Wetland Mosquito Survey Handbook

Assessing suitability of British wetlands for mosquitoes

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FOREWORD

It is an exciting time for people who care about biodiversity in the United Kingdom. There is an increasing realisation about what we have lost over the last 50 years and a growing understanding of what biodiversity and natural habitats contribute to the nation's economy and its people's well-being. There is widespread enthusiasm about habitat restoration and recreation, as well as new ideas about how "nature-based solutions" may help us to confront some of the major challenges of the 21st century such as climate change, often more cheaply than human-based alternatives.

I share this excitement and sense of optimism, but strongly believe that to improve our environment to benefit both us and biodiversity we need to squarely and fairly address the constituencies that may in the short term lose out from these changes. For example, as the UK replaces the agricultural subsidies in the Common Agricultural Policy with payments based on "public money for public good" it is critical for environmentalists to engage with the farming industry to address their concerns, and ideally forge a consensus of how change is best introduced.

The case of wetlands is another example where the potential for negative effects has to be taken into account and this book considers the possibility of the increased nuisance from more biting mosquitoes. This is an important topic because wetlands are a relatively easy habitat type to recreate and there have been some outstanding successful projects over the last couple of decades. These range from small urban projects, such as the London Wetland Centre in Barnes that provides an introduction to wetland biology to a massive population in its immediate vicinity, to the Somerset Levels, which now consist of a network of reserves with wonderfully enhanced biodiversity and a richness of breeding birds I could only of dreamed about as a teenager in the 1970s when I taught myself birdwatching in an area that was then largely devoted to active peat extraction. We are hugely fortunate that in the UK the nuisance from mosquito biting is much less than further north in Europe or at similar latitudes to ours in much of North America, and that the risk of disease transmission is currently negligible. Nevertheless, we risk undermining the positive gains from wetland restoration and creation if we do not take seriously, and address, the legitimate concerns of local people who may be negatively impacted by changes in mosquito populations.

The authors of this book should be congratulated on providing an immensely important compendium of knowledge to assess and address exactly this issue. Written in a clear and accessible style, it explains exactly what might be the consequences of new wetland sites to population levels of biting mosquitoes, and provides a novel prediction tool that will be very valuable to habitat managers and public health workers. It provides vignettes of the most important mosquito species and their ecologies, information on sampling and control, and much to be welcomed simplified identification keys to adults and larvae (that I hope will give more people the courage to move onto the more technical literature). It also addresses the very significant issue of engaging with people experiencing issues with mosquitoes who may not be biologists (though some will be very expert) but bring critically important novel perspectives to the discussion. Speaking down to such audiences is highly counter-productive (as I know from experience having foolishly told my wife she would be less bothered by the biting mosquitoes in the garden – *Aedes cantans* – if she knew their scientific name!).

Asking people to love mosquitoes is a hard sell, but I hope that non-entomologists coming to this topic for the first time will at least be fascinated by the rich biology of these insects. How extraordinary is it that one of the commonest British mosquitoes (*Culex pipiens*) has two types – the common one which is the mosquito most frequently seen in houses overwintering that almost exclusively feeds on birds, and one found in the London underground that is highly partial to humans. In addition to its main goal this book does a great job of telling us about these extraordinary creatures in an engaging style that never compromises on the underlying science.

Professor Sir Charles Godfray CBE FRS
Director, Oxford Martin School, Oxford University
15th July 2020

PREFACE

Wetlands across Britain provide enormous benefits to people and wildlife. They support a huge range of biodiversity, including resident and migratory wildlife, and generate significant benefits to the people who live and work in them. Recreational visitors enjoy their landscapes and opportunities for encounters with wild nature, and wider communities gain, too, due to the diverse ecosystem services that wetlands provide. For instance, wetlands can protect distant communities against the impacts of climate change by absorbing flood waters from sea level rise and extreme weather events.

It was with a view to understanding these benefits that the WetlandLIFE project (www.wetlandlife.org) set out to explore the values associated with wetlands, focusing on wetland sites in England. Uniquely, the project also sought to investigate how these social, cultural and economic values may be shaped by the presence of our native and non-native mosquito fauna. This involved qualitative research on the associations between wetlands and mosquitoes, particularly how wetland users, residents and visitors perceive these insects and how they are represented in contemporary culture. The project also undertook assessments of the potential economic impacts of mosquitoes now and in the future, historical reviews of mosquito research in Britain, as well as ecological research on the British mosquitoes and their habitats.

Driving this agenda were recent examples where wetland creation, expansion or restoration – and the myriad benefits it could bring – had been the source of tension over land use. Concerns can be voiced about the possible impact that creating, expanding or restoring wetland habitats may have on mosquito populations, and the potential for consequent nuisance or future disease transmission risk this may pose. Public anxiety around these risks may impede progress in implementing the *Wetland Vision for England*, which seeks to promote management of existing wetlands to maintain diversity of aquatic habitats and encourage restoration and expansion of wetlands through arable reversion and is backed by the UK Environment Agency, Natural England, The Wildlife Trusts and the UK Department of Environment, Food and Rural Affairs. The aim of the partnership is to place wetlands at the heart of efforts to help people and wildlife adapt to climate change, protect the cultural heritage associated with wetlands and biodiversity, and enhance the many added benefits that wetlands can provide to human health and wellbeing.

To avoid possible local land use conflicts where new or restored wetlands are proposed, it is vital that decision-makers and those with day-to-day responsibilities for wetland management consider the public and veterinary health implications of mosquito populations, nuisance-biting levels and public perceptions around these issues. It should not be the case that the numerous benefits associated with wetland habitats do not materialise due to a lack of information or misunderstandings about the relationships between people, wetlands, and mosquitoes. Wetland management, restoration and creation initiatives can balance these priorities by drawing on available knowledge and tools. This handbook aims to summarise the evidence on the biology, behaviour, ecology and phenology of the 30+ recorded British mosquito species and outline a guiding approach for assessing habitat suitability for these. It also presents guidance on the assessment of mosquitoes *in situ* for evaluating potential human and veterinary health implications, and, where required, possible population mitigation strategies. It is hoped that a proactive approach to understanding the ecological and social dimensions of mosquito biology, utilising the information and tools in this book and other resources, can enable wetland managers, communities and other stakeholders to work together to both deliver and derive environmental, economic and wellbeing benefits from the wonderful diversity of wetland habitats in the UK.

1. INTRODUCTION

1.1 Introducing mosquitoes

Mosquitoes are a diverse group of insects and are found throughout Britain. Well-known to many due to their blood-feeding behaviour, and often maligned because of this, they hold a distinct place in the public imagination. However, important nuances of their biology are often less familiar and can be the subject of myth and misunderstanding. Despite the potential nuisance that may be associated with some species, mosquitoes are an integral part of the British wildlife fauna and contribute in complex ways to both aquatic and terrestrial food webs.

As of 2020, 36 species of mosquito have been recorded in Britain. These vary widely in their ecology and behaviour. While many of these species will occasionally bite a human, only a small handful will sometimes cause a biting nuisance. Just as some species of rodent are considered to be important contributors to biodiversity, such as the dormouse (*Muscardinus avellanarius*), red squirrel (*Sciurus vulgaris*) and European water vole (*Arvicola amphibius*), while others, such as the brown rat (*Rattus norvegicus*), are considered as pests in certain situations, the same may be said of the mosquitoes. They are a heterogenous group of insects and from a conservation and management perspective it is important to acknowledge and respond to this diversity.

Aquatic insects, such as mosquitoes, are acutely responsive to changes in temperature and rainfall. The rate of development of all insects is directly proportionate to temperature, and in the case of mosquitoes this governs the rate of immature development, blood digestion, and egg production, as well as incidental issues such as pathogen development within the mosquito. However, as an obligate aquatic insect, the degree of water availability has profound implications for the survival and abundance of mosquitoes. This is exemplified by the fact that melting of winter snows in the Arctic lead to the highest global abundances of mosquitoes, despite the cool spring temperature. In addition to the availability of water, the permanent/transient nature of water bodies impacts on the mosquito's competitors and predators and hence any weather-driven or human-driven process that affects this (including heavy rainfall or wetland management) will impact to varying degrees on mosquito diversity and density.

Figure 1.1. Aedes sticticus, *a relatively rare species of the 36 recorded British mosquitoes.*

1.2 What are wetlands?

The Ramsar Convention on Wetlands of International Importance defines wetlands as

> ***"areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six metres."***

This encompasses an incredibly diverse range of environments. Wetlands in Britain reflect this diversity and are home to a spectrum of valuable wetland types, often of high nature conservation value. Many British wetlands are the result of human activity and have been formed or managed in one way or another by people.

Figure 1.2. *Peat extraction on the Somerset Levels in South West England began with the Romans and has shaped the wetland landscape over hundreds of years. Top: Peat gathering in Somerset in 1905 (Image: A.E. Hasse); and Bottom: in 2019.*

Some of the oldest human-made wetland landscapes include the Somerset Levels in the southwest (Figure 1.2) and the East Anglian Fens in the east. Both landscapes have been modified over the centuries via artificial drainage and irrigation activities that allowed these low-lying areas to be used as agricultural land. Crucially, wetland landscapes are not static; in the absence of interventions, their ecological communities change over time, so ongoing management is often required to maintain specific wetland habitat types.

There has long been a recognition that extant highly biodiverse wetland habitats require ongoing management to maintain a range of wetland communities with various seral stages i.e. the intermediate stages found in ecological succession in an ecosystem advancing towards its climax community, such as open water through to woodland, including tall fen, fen meadow, rush pasture, swamp, open water, permanent and temporary ditches, and wet woodland. An unmanaged wetland eventually becomes woodland. These different wetland types support a varied range of mosquito diversity and abundance. The impact of seasonal rainfall and/or management of water levels can impact significantly on the survival and abundance of these species.

1.3 What is the link between wetlands and mosquitoes?

Without exception, all mosquito species require water into which their eggs can hatch and go on to develop through larval (Figure 1.3) and pupal stages. Being aquatic, the immature life stages of mosquitoes are quite different to the winged free-flying adult (imago) stage. The requirement for females to oviposit in or very close to water, or in areas that are likely to be inundated by water, means that the adult stages are also commonly found in close proximity to the aquatic habitats that are suitable for their offspring. A number of species can disperse great distances from these breeding sites in search of blood meals, returning only when ready to lay eggs, though many will not stray further than a few hundred metres. It is this obligate need for immatures to develop in aquatic habitats that so inherently binds the mosquito to the availability of water. Mosquitoes are therefore closely associated with wetland habitats, but also the water which people store around their homes. It is these synanthropic habitats that are generally associated with many mosquito-borne diseases of humans.

Figure 1.3. *Larva of* Culiseta morsitans. *All mosquito larvae develop in aquatic habitats, before emerging as adults.*

As a diverse group of insects – there are over 3,500 recorded species of mosquito worldwide – it is perhaps not surprising that some species have adapted to specialist aquatic niches. Others are more generalist or able to tolerate greater ranges in water quality, such as salinity and pH, and variation in the presence or absence of vegetation. Some species require permanent water, others transiently flooded environments.

The table in Appendix III summarises how wetland creation and management may influence British mosquito species. It is important to consider the general life-histories of mosquitoes and how these relate to wetland types. Some mosquito species exploit only permanent wetlands such as ponds and ditches. Wetland types (such as reedbeds) with extensive drawdown zones do not tend to support mosquitoes. A vegetated substrate or the presence of floating or emergent vegetation is generally required to support mosquitoes in permanent wetlands. Another group of mosquitoes thrive in temporary water that is subjected to seasonal flooding and drying. Mosquitoes of wet woodland tend to exploit winter flooded habitats, with immature development occurring during late winter and early spring prior to summer drying. Mosquitoes of wet grassland remain dormant during winter as eggs, awaiting summer floods, upon which immatures develop in late spring for a summer emergence of adults. Wetlands that routinely dry and re-wet tend to have the associated groups of invertebrates adapted to this habitat which also act as competitors and predators to the mosquitoes, however the erratic nature of such ephemeral habitats leads to higher than average mosquito densities.

For healthy permanent wetlands, mosquito numbers are maintained by the food web, owing to the multitude of mosquito predator species. One of the main issues occurs with extreme events such as drought which results in the unnatural drying of permanent wetlands, followed by a re-wetting event with a subsequent dramatic increase in mosquito numbers in the absence of competitors and predators.

Excessive rainfall and subsequent flooding impacts greatly on the available mosquito habitat, however, this is not always a positive impact on mosquito density as excess flooding can denude aquatic habitats of mosquitoes through flushing. Similarly, artificial storage of rain or river water in wetlands can provide opportunities for mosquitoes. Coastal flooding and sea incursion following high spring tides may also promote mosquito habitats, independent of rainfall.

While many types of wetland can, in principle, provide appropriate habitat for one or more species, it is important to note that not all wetlands are suitable for mosquito development. Some of the most visually obvious wetlands with open water may not be suitable for mosquitoes. Larger lakes tend to be inimical for mosquitoes as they are subject to surface movements that reduce immature mosquito survival.

Additionally, a small number of temperate and tropical mosquitoes are not associated with wetland habitats *per se*, having instead adapted to breed in other sources of water, sometimes called “container habitats”. These are usually rain-filled niches such as tree holes, with some tropical species even developing in the rainwater that collects in the leaf axils of bromeliad plants. Others have adapted to exploit human-made water containers. These include intentional water storage containers, such as water drums and butts and the water dishes under plant pots, and incidental containers where rainwater can easily pool, such as inside old tyres or refuse items like aluminium drinks cans and plastic food containers.

1.4 The value of wetlands in Britain today: examples from England

- Tim Acott & Adriana Ford

There are many direct and indirect benefits to society that arise through the functioning of wetland ecosystems. The Ramsar Convention recognises that human welfare, environmental quality and wildlife are all supported by wetlands.

However, understanding the values of wetlands is complex, in part because they cover such a range of values, from the biophysical to the spiritual. Wetlands are important for the wellbeing benefits they bring to people (instrumental values) and also in themselves (intrinsic values). Wetlands in Britain have always been an integral part of the landscape and can bring a huge range of benefits to people and wildlife. Healthy wetlands provide important ways to mitigate short- and long-term impacts of climate change, provide habitats for wildlife and enhance human health and wellbeing, particularly in relation to physical and socio-cultural benefits. Expanding and reinstating wetlands are important components of interventions seeking to create sustainable, resilient communities. However, through history, there have been instances where wetlands have been vilified as places of disvalue, locations in which disease and poor health proliferate. The great wetland drainage programmes through the nineteenth and twentieth centuries testify to the 'productivist' aim to 'improve' marginal landscapes. Today, concerns can still manifest about negative aspects of wetlands, as perceptions of swamps and hazardous, boggy terrain may be connected to unwelcome insects, such as mosquitoes.

WetlandLIFE

In recognition that mosquitoes are often presented and amplified in the media in terms of their disvalues, a research project called WetlandLIFE, funded by UK Research and Innovation, set out to explore the diverse values associated with English wetlands, with a focus on how these may be shaped by mosquitoes. The overarching aim of the project was to provide the evidence-base to support healthy wetland management by delivering ecological guidance on wetland-dwelling mosquitoes – ecological results from this project support the material presented in this book – within the context of the many health and wellbeing values provided by wetlands. Numerous wetland values were identified during the research. These include diverse recreational uses with associated physical benefits (from walking to kayaking), as well as value in promoting personal growth, curiosity and learning (e.g. in wildlife-centred hobbies, such as birding, Figure 1.4), and supporting social connections (e.g. events, volunteering activities and intergenerational links via a wetland's history and memorials).

Benefits extend beyond these to encompass opportunities for mental wellbeing, including a sense of rest and restoration provided by features of the wetland landscapes specifically, such as their often remote and

Figure 1.4. *Bird watching, an iconic wetland hobby because of the importance of these habitats for endangered and migratory birds, is only one of many diverse ways people enjoy and make use of these spaces for recreation, relaxation and personal development.*

Figure 1.5. *Urban wetlands, in close proximity to human settlements, can provide important 'blue space' for local communities, supporting their health and wellbeing, while also providing valuable habitat for wildlife.*

quiet characteristics, open skies, and the nature of light reflecting on water and through mists. Wetlands also deliver energising and regenerative properties that give a sense of fun and freedom and provide embodied experiences from being 'in' nature, including the sensorial aspects of wetland sight, sound, smell, taste and touch. Wellbeing benefits go beyond the restorative effects of being in nature and include the sense of community and strong social relations that can centre around a local wetland. In some cases, this is the dominant contributor (compared to nature itself) for mental wellbeing, demonstrating that the social and cultural attributes that arise from wetlands are arguably as important as their provision for biodiversity and climate change mitigation.

It is also important to understand that the value people assign to wetlands can change and be shaped by the creative imagination. Wetlands can act as a source of inspiration for artists who produce artworks which subsequently inspire others. In this way, positive wetland representations can develop and be incorporated into wider ambitions for sustainable futures where wetlands play a key role.

These benefits are hugely important to local communities and those further afield and can translate into significant economic benefits (Figure 1.5). For instance, at one urban wetland studied during the research, benefits arising from the wetland ecosystem, including services such as carbon sequestration, flood regulation and water quality, as well as cultural, health and wellbeing benefits, were estimated to be in excess of £2 million a year (in 2019 prices); costs related to site management were estimated at around only £60,000 a year.

In summary, wetlands have many positive wellbeing values associated with them. Ecological knowledge of mosquitoes can help to facilitate wetland management and minimise perceived and actual disvalues. However, in situations where media can unfairly amplify negative values, inputs from social science research and creative arts based approaches can provide opportunities to open up understanding of wetlands, create empathy and provide opportunities for people to reappraise their understanding of mosquitoes alongside the many other benefits that wetlands bring.

1.5 Wetland expansion and mosquito habitat

In Britain, the rationale for wetland expansion is rooted in three main types of wetland creation schemes. These focus on wetlands in coastal, rural and urban settings. The first of these is the creation of new coastal wetlands through managed realignment (MRA) schemes, where the shoreline is allowed to move more naturally and/or where coastal defences are relocated landward of breached defences. MRA schemes are driven by legislation to reduce the impact of coastal squeeze on protected habitats and offset their loss by requiring compensation in the form of replacement habitat. They can also be necessary where the cost of maintaining existing hard defences such as seawalls is prohibitive and provide a more sustainable, long-term solution. These coastal wetlands can also form part of regional flood risk management plans to mitigate urban flooding, by the creation of saltmarshes that can absorb excess water during flooding events or perigean spring tides. Secondly, and core to the Wetland Vision, are projects that extend coverage of wetland habitats by supporting wetland creation and expansion. Often this is achieved via reversion of arable areas to the flooded grassland, floodplain meadows or other wetland habitat that existed in the area before drainage and conversion to arable use. This can be driven by the need to store floodwater or to increase the available habitat for aquatic species of nature conservation concern and seeks to achieve this by defragmenting habitats and, ultimately, re-creating a lost wetland landscape. Finally, the impacts of development on protected species and habitats must be considered under legislation designed to protect wildlife, habitats, and biodiversity. These can help to absorb urban floodwaters or create mitigation habitat for protected species at risk from development. Urban wetlands also have the additional benefits of reducing the urban heat island effect, giving residents access to blue space, and providing the recreational, psychological and cultural benefits to community wellbeing associated with it.

At the local level, there may be many motives to maintain, create or restore wetlands. Often, the management of wetlands can create opportunities for multiple benefits to the immediate community and further afield. However, such schemes can sometimes be contentious, at least initially. Local economies and identities are often closely tied to the surrounding landscape and changes to this can cause unease and even opposition. Wetland environments can be hydrologically complex and are often connected to surrounding landscapes. Consequently, many agencies and organisations operating at different spatial scales and with specialised remits will be involved in decision-making. Whether and how successfully wetlands are managed, restored or created will depend on how local conditions, stakeholder support and resources are managed within the context of regional, national and international frameworks.

The expansion of existing wetlands, their creation from arable land, and the creation of new salt-marsh to alleviate coastal erosion and flooding are important UK issues as the environment sector adapts to the possible impacts of climate change and continues to meet its goals of providing increased wetland habitat for wildlife, and an outdoor space for human wellbeing. Concerns have been raised, however, over the potential impacts that such initiatives might have on mosquitoes and the possible future transmission of infectious diseases. Coastal aquatic habitats have long been known to provide suitable habitats for brackish-water mosquitoes and historically, coastal marshes were considered to support mosquito populations that were responsible for local malaria transmission.

Some species of mosquito are associated with nuisance and disease transmission that needs to be addressed by practical interventions, as recognised by The National Adaptation Programme for making the UK resilient to climate change. In addition, NAP acknowledges that health organisations, such as Public Health England (PHE), have a responsibility to address health impacts that may be caused, inadvertently, by climate change mitigation activities that can create habitats for disease vectors.

One of the challenges therefore for wetland managers, those involved with environmental health and flood alleviation, and entomologists involved with public health assessment, is ensuring that existing and new wetlands as well as flooding events (and flood risk plans) do not cause concern for public health disease risk either now or in the future. It is vital that wetland creation, expansion and management plans take into account the effects that wetland management might have on mosquito populations, nuisance-biting levels, and public and veterinary health. It is also necessary that such biodiversity initiatives have the knowledge and tools to enable them to assess and manage this impact as their work proceeds. It is crucial that environmentally friendly mitigation strategies and wetland site locations are chosen with mosquito life histories in mind in order to minimise or avoid potentially deleterious effects. The environment sector recognises that there is a need for an evidence-base to inform future wetland creation and management initiatives; this publication intends to go some way to providing this by summarising the current knowledge of British mosquito ecology within the context of wetlands and their design and management.

Further reading

Convention on Wetlands of International Importance especially as Waterfowl Habitat. Ramsar (Iran), 2 February 1971.

Brown, L., Medlock, J.M. & Murray, V. (2014) Impact of drought on vector-borne disease. How do we manage the risk? *Public Health*, 128(1):29-37.

Darby, H.C. (2011) *The Draining of the Fens; The Medieval Fenland.* Cambridge: Cambridge University Press.

HM Government (2013) The National Adaptation Programme: Making the country resilient to a changing climate. Available from: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/209866/pb13942-nap-20130701.pdf. Accessed 15th May 2020.

Hume, C. (2008) Wetland Vision Technical Document: overview and reporting of project philosophy and technical approach: The Wetland Vision Partnership.

Gearey, M., Church, C. & Ravenscroft, N. (2020) *English Wetlands: Spaces of Nature, Culture, Imagination*. Palgrave Pivot.

Kasperson, R.E., Renn, O., Slovic, P., Brown, H.S., Emel, J., Goble, R., Kasperson, J.X. & Ratick, S. (1998) The social amplification of risk: A conceptual framework. *Risk Analysis*, 8(2):177-187.

Maltby, E. & Ormerod, S. (2011) Freshwaters - Openwaters, Wetlands and Floodplains. In: The UK National Ecosystem Assessment Technical Report. Cambridge: UNEP-WCMC.

Medlock, J.M. (2015) Impact of the creation, expansion and management of English wetlands on mosquitoes (Diptera: Culicidae). PhD Thesis. University of Bristol.

Medlock, J.M. & Leach, S. (2015) Effect of climate change on vector-borne disease in the UK. *Lancet Infectious Diseases*, 15(6):721-730.

Medlock, J.M. & Vaux, A.G.C. (2011) Assessing the possible implications of wetland expansion and management on mosquitoes in Britain. *European Mosquito Bulletin*, 29:38-65.

Medlock, J.M. & Vaux, A.G. (2015) Impacts of the creation, expansion and management of English wetlands on mosquito presence and abundance - Developing strategies for future disease mitigation. *Parasites and Vectors*, 8(1)142.

Purseglove, J. (2015) *Taming the Flood: Rivers, Wetlands and the Centuries-Old Battle Against Flooding.* London: William Collins.

Wilcox, H.A. (1933) *The Woodlands and Marshlands of England.* Liverpool: Liverpool University Press.

2. MOSQUITOES AND THEIR PLACE IN BRITISH WETLANDS

Where present, mosquitoes can play an important role in the ecological relationships within wetland ecosystems and can be a valuable source of biomass in both aquatic and terrestrial environments.

Larval stages are essentially detritivores, filter feeding on particulate organic matter in the water. They graze on vegetative *detritus*, algae and the remains of other animals. As adults, both males and females feed on plant juices (Figure 2.1), such as floral nectar. In so doing, mosquitoes can play a role in pollination, although this is not well understood and there are no known British plant species that are dependent on mosquitoes for pollination. Males survive solely on plant sources of energy and nutrients; only the adult females procure a blood meal from suitable vertebrate hosts to obtain the protein and nutrients necessary for egg development.

Figure 2.1. *An adult female* Aedes cantans *feeding on nectar from a flowering blackthorn* (Prunus spinosa).

Significantly, all mosquito life stages are a valuable and prolific food source for many other species. Mosquitoes can be predated as larvae and pupae by other aquatic organisms, and it is assumed that their eggs may be predated, too. A range of terrestrial organisms predate adult mosquitoes while they rest in vegetation, mate or seek resources on the wing, and during diapause in their over-winter refuges. During adult emergence from the pupal stage, when the mosquito is particularly vulnerable at the water's surface, they can face attack from both aquatic and terrestrial predators (Figure 2.2).

Laboratory and field studies on the predators of British mosquitoes have focused on a handful of the most abundant mosquito species at various life stages and during different behaviours. These have identified a huge range of predatory taxa, including multiple species from thirteen arachnid families and six insect orders, as well as twelve species of fish, twenty-four species of birds and various crustaceans, amphibians and mammals, several of which are of significant conservation importance (Table 1). It is likely that these confirmed predators represent only a fraction of the total number of species that predate live mosquitoes or feed on their remains. While not definitive, this list is illustrative of the multiple interactions between mosquito fauna and other British wildlife.

Quantifying the contribution that mosquito populations make to a given ecosystem in terms of nutrient cycling and as a prey item is challenging, as these interactions can be difficult to observe and measure. However, as r-selected organisms – producing hundreds of offspring per parent – mosquitoes can account for abundant biomass in aquatic habitats that, due to predation, does not necessarily translate into large adult populations, which can themselves be heavily predated. An initial survey to determine the mosquito species and their relative abundance in a given area can provide useful information for site managers, which may be relevant to biodiversity or conservation strategies. The role of mosquitoes as a prey species should be an important consideration in balancing priorities that arise from habitat protection, wildlife conservation and mosquito control.

Within the mosquito fauna, there are also rare and endangered species. According to the Natural History Museum website on IUCN Red Data List insects, there is reference to six species of mosquito found in Britain: *Aedes communis*, *Aedes dorsalis*, *Aedes flavescens*, *Aedes leucomelas*, *Aedes sticticus* and *Culiseta longiareolata*. It is perhaps surprising that these are included as it is relatively uncommon for mosquito fauna to be included in biodiversity audits of conservation habitat or areas of planned development. This is likely in part because many of the standard methods for sampling invertebrates, such

Figure 2.2. *A* Culex pipiens *male emerging from its pupal case at the water surface. During emergence, when the mosquito hatches from its aquatic pupal stage into a fully formed terrestrial adult, the mosquito is unable to escape and vulnerable to attack from predators, both beneath the water and from above.*

as pitfall trapping and sweep netting, are not suited to detecting mosquito species; for instance, sweep-netting tends to capture male mosquitoes which are usually worn specimens and are not easy to identify. Mosquito sampling requires more specialized, albeit simple approaches. The frequent absence of mosquitoes from sites' species lists may also reflect casual treatments of all mosquitoes as 'pests', as opposed to important constituents of an area's overall biodiversity, without differentiating between the many different species and their different nuisance potential. Consequently, despite their intrinsic biodiversity value and role as a prolific source of biomass in the food web, site-specific baseline data on mosquito species composition and abundance is often of poor quality or lacking entirely.

Table 1. Predators of mosquitoes according to mosquito life stage. Predator species are listed with common name first, if applicable, followed by binomial name. For holometabolous arthropod predators, square brackets indicate which life stage is implicated as a predator, i.e. [nymphs], [larvae] and [adults]. Where field or laboratory observations of predations have been recorded for specific mosquito species, these are indicated. Adapted from Medlock and Snow (2008).

MOSQUITO LIFE STAGE & SPECIES	PREDATOR SPECIES
Immatures	
In Freshwater Evidence for predation of: • *Aedes cantans* • *Aedes punctor* • *Anopheles claviger* • *Culex pipiens* s.l. • *Culex torrentium*	**Odonata** Emperor dragonfly *Anax imperator* [nymphs] Azure damselfly *Coenagrion puella* [nymphs] Southern damselfly *C. mercurial* [nymphs] Common blue damselfly *Enallagma cyathigerum* [nymphs] Blue-tailed damselfly *Ischnura elegans* [nymphs] Broad-bodied chaser *Libellula depressa* [nymphs] Large red damselfly *Pyrrhosoma nymphula* [nymphs] Common darter *Sympetrum striolatum* [nymphs]  Emperor dragonfly *Anax imperator*

MOSQUITO LIFE STAGE & SPECIES	PREDATOR SPECIES
Immatures (cont'd)	

Coleoptera

Agabus bipustulatus [adults, larvae]
Agabus sturmii [larvae]
Colymbetes fuscus [larvae]
Great diving beetle *Dytiscus marginalis* [adults, larvae]
Brown-bellied great diving beetle *Dytiscus semisulcatus* [larvae]
Whirligig beetle *Gyrinus natator* [adults]
Hydroporous spp. [adults, larvae]
Diving water beetle *Hyphydrus ovatus* [adults]
Crawling water beetle *Peltodytes* spp. [larvae]
Rhantus spp. [larvae]
Hygrotus spp.

Hemiptera

Lesser water boatman *Corixa punctate* [adults]
Water boatman *Cymatia bonsdorfii*
Pond skater *Gerris gibbifer*
Pond skater *Gerris lacustris* [adults]
Water measurer *Hydrometra stagnorum* [adults]
Water scorpion *Nepa cinereal* [adults]
Water boatman *Notonecta glauca*
Water cricket *Velia caprai* [adults]

Trichoptera

Caddisfly *Glyphotaelius pellucides*
Caddisfly *Trichostegia minor*

Fish

Bleak *Alburnus alburnus*
Carp *Cyprinus carpio*
Curcian carp *Carassius carassius*
Goldfish *Carassius auratus*
Gudgeon *Gobio gobio*
Goby *Gobius microps*
Minnow *Phoxinus phoxinus*
Perch *Perca fluviatilis*
Roach *Rutilus rutilus*
Rudd *Scardinus erythrophthalmus*
Stickleback *Gasterosteus aculeatus*
Tench *Tinca tinca*

Amphibians

Common toad *Bufo bufo*
Common frog *Rana temporaria*
Great crested newt *Trituris cristatus*
Smooth newt *Trituris vulgaris*
Land flatworm *Tricladida* spp.

Pond skater *Gerris lacustris*

Carp *Cyprinus carpio*

Common toad *Bufo bufo*

Common frog *Rana temporaria*

MOSQUITO LIFE STAGE & SPECIES	PREDATOR SPECIES
Immatures (cont'd)	
In brackish water/ saltmarsh Evidence for predation of: • *Aedes detritus*	**Amphipods** Brackish water amphipod *Gammarus duebeni* Talitrid amphipod *Orchestia cavimana* **Crustaceans** Common ditch shrimp *Palaemonetes varians*
In artificial containers Evidence for predation of: • *Culex pipiens* s.l. • *Culex torrentium*	**Coleoptera** *Agabus bipustulatus* [adults, larvae] Great diving beetle *Dytiscus marginalis* [adults, larvae] *Helophorus aquaticus* Diving water beetle *Hydroporus memnonius* [adults] *Hydroporous* spp. Hyphydrus ovatus [adults]  Great diving beetle *Dytiscus marginalis*

MOSQUITO LIFE STAGE & SPECIES	PREDATOR SPECIES
Adults	
Emerging from pupae Evidence for predation of: • *Aedes cantans* • *Aedes geniculatus* • *Aedes punctor* • *Culex* spp.	**Empididae (Dance flies)** *Hilara cornicula* *Hilara interstincta* *Hilara lugubris* *Hilara pilosa* *Rhamphomyia crassirostris* **Dolichopodidae (Long-legged flies)** *Campsicnemus scambus* *Campsicnemus survipes* *Dolichopus popularis* *Hercostomus* spp. *Poelcilobothrus nobilitatus* **Anthomyiidae** *Hydrophoria ruralis* Emperor dragonfly *Anax imperator* Common darter *Sympetrum striolatum* **Odonata** Emperor dragonfly *Anax imperator* Common darter *Sympetrum striolatum* **Arachnida** Orb-web spider *Meta megai* Orb-web spider *Meta segmentata* *(Metallina segmentata)* Large wolf spider *Pirata piscatorius* Comb-footed spider *Theridion ovatum*  Long-legged fly *Dolichopus popularis*  Common darter *Sympetrum striolatum*

MOSQUITO LIFE STAGE & SPECIES	PREDATOR SPECIES
Adults (cont'd)	
Resting in vegetation Evidence for predation of: • *Aedes cantans*	**Araneidae (Orb-weaver spiders)** European garden spider *Araneus diadematus* Orb-weaver spider *Cyclosa conica* Meta segmentata *(Metallina segmentata)* **Linyphidae (Money spiders)** *Erigone promiscua* *Linyphia clathrate* *Linyphia hortensis* *Linyphia peltate* *Linyphia triangularis* *Neriene montana* **Thomiscidae (Crab spiders)** *Ozyptila atomaria* *Xysticus lanio* **Lycosidae (Wolf spiders)** Meadow spider *Lycosa amentata* *Pirata piraticus* *Pardosa pullata* **Salticidae (Jumping spiders)** Zebra spider *Salticus scenicus* *Theridiidae* (Comb-footed spiders) *Theridion ovatum* Mothercare spider *Theridion sisyphium* *Theridion lunatum* **Agelenidae (Funnel-web spiders)** *Tegenaria domestica* *Tegenaria duellica/saeva* **Pisauridae (Nursery web spiders)** *Pisaura mirabilis* **Tetragnathidae (Long-jawed orb weaver spiders)** *Tetragnatha montana* *Tetragnatha* spp. **Amourobiidae** Black lace-weaver spider *Amaurobius ferox* **Opiliones (Harvestmen/Daddy longlegs)** *Leiobunum blackwalli* *Leiobunum rotundum*


Money spider *Linyphia triangularis*


Crab spider *Xysticus lanio*


Zebra spider *Salticus scenicus*


Nursery web spider *Pisaura mirabilis*


Harvestman spider
Leiobunum rotundum

MOSQUITO LIFE STAGE & SPECIES	PREDATOR SPECIES
Adults (cont'd)	
In flight Evidence for predation of: • *Anopheles plumbeus*	**Aves (Birds)** Mallard *Anas platyrhynchus* Swift *Apus apus* Moorhen *Gallinula chloropus* Coal tit *Periparus ater* Marsh tit *Poecile palustris* Willow tit *Poecile montanus* Blue tit *Cyanistes caeruleus* Swallow *Hirundo rustica* House Martin *Delichon urbica* Long-tailed tit *Aegithalos caudatus* Willow warbler *Phylloscopus trochilus* Chiffchaff *Phylloscopus collybita* Whitethroat *Sylvia communis* Goldcrest *Regulus regulus* Wren *Troglodytes troglodytes* Spotted flycatcher *Muscicapa striata* Pied flycatcher *Ficedula hypoleuca* Grey wagtail *Motacilla cinerea* Pied wagtail *Motacilla alba* Meadow *pipit Anthus pratensis* Linnet *Linaria cannabina* Lesser redpoll *Acanthis cabaret* Siskin *Spinus spinus* Yellowhammer *Emberiza citrinella* **Chiroptera [bats]** Natterer's bat *Myotis nattereri* Whiskered bat *Myotis mystacinus* Daubenton's bat *Myotis daubentonii* Pipistrelle bat *Pipistrellus pipistrellus* Dragonfly spp. Dancefly *Tacydromia* spp.  Yellowhammer *Emberiza citrinella*  Moorhen *Gallinula chloropus*  Grey wagtail *Motacilla cinerea*  Daubenton's bat *Myotis daubentoniid*
While overwintering Evidence for predation of: • *Culex* spp.	**Tetragnathidae (Long-jawed orb-weaver spiders)** *Meta merianae* *Meta segmentata (Metallina segmentata)* **Agelenidae (Funnel-web spiders)** *Tegenaria atrica* House spider *Tegenaria domestica* *Tegenaria silvestris* **Linyphiidae (Money spiders)** *Lepthyphantes leprosus*  Funnel-web spider *Tegenaria silvestris*

MOSQUITO LIFE STAGE & SPECIES	PREDATOR SPECIES
Adults (cont'd)	
	Amourobiidae *Amaurobius ferox* *Amaurobius* spp. **Scytodidae** Spitting spider *Scytodes thoracica*  Lace webbed spider *Amaurobius fenestralis*

Further reading

British Dragonfly Society (2007) Available from: http://www.dragonflysoc.org.uk/frameset.htm?home&home. Accessed 15 May 2020.

Jeffries, M. (1988) Individual vulnerability to predation: the effect of alternative prey types. *Freshwater Biology*, 19:49-56.

Lockwood, A.P.M. (1986) *Gammarus duebeni* as a predator of mosquito larvae. *Porcupine Newsletter*, 3:201-203.

Medlock, J.M. & Snow, K.R. (2008) Natural predators and parasites of British mosquitoes–a review. *European Mosquito Bulletin*, 25(April): 1–11.

Molenkamp, A.N. (1998) Seasonal emergence pattern, sex ratio and biological control of the saltmarsh mosquito, *Aedes detritus* (Haliday). University of East London. M.Phil. Thesis.

Onyeka, J.O.A. (1983) Studies on the natural predators of *Culex pipiens* L. and *C. torrentium* Martini (Diptera: Culicidae) in England. *Bulletin of Entomological Research*, 73:185-194.

Onyeka, J.O.A. & Boreham, P.F.L. (1987) Population studies, physiological state and mortality factors of overwintering adult populations of females of *Culex pipiens* L. (Diptera: Culicidae). *Bulletin of Entomological Research*, 77:99-112.

Ramsdale, C.D. & Snow, K.R. (1995) *Mosquito Control in Britain*. University of East London.

Service, M.W. (1967) Tachydromia spp. (Diptera: Empididae) as predators of adult anopheline mosquitoes. *Entomologist's Monthly Magazine*, 104:250-251.

Service, M.W. (1968) Observations on the ecology of some British mosquitoes. *Bulletin of Entomological Research*, 59:161-194.

Service, M.W. (1973) Study of the natural predators of *Aedes cantans* (Meigen) using the precipitin test. *Journal of Medical Entomology*, 10:503-510.

Roberts, G.M. (1995) Salt-marsh crustaceans, *Gammarus duebeni* and *Palaemonetes varians* as predators of mosquito larvae and their reaction to *Bacillus thuringiensis* subsp. *israelensis*. *Biocontrol Science and Technology*, 5:379-385.

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

Sulaiman, S. & Service, M.W. (1983) Studies on hibernating populations of the mosquito *Culex pipiens* L. in southern and northern England. *Journal of Natural History*, 17:849-857.

Wray, A.K., Jusino, M.A., Banik, M.T., Palmer, J.M., Kaarakka, H., Paul White, J., Lindner, D.L., Gratton, C. & Zachariah Peery, M. (2018) Incidence and taxonomic richness of mosquitoes in the diets of little brown and big brown bats. *Journal of Mammalogy*, 99(3), 668–674.

3. PUBLIC HEALTH ISSUES ASSOCIATED WITH MOSQUITOES

While mosquitoes contribute to biodiversity and are a natural component of many wetland ecosystems, certain aspects of the biology of some species can give rise to public and veterinary health concerns. These stem from the blood-feeding behaviour of adult female mosquitoes, which can have the potential to cause a nuisance and, in certain settings, can facilitate the transmission of pathogens. This is because some species of mosquitoes are vectors of viruses, parasites and other microorganisms that can cause disease.

Currently in the UK, these risks are negligible or minimal. However, these are important considerations to be factored into wetland planning and management. Addressing the potential impact of mosquitoes should be an essential component of the health chapter of any Environmental Impact Assessment and it ought to be routine to assess the potential for mosquito nuisance, with plans to mitigate these impacts where necessary, at the early stages of wetland design or as part of wetland management. Wetland management plans should develop a contingency for mosquito management (through wetland management strategies rather than just biocide usage) in the event of an outbreak. There will be no time to devise such plans in the face of an outbreak, so developing an understanding of the role of mosquitoes in possible disease transmission and prior planning are highly recommended. The fact that wetlands do produce aquatic habitats for mosquitoes should be accepted, but it should also be recognised that evidenced-based management strategies targeted at key mosquito species will be crucial in managing disease outbreaks (or nuisance mosquito problems). The table in Appendix III summarises the potential nuisance and vector concerns associated with each of the British mosquito species, with possible mitigation strategies where possible.

Steps to considering mosquitoes during Environmental Impact Assessment

1. Identify current or planned aquatic habitats that may be suitable for mosquitoes and how they are or will be managed.
2. Establish which mosquito species are associated with or likely to colonise these habitats using the Wetland Mosquito Prediction Tool (see Chapter 7); where possible, verify this in extant wetlands via larval and adult sampling.
3. Determine the behaviour and ecology of the species identified, including their host animal preference/s, propensity to move away from breeding sites, and daily and seasonal peaks in activity and abundance, alongside other species-specific factors that may influence their potential to cause nuisance biting (see Chapter 6).
4. Consider where and when people are expected to visit the site and the proximity of these areas to habitats associated with potential nuisance mosquito species. Such areas may include residential, commercial and industrial areas and visitor amenities (e.g. car parks, education centres, footpaths, hides, cafes). Scope off-site areas adjacent to habitats that may be similarly frequented by people.
5. Evaluate the likelihood of human-mosquito contact by assessing the ecological and spatio-temporal information.
6. Consider mitigation actions to reduce potential nuisance if this is deemed necessary; examples of suitable mitigation may include action to minimise visitor numbers in areas adjacent to specific habitat types at certain times or adapting management plans to reduce the suitability of a given habitat to specific mosquito species.

There are occasions when public fear and misperceptions surrounding the risks associated with mosquitoes should also be considered. Misunderstandings about the basic biology of mosquitoes and the link between these insects and disease can cause concern. This may lead to public opposition to wetland habitats, which can be a particular issue for new wetland creation and restoration schemes. Access to up-to-date information and dissemination of the available evidence may alleviate these concerns and help to inform sensitive wetland management strategies.

3.1 Nuisance biting

Female mosquitoes of most species need a blood meal from a vertebrate host to obtain the nutrients necessary to develop their eggs. In the process of biting, the female inserts a proboscis into the skin of the host animal (Figure 3.1). The proboscis is composed of mouthparts specially adapted to blood-feeding. A tube-like structure, called the labrum, is used to imbibe blood, while another, called the hypopharynx, injects a small volume of saliva, which contains compounds that anaesthetise the area and prevent the host's blood from clotting. Bites can cause an itchy welt in some people, or go entirely unnoticed by others, a result of individual immune responses to the mosquito's saliva. Occasionally, as with any small break in the skin, the puncture site itself can become infected by bacteria.

Figure 3.1. *A female* Aedes cantans *during feeding on a human arm. The straw-like labrum can be seen drawing blood from the arm, while the mosquito's abdomen fills with the blood meal. After feeding, the insect will take a period of rest to digest the meal, nutrients from which are used to develop eggs.*

While the majority will take blood meals from birds, reptiles, amphibians and/or other mammals, around 25 of the 36 recorded British mosquito species are documented to engage in some degree of human biting. Beyond the occasional bite, which most people will experience at some time, mosquitoes can cause a public health nuisance in certain situations. These are more likely to occur where the following three criteria are met:

1. The mosquito population is composed of species with a preference for feeding on humans, a trait known as anthropophagy. This preference can vary depending on the availability of other host animals;
2. The adult female mosquito population is highly abundant and actively searching for hosts to feed on. Depending on the species, the intensity of this host-seeking behaviour can vary temporally, both annually across the seasons and daily between day, night and crepuscular periods, and spatially, as some species are unwilling to enter indoor environments to feed; and
3. The host-seeking females are located in sufficient proximity to a human host population to allow human biting to take place.

Figure 3.2 represents how biting intensity on humans is likely to be highest (red) where there is a high abundance of very anthropophagic mosquitoes and lowest (green) where the mosquito population is small and exhibits weak anthropophagy. It is worth nothing that low abundances of highly anthropophagic mosquitoes may still cause a notable biting nuisance. Importantly, human biting can only occur where the human population is within flight range of the mosquito population. Depending on species, flight range can be between a few hundred metres from larval habitats, to several kilometres.

Species with little or no degree of anthropophagy are unlikely to ever cause a nuisance to people, even when present in high numbers. However, they can occasionally contribute to perceived risks of nuisance biting. For instance, the abundant and widespread mosquito *Culex pipiens* biotype *pipiens* is strongly ornithophagic (bird-

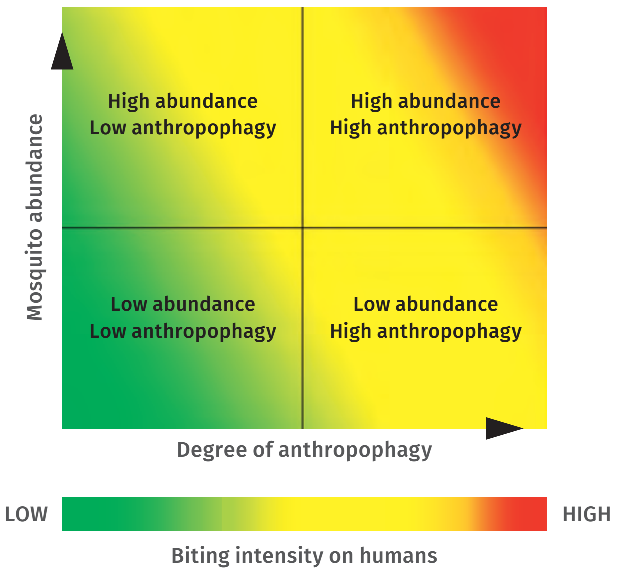


Figure 3.2. *Representation of biting intensity as a function of mosquito abundance and degree of anthropophagy.*

Table 2. The five species most commonly associated with nuisance biting in the UK and a summary of their characteristics.

SPECIES	DISTRIBUTION	AQUATIC HABITATS	PUBLIC HEALTH CONCERN
Anopheles maculipennis sensu lato	Widespread	Open sunlit permanent pools of fresh or slightly brackish water	Can cause biting nuisance, especially local to coastal populations; the *atroparvus* member of the complex is the historical malaria vector in the UK
Culex pipiens 'molestus' biotype	Highly localised but locally abundant	Sewage works, cloistered, underground water bodies (e.g. flooded cellars and mines)	Aggressively bites humans in vicinity of larval habitats; known for biting Londoners sheltering in the London Underground during the Blitz
Culiseta annulata	Widespread	Wide range of permanent and temporary wetlands and container habitats	A common nuisance species and conspicuously large; its striped legs are often confused with invasive species
Aedes cantans	Widespread	Shaded pools and ditches in wet woodland subject to drying and re-wetting	Serious nuisance pest; will bite throughout the day and at dusk
Aedes detritus	Widespread	Brackish coastal pools subject to drying and re-wetting; some freshwater populations recorded	Persistent nuisance biter, will fly up to 10 km in search of a blood meal; responsible for several UK mosquito control programmes

feeding) with a very low likelihood of taking a blood meal from a person. However, during the cold winter months it will seek shelter, often inside domestic dwellings, basements and attics, where residents may observe it resting and incorrectly associate it with a biting risk. Similarly, 'swarms' of insects observed flying in groups may belong to a wide range of taxa unrelated to biting insects but can be casually identified as mosquitoes (or 'midges' and 'gnats') and assumed to be nuisance species.

Conversely, a small population of highly anthropophagic species has the potential to cause a considerable nuisance if they are found close to human settlements or encountered by visitors to the areas they inhabit (see Table 2).

In addition to these, in recent years, there have been severe, but highly localised nuisance issues reported, attributable to *Aedes vexans* and *Culex modestus*. Records of these species have increased since 2010, although their populations appear to be geographically confined to very localised areas in Eastern and Central England, and Southeast England, respectively. *Aedes vexans* is associated with low-lying grassland that inundates during riverine flooding, while *Culex modestus* has a narrow coastal distribution in often sparsely populated areas of grazing marsh.

3.2 Responding to a mosquito nuisance

In 2009, a survey of UK Local Authorities (LAs) found that 57 out of 221 reported biting nuisance incidents caused by mosquitoes in the previous ten years, and 29 confirmed them in the previous 12 months. All incidents were attributed to local species. However, this represented a doubling in nuisance biting reports compared to the ten years prior to the previous LA survey on mosquito nuisance, which took place in 1996.

Environmental Health Officers from LAs are likely to be the first to receive complaints about nuisance biting insects and are required to respond to pest issues under the Public Health Act 1936 and Clean Neighbourhood and Environment Act 2005. The latter gives LAs, the Environment Agency and community and parish councils powers to deal with poor environmental quality when it arises from insects, as well as litter and dogs. Section 101 of this act states that statutory nuisances include:

> ***"insects emanating from relevant industrial, trade or business premises and being prejudicial to health or a nuisance"***

and this includes sufficient quantities of mosquitoes as to cause a nuisance. Such numbers may occur from time-to-time on wetland amenity habitats, but are associated more often with sewage treatment works, used tyre recycling businesses and landfill sites.

Responding to public enquiries about mosquitoes

Occasionally, those with responsibility for a wetland may receive enquiries regarding mosquitoes. Having ready access to accurate site data and evidence-based information on the biology, ecology and behaviour of British mosquitoes can help in preparing a timely and credible response. The information in this book summarises what is currently known and provides information on where more detailed data can be found. An informed response, based on the available evidence, can build trust and confidence with the public. The following steps can help in responding to enquiries or concerns about mosquitoes:

Audit predicted/actual mosquito fauna on site: use the mosquito prediction tool in this book (see Chapter 7) and/or data from samples collected on site to determine which mosquito species, if any, may be present. Information on their relative abundance may also be helpful where potential nuisance species are identified. Doing this before an enquiry is received will allow for a timely, informed response. Relevant information on the species (summarised in Chapter 6 in this book and in detail elsewhere), either predicted or confirmed, can then form part of a rapid, accurate, site-specific reply to the enquiry received.

Evaluate any potential public health issues: once you have predicted or confirmed which species may be found on site, evaluate any possible nuisance or future vector concerns. This process can be incorporated into preparing site risk assessments. Where they may be necessary, mitigation actions can be described and implemented. While good practice in its own right, this process can also reassure stakeholders and the public by demonstrating a responsible and proactive approach to wetland management with respect to mosquitoes.

Communicate the wider ecological context: mosquitoes are part of many healthy wetland environments. The British mosquito species are diverse and themselves form part of wetland biodiversity. They are important prey for hundreds of other species, many beloved by the public or of conservation value. The biting activity of females is usually very spatially and temporally constrained. Such information may be helpful in contextualising a response.

Consider creative ways to engage the public: often, misunderstandings about mosquito biology and invasive mosquito species can lie at the heart of concerns. Creative ways of communicating ecological information about mosquitoes on site can dispel myth and misapprehension, evoke empathy and understanding and an appreciation of the role of mosquitoes in the wider wetland ecosystem. This may take the form of including information about local mosquito species on information boards, in planned public activities, like guided walks (Figure 3.2) and pond dipping, as well as at specific creative events, such as performances, exhibitions and competitions.

Be aware of the public health situation: while there are currently no mosquito-borne diseases affecting humans in the UK, there is the possibility that this may change in the future. Remaining informed of any changes to public health risk will allow for risk assessments to be re-evaluated where necessary.

It is worth remembering that adult mosquitoes, while they generally do not disperse over great distances, are mobile and can fly onto sites from aquatic breeding habitats beyond the site's boundaries. Thus, reports of mosquitoes (which are likely to relate to biting adult females, rather than larvae) may be driven by the production of larvae in breeding sites situated in neighbouring areas outside of your immediate control. Dialogue with the wider community, including industry, can help to resolve such issues.

Figure 3.3. *A guided "Mosquito Safari" in Bedfordshire, where members of the public joined an entomologist to explore wetlands and their surrounding habitats, including pond dipping activities, with a view to understanding where and how the various life stages of different British mosquito species fit into the landscape. Discussion covered some of the less well-known aspects of mosquito biology and participants reported changed perspectives on mosquitoes, including empathy and fascination. Image: Gillian Summers/NRI.*

3.3 Disease

As described above, the process of blood feeding involves the female mosquito both sucking up blood from the host animal and injecting its own saliva into the animal. It is this process that allows a small number of mosquito species to transmit pathogens that can cause disease in humans and animals. These mosquito species are called *vectors*, meaning they can transmit a pathogen from one animal host to another. Pathogens, including viruses, bacteria and parasitic microorganisms can be picked up in a blood meal from an infected animal host, after which the pathogen usually, although not always, undergoes some form of development in the mosquito's gut. Then, the infectious stage of the pathogen migrates to the mosquito's salivary gland, from where it can be injected into a new host animal or person when the mosquito next takes a blood meal.

Currently in the UK, there are no known mosquito-borne diseases that affect humans, although several endemic mosquitoes have the ability to act as vectors, should they take a blood meal from an infected animal. The species of mosquitoes that feed primarily on non-human hosts can play a role as *enzootic vectors* of arboviruses, that is they spread pathogens between animal hosts, and therefore may need to be considered in disease management, even though they may cause no direct transmission to humans.

With respect to animals, there are primarily three diseases associated with mosquitoes in the UK. Firstly, mosquitoes transmit the parasites that cause avian malaria. These parasites belong to the same *Plasmodium* genus as those that cause human malaria, but are a different species called *Plasmodium relictum*. These are transmitted in Britain by *Culex pipiens* mosquitoes. Avian malaria infections in wild birds are rarely fatal, however, there have been several reports of collapses of penguin colonies in British safari parks, thought to be because these birds are more susceptible because they have evolved in cold climates which are not suited to transmission of mosquito-borne diseases. The second, myxomatosis, infects European rabbits (*Oryctolagus cuniculus*). The virus that causes myxomatosis (*Myxoma virus*) is transmitted passively on the mouthparts of various biting insects, including mosquitoes, as well as fleas, lice, mites and other flies. The third, also a virus, causes avian pox, and is also likely to be transmitted by other biting insects alongside mosquitoes, as well as through bird to bird contact and contact with contaminated material such as bird feeders. Mosquitoes also transmit a range of other generally benign microorganisms to wild birds, and possibly to poultry and amphibians.

Since the turn of the 21st century, the status of vector-borne diseases in Europe has changed dramatically,

Figure 3.4. *An overwintering female* Anopheles maculipennis *sensu lato.*

following the emergence of mosquito-borne viruses new to Europe, such as chikungunya and Zika, and the re-emergence of once eradicated diseases like malaria and dengue. These events are complex and driven by a wide range of factors, such as increased globalisation and infrastructure, intercontinental travel and global shipping transport, as well as changes in climate, land use and the environment. The role of wetland management strategies may be important in preventing or mitigating any potential future UK disease risk from mosquito-borne pathogens. Crucially, in the event of an outbreak of mosquito-borne disease, strategies to manage mosquitoes in wetlands will be a priority. Understanding the role of wetlands and their management with respect to key mosquito species ahead of time will prevent inefficient and inappropriate actions in the golden hour.

3.3.1 Human Malaria

Now eradicated in the UK, it was only last century that malaria was endemic in the lowland fens and coastal marshes of England. This caused significant mortality in these areas between the 15^{th} and 19^{th} Centuries. Local malaria, or "ague" is suspected to have resulted from transmission of *Plasmodium vivax*, one of five species of malaria parasite known to infect humans.

Malaria can only be transmitted by mosquitoes of the genus *Anopheles* but not all *Anopheles* species can transmit the parasite. Britain is home to several of these *Anopheles* species and they maintained localised malaria transmission until the early years of the 20th Century, with occasional outbreaks until the 1950s. The principal British vector was thought to be *An. atroparvus*, which is associated with the brackish waters of coastal marshes and ditches and is member of the *An. maculipennis* sensu lato species complex (Figure 3.4).

Eradication of malaria in the UK came about gradually due to socio-economic development, marsh drainage and changes in agricultural practices from the 1880s onwards, rather than as a result of a targeted public health campaign. Historically, isolated communities in areas where malaria was endemic lived in very close proximity to their livestock, often occupying rudimentary first floor quarters above ground floor cattle sheds. Although *An. atroparvus* does bite humans, its preferred source of a blood meal is cattle. Thus, infected host-seeking females would come into frequent contact with humans, who would get bitten alongside their livestock. As standards of living increased, families would construct better quality, mosquito-proof dwellings away from their cattle sheds, and areas of breeding habitat for *An. atroparvus* were drained to bring under cultivation. Following mechanization, the human population in these areas fell, while cattle numbers increased as winter fodder such as turnips became plentiful; *An. atroparvus* were diverted to their preferred and more abundant cattle host, thus reducing opportunities for the parasite to enter and reproduce in human hosts. Eventually, this broke the chain of transmission between people.

Anopheles atroparvus remains widespread. Other species of Anopheles mosquitoes found in Britain are competent malaria vectors, but not thought to have been significantly involved in malaria transmission here. These include other members of the *An. maculipennis* s.l. species complex (*An. atroparvus*, *An. messeae* and *An. daciae*), *An. plumbeus* and *An. claviger*, one of the most common species in the UK. Although Europe was declared malaria free in 1975, sporadic cases do still occur following the arrival of infected travellers, who can reintroduce the parasite into receptive local anopheline mosquitoes. Since 2011, P. vivax malaria returned to Greece and local and imported cases occur periodically. It is therefore prudent to record local populations of anopheline mosquitoes. However, the risk of malaria re-establishing in the UK is likely to be small because the incidence of human biting by anophelines is very localised, and infected patients would have access to a well-developed healthcare system and antimalarial drugs to reduce the likelihood of onward infection.

3.3.2 Arboviruses

An arbovirus (**ar**thropod-**bo**rne **virus**) is any of a group of viruses which are transmitted by arthropods, such as mosquitoes and ticks. While there is no evidence of current or historic transmission of arboviruses to humans by mosquitoes in the UK, they are an issue of growing concern globally, including in temperate regions of North America and Europe.

West Nile virus

West Nile virus (WNV) is an increasingly significant mosquito-borne arbovirus in temperate regions. The 1999 emergence of WNV in North America as a serious vector-borne disease and, more recently, the establishment of local ongoing WNV transmission in Europe, suggest the range of the virus is expanding. In 2018, Europe experienced its most severe WNV season, with more cases in 2018 than in the previous seven years combined, resulting in 180 deaths.

Birds are the natural host of the virus, which is circulated between individuals by infected mosquito bites. WNV is transmitted by several species of mosquitoes, some of which are present in the UK. Human-biting *Culex* mosquito species are implicated as the primary vectors. Other animals, including humans and horses, can become infected, although they are considered to be 'dead-end' hosts, meaning levels of the virus in their blood are too low to pass on to mosquitoes. Nonetheless, birds, humans and horses can develop clinical symptoms, although most infected individuals are asymptomatic. In rare instances, however, the resulting disease can be serious, and sometimes fatal.

Although WNV has not yet been reported from the UK, several species of mosquito capable of transmitting the virus are found in the UK. Of most concern to humans is *Culex modestus*, as this species will bite both birds and mammals, including humans, and so would be capable of acquiring the virus from wild bird hosts and passing it on to mammals, such as humans and horses. As primarily a virus of birds, some of which are migratory, it is possible that infected birds could arrive in the UK and pass on the virus to receptive local mosquito populations, including *Cx. pipiens* as a vector between birds (*enzootic vector*). Currently, *Cx. modestus* has a very restricted, predominantly coastal distribution in the southeast of England. Awareness of the presence of this mosquito in a wetland site may influence management activities in the event of future arrival of WNV in the UK.

Dengue, Zika and chikungunya viruses

These viruses are found in many parts of the world, the distribution of which having expanded due to establishment of the principal vectors *Aedes albopictus* and *Aedes aegypti*. These mosquitoes are tree hole mosquito species but have adapted to exploit anthropogenic container habitats for their aquatic stage, particularly in urban and peri-urban landscapes, and are consequently associated with people's homes, gardens, and yards, in water holding containers such as tyres, buckets, litter, and blocked drains. In the past three decades, *Aedes albopictus*, the Asian tiger mosquito, has established in Europe and expanded its range, having been reported in at least 28 countries in Europe (see 3.4 Non-native species). As a result of its establishment and increased abundance, coupled with the importation of travellers infected with a range of arboviruses, there have been locally acquired cases of dengue, chikungunya, and Zika in Europe, particularly France.

In the UK, there have been no locally acquired cases of these mosquito-borne arboviruses. In order to provide up to date information to direct risk surveillance for these viruses, and to prevent or delay the establishment of *Aedes albopictus* (or other invasive *Aedes* (*Stegomyia*) mosquito species) by detection and mosquito control, PHE maintains a surveillance scheme aimed at identifying incursions of this mosquito.

3.4 Non-native species

Invasive and non-native species can pose problems for conservation and biodiversity. As with other taxa, the possibility of invasive mosquitoes arriving in the UK is of some concern, especially where those species may be potential vectors. Several exotic mosquito species have become established in Europe in recent years, some of which are vectors, and it is possible similar colonisation events could occur in the UK.

Of particular concern is the Asian tiger mosquito, *Aedes albopictus* (Figure 3.5). Large areas of continental Europe are now colonised by this species. It is recognized as one of the top 100 most invasive species by the IUCN's Invasive Species Specialist Group. It has rapidly expanded its range from endemic territory in southeast Asia and is now globally widespread, largely due to its strong competitive fitness, ability to exploit global transport networks and international movement of goods, and an apparent tolerance for cooler climates. *Aedes albopictus* can be a significant biting nuisance and is a confirmed vector of several arboviruses and nematodes. This mosquito will feed opportunistically on humans, birds, reptiles, amphibians and stock animals. Human biting during the day and outdoors by this species makes it a serious nuisance.

However, it is important to note that this species is not associated with wetland habitat. Instead, its eggs are generally laid in 'container' habitats, where rainwater pools. These may be naturally-occurring phytotelmata – water-filled cavities in plants such as rain-filled tree holes – or produced when water collects in human-made containers, such as blocked gutters and drains, drinking

Figure 3.5. Aedes albopictus, *the Asian tiger mosquito, is not native to the UK.*

troughs for livestock, litter (e.g. discarded steel/tin cans), flowerpots, old tyres and other human-made crevices where water can collect.

Routine surveillance for invasive mosquito species, including *Ae. albopictus*, is coordinated by PHE with support from a range of local authorities, organisations and individuals across the UK. Through its network of monitoring stations, in September 2016 PHE detected a small number of *Ae. albopictus* eggs in Kent and advised the LA to use larvicides to prevent the development of any adult mosquitoes. Enhanced surveillance found no further evidence of *Ae. albopictus* in that area. In July 2017, both eggs and larvae were identified in another location in Kent and again followed by treatment and follow-up surveillance. The species was found again in 2018 and 2019, and again locally controlled with no subsequent evidence of survival. As of 2020, *Ae. albopictus* is not yet thought to have become established in the UK. Despite active surveillance and control, it is possible that this species, and others, may eventually become established following future arrivals. Ongoing targeted surveillance and data collection regarding mosquito fauna are important components in preparing the response to future detection of non-native mosquito species.

3.5 Public perceptions of mosquitoes

Mosquitoes can be found on all continents except Antarctica and most people have experienced an irritating mosquito bite at some point in their life. Many can also recognise these insects, either by the familiar droning whine of an adult on a summer's night, or as 'wrigglers', the larval stages which can often be found in garden ponds and water butts. However, there can be confusion and misattribution of any insect bites or stings to mosquitoes. Swarms of small flying insects can also be inaccurately grouped variously under the name of gnats, midges and mosquitoes, these being used interchangeably as a colloquial term for any small flies.

In the WetlandLIFE project, people living and working on wetlands were interviewed about their perceptions of mosquitoes. The results showed that among participants mosquitoes were generally not considered a serious concern. Only in some exceptional cases were they perceived as a serious issue or with impacts upon human health. It was found that those who were affected by mosquitoes – particularly nature watchers, volunteers, and those living very near or working in wetlands – would often take precautions or make simple adaptations. These include wearing appropriate clothing, avoiding certain places at certain times of day and using repellents and fire smoke. In one extreme case, a family in Somerset have used mosquito nets in their home, with a farmer explaining, *"They do have quite a significant impact on our life, to the point that a couple of our children sleep in the summer under mosquito nets because they get so badly bitten"*, although this was an exceptional report. Mosquitoes were also reported to have had some impact upon cattle and horses, although again as an occasional irritant and only at certain times of year.

Attitudes towards mosquito presence were mostly quite muted and they were generally met with annoyance rather than a hostile response (with occasional exceptions). Other biting insects – particularly horseflies – were the subject of greater disdain than the mosquito. In fact, there was some admiration for mosquitoes: for instance, a conservation professional said; *"I love mosquitoes! I'll say it again, I love mosquitoes!... I'm convinced that one of the biggest problems facing... our bird life, certainly farmland birds and wetland birds, is the lack of insects"*. The importance of mosquitoes as food for birds and bats, and also in the context of the broader decline of insects, in Europe and globally, over recent decades (and the impact this has on bird populations) was widely acknowledged. Mosquitoes were also referred to as a subject of interest and there were some opinions expressed regarding the intrinsic rights of mosquitoes to exist as part of life on Earth (in a disease-free context); *"They're just part of the wildlife. They've got as much right to be here as anything else."*

The risks of mosquitoes to human health were not at the forefront of participants' concerns, either generally or in relation to wetlands. Although there was some unease and anxiety about future disease risk (malaria and Zika virus in particular, and also disease risk for horses and cattle) there was more concern about the human or environmental impact of control methods, for instance chemical control via insecticides. One wetland resident explained; *"I've got more of a problem with people using what I would consider to be questionable chemicals, I'd be far more worried about people using chemicals to destroy things* *when I was concerned about the effect that that had on the environment and people"*. Most participants felt they would adapt to increases in mosquito populations and/or disease risk, should these occur, with minimal impact on their use and enjoyment of wetlands. However, there was some concern that the situation might change and speculation that increased disease risk would deter some members of the public from enjoying and supporting wetlands.

These responses suggest that, in general, the majority of people living and working on or near wetlands co-exist with the diverse British mosquito fauna. Only in exceptional circumstances do nuisance issues require an adaptation in behaviour. In the majority of situations, the presence of mosquitoes does not cause concern or prevent people accessing the wealth of benefits that wetlands bring (environmentally, socially, culturally and economically). In the context of wider insect declines and the role of mosquitoes in the food web, people appreciate their place within healthy wetlands and are generally very tolerant of receiving the occasional mosquito bite. Given that the majority of British mosquito species are only ever likely to cause an occasional and generally short-lived risk of biting, which, should it manifest, can be mitigated with simple adaptations such as appropriate clothing, mosquitoes should not represent a reason to prevent wetland creation, expansion and restoration.

Further reading

Chin, T. & Welsby, P.D. (2004) Malaria in the UK: Past, present, and future. *Postgraduate Medical Journal*, 80(949):663-666.

Clean Neighbourhoods and Environment Act 2005. Available from: http://www.legislation.gov.uk/ukpga/2005/16/contents. Accessed 18 May 2020.

Dobson, M.J. (1989) History of malaria in England. Journal of the *Royal Society of Medicine, Supplement*, 82(17), 3-7.

European Centre for Disease Prevention and Control (2020) Mosquito-borne diseases. Available from: https://www.ecdc.europa.eu/en/mosquito-borne-diseases. Accessed 18 May 2020.

Golding, N., Nunn, M.A., Medlock, J.M., Purse, B.V., Vaux, A.G.C. & Schäfer, S.M. (2012) West Nile virus vector *Culex modestus* established in southern England. *Parasites and Vectors*, 5(1)32.

Medlock, J.M., Hansford, K.M., Anderson, M., Mayho, R. & Snow, K.R. (2012) Mosquito nuisance and control in the UK – A questionnaire-based survey of local authorities. *European Mosquito Bulletin*, 30(February):15-29.

Medlock, J.M., Hansford, K.M., Vaux, A.G.C., Cull, B., Gillingham, E. & Leach, S. (2018) Assessment of the public health threats posed by vector-borne disease in the United Kingdom (UK). *International Journal of Environmental Research and Public Health*, 15(10).

Medlock, J.M., Snow, K.R. & Leach, S. (2007) Possible ecology and epidemiology of medically important mosquito-borne arboviruses in Great Britain. *Epidemiology and Infection*, 135(3):466-482.

Medlock, J.M. & Leach, S.A. (2015) Effect of climate change on vector-borne disease risk in the UK. *Lancet Infectious Diseases*, 15(6), 721-730.

Public Health Act 1936. Available from: http://www.legislation.gov.uk/ukpga/Geo5and1Edw8/26/49/contents. Accessed 18 May 2020.

Schaffner, F., Medlock, J.M. & Van Bortel, W. (2013) Public health significance of invasive mosquitoes in Europe. *Clinical Microbiology and Infection*, 19(8):685-692.

Vaux, A.G.C. & Medlock, J.M. (2015) Current status of invasive mosquito surveillance in the UK. *Parasites and Vectors*, 8(351).

4. HISTORICAL PERSPECTIVES ON BRITAIN'S 'NUISANCE' MOSQUITOES BETWEEN THE WARS - *Peter A. Coates*

The opening scene of Charles Dickens' *Great Expectations* (1861) is set in a bleak graveyard in north Kent, on the edge of the marshes fringing the Thames estuary. As the novel's young hero, Pip, says to Magwitch, the escaped convict hiding out among the gravestones:

'I think you have got the ague... It's bad about here, you've been lying out on the marshes, and they're dreadful aguish'.

Anopheles atroparvus, Europe's principal malaria carrier, was probably the species responsible for transmitting the native strain of malaria known as ague. Endemic for centuries to the coastal marshlands of Essex and Kent, and other watery lowlands including the fenlands of East Anglia and Somerset Levels, ague (aka marsh fever) killed or debilitated thousands of the young, old, undernourished, sick and poorer residents of wetland regions (Figure 4.1). By 1900, ague had pretty much died out. Not because the parasite's mosquito vector had been eliminated, but thanks to a combination of other factors: more extensive drainage; advances in public health care and improved sanitation; increased separation of human dwellings from livestock and a growing cattle population that transformed biting habits (providing an alternative source of bloodmeals); decreasing virulence of the malaria parasite; growing resistance in the human patient and greater availability of the medicine quinine. Once ague was gone, the mosquito also effectively disappeared from domestic British history.

Figure 4.1. *'Pip's Graves' in the churchyard of St James' Church, Cooling, close to the marshes of north Kent. So-called because they are thought to feature in Charles Dickens' Great Expectations, in which they are described as "little stone lozenges", Pip's Graves are those of 13 infants who are thought to have died of ague, or malaria, between 1767 and 1854.*

And yet, just as anopheline mosquitoes had not been wiped out, Britain's 'nuisance' (aka non-lethal, or pest) species were also still around and capable of inflicting their own kind of 'injury' in terms of depressed property values and lost tourist revenue. Even in Britain, nuisance mosquitoes claim the occasional human life when a bite becomes inflamed and infected, resulting in blood poisoning (sepsis). Between 1921 and 1928, A. Moore Hogarth, the founder and chairman of the London College of Pestology, recorded twenty-one deaths attributable to mosquito bites. At the time, little was known about Britain's nuisance species. With the exception of G.H.F. Nuttall and A.E. Shipley's study of the distribution, habits and natural history of the Anopheline group in England published in the *Journal of Hygiene* in 1901 and W.D. Lang's 1920 *Handbook of British Mosquitoes*, publications in English on mosquitoes and their control were almost exclusively concerned with the disease-carrying mosquitoes of the tropics. As such, they were virtually irrelevant to efforts to combat nuisance varieties in Britain, which appear to have been particularly troublesome during the period between the world wars.

This was preceded by an unusual episode in the global history of malarial mosquitoes. During the latter stages of World War One, hundreds of cases of malaria were contracted on British soil by those who had never set foot abroad (though none was classified as severe and nobody died). In north Kent, for example, at the military camps and hospital near Sheerness, Isle of Sheppey, *Anopheles* mosquitoes were reportedly abundant in surrounding marshlands. (The sites and distribution of locally contracted cases in 1917-18 closely matched the incidence of indigenous malaria in 1860, with the highest incidence along the south and south east coasts.) Ministry of Health officials worried that soldiers returning infected from campaigns in Salonika, Mesopotamia, Egypt and German

East Africa, if bitten by local *Anopheles* mosquitoes, would spread malaria during mass demobilization. A section of the 1st London Sanitary Company (part of the Royal Army Medical Corps) was assigned to mosquito control duties in hotspots such as north Kent (Figure 4.2). The Company's anti-malaria detachment's tasks included applying chemical larvicides to pools and sheep-dipping wells, fumigating farm steadings, cleaning cobwebby attics and lime-washing stables (where *Anopheles maculipennis* overwintered). Mainly, though, their job consisted of clearing algae and duckweed from ditches, dykes and ponds.

Figure 4.2. *Anti-malaria treatment in Kent 1914–1918. Troops of the 1st London Sanitary Company proceeding to work, with the tools needed to clear vegetation from the ditches that still crisscross the coastal marshes in this area. Image: George P. Lewis, ©Imperial War Museum.*

A new front against a different kind of mosquito was opened within a year in an area of coastal marshland in Hampshire. A private organisation known as the Hayling Mosquito Control was set up on Hayling Island in 1920 by local resident John F. Marshall (Figure 4.3). A mechanical engineer and barrister, the independently wealthy Marshall became a self-taught entomologist of international repute and his era's unrivalled authority on British mosquitoes, author of the landmark and still regularly consulted work, *The British Mosquitoes* (1938).

Figure 4.3. *John Frederick Marshall, founder of the Hayling Mosquito Control and, later, the British Mosquito Control Institute. Image: Anon.*

According to Mike Service, a British medical entomologist who donated some of Marshall's records to the Wellcome Library for the History and Understanding of Medicine, Marshall was moved to act 'when his guests were playing on the tennis court of his Hayling Island home and afterwards eating cucumber sandwiches on the lawn they were bitten by mosquitoes'. And garden parties were not the only outdoor activities nuisance mosquitoes apparently ruined in the 1920s. And Hayling Island was not the only place afflicted. The mosquito 'menace' along England's south coast after 1919 resulted from greater numbers combined with more frequent human contact. On Hayling Island, neglect of maintenance work on coastal defences restored the stagnant, brackish waters that were the breeding grounds of *Aedes detritus*, one of two British saltwater varieties, which, of the seventeen species of mosquito recorded locally, was soon identified as the main culprit. Craters left by wartime bombing practice and exposed latrines at military camps where water accumulated became human created breeding sites.

Newly fashioned recreational landscapes were also mosquito friendly. Golf, like tennis, became a fashionable sport – and proliferating courses near coastal resorts included many designed water features. And at mushrooming campsites and scout camps, rainwater collected in discarded sardine tins and jam jars. Meanwhile, the rising popularity of seaside vacations (facilitated by rising private automobile ownership), alongside a more 'open-air' and active recreational life, pursued in 'modern clothing', revealed more flesh. The biting problem was so intolerable, Marshall reported, that Hayling Islanders routinely abandoned the island to the mosquitoes at the height of summer and vacationers were also driven away.

The Hayling Mosquito Control's locally successful 'anti-mosquito crusade' (1921-24) was followed by an expanded (and global) remit under a new name, the British Mosquito Control Institute, in purpose-built premises (1925-39; Figure 4.4). Marshall's operation was not just the first attempt in the UK to eliminate nuisance mosquitoes. His Institute also furnished (in Marshall's words) 'the only opportunity available in this country for studying the various details of a mosquito control organization in actual and continuous operation', not least the particular challenges presented when the site of operations was in a residential area. Those involved in anti-malarial work around the world followed the Institute's work progress and many overseas mosquito scientists and control officials visited Hayling Island.

Figure 4.4. *The research laboratory in the newly built British Mosquito Control Institute. Image: J.F. Marshall, 1925.*

The Institute's small work forces of local volunteers were known as mosquito brigades (Sir Ronald Ross, recipient of a Nobel Prize in 1902 for establishing the link between mosquitoes and malaria, had coined this name and pioneered the practice in the Indian Medical Service thirty years earlier). Working within carefully mapped districts, their task was to wipe out or treat ('petrolage') all sources of standing water, not just marshes, ponds and ditches, large and small in extent, but also puddles and accumulations of water in tree boles, sites that sanitarians would not have considered as breeding environments when the miasma theory held sway.

Ross-style brigades played a particularly crucial role on Hayling Island because of the lack of responsibility on the part of public authorities in Britain at the time for non-lethal mosquito control. In many countries, Marshall pointed out, the owner of the land on which mosquitoes breed is required by law to assume at least part of the costs of control and controllers have the right to access private lands. In Britain, however, despite the provisions of the Public Health Act of 1876, which included 'any pool, ditch, gutter, watercourse, sink, cistern, cesspool or drain so foul or in such a state or so situated as to be nuisance or injurious or dangerous to health', local municipalities had been reluctant to act (Marshall, 1928). The official line adopted by the town council in a south coast resort in the neighbouring county of Dorset, reportedly, was 'there are no mosquitoes in Weymouth' (Hogarth). One of Hogarth's correspondents disputed this, insisting that the council was 'afraid of the existence of mosquitoes getting known' – for fear of putting off visitors – and, so, 'takes no steps to destroy them' (Hogarth). Marshall also suspected that the local authorities in a string of seaside resorts adopted a do-nothing policy because they figured that 'first-time' (blissfully mosquito-unaware) visitors would come in sufficient numbers to compensate for those that did not return because of the nasty mosquito surprise that greeted them.

Not only was permission required to 'drain away [a private landowner's] mosquito-infested waters' but funding also had to be secured. The British Mosquito Control Institute and its predecessor were private initiatives financed predominantly from private sources, largely Marshall's substantial personal inherited wealth (derived from the department store, Marshall and Snelgrove). In the absence of governmental backing, promotional and educational work in the local community was particularly vital. The headmaster of the local school, for example, organized an annual 'Mosquito Control Class' that enlisted schoolchildren in the work of sample collection (Figure 4.5). By the summer of 1923, unsolicited testimonies from local residents pointed to the success of the control campaign. And in August 1926, a happy repeat vacationer reported that during their current stay of two months, 'I have not seen a mosquito with the exception of those in your [Institute's] cages'.

Figure 4.5. *"Methods of examining water for mosquito larvae being demonstrated to School Mosquito Class (Hayling Island).", in Principles and Practice of Mosquito Control: Being a Handbook to the British Mosquito Control Institute by John F. Marshall (1928).*

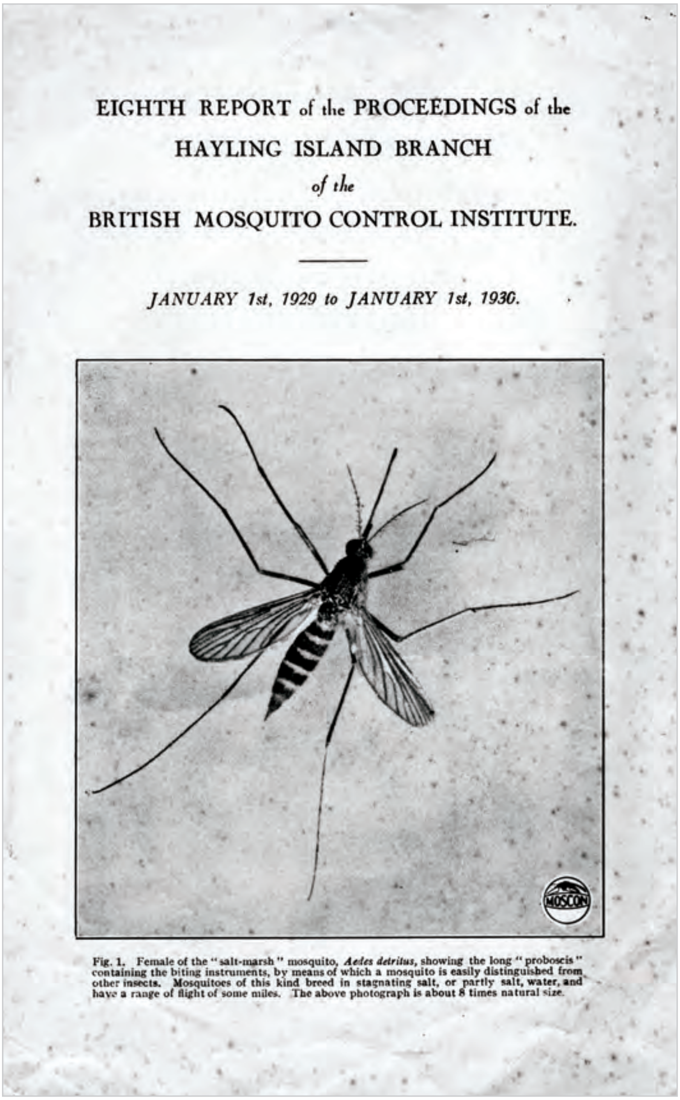
For Marshall, 'seaside' mosquitoes' non-lethality was no reason to accept that they were an unavoidable part of life: something, like the weather or taxes, about which you could complain ad nauseam, but just had to live with. At Hayling Island, Marshall saw no possibility of coexistence. Either he and his fellow residents had to go, or their little tormentors had to go; and he refused to be evicted from his chosen place of residence.

Once it had figured out (with the help of Lang's freshly published *Handbook of British Mosquitoes*) which type of mosquito was biting the townsfolk and vacationers, Marshall's organization had unleashed a multi-pronged assault on the larvae and breeding grounds of *Ae. detritus* in June 1921. The operation was based on the conviction that control strategies were necessarily micro-strategies, carefully tailored to the habits and micro-habitats of individual species. As the *British Medical Journal* observed in 1930: 'it is idle to blame the domestic water butt if the insects are coming from a pond in a neighbouring wood'. Marshall's team quickly learnt that in the British world of pestiferous mosquitoes they were dealing with enormous diversity in species, hatching habits and breeding places. Initial collecting activities in the autumn of 1920 disclosed that the 'local nuisance' was almost exclusively caused by *Ae. detritus*, a species particularly active in daytime (diurnal) that was unusual among British mosquitoes in various other ways (Figure 4.6). After experiments in a makeshift laboratory revealed that *Ae. detritus* would breed in stagnant water comparable to the sea in salinity as well as brackish conditions, Marshall and his staff established that this was a species with an unusually lengthy flight range (up to five kilometres), whose breeding grounds were two kilometres from its biting grounds in the central residential district.

They also discovered that, exceptionally among British mosquitoes, *Ae. detritus* eggs and larvae can survive the winter. Eggs laid in dry marshland vegetation remained in suspended animation until eventually submerged by tidal action or otherwise brought into contact with water. If the weather was mild, the production of adults could continue from April to November – a remarkably long hatching out period for British mosquitoes. The Hayling Island campaign's key finding was that success in control at the local level cannot be expected until the precise identity of the problem-causing mosquito is firmly identified and all its idiosyncratic attributes are thoroughly studied. Not least, Marshall warned against indiscriminate application of chemical larvicides and paraffin to water bodies that might inflict collateral damage, wiping out the mosquito's 'benevolent' 'natural enemies', such as fish and amphibians that feast on mosquito eggs and larvae.

Despite mission accomplished on Hayling Island (subject to regular inspection, maintenance of sluices and drainage works and treatment of stagnant water), Marshall accepted that 'permanent eradication of mosquitoes from even a limited area is... a matter of impossibility'. This stance reflected the position of someone who respected the resourcefulness and indomitability of his insect opponent and appreciated the limits of the science and technology of control at a time before the invention of DDT.

Figure 4.6. The front cover of a report by the British Mosquito Control Institute for the year 1929, showing a photograph of Aedes detritus*, taken by means of a 'Moscon', a photographic technique developed by Marshall which magnified small mosquito specimens for examination and teaching.*


EIGHTH REPORT of the PROCEEDINGS of the
HAYLING ISLAND BRANCH
of the
BRITISH MOSQUITO CONTROL INSTITUTE.

JANUARY 1st, 1929 to JANUARY 1st, 1930.

Fig. 1. Female of the "salt-marsh" mosquito, *Aedes detritus*, showing the long "proboscis" containing the biting instruments, by means of which a mosquito is easily distinguished from other insects. Mosquitoes of this kind breed in stagnating salt, or partly salt, water, and have a range of flight of some miles. The above photograph is about 8 times natural size.

Further reading

Hogarth, A.M. (1928) *British Mosquitoes and How to Eliminate Them*. London: Hutchinson.

James, S.P. (1929-30) The disappearance of malaria from England. *Proceedings of the Royal Society of Medicine*, 23(1929-30):70-87.

Lang, W.D. (1920) *Handbook of British Mosquitoes*. London: British Museum of Natural History.

Macdonald, A. (1919) Report on indigenous malaria and on malaria work performed in connection with the troops in England during the year 1918, in *Observations on Malaria by Medical Officers of the Army and Others*, ed. Ross, R. London: War Office/HMSO, 175-255.

Marshall, J.F. (1928) *Principles and Practice of Mosquito Control: Being a Handbook to the British Mosquito Control Institute*. Hayling Island, Hampshire.

Marshall, J.F. (1938) *The British Mosquitoes*. London: British Museum of Natural History.

Olver, C. (2014) Malaria in the UK, 25 April 2014, Library and Archives Service blog, London School of Hygiene and Tropical Medicine. Available from: https://blogs.lshtm.ac.uk/library/2014/04/25/malaria-in-the-uk/. Accessed 12 June 2020.

Snow, K. & Snow, S. (1991) John Frederick Marshall and the British Mosquitoes. *Bulletin of the British Museum of Natural History*, 19/1 (27 June 1991):1-50.

Snow, K.R. & Snow, S.E. (2004) John Frederick Marshall and "The British Mosquitoes". *European Mosquito Bulletin: Journal of the European Mosquito Control Association*, 17:23-28.

5. INTRODUCTION TO MOSQUITO BIOLOGY AND ECOLOGY

5.1 Taxonomy

Mosquitoes fall under the Insect order Diptera, or two-winged flies, and the suborder Nematocera, which means 'thread-horned' and describes the long thread-like antennae of insects in this suborder. Within the Nematocera, mosquitoes belong to a single family called the Culicidae, which is divided into three sub-families: Culicinae, Anophelinae and Toxorhynchitinae (Figure 5.1). At the time of writing, 36 species of mosquito have been recorded in Britain, including some that are considered to be non-native. There are 30 species in the sub-family Culicinae, across six genera (*Aedes, Ochlerotatus, Coquillettidia, Culex, Culiseta* and *Orthopodomyia*); within the *Culex* genus, there are two biotypes of *Culex pipiens*, meaning they are a single, genetically identical species, but express different behaviours. There are six species of the Anophelinae, all of the genus *Anopheles*. No members of the sub-family Toxorhynchitinae are found in Britain.

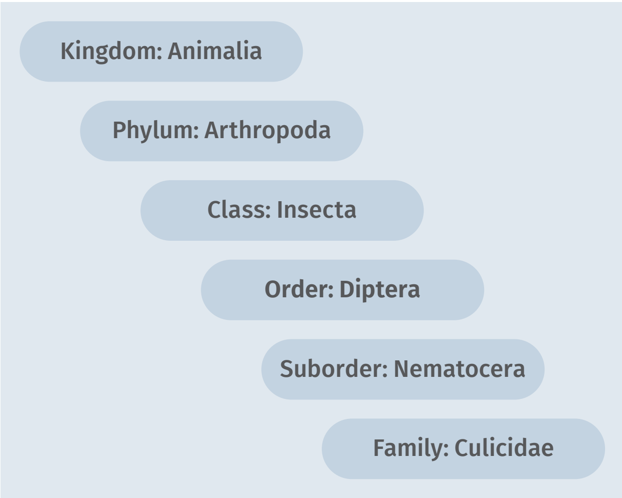


Figure 5.1. *Scientific classification of the* Culicidae *(mosquitoes).*

Simplified keys for adult and larval British mosquitoes can be found in Appendix V and VI, respectively.

Because many of the species names begin with the same letter, the convention for abbreviating these binomial names uses the following two-letter system, which is adopted throughout this book:

- *Aedes* is abbreviated to *Ae.* (e.g. *Ae. flavescens*)
- *Anopheles* is abbreviated to *An.* (e.g. *An. plumbeus*)
- *Culex* is abbreviated to *Cx.* (e.g. *Cx. modestus*)
- *Culiseta* is abbreviated to *Cs.* (e.g. *Cs. subochrea*)
- *Coquillettidia* is abbreviated to *Cq.* (e.g. *Cq. richiardii*)
- *Orthopodomyia* is abbreviated to *Or.* (e.g. *Or. pulcripalpis*)

5.2 Recorded mosquitoes of Britain

Sub-family Anophelinae		
Genus *Anopheles*		
Anopheles (Anopheles) algeriensis	*Anopheles (Anopheles) claviger*	*Anopheles (Anopheles) messeae*
Anopheles (Anopheles) atroparvus	*Anopheles (Anopheles) daciae*	*Anopheles (Anopheles) plumbeus*
Sub-family Culicinae		
Genus *Aedes*		
Aedes (Stegomyia) albopictus	*Aedes (Ochlerotatus) communis*	*Aedes (Ochlerotatus) leucomelas*
Aedes (Ochlerotatus) annulipes	*Aedes (Ochlerotatus) detritus*	*Aedes (Ochlerotatus) nigrinus*
Aedes (Ochlerotatus) cantans	*Aedes (Ochlerotatus) dorsalis*	*Aedes (Ochlerotatus) punctor*
Aedes (Ochlerotatus) caspius	*Aedes (Ochlerotatus) flavescens*	*Aedes (Ochlerotatus) rusticus*
Aedes (Aedes) cinereus	*Aedes (Aedes) geminus*	*Aedes (Ochlerotatus) sticticus*
	Aedes (Dahliana) geniculatus	*Aedes (Aedimorphus) vexans*
Genus *Coquillettidia*	**Genus *Culiseta***	**Genus *Culex***
Coquillettidia (Coquillettidia) richiardii	*Culiseta (Culiseta) alaskaensis*	*Culex (Culex) modestus*
	Culiseta (Culiseta) annulata	*Culex (Culex) pipiens* biotype *molestus*
	Culiseta (Culicella) fumipennis	*Culex (Culex) pipiens pipiens*
	Culiseta (Culicella) litorea	*Culex (Culex) territans*
	Culiseta (Allotheobaldia) longiareolata	*Culex (Culex) torrentium*
	Culiseta (Culicella) morsitans	
	Culiseta (Culiseta) subochrea	**Genus *Orthopodomyia***
		Orthopodomyia (Orthopodomyia) pulcripalpis

5.3 Life cycle

Mosquitoes progress through four life stages (Figure 5.2): egg, larva, pupa and adult. Mosquitoes can be recognized by the distinctive proboscis in adults (Figure 5.3), and the many fine hairs on larvae. Appendix VIII may be used to help distinguish both common aquatic fly larvae from those of mosquitoes, and mosquito wing shape from other flies with which they can be confused.

The immature larval and pupal stages are aquatic and mosquito larvae, or 'wrigglers', are a familiar sight in water butts. In many genera (e.g. *Culex, Culiseta, Anopheles*), females typically lay eggs directly on the water's surface as either single eggs or in rafts (Figure 5.4), after which they hatch within a day or two.

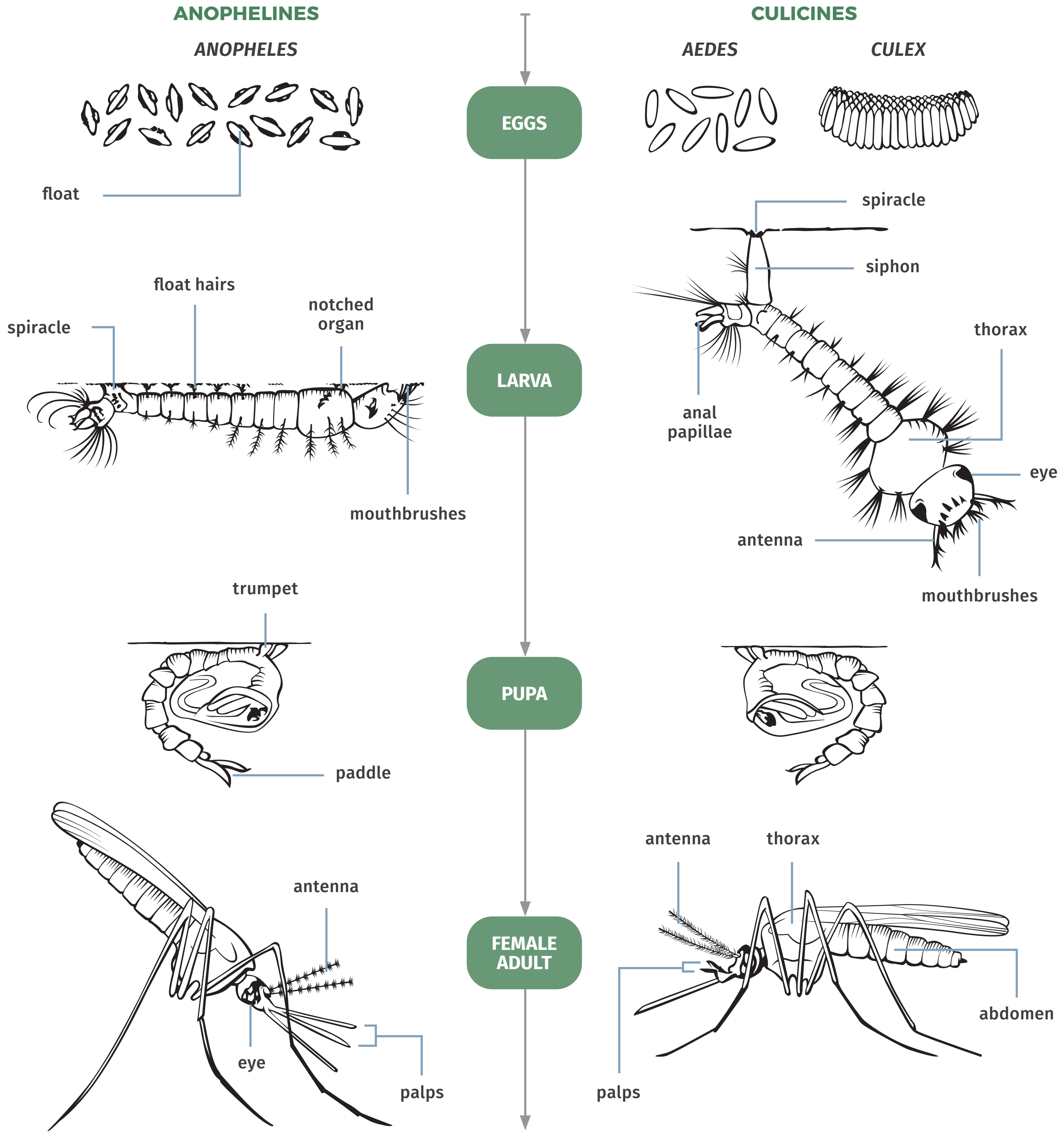


Figure 5.2. *Mosquito life stages, highlighting key differences between anophelines and culicines.*

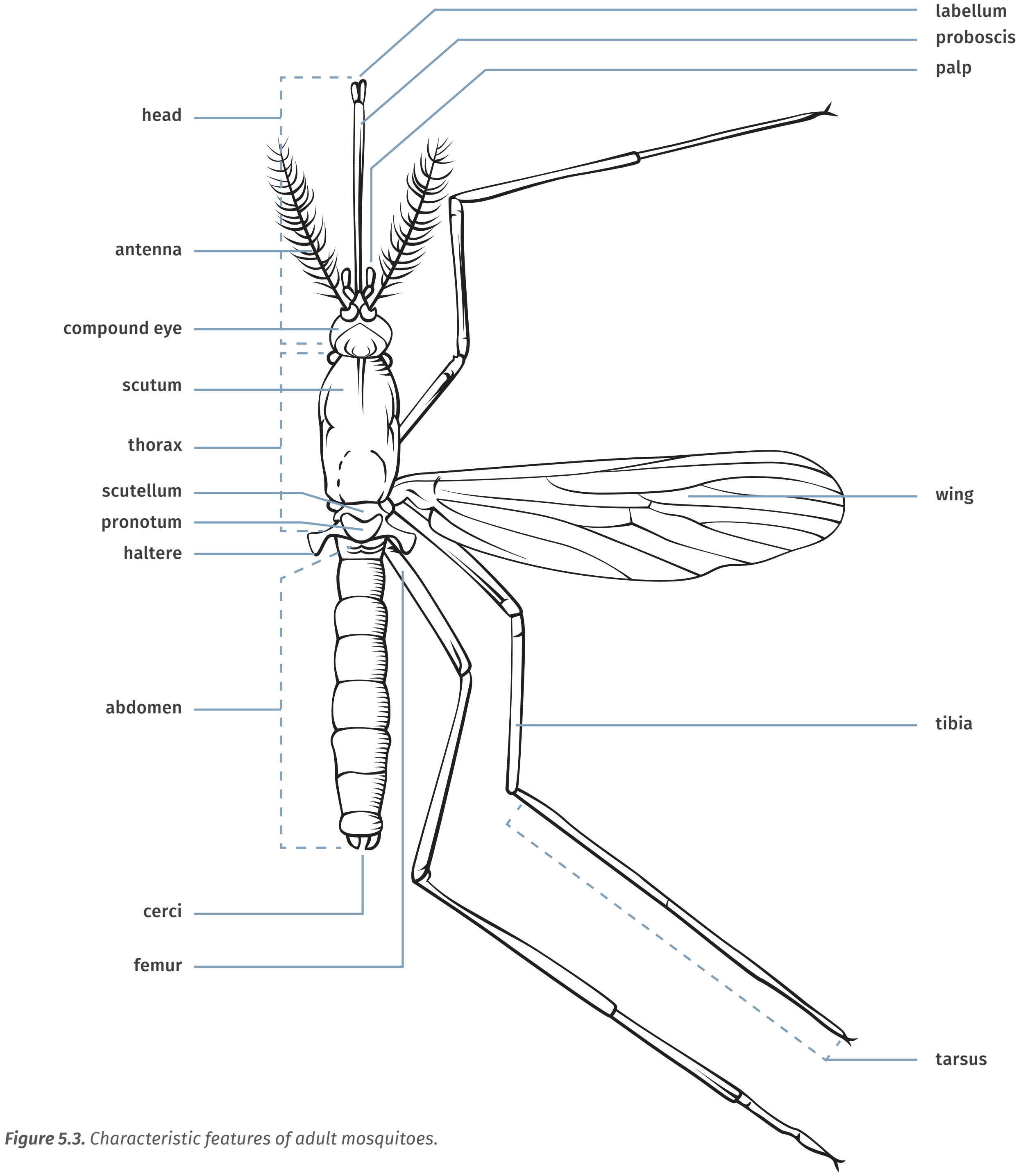


Figure 5.3. *Characteristic features of adult mosquitoes.*

For *Aedes* species, however, the female will deposit eggs on damp soil or leaf litter at the edge of a body of water, or even away from water but where it is likely to be inundated. Wet woodland, for example, can be completely dry in summer when eggs are laid, only later wetting during autumn through to spring flooding. When so desiccated, eggs can remain dormant for several months or even years; eggs of *Ae. vexans* have been reported to be viable after up to five years of dormancy. Desiccated eggs will hatch following immersion after a period of rain or when seasonal flooding events cause the water level to rise. Once hatched, the insect matures through four larval stages, or instars, over the course of around three to four weeks, although this period can be shorter in warmer temperatures. Larvae filter feed on *detritus*, bacteria and other organic matter in the water.

Figure 5.4. Culex pipiens *rests on the surface tension of water when ovipositing, with eggs cemented together into a raft-like mass.*

The larvae of all but one British mosquito species absorb atmospheric air at the water's surface via respiratory spiracles, openings that break through the surface tension of the water and allow the insect to absorb air. Larvae can be distinguished to subfamily according to their position relative to the surface of the water and the presence of a respiratory siphon in Culicinae, which is absent in Anophelinae (Figure 5.5). These spiracles are easily inundated when the surface of the water is moving, either through water flow, wind-created waves or other turbulence and the larvae can readily drown. Therefore, one unifying feature of all aquatic environments where mosquitoes are found is that the surface of the water is generally still or has only very slight movement. Thus, mosquito immatures generally require stagnant, still, or very slowly flowing water.

Larvae develop through four larval stages, called instars, each larger than the last. Between each stage they moult and shed their skin (exuviae). Once the larvae have developed sufficient nutritional reserves, they will progress through a final moult and begin the process of pupation (Figure 5.6). Like larvae, pupae are aquatic and must absorb atmospheric air at the water's surface through a pair of respiratory siphons that act like snorkels. It is during pupation that metamorphosis occurs, and the insect reconfigures its anatomy from larval to adult features. This typically takes several days, during which the insect ceases eating but remains mobile. On completion of metamorphosis, the adult mosquito emerges from the pupal case at the water's surface and will rest briefly on the water while its exoskeleton dries and hardens.

While it is difficult to distinguish the sex of larvae and pupae, male and female adult mosquitoes are sexually

Figure 5.5. *The subfamily of mosquitoes can be determined at the larval stage by the position of the larvae with respect to the surface of the water. Larvae of subfamily* Anophelinae *(such as* Anopheles maculipennis *s.l., top) lie parallel to the surface to absorb air through many respiratory spiracles that break through to the air; whereas larvae of subfamily* Culicinae *(such as* Culiseta annulata, *bottom) hang at around 45 degrees from the surface, with a single respiratory spiracle called a siphon protruding into the air.*

Figure 5.6. *A pupa of* Culex territans, *an uncommon mosquito in Britain. The snorkel-like respiratory siphons break through the surface of the water, allowing the organism to absorb atmospheric air.*

dimorphic (Figure 5.7). They can be differentiated morphologically by the appearance of their antennae; male antennae are characterised by the presence of many fine hair-like whorls, giving them a plumose structure and bushy appearance, whereas female antennae are slender and pilose, with very few visible hairs.

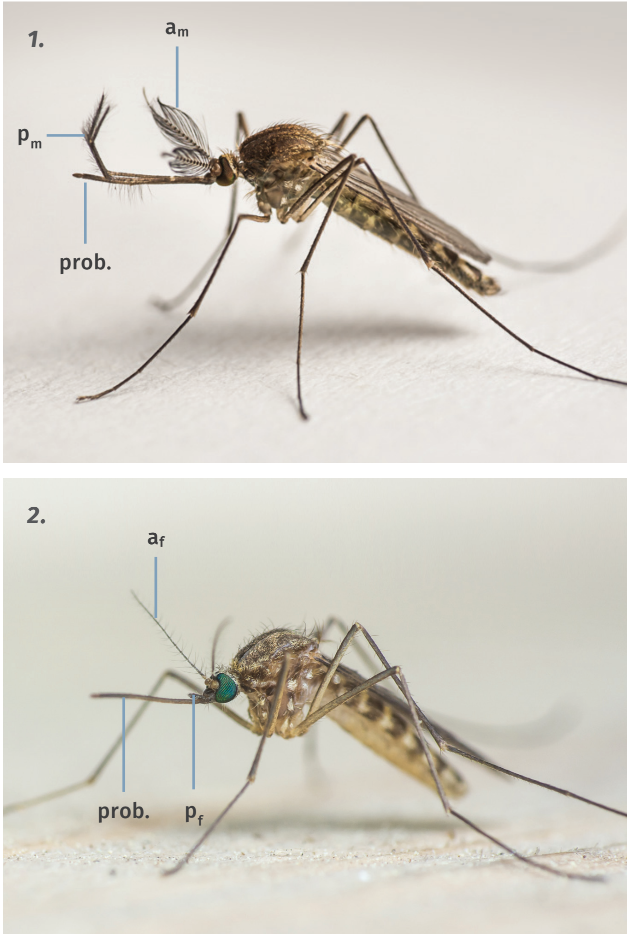


Figure 5.7. Male (1) and female (2) Culex pipiens. *The male antennae (a_m) are noticeably larger than the female (a_f). Male palps (p_m) – a pair of sensory appendages parallel to the proboscis (prob.) – also tend to be larger than the female palps (p_f), with an elongated 'hockey stick' appearance.*

After emergence, the behaviour of males and females is quite different. Besides feeding on plant sugars and resting, adult male mosquitoes will seek mates, typically in "mating swarms" (Figure 5.8). These differ from conventional insect swarms in that they can be composed of as few as one or two individuals, although they are often larger, and can be as large as a hundred individuals. Mating swarms form around dusk and centre over visibly conspicuous marks on the ground. They tend to last no more than thirty minutes. Females enter swarms and are pursued by males, subsequently forming copula and leaving the swarm.

Figure 5.8. *Barely visible against the sky, a swarm of male mosquitoes forming just before sunset in Kent.*

An exception to this behaviour is Anopheles *atroparvus*, which mate indoors. After mating once, females have enough sperm to last throughout their life and do not seek mates again. Their behaviour switches to a cycle of finding and taking blood-meals, then resting to digest this and develop eggs, followed by ovipositing in a suitable habitat, after which the cycle begins again with host-seeking (Figure 5.9).

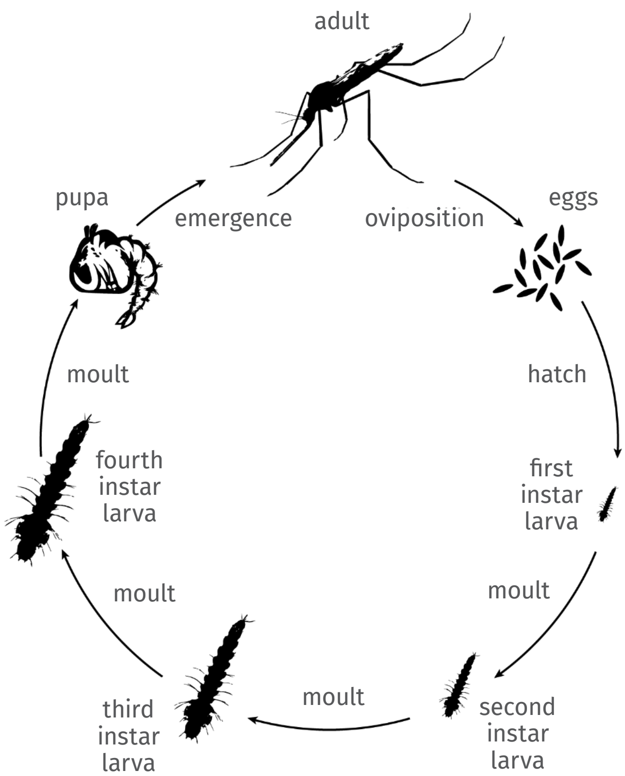


Figure 5.9. *The mosquito life cycle, showing typical development of an anopheline mosquito; culicine mosquitoes lay eggs in rafts (Figure 5.4) and as adults adopt a resting position that is more parallel to the surface, rather than the 45-degree angle adopted by anophelines. Image: Louise Malmgren/NRI.*

5.4 Oviposition habitats

Oviposition is the process of laying eggs. For oviparous animals that do not tend their young, such as mosquitoes, the location where the eggs are laid can be crucial in determining the survival of offspring. The aquatic habitat must provide food and minimal risk of predation.

There is a wide variety of aquatic habitats that are suitable for mosquitoes to lay eggs in (Table 4). Many of the aquatic habitats used by mosquitoes are managed in some way, be it through control of water levels or vegetation management. Key habitats in the UK include ditches, ponds and the sheltered, vegetated margins of larger lakes, as well as flooded grassland, wet woodland, bogs, fen and reedbeds. While some of the more common mosquito species are able to exploit a range of these, such as *Cs. annulata* and *Cx. pipiens*, others are more selective or require a specific water quality, such as *Ae. punctor*, which prefers slightly acidic pools, or *Ae. detritus*, which prefers brackish waters. Variations in the permanence of a water body, its light levels and presence of pollutants can all determine its suitability for a given mosquito species. Several British mosquitoes are adapted to laying eggs in water-filled tree holes. Some woodland *Aedes* species lay eggs in depressions in woodland that will become wet following flooding or rainfall, rather than in existing pools in wet woodland. The larger the area for regular inundation, the larger the surface area for oviposition. Certain species are associated with specific vegetation. For instance, *Cq. richiardii* requires the presence of particular aquatic plants, the underwater tissues of which it pierces to acquire oxygen, a unique habit in the British mosquitoes. A handful of species will tolerate brackish water, laying eggs in coastal drains and salt marsh. *Aedes detritus*, for example, is found in brackish coastal waters and inland where water is made brackish by salt deposits. Several species are also able to exploit explicitly human-made habitats, such as garden water butts and water collected in refuse and there have been reports of sewage treatment works being colonised by mosquito larvae.

Table 4. Most common British mosquito species by principal aquatic oviposition site.

Temporary freshwater pools (e.g. flooded meadows, woodland pools, ditches)	**Temporary saline water pools** (e.g. salt marsh, areas subjected to tidal incursion)	**Artificial water collections** (e.g. tanks, rain barrels, wells, cisterns, troughs, buckets, cans)	**Underground water** (e.g. water in basements, mines, underground train tunnels, broken drains)	**Permanent ground-water** (e.g. ditches, pools, ponds, canal and river edges)	**Tree holes** (e.g. rot holes and pans)
Ae. cinereus *Ae. vexans* *Ae. annulipes* *Ae. cantans* *Ae. flavescens* (also brackish) *Ae. punctor* *Ae. rusticus*	*An. atroparvus* *Ae. caspius* *Ae. detritus* *Ae. dorsalis*	*Cx. pipiens* biotype *pipiens* *Cx. torrentium* *Cs. annulata* *Cs. subochrea*	*Cx. pipiens* biotype *molestus*	*An. claviger* *An. daciae* *An. messeae* *Cq. richiardii* *Cx. modestus* *Cs. fumipennis* *Cs. litorea* *Cs. morsitans*	*Ae. geniculatus* *Or. pulcripalpis* *An. plumbeus*

5.5 Functional groups

Categorising the many species of mosquito into groups with similar life histories can enable a better understanding of the Culicid family. Functional groups give an overview of relatedness between different mosquito species according to their behaviour, seasonality and life history traits (rather than their taxonomic closeness, though of course there can be overlap between these). For mosquitoes, key features that determine functional groupings are:

i. Oviposition site – either in water or on land

ii. Overwintering stage – as primarily larvae, eggs or adult females

iii. Preferred blood meal host – either mammals or birds

iv. Number of generations per year – either single (univoltine) or multiple (multivoltine)

The groupings provide a quick way to reference those species that share particular traits (Figure 5.10).

For instance, those species that primarily feed on birds (and thus will have limited to zero impact on humans through nuisance biting) can quickly be found by following those in the "bird" biting categories. Let us consider these life history traits in more detail.

(i) Oviposition site:

The group of mosquitoes that lay eggs directly on the surface of water are highly reliant upon permanent aquatic habitats for their long-term survival; if the water they oviposit on dries out, their offspring will not survive. These include many of the common species, such as *Cx. pipiens*, *Cs. annulata*, *Cq. richiardii*, *Cx. torrentium*, *An. maculipennis* s.l. and *An. claviger*. All these species can be common in wetland habitats and although each have specific needs, they can all exploit a range of wetland habitats.

In contrast, the species that lay eggs out of water, in areas prone to inundation, mostly account for all the *Aedes* species, as well as the three British species of *Culiseta* subgenus *Culicella*. This differentiation between two main life strategies is fundamental to understanding the diversity of mosquitoes in either permanent or seasonal aquatic habitats.

The aquatic habitats (oviposition sites) of each of the British mosquito species is summarised in the table in Appendix III.

(ii) Overwintering stage:

Some mosquitoes can overwinter as eggs, which is generally the case for species of *Aedes* and *Culiseta (Culicella)*. Other species, such as *An. claviger*, *An. plumbeus* and *Cq. richiardii* will spend the winter as larvae, with some

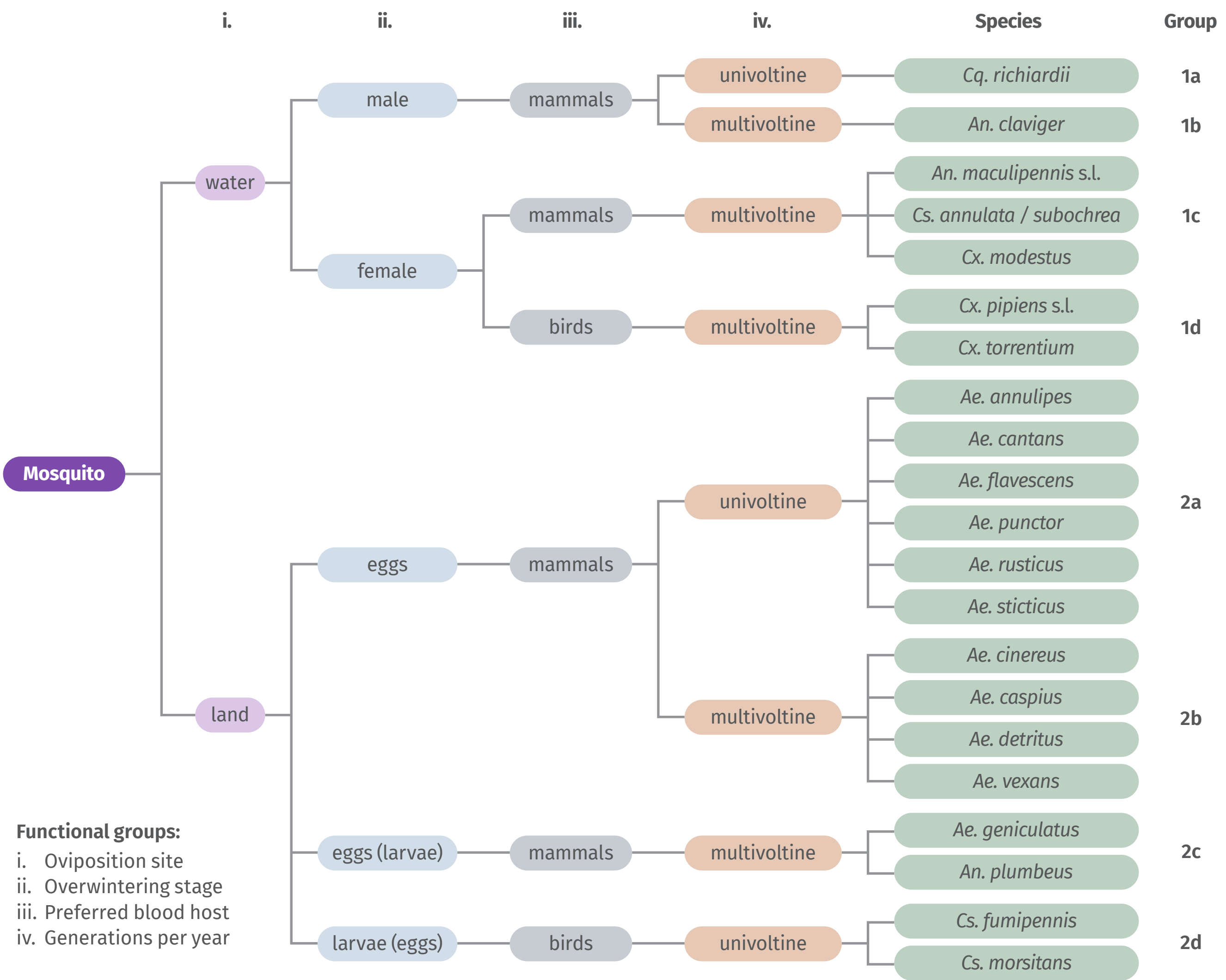


Figure 5.10. *Functional groups of selected British mosquito species.*

larvae even able to survive the winter when the water is covered in ice. A small number of species, such as *Cx. pipiens* biotype *pipiens*, *Cx. torrentium*, *Cs. annulata* and *An. maculipennis* s.l., will overwinter as adult females. The former two species enter complete hibernation, whereas the latter two species show incomplete hibernation, becoming active at intervals to blood-feed.

(iii) Preferred blood meal host:

Many species of British mosquito are mammalophagic, biting mammals including humans, however some will feed on a wide range of hosts and there are a few that are almost exclusively ornithophagic (Figure 5.11). These include rare and uncommon species like *Or. pulcripalpis* and *Cs. litorea*, but also very common species such as *Cx. pipiens* biotype *pipiens*, *Cx. torrentium* and *Cs. morsitans*.

(iv) Number of generations per year:

In the tropics, many mosquito species are multivoltine, that is they continuously have many generations a year. In more temperate climes, such as Britain, this is not a favourable life strategy as species need to enter an inactive phase to overcome the winter. Different species adopt either a univoltine (the wet woodland mosquitoes), or multivoltine strategy, with a few adopting a very specific bivoltine life strategy. This enables a better understanding of species activity and can be important in predicting when adult mosquitoes may bite, when larvae may be active for predators, or for timing control activities. In the main, all species peak during July and August, but some can be active into early autumn, and others show some activity in late spring and winter.

Figure 5.11. *Wetland habitats are home to an abundance of vertebrate animals, often including domestic livestock as well as wildlife. Cattle are particularly common on grazing marsh and many wetlands are important for native and migratory birds. These animals can provide a source of blood for female mosquitoes; however, each species varies in the animals on which it will feed.*

Further reading

Becker, N., Petrić, D., Zgommba, M., Boase, C., Madon, M., Dahl, C. & Kaiser, A. (2010) *Mosquitoes and Their Control*, Second Edition (Second). New York, Springer.

Clements, A.N. (1999) *The Biology of Mosquitoes Volume 2.* Oxfordshire: CABI Publishing.

Medlock, J.M. (2015) Impact of the creation, expansion and management of English wetlands on mosquitoes (Diptera: Culicidae). PhD Thesis. University of Bristol.

Medlock, J.M. & Vaux, A.G.C. (2015) Seasonal dynamics and habitat specificity of mosquitoes in an English wetland: Implications for UK wetland management and restoration. *Journal of Vector Ecology*, 40(1):90-106.

Schafer, M.L., Lundstrom, J.O., Pfeffer, M., Lundkvist, E. & Landin, J. (2004) Biological diversity versus risk for mosquito nuisance and disease transmission in constructed wetlands in southern Sweden. *Medical and Veterinary Entomology*, 18:256-267.

Snow, K.R. (1990) *Naturalists' Handbook 14: Mosquitoes.* Slough: The Richmond Publishing Co. Ltd.

Wilkerson, R.C. & Linton, Y.-M. (2015) Elevation of *Pseudoskusea, Rusticoidus* and *Protomacleaya* to valid subgenera in the mosquito genus *Aedes* based on taxon naming criteria recently applied to other members of the Tribe Aedini (Diptera: Culicidae). *Parasites and Vectors*, 8:668.

6. SPECIES PROFILES

In this section are factsheets that describe key information and details of the most common of the British mosquitoes. The species profiled here were included based on their relatively widespread distribution and their potential association with nuisance and future disease risk. Therefore, the information provided may be of interest and useful in the context of wetland management and risk assessment.

Points for consideration

Some species are closely related, for instance they are morphologically identical but behaviourally different sibling species, or they share very similar ecology. In these instances, the species have been addressed within a single profile. Additionally, the biology of some well-studied species is much better understood than others, and therefore the same kinds of information cannot necessarily be provided for each species.

The reader must appreciate that the information provided here is meant to provide an overview of the most important characteristics and is not exhaustive. However, these profiles have been developed to encompass the information most likely to be of value in wetland management. This includes aspects that may be relevant to planning new wetland provision, type and timing of habitat management activities and risk assessment. Research continues to provide updated and refined data and the information here may be subject to change as this is made available.

Profile header explained

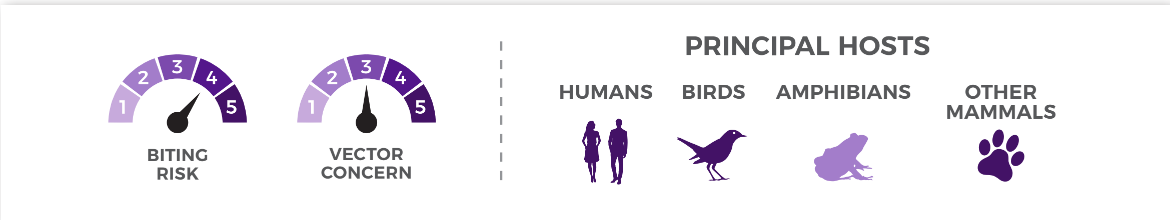
The header for each profile contains a quick visual summary of the species' characteristics. Distribution maps included in the species profiles are based on data from the National Biodiversity Network (NBN) Atlas accessed in June 2020 (www.nbnatlas.org). Full acknowledgement of this resource and its Data Providers is in Appendix XI. Tables summarising the seasonal activity of larvae (green), pupae (brown) and adults (purple) can be found under "Life history and phenology". Dark purple indicates the period when the adult population is typically at its peak.

Both the biting risk to humans and vector concern for the species is presented, and these are scored on a scale of 1-5. Because there are no mosquito-borne diseases in the UK at the time of writing, the score for vector concern is based on the current understanding of each species' role in pathogen transmission outside the UK, and the potential for future disease transmission risk. The scores correspond to the following attributes and have been determined in an assessment made by PHE:

Biting risk	Vector concern
1. Does not bite humans	1. Does not bite humans
2. Can bite	2. Bites humans and animals (enzootic) so potential for vector role, but not considered primary/secondary
3. Can bite in its habitat	3. Secondary or largely unproven vector
4. Severe biting in habitat	4. Potential vector of malaria and Rift Valley fever
5. Severe biting, can cause a nuisance in and out of habitat (leaves habitat)	5. Primary West Nile virus vector

The species' principal hosts are listed, with preferred host animals shown in **dark purple**, and other animals that they are known to feed on shown in light purple. The key habitats with which the species is most frequently associated are also listed in green.

KEY HABITAT: Permanent water with abundant emergent vegetation



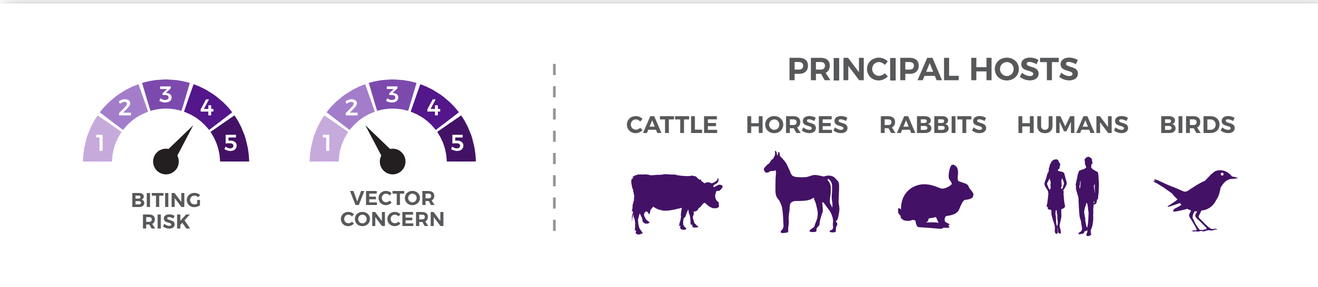
Aedes cantans and *Aedes annulipes*

BACKGROUND

These two species are morphologically very similar and can only be distinguished by subtle differences in coloration or examination of the male genitalia. However, as they share very similar life histories, field studies using morphological identification do not tend to separate these species.

Recently, these species have been reassigned from the genus *Aedes* to *Ochlerotatus*, their new names now being *Ochlerotatus cantans* and *Oc. annulipes*. However, much literature still refers to them as belonging to the genus *Aedes* and they are referred to as such in this book .

KEY HABITAT: Wet woodland subject to winter flooding



DISTRIBUTION

Historical records suggest *Ae. cantans* is far more widely distributed and abundant than *Ae. annulipes*, occurring in 45 and 36 vice counties, respectively. *Aedes annulipes* has been recorded in England and Wales only.

UK distribution of Aedes cantans *(a) and* Aedes annulipes *(b) (NBN).*

LIFE HISTORY AND PHENOLOGY

Both species are univoltine, with just one generation per year. Groups of around 30 eggs are laid in damp leaf litter of shaded pools when they dry out during June to September. Eggs do not hatch when flooded by autumn rains as they require environmental conditioning brought on by cold temperatures. Egg-hatching in spring is incremental and studies in southern England found that the majority of *Ae. cantans* eggs hatch by late-March.

Larval development is usually completed by June but can finish as early as May. Females undergo no more than three gonotrophic cycles.

	J	F	M	A	M	J	J	A	S	O	N	D
Larvae												
Pupae												
Adults												

LARVAL HABITATS

Owing to their habit of laying eggs in dried-up hollows in woodlands subject to periodic flooding, the immature stages of *Ae. cantans* and *Ae. annulipes* are typically found in shaded woodland pools and wet woodland, often co-habiting the same aquatic sites.


Wet woodland habitat typical of Ae. cantans. *Shaded woodland pools and ditches are particularly suitable for* Ae. annulipes.

HOST PREFERENCE AND BITING BEHAVIOUR

Aedes cantans is documented to bite cattle, rabbits, humans, birds and horses; *Ae. annulipes* also bites humans and cattle. Human biting can be aggressive, with maximum biting occurring during July and typically most intense just after sunset, although day-biting occurs, especially in shaded woodland environments. Daily biting density is strongly temperature dependent, with little biting below 12-13°C. They are known to disperse from their larval habitat to find hosts, although there is no information on their dispersal range.

VECTOR POTENTIAL

Based upon their host-feeding habits (taking blood meals from both humans and birds), both species are potential arbovirus vectors, however they are not considered to be primary vectors of West Nile virus or Sindbis virus.

MITIGATION OPTIONS

High amounts of winter flooding in their woodland habitats and persistence of flooded woodland in spring can significantly increase the densities of these species. Allowing ditches to dry out and re-wet with pools of water can make the ditches more suitable than those ditches which remain permanently wet. Regularly slubbed (de-silted) and re-graded woodland ditches are less suitable for both species.

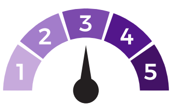
Isolating individual pools and draining them may be a viable strategy to mitigate against these species but requires permissible local hydrology to be a practical solution. Short-term, targeted draining in spring may provide an opportunity to render confirmed populations unviable, although this is only likely to be applicable in confined and highly managed landscapes and will depend on the nature of the hydrology and specific habitat. As *Ae. cantans* and *Ae. annulipes* depend on periodic drying and re-wetting of their aquatic habitats, an alternative approach may be to make smaller aquatic habitats more permanent. This could be achieved by giving water bodies steeper sides so that they hold water, thus lessening the impact of seasonal flooding. In large ranging swamp habitats with many natural depressions, management of these species could prove difficult.

Aedes caspius

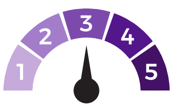
BACKGROUND

Aedes caspius **is a relatively widespread species and can be a nuisance biter in coastal areas. It can also be associated with flooded areas along estuaries.**

KEY HABITAT: Summer flooded grassland and fen; coastal grassland and flood plains subject to drying and re-wetting



BITING RISK



VECTOR CONCERN

PRINCIPAL HOSTS

HUMANS

OTHER MAMMALS

IDENTIFICATION

This species is similar to *Aedes dorsalis*, as one of only two species with white bands either side of the tarsal segments.

DISTRIBUTION

Aedes caspius has been recorded in 23 vice counties. This species is commonly found in slightly brackish waters of coastal districts, but freshwater inland populations have been recorded.

UK distribution of Aedes caspius *(NBN).*

LIFE HISTORY AND PHENOLOGY

Aedes caspius overwinters in the egg stage. Following flooding events in spring, eggs hatch in March. It has been shown that vibrations simulating rainfall can significantly increase egg hatching rates. Adults appear from April and are active until October.

	J	F	M	A	M	J	J	A	S	O	N	D
Larvae												
Pupae												
Adults												

LARVAL HABITATS

Able to tolerate both fresh and slightly brackish waters, *Ae. caspius* can be found in both coastal and inland areas. Typical habitats include coastal marsh and flooded fen or grassland. Also found in areas flooded with estuarine river flooding. This species can be common in newly flooded wet grassland habitats or in areas of fresh or weakly brackish water sites along the coastline or estuaries.

Estuarine flooded habitat for Aedes caspius *at a managed realignment site in Lincolnshire.*

HOST PREFERENCE AND BITING BEHAVIOUR

This species can be an aggressive human biter, chiefly outdoors although individuals will occasionally enter dwellings to feed. Presumably, other mammals are also suitable hosts.

VECTOR POTENTIAL

Although not considered to be a primary vector, *Ae. caspius* is able to transmit Rift Valley fever virus in Africa and is a principal vector of this virus in Egypt.

MITIGATION OPTIONS

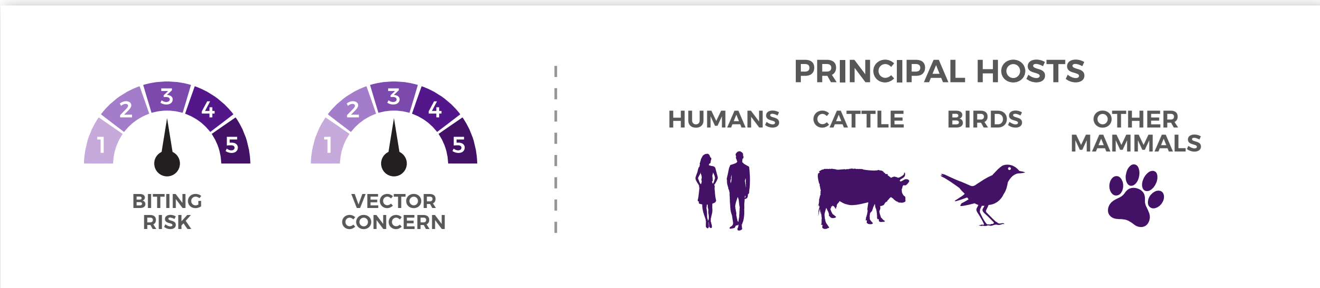
Management of inland freshwater populations will depend on the local capacity to manage water levels in wet grassland and fen. Summer flooding (high groundwater levels and/or precipitation leading to puddles and pooling) will submerge dormant eggs leading to hatching, and so could be avoided. Managing coastal tidal flooding in estuaries may be considered to minimize populations if problematic.

Aedes cinereus and *Aedes geminus*

BACKGROUND

Aedes cinereus **and *Aedes geminus* are morphologically very similar and the presence of the latter has only recently been confirmed in the UK. They can only be separated by examination of male genitalia. Although little is known of the biology and ecology of *Ae. geminus*, it is assumed to be similar to that of *Ae. cinereus*.**

KEY HABITAT: Semi-permanent and acidic pools with vegetation



DISTRIBUTION

Aedes cinereus is relatively widespread in the UK and has been recorded in 29 vice counties. It is known to occur in sympatry with *Ae. geminus*.

UK distribution of Aedes cinereus *(NBN).*

LIFE HISTORY AND PHENOLOGY

Overwintering occurs as eggs, which have been deposited during the summer in dry depressions prone to flooding. Hatching usually requires between eight and twelve soakings of the eggs, so larvae appear later in the spring than some other *Aedes* species.

Compared to other British mosquito species, there is a relatively short adult season from May to August or September.

Both species have two or more generations per year, although in northern latitudes this may be reduced to one or two.

	J	F	M	A	M	J	J	A	S	O	N	D
Larvae				■	■	■	■	■	■			
Pupae					■	■	■	■	■			
Adults					■	■	■	■	■			

LARVAL HABITATS

The immature stages of both species can be found in the same aquatic habitats. These include sedge marsh, Sphagnum species bogs, and other semi-permanent, partly shaded pools in summer-flooded meadows, wet grassland, marshes and reedbeds. They may also be found where there is sufficient emergent vegetation at the edges of lakes.

Aedes cinereus *larvae develop in a broad range of summer-flooded habitats where there is ample vegetation, such as sedges, reeds and Sphagnum species.* Aedes geminus *occupy similar habitats but seem less tolerant of acidic conditions.*

Aedes cinereus is considered to be slightly acid-loving. Work from Germany in the 1970s found *Ae. cinereus* to be abundant in more acidic swamps with low nutrient levels and intermediate productivity, as well as acidic pools in wet woodlands, whereas *Ae. geminus* seem to have a lower tolerance for such acidic habitats.

HOST PREFERENCE AND BITING BEHAVIOUR

Aedes cinereus is considered to be a nuisance mosquito and will feed on humans, livestock and other mammals. Biting peaks at dusk and dawn, continuing throughout the night, and also during daylight hours in shaded situations. Dispersal is thought to be less than 800 m; they tend to avoid the open unshaded field, suggesting dispersal may be somewhat restricted by surrounding habitat structure.

VECTOR POTENTIAL

Aedes cinereus is a confirmed vector of Sindbis virus in Sweden. Both *Ae. cinereus* and *Ae. geminus* are human and bird biting mosquito, so both are possible bridge vectors of arboviruses.

MITIGATION OPTIONS

Research has shown that high summer groundwater levels can significantly increase the density of *Ae. cinereus*. As eggs require successive immersions in order to hatch, one strategy may be to prevent inundation to keep eggs dry. Flooding in winter would be less favourable to this species than spring flooding and draining spring floodwater would reduce immature survival rates.

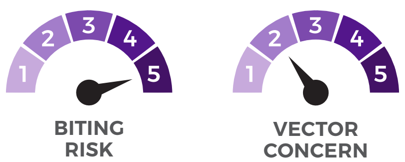
Due to the ability of this species' eggs to withstand long periods without desiccating, it is possible for eggs to survive through to subsequent years for later hatching.

Aedes detritus

BACKGROUND

Aedes detritus **is locally common and is sometimes referred to colloquially as the saltmarsh mosquito.**

KEY HABITAT: Transient brackish pools



PRINCIPAL HOSTS

HUMANS BIRDS LIVESTOCK

DISTRIBUTION

Aedes detritus has been reported in 38 vice counties and, while widespread, is generally confined to coastal and estuarine distributions, although inland populations have been recorded.

UK distribution of Aedes detritus *(NBN).*

LIFE HISTORY AND PHENOLOGY

Eggs of *Ae. detritus* are laid above the water line in anticipation of flooding; some eggs require successive immersion and drying to prompt hatching. Any eggs not submerged can survive the winter, otherwise this species overwinters as larvae. Adults emerge in March and the species can be active until as late as November.

Typically, one generation follows each immersion in floodwater and there can be many generations in a year, depending on the number of inundations. Large populations can occur after flooding from spring tides, particularly around the equinoxes, leading to a bimodal peak in biting density.

	J	F	M	A	M	J	J	A	S	O	N	D
Larvae												
Pupae												
Adults												

LARVAL HABITATS

Aedes detritus principally lay eggs in areas experiencing periodic flooding with saline waters. Ditches in coastal grazing marsh and other saltmarsh habitats, saline borrow-ditches and tidal-influenced pools, especially adjacent to ballast banks, seawalls, rock ballast lips and other coastal defences, and saline lagoons provide water with the salinity favoured by *Ae. detritus* for its immatures. They are also suitably transient to support the cycle of drying and re-wetting required by eggs of this species.


Aedes detritus *aquatic habitats on the Humber Estuary associated with a subsidiary bank of ballast adjacent to and in front of a new sea wall.*

Additionally, larvae may develop in reedbeds at the margins of the high tide line. It should be noted that freshwater populations have been reported, but these are thought to be due to inland freshwater sites with salt deposits.

HOST PREFERENCE AND BITING BEHAVIOUR

This species is responsible for several UK mosquito control programmes as it can be a persistent biting nuisance; it is generally considered to be one of the most significant nuisance biting mosquitoes in the UK. Where it is a nuisance biter, it can be the cause of significant annoyance to the public. *Aedes detritus* will bite humans, predominantly outdoors, but occasionally indoors, as well as livestock and birds, and is reported to fly up to 10 km from its larval sites in search of a blood meal. Biting behaviour tends to be crepuscular.

VECTOR POTENTIAL

The mammalophagic and ornithophagic tendencies of this species make it a candidate arbovirus vector and vector competence has been demonstrated in laboratory studies.

MITIGATION OPTIONS

Aedes detritus is likely to be the main mosquito species colonising areas of newly created coastal wetland habitat. Colonisation is likely to be acute in isolated pools and ditches around the high tide mark where these may capture brackish water.

Regular flushing of larval habitats (with salt or fresh water) can expel mosquito larvae and may provide a means of reducing numbers of adults emerging immediately after the flushing event. Closing sluices to manage spring tide water ingress into these habitats may help to manage their permanence. Where tides regularly leave isolated pools with no drainage, biocidal treatment may be required.

Eggs of *Ae. detritus* can tolerate desiccation for over a year, so a season without flooding events and with low or no adults detected does not necessarily mean the population has been eliminated.


This culvert (left) in Essex was dug to create a new sea wall. The main ditch (right) does not support mosquitoes, but on Spring tides the coastal waters flood the vegetated bank and provide habitat for Aedes detritus *larval development.*

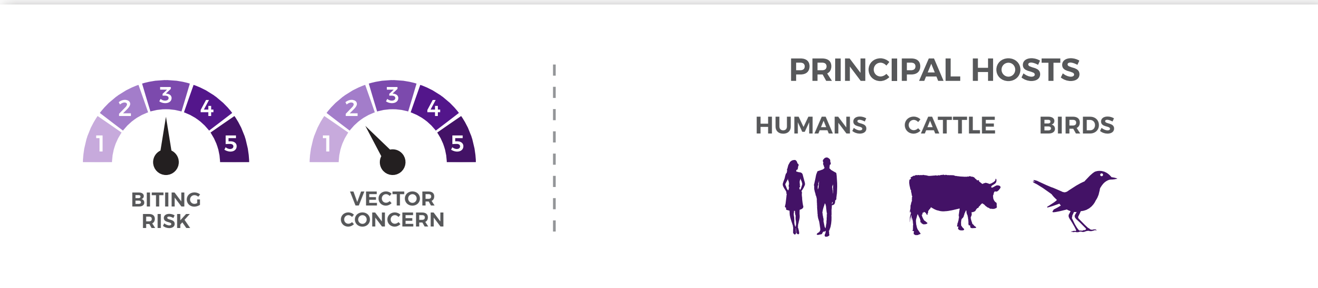
Aedes punctor and *Aedes rusticus*

BACKGROUND

Aedes punctor and Aedes rusticus occupy similar niches. Aedes punctor is widespread in Britain and can be a local nuisance biter.

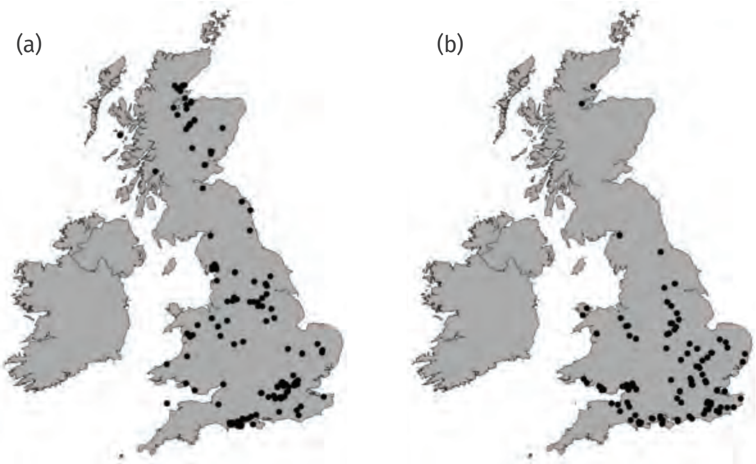
Alongside some other species in the genus *Aedes*, these species have recently been reassigned within the *Ochlerotatus genus* and in future literature are likely to be referred to as *Ochlerotatus punctor* and *Ochlerotatus rusticus*.

KEY HABITAT: Temporary woodland pools; acid bog



DISTRIBUTION

Aedes punctor has been reported in 51 vice counties and is considered to be a widespread species; *Aedes rusticus* is known to occur in 40 vice counties. There are only a small number of records of *Ae. rusticus* in Scotland.



UK distribution of Aedes punctor *(a) and* Aedes rusticus *(b) (NBN).*

LIFE HISTORY AND PHENOLOGY

Eggs laid in summer are deposited above the level of standing water in dried ditches or depressions. Following flooding in the autumn and winter months, the eggs hatch from December. The first adults emerge from May and remain on the wing until September. Numbers peak in June, when biting can be intense, followed by a rapid decline. There is one generation per year.

	J	F	M	A	M	J	J	A	S	O	N	D
Larvae												
Pupae												
Adults												

LARVAL HABITATS

This species occupies temporary woodland pools. It has been reported that immatures of *Ae. punctor* are often found in more or less acid waters, including bogs and sandy or gravelly pools lined with dead leaves or Sphagnum species. It can also be found in open heath or woodland where birch or pine predominate. It is possible this this species is associated with acid bog habitats.

Aedes rusticus appears to prefer pools lined with dead leaves upon which the larvae feed, and bordered by deciduous hedges and trees, which are presumably a source of this organic material.

Slightly acidic standing water, such as found in acid heath, can provide habitat for Ae. punctor.

HOST PREFERENCE AND BITING BEHAVIOUR

Both species can cause some localised nuisance biting of humans in areas adjacent to their larval habitats, predominantly at dusk. They will bite humans readily, although they also feed on other mammals and birds.

VECTOR POTENTIAL

Neither *Ae. rusticus* nor *Ae. punctor* are considered principal arbovirus vectors. However, their behaviour of feeding on both humans and birds does identify them as putative West Nile virus vectors.

MITIGATION OPTIONS

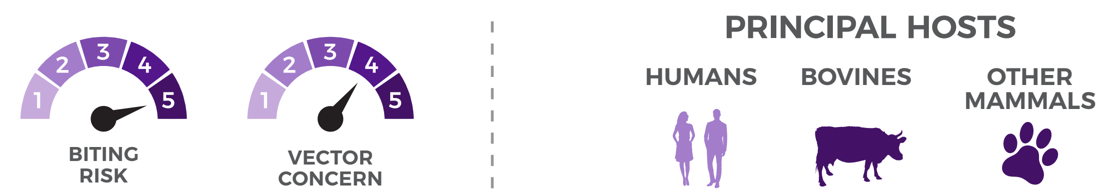
It is likely that these species will benefit from the creation of woodland pools albeit perhaps on acid soils, and the impacts of changing hydrology during winter/early spring and the maintenance of these aquatic sites through April are likely to be important factors in determining the survival of the immature populations. Winter/spring flooding can dramatically increase the numbers of these species in acid habitats, particularly bogs, mires and lowland moor areas. As seasonal flooding is principally rain-fed (rather than ground-fed), management may be difficult.

Aedes vexans

BACKGROUND

Although *Aedes vexans* has always been included in the list of British mosquitoes on account of several historical records in England and Wales, there was never any evidence that most of these records constituted a significant nuisance population. However, since 2017 populations of these mosquitoes have been found, sometimes in high abundance in a few areas of Eastern and central England.

KEY HABITAT: Summer flooded grassland, especially in river valleys



DISTRIBUTION

Although there are several historical records, there are few known populations of this mosquito in the UK. However, where they occur, they can be abundant and a nuisance.

UK distribution of Aedes vexans *(NBN).*

LIFE HISTORY AND PHENOLOGY

Aedes vexans is a polycyclic mosquito species breeding predominantly in inundated areas such as floodplains of rivers and lakes with fluctuating water levels. Larval development can be rapid in temporary water bodies that remain wet from just a few days to several weeks. The mosquito overwinters in egg diapause with eggs hatching on flooding at temperatures over 9°C. Adults usually peak during July and August and can remain on the wing until October.

	J	F	M	A	M	J	J	A	S	O	N	D
Larvae												
Pupae												
Adults												

LARVAL HABITATS

These commonly include flooded meadows, low-lying areas with willow and reed. Where conditions support development, huge numbers of larvae can be found, with hundreds per litre and more than 100 million per hectare. This mass emergence creates pressure for seeking blood meals and females may be forced to migrate up to 15 km from their breeding sites.

Larval development can be as rapid as 1 week at 30°C and up to 3 weeks at 15°C. Eggs can survive for up to 5 years if no flooding occurs after oviposition. Upon flooding, eggs hatch in response to oxygen depletion and not all eggs hatch synchronously, with the species adopting instalment hatching to maximise the survival of the populations should aquatic habitats dry out before adult emergence.

Typical larval habitat for Aedes vexans *in low-lying areas adjacent to rivers prone to summer flooding.*

HOST PREFERENCE AND BITING BEHAVIOUR

Aedes vexans can be a severe nuisance biting mosquito. Throughout its range it is reported to feed readily on humans and domestic animals. Adult *Ae. vexans* can travel around 1 km per night during favourable warm and humid conditions and have been documented to fly up to 10 km, and as much as nearly 50 km, from their larval habitats.

VECTOR POTENTIAL

In parts of Europe, particularly after flooding events, Ae. vexans can become a very abundant nuisance species, often during daytime, particularly along the river valleys of central Europe and the wetlands of Scandinavia. In the case of the former, the mosquito has been implicated in the transmission of Tahyna virus and further afield in Africa it is a notable vector of Rift Valley fever virus. It is also considered to be a vector of *Dirofilaria* (roundworms) in Europe. Although it is considered a vector elsewhere within its range, there is no reason to suspect that this species is involved in any disease transmission in the UK. However, owing to its known nuisance habits, it is likely to present a biting nuisance locally.

MITIGATION OPTIONS

This species benefits from flooded areas close to rivers, such as flooded grasslands. Therefore, preventing flooding of areas with eggs is the best method of reducing populations. However, this may not be possible, so where this mosquito is problematic, biocidal treatment is the main option and this is practiced widely in other parts of Europe where *Ae. vexans* is a nuisance.

Anopheles claviger

BACKGROUND

Anopheles claviger **is one of the most common mosquitoes of permanent wetlands in the UK. The 1898 discovery that mosquitoes of the genus *Anopheles* can transmit the malaria parasite Plasmodium falciparum was based on experimental infections of *An. claviger* by the Italian zoologist, Giovanni Battista Grassi.**

KEY HABITAT: Permanent ditches and those that dry out and re-wet; scrapes

DISTRIBUTION

With records from 85 vice counties, *An. claviger* is the most widespread mosquito species in Britain. Where present, it can be the most abundant mosquito in trap collections.

UK distribution of Anopheles claviger *(NBN).*

LIFE HISTORY AND PHENOLOGY

Anopheles claviger is bivoltine, with two generations each year. They overwinter as second, third and fourth instar larvae. Each larva remains in its current instar during a period of arrested development between January and March. In the south, larvae typically become active in March (although this may be later in northern latitudes) and pupate between April and May.

	J	F	M	A	M	J	J	A	S	O	N	D
Larvae												
Pupae												
Adults												

The adult population reaches its first peak from May to June, the first eggs and larvae re-appearing from May, and the first instar larvae peaking in June. This first generation may seek shelter in animal-houses, although later generations do not seem to exhibit this behaviour. A second generation of adults peaks between August and October, usually in September, with first instar larvae following in October. Most adult females will go through one to two gonotrophic cycles, but some will go through up to four. All adults succumb in autumn.

LARVAL HABITATS

This species breeds in reedbeds and ditches with dense vegetation and is common in permanently wet habitats. The larvae generally do not occupy waters with temperatures over 20°C so are more often found in cool shaded pools, ditches and ponds, particularly those with floating or marginal vegetation, or in the margins of ditches sheltered under overhanging trees. They have been associated with Lemna (duck weed) species. *Anopheles claviger* will also breed in ditches that have dried and re-wetted.

Typical larval breeding habitats of Anopheles claviger *are characterised by abundant emergent and marginal vegetation, either across the entire surface of the water, as in reed beds, or at the edges of ditches and pools.*

HOST PREFERENCE AND BITING BEHAVIOUR

Although not a significant nuisance biting species in Britain as their preferred hosts are large domestic animals, *An. claviger* will readily bite humans outdoors during the day, with biting also observed on rabbits and bovids. There are no records of bird biting behaviour.

VECTOR POTENTIAL

As with all British anophelines, their potential as malaria vectors should be considered, however, *An. claviger* was not considered to be the main malaria vector in Britain in the 19th century. This species is also not considered to be involved in transmission of bird-related pathogens owing to preference for feeding on mammals.

MITIGATION OPTIONS

There is some evidence that cutting marginal vegetation or regularly brinking ditches (cutting back their marginal vegetation) to increase sunlight may temporarily reduce numbers of *An. claviger*, although they are likely to rebound as vegetation re-grows. Maintaining healthy ditches with abundant macro-invertebrate competitors and predators will also contribute to keeping the species in check.

Periodically clearing dense vegetation from the edge of ditches producing Anopheles claviger *increases the level of sunlight over the water, making it less suitable for this species; however this may create conditions favoured by* Anopheles maculipennis *s.l. Where water flow is returned or increased by removing vegetation, this may make the aquatic habitat refractory to most mosquito species.*

It is not advised to completely clear vegetation or fully drain habitats, even though this may temporarily reduce the population of this species. Doing so would reduce overall biodiversity, including competitors and predators, and could make the habitat more suitable for sun-loving *An. maculipennis* sensu lato. When refilled with water, this could create a new habitat for other opportunistic mosquito species to colonise.

Anopheles maculipennis sensu lato

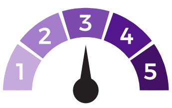
BACKGROUND

The *Anopheles maculipennis* sensu lato complex is a Palearctic species complex comprising at least ten species, almost all morphologically indistinguishable except in the egg stage.

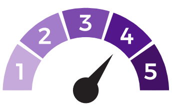
Only three members of the complex are known to occur in Britain: *Anopheles atroparvus*, *An. messeae* and *An. daciae*, the latter having only been identified through DNA analysis in 2005. Therefore, little is known about the distribution, biology and ecology of *An. daciae*.

Anopheles atroparvus and, to a lesser extent, *An. messeae* were historic malaria vectors in Britain.

KEY HABITAT: Ponds, scrapes and sunlit ditches



BITING RISK



VECTOR CONCERN

PRINCIPAL HOSTS

HUMANS | BOVINES | OTHER MAMMALS

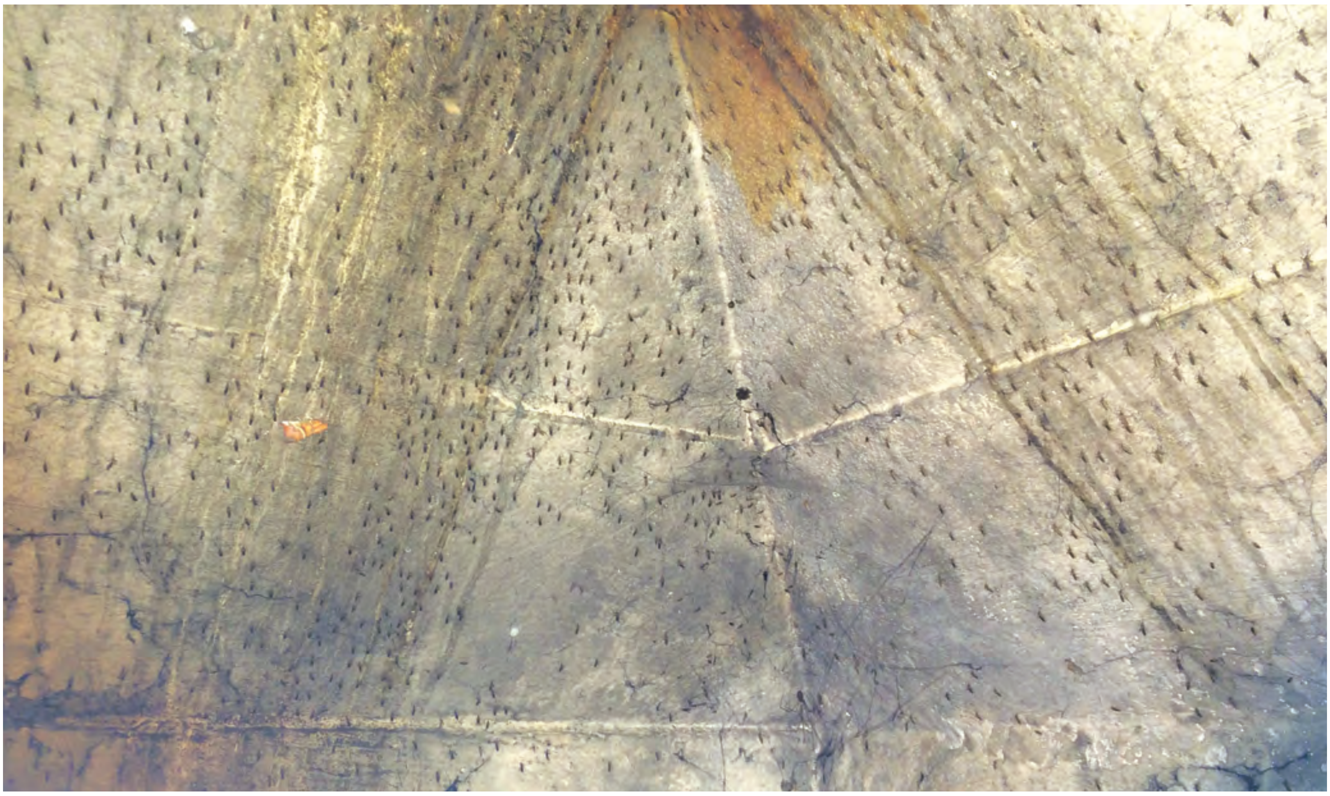
DISTRIBUTION

Members of this species complex have been reported in 69 vice counties, making it the second most common species after *An. claviger*. Although larvae of both *An. atroparvus* and *An. messeae* can occur together, *An. atroparvus* can tolerate higher saline concentrations, and so has a more coastal and estuarine distribution than *An. messeae*.

UK distribution of Anopheles maculipennis *sensu lato (NBN).*

LIFE HISTORY AND PHENOLOGY

Anopheles messeae invariably uses cold overwintering sites. *Anopheles atroparvus* will also use the same cold sites, but most will remain in the buildings in which the summer generations fed and rested.



Mosquitoes, including Anopheles maculipennis *s.l. (probably* Anopheles atroparvus*) overwintering in an old munitions tunnel in Kent. Such structures provide cool, stable temperatures throughout much of the year.*

Both species undergo ovarian diapause, overwintering as inseminated but nulliparous adult females from October. Surviving females reactivate in March/April with the first adults on the wing by the end of May. This gives rise to peak abundances in June and July. There may be two or three generations per year. Adult males do not survive the winter.

	J	F	M	A	M	J	J	A	S	O	N	D
Larvae												
Pupae												
Adults												

LARVAL HABITATS

Species in the *An. maculipennis* sensu lato complex tend to prefer sunlit water. The aquatic stages of *An. atroparvus* and *An. messeae* require relatively clean, permanent, standing or slowly moving water that supports algal growth or emergent vegetation. These conditions are generally found in ditches, drains, ponds and seasonally flooded marshes, and occasionally in the shallows or edges of slow-moving rivers. Suitable habitats for *An. atroparvus* extend to drains and grazing marsh in coastal areas, due to its higher tolerance for brackish water.

Ditches with minimal vegetation and ample exposure to sunlight are prime habitat for mosquitoes in the An. maculipennis *sensu lato species complex.*

HOST PREFERENCE AND BITING BEHAVIOUR

Anopheles atroparvus can cause a local nuisance, particularly in coastal areas, although a flight range of at least 3 km has been reported. These mosquitoes will feed on humans inside and outside of dwellings, but they predominantly feed on livestock, especially in their winter refugia of animal shelters. They are reported to bite indoors during the day. Occasional winter blood meals are taken from vertebrates co-occupying their winter refuges, in order to replenish fat reserves. *Anopheles messeae* feeds predominantly on livestock, although will bite people if access to other host animals is limited.

VECTOR POTENTIAL

Both *An. atroparvus* and *An. messeae* are competent vectors of malaria parasites and were historically implicated in disease transmission. Reintroduction of malaria parasites into British populations of these species is unlikely due to the highly localised nature of biting by these species, but it is possible, and should be taken into consideration.

MITIGATION OPTIONS

Ditches that have been brinked are associated with a higher abundance of *An. messeae* immatures owing to the increased availability of sunlight. However, vegetated ditches are likely to then become suitable for *An. claviger*, provided that they are cool enough. It may prove difficult to balance these two species.

The overwintering population may be targeted if key local hibernation sites can be identified.

Coquillettidia richiardii

BACKGROUND

Coquillettidia richiardii **is relatively common in the UK and can be a persistent biter. Uniquely among the British mosquito fauna, immatures of *Cq. richiardii* do not absorb atmospheric air at the water's surface via larval siphons and pupal trumpets. Instead, these anatomical features are specialised for piercing the aerenchyma, or aerated stems and roots, of specific aquatic plants.**

This unusual behaviour seems to be obligatory, at least for the older larvae and pupae. Consequently, larvae are very difficult to sample by conventional dipping methods; they can generally only be detected as adults, unless aquatic plant stems and root systems are removed and examined for the presence of larvae and pupae.

KEY HABITAT: Permanent water with abundant emergent vegetation

DISTRIBUTION

Even though formally reported in only 15 vice counties, *Cq. richiardii* is a relatively common mosquito species in Britain.

UK distribution of Coquillettidia richiardii *(NBN).*

LIFE HISTORY AND PHENOLOGY

A univoltine species with only one generation per year, *Cq. richiardii* overwinter as fourth instar larvae. These pupate in spring, with adults appearing from late May to September. In the summer months, swarms of male mosquitoes may be observed one hour after sunset and again at dawn. Eggs are laid as rafts on the water's surface.

	J	F	M	A	M	J	J	A	S	O	N	D
Larvae												
Pupae												
Adults												

LARVAL HABITATS

This species is common in ditch, pond and fen habitats vegetated with the plants from which *Cq. richiardii* immatures acquire oxygen. Plants known to be associated with *Cq. richiardii* include sweet flag *(Acorus)*, species of sweet grass in the genus *Glyceria*, water crowfoot *(Ranunculus)* and reedmace/bulrush species (*Typha*). Due to this reliance on aquatic plants for oxygen, *Cq. richiardii* requires more or less permanent water to support these plants. As the immatures are very difficult to detect, presence of these aquatic plants can be taken as an indicator of suitability.

Typha *species, commonly called reedmace or bulrush, are symbolic of wetlands and can provide immature* Cq. richiardii *with oxygen for respiration.*

HOST PREFERENCE AND BITING BEHAVIOUR

This species can be a persistent biter during summer nights and will readily enter dwellings to feed. Biting is often most acute when the population is densest in July and August, although the adult season is relatively short compared to other British mosquito species. Biting is most intense around dusk and dawn. It is known to feed on humans, other mammals and birds, with some records of biting amphibians, and can be a significant nuisance to livestock. Biting usually takes place close to the aquatic breeding site, but there is evidence that *Cq. richiardii* can travel up to nearly a kilometre on ascendant air currents.

VECTOR POTENTIAL

Cq. richiardii is not considered to be a principal arbovirus vector, although its human and bird feeding behaviour means that it should be taken into consideration as a possible route for arbovirus transmission.

MITIGATION OPTIONS

It is possible, though untested, that cutting back target vegetation below the water line in winter may inhibit development of *Cq. richiardii* immatures, as they overwinter, including under ice, attached to these plants. While likely to be undesirable in a conservation context, complete drainage of the aquatic habitat would negatively impact these species and may be suitable in other situations.

Culex modestus

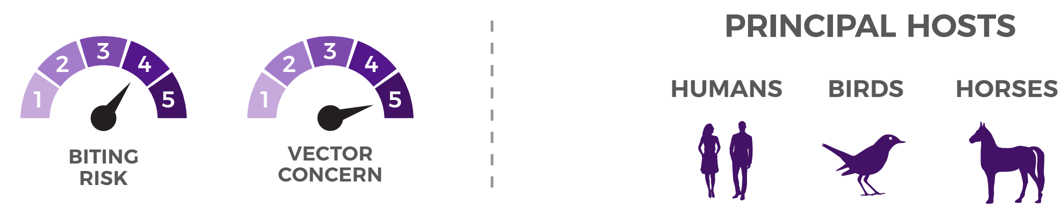
BACKGROUND

***Culex modestus* can be a localised nuisance mosquito in the UK and is a significant vector of arboviruses and parasites in Europe.**

The history of *Culex modestus* in the UK is sketchy. In 1944, thirteen individual specimens were found in and around Portsmouth. No subsequent reports were made until 2010, when a seemingly well-established population was detected in north Kent. Since then, surveying suggests *Cx. modestus* is established along a narrow band of south eastern coastline leading in towards the Thames estuary and also up the Essex coast, where it can be locally abundant.

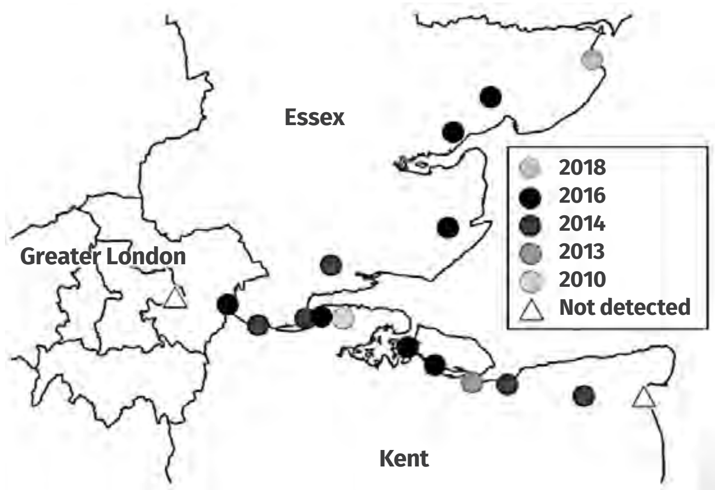
Most information on the biology of *Cx. modestus* comes from studies in Europe and its precise ecology and behaviour in the UK are still the subject of study

KEY HABITAT: Permanent brackish wetlands with emergent vegetation



DISTRIBUTION

This species has a narrow distribution in the south east of England but can be locally abundant. Populations of *Cx. modestus* have been found along the coastlines of north Kent and all up the Essex coast. Individuals have also been identified in Dorset and Cambridgeshire. There are no records from Scotland, Wales or Northern Ireland.



As of 2018, the distribution of Culex modestus *is largely confined to coastal areas in south east England. The species has been detected as far west as Rainham in Essex and as far east as Stodmarsh in Kent. The northerly distribution reaches to Hamford Water in Essex. Additionally, the species has been detected in Dorset and Cambridgeshire (PHE).*

LIFE HISTORY AND PHENOLOGY

Culex modestus is multivoltine and larvae appear from late spring until late autumn. Adults have been detected from late June, with a peak in August. The last adults survive until at least September.

	J	F	M	A	M	J	J	A	S	O	N	D
Larvae												
Pupae												
Adults												

LARVAL HABITATS

In the UK, immatures of *Cx. modestus* seem to be largely localised to ditches in coastal and floodplain grazing marsh, especially where algae, floating and/or emergent vegetation can be found. In its UK distribution, habitats positive for *Cx. modestus* are associated with sedges and densely-growing reeds. In Europe, documented habitats include rice fields, reedbeds, irrigation channels, meadows and other shallow, sunlit habitats. This species will tolerate fresh to slightly brackish water.

This ditch on the marshes of North Kent has abundant emergent vegetation including algae and sedges and supports larvae of Culex modestus. *Image: Anthony Abbott/LSTM.*

HOST PREFERENCE AND BITING BEHAVIOUR

This species will readily bite birds, humans and horses. Biting peaks in the evening and occurs outdoors, including in the open field. It can be a local nuisance biter along the Thames estuary.

VECTOR POTENTIAL

Culex modestus is one of the principal vectors of West Nile virus in Europe. It has been involved in outbreaks of West Nile fever, including in France, Italy, Romania, and Russia. Experimental laboratory work suggests that *Cx. modestus* has a higher West Nile virus transmission rate than any other mosquito species tested. Its feeding behaviour means it can readily transfer the virus from its amplifying hosts, birds, to humans and horses, which are dead-end hosts, meaning that they can develop clinical symptoms, but are unable to infect other mosquitoes.

This species is also implicated in transmission of several other pathogens, including Tahyna virus in humans and *Dirofilaria immitis* (heartworm) in dogs, and has been found to be infected with Sindbis and Lednice viruses.

MITIGATION OPTIONS

There are currently no clear examples of the impact of water or vegetation management on control of this species. Therefore, management in permanent ditches may require biocide application.

Culex pipiens sensu lato and *Culex torrentium*

BACKGROUND

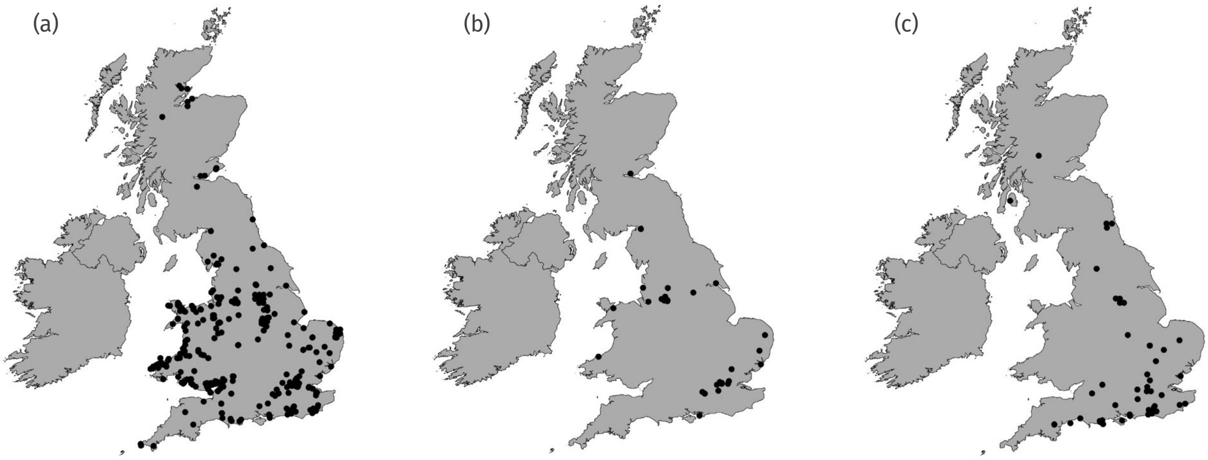
Culex pipiens **sensu lato and** ***Culex torrentium*** **can only be distinguished morphologically by examination of the male genitalia. However, they occur in a wide sympatric distribution in Britain and share many biological features.**

Additionally, there are two biotypes of *Cx. pipiens*: the nominate *pipiens* biotype and the *molestus* biotype. The *pipiens* biotype is the most abundant and widely distributed of all British mosquito species and is sometimes referred to as the common house mosquito. The habitat of the *molestus* biotype differs considerably from the *pipiens* biotype and indeed all other British mosquitoes in that both adult and larval forms are almost entirely confined to underground shelters.

KEY HABITAT: Transient wet woodland and grassland, fen, ditches, ponds, scrapes and reedbeds.

DISTRIBUTION

Culex pipiens biotype *pipiens* is widespread across England, Scotland and Wales and has been recorded in 60 vice counties. The *molestus* biotype has been recorded less frequently, in only 17 vice counties but may be more widely distributed than records show. There are at present no records of *Cx. torrentium* from Wales or Ireland, although this could reflect under-recording, and 24 vice county records from England and Scotland.



UK Distribution of: (a) Culex pipiens *biotype* pipiens*, (b)* Culex molestus*, and (c)* Culex torrentium *(NBN).*

LIFE HISTORY AND PHENOLOGY

Both *Cx. pipiens* and *Cx. torrentium* undergo complete hibernation during the winter in cold cellars, out-buildings and natural shelters. Males of the *pipiens* biotype die off at the onset of winter, while inseminated females seek overwintering sites from August to October. Adult mortality in winter is high, with surviving females breaking diapause in spring. Following a blood meal on birds, eggs are deposited as rafts and the adults die.

The subsequent generation of adults appear from May. Adult density increases rapidly in June and remains high until the autumn. Females emerging after August feed exclusively on plant juices, building up fat reserves in anticipation of diapause. Development in *Cx. torrentium* seems to be a little slower than in *Cx. pipiens*, possibly making them univoltine in northern areas.

Cx. pipiens biotype *pipiens* and *Cx. torrentium*

	J	F	M	A	M	J	J	A	S	O	N	D
Larvae												
Pupae												
Adults												

The biology of the *molestus* biotype is quite different from the *pipiens* biotype. Mating readily occurs in confined underground buildings and females are autogenous (able to lay eggs without prior acquisition of a blood meal). If hosts are available, both adults and larvae can remain active throughout the year with no overwintering diapause.

Cx. pipiens biotype *molestus*

	J	F	M	A	M	J	J	A	S	O	N	D
Larvae												
Pupae												
Adults												

LARVAL HABITATS

Both species develop in a wide variety of rural, suburban and urban natural and artificial water collections such as ponds, ditches, marshes, tanks and water butts, in which they are often found together. The nominate *pipiens* biotype is opportunistic and is common in a wide range of more or less transient aquatic habitats, occupying wheel ruts or containers associated with declining farms. It is a typical pioneer species and in the first stages of wetland regeneration will exploit new wetland pools and flooded grassland. *Culex torrentium* has occasionally been observed to lay eggs in tree holes and seems better able to colonise container habitats than *Cx. pipiens*.

Culex pipiens *can quickly colonise rain-filled depressions and wheel ruts, as well as newly created scrapes and pools in wetland sites.*

Flower vases in this Hampshire cemetery provide aquatic 'container' habitats for Culex pipiens/torrentium.

The hypogeal habit of *Cx. pipiens* biotype *molestus* means that larvae can be found in deep mines, subterranean transport systems, such as the London Underground, and tenement blocks, as well as other flooded underground structures such as cellars and boiler rooms. They will tolerate variability in water quality, from clean water to highly polluted water in sewage storage and treatment plants.

HOST PREFERENCE AND BITING BEHAVIOUR

Culex pipiens biotype *pipiens* and *Cx. torrentium* are not considered to be a cause of nuisance of humans. These species are strongly ornithophagic and will fly up to 12 m into the canopy to find a bird host, typically dispersing no more than 500 m from their aquatic larval habitat. *Culex torrentium* is entirely ornithophagic, whereas *Cx. pipiens pipiens* has been reported to bite humans, frogs, lizards and snakes, although human biting is rare.

In contrast to this, *Cx. pipiens* biotype *molestus* will readily bite humans and, as the name suggests, can be a considerably but highly localised nuisance. This can persist throughout the year as their sheltered environments negate the need for diapause. They can even mate in confined spaces underground and produce a batch of eggs without a bloodmeal.

VECTOR POTENTIAL

Collectively, these species are the most important enzootic vectors of bird-associated viruses in Europe, e.g. West Nile virus and Sindbis virus. The marked ornithophagy of *Cx. torrentium* and *Cx. pipiens* biotype *pipiens* make both prime suspects of arbovirus transmission between birds, and the more catholic feeding habits of the *molestus* biotype marks it as a vector between birds, a bridge vector and a vector between mammals, including humans. In the event of a disease outbreak, management of their populations will be crucial in managing the enzootic transmission of the viruses.

MITIGATION OPTIONS

Reducing the number of container habitats or monitoring and periodically emptying water from containers can be an effective local mitigation strategy for the *pipiens* biotype. Similarly, minimising the number of depressions from wheel ruts and the associated pooling water can help to limit the availability of aquatic breeding habitats if practicable and if required.

Identification of key overwintering sites (which may include barns and other buildings in wetlands) may provide an opportunity for reducing overwintering populations.

Culiseta annulata

BACKGROUND

Also known as the banded mosquito because of the distinctive striped markings on its legs, *Culiseta annulata* is a Palearctic species and is a common nuisance biter in the UK. Due to its large size and coloration, it is often confused with smaller invasive species, which can cause concern.

KEY HABITAT: Ditches, scrapes, ponds, reedbeds, wet woodland, acid bogs, flooded grassland and fen

DISTRIBUTION

Culiseta annulata is found across the UK and can be abundant. It has been reported in 72 vice county records.

UK distribution of Culiseta annulate *(NBN).*

LIFE HISTORY AND PHENOLOGY

Culiseta annulata is present in all its life stages throughout the year. It appears able to survive winter without recourse to diapause: aquatic stages, adult males and gonoactive (including parous) adult females may be found throughout winter. Overwintering adults will shelter in cellars, attics and animal shelters. Eggs are laid in rafts of around 200 and there can be several generations a year.

	J	F	M	A	M	J	J	A	S	O	N	D
Larvae												
Pupae												
Adults												

LARVAL HABITATS

This species can develop in diverse aquatic habitats and can tolerate brackish conditions. In wetland environments, ponds, ditches and marshes are all suitable habitats. Larvae of *Cs. annulata* tolerate various levels of light, from sunlit to shaded, as well as a wide range of water quality, from clean, fresh water to polluted or brackish conditions. Equally, it can be found in rural and urban areas, where it exploits artificial containers and organic-rich habitats (e.g. cisterns, water butts and blocked gutters and drains).

Culiseta annulata *makes use of a wide range of aquatic niches, including those in urban environments not associated with wetlands. Here, plastic drums used for collecting rainwater contain plentiful organic matter such as algae and represent one of many suitable habitats for* Cs. annulata, *as do domestic gutters. When blocked by moss, fallen leaves and other organic debris, gutters will retain water, which becomes enriched with food for larvae as the vegetation decomposes.*

HOST PREFERENCE AND BITING BEHAVIOUR

This species can be an aggressive human biter in both urban and rural areas and represents a considerable nuisance. The adults rest indoors and will readily bite humans both indoors and out. *Culiseta annulata* also has the longest biting season of any British mosquito species, as the females remain active during winter, and so can present a biting nuisance throughout the year; mosquito bites acquired between late autumn and early spring are most likely to be from *Cs. annulata*.

Adult females will procure blood meals from a broad range of hosts including humans, birds, rabbits, pigs and probably other livestock animals, pets and wild mammals, too.

VECTOR POTENTIAL

Culiseta annulata is a putative vector species, having been implicated as a potential bridge vector of West Nile virus and Tahyna virus due to its wide host choice, however it is not a principal vector.

MITIGATION OPTIONS

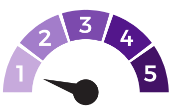
The ubiquity of this species and its ability to develop in a wide range of aquatic habitats makes developing a mitigation strategy problematic.

Culiseta morsitans

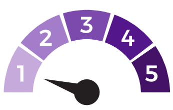
BACKGROUND

***Culiseta morsitans* is a common species in British wetlands, especially fenland and acid bog.**

KEY HABITAT: Fenland, shaded water, heavily vegetated water



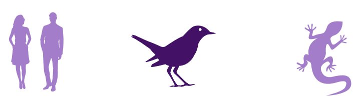
BITING RISK



VECTOR CONCERN

PRINCIPAL HOSTS

HUMANS BIRDS REPTILES



DISTRIBUTION

Culiseta morsitans has been recorded in 49 vice counties across the UK.

UK distribution of Culiseta morsitans *(NBN).*

LIFE HISTORY AND PHENOLOGY

Eggs are laid in batches above the level of standing water. They hatch following immersion by autumn or winter rainfall, with the majority hatching on first flooding. However, eggs are very drought resistant and during dry winters will survive over winter without desiccation. Fourth instar larvae appear in November and can survive under ice for long periods but cannot withstand freezing. Pupation is delayed until the spring, with pupae appearing from around April to June. Adults first appear in April, reach peak abundance in June and can be found until mid-October. *Culiseta morsitans* is univoltine.

	J	F	M	A	M	J	J	A	S	O	N	D
Larvae												
Pupae												
Adults												

LARVAL HABITATS

Research from the 1930s considered *Cs. morsitans* to be the most common mosquito of fenland habitats, where larvae abound in shallow water, particularly among the sedge, *Cladium mariscus*. It additionally exploits a variety of shaded freshwater habitats in ditches, wet woodland, reedbeds and acid bogs. It can also be found in vegetated margins of open water and can tolerate slightly brackish conditions.

Culiseta morsitans *is common in the fens in the east of England, where its larvae can be found in many wet wetland habitats, including in emergent vegetation, such as this area of great fen-sedge (*Cladium mariscus*, also known as saw-sedge) growing in standing water at the edge of a large pond in Cambridgeshire.*

HOST PREFERENCE AND BITING BEHAVIOUR

This species is not likely to be a nuisance as it feeds almost exclusively on birds, although they will occasionally bite people outdoors. Some feeding on reptiles and small mammals has been reported.

VECTOR POTENTIAL

Its ornithophagic nature makes *Cs. morsitans* a suitable enzootic vector of bird-associated viruses, including West Nile virus and Sindbis virus. In the absence of pathogen transmission and human biting, it is questionable how important this species is to human health, although its possible status as an enzootic vector should not be ignored.

Further reading

Abbott, A.J. (2018) The ecology of *Culex modestus*, a potential vector of West Nile Virus in the UK. PhD Thesis, University of Greenwich.

Becker, N., Petrić, D., Zgommba, M., Boase, C., Madon, M., Dahl, C. & Kaiser, A. (2010) Mosquitoes and Their Control, Second Edition (Second), Springer, New York.

Cranston, P.S., Ramsdale, C.D., Snow, K.R. and White, G.B. (1987) *Adults, Larvae and Pupae of British Mosquitoes (Culicidae): A Key.* Freshwater Biological Association, Ambleside, UK.

European Centre for Disease Prevention and Control (2020) Mosquito-borne diseases. Available from: https://www.ecdc.europa.eu/en/mosquito-borne-diseases. Accessed 5 June 2020.

Golding N., Nunn, M.A., Medlock, J.M., Purse, B.V., Vaux, A.G.C. & Schäfer, S.M. (2012) West Nile virus vector *Culex modestus* established in southern England. *Parasites and Vectors*, 5:32.

Graham, A., Day, J., Bray, B. & Mackenzie, S. (2012) Sustainable Drainage Systems: Maximising the potential for people and wildlife. A guide for local authorities and developers. RSPB and WWT.

Marshal, J.F. (1938) *The British Mosquitoes*. Johnson Reprint Corporation, 1966.

Medlock, J.M. (2015) Impact of the creation, expansion and management of English wetlands on mosquitoes (Diptera: Culicidae). PhD Thesis. University of Bristol.

Medlock, J.M., & Snow, K.R. (2008) Natural predators and parasites of British mosquitoes–a review. *European Mosquito Bulletin*, 25(April):1-11.

Medlock, J.M. & Vaux, A.G.C. (2011) Assessing the possible implications of wetland expansion and management on mosquitoes in Britain. *European Mosquito Bulletin*, 29(March):38–65.

Medlock, J.M. & Vaux, A.G.C. (2013) Colonization of UK coastal realignment sites by mosquitoes: Implications for design, management, and public health. *Journal of Vector Ecology*, 38(1):53–62.

Medlock, J.M. & Vaux, A.G.C. (2014) Colonization of a newly constructed urban wetland by mosquitoes in England: implications for nuisance and vector species. *Journal of Vector Ecology*, 39(2):249–260.

Medlock, J.M. & Vaux, A.G. (2015) Impacts of the creation, expansion and management of English wetlands on mosquito presence and abundance - Developing strategies for future disease mitigation. *Parasites and Vectors*, 8(1)142.

Medlock, J.M. & Vaux, A.G.C. (2015) Seasonal dynamics and habitat specificity of mosquitoes in an English wetland: Implications for UK wetland management and restoration. *Journal of Vector Ecology*, 40(1), 90–106.

NBN Atlas (2019) Available from: http://www.nbnatlas.org. Accessed 5 June 2020.

Roberts, D.M. (2001) Egg hatching of mosquitoes *Aedes caspius* and *Ae. vittatus* stimulated by water vibrations. *Medical and Veterinary Entomology*, 15(2):215-218.

Snow, K.R. (1990). *Naturalists' Handbook 14: Mosquitoes*. Slough: The Richmond Publishing Co. Ltd.

7. MOSQUITO SPECIES ASSOCIATIONS WITH WETLAND HABITAT TYPES

7.1 Introduction to the species prediction tool

Purpose

Mosquitoes occur in a range of wetland habitats, with varying degrees of habitat specificity according to the species concerned. The tool has been designed to assist those with responsibility for managing or planning wetland habitats to ascertain the species they might expect to find in those habitats. The tool is not intended to replace expert advice or confirmation of species by sampling; rather it is intended to be a complementary tool to be used alongside empirical data collection and other biodiversity assessments, and the risk assessment process.

How was the tool developed?

The Wetland Mosquito Prediction Tool draws together current data on the ecology of the British mosquito species that are of greatest relevance from a public health perspective. Developing the tool was an iterative process that combined published literature with empirical field work (Figure 7.1). First, an initial draft of the tool was developed based on a review of the existing literature and data from 10 years of PHE's Nationwide Mosquito Surveillance Project. Additionally, the experience of entomologists at PHE in responding to questions from the public and wetland managers, their field research on mosquitoes in wetlands plus their understanding of field sampling, were drawn in to frame how the tool was written and presented.

The initial draft was tested in 2017 in a comprehensive survey of adult and larval mosquitoes across England, focusing on six wetland areas with a diverse array of habitats. Covering a wide geographical area, including nature reserves, country parks and sites of special scientific interest (SSSIs), data were collected from wetland sites: farm reversion, ditches, reedbeds and wet woodland on the Somerset Levels; valley mires, and diverse brackish and freshwater habitats at Arne near Poole Harbour; flooded and riverine coastal habitats along the River Otter in Devon; in urban country parks and local nature reserves with wetland habitats around Bedford; on the coastal marshes of north Kent at Northward Hill; and in fen and wet woodland at Chippenham in the Cambridgeshire fens. In the first instance, the wetland manager/s responsible for the area gave detailed information about the types of wetland habitats present, their management activities and natural and/or artificial flooding regimes. Larval sampling from 48 discrete aquatic habitats were sampled three times (in May, July

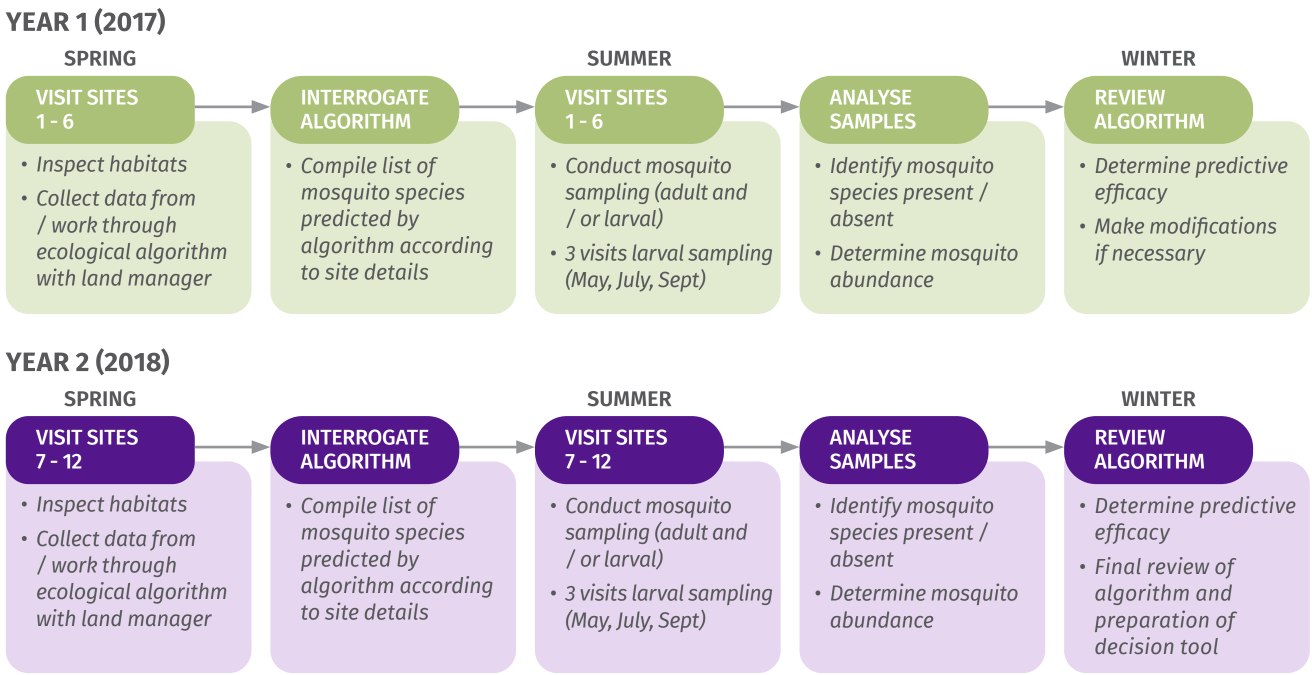


Figure 7.1. *The process followed for developing the Wetland Mosquito Prediction Tool.*

and September) and adults were sampled for four nights, every fortnight, from April to October. This structure ensured both attribution of species to specific aquatic habitats, plus detection of both those species that can only reliably be found via adult trapping and adults from habitats to which it was not possible to gain access safely (for instance, because of difficult access across terrain). Over 1,900 larvae and over 11,000 adult mosquitoes were collected and identified, alongside detailed habitat descriptors for every sampling location.

Once the samples were identified and compared to what was predicted for each habitat, the tool was reviewed and updated with refinements and modifications that reflected the data collected. The process of field validation for the second version of the algorithm was undertaken in 2018 and followed the same protocol: six new wetland areas were identified, then scoped, and adult and larval mosquitoes sampled throughout the season as before, with larvae collected from 37 discrete aquatic habitats. Samples were collected from: Radipole Lake adjacent to urban Weymouth; Alkborough Flats, a coastal realignment project along the River Humber; wet woodland pools in Hurcott, Worcestershire; saltmarsh and estuarine habitat at Steart in Somerset; in flooded grassland, fen and wet woodland at Greywell in Hampshire; and at a sustainable urban drainage scheme in Milton Keynes. In this round of data gathering, over 600 larvae and over 27,000 adult mosquitoes were collected and identified. A final iteration of analysis and review was completed to produce the final version of the tool, presented here.

Introduction to the habitats

The habitats included in the tool are intended to be simple, generic descriptors that cover a range of more refined habitat typologies. There are clearly many different types of wetland habitat and the generic approach taken here is the most appropriate for assessing mosquito habitat, rather than using other advanced systems, such as the British National Vegetation Classification. Essentially, British mosquito species respond in different ways to breeding in aquatic habitats depending upon whether the wetland remains wet all year, dries out in winter or summer, and whether the wetland is wooded, shaded or open. Depth of water is also important.

Figure 7.2. Aedes geniculatus, *one of a small number of tree-hole breeding mosquitoes found in Britain.*

As described previously, British mosquitoes can essentially be separated into different functional groups (see Chapter 5.5). They either oviposit on water or on land (likely to be subsequently submerged). For those species that oviposit on land, the eggs hatch either in autumn/winter and develop in winter/spring flooded habitats (i.e. the woodland *Aedes* species) or the eggs hatch in spring and develop in summer flooded habitats (i.e. the floodwater *Aedes* species, usually in open habitats). In a few species, such as *Ae. geniculatus* (Figure 7.2), *An. plumbeus* and *Or. pulcripalpis*, they lay their eggs in tree holes, and hatch when the tree hole is subsequently flooded.

For those species that lay on water, some species (i.e. *An. maculipennis* s.l. [i.e. *An. messae*], *An. claviger*, *Cq. richiardii*) tend to exploit permanent habitats. Other species (i.e. *Cs. annulata*, *Cx. pipiens*, but also *An. claviger*) are pioneer species, exploiting flooded habitats.

The types of habitat listed in the Wetland Mosquito Prediction Tool are based on the ecological, hydrological and management characteristics that are most relevant to these aspects of mosquito ecology. The most important factors that influence the mosquito species suitability of a given aquatic habitat are:

- Permanence of the water, as determined by the timing and duration of natural or deliberate flooding
- Water movement (both lotic and surface water movement)
- Water salinity
- Degree of vegetation cover
- Whether the habitat is cloistered or open

Other features that are considered in the tool include the level of sunlight on the water, its temperature, pH and nutrient load, and associations with certain species of aquatic flora.

It is important to remember that just because a habitat may be suitable for a species it does not necessarily mean that that species will be found there. There are many other aspects that can determine whether a particular mosquito species will be found in any given habitat. These include its ability to disperse and the presence of aquatic and terrestrial predators in the immediate habitat and wider landscape, which will influence the abundance of mosquitoes at different life stages, as will the availability and proximity of potential hosts for adults. Planned, chance and unexpected events can affect a habitat's suitability in the long and short term, and these influences may not always be obvious, even when there is close oversight and stringent management of an area. Extreme weather events such as drought and floods can impact different mosquitoes in different ways, both in denuding habitat for some species, or creating mass emergence of mosquitoes in others. Such events can see a consequent shift in species diversity and abundance. In the case of summer flooding, whether natural or human-influenced, the soaking of previously unflooded mosquito eggs (usually *Aedes* species) can lead to the most dramatic impacts. In coastal areas, spring tides around the equinoxes can have a similar impact on stranded mosquito eggs (e.g. *Ae. detritus*).

Appendix III summarises the aquatic oviposition habitats of each of the British mosquito species, how they may be impacted by wetland creation and management practices, and their potential nuisance and vector concern.

How to use the Wetland Mosquito Prediction Tool

Section 7.2 Wetland Mosquito Prediction Tool (below) contains a series of flow charts and supporting text. Chart 1 provides an overview flow chart corresponding to broad aquatic wetland habitat types according to whether they are brackish and coastal or freshwater. Each of these eleven habitat types is explored in further detail in subsequent flow charts, many of which include questions regarding the specific nature of the habitat with respect to characteristics that are relevant to mosquito ecology. Answering these questions will lead to a list of mosquito species that may find such habitat suitable, with more detailed text following the flow charts.

These species lists are generalised from what is currently known about the ecology of the most common British mosquito species and are meant to be indicative, rather than definitive. It is important to note that even if a habitat is indicated to be suitable for a particular mosquito species, this does not necessarily mean that species will be present, as other factors such as habitat connectivity (or isolation) will influence colonisation. Similarly, it is possible that, on occasion, species may be found in atypical habitat. It is highly recommended that use of this tool is supported by data gathering to verify the exact species present in an aquatic habitat, and their relative abundances. Procedures for sampling adult and larval mosquitoes are described in Chapter 8.

7.2 Wetland mosquito prediction tool

Chart 1. Overview of wetland habitats according to whether the water is brackish and/or found in coastal areas, or whether it is predominantly freshwater.

Chart 2. Predicted mosquito species in saltmarsh, mudflat and other coastal habitats.

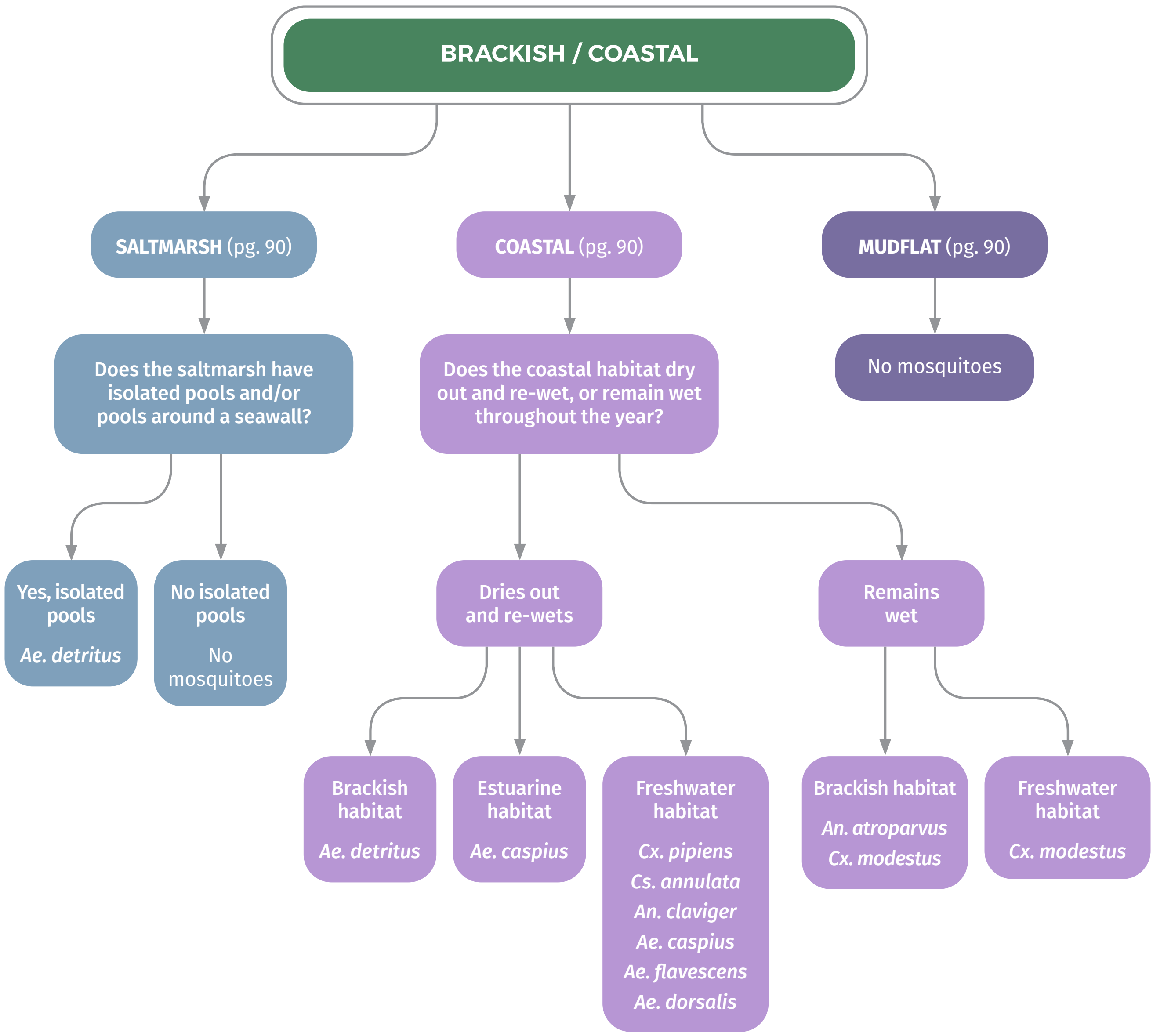


Chart 3. Predicted mosquitoes in wet woodland habitats.

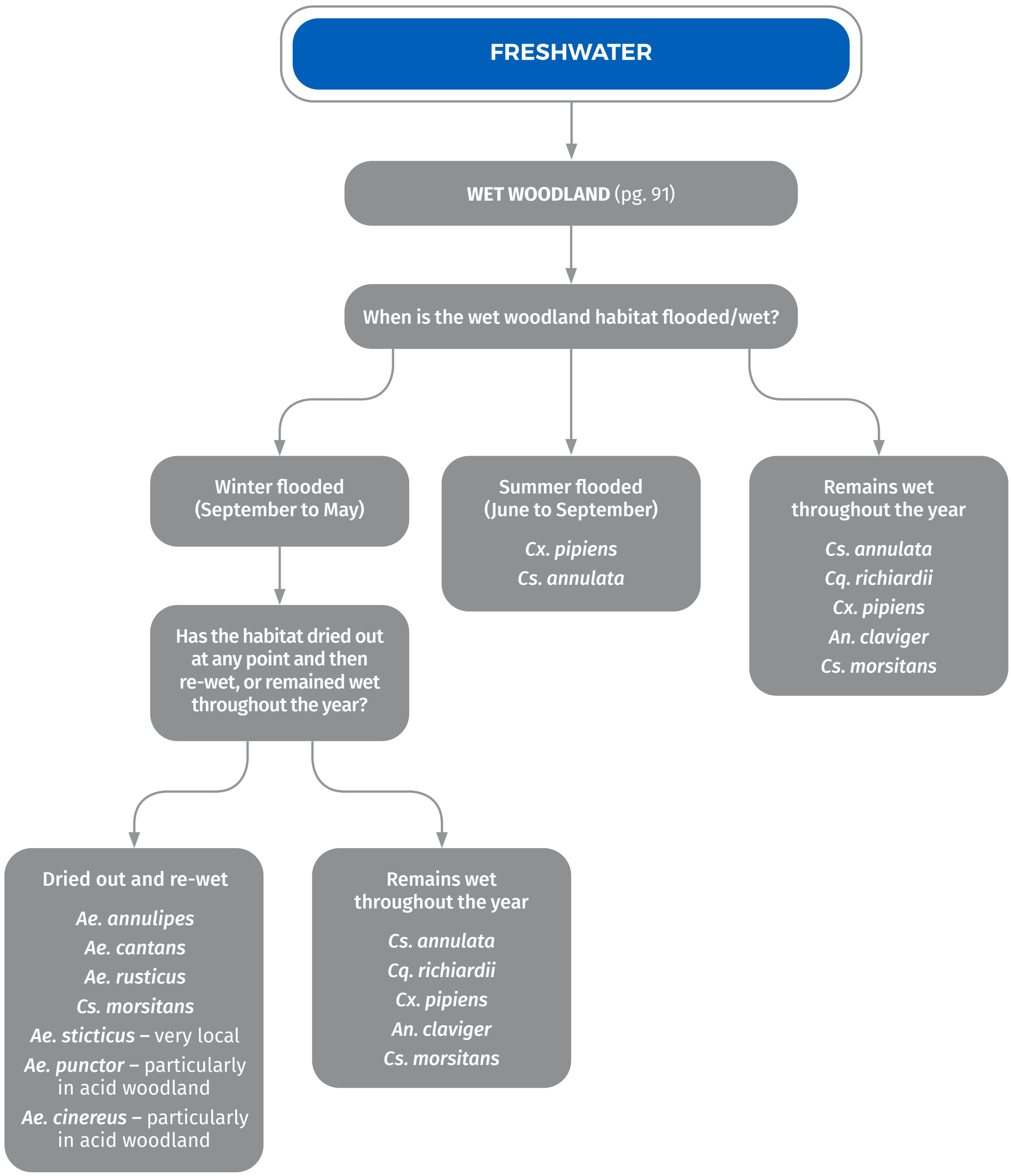


Chart 4. Predicted mosquitoes in wet grassland, fen and ditch habitats.

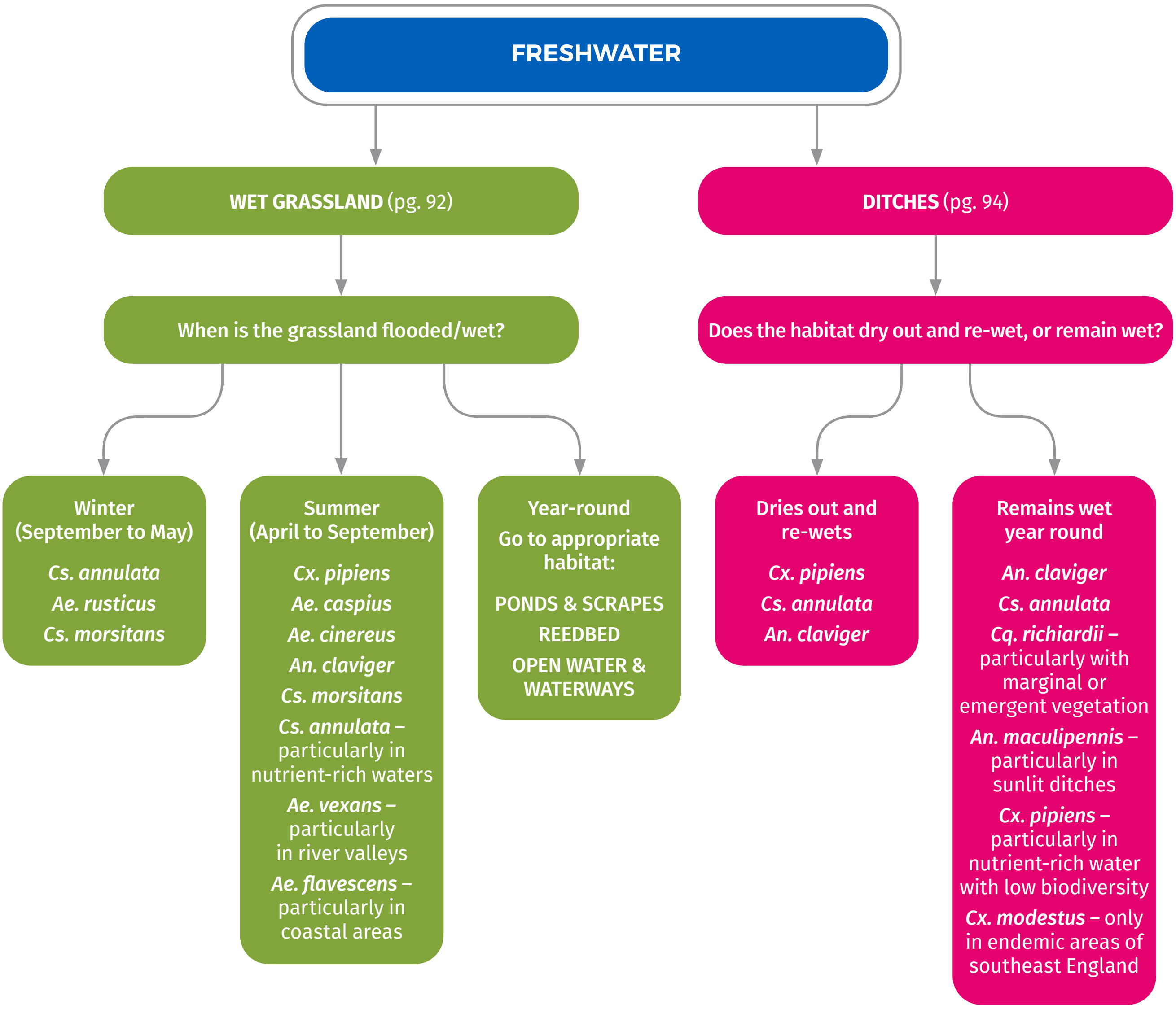


Chart 5. Predicted mosquitoes in acid bogs, ponds and scrapes, reedbed and tree holes.

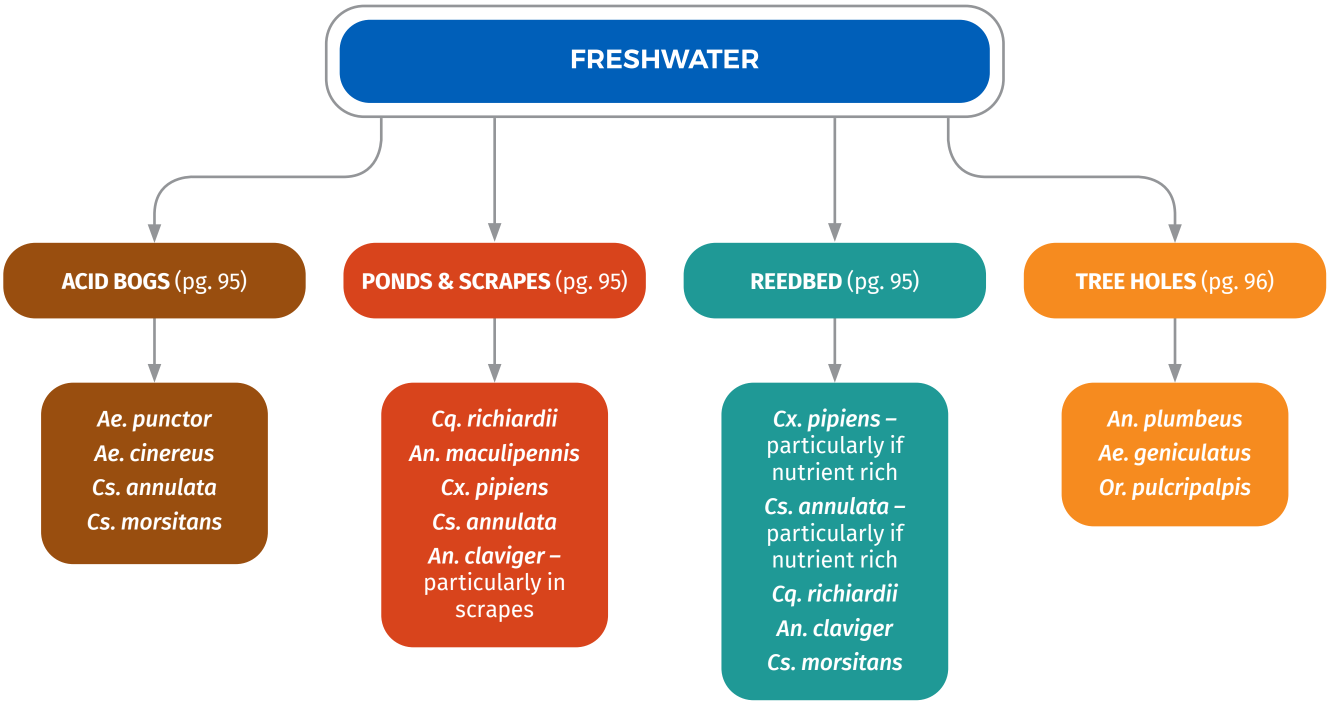
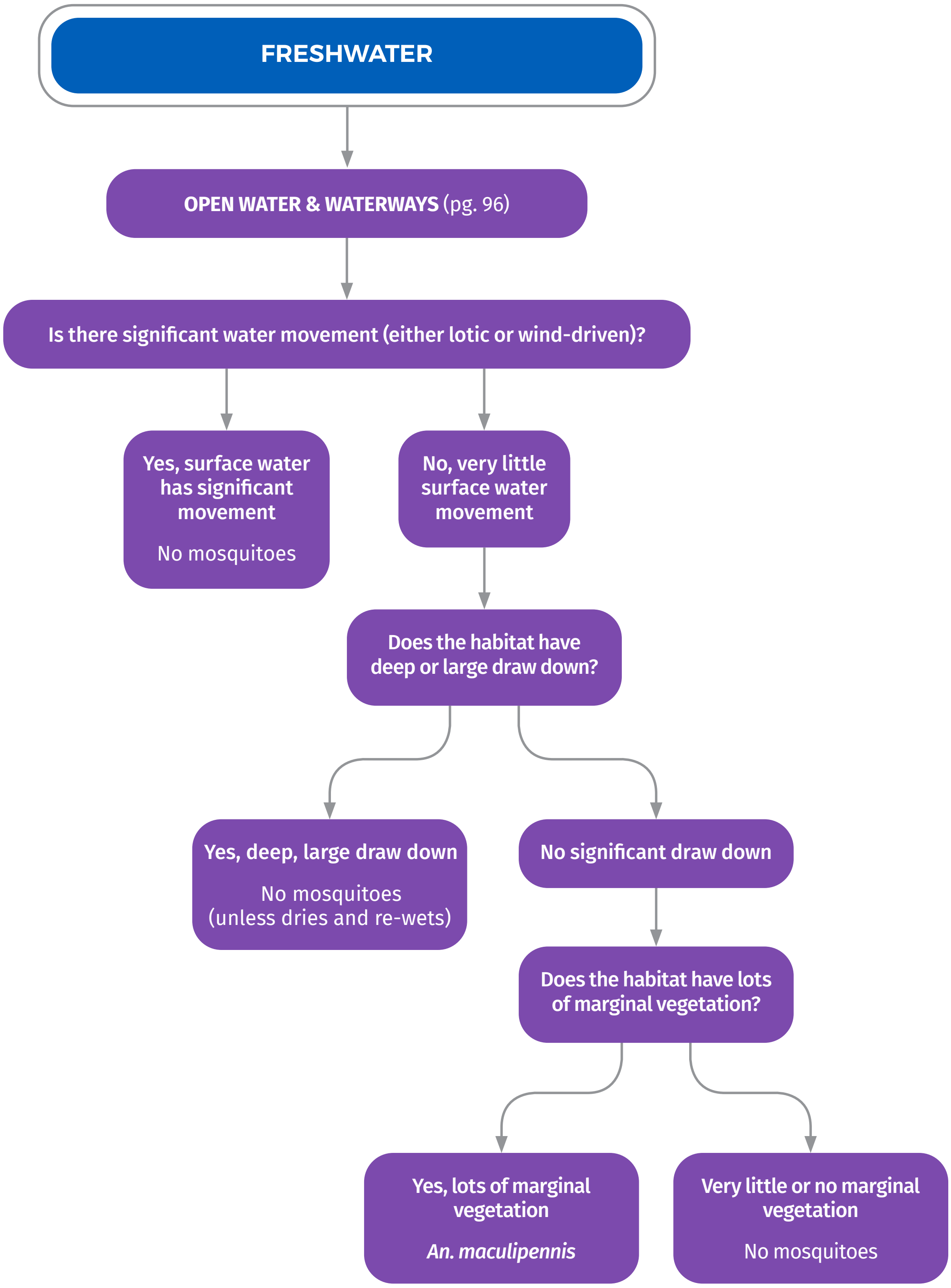


Chart 6. Predicted mosquitoes in open water and waterways.



7.3 Mosquito habitats

7.3.1 Brackish Habitats

The majority of British mosquito species undergo larval development in freshwater aquatic habitats, and although some species can tolerate low degrees of salinity, there are only a few species (e.g. *Ae. detritus*, *An. atroparvus*) that are truly considered as mosquitoes of brackish water. It is possible that some other species (e.g. *Cx. modestus*, *Ae. flavescens*, *Ae. caspius*) can also be considered to be coastal species, but they are not typically considered species of brackish water. Within this tool, we have identified three broad brackish habitat types that categorise most brackish environments according to their suitability for mosquitoes.

Aedes detritus remains the most common nuisance species associated with salt-water habitats, however there are unusual records of larvae of this mosquito occurring inland, in apparently freshwater habitats. There is a suggestion that underground salt deposits associated with the freshwater can afford suitable aquatic habitats for this species inland. There is also a suggestion that as this species is a species complex, one subspecies could be considered to be a freshwater species. For the purposes of this tool, *Ae. detritus* will be considered as a brackish water mosquito. With regard to *An. atroparvus* (part of the *An. maculipennis* complex), this species is considered to be one of the historical vectors of malaria in the UK.

Mudflats

Not all brackish water habitats are suitable for mosquitoes (Figure 7.3). Essentially, if the water is flushed regularly by the tide (and hence drains or has high velocity) then it is unsuitable for mosquitoes. For example, mudflat is regularly washed by the tide, and the lack of vegetation makes it unsuitable for mosquitoes, even in areas with halophytic vegetation provided there are no pools left above the intertidal zone. Even silty/muddy runnels in the mud with water and no vegetation are unlikely to support mosquito larvae.

Saltmarsh, coastal drains and other coastal habitats

However, where there is vegetation and where water pooling occurs (at low tide), there is potential for mosquito larval habitat to occur. If this habitat is regularly flooded on the majority of tides, and covered by coastal waters, then mosquitoes may not be present. Where there are isolated pools left by spring high tides, either amongst vegetation, or in open pools at the high tide limit, then these can support *Ae. detritus*, and in high numbers (Figure 7.4). Flooded vegetation in coastal areas may also support *Ae. caspius* and *Ae. flavescens*. Large populations of *Ae. caspius* have been found by impounded pools and flooded vegetation at the high tide limit in coastal areas (Figure 7.5), although these tend to be where salinity levels are low (at the head of estuaries), and therefore more likely to be an impact of estuarine or river flooding rather than heavily saline waters. In some locations, *Ae. dorsalis* may be recorded, although this species does not appear to be widespread.

Figure 7.3. *Neither of these areas of newly created mudflat in Essex are suitable for mosquitoes. There is little vegetation and the habitat is flushed and drained on each tidal cycle.*

Research at MRA sites in England found that the aquatic habitats that supported mosquitoes resulted from specific design aspects of the new sea wall such as (a) an additional bank of ballast to mitigate wave action providing a linear habitat supporting significant numbers of mosquitoes, (b) constructed saline borrow ditches, excavated during construction, that receive brackish waters at spring high tides, with tidal waters collecting on vegetated banks in culverts with minimal tidal flushing and (c) isolated pools created through silt accretion or expansion of flooded zones to neighbouring pasture. This study reported there was likely to be some nuisance biting associated with *Ae. caspius* and *Ae. detritus* at sites that support flooded habitats that are not regularly flushed by the tide. Management plans may be needed to deal with such sites if nuisance biting by *Ae. detritus* and *Ae. caspius* is found to be problematic. Similar controls would also be needed if, in the future, these species become implicated in disease transmission cycles. Ideally, prior to any MRA construction, consideration should be given to the creation of potential aquatic mosquito habitats (as part of the Environmental Impact Assessment), with further consideration to how such habitats could be minimised. For example, closing of sluices to prevent over-flooding of ditches at spring high tides would minimise vegetation flooding and thus mitigate the problems with *Ae. detritus*; however, each site must be considered on a case-by-case basis.

Flooded coastal grasslands with freshwater areas, particularly in summer, may also provide aquatic habitat for larvae of *Cs. annulata* and *Cx. pipiens* s.l. Coastal ditches with brackish waters may well support *An. atroparvus* and *Cx. modestus*. *Culex modestus* is a species which has recently colonised coastal ditches in the Thames estuary and Essex coast. An updated map of its range is maintained by PHE on the gov.uk website (https://www.gov.uk/guidance/west-nile-virus), and the species should be considered within its known geographic range.

Figure 7.4. *Breeding habitats for* Aedes detritus *in coastal marshes at Poole Harbour. The saline channel to the left is unsuitable, but the stranded pool of brackish water to the right is suitable.*

Figure 7.5. *Isolated pools of vegetated estuarine floodwater along the coast in Lincolnshire provide suitable habitat for* Aedes caspius.

7.3.2 Freshwater Habitats

For the freshwater habitats in this algorithm, we have identified eight generic wetland types: wet woodland, flooded grassland and fen, tree holes, ditches, acid bog, permanent ponds and scrapes, open water (lakes, meres), and reedbed (natural and sewage treatment). The following text provides further information and details regarding their suitability for mosquito larvae.

Wet woodland

When we refer to wet woodland, we are referring to any sort of woodland that contains permanent wet ditches, woodland pools, or that regularly flood at some point during the year, especially in summer or winter. It is usually birch, alder or willow woodland, and within these specifically the low-lying areas that periodically flood, or areas of ditches that have afforested.

The dominant mosquito species of wet woodland are *Aedes* subgenus *Ochlerotatus*, specifically *Ae. cantans*, *Ae. annulipes*, *Ae. rusticus* and *Ae. punctor*. In some locations *Aedes sticticus* may occur. These univoltine species (one generation per year) rely upon ovipositing their eggs in areas on the woodland floor that are dry but will be later submerged by water (Figure 7.6). They do not oviposit on water. Therefore, areas prone to flooding are ideal, and the greater the surface area of flooding, the greater the scope for these mosquitoes to develop. Larval development tends to occur, for these species, in the late autumn, winter and early spring, and therefore winter flooding is ideal. Adults emerge in late spring and early summer. If these areas dry out during summer, then the females are able to oviposit ready for winter flooding.

Figure 7.6. *These seasonal ditches in the Cambridgeshire fens dry out during summer, making them suitable for* Aedes cantans, Aedes annulipes *and* Aedes rusticus.

If there are ditches or pools in the woodland that remain wet all year round, the opportunities for flooding of *Aedes* eggs is reduced. Instead there may be colonisation of *Cs. annulata* and *Cx. pipiens*. These two species may also exploit summer flooded areas in woodland, and also winter flooded areas that remain wet longer in summer after the *Aedes* development is complete.

Figure 7.7. *A male* Aedes rusticus, *a mosquito associated with the shady edges along hedge-lines and at the edges of wet woodland habitats, is thought to disperse only a few hundred meters from its larval breeding grounds.*

Figure 7.8. *Larval sampling in acid woodland pools in birch woodland, Poole Harbour, which can support* Aedes punctor. *The semi-shaded situation also makes this a potential habitat for* Aedes cinereus.

For further information on these woodland *Aedes*, it is useful to refer to their species profiles. In general, *Ae. cantans* and *Ae. annulipes* are morphologically similar with similar life histories. *Aedes rusticus* (Figure 7.7) reportedly prefers shaded habitats on the edge of woodland and along hedge-lines but has been found in flooded grassland. *Aedes punctor* reportedly prefers acid soils and can be found in woodland pools in birch woodland (Figure 7.8), and in mire habitat. It can also be found with *Ae. cinereus*. A species previously considered rare, *Ae. sticticus*, is recently more commonly being found in wet woodland.

Wet grassland and fen

Floodwater habitats, such as those in grassland and along the margins of rivers can provide aquatic habitat for the larvae of a number of floodwater mosquito species, principally floodwater *Aedes* that lay their eggs on the grassland during dry periods. These aquatic habitats, if they remain wet through summer, can also be exploited by other species.

Most development of floodwater species, such as *Ae. cinereus*, *Ae. caspius* and *Ae. vexans* (this species having recently been found in a few locations, where it is highly abundant), occurs during the summer months. Therefore, areas of grassland (Figure 7.9), either along coastlines, river valleys (Figure 7.10) or in grasslands subjected to summer flooding by rain, or management of water levels by wetland managers, can support development of large numbers of larvae.

Figure 7.9. *Newly created flooded grassland, like this area in the Cambridgeshire fens, can support a range of floodwater species like* Aedes cinereus *and* Aedes caspius, *as well as pioneer species such as* Culex pipiens *and* Culiseta annulata. *The more permanent wet areas can provide a habitat for* Anopheles maculipennis *s.l.*

Figure 7.10. *Typical* Aedes vexans *habitat in Nottinghamshire. Riverine flooding on low-lying grassland can inundate large numbers of eggs, which rapidly develop during summer to produce huge numbers of mosquitoes.*

A very wet late spring and summer, or a wetland subjected to management of summer water levels will have a profound effect in supporting nuisance and vector mosquitoes. Wetlands that either stay very wet, or remain very dry will probably have a lower impact. There appears to be a depth threshold in these wet grasslands above which mosquitoes cease to exist. Therefore, it may be possible that in situations where it is desirable to control mosquito numbers, raising water levels above specific depth thresholds will make the habitat inimical for mosquito development. However, natural or unnatural re-wetting of wet grassland during summer will contribute to large numbers of nuisance and potential vector species.

Flooding during the months of April to September appears to be essential for the larval development of these *Aedes* species, whereas winter flooding of these habitats will not lead to their development. When floodwater remains, other species such as *Cx. pipiens* and *Cs. annulata* may colonise (Figure 7.11). If deeper areas of floodwater persist through summer, then *An. maculipennis* s.l. may also colonise these areas (Figure 7.12). *Culiseta moristans* and *An. claviger* may also be found in flooded grassland, and *Ae. flavescens* may be present in coastal areas.

Figure 7.11. *Transiently groundwater-flooded habitats can support a range of mosquito species, including* Culex pipiens.

Late summer rains can also be controlled by wetland managers in wet grassland habitats through the operation of sluices and other interventions, thus allowing water to be retained on the grasslands through winter to promote visiting wildfowl. The timing of the commencement of this flooding is critical. Flooding as late as September and October can still promote immature mosquito development, particularly if unseasonably high temperatures promote rapid development through to emergence of nuisance adults. These are important considerations during arable reversion to wet grassland.

Figure 7.12. *Deeper water in flooded grassland can support* Anopheles maculipennis *s.l.*

Ditches

Ditches usually provide the largest linear network of permanent water in a wetland. If maintained, these can be very biodiverse, supporting a range of invertebrate (e.g. diving beetles, dragonflies & damselflies), amphibian and fish predators of mosquitoes.

Scrapes can provide aquatic habitat for mosquito larvae, but not if they tend to be poorly vegetated (Figure 7.13) or frequently dry out. If they remain wet into summer with emergent vegetation, then *Cx. pipiens* and *An. claviger* are likely to become well established. If the scrapes become more permanent, then their mosquito fauna will be similar to permanent ponds (Figure 7.14).

Figure 7.13. *This shallow ditch, created as part of a sustainable urban drainage system in Milton Keynes, does not support mosquitoes. It has little emergent and floating vegetation to support mosquito development.*

Figure 7.14. *A typical freshwater ditch in the Cambridgeshire fens. Such ditches can support* Anopheles maculipennis *s.l. (prinicipally* An. messeae*) and* Coquillettidia richiardii*, as well as many of their predator species. If these ditches are not managed and allowed to dry and over-vegetate, they can support a range of other mosquitoes, including some nuisance species.*

If ditches dry out during drought conditions (or if they are not managed, Figure 7.15) and then re-wet, the usual pioneer species (*Cx. pipiens* and *Cs. annulata*) as well as *An. claviger* can be found. *Culiseta annulata* may also be found in permanent ditches that are nutrient enriched or heavily vegetated.

Figure 7.15. *Ditches that remain permanently wet enable stable communities of mosquito predators to form. Where conservation and other priorities allow and where the hydrological infrastructure is present this can be achieved through various management practices, such as the operation of sluices, to maintain water levels across networks of ditches. However, artificially re-wetting dried woodland ditches or wet woodland in spring can lead to persistence of nuisance* Aedes *species.*

Acid Bog

Acidic conditions on acid heathland (Figure 7.16) are known to support specific species of mosquito, notably *Ae. punctor*, but also *Cs. morsitans* and *Ae. cinereus*, and sometimes *Cs. annulata*.

Figure 7.16. *Valley mire habitat (acid bog) in Dorset. A good habitat for* Aedes cinereus.

Permanent ponds and scrapes

Ponds tend to have the same mosquito species as ditches (*Cq. richiardii*, *An. maculipennis* s.l., *Cx. pipiens*, *Cs. annulata*). Their numbers are restricted by predators (fish, tadpoles, etc.) in the same way as they are in permanent ditches (Figure 7.17). Often ponds support no mosquitoes, and this depends upon the pond's size, the population of predators it supports, as well as its connectivity to neighbouring habitat that might be more suitable for mosquitoes.

Scrapes can support mosquito development, but not if they tend to be poorly vegetated and frequently dry out. If they remain wet into summer with emergent vegetation, then *Cx. pipiens* and *An. claviger* may occur. If they become more permanent, then their mosquito fauna will be similar to permanent ponds.

Figure 7.17. Coquillettidia richiardii, Anopheles maculipennis s.l., Culex pipiens *and* Culiseta annulata *may find suitable habitat in this pond, maintained at a country park for conservation and amenity value. However, the community of predators (including tadpoles, dragonfly and damselfly larvae, water beetles and other aquatic invertebrates) are likely to regulate the size of the mosquito population.*

Reedbed

Very few mosquitoes appear to exploit reedbed habitat, either because reedbed can fluctuate in depth, leaving areas of drawdown and silt, or because they are an extension of deep water, which is either inimical to mosquitoes or suitable for predators (i.e. fish). If reedbed is accompanied by emergent and marginal vegetation, then similar species assemblages to ditches may be found, with the addition of *Cs. morsitans*. During the early phases of reed planting, fluctuations in the water depth can lead to drying out or flooding, which may delay mosquito colonisation. Preventing the habitat from drying out will support an assemblage of predators that will contribute to regulation of larval mosquito populations within the reedbed (Figure 7.18).

Figure 7.18. *A large reedbed at Radipole, Dorset. At the margins lie areas of willow carr, where larvae of* Culex pipiens, Culiseta annulata *and* Anopheles claviger *may be found.*

In some areas, there is a drive to provide sustainable drainage systems (SuDs) which can involve harnessing the ability of wetlands to sanitise sewage to minimise local environmental pollution and absorb floodwater. In SuDS, reedbeds can be developed to act as natural sponges to trap silt and remove phosphorous from effluent, as well as slowing down the flow of water. Unvegetated stilling basins (used to hold sewage prior to passage through the reedbed) may support significant numbers of *Cx. pipiens*, with immature mosquito densities of several thousand per litre of surface water having been recorded. Within constructed reedbed, which is generally separated hydrologically from the rest of the wetland, increased nutrient enrichment can support pioneer species such as *Cx. pipiens* and *Cs. annulata* (Figure 7.19). Dredging nutrient-rich sediments (particularly around well-vegetated outlets and inlets) may reduce suitable habitat for these species.

Tree Holes

A small number of mosquito species are able to develop in cavities in trees that contain rainwater (Figure 7.20). *Anopheles plumbeus* and *Ae. geniculatus* are common tree hole species, although rarely abundant. Beech, chestnut, oak and plane are usually utilised, although these trees are not generally associated with wetlands. However, where they occur nearby then a small number of these species may be found. *Orthopodomyia pulcripalpis* is a rare species, generally found in low numbers in ancient beech pollarded woodland.

Open Water and Waterways

In general, areas of open water are unsuitable for mosquito larvae (Figure 7.21). They are either too deep or there is too much surface movement for mosquito larvae to breathe at the water surface, or where there is large drawdown, the silty aquatic environment, free of vegetation, becomes unsuitable. Where there are large areas of emergent and marginal vegetation at the edge of open water, the structure of the vegetation can support larvae of *An. maculipennis* s.l.

Figure 7.19. *Due to its high nutrient load, this sewage treatment reedbed in Wiltshire can support large numbers of* Culex pipiens, *as well as lower numbers of* Culiseta annulata.

Figure 7.20. *Naturally occurring rain-filled tree holes, such as found at the base of mature trees such as beech, and even in the upper canopy where fallen branches leave cavities, can provide suitable aquatic habitats for* Anopheles plumbeus, Aedes geniculatus *and* Orthopodomyia pulcripalpis.

Figure 7.21. *This amenity wetland in an old Bedfordshire gravel pit does not support mosquitoes. The wind-driven movement of water at the surface, the large draw down (it is a flood balancing lake) and the minimal emergent vegetation make it unsuitable for mosquito development.*

8. MOSQUITO SURVEYING AND CONTROL

To know accurately which mosquito species are present on a given site, it is necessary to conduct a survey. Results can contribute to a more comprehensive record of the overall biodiversity of an area and provide some insight into the ecological relationships within it. A site manager may also need the information for risk assessment and other strategic purposes, for example, when planning habitat management and designing visitor access. Furthermore, the information may be useful when providing a response to public enquiries or concerns about local mosquito populations. Therefore, it is advisable to undertake a baseline mosquito survey when acquiring new sites or at sites where data on mosquito populations are lacking. Subsequent surveying can be included as part of routine periodic biodiversity audits.

Very often, mosquitoes are missed by traditional general entomological survey techniques, such as pitfall trapping, sweep netting and tree-beating, and consequently tend to be absent from species lists that arise from biodiversity audits. Male mosquitoes can be collected through sweep netting, but old worn specimens and problematic identification of male genitalia generally puts off most entomologists and naturalists from exploring the group any further. However, a range of specific and effective sampling methods have been developed for detecting mosquitoes as immatures (eggs, larvae or pupae), or as adults, either flying or resting.

Figure 8.1. *Sampling larvae in wet woodland, Cambridgeshire, using a homemade dipper made from a white plastic food container and a retractable decorating pole.*

The presence of adult mosquitoes in a terrestrial trap indicates that the insects are active in the area but, as they can fly in from distant aquatic breeding habitats in the surrounding landscape, it does not indicate their origin, which may lay outside the site of interest. Collection of immatures from a water body is the only way to confirm that a specific aquatic larval habitat is a breeding site capable of supporting mosquitoes (Figures 8.1 and 8.2). There are two notable exceptions to this. Firstly, those species which exploit tree holes and secondly, *Cq. richiardii*, a species that does not obtain oxygen at the surface of water and so is not found when surface dipping for larvae. These species cannot be readily surveyed in their aquatic life stages and are likely to only be detectable by adult sampling methods. Surveys combining both adult and larval sampling methods are therefore best suited to providing comprehensive data on the species present, their relative abundance and, for many species, their likely larval habitat.

Before designing a mosquito survey

A good background knowledge of the ecology and meteorology of the area of interest will facilitate a more effective and successful sampling strategy. Landcover maps of the immediate and surrounding area, and active plans for habitat and water level management can provide information useful for identifying where to target sampling. Consult biodiversity reports and check for records lodged with the National Biodiversity Network to see whether there are any existing data on local mosquito populations. Work through the Wetland

Mosquito Prediction Tool (see Chapter 7) to determine the mosquito species that might be expected in the habitats present on site and use this as a basis for guiding confirmatory surveys.

8.1 Adult sampling

Sampling methods for flying adults fall into one of two categories. The first category covers passive traps. In these, both male and female mosquitoes are intercepted as they fly between breeding sites, refugia and food sources (i.e. blood hosts and plant sugars) during dispersal and foraging. Examples of passive traps include malaise and electrocution traps. Yields from these methods can be low and therefore they are not advised for the purposes of determining presence/absence and abundance. The second category encompasses those that lure mosquitoes to them. These tend to rely on emitting odours associated with host animals, to which predominantly female mosquitoes are attracted. Bait odours include carbon dioxide, lactic acid and octenol. Carbon dioxide is produced in the breath of all vertebrates and is highly attractive to most blood-sucking insects, including essentially all females of the British mosquitoes of any species, because it is a very reliable indication of the presence of a living host animal. It can be produced from a number of different sources, such as from sublimation of dry ice, via yeast fermentation of sugar in water, and from combustion of certain fuels. Commercially available synthetic versions of other odours associated with animal sweat (e.g. lactic acid, octenol) can be used in conjunction with carbon dioxide to enhance attraction. These are more selective as they tend to be associated with specific types of animal, and so the host preferences of the mosquito species that they attract reflect this.

Adult sampling methodologies

While there are a number of ways to sample adult mosquitoes, each has its own strengths and weaknesses. Many methods are effective for females only, as they use a combination of characteristics that mimic animal hosts to attract females seeking a blood meal. Other approaches, such as aspirating potential resting sites for males, can be labour intensive with very low yields.

The methods below cover the approaches most suited to sampling British mosquito species for the purposes of determining species presence and abundance, with a description of potential limitations particular to each method. Both actively lure mosquitoes, predominantly females, towards the device and use suction to trap the specimens in a container for later inspection.

Figure 8.2. *Examining larval samples collected by dipping in an area of wet woodland adjacent to fen in Cambridgeshire.*

MOSQUITO MAGNET®

Overview: These traps have a good record of sampling a wide diversity of British mosquitoes in high numbers and are used in the Nationwide Mosquito Surveillance Project run by PHE, which operates across the mosquito season from April to October. The trap is powered by bottled propane gas. Controlled burning of the gas releases carbon dioxide and heat, both mosquito attractants associated with warm-blooded animals. The trap can also be baited with an odour lure that releases octenol, a compound associated with cattle and attractive to many mammalophagic mosquito species. Theses traps run day and night, so collect both day and night-flying mosquitoes, often in good numbers. Originally designed for domestic mosquito control, several models are available.

Equipment and method: The Mosquito Magnet® traps mosquitoes by means of a fan which sucks them into a collection bag or box, which can be easily removed without insects escaping. One trap can run continuously for about three weeks on a 13 kg propane cylinder; however, this is not usually necessary for mosquito sampling. In a more typical mosquito surveillance programme, these traps can be run for four days every fortnight, for approximately six weeks. As the trap operates continuously, this means that the trap can be left untended once turned on, and only revisited to switch it off and collect samples. If used, octenol lures are ideally replaced once a month.

Practical considerations: Samples are often in sufficiently good condition to enable morphological identification; however, if the trap is only monitored every four days, the quality of specimens caught early in the sampling period may deteriorate. Because of their design, Mosquito Magnet® traps are highly specific to mosquitoes, with very little, if any, by-catch of non-target insects, a factor that may be important in conservation settings. However, they are relatively costly in initial outlay (~£900 plus propane) and their bulky size (74 x 44 x 84 cm) plus the weight of gas bottles can pose logistical issues in moving traps to sampling locations. They are best used in secluded areas away from public access to reduce the likelihood of damage or theft. These traps are quite resistant to inclement weather, including rain, and can tolerate typical British temperature ranges between late Spring and early Autumn, but benefit from sheltered locations that limit exposure to strong winds.

Figure 8.3. *Mosquito Magnet® (Executive model) trap in situ. Host-associated odours and carbon dioxide are expelled through a central outlet to the left, while air is sucked up through the surrounding grey cone, drawing attracted mosquitoes into the net bag on top, which is protected with a transparent plastic cover.*

LIGHT TRAPS

Overview: These traps are hung with the insect entrance around 1 to 1.5 m above ground level for routine surveillance. Insects, including mosquitoes, are attracted to a small bulb which emits light. This can be supplemented with carbon dioxide to increase the attraction of mosquitoes to the trap. A fan then draws insects into a collection bag or cup. Although the majority of mosquitoes sampled by light traps are females, males do respond to light stimuli and so may also be found in collections. Globally, these traps are used extensively in malaria surveillance, as they are effective for collecting crepuscular and nocturnal *Anopheles* species.

Equipment and method: The bulb and fan are powered by a single 6 V battery which, when fully charged, provides ample power for a twelve-hour overnight collection. Because of their mode of attraction, light traps are only used between dusk and dawn and are more effective in the absence of other competing light sources. If used, around 800 g of dry ice is required to produce enough carbon dioxide for one night's collection, and this should be replenished every evening. Batteries should be recharged before each use.

Practical considerations: These traps are a more affordable option (~£150200) than Mosquito Magnets® and are relatively lightweight and portable, so can be carried easily to remote sampling locations. Samples are in good condition to allow identification by morphology. However, they tend to collect fewer mosquitoes than Mosquito Magnets® and because light traps are operated overnight, they typically do not capture diurnally active species. A significant limitation of this method is that light is not uniquely attractive to mosquitoes, so a range of non-target nocturnal insects may be collected, particularly moths. This may conflict with conservation priorities. They can be used throughout the year and are relatively unobtrusive, although it is advisable to shield them from public view to prevent theft or vandalism.

Figure 8.4. *Centre for Disease Control and Prevention Light Trap. Mosquitoes are attracted to the light and fly close enough for a fan to draw them into the collection pot. These traps can be supplemented with carbon dioxide from dry ice.*

Timing and intensity of adult surveys will depend in part on whether particular species are being targeted for detection. The majority of British mosquito species can be detected by an adult sampling programme that runs from mid-April to mid-October. PHE's Nationwide Mosquito Surveillance Project operates on this basis, using Mosquito Magnets®. The traps are operated for four days continuously every other week during this period. The number of traps operated per unit area will largely depend on the number available, and even a single trap will provide useful data. This can be positioned in different locations over a site to improve representation of species with more limited dispersal ranges.

Complete season sampling represents a relatively intensive programme which may be most appropriate where baseline information is required for new or previously un-surveyed sites. Once species assemblages are established, or when a specific issue requires investigation, more spatially and temporally targeted sampling may be used to keep track of changes in species compositions and abundances. This may be particularly useful where wetland habitats are undergoing change, either through creation, expansion or restoration, or because of changes in management activities.

8.2 Larval sampling

While interesting in its own right, determining the aquatic source of adult mosquito populations can also be very important in the event that nuisance or public health issues arise from biting mosquitoes. This is because it allows for any management response to be targeted at the specific water body that is supporting larval populations of the species that has been implicated as causing an issue as adults.

In wetland environments, a range of different aquatic niches may be suitable oviposition sites for mosquitoes. Assembling a list of these in a given area will support design of a larval survey. For any wetland, there are likely to be many discrete aquatic habitats and/or larger networks of connected bodies of water, and it may not be practical to sample all of these for larvae. Therefore, a subset of those that are representative of the range of habitats can be targeted instead. Some habitats may be totally inaccessible, for instance remote areas of saltmarsh which are treacherous to reach. Where such habitats are known to exist on site but cannot be accessed for larval surveys, complementary adult trapping is advised to help to identify which species, if any, are present.

In more urban environments, or areas with more intense localised human activity, such as around work yards or farm complexes, it is not necessarily practical to identify all larval habitats, which may mostly constitute small containers that have collected rainwater. Many crevices and inadvertent water containers are likely to be inaccessible or difficult to find. However, it may be useful to inspect more obvious pools of water, such as in water storage drums, water butts, drinking troughs for animals, rain-filled tarpaulins, tyre tracks, discarded containers and blocked drainage channels, such as gutters and deep road sidings.

Larval sampling methodology

Although there are several slightly different ways of collecting immature mosquitoes, the simplest and most widely used is dipping. This is suitable for sampling larvae of the majority of British wetland mosquito species.

Figure 8.5. (Page 103). *Demonstration of good dipping technique for sampling mosquitoes. 1. Approach the habitat at an angle, ensuring not to create a shadow, as shadow and movement can trigger evasive diving responses in immature mosquitoes. 2. Carefully lower the dipper into the water, keeping the angle of the dipper at 30 to 45 degrees; it is not advisable to crash the dipper into the water and scoop up the disturbed water as again immature mosquitoes will make a dive response. 3. Allow the dipper ladle to flood to the necessary volume. 4. Carefully withdraw the dipper, taking care not to spill any water, and allow the water and any sediment to settle. 5. Sometimes immatures, particularly anophelines, will 'play dead' and therefore at least 10 to 20 seconds are required before collection to allow mosquitoes to return to normal activity. 6. The culicine larvae, with their suspended respiratory siphon, are more easily seen; however, the first instars are particularly small. The anopheline immatures are more cryptic and can mimic midge and dixid larvae (see Appendix VIII). All immatures in the sample are collected using a pipette and transferred to a labelled collection tube in the sampled water.*

DIPPING

Overview: Mosquito larvae can be collected using pond dippers. This approach relies on collecting larvae while they float near the surface of the water, because larval mosquitoes (with the exception of *Cq. richiardii*) must spend a significant proportion to their time in this position to breath. The objective is to remove a roughly equal volume of water with each dip and then collect individual larvae from the sample water so they can be identified and counted. Other aquatic organisms, especially mosquito predators, may be noted for interest, but can be safely returned to the water.

Equipment and method: A typical survey will take five dips from a given habitat; this is repeated three times in different areas of the habitat (although this will depend on the size of the habitat and whether there are different microhabitats within it). Care should be taken to leave several minutes between each consecutive dip as larvae, especially of *An. claviger,* are very sensitive to disturbance and will dive for cover when the water is disturbed. The most effective dipping technique for the majority of British species is demonstrated in Figure 8.5. Hold the dipper's ladle at around a 45-degree angle relative to the surface of the water; the dipper can then be gently submerged a few centimetres into the water, allowing the surface water to flow into the ladle by suction. The ladle should then be righted firmly and in a controlled way to prevent water spilling out of it. Try not to create a shadow on the area of water about to be surveyed. For a robust survey, a mark denoting a given water volume (typically 200 ml) can be made inside the ladle to help to ensure that the same volume of water is sampled in each dip; thus, five dips will, in total, sample 1 L of water. Larvae can be removed with a disposable plastic pipette; cutting the very end off the pipette to increase the size of the opening may be necessary for retrieving third and fourth instar larvae and pupae. It may be necessary to allow any sediment collected to settle to the bottom of the ladle before larvae are visible or come to the surface.

Practical considerations: Dippers are readily available and relatively cheap to buy from many online suppliers, although there is no specific UK supplier. Alternatively, they can be made by securely attaching a suitable container (the ladle) to the end of a pole. White or light-coloured ladles make observing the content of the water sample easier than dark-coloured ladles. While larval mosquitoes can be a challenge to identify, they can be easily differentiated between the two subgroups by observing whether they float flat (parallel) against the surface of the water (Anophelinae) or hang down from the surface at about 45-degrees from a conspicuous siphon (Culicinae). The Culicinae can be separated easily to genus by inspecting the arrangement of hairs on the siphon.

8.3 Sample storage

Adult mosquitoes can be dispatched by placing in a domestic freezer for 24 hours. If possible, mosquitoes should be placed in storage containers (specimen tubes are ideal); in a tightly sealed container, a few crystals of silica gel placed under a piece of cotton wool, with mosquitoes placed on top of the cotton wool, should be sufficient to desiccate up to 50 specimens and allow for longer-term storage at room temperature. They can remain frozen if this is not possible.

Larvae are ideally stored in screw-top specimen tubes (Figure 8.6). Larval samples are best stored in 70-80% ethanol; as much water should be removed from the tube as possible, then the ethanol can be added to fill the container. Samples should not be frozen. For all specimens, the date and precise location of collection should be written on the container in permanent ink and a record kept to the sampling method used.

Figure 8.6. *Mosquito sample storage: Top: desiccated adults are stored in labelled tubes with silica gel; the cotton prevents the silica crystals from damaging the samples. Bottom: labelled tubes contain mosquito larvae suspended in 80% ethanol.*

8.4 Species identification and reporting

Where mosquito samples have been collected, these can be identified using published keys to determine the species. Simplified keys to identifying the mosquitoes found in Britain are included in the Appendices (adult female identification key can be found in Appendix V and a simple key to 4th instar larvae in Appendix VI). Additionally, some British culicine species can be distinguished according to the pattern of relative light and dark stripes on their tarsi, and a key for this can be found in Appendix VII. A hand lens or dissecting microscope are useful aids to identifying small features.

Alternative and readily available keys to the adults and larvae of British mosquitoes include:

Snow, K.R. (1990) *Naturalists' Handbooks 14: Mosquitoes.* The Richmond Publishing Company Limited, Slough.

Cranston, P.S., Ramsdale, C.D., Snow, K.R. & White, G.B. (1987) Adults, Larvae and Pupae of British Mosquitoes (Culicidae). A Key. Freshwater Biological Association. Ambleside.

Otherwise, entomologists may be approached to assist in identification. If expertise in mosquito biology, identification and management are sought, these can be found at several organisations, including PHE, the National Pest Advisory Panel of the Chartered Institute of Environmental Health and some university departments.

PHE run a mosquito recording scheme and the Nationwide Mosquito Surveillance Project. The mosquitoes collected through the scheme enhance existing data on the distribution of all British mosquitoes, helping to understand the impacts of mosquitoes on people, and is an important mechanism for detecting exotic species; more information is available online (https://www.gov.uk/guidance/mosquitoes-how-to-report#sending-mosquitoes-to-us). PHE also runs a recording scheme which relies on members of the public and Environmental Health Officers to submit mosquitoes. The Nationwide Mosquito Surveillance Project has gathered >100,000 records of all 36 British mosquito species, with data comprising >3500 submissions, and a further 7000 records from historical datasets, with records as far back as the 1850s. These data are made publicly accessible via the National Biodiversity Network Gateway (https://data.nbn.org.uk).

Figure 8.7. *Larval sampling for* Aedes detritus *in Poole harbour. These vegetated saline pools are stranded at high tide and can support large numbers of larvae. Such habitat can often be difficult to reach safely on foot or by vehicle making larval sampling a challenge.*

Data can be submitted by emailing mosquito@phe.gov.uk. A data recording sheet is provided in Appendix IX, with contact details for submission in Appendix X.

8.5 Mosquito control

Mosquito control in the UK is not routinely practiced in most regions. Although many British species bite mammals including humans, most do so only very locally in close proximity to their larval habitats, and adult mosquito populations are not usually sufficiently abundant to cause significant problems, however there are a few exceptions. When surveyed, LAs have reported responding to mosquito nuisance arising from sewage works, water treatment works and saltmarsh and coastal wetlands. There is no current evidence of mosquito borne disease in Britain, although human mosquito-borne diseases are emerging in other parts of Europe and returning to areas in which they have previously been eradicated. If disease transmission were to occur in the UK, then there may be a requirement for control of particular mosquito species. This section considers habitats which may require mosquito control, and the methods and products that may be available.

When mosquito control might be necessary

In most cases, people come across mosquito biting within defined areas of habitat. Visitors to wet woodland for example, may be bitten by various woodland *Aedes* species (e.g. *Ae. cantans*, *Ae. annulipes*, *Ae. punctor*, Ae. sticticus), which are well known for high rates of primarily daytime biting within shaded areas close to their larval habitats. However, mosquito biting will probably cease when visitors leave those shaded areas, and as a result, visitors tend to have a high degree of tolerance to this nuisance biting. Control is usually not considered or required in these situations and larval numbers can usually be managed through management of water levels and their relative permanence.

Saltmarsh habitats, such as those around Hayling Island, Sandwich Haven and the Dee Estuary have at times required mosquito control targeting *Ae. detritus* larval habitats, to reduce the impact of nuisance biting on local residents and tourists. The larval habitats for *Ae. detritus* are usually small pools of saline water, wetted during spring tide events. Identification of these pools can be difficult, as they are often in inaccessible locations on the saltmarsh (Figure 8.6), but if they can be identified and larvae seen to be present, then mosquito control products can be applied.

Similarly, in North Kent, mosquito control has been conducted in response to significant *Cx. modestus* nuisance biting. *Culex pipiens* biotype *molestus* has also been the subject of control efforts. This mammalophagic form of *Cx. pipiens* s.l. is much rarer than the typical ornithophagic form and is found in underground flooded basement environments such as tunnels, and old industrial or sewage work sites, and often causes a local biting nuisance where it occurs. In all these cases, larvicidal products to reduce the adult mosquito population have been deployed.

When detected, *Ae. albopictus* also requires control. This vector of dengue and chikungunya is now widespread in Europe and has been detected during targeted mosquito surveillance at goods importer sites in the South of England (see section 3.4 on Non-native species). The species utilises container habitats such as blocked drains and litter containing rainwater for larval development, and not natural wetland habitat. Control of this species consists of the systematic finding and removal of all suitable larval habitats, and treatment using an appropriate larvicide.

Methods of controlling mosquito populations

On the occasions that it is implemented, control focusses on targeting the immature aquatic larval and pupal stages. Control strategies that have been employed by LAs in the past include habitat reduction and drainage of land, gulley cleansing and flushing of drains, manual ditching, netting, trapping and decommissioning of filter beds, and the use of microbial biocides.

Ecological management

It has been suggested that the role of, and provisioning for, invertebrate and vertebrate predators and competitors in limiting mosquito populations, particularly in healthy ecosystems, should be a main consideration when exploring options for controlling mosquitoes as part of an integrated environmentally friendly mosquito management system. In the United States, it has been demonstrated that wetland restoration projects can manage mosquito numbers by focusing on provision of habitats for predators and competitors; one project using such an approach reported a 90% reduction in mosquito numbers.

Figure 8.8. *Mosquitoes can be predated by numerous other species, such as several species of arachnids. Although not specialist mosquito-feeders, web-building spiders will capture insects in flight, including mosquitoes, and are able to do so in both indoor and outdoor environments.*

By creating a healthy wetland ecosystem, where predators can thrive, it may be possible to regulate, rather than eliminate, populations of mosquitoes that may pose a nuisance risk (Figure 8.8). Specific features may also help to promote these ecological interactions. For instance, design of meandering channels that connect shallow and deeper waters will allow aquatic predators, especially fish, to flow in and out of habitats and therefore help to reduce mosquito numbers in the shallower areas. Many of the predators of British mosquito species are appreciated in their own right because of their conservation value and supporting their presence in wetlands is perhaps the most sustainable approach, and certainly desirable in situations where there is no imminent public health risk.

Water and vegetation management

Water availability is crucial for larval development, and availability of water at key times of year will influence larval development and mosquito populations. This can be harnessed to control target species. When undertaking water level management as part of routine conservation activities, consideration should also be given to its potential impact on local mosquito populations; in Australia, draining an urban wetland as part of efforts to control an invasive fish species led to an unexpected increase in numbers of mosquito larvae compared to undrained areas.

In urban areas, water management is likely to be relatively straight forward, perhaps by the use of lids on water butts to prevent mosquito access, clearing debris and blocked gutters that may collect rainwater, or flushing drains to ensure water does not pool. In wetland habitats, water is likely to be crucial for the provision of habitat at key times of year for a range of species and therefore changing water regimes may not be possible or considered. However, if this is possible, then such water management could be a tool to reduce particular mosquito species. This could include physical interventions, such as the connection of saline pools to saltmarsh runnels, to provide drainage at low tide; delaying flooding grassland areas in summer to early autumn; or preventing winter flooding of wet woodland.

Maintaining high water levels in early spring, followed by drawdown (i.e. allowing water to recede to expose bare soil/vegetation) in late spring, can reduce mosquito populations as this can desiccate the larvae. After drawdown the water is allowed to return to pre-drawdown levels, however care must be taken in how this process of drying and flooding might adversely affect the aquatic flora and fauna. If wetlands are routinely drained, then internal re-grading (i.e. regular re-digging of a wetland to affect slope and depth and to remove silt build-up) will promote rapid dewatering (i.e. increased out-flow of water) and prevent pooling (i.e. smaller body of standing water), which can reduce mosquito colonisation.

It is often a misconception that draining a wetland will always reduce mosquitoes and resolve the problem. However, both naturally and artificially drained permanent wetlands can exacerbate issues with mosquitoes. Increasing the rate of water flow and aeration of the wetland, however, can impact negatively on mosquito larvae. Water flow, which may be subsurface flow, wind-assisted water movement or human-assisted turbulence (i.e. pumping), impacts the larvae by inhibiting their ability to acquire oxygen at the water surface. Deep water is generally considered to be unfavourable for mosquito larvae, and more favourable for their predators, such as fish.

Poor quality water, or water with high nutrient loading and sedimentation (e.g. by cattle/livestock entering the wetland) on the other hand can increase numbers of mosquitoes that prefer organic-rich waters. Controlling vegetation in wetlands is generally advised for controlling mosquitoes. This may be applicable for constructed wetlands, particularly those utilised in water treatment, but for biodiversity-rich wetlands, the removal of vegetation is perhaps not always desired, and would need to be considered on a case-by-case basis. Periodic harvesting of dense stands of emergent vegetation will reduce mosquitoes and sediment build-up. A wetland habitat with a simple shape, low edge-area ratio, steep banks and deep water will generally have less vegetation and consequently fewer mosquitoes, as emergent and floating vegetation provides shelter from the wind and predators and also promotes pooling.

Not all water or habitat management interventions will be feasible in all circumstances. Further empirical research into this area of work is needed to test the impact of changes in water availability on target mosquito species in wetlands.

Open Marsh Water Management

There are some saltmarsh specific challenges – and possible solutions. Aspects that exacerbate the potential There are some saltmarsh specific challenges – and possible solutions. Aspects that exacerbate the potential nuisance caused by saltmarsh mosquitoes are thought to be related to (a) the high marsh where pools of water in mudflats or saltmarsh vegetation are left by the highest tides, or alternatively are filled by rainfall/runoff or not flushed by daily tide movements, and (b) the low marsh that is not well drained and where mosquitoes exploit impounded stagnant pools that are retained, usually due to siltation/blockage of tidal channels and hence not flushed. Management strategies include:

i. Elimination of the potential aquatic habitat (by draining or filling),

ii. Modification (with water management), and

iii. Treatment with a control agent to kill the mosquito larvae.

Habitat elimination is usually not possible and treatment (more generally) is discussed below. Modification with 'Open Marsh Water Management' (OMWM) or the use of shallow ditches (runnels), on the other hand, has been reported to be acceptable, practical and effective.

OMWM was developed in Australia to control saltmarsh mosquitoes by introducing their predators. With a system of pools connected by radial ditches, fish feed on mosquitoes during high tide, then retreat to sumps or reservoirs at low tide. OMWM has been found to be an effective long-term method of controlling mosquito populations in saltmarsh without using sprays. OMWM promotes/restores 'full tidal flushing' by advocating the renovation of tidal channels and maintaining them in a condition which allows a) full tidal exchange and precludes the formation of impounded pools and b) 'natural de-watering' whereby saltmarsh pools that hold water after highest tides and rainfall are connected for tidal influence using various sized channels and with persisting ponds to support predatory fish.

Runnelling is the creation of shallow, spoon shaped drains ('runnels') that enhance tidal flushing of ponds isolated from main tributaries. Runnels may also provide access to mosquito habitats for fish that prey on mosquito larvae. Specifications for runnels are:

a. they should be hand-dug or constructed with minimal impact,

b. be less than 30 cm deep, with width:depth ratio of 3:1,

c. should follow and be confluent with existing drainage lines,

d. spoil created should be used as fill for very deep depressions or isolated pools, and

e. spoil should not be used as levees but can be broadcast if dispersed to undetectable levels.

Larval control products

There are some mosquito control products licensed for use to control mosquito larvae in the UK. These fall in to two categories: silicon based biodegradable liquids, and formulations containing *Bacillus thuringiensis* subspecies *israelensis* (*Bti*). *Bti* is a group of bacteria which act as insect growth inhibitors, specifically acting on dipteran larvae, and can be used in natural habitats with limited impacts on other fauna, as well as in *Cx. pipiens* biotype *molestus* habitats. Available in either liquid or solid formulations, *Bti* can last in the water for two to three days and must be ingested by the mosquito larvae. Silicon based larvicides work by preventing mosquito larvae from reaching the water's surface to breathe. Silicon based products are more suited to discrete water bodies such as concrete drains, water butts, or other man-made objects, and so are used for control of *Aedes albopictus*. Products are available for targeting adult mosquitoes; however, these are rarely used in the UK as they are broad-spectrum insecticides that impact upon a wide range of insects. The Chartered Institute for Environmental Health (CIEH) has produced guidance for the control of invasive mosquitoes.

Further reading

Chartered Institute of Environmental Health (2017) Management of invasive species of mosquitoes. CIEH, London.

Chase, J.M. & Knight, T.M. (2003) Drought-induced mosquito outbreaks in wetlands. *Ecology Letters*, 6:1017-1024.

Dale, P.E.R. & Knight, J.M. (2008) Wetlands and mosquitoes: a review. *Wetlands Ecology and Management*, 16:4:255-276.

Department of Planning and Local Government (2010) Water Sensitive Urban Design Technical Manual for the Greater Adelaide Region. Government of South Australia, Adelaide.

European Centre for Disease Prevention and Control, & European Food Safety Authority (2018) Field sampling methods for mosquitoes, sandflies, biting midges and ticks - VectorNet project 2014-2018. Stockholm and Parma, ECDC and EFSA.

Hanford, J.K., Webb, C.E. & Hochuli, D.F. (2019) Management of urban wetlands for conservation can reduce biodiversity and increase mosquito risk. *Journal of Applied Ecology*, 57(4):794-805.

Malan, H.L., Appleton, C.C., Day, J.A. & Dini, J. (2009) Wetlands and invertebrate disease hosts: are we asking for trouble? *Water South Africa*, 35(5):753-768.

Medlock, J.M. (2015) Impact of the creation, expansion and management of English wetlands on mosquitoes (Diptera: Culicidae). PhD Thesis. University of Bristol.

Medlock, J.M. & Vaux, A.G.C. (2011) Assessing the possible implications of wetland expansion and management on mosquitoes in Britain. *European Mosquito Bulletin*, 29:38-65.

Russel, R. (2020) Saltwater wetlands: Mosquito production & management. Available from: http://medent.usyd.edu.au/fact/saltwet.htm. Accessed 9 June 2020.

Silver, J.B. (2008) *Mosquito Ecology: Field Sampling Methods*, Third Edition. Springer Netherlands.

USDA [United States Department of Agriculture] (2008) Biology Technical Note: Wetlands, mosquitoes and West Nile virus. Natural Resources Conservation Service, Indiana, pp7. Available from: https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs144p2_030724.pdf. Accessed, 8 June 2020.

Appendices

Appendix I – Glossary

Aerenchyma	Spongy plant tissue containing air spaces, often found in aquatic plants.
Anthropophagy	Feeding on the blood of humans.
Anthropophily	Preferring to feed on the blood of humans.
Arbovirus	A virus which is transmitted by arthropods, such as mosquitoes.
Biotype	A group of organisms with the same genetic constitutions.
Bridge vector	A vector that acquires a disease-causing agent from an infected animal and then transmits that agent to another animal of a different species. For example, the mosquito *Culex modestus* is the bridge vector of West Nile virus from birds to humans.
Brink	The process of cutting back marginal vegetation at the edges of ditches and other narrow waterways.
Diapause	A period of dormancy in an insect, especially during unfavourable environmental conditions, for example during winter.
Drawdown	The lowering of the surface water level of a body of water as the result of the withdrawal of water.
Enzootic	A disease endemic in or regularly affecting animals in a given area or at a particular time.
Gonoactive	A mated female mosquito in any stage of the **gonotrophic** cycle.
Gonotrophic	Describing a cycle of alternate feeding and **oviposition**.
Host	A vertebrate animal upon which mosquitoes feed.
Hypogeal	Underground or otherwise subterranean habitats.
Instar	An insect larval stage between one moult and another.
Malaria	A disease caused by protozoan parasites of the genus *Plasmodium*.
Mammalophagic	Feed on the blood of mammals.
Managed realignment	A deliberate process of altering coastal flood defences to allow flooding of a presently defended area. Old defences are purposefully breached and the shoreline then moves more naturally, while flooding is typically managed by new defences located in a more landward position.
Multivoltine	Having more than one generation per year.
Nulliparous	A female animal that has never given birth.
Ornithophagic	Feeding on the blood of birds.
Oviposition	Process of laying eggs by animals where little or no embryonic development occurs within the mother (oviparous).

Parous A female animal that has produced offspring one or more times.

Pathogen A microorganism, such as a virus, bacterium or parasite, that can cause disease.

Phytotelmata Small water-filled cavities in non-aquatic plants which may serve as habitat for other flora and fauna, e.g. tree holes and leaf-axils capable of collecting and holding rainwater.

Proboscis In invertebrates, an elongated tubular feeding and sucking organ; in mosquitoes specifically, composed of six parts adapted to sucking vertebrate blood.

Refugia Areas in which organisms can retreat to in escape of unfavourable conditions, such as extremes of heat or cold.

Runnel Shallow, spoon-shaped drains that enhance tidal flushing of saltmarsh ponds isolated from main tributaries.

Slub The process of removing silt that accrues in ditches and other waterways, usually to improve water flow.

Species complex A group of related species where the exact demarcation between species is often unclear or cryptic; such a group can be denominated with the representative species name with the addition 'sensu lato' (s.l.).

Sympatric Two or more species with a common geographical range but without evidence of interbreeding.

Synanthropic Ecologically associated with humans.

Univoltine Having only one generation per year.

Vector An organism that is capable of transmitting a disease-causing agent to a susceptible vertebrate **host**.

Appendix II – Abbreviations

BTi	*Bacillus thuringiensis* subspecies *israelensis*
CIEH	Chartered Institute of Environmental Health
LA	Local Authority
MRA	Managed realignment
NBN	National Biodiversity Network
PHE	Public Health England
SuDS	Sustainable Drainage System

Appendix III - Summary of the impact of wetland creation and management on British mosquito species, with summary of potential for mitigation and possible nuisance/vector concern.

Species in **bold** are the more common wetland species; Status: +++ widespread, ++ more localised but locally abundant, + very focal or rare; CHIKV (Chikungunya virus), DENV (Dengue virus), ZIKV (Zika virus), WNV (West Nile virus), SINV (Sindbis virus), RVFV (Rift Valley fever virus), TAHV (Tahyna virus). Key references are indicated below.

SPECIES	STATUS	AQUATIC HABITATS	IMPACT OF WETLAND CREATION	IMPACT OF WETLAND MANAGEMENT AND POSSIBLE MITIGATION	NUISANCE OR VECTOR CONCERN
Ae. albopictus	+	Invasive species; detected in the UK each year since 2016, in the south-east, but not considered established. Uses container habitats (e.g. rain-filled tyres, drinking troughs) Incursions have been found in truck stops and distribution centres.	Not associated with wetland habitats, preferring natural and artificial containers, so is not likely to be affected by provision of new wetland habitats.	There is no association between this species and wetland management practices. Current mitigation, if detected, focuses on intensive localised control via insecticides and removal of potential breeding sites to prevent establishment in the UK.	This species is a vector of several arboviruses, including CHIKV, DENV and ZIKAV in Europe, as well as other pathogens such as *Dirofilaria*. Across its extensive geographical range, it is considered to be a serious biting nuisance for humans and a wide range of other hosts, and therefore has potential as a bridge vector. It seems likely there will be future introductions of this species into the UK.
Ae. annulipes / Ae. cantans	+++	Wet woodland	Not all wetland creation schemes intend to create wet woodland, however where this does occur then consideration needs to be given to the impact of these species.	The amount of winter flooding, and the persistence of flooded woodland in spring will impact significantly on the densities of these species. Woodland ditches that are regularly slubbed and re-graded will be less suitable for these species. However, if they are allowed to dry out and pool then they will become suitable.	These species are serious nuisance biters of humans, and unlike other species, they will bite during the day as well as at dusk. They also disperse from their habitat to find a host. There is no information on dispersal ranges, so siting of new developments near wet woodland, or the creation of new wet woodland near dwellings will be a serious issue during June-August. Both species have been implicated as potential arbovirus vectors based upon their host-feeding habits (human and bird blood), however they are not classed as primary vectors of WNV or SINV.
Ae. caspius	+++	Coastal habitat; also flooded fen/grassland	Historical records of this species are mainly coastal with a few around London. However, data from the fens show that it can be very common in flooded fen and newly created wet grassland. Furthermore, it has been recorded to colonise newly created freshwater (or weakly saline) habitats in managed re-alignment sites in estuaries.	Managing this species inland will be largely related to controlling water levels. High groundwater levels in summer, supplemented by precipitation leading to pooling and puddling in fen and wet grassland will provide submergence of dormant eggs. Summer flooding, where this species is an issue, should be avoided.	Can be a nuisance species, and although not considered as a primary vector of RVFV, it has been implicated as a main vector in Egypt. Further work to establish the role of this mosquito in potential arbovirus transmission has been recommended, particularly considering its potential for wet grassland colonisation.
Ae. cinereus / Ae. geminus	+++	Flooded fen/grassland	Exploit a range of groundwater-fed summer flooded habitats like fens and wet grassland. How quickly they colonise new flooded grasslands is not yet known as very few immatures were found in newly constructed wet grassland in the fens despite high adult densities in the traps and resting in grazing exclosures. It is expected that colonisation will take place.	High groundwater levels in the summer will dramatically enhance the density of this species where it occurs. This was proven in the Cambridgeshire study. It is possible that the timing of flooding could be planned so that the eggs are left high and dry. Winter flooding rather than spring flooding would be less favourable for this species, as immatures tend not to appear until April. Draining of flooded areas during spring would impact significantly on survival of immatures.	The distribution of this species is patchy, however where it does occur it can be a biting nuisance, but there is limited information on dispersal ranges. Owing to its anthropophagy and ornithophagy it has been implicated as a possible bridge vector of a number of arboviruses in Europe. This species will benefit from expansion of reedbeds, flooded meadows and seasonal summer flooding in open habitats.
Ae. communis	+	Rare, few old records	Unknown, too rare	N/A	Too rare currently to be of concern as a nuisance or vector species

SPECIES	STATUS	AQUATIC HABITATS	IMPACT OF WETLAND CREATION	IMPACT OF WETLAND MANAGEMENT AND POSSIBLE MITIGATION	NUISANCE OR VECTOR CONCERN
Ae. detritus	+++	Coastal, brackish; also, freshwater	Likely to be the principal mosquito colonising newly created coastal habitats, particularly at the spring high tide mark in isolated pools and in saline borrow ditches capturing brackish water.	This species exploits saline waters left by spring high tides. This may be at the limits of existing salt-marshes, in pasture or grassland subjected to flooding at high tides, or in vegetated ditches allowed to flood during high tides. Any regular tidal flushing usually makes their habitat inimical. Where possible management of spring tide waters (through closure of sluices) could mitigate this species. However, where tides regularly leave isolated pools with no drainage then biocidal treatment following such tides may be required.	This species is a persistent biting nuisance and responsible for several mosquito control programmes in the UK. Although it is not considered to be a principal potential vector, its human and bird biting makes it a candidate vector of arboviruses. However, its nuisance value alone makes it worthy of consideration and control.
Ae. dorsalis	+	Rare, coastal	Unknown, too localised	N/A	Not considered as either a nuisance or vector species. Not widely distributed.
Ae. flavescens	++	Coastal, brackish	Coastal marshes, although the species is not common	N/A	Not considered as either a nuisance or vector species. Not widely distributed.
Ae. geniculatus	++	Tree-holes	None	N/A	Not considered to be an important nuisance species or potential disease vector.
Ae. leucomelas	+	Rare, only in a few locations	N/A	N/A	Too rare currently to be of concern as a nuisance or vector species.
Ae. punctor	++	Acid pools, bogs	Wet woodland sites on acid soils appear to favour this species. Therefore, not all wet woodland would be suitable, however in certain parts of England this species might benefit.	Winter/spring flooding of acid habitats, particularly in bog/mire/lowland moor areas can dramatically impact the numbers of this species. These habitats are naturally flooded by rainfall rather than groundwater, so management might be difficult. Dwellings close to such habitats will likely be impacted by wet winters/springs.	This species is not considered to be a principal vector of arboviruses although it is a nuisance species adjacent to its favoured habitat.
Ae. rusticus	+++	Wet woodland, flooded rush pasture	This species would benefit from wet woodland creation and has also been found in new wet grassland habitats, particularly those dominated by rushes.	Spring flooding of wet grassland could provide a habitat for this species. Although they have not been found in high numbers. Spring and winter flooding of wet woodland would create suitable habitat for this species.	This species is not routinely considered as a potential vector, and although it does bite humans, its pest status is not as high as *Ae. cantans/annulipes* or *Ae. detritus*. However, it will cause nuisance biting and will benefit from transient habitats subjected to winter/spring flooding.
Ae. sticticus	+	Rare, wet woodland	Unknown, rare. There is little information on how such a species will respond to wetland creation. There are increasing reports of this species, but further ecological work is needed.	Timing of winter and spring flooding of wet woodland where this species occurs would be a consideration.	Nuisance and vector species elsewhere in Europe, but rare in the UK. Where this species does occur however it can be a serious pest.
Ae. vexans	++	Rare, but confirmed populations have recently been reported; flooded grassland	As this is a riverine floodwater species, then wetland creation schemes that promote freshwater flooding by seasonal river flooding could provide a habitat. However so far this species is considered rare.	Managing flooded grassland habitat adjacent to rivers where possible.	Potential vector of RVFV and *Dirofilaria*, however this species is currently rare in the UK. Serious nuisance in its European range.

SPECIES	STATUS	AQUATIC HABITATS	IMPACT OF WETLAND CREATION	IMPACT OF WETLAND MANAGEMENT AND POSSIBLE MITIGATION	NUISANCE OR VECTOR CONCERN
Anopheles species					
An. algeriensis	+	Fen, only in two local areas	None	N/A	Not considered to be an important nuisance species or potential disease vector.
An. maculipennis s.l. (*An. atroparvus*)	++	Coastal, brackish	No current evidence that newly created coastal wetlands created under managed re-alignment will actually support this species.	N/A	Still causes nuisance in some coastal areas, however, is less of a concern than *Ae. detritus*. Still has the potential to be a malaria vector, although the risk of local transmission is considered to be very low.
An. claviger	+++	Primarily exploits permanent water found in ditches and pools, and generally favours those that are heavily vegetated. It may also be found in transient aquatic habitats.	New permanent wetlands with ditches and pools will provide new habitats for this ubiquitous species. They can also be found in flooded meadows. If ditches are not regularly brinked or slubbed, or if they are left to dry out then this will favour this species. Recent wet years have seen large numbers of *An. claviger.*	Maintaining healthy ditches with predator competition is recommended. Furthermore, regular cutting of marginal vegetation, thus allowing sunlit waters, appears to not favour this species.	This species is already widespread and is not currently significantly associated with nuisance biting. Although new wetlands might create a new habitat, there is no evidence to suggest that it will become problematic.
***An. maculipennis* s.l. (*An. messeae* / *An. daciae*)**	+++	Primarily exploits open sunlit freshwater pools and ditches. Also colonises the margins of open freshwater pools in flooded grassland.	New permanent wetlands with ditches and pools will provide new habitats for this ubiquitous species. This species also appears to colonise the margins of open water in flooded grasslands. As these flooded habitats are seasonal this is presumably the result of re-colonisation.	Brinking of ditches appears to be associated with higher abundances of immatures of this species. Flooding wet grassland in late spring will provide new habitats for this species.	There is no evidence that this species is a nuisance biter, with very few individuals of this mosquito caught in mammal-lured traps, despite the local abundance of immatures. Furthermore, they are rarely caught in landing catches. Although a potential malaria vector, owing to limited human biting this species is unlikely to be a concern.
An. plumbeus	++	Tree-holes	None	N/A	Potential malaria vector, although not previously considered to be a principal vector.
***Coquillettidia* species**					
Cq. richiardii	+++	Permanent: ditches, vegetated pools	Newly created ditches with emergent vegetation will provide a suitable habitat for this species in time.	Owing to its enigmatic life cycle, the impact of management is difficult to determine. Vegetated ditches and ponds will provide a suitable habitat, but there is no clear evidence that management would be required although this species can be abundant in July and cause a nuisance.	Can be a persistent biter after dark in high summer. Is known to enter dwellings to bite. Not considered a principal arbovirus vector but does feed on both birds and humans.
Orthopodomyia species					
Or. pulcripalpis	+	Tree holes, rare	N/A	N/A	Owing to its ornithophagic tendencies, this species is not considered to be an important nuisance species of potential disease vector.
***Culex* species**					
Cx. modestus	++	Localised in coastal ditches, possibly spreading in distribution in south-east England	Some evidence of being found in newly created wetlands, although a few records from wet grassland.	Currently considered localised to North Kent and parts of Essex along the Thames estuary, although possible expansion may occur. Newly created ditches in this area would provide suitable habitat. Management of this species in permanent ditches might require biocidal control as there are no clear examples of the impact of water or vegetation management. However emergent and floating vegetation appears to be a pre-requisite.	Known to be a nuisance species where it occurs along the Thames estuary. Is also considered to be a principal vector of WNV elsewhere in Europe.

SPECIES	STATUS	AQUATIC HABITATS	IMPACT OF WETLAND CREATION	IMPACT OF WETLAND MANAGEMENT AND POSSIBLE MITIGATION	NUISANCE OR VECTOR CONCERN
***Culex* species**					
Cx. pipiens* s.l./ *torrentium	+++	Usually transient (e.g. dried ditches, flooded grasslands) and container habitats	The typical biotype of *Cx. pipiens* and *Cx. torrentium* do colonise transient habitats post flooding, and will therefore benefit hugely from wetland creation, particularly in the early pioneer stages of wetland development. It is unclear which species dominates and further studies are required. Any nutrient rich wet grassland or nutrient rich permanent habitat (i.e. polluted ditches, post-drought ditches, or sewage treatment reedbeds) will provide aquatic habitats for this species. In aquatic habitats hostile to predators/competitors then mosquitoes will increase to large densities. It is unclear whether the *molestus* form of *pipiens* will be affected by wetland creation. Container habitats for these species are unlikely to be affected by wetland creation.	For transient aquatic habitats, water-level management and precipitation will be crucial. Drying and re-wetting cycles of transient habitats, or unnatural drying of permanent habitats needs to be considered in relation to the rapid colonisation by these species. Raising water levels in wet grassland or wet fen summer could be avoided to mitigate these species. Furthermore, permanent aquatic habitats should not be allowed to dry out. Mosquitoes associated with sewage treatment reedbeds may require biocidal control if deemed necessary, although this may not be efficient in nutrient-rich waters.	Neither the typical biotype of *Cx. pipiens* nor *Cx. torrentium* are nuisance species as they almost exclusively feed on birds. They are both considered to be important *enzootic vectors* of WNV and SINV, respectively. In the event of such an outbreak, management of their populations will be crucial in managing the enzootic transmission of the viruses. The *molestus* form is also a potential WNV vector but is unlikely to be affected by wetland management given its predilection for underground and cloistered container habitats.
Cx. territans	+	Rare, permanent habitats	Unknown, too under-recorded	N/A	Not considered to be an important nuisance species or potential disease vector.
Culiseta species					
Cs. alaskaensis	+	Northern species: rare, too few records	Unknown, too rare	N/A	Not considered to be an important nuisance species or potential disease vector.
Cs. annulata	+++	Exploits a range of permanent, transient and container habitats	Will benefit from a range of wetland creation schemes such as ditches subjected to drying, wet woodland with water persisting through to late summer, nutrient-rich wet grassland in late summer and drying nutrient rich reedbeds.	Wet woodland which remains wet throughout the year will provide a habitat for this species. Similarly, it will also dominate in nutrient rich wet grassland. If this species is a problem, then late summer flooding will be significant. Ditches allowed to dry and re-wet will also provide a suitable habitat. This species will also colonise polluted container habitats in urban areas, where they may be more of an issue.	This species is a nuisance species and is the most common nuisance species in the UK, although not necessarily biting in as high numbers as other species. It is large and owing to its colouration is often confused with a much smaller invasive species, *Ae. albopictus*. Although not a principal arbovirus vector, its ability to feed on humans and birds (in urban areas) makes it a candidate vector.
Cs. fumipennis	+	Rare, too few records	Unknown, too rare	N/A	N/A
Cs. litorea	+	Coastal, rare, too few records	Unknown, too rare	N/A	Not considered an important nuisance species or potential disease vector.
Cs. longiareolata	+	Rare, too few records	Unknown, too rare	N/A	N/A
Cs. morsitans	++	Permanent and transiently wet habitats	This species will benefit from the development of permanent waters, although it is not recorded in any great numbers to determine the full impact of wetland creation. It can also be found in other transiently flooded habitats in wet woodland and acid bogs.	There is little available information on the impact of wetland management, although vegetated ditches and reedbed that are subjected to drying and remain wet thereafter do provide a habitat for this species. It may not be necessary to control this species, but if required, certainly water level management will be crucial.	Not considered to be an important nuisance species owing to its largely ornithophagic tendencies. However, they are potential enzootic disease vectors in Europe and have been reported to bite humans. However, they are heavily under-recorded in adult mosquito sampling.
Cs. subochrea	+	Similar to *Cs. annulata*, likely under-recorded. Ecology not considered distinct from *Cs. annulata*	N/A	N/A	Not considered to be an important nuisance species or potential disease vector.

Further reading

Cranston, P.S., Ramsdale, C.D., Snow, K.R. & White, G.B. (1987) *Adults, Larvae and Pupae of British Mosquitoes (Culicidae): A Key*. Freshwater Biological Association. Ambleside.

Golding, N., Nunn, M.A., Medlock, J.M., Purse, B.V., Vaux, A.G.C. & Schafer, S.M. (2012) West Nile virus vector *Culex modestus* established in southern England. *Parasites and Vectors*, 5:32.

Marshall, J.F. (1938) *The British Mosquitoes*. London: British Museum (Natural History).

Medlock, J.M. (2015) Impact of the creation, expansion and management of English wetlands on mosquitoes (Diptera: Culicidae). PhD Thesis. University of Bristol.

Medlock, J.M., Snow, K.R. & Leach, S. (2005) Potential transmission of West Nile virus in the British Isles: an ecological review of candidate mosquito bridge vectors. *Medical and Veterinary Entomology*, 19:2–21.

Medlock, J.M., Snow, K.R. & Leach, S. (2007) Possible ecology and epidemiology of medically important mosquito-borne arboviruses in Great Britain. *Epidemiology and Infection*, 135:466–82.

Medlock, J.M. & Vaux, A.G.C. (2012) Distribution of West Nile virus vector, *Culex modestus* in England. *Veterinary Record*, 171(11):278.

Medlock, J.M. & Vaux, A.G.C. (2015) Impacts of the creation, expansion and management of English wetlands on mosquito presence and abundance - Developing strategies for future disease mitigation. *Parasites and Vectors*, 8(1).

Medlock, J.M., Cull, B., Vaux, A.G.C., Irwin, A.G. (2017a) The mosquito *Aedes vexans* in England. *Veterinary Record*, 181(9):243.

Medlock, J.M., Vaux, A.G.C., Cull, B., Schaffner, F., Gillingham, E., Pfluger, V. & Leach, S. (2017b) Detection of the invasive mosquito species *Aedes albopictus* in Southern England. *Lancet Infectious Diseases*, 17(2):140.

Service, M.W. (1968) Observations on feeding and oviposition in some British mosquitoes. *Entomologia Experimentalis et Applicata*, 11:286–90.

Service M.W. (1969) Observations on the ecology of some British mosquitoes. *Bulletin of Entomological Research*, 59:161–94.

Service M.W. (1971) Feeding behaviour and host preferences of British mosquitoes. *Bulletin of Entomological Research*, 60:653–61.

Service M.W. (1973) The biology of *Anopheles claviger* (Mg.) (Diptera, Culicidae) in southern England. *Bulletin of Entomological Research*, 63:347–59.

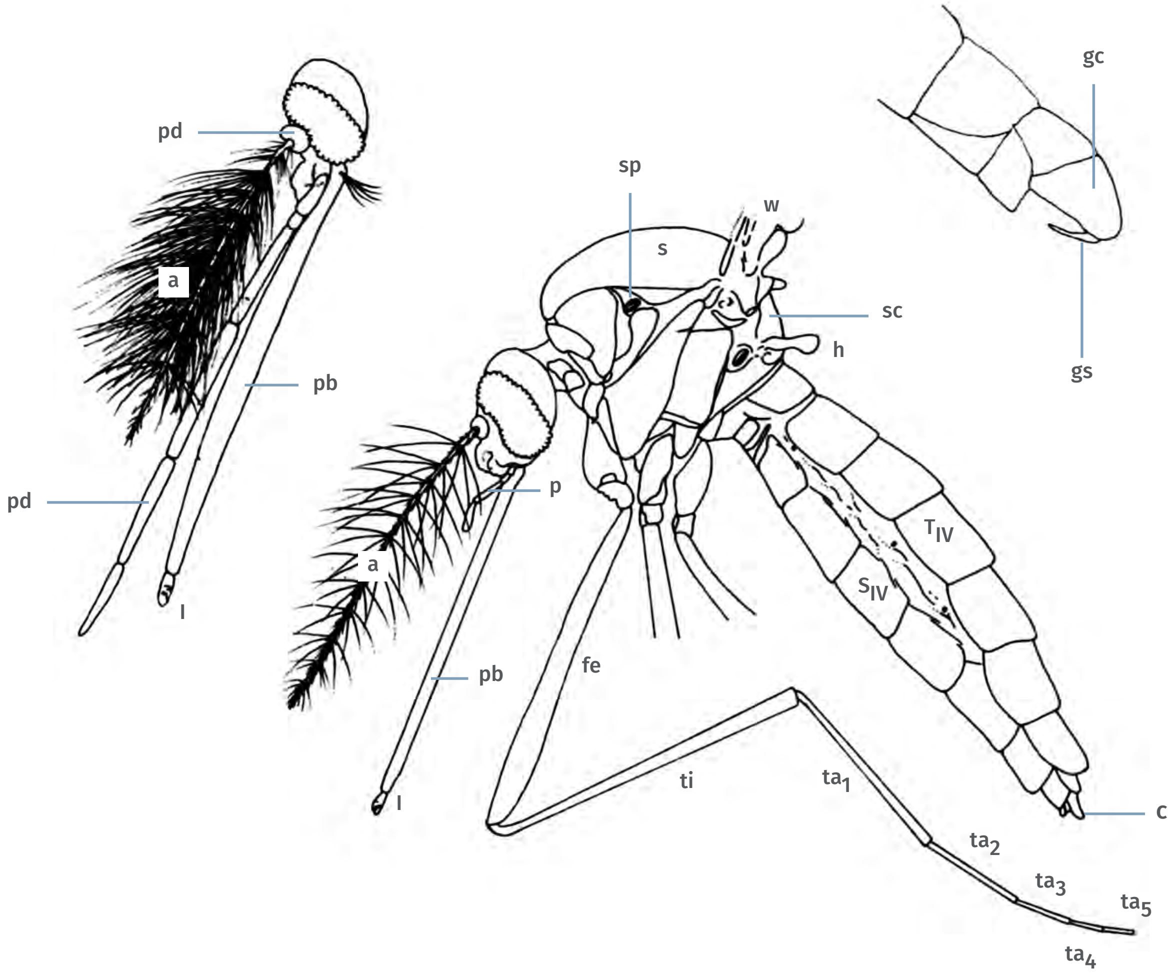
Service, M.W. (1994) The biology of *Culiseta morsitans* and *Culiseta litorea* in England. *Bulletin of Entomological Research*, 84:97–104.

Snow, K.R. (1990) *Naturalists' Handbook 14: Mosquitoes*. Slough: The Richmond Publishing Co. Ltd.

Snow, K.R. & Medlock, J.M. (2008) The mosquitoes of Epping Forest, Essex, UK. *European Mosquito Bulletin*, 26:9–17.

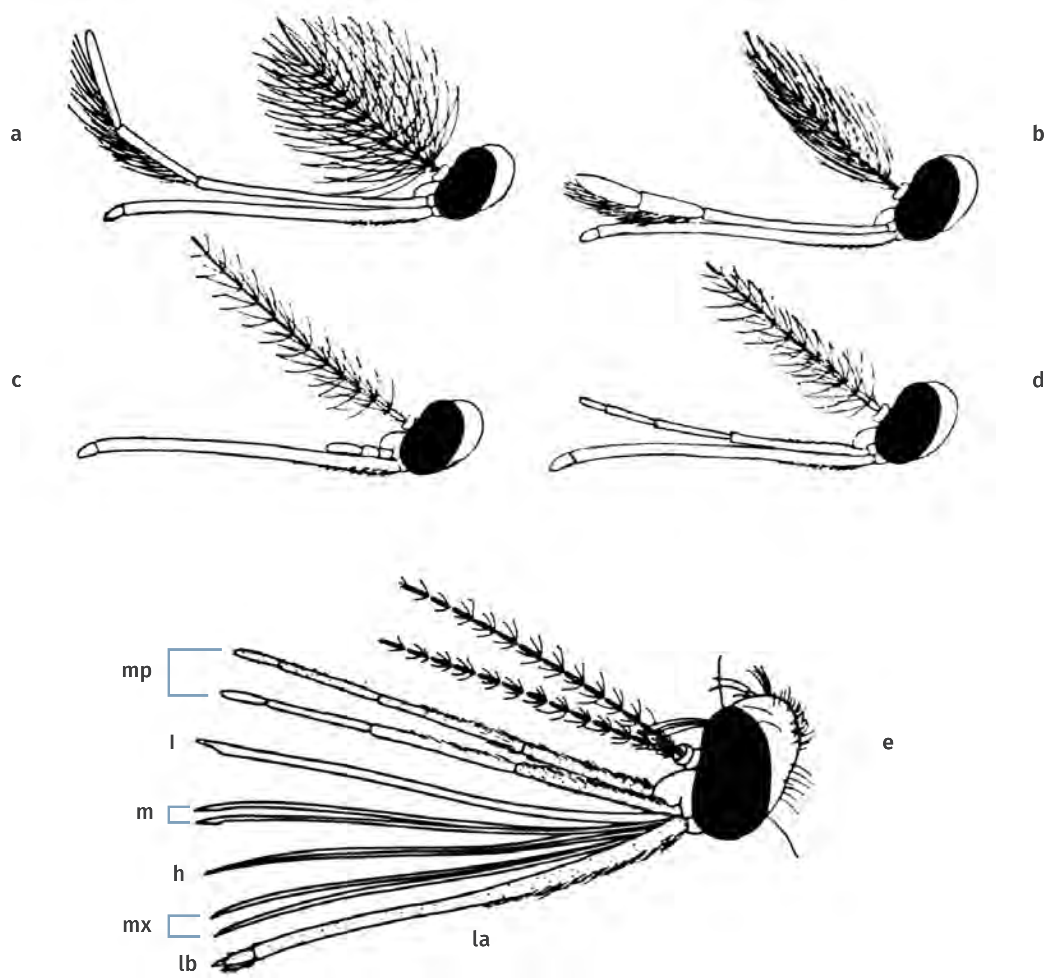
Vaux, A.G.C., Gibson, G., Hernandez-Triana, L.M., Cheke, R.A., McCracken, F., Jeffries, C.L., Horton, D.L., Springate, S., Johnson, N., Fooks, A.R., Leach, S. & Medlock, J.M. (2015) Enhanced West Nile virus surveillance in the North Kent marshes, UK. *Parasites and Vectors*, 8:91.

Appendix IV – Generalised adult mosquito anatomy



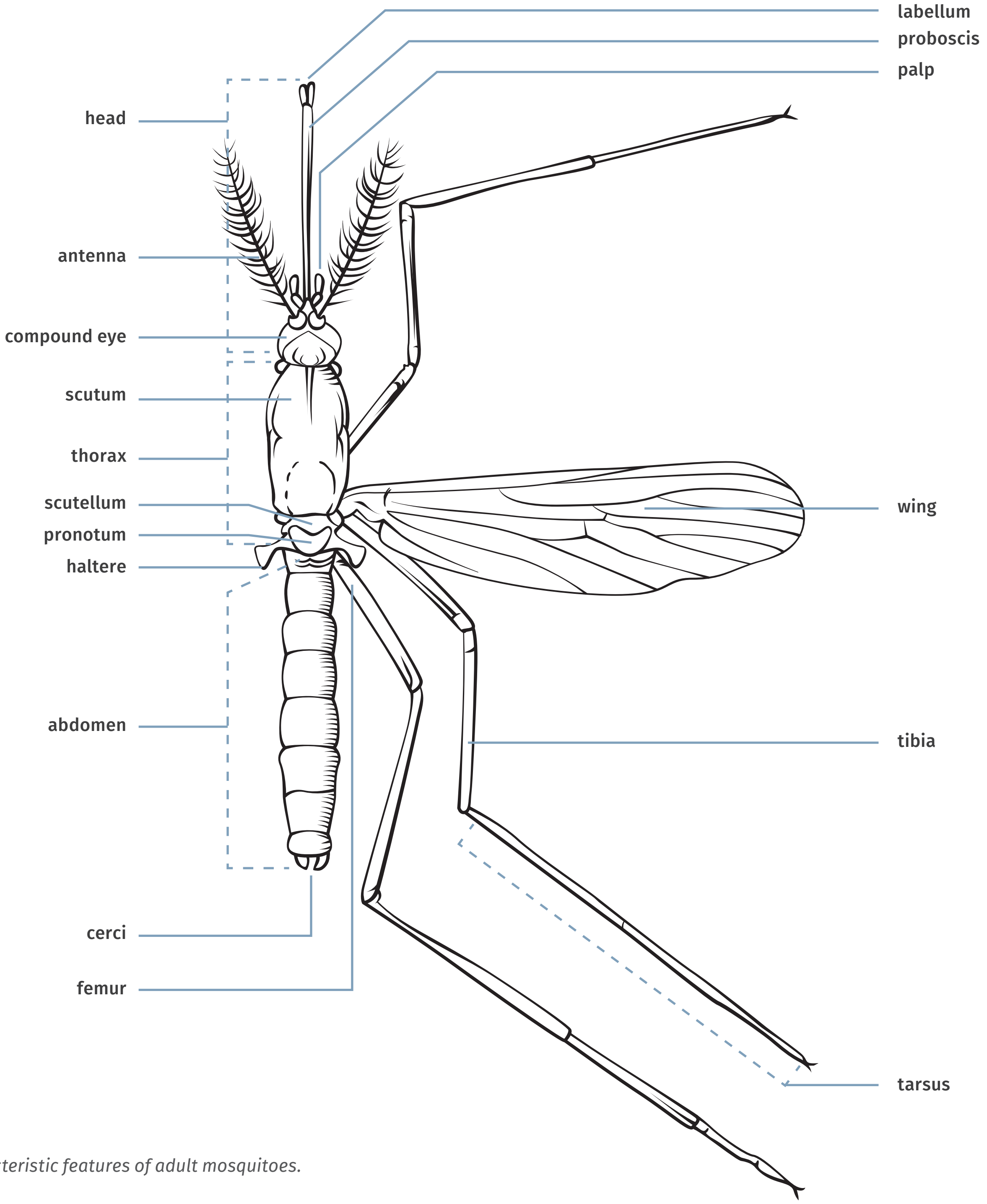
Adult Mosquito (generalised): a- *antenna,* c- *cercus,* fe- *femur,* gc- *gonocoxite,* gs- *gonostylus,* h- *haltere,* l- *labellum,* p- *palp,* pb- *proboscis (labium),* pd- *pedicel,* s- *scutum,* SIV- *sternite IV,* sc- *scutellum,* sp- *spiracle,* TIV- *tergite IV,* ta1-5- *tarsomeres 1-5,* ti- *tibia,* w- *wing base. Image courtesy of the Freshwater Biological Association.*

Appendix IV – Generalised adult mosquito anatomy *(cont'd)*



Mosquito head: a- *male culicine with plumrose antenna and long slender hairy palps,* b- *male anopheline with plumrose antenna and long clubbed palps,* c- *female culicine with pilose antenna and short palps,* d- *female anopheline with pilose antenna and long slender palps,* e- *female anopheline with proboscis components artificially displayed (*h- *hypopharynx,* l- *labrum,* lb- *labella,* m- *mandibles,* mp- *maxillary palps,* mx- *maxillae). Image courtesy of the Freshwater Biological Association.*

Appendix IV – Generalised adult mosquito anatomy *(cont'd)*



Characteristic features of adult mosquitoes.

Appendix V – Simple key to adult female Culicidae

1. Plumose antennae .... Male
   - Pilose antennae .... Female
2. Palps as longs as proboscis .... (*Anopheles*) 3
   - Palps no longer than half proboscis length 5
3. Wings with 'spots' .... *An. maculipennis* s.l.
   - Wings without 'spots' (clusters of scales) 4
4. With prominent white scales (tufts) on head .... *An. plumbeus* or *An. claviger*
   - Without such prominent white scales .... *An. algeriensis*
5. Abdomen evenly tapered; fore and mid leg claws with inner tooth; cerci long .... (*Aedes*) 6
   - Abdomen parallel-sided; lacking claws on inner tooth 12
6. Tarsi without rings of pale scales 7
   - Tarsi with rings of pale scales 10
7. White abdominal bands do not join 8
   - White abdominal bands do join 9
8. Triangular white patches on sides of abdomen and 'white knees' (tips of femora) .... *Aedes geniculatus*
   - Scales form pale stripes on side of abdomen; with russet red scutum .... *Aedes cinereus/geminus*
9. - a) Bands on posterior tergites form a central line .... *Ae. rusticus*
   - b) Bands on tergites restricted in middle .... *Ae. punctor*
   - c) Peppering of scales in black band on tergites .... *Ae. detritus*

   (note *Ae. detritus* can be cf. with *Ae. communis* and *Ae. leucomelas*, both extremely rare in UK)
10. Tarsi with rings above and below joints .... *Ae. caspius/dorsalis*
    - Tarsi with rings below the joint only 11

    (note the scutum on *Ae. caspius* has reddish fawn scales with two sublateral pale stripes. On *Ae. dorsalis* the lateral patches of the scutum are covered in white scales and do not form stripes).
11. - a) Abdominal tergites covered in yellow scales .... *Ae. flavescens*
    - b) Abdominal tergite bands uniform .... *Ae. cantans/annulipes*
    - c) Abdominal tergite bands lobed .... *Ae. vexans*
12. Tarsi without pale bands .... (*Culex*) 13
    - Tarsi with pale bands 14

13. - a) No abdominal bands on tergites, lateral patches of pale scales sometimes extending into stripes ...... *Cx. modestus*

 - b) Abdominal bands on front margin of tergite .... *Cx. pipiens* s.l., *Cx. torrentium*

 - c) Abdominal bands on hind margin of tergites .... *Cx. territans*

 (note: the first segment of the hind tarsus of *Cx. modestus* is distinctly shorter than the hind tibia, in contrast to other *Culex*)

14. Black scutum with distinctive white stripes........ *Or. pulcripalpis*

 - Otherwise 15

15. Prespiracular hairs absent; broad wing scales........ *Cq. richiardii*

 - Prespiracular hairs present; narrow wing scales ....(*Culiseta*)........ 16

16. Spotted wings .... *Cs. annulata, Cs. subochrea, Cs. alaskaensis*

 - Wings without spots 17

17. - a) Scutum with distinct white stripes........ *Cs. longiareolata*

 - b) Pale rings on last two hind tarsomeres .... *Cs. fumipennis*

 - c) Pale rings absent from last two hind tarsomeres .... *Cs. morsitans/litorea*

Source

Medlock, J.M. (2015) Impact of the creation, expansion and management of English wetlands on mosquitoes (Diptera: Culicidae). PhD Thesis. University of Bristol.

Further reading

Cranston, P.S., Ramsdale, C.D., Snow, K.R. and White, G.B. (1987) *Adults, Larvae and Pupae of British Mosquitoes (Culicidae): A Key.* Freshwater Biological Association, Ambleside, UK.

Snow, K.R. (1990). *Naturalists' Handbook 14: Mosquitoes.* Slough: The Richmond Publishing Co. Ltd.

Appendix VI – Simple key to 4th instar larvae of Culicidae

1. Siphon absent ... (*Anophelinae*) ... 2

    - Siphon present ... (*Culicinae*) ... 5

2. Frontal hairs of head small and unbranched ... *An. plumbeus*

    - Frontal hairs large and feathery ... 3

3. Outer clypeal hairs with multiple branches ... *An. maculipennis* s.l.

    - Outer clypeal hