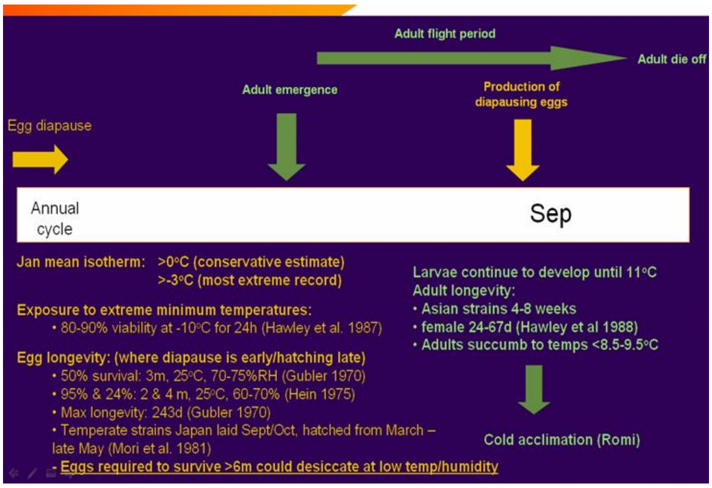
In Rome, studies by (Toma et al., 2003) reported adult *Ae. albopictus* were reported to be active from late March, and based on a three-week development time (at 14-18^{o}C) from egg hatch to pupation (Galliard and Golvan, 1957, Udaka, 1959, Hawley, 1988), it was assumed that the first overwintering eggs hatched when daylight reached 11-11.5hrs of daylight and the mean temperature of 10-11^{o}C (Toma et al., 2003).

Summary of model and input parameters

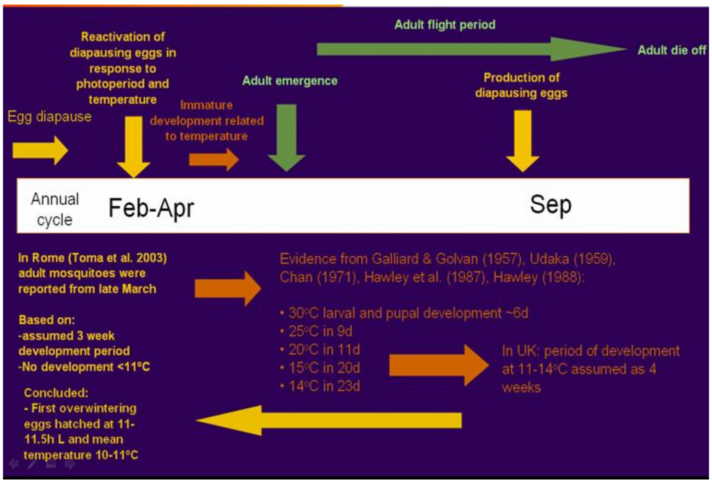
Critical photoperiod initiating autumn production of diapausing eggs



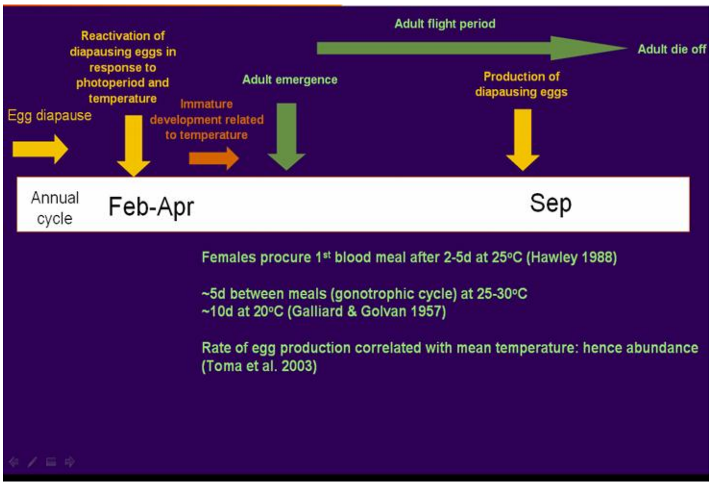
Parameters stimulating re-activation of eggs in spring, and adult die-off in autumn



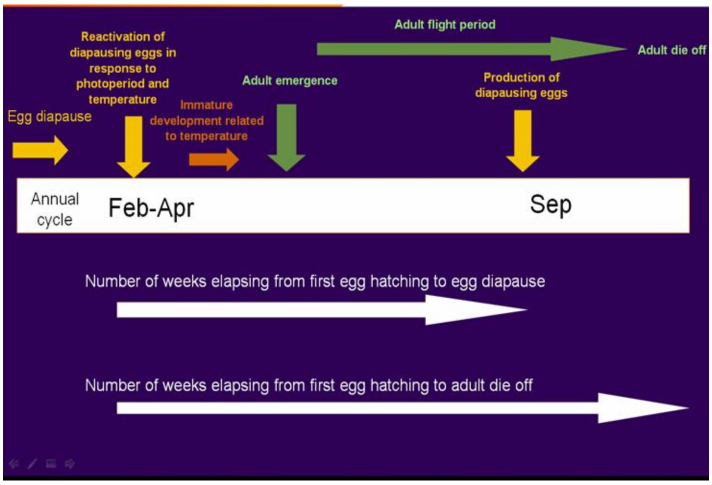
Development of immature stages through to first adult generation



Parameters affecting gonotrophic cycle



Key outputs of model



Scenarios tested

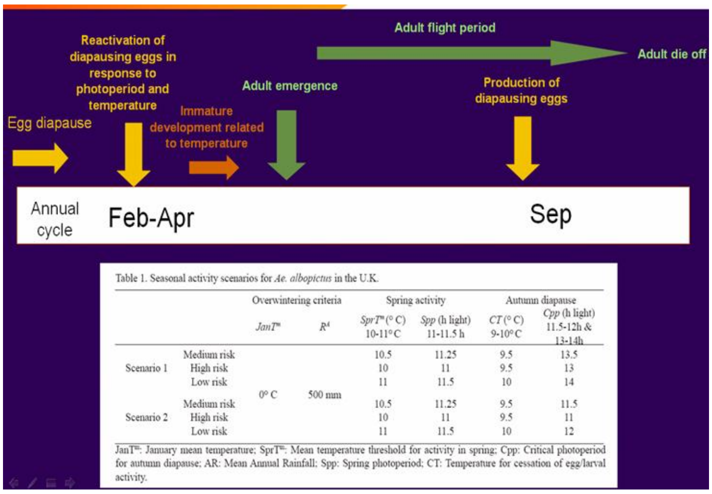


Table 1. Seasonal activity scenarios for *Ae. albopictus* in the U.K.

		Overwintering criteria		Spring activity		Autumn diapause	
		JanT^{m}	*R*^{A}	*SprT*^{m} (° C) 10-11° C	*Spp* (h light) 11-11.5 h	*CT* (° C) 9-10° C	*Cpp* (h light) 11.5-12h & 13-14h
Scenario 1	Medium risk	0° C	500 mm	10.5	11.25	9.5	13.5
	High risk			10	11	9.5	13
	Low risk			11	11.5	10	14
Scenario 2	Medium risk			10.5	11.25	9.5	11.5
	High risk			10	11	9.5	11
	Low risk			11	11.5	10	12

JanT^{m}: January mean temperature; SprT^{m}: Mean temperature threshold for activity in spring; Cpp: Critical photoperiod for autumn diapause; AR: Mean Annual Rainfall; Spp: Spring photoperiod; CT: Temperature for cessation of egg/larval activity.

Results & Discussion

Models developed were based on the following input variables (based on studies elsewhere):

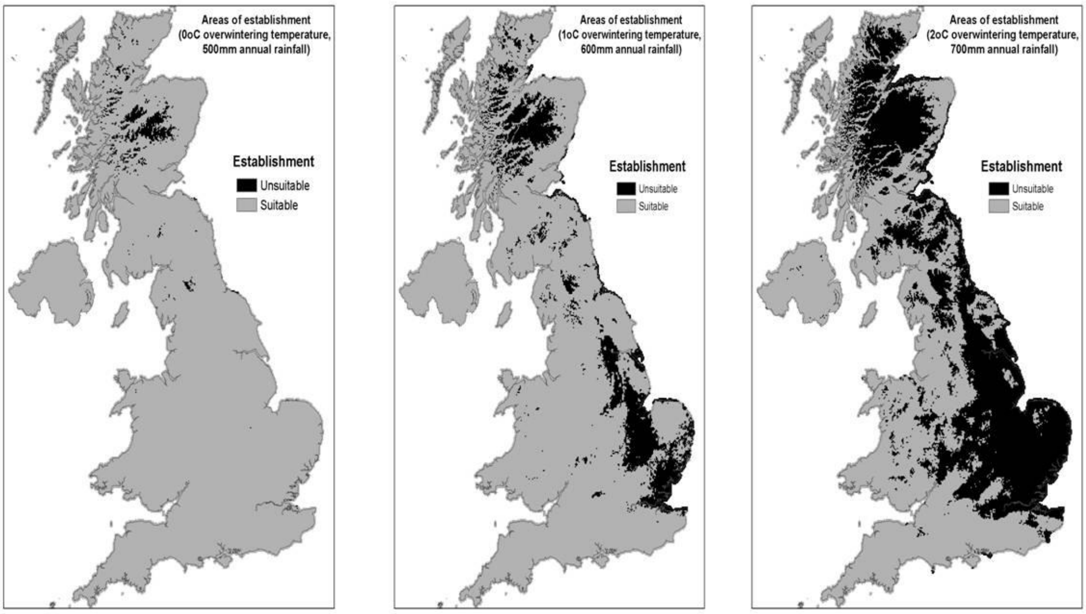
Table 1. Seasonal activity scenarios for *Ae. albopictus* in the U.K.

		Overwintering criteria		Spring activity		Autumn diapause	
		JanT^m	*R*^{A}	*SprT*^{m} (° C) 10-11° C	*Spp* (h light) 11-11.5 h	*CT* (° C) 9-10° C	*Cpp* (h light) 11.5-12h & 13-14h
Scenario 1	Medium risk	0° C	500 mm	10.5	11.25	9.5	13.5
	High risk			10	11	9.5	13
	Low risk			11	11.5	10	14
Scenario 2	Medium risk			10.5	11.25	9.5	11.5
	High risk			10	11	9.5	11
	Low risk			11	11.5	10	12

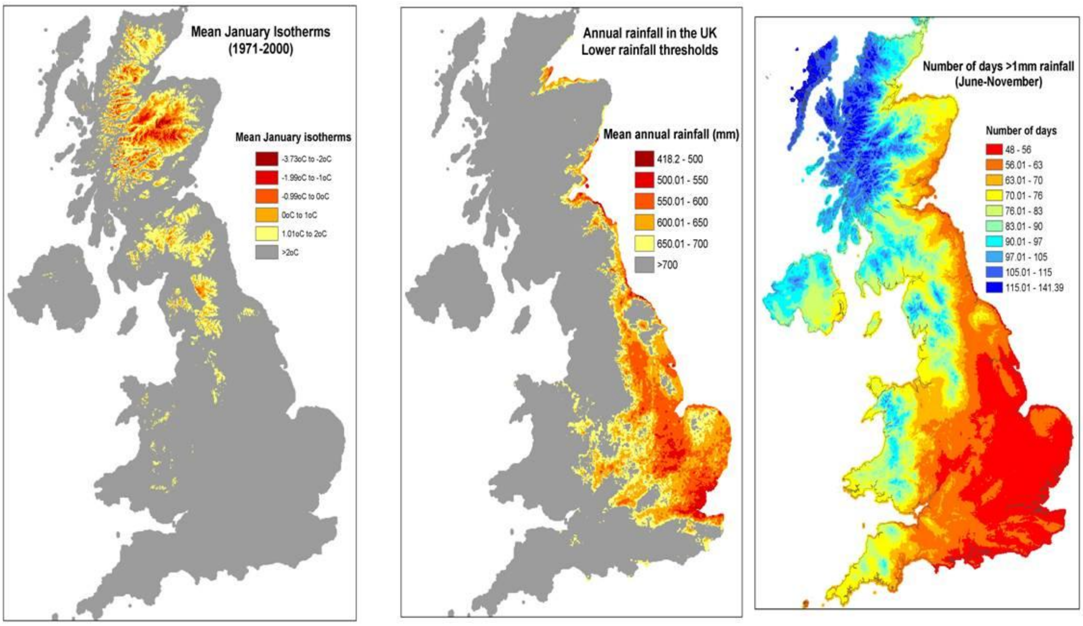
JanT^m: January mean temperature; SprT^m: Mean temperature threshold for activity in spring; Cpp: Critical photoperiod for autumn diapause; AR: Mean Annual Rainfall; Spp: Spring photoperiod; CT: Temperature for cessation of egg/larval activity.

Area for establishment

Establishment scenarios investigated the impact of annual rainfall and January isotherm at 0^{o}C, 500mm (A), 1^{o}C, 600mm (B), 2^{o}C, 700mm (C). Even with conservative thresholds (C) these criteria would not limit the establishment of *Ae. albopictus* across much of eastern UK. Raw data illustrate areas where establishment might be restricted in years with cold winters (D) and dry summers (E). However, these restrictions are limited, and with frequent summer rainfall (F), none of these criteria are significantly limiting.



Figures: (A) 0^{o}C, 500mm; (B) 1^{o}C, 600mm; (C) 2^{o}C, 700mm;

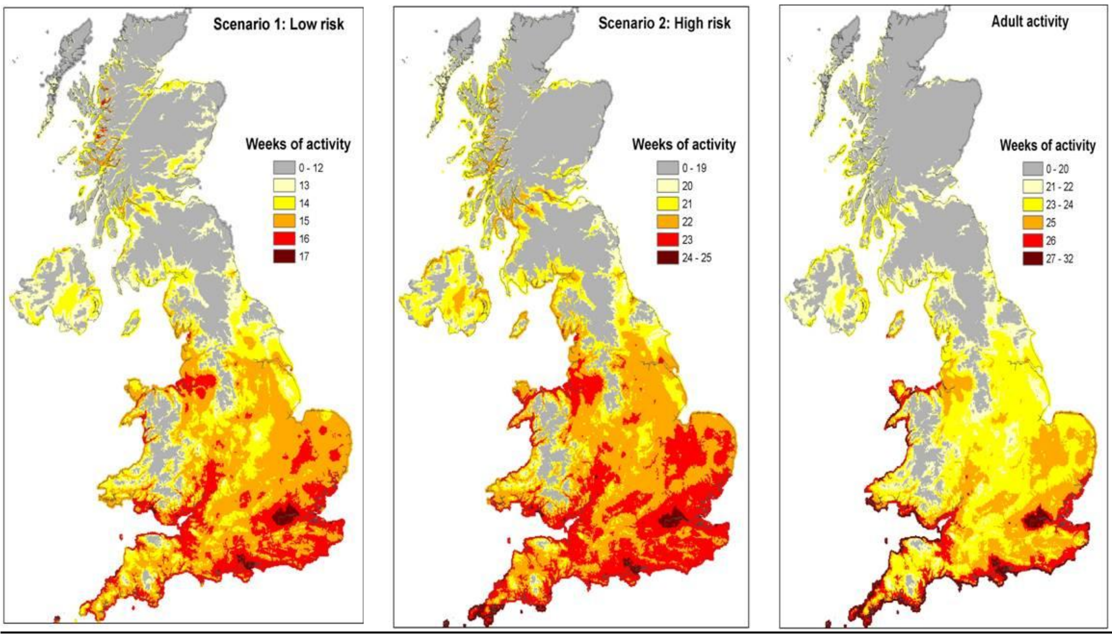


Figures (D) Mean Jan temp; (E) Annual rainfall; (F) No. days >1mm rain

Predicted seasonal activity

Spring egg hatching in Italy occurs with weekly temperatures of 10-11^{o}C and photoperiod of 11-11.5 hours of daylight. Immature development assumed to take 4 weeks (see methods) at 11-14^{o}C. Production of diapausing eggs in autumn related to critical photoperiod of 13-14hrs daylight in Italy, USA, China, and 11-12hrs in Japan. All scenarios were tested.

For scenario 1 (medium risk), 16 weeks would be expected to elapse between egg hatching of overwintering eggs in spring (weeks 17-19: April/May) and the production of diapausing eggs in autumn (wks 36-37: September). More prolonged activity would occur throughout SE England, Severn and Mersey basins, with 18 weeks in London and south coast ports.



For scenario 2, this period would extend to 20-22 weeks. Assuming adult mosquitoes succumb to winter temperatures $<9.5^{o}$C, biting adults could be on the wing for up to 5-6 months. Given the recent outbreak of chikungunya virus in Italy, and the vector competence of *Ae. albopictus* for dengue, *Dirofilaria* and many other arboviruses, the UK must be vigilant to ensure that the UK is not added to the list of infested regions. Targeted surveillance should be in place in prolonged activity zones, with particular attention at ports and neighbouring urban areas.

Appendix 5: List of all insects identified through the preliminary stages of this project as having the potential to cause nuisance. The species included in the main body of the report are a subset of this list and represent species identified as representing statutory nuisance or significant non-statutory nuisance.

Scientific name	Common Name		Taxonomy	Severity (potential)	Nuisance Impact
Blatta orientalis	Oriental cockroach		Blattodea: Blattellidae	Intermediate	Vector, causes allergies
Blattella germanica	German cockroach		Blattodea: Blattellidae	Intermediate	Vector, causes allergies
Periplaneta americana	American cockroach		Blattodea: Blattidae	Intermediate	Disease vector
Periplaneta australasiae	Australian cockroach		Blattodea: Blattidae	Intermediate	Disease vector
Supella longipalpa	Brown-banded cockroach		Blattodea: Blattidae	Intermediate	Disease vector
Supella supellectilium	Brown-banded cockroach		Blattodea: Blattidae	Intermediate	Vector, causes allergies
Anobium punctatum	Woodworm		Coleoptera: Anobiidae	Minor	Destroying household wood
Lasioderma serricorne	Cigarette beetle		Coleoptera: Anobiidae	Minor	Spoils carbohydrate-rich stores
Stegobium paniceum	Biscuit beetle		Coleoptera: Anobiidae	Minor	Spoils carbohydrate-rich stores
Xestobium rufovillosum	Deathwatch beetle		Coleoptera: Anobiidae	Minor	Destroys structural timbers
Lyctus brunneus	Powderpost beetle		Coleoptera: Bostrichidae	Minor	Destroys structural timbers
Harmonia axyridis	Harlequin ladybird		Coleoptera: Coccinellidae	Minor	Aggregate indoors over winter in huge numbers, fo
Curculionidae spp.	Weevils		Coleoptera: Curculionidae	Minor	Spoils carbohydrate-rich stores
Euophryum confine	New Zealand wood weevil		Coleoptera: Curculionidae	Minor	Destroys structural timbers
Euophryum rufum	Wood-boring weevil		Coleoptera: Curculionidae	Minor	Destroys structural timbers
Otiorhynchus armadillo	Vine weevil		Coleoptera: Curculionidae	Intermediate	Kills garden ornamentals
Otiorhynchus aurifer	Vine weevil		Coleoptera: Curculionidae	Minor	Kills garden ornamentals
Otiorhynchus coecus	Vine weevil		Coleoptera: Curculionidae	Minor	Kills garden ornamentals
Otiorhynchus salicicola	Vine weevil		Coleoptera:	Minor	Kills garden ornamentals

			Curculionidae		
Pentarthrum huttoni	Wood boring weevil		Coleoptera: Curculionidae	Minor	Destroys structural timbers
Sitophilus granarius	Grain weevil		Coleoptera: Curculionidae	Minor	Spoils carbohydrate-rich stores
Sitophilus oryzae	Rice weevil		Coleoptera: Curculionidae	Minor	Spoils carbohydrate-rich stores
Anthrenus verbasci	Varied Carpet Beetle		Coleoptera: Dermestidae	Minor	Destroys carpets
Attagenus pelio	Fur beetle		Coleoptera: Dermestidae	Minor	Destroys fabrics
Attagenus unicolor	Black carpet beetle		Coleoptera: Dermestidae	Minor	Destroys carpets
Dermestes haemorrhoidalis	Black larder beetle		Coleoptera: Dermestidae	Minor	Spoils carbohydrate-rich stores
Dermestes lardarius	Larder beetle		Coleoptera: Dermestidae	Minor	Spoils carbohydrate-rich stores
Dermestes maculatus	Leather beetle		Coleoptera: Dermestidae	Minor	Destroys fabrics
Trogoderma granarium	Khapra beetle		Coleoptera: Dermestidae	Minor	Spoils carbohydrate-rich stores
Cryptolestes ferrugineus	Rusty grain beetle		Coleoptera: Laemophloeidae	Minor	Spoils carbohydrate-rich stores
Lathiiridae spp.	Fungus beetles		Coleoptera: Lathiiridae	Minor	Annoyance when numerous
Thes bergrothi	Fungus beetle		Coleoptera: Latridiidae	Minor	Annoyance when numerous (on damp plaster)
Niptus hololeucus	Golden spider beetle		Coleoptera: Ptininae	Minor	Spoils carbohydrate-rich stores
Ptinidae spp.	Spider beetles		Coleoptera: Ptininae	Minor	Spoils carbohydrate-rich stores
Ptinus tectus	Australian spider beetle		Coleoptera: Ptininae	Minor	Spoils carbohydrate-rich stores
Sphaericus gibboides	A spider beetle		Coleoptera: Ptininae	Minor	Spoils carbohydrate-rich stores
Trigonogenius globulus	Globular spider beetle		Coleoptera: Ptininae	Minor	Spoils carbohydrate-rich stores
Oryzaephilus mercator	Merchant grain beetle		Coleoptera: Silvanidae	Minor	Spoils carbohydrate-rich stores
Oryzaephilus surinamensis	Saw-toothed grain beetle		Coleoptera: Silvanidae	Minor	Spoils carbohydrate-rich stores
Oligota parva	Rove beetle		Coleoptera: Staphylinidae	Minor	Spoils carbohydrate-rich stores
Gnathocerus cornutus	Broad-horned flour beetle		Coleoptera: Tenebrionidae	Minor	Spoils carbohydrate-rich stores
Tenebrio molitor	Yellow mealworm beetle		Coleoptera: Tenebrionidae	Minor	Spoils carbohydrate-rich stores
Tribolium castaneum	Rust red flour beetle		Coleoptera:	Minor	Spoils carbohydrate-rich stores

			Tenebrionidae		
Tribolium confusum	Confused flour beetle		Coleoptera: Tenebrionidae	Minor	Spoils carbohydrate-rich stores
Hylotrupes bajulus	House longhorn		Coleptera: Cerambycidae	minor	Destroys structural timbers
Blithopertha orientalis	Oriental beetle		Coleptera: Scarabaeidae	Minor	Eats grass roots
Liriomyza huidobrensis	South American leaf miner		Diptera: Agromyzidae	Minor	Disfigures ornamentals
Liriomyza sativae	Vegetable leaf miner		Diptera: Agromyzidae	Minor	Disfigures ornamentals, vector
Liriomyza trifolii	Chrysanthemum leaf miner		Diptera: Agromyzidae	Minor	Disfigures ornamentals, vector
Nemorimyza (Amauromyza) maculosa	Chrysanthemum leaf miner		Diptera: Agromyzidae	Minor	Disfigures ornamentals
Calliphora vomitoria	Bluebottle		Diptera: Calliphora	Minor	Vector, annoyance wne numerous
Pollenia rudis	Cluster fly		Diptera: Calliphora	Minor	Annoyance when numerous
Musca domestica	House fly		Diptera: Calliphoridae	Minor	Vector
Culicoides imicola	Midge		Diptera: Ceratopogonidae	Intermediate	Bites, vector
Culicoides impunctatus	Highland midge		Diptera: Ceratopogonidae	Minor	Bites
Culicoides obsoletus	Midge		Diptera: Ceratopogonidae	Intermediate	Bites, vector
Culicoides pulicaris	Midge		Diptera: Ceratopogonidae	Intermediate	Bites, vector
Aedes albopictus	Asian tiger mosquito		Diptera: Culicidae	Major	Bites, potential vector
Aedes cinereus	Mosquito		Diptera: Culicidae	Major	Bites, potential vector
Aedes vexans	Floodwater mosquito		Diptera: Culicidae	Minor	Bites, potential vector
Anopheles claviger	Mosquito		Diptera: Culicidae	Minor	Bites, potential vector
Anopheles plumbeus	Mosquito		Diptera: Culicidae	Major	Bites, potential vector
Coquillettidia richiardii	Mosquito		Diptera: Culicidae	Major	Bites, potential vector
Culex pipiens molestus	Mosquito		Diptera: Culicidae	Major	Bites, potential vector
Culiseta annulata	Mosquito		Diptera: Culicidae	Minor	Bites, potential vector
Culiseta litorea	Mosquito		Diptera: Culicidae	Major	Bites, vector
Ochlerotatus annulipes	Mosquito		Diptera: Culicidae	Major	Bites, potential vector
Ochlerotatus atropalpus	Mosquito		Diptera: Culicidae	Major	Bites, vector

Ochlerotatus cantans	Mosquito		Diptera: Culicidae	Major	Bites, potential vector
Ochlerotatus caspius	Mosquito		Diptera: Culicidae	Major	Bites, potential vector
Ochlerotatus detritus	Mosquito		Diptera: Culicidae	Major	Bites, potential vector
Ochlerotatus japonicus	Mosquito		Diptera: Culicidae	Major	Bites, potential vector
Ochlerotatus punctor	Mosquito		Diptera: Culicidae	Major	Bites, potential vector
Ochlerotatus triseriatus	Mosquito		Diptera: Culicidae	Major	Bites, vector
Drosophila acuminata	Fruit fly		Diptera: Drosophila	Minor	Annoyance when numerous
Drosophila ananassae	Fruit fly		Diptera: Drosophila	Minor	Annoyance when numerous
Drosophila andalusiaca	Fruit fly		Diptera: Drosophila	Minor	Annoyance when numerous
Drosophila busckii	Fruit fly		Diptera: Drosophila	Minor	Annoyance when numerous
Drosophila cameraria	Fruit fly		Diptera: Drosophila	Minor	Annoyance when numerous
Drosophila confusa	Fruit fly		Diptera: Drosophila	Minor	Annoyance when numerous
Drosophila fenestrarum	Fruit fly		Diptera: Drosophila	Minor	Annoyance when numerous
Drosophila funebris	Fruit fly		Diptera: Drosophila	Minor	Annoyance when numerous
Drosophila helvetica	Fruit fly		Diptera: Drosophila	Minor	Annoyance when numerous
Drosophila histrio	Fruit fly		Diptera: Drosophila	Minor	Annoyance when numerous
Drosophila hydei	Fruit fly		Diptera: Drosophila	Minor	Annoyance when numerous
Drosophila immigrans	Fruit fly		Diptera: Drosophila	Minor	Annoyance when numerous
Drosophila kuntzei	Fruit fly		Diptera: Drosophila	Minor	Annoyance when numerous
Drosophila limbata	Fruit fly		Diptera: Drosophila	Minor	Annoyance when numerous
Drosophila littoralis	Fruit fly		Diptera: Drosophila	Minor	Annoyance when numerous
Drosophila melanogaster	Fruit fly		Diptera: Drosophila	Minor	Annoyance when numerous
Drosophila obscura	Fruit fly		Diptera: Drosophila	Minor	Annoyance when numerous
Drosophila phalerata	Fruit fly		Diptera: Drosophila	Minor	Annoyance when numerous
Drosophila picta	Fruit fly		Diptera: Drosophila	Minor	Annoyance when numerous
Drosophila repleta	Fruit fly		Diptera: Drosophila	Minor	Annoyance when numerous
Drosophila rufifrons	Fruit fly		Diptera: Drosophila	Minor	Annoyance when numerous
Drosophila simulans	Fruit fly		Diptera: Drosophila	Minor	Annoyance when numerous
Drosophila spp.	Fruit fly		Diptera: Drosophila	Minor	Annoyance when numerous

Drosophila subobscura	Fruit fly		Diptera: Drosophila	Minor	Annoyance when numerous
Drosophila subsilvestris	Fruit fly		Diptera: Drosophila	Minor	Annoyance when numerous
Drosophila transversa	Fruit fly		Diptera: Drosophila	Minor	Annoyance when numerous
Drosophila tristis	Fruit fly		Diptera: Drosophila	Minor	Annoyance when numerous
Fannia canicularis	Lesser house fly		Diptera: Fanniidae	Minor	Vector
Psychoda albipennis	Sewage filter fly		Diptera: Nematocera	Minor	Annoyance when abundant
Phlebotomus ariasi	Sandfly		Diptera: Phlebotomidae	Intermediate	Vector of Leishmania infantum, causes Leishmania
Phlebotomus mascittii	Sandfly		Diptera: Phlebotomidae	Intermediate	Vector of Leishmania infantum, causes Leishmania
Phlebotomus neglectus	Sandfly		Diptera: Phlebotomidae	Intermediate	Vector of Leishmania infantum, causes Leishmania
Phlebotomus perfiliewi	Sandfly		Diptera: Phlebotomidae	Intermediate	Vector of Leishmania infantum, causes Leishmania
Phlebotomus perniciosus	Sandfly		Diptera: Phlebotomidae	Intermediate	Vector of Leishmania infantum, causes Leishmania
Phlebotomus tobbi	Sandfly		Diptera: Phlebotomidae	Intermediate	Vector of Leishmania infantum, causes Leishmania
Piophila casei	Cheese skipper		Diptera: Piophilidae	Minor	Develops in cheese
Tinearia alternata	Moth fly		Diptera: Psychodidae	Minor	Annoyance when numerous
Simulium equinum	Black fly		Diptera: Simuliidae	Intermediate	Bites
Simulium posticatum	Blandford fly		Diptera: Simuliidae	Intermediate	Bites
Eumerus tuberculatus	Lesser bulb fly		Diptera: Syrphidae	Minor	Kills garden ornamentals
Merodon equestris	Greater bulb fly		Diptera: Syrphidae	Minor	Disfigures ornamentals
Chrysops caecutiens	Horsefly		Diptera: Tabanidae	Minor	Bites
Chrysops relictus	Horsefly		Diptera: Tabanidae	Minor	Bites
Chrysops sepulcralis	Horsefly		Diptera: Tabanidae	Minor	Bites
Chrysops viduatus	Horsefly		Diptera: Tabanidae	Minor	Bites
Haematopota crassicornis	Horsefly		Diptera: Tabanidae	Minor	Bites
Haematopota pluvialis	Horsefly		Diptera: Tabanidae	Minor	Bites
Hybomitra bimaculata	Horsefly		Diptera: Tabanidae	Minor	Bites
Hybomitra distinguenda	Horsefly		Diptera: Tabanidae	Minor	Bites
Hybomitra expollicata	Horsefly		Diptera: Tabanidae	Minor	Bites
Hybomitra montana	Horsefly		Diptera: Tabanidae	Minor	Bites
Hybomitra solstitialis	Horsefly		Diptera: Tabanidae	Minor	Bites

Tabanidae spp.	Horseflies & clegs		Diptera: Tabanidae	Minor	Bites
Tabanus autumnalis	Horsefly		Diptera: Tabanidae	Minor	Bites
Tabanus bovinus	Horsefly		Diptera: Tabanidae	Minor	Bites
Tabanus bromius	Horsefly		Diptera: Tabanidae	Minor	Bites
Tabanus glaucopis	Horsefly		Diptera: Tabanidae	Minor	Bites
Tabanus maculicornis	Horsefly		Diptera: Tabanidae	Minor	Bites
Tabanus miki	Horsefly		Diptera: Tabanidae	Minor	Bites
Cimex lectularius	Bed-bug		Hemiptera: Cimicidae	Minor	Vector, bites
Eulecanium excrescens	Wisteria scale		Hemiptera: Coccoidea	Minor	Kills garden ornamentals
Pseudaulacaspis pentagona	White peach scale		Hemiptera: Diaspididae	Intermediate	Kills long-lived garden species
Pulvinaria regalis	Horse chestnut scale		Hemiptera: Homoptera: Coccoidea	Minor	Disfigures ornamental trees
Eucallipterus tiliae	Lime aphid		Homoptera: Aphididae	Minor	Drips honeydew onto paintwork
Lasius neglectus	Invasive garden ant		Hymenoptera: Formicidae	minor	Swarms, potentially inside
Lasius niger	Black garden ant		Hymenoptera: Formicidae	Very minor	Enters houses, annoyance when swarming
Linepithema humile	Argentine ant		Hymenoptera: Formicidae	Intermediate	Invades houses & gardens, aggressive, can vector
Monomorium pharaonis	Pharaoh ant		Hymenoptera: Formicidae	Minor	Infest houses, vector
Solenopsis invicta	Red imported fire ant		Hymenoptera: Formicidae	Intermediate	Stings
Dolichovespula media	Wasp		Hymenoptera: Vespidae	minor	Stings
Dolichovespula norvegica	Norwegian wasp		Hymenoptera: Vespidae	Minor	Stings
Vespa crabro	Hornet		Hymenoptera: Vespidae	Very minor	Stings
Vespula germanica	German wasp		Hymenoptera: Vespidae	Minor	Stings
Vespula vulgaris	Common wasp		Hymenoptera: Vespidae	Minor	Stings
Reticulitermes grassei	Mediterranean termite		Isoptera: Rhinotermitidae	Intermediate	Destroys structural timbers
Reticulitermes santonensis	Saintonge termite		Isoptera: Rhinotermitidae	Intermediate	Destroys structural timbers
Blastobasis decolorella	Straw-coloured apple moth		Lepidoptera: Gelechioidea	Minor	Eats stored fruits

Cameraria ohridella	Horse chestnut leaf miner		Lepidoptera: Gracillariidae	Minor	Leaf browning / early fall
Phyllonorycter platani	Leaf miner		Lepidoptera: Gracillariidae	Minor	Disfigures ornamental trees
Cacyreus marshalli	Geranium bronze		Lepidoptera: Lycaenidae	Minor	Eats common garden flowers
Euproctis chrysorrhoea	Brown tail Moth		Lepidoptera: Lymantriidae	Minor	Larval hairs cause extreme irritation
Orgyia pseudotsugata	Douglas-fir tussock moth		Lepidoptera: Lymantriidae	Intermediate	Respiratory problems
Ectoedemia heringella	Leaf-miner on Holm Oak		Lepidoptera: Nepticulidae	Minor	Leaf browning / early fall
Endrosis sarcitrella	White-shouldered house moth		Lepidoptera: Oecophoridea	Minor	Destroys fabrics
Hofmannophila pseudospretella	Brown house moth		Lepidoptera: Oecophoridea	Minor	Destroys fabrics
Ephestia elutella	Cacao moth		Lepidoptera: Pyralidae	Minor	Spoils carbohydrate-rich stores
Ephestia kuehniella	Mediterranean flour moth		Lepidoptera: Pyralidae	Minor	Spoils carbohydrate-rich stores
Galleria mellonella	Wax moth		Lepidoptera: Pyralidae	Minor	Harms beehives
Plodia interpunctella	Indian meal moth		Lepidoptera: Pyralidae	Minor	Spoils carbohydrate-rich stores
Pyralis farinalis	Meal moth		Lepidoptera: Pyralidae	Minor	Spoils carbohydrate-rich stores
Thaumetopoea pityocampa	Pine processionary moth		Lepidoptera: Thaumetopoeidae	Intermediate	Caterpillars defoliate trees, hairs cause dermatitis & problems
Thaumetopoea processionea	Oak processionary moth		Lepidoptera: Thaumetopoeidae	Intermediate	Caterpillars defoliate trees, hairs cause dermatitis & problems
Tinea pallescentella	Large pale clothes moth		Lepidoptera: Tineidae	Minor	Destroys fabrics
Tinea pellionella	Case-bearing clothes moth		Lepidoptera: Tineidae	minor	Larvae feed on fabrics
Tineola bisselliella	Common clothes moth		Lepidoptera: Tineidae	Minor	Destroys fabrics
Trichophaga tapetzella	Tapestry moth		Lepidoptera: Tineidae	minor	Larvae feed on fabrics
Acheta domesticus	House cricket		Orthoptera: Gryllidae	Minor	Noise
Pediculus humanus capitis	Head louse		Phthiraptera: Pediculidae	Intermediate	Bite
Pediculus humanus humanus	Body louse		Phthiraptera: Pediculidae	Minor	Bite
Pthirus pubis	Crab louse		Phthiraptera: Pediculidae	Intermediate	Bites
Liposcelididae spp.	Booklice		Psocoptera: Liposcelididae	Minor	Eat bookbindings & similar

Liposcelis bostrychophila	Booklice		Psocoptera: Liposcelididae	Minor	Spoils carbohydrate-rich stores
Lepinotus patruelis	Booklice		Psocoptera: Trogiidae	Minor	Spoils carbohydrate-rich stores
Ctenocephalides canis	Dog flea		Siphonaptera: Pulicidae	Minor	Bites
Ctenocephalides felis	Cat flea		Siphonaptera: Pulicidae	Minor	Bites
Frankliniella occidentalis	Western flower thrips		Thysanoptera: Thripidae	Intermediate	Ruins appearance of garden ornamentals
Lepisma saccharina	Silverfish		Thysanura: Lepismatidae	Minor	Eats carbohydrate-rich stores
Thermobia domestica	Firebrat		Thysanura: Lepismatidae	Minor	Eats carbohydrate-rich stores

References:

Asher, J., Warren, M., Fox, R., Harding, P., Jeffcoate, G. & Jeffcoate, S. (2001) ***The millennium atlas of butterflies in Britain and Ireland.*** **Oxford University Press, Oxford.**

Ayres, M.P. & Lombardero, M.J. (2000) Assessing the consequences of global change for forest disturbance from herbivores and pathogens. ***The Science of the Total Environment,*** **262, 263-286.**

Bonnefoy, X., Kampen, H. & Sweeney, K. (2008) Public Health Significance of Urban Pests. World Health Organisation, Europe.

Brenner, B.L., Markowitz, S., Rivera, M., Romero, H., Weeks, M., Sanchez, E., Deych, E., Garg, A., Godbold, J., Wolff, M.S., Landrigan, P.J. & Berkowitz, G. (2003) Integrated pest management in an urban community: A successful partnership for prevention. ***Environmental Health Perspectives,*** **111, 1649-1653.**

Estrada-Franco, J.G. & Craig, G.B. (1995) Biology, disease relationships, and control of ***Aedes albopictus*** **Pan American Health O rganisation Technical Paper. pp. 42-49. Washington, D.C.**

Galliard, H. & Golvan, Y.J. (1957) Influences de certains facteurs nutritionels et hormonaux, à des températures variables, sur la croissance des larves d'***Aedes (S.) aegypti*****,** ***Aedes (S.) albopictus et Anopheles stephensi*****.** ***Ann. Parasitol. Hum. Comp,*** **32, 563-579.**

Goulson, D., Derwent, L.C., Hanley, M.E., Dunn, D.W. & Abolins, S.R. (2005) Predicting calyptrate fly populations from the weather, and probable consequences of climate change. ***Journal of Applied Ecology,*** **42, 795-804.**

Hawley, W.A. (1988) The biology of ***Aedes albopictus*****.** ***J Am Mosq Control Assoc Suppl,*** **1, 1-39.**

Hickling, R., Roy, D.B., Hill, J.K., Fox, R. & Thomas, C.D. (2006) The distributions of a wide range of taxonomic groups are expanding polewards. ***Global Change Biology*** **12, 450-455.**

Hill, M., Baker, R., Broad, G., Chandler, P.J., Copp, G.H., Ellis, J., Jones, D., Hoyland, C., Laing, I., Longshaw, M., Moore, N., Parrott, D., Pearman, D., Preston, C., Smith, R.M. & Waters, R. (2005) Audit of non-native species in England. Research Report No. 662. English Nature, Peterborough.

Imai, C. & Maeda, O. (1976) Several factors effecting on hatching on ***Aedes albopictus*** **eggs.** ***Japanese Journal of Sanitary Zoology,*** **27, 363-372.**

Kobayashi, M., Nihel, N. & Kurihara, T. (2002) Analysis of northern distribution of ***Aedes albopictus*** **(Diptera : Culicidae) in Japan by**

geographical information system. *Journal of Medical Entomology,* 39, 4-11.

Maier, H., Spiegel, W., Kinaciyan, T. & Honigsmann, H. (2004) Caterpillar dermatitis in two siblings due to the larvae of *Thaumetopoea processionea* L., the oak processionary caterpillar. *Dermatology,* 208, 70-73.

Maier, H., Spiegel, W., Kinaciyan, T., Krehan, H., Cabaj, A., Schopf, A. & Honigsmann, H. (2003) The oak processionary caterpillar as the cause of an epidemic airborne disease: survey and analysis. *British Journal of Dermatology,* 149, 990-997.

Majekodunmi, A., Howard, M.T. & V., S. (2002) The perceived importance of cockroach [*Blatta orientalis* (L.) and *Blattella germanica* (L.)] infestation to social housing residents. *Journal of Environmental Health Research,* 1.

Medlock, J.M., Avenell, D., Barrass, I. & Leach, S. (2006) Analysis of the potential for survival and seasonal activity of *Aedes albopictus* (Diptera : Culicidae) in the United Kingdom. *Journal of Vector Ecology,* 31, 292-304.

Mitchell, C.J. (1995) Geographic spread of *Aedes albopictus* and potential for involvement in arbovirus cycles in the Mediterranean basin. *Journal of Vector Ecology,* 20, 44-58.

Mori, A., T. O. & Wada, Y. (1981) Studies on the egg diapause and overwintering of Aedes albopictus in Nagasaki. *Tropical Medicine,* 23, 79-90.

Nawrocki, S.J. & Hawley, W.A. (1987) Estimation of the northern limits of distribution of *Aedes albopictus* in north America. *Journal of the American Mosquito Control Association,* 3, 314-317.

Parmesan, C. & Yohe, G. (2003) A globally coherent fingerprint of climate change impacts across natural systems. *Nature Reviews Microbiology,* 421, 37-42.

Pinneger, D.B. & Child, R.E. (1996) Woodworm - a necessary case for treatment? New techniques for the detection and control of Furniture Beetle. *Proceedings of the Second International Conference on Urban Pests* (ed K. B. Wildey).

Pumpuni, C.B., Knepler, J. & Craig, G.B. (1992) Influence of temperature and larval nutrition on the diapause inducing photoperiod of *Aedes albopictus*. *Journal of the American Mosquito Control Association,* 8, 223-227.

Purse, B.V., McCormick, B.J.J., Mellor, P.S., Baylis, M., Boorman, J.P.T.,

Borras, D., Burgu, I., Capela, R., Caracappa, S., Collantes, F., De Liberato, C., Delgado, J.A., Denison, E., Georgiev, G., El Harak, M., De La Rocque, S., Lhor, Y., Lucientes, J., Mangana, O., Miranda, M.A., Nedelchev, N., Nomikou, K., Ozkul, A., Patakakis, M., Pena, I., Scaramozzino, P., Torina, A. & Rogers, D.J. (2007) Incriminating bluetongue virus vectors with climate envelope models. *Journal of Applied Ecology,* 44, 1231-1242.

Robinet, C., Baier, P., Pennerstorfer, J., Schopf, A. & Roques, A. (2007) Modelling the effects of climate change on the potential feeding activity of *Thaumetopoea pityocampa* (Den. & Schiff.) (Lep., Notodontidae) in France. *Global Ecology and Biogeography,* 16, 460-471.

Robinson, W.H. (2005) *Urban insects and arachnids: a handbook of urban entomology.* Cambridge University Press, Cambridge.

Roy, H.E., Hails, R.S., Hesketh, H., Roy, D.B. & Pell, J.K. (in press) Beyond biological control: non-pest insects and their pathogens in a changing world. *Insect Diversity and Conservation*.

Sarukhán, J., Whyte, A. & Editors, M.B.o.R. (2005) Ecosystems and human well-being: Biodiversity synthesis. *Millennium Ecosystem Assessment*. World Resources Institute, Washington.

Thomas, M.B. & Blanford, S. (2003) Thermal biology in insect-parsite interactions. *Trends in Ecology and Evolution,* 18, 344-350.

Toma, L., Severini, F., Di Luca, M., Bella, A. & Romi, R. (2003) Seasonal patterns of oviposition and egg hatching rate of *Aedes albopictus* in Rome. *Journal of the American Mosquito Control Association,* 19, 19-22.

Udaka, M. (1959) Some ecological notes on *Aedes albopictus* in Shikoku, Japan. *Kontyo,* 27.

Wang, K.C. (1966) Observations on the influence of photoperiod on egg diapause in *Aedes albopictus*. *Acta Entomol. Sinica,* 15.

Whyatt, R.M., Camann, D.E., Kinney, P.L., Reyes, A., Ramirez, J., Dietrich, J., Diaz, D., Holmes, D. & P, P.F. (2002) Residential pesticide use during pregnancy among a cohort of urban minority women. *Environmental Health Perspectives,* 110 507-514.

Wilson, A.J., Carpenter, S., Gloster, J. & Mellor, P.S. (2007) Re-emergence of BTV-8 in northern Europe in 2007. *Vet. Rec.,* 161, 487-489.