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# The potential impact of climate change on the distribution and prevalence of mosquitoes in Britain

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The aquatic habitats of the 33 species of mosquito recorded in Britain vary considerably. Some species develop in permanent ground water, while others occupy temporary fresh-water or saline pools, some mature in the water that collects in holes in trees and yet others in containers such as rain water barrels and horse troughs. Some species exploit a variety of larval habitats; others are more specialised. One British mosquito selects underground water that collects in flooded basements, the foundations of dwellings, drains, underground railway tunnels and similar cloistered situations. To predict how these quite varied aquatic habitats will change when subjected to global climate change is difficult. What is certain is that they will not all alter in either the same way or to the same extent.

Developing an understanding of the likely effects of climate change on different mosquito species is not only valuable from an insect ecology perspective, but has implications for the transmission of mosquito-borne infections. The increased breeding ability of one putative vector species or the occurrence of favourable conditions for exotic species could have implications for the occurrence and intensity of transmission of mosquito-borne infections. Understanding which mosquito species could be involved in the transmission of infectious diseases (Higgs *et al.*, 2004; Medlock *et al.*, 2005) and the effect that a changing climate might have on these putative vectors (Snow, 1999), is an important pre-requisite for assessing the implications of climate change on the distribution (Snow *et al.*, 1998) and abundance of British mosquitoes, and the future public and veterinary health consequences.

There are many ongoing influences on the distribution and abundance of mosquitoes in Britain that are independent of climate change, which also need to be considered and brief mention will be made of these. One of the major factors is the evolving landscape with continuing urbanisation, changes in agricultural practices and land use, development of wetlands for wildlife and recreation and increased abstraction of water from our rivers with its subsequent effect on existing wetlands. To this list can be added the direct effect on mosquitoes of pollution arising from industry, transport and agribusiness and the use of insecticides to control agricultural pests. Some of these will almost certainly be influenced by public works designed to ameliorate the impact of climate change.

Though the endophilic and endophagic *Anopheles maculipennis* complex are considered to have been the principal vectors of the malaria formerly prevalent in parts of Britain, these currently bite people too infrequently to be classed as pest mosquitoes. With the exceptions of the anthropophilic Culex *pipiens* biotype *molestus*, which spends its life in enclosed situations, and the omnivorous *Culiseta annulata*, a mosquito which continues to feed throughout the winter if and where opportunities exist, the British pest mosquitoes are essentially exophilic, though some of these may occasionally enter buildings briefly to feed. The ornithophilic *Culex pipiens* nominate biotype, considered in continental Europe to be important in maintaining feral arbovirus transmission cycles, may inhabit a variety of sites, but hibernates in places where uniformly cool temperatures offer optimum conditions for long survival of diapausing adult mosquitoes (Cranston *et al.*, 1987).

## Recent trends in global and UK climate

Mean temperatures in Britain, as measured in 'Central England', have risen by about 0.7°C since 1700 and by about 0.5°C since 1900. In the present century, the temperature increase has occurred in all seasons but is most pronounced in summer and autumn (Jones & Hulme, 1997). According to Hulme *et al.* (2002), over the past century a number of climatic changes have taken place in Britain that act as a warning for future climate change. In the early part of the 20$^{th}$ century, the thermal growing season (period of the year where daily temperatures exceed a 5.5°C threshold for five consecutive days) on average lasted 225-240 days. By the end of the century, the average was 265 days, with the longest ever season reported in 2000 as lasting 328 days. In addition, the frequency of 'very hot days' (maximum temperature >25°C) has risen from 4 days in the 1960s to 12 days at the end of the century, with a record of 34 days reported for 1995. Although there has been no long-term trend in annual precipitation, winters during 1970-2000 in England and Wales, compared to those in 1770-1800, have become 55mm wetter, with summers 45mm drier. There has also been a reduction in the number of snow cover days, an increase in the global average sea-level (by 1.5mm per year) and an upward trend of 10-15% in the average significant wave height, which acts to increase the occurrence of sea surges and consequent inundation of coastal land by salt water.

**Predicted climatic change**

The United Kingdom Climate Impacts Programme (UKCIP), carried out by the Tyndall and Hadley Centres for Climate Change Research, forecasts that the country's climate will become warmer (Intergovernmental Panel on Climate Change, 2001). Annual temperatures are predicted to rise by between 2°C and 3.5°C by the 2080s. Warming will be greatest in parts of the south-east, where temperatures may rise by 5°C in the next 80 years. The variability of seasonal temperature will also differ, with the inter-annual variability (% change in sd of the average seasonal climate) of winter and spring temperatures reducing by 20% but increasing by >25% for summer and autumn temperatures, with high summer temperatures more frequent and very cold winters rarer. The hot August of 1995, or the heat wave of 2003, may occur as commonly as three out of five summers by 2080 (Tyndall Centre, 2005). Winters will become wetter (by 2080: 5-15% increase in best case scenario, up to 30% increase in worst case scenario) and summers drier across the UK (England: 20% decrease for best scenario, 40% decrease for worst scenario), with dry summers similar to 1995 (37% less rainfall than average) likely to occur every other year by 2080. In the south and south-east, the changes may be greatest with summer precipitation declining by up to 50% by the 2080s. Heavy precipitation in winter will become more frequent leading to increased probability of flooding, however soil moisture and relative humidity are likely to decrease over most of Britain and the frequency of snowfalls is likely to be reduced significantly. Sea levels will continue to rise and could be between 26 and 86cm above current levels in south-east England in 80 years' time (Hulme *et al.*, 2002).

**Climatic effects on mosquito biology and ecology**

In order to assess the effects that climate change may have on mosquitoes in Britain it is necessary to consider the ecological requirements of a mosquito. These include:

- Suitable aquatic sites in which to develop (breeding sites), present at the appropriate time of the year and maintained long enough for the development of the immature stages. They must contain sufficient food materials and ideally a minimum of competitors, predators, pathogens and parasites.
- Suitable resting sites for adult mosquitoes.
- Availability of hosts in sufficient numbers and at appropriate times.
- Availability of nectar sources for both male and female adult mosquitoes.
- Suitable temperature for development and survival, and appropriate relative humidity for adult survival.
- Suitable overwintering conditions.
- Absence or minimal presence of pollutants and toxic materials, including agricultural pesticides, and insecticides.

Mosquitoes show numerous adaptations to survive climatic extremes, for example those belonging to the genera *Aedes, Ochlerotatus* and *Finlaya* (Reinert & Harbach, 2005a) and some *Culiseta* species have drought resistant eggs, and all species have evolved strategies to colonise suitable conditions. Overwintering by species inhabiting temperate and cold climates is also a major adaptation and may occur in the adult, egg or larval stage.

The ability of mosquitoes to adapt to available conditions is shown well by *Culex pipiens*. This mosquito is very common throughout Britain in its nominate biotype, a bird-feeding mosquito which mates in large swarms, overwinters as a fertilised female, selects ground pools and artificial containers as aquatic sites, and requires a blood-meal before laying each batch of eggs. In contrast there are seemingly isolated populations, *molestus* biotype, which feed on humans, mate in enclosed areas, breed continuously throughout the year, have a marked preference for cloistered or underground water to develop, and are able to lay the first egg batch without recourse to a blood-meal (autogeny). These two biotypes are morphologically identical. Individuals from autogenous populations interbreed only rarely with members from anautogenous populations. However, in southern Europe the differences in habitat choice may be less clearly defined, with some interbreeding reported (Clements, 1992). That such adaptations exist so clearly in one species is an indication that others may exist more universally. If this is so, then species will be able to adapt to changing climate conditions readily.

The mosquito populations that are present now have either evolved through periods of dramatic changes in temperature, precipitation levels and other environmental conditions, or established themselves as changing conditions became favourable, and both processes are likely to continue as responses to future changes in climate. It is also important to appreciate that the climate of Britain is, and has been, extremely variable throughout both its length and breadth.

**Currently indigenous species**

Most species develop in more than one habitat, but in the following listing only one such site is given for each species and only those species recorded in Britain as larvae are included. For details of the fuller range of habitats occupied by each species see Cranston *et al.* (1987), Snow (1990) and Becker *et al.* (2003). For details of current nomenclature see Reinert & Harbach (2005b).

**Temporary fresh water pools** (flooded meadows, woodland pools, ditches): *Aedes cinereus, Ae. vexans, Oclerotatus annulipes, Oc. cantans, Oc. dorsalis, Oc. flavescens, Oc. punctor, Oc. rusticus*

**Temporary saline water pools** (saltmarshes, areas subjected to sea incursion): *Anopheles atroparvus, Oc. caspius, Oc. detritus*

**Artificial water collections** (tanks, rain barrels, wells, cisterns, troughs, buckets, cans): *Culex pipiens* nominate biotype, *Cx. torrentium, Culiseta annulata, Cs. subochrea*

**Tree holes** (rot holes and pans): *An. plumbeus, Finlaya geniculatus, Orthopodomyia pulcripalpis*

**Permanent groundwater** (ditches, pools, ponds, canal and river edges): *An. claviger, An. daceae, An. messeae, Coquillettidia richiardii, Cs. fumipennis, Cs. litorea, Cs. morsitans, Cx. europaeus*

**Underground water** (flooded basements, underground train tunnels and other more or less cloistered water collections including those caused by faulty or broken drains): *Cx. pipiens* biotype *molestus*

**What are the possible consequences of climate change on mosquitoes and their habitats?**

**Temporary fresh water pools**

As at present, such sites will be tend to intermittently or completely dry out in summer and present suitable oviposition sites for *Aedes* and *Ochlerotatus* species. They will fill more reliably in winter as increased precipitation is predicted in this season and the water table will be higher. The consequent increase in numbers of aquatic sites and predicted warmer spring temperatures could lead to a greater abundance of mosquitoes emerging earlier in spring, prior to premature drying of transient pools over the summer, followed by a submergence of aquatic sites due to autumn precipitation. It is not anticipated that these aquatic sites will be longer lasting than at present and hence predators and parasites will not establish themselves and so will not assume greater importance. However, as now, there is likely to be variation between years in the spatial and temporal distribution of summer rainfall, and some presently univoltine species may produce an extra generation, as sometimes happens in continental Europe.

**Temporary saline water pools**

It has been estimated that climate change will lead to sea level rises and an increase in storms which will result in loss of saltmarsh at the rate of 100 ha per year (Hulme *et al.*, 2002). Saltmarshes and intertidal mudflats will also be squeezed out between new developments such as wind farms, port expansions, gravel dredging and sea defences. Shallow saline pools may also dry more quickly at higher temperatures, but these may be regularly replenished by tidal inflow as well as by rainfall.

However there are plans for coastal realignment, such as at Abbotts Hall Farm in Essex, where a sea wall has been breached to convert over 80 ha of arable farmland into saltmarsh. If this practice continues, then saltmarsh will be recreated as a cost-effective, sustainable sea defence, supporting a rich variety of wildlife, including mosquitoes. Additionally, an increased frequency of storm surges would lead to greater inundation of coastal regions, which could provide transient saltwater aquatic sites for mosquitoes prior to rapid drying in summer, as well as encouraging salt water intrusion into coastal marshland.

**Artificial water collections**

It is difficult to predict what will happen regarding artificial collections of water. Water collecting in poorly drained water-filled gutters and in buckets, watering cans and other containers in gardens will presumably diminish in summer but animal troughs will remain the same, as they are essential and will be replenished as they empty.

If there is less summer rainfall then more gardeners may acquire water butts to store winter rainfall for use throughout the year. This may lead to species that breed in containers such as *An. claviger, Cx. torrentium, Cx. pipiens, Cs. annulata* and *Cs. subochrea* becoming more abundant, particularly in synanthropic settings.

**Tree holes**

Water-filled tree holes take the form of both rot holes and pans. Both depend on precipitation and rot holes also on rising sap but both may dry out more rapidly and/or completely if there are dryer, warmer periods due to both less rainfall and enhanced evaporation. This may reduce the numbers of *An. plumbeus, Fl. geniculatus* and *Or. pulcripalpis* which rely wholly or principally on tree-holes for development.

**Permanent ground water**

All pools, ponds and lakes will fill in the winter but small pools may dry in summer and larger water masses will become shallower. Mosquitoes that breed in ground water, for example *An. claviger* usually select ponds rather than lakes, which may be prone to drying out and hence the habitats may be lost for part of the year.

Nonetheless quite large overwintering larval populations of *An. claviger* have been found in the south of England in quite sizable lakes originally created by sand and gravel extraction. These lakes never dry out but the shorelines alter in character with seasonal drying of the shallow, overgrown margins, exposing larvae to increased predation and making the sites less attractive to ovipositing females (C.D. Ramsdale, personal communication).

However although summer precipitation is expected to decrease, when precipitation in summer does occur it is likely to be heavy, particularly in areas where an increasing frequency of intense summer thunderstorms is predicted. The effect of summer flash flooding will be exacerbated by the inability of parched soils to absorb heavy rain fast enough to prevent flooding. Water loss by evaporation due to higher temperatures however, is likely to occur in all seasons.

As water levels diminish with reduced summer precipitation, so river and canal water velocities will decrease and the edges of rivers and canals may become sluggish and suitable breeding sites for mosquitoes. River slowing will also be caused by increased water abstraction for domestic and commercial needs. The total snowfall, and hence snowmelt, is predicted to be reduced by up to 90% by the 2080s (Hulme *et al.*, 2002) which will impact on late winter/spring river flow in areas prone to heavy or prolonged snow cover.

**Underground water**

Basements, underground train tunnels and drains may become flooded more often with increased winter rain and this may lead to an increase in the incidence of *Cx. pipiens* biotype *molestus* at this time. This may become an increasing occurrence as many urban drainage systems are outdated (Ramsdale & Gunn, 2005) and as more houses are built in flood-risk areas.

**Greater risk of biting**

Warmer weather means that people will wear less clothing in the summer months with greater skin exposure and will spend more time out-of-doors including socialising and eating *al fresco* in the evenings. It will also mean that windows and doors of dwellings will be open more thus allowing the entry of mosquitoes to houses. This will inevitably mean that there will be more mosquitoes biting and hence they will assume a greater nuisance value.

**Effects on native species**

Many species of mosquito found in this country occupy an extensive Palaearctic range, at their southernmost limits in continental Europe experience conditions of high temperature and low rainfall beyond that which would be reached in UK by climatic change over the next several centuries. The effect on these species of predicted climate change will therefore be minimal. From the remaining species, only species which rely almost exclusively on human dwellings for breeding, feeding and resting, such as *Cx pipiens* biotype *molestus* will escape the effects of climate change. However as the biotype might to a very limited extent utilise outdoor surface water in the summer months its numbers may be enhanced.

Milder winter temperatures may have an impact on the overwintering survival of mosquitoes. Different mosquito species adopt differing overwintering strategies, as adults (*Cx. pipiens*), larvae (*Cq. richiardii*) or eggs (*Oc. punctor*). Whichever strategy is employed, the impact of milder winter temperatures on overwintering stages is likely to promote winter survival rates, which could favour some species at the expense of others. Higher temperature may also mean enhanced speed of egg, larval and pupal development leading to a faster generation time and perhaps the appearance of additional generations each year. If spring-like conditions occur earlier in the year, overwintering adults may emerge sooner and developing forms mature more quickly. For example, Haufe & Burgess (1956) showed that the duration of the larval and pupal phases of *Oc. communis* range from 18-20 days at 12°C to 38 days at 8°C, which may allow an extra generation to develop in a protracted season. More generations and a protracted adult season mean a greater biting nuisance.

Experiments on non-native *Stegomyia albopicta* indicate that populations occurring in regions with relatively high summer temperatures are likely to have high rates of population growth with populations of adults peaking early in the season. These populations may attain relatively low peak densities of adults. However populations occurring in regions with low summer temperatures are likely to experience slow, steady production of adults throughout the season with population size peaking later in the season (Alto & Juliano, 2001).

Importantly, digestion and egg development are also temperature dependent. Thus female mosquitoes are likely to digest their blood meals and mature their eggs more quickly with enhanced temperature (Clements, 1992). For example, Service (1977) showed that at 4°C, *Oc. cantans* in Britain completed bloodmeal digestion in 30 days, reducing to 14 days at 8°C and 5 days at 20°C, with rates of embryonic development reducing from 42 days at 4°C to 22 days at 12°C and 8 days at 20°C. This effect could lead to an increase in the number of egg-laying cycles and hence enhanced fecundity.

However increased temperature could also decrease the longevity of adults due to desiccation, unless, as tends to happen, they occupy favourable microclimates. The reduction in aquatic sites and earlier drying of temporary pools could if extreme, prevent the completion of cycles as habitats dry before development is completed. It is possible that there will be a decrease in cold-adapted species in the north of Britain e.g. *Cs. alaskaensis* whereas species like *Or. pulcripalpis* and *Cs. litorea*, that are currently thought to be only present in the south of the country and at their northern limits of their ranges, will extend their distribution northerly.

Temperature increase may affect the sex ratio in certain *Aedes* mosquitoes of cold areas such that the ratio is distorted in favour of females. This could at low levels of impact enhance the reproductive capacity of a species yet at higher levels distort the sex ratio such that males would be insufficient in the populations. Certain species e.g. *Oc. punctor* and *Oc. communis*, characterised by sub-arctic and temperate zone distribution, are heat-sensitive in that different degrees of feminisation may occur when larvae with the male genotype are reared at high temperatures. These species normally begin development at 5-10°C in places where the temperature rarely exceeds 20°C. When reared at 23-27°C different degrees of feminisation occur (Horsfall, 1974) with individuals having the competence to become phenotypic males or females (Clements, 1992). In contrast, individuals with the female genotype develop into females at all temperatures that permit survival (Clements, 1992). The consequence of this could be a smaller number of functional males in the population, which could have an effect on swarm sizes and mating efficiency.

In addition to these factors, all of the current indigenous species may experience competition from, and even replacement by, exotic species arriving in the country.

**Invasion by exotic species**

With global climate change, species present in the south of Britain and more southerly European areas may be expected to move northwards when suitable conditions occur. Habitat fragmentation due to agriculture, urbanisation and natural barriers may however hinder the northerly movement of individuals as they seek suitable habitats to invade. The autogenous and anautogenous forms of *Culex pipiens* have been reported to interbreed in southern Europe and the Middle East and migrants from these areas could have an impact on the degree of hybridisation of British populations of this species.

Marginal species currently present in Britain such as *An. algeriensis* and newly introduced tropical and sub-tropical mosquitoes may find warmer conditions more amenable, enabling them to survive longer and to extend their ranges as the unfavourable-effects of low temperatures are removed.

**Other factors**

Apart from climate change, other issues may have an impact on the presence and distribution of mosquitoes in Britain. One of these involves conservation issues. Wetlands, with their flora and fauna often under pressure from many sources, are of special importance to conservation bodies. It is in these areas that mosquito problems are often most severe. With increased sensitivity regarding conservation of habitats, many wetlands are being restored, and additional sites throughout the country are and will be designated as Sites of Special Scientific Interest (SSSIs). As many of these SSSIs are coastal and breeding areas for nuisance mosquitoes such as *Oc. detritus*, the lack of future pest control may be significant. An increase in saltmarsh as a result of coastal realignment may also be significant by providing more aquatic sites for this and other salt-water breeding species.

As conservation issues become more prominent, legislation may become more stringent and more insecticides, useful against adult mosquitoes, may be banned. At present only one larvicide is permitted in UK, the microbial *Bti*. This has many advantages, the chief of which is that it is non-toxic to humans and other vertebrates, most invertebrates (exceptions are allied insects) and plants. It does not enter food chains, causes no environmental contamination and there are few reports of resistance. As it does not kill natural predators it can be used in conjunction with biological control. If our nuisance species suddenly become resistant to *Bti* there may be considerable delay in finding an acceptable replacement.

In direct contrast there may be increased pressures from individuals and commerce to initiate control measures. This will happen where mosquito-biting nuisance becomes intolerable, affects the quality of life and has an adverse effect on tourism and leisure activities. Examples of this have been measures directed at the control of coastal mosquitoes in Hayling Island and in the Dee and the Thames Estuaries (Ramsdale & Snow, 1995).

The growth in gardening and wildlife-friendly gardens are encouraging households to install ponds for wildlife and provide food and bathing for birds. Additionally, the prospect of drier summers will lead to water shortages with gardeners being more inclined to collect winter rainfall in water butts for summer watering of plants and flowers. Several mosquito species thrive in such habitats and whilst certain species (*Cx. pipiens* nominate biotype and *Cx. torrentium*) are not known in Britain to bite humans, there will certainly be more awareness of the presence of mosquitoes, particularly during autumn, when females are seeking hibernation sites. An increase in *Cs. annulata* however, may cause considerable nuisance biting with adults occurring for much of the year in Britain.

The increase in abundance of bird-feeding mosquitoes in synanthropic settings could lead to increased possibilities for enzootic urban transmission of bird-related mosquito-borne infections known to occur elsewhere in Europe. In turn, this may increase the possibility for exposure of humans to such infections through local bridge vector populations.

Natural ageing of trees also has an impact. Three mosquito species in Britain are known to develop virtually exclusively in water-filled tree holes (*An. plumbeus, Fl. geniculatus* and *Or. pulcripalpis*) (Snow, 1990). These sites are characteristic of mature trees and develop where large branches have broken off and rot taken place. Pollarding often increases the incidence of cavities. In areas where pollarding was once practised and has been discontinued, the branches are large, easily detached and produce rot holes. Numerous potential breeding sites are also being created on new housing estates, recently developed recreational land and roadside and motorway verges where trees have been planted. Indeed it is now policy for trees to be planted to counteract carbon dioxide emission as well as providing a more aesthetically pleasing urban environment.

Furthermore, climate change is likely to impact on tree coverage with drier summers in the south-east possibly impacting negatively, providing more areas of forest and woodland clearance suitable for species that prefer temporary ground pools exposed to full sunlight. However, during milder, wetter springs in the north and north-west, tree flowering and propagation will be less restrained by heavy frost, with consequent increased tree coverage promoting the survival of tree-hole breeding mosquitoes during wet springs. A succession of very dry summers in areas of the south and south-east could lead to mortality of broadleaf trees such as beech, and whilst this would ultimately lead to woodland clearing, deteriorating trees would, in the interim, provide additional tree hole aquatic sites.

Transport also has a major impact on mosquitoes. A consequence of the country's long maritime tradition was the occasional importation of disease and sometimes the mosquito vectors, especially when larger ships and growing overseas interests made long voyages more frequent. Today transport has an effect on mosquito distribution in that insects can be carried both short and long distances in motor vehicles and in the cabins/ holds of ships and aircraft. With the current increased volume of world travel, the opportunities become greater and, with climate change, the possibilities of establishment enhanced.

In the surveys by John Marshall and John Staley in the middle of the last century, larvae of a Mediterranean species, *Cx. modestus*, were discovered in 1945 in a National Fire Service tank in Portsmouth and in a brackish pool at Gosport. At the same time, adults were captured at Haying Island and on the mainland, all within a 5 km radius (Cranston *et al.*, 1987). This species has not been recorded since and was presumably introduced through the port and did not become established.

A further documented introduction of an exotic species into Britain concerns *Cs. longiareolata*, normally confined to Mediterranean region, Russia, Asia Minor and eastwards to India, as well as tropical Africa. This has been recorded twice on the coast in southern England, from Portsmouth and from Brownsea Island in Dorset, and inland at Epsom, Surrey (Cranston *et al.*, 1987). It would appear that introduced *Cs. longiareolata* may not survive our current winters.

Two other species are of interest because of their unexpected appearance in Britain, one fairly recently. *Oc. leucomelas*, normally found in northern Europe and the former USSR was recorded from Widmerpool, Nottinghamshire in 1919 (Marshall, 1938) but has not been reported since. However *An. algeriensis*, first reported in 1932 in the Norfolk Broads, reappeared in the same area in 1945 and for some years after (Cranston *et al.*, 1987), but despite extensive searches it has not been found in Norfolk since. However, in 1987 it made an appearance in Anglesey, North Wales. There it withstood the winter conditions, for it remained in Anglesey for at least two further years (Rees & Rees, 1989). It is not known whether it is still present, as no recent searches of the area have been made (A.T. Rees, personal communication).

Trade is also an important factor in determining mosquito distribution. Three decades ago, *Stegomyia albopicta*, the Asian tiger mosquito, was unknown in Europe, Africa and the Americas. However, since the early to mid 1980s it has extended its geographic range significantly and rapidly (as had *Stegomyia aegypti*) and was first recorded outside of its indigenous area in the USA (Reiter & Darsie, 1984). Since then it has become established in over half of the States of the USA, and it is also now present in South America, Australia, New Zealand, Africa, Middle East and Europe (Albania, Italy, France, Belgium, Montenegro, Greece, Switzerland, Spain and the Netherlands) (Samanidou-Voyadjoglou *et al.*, 2005; RIVM, 2005). These introductions were made primarily through the international trade in new and used tyres containing desiccant-resistant eggs, but also in containments of 'wet-foot' plants such as *Dracaena* sp. ('lucky bamboo').

The example of *St. albopicta* not only demonstrates the speed with which a species can extend its range but also the speed with which mosquitoes can adapt. The international car tyre trade is relatively new and yet a species has adapted to lay its eggs in stacked tyres and await their inundation with rainwater, instead of utilising other natural water. This speed of evolution may be vital in considering the adaptation of mosquitoes to climate change. Quite how many more such introductions pass unnoticed is impossible to estimate. More recently there have been reports of additional exotic 'vector' species in France, Italy and Belgium including *Oc. atropalpus, Oc. japonicus* and *Oc. triseriatus* (Romi *et al.*, 1997; Romi *et al.*, 1999; Schaffner *et al.*, 2003; Adege-EID, 2005) all thought to have been imported into Europe on used-tyres from the USA.

Increase in temperature may have an effect on the growth of aquatic vegetation such as *Lemna* and *Azolla* that may make permanent ground water unavailable to mosquitoes. Fungal, bacterial, viral and nematode parasites characteristic of warmer areas of the world may also appear in Britain and have a limited adverse effect on mosquito populations, especially if they are newly established pathogens.

**Conclusion and the paradoxical cooling argument**

Predicted climate change is likely to impact on British mosquitoes in both positive and negative ways, and whilst the majority of future climate scenarios are likely to act to increase future abundance and distribution of endemic mosquitoes, and allow the establishment of exotic species, the predicted decrease in summer precipitation may be a limiting factor, particularly in areas of south-east England.

Recently however, there have been arguments that a paradoxical cooling of Britain might occur due to the breakdown of the North Atlantic Gulf Stream (oceanic conveyor). The reasons for this are linked to the warming of the Polar Regions which is causing the release of large amounts of fresh water that is diluting the salinity of the ocean, thereby distorting the delicate balance of the Gulf Stream. It is thought that the ultimate disruption of the Gulf Stream in this way could possibly prevent the warm waters of the tropics from bathing the British Isles in a much milder climate compared to areas of similar latitude.

This scenario has occurred in the past and if it were to occur again, with the dramatic proportions that some are predicting, then a totally different scenario would ensue. Whilst UKCIP admit that there is a slight cooling of the oceans due to this phenomenon, they do not predict that a paradoxical cooling scenario is likely by 2100. Furthermore, the current degree of cooling as a result of the breakdown has been factored into climate change models by UKCIP and the warming due to greenhouse gas emissions appears to be offsetting the cooling effect, leading to the predicted warming of climate around Britain.

There are predictions that the breakdown of the Gulf Stream conveyor will occur sooner than expected, and that there will be a consequent drop in temperatures over Europe by as much as 4°C (Bryden *et al.*, 2005). In the event of this occurring, the effect on British mosquitoes will be different from that discussed here. Cold-adapted mosquitoes, and particularly snow-melt mosquitoes, will thrive in an environment that is dominated by spring melting of snow, leading to a tundra-dominated landscape with abundant summer lakes not dissimilar to current day Scandinavia, where mosquitoes are currently a major nuisance-biting pest and are vectors of arboviral infections.

Whether the future climate will be warmer or cooler is still open to debate. Either way, different mosquito species will either benefit or be disadvantaged, and the subsequent effects of future climate, along with changing societal, land use and agricultural practices are likely to present a different ecological scenario from that which currently exists in Britain. The effects that these will have need to be taken into account when considering the future mosquito fauna of Britain and its impact on the human population.

In the short and medium term future, the most important factors affecting changes in mosquito prevalence, distribution and population makeup will almost certainly be related to environmental outcomes of changes in land use and public works necessitated by climatic amelioration, especially works connected with urban and periurban drainage, or with flood control and other aspects of hydrology.

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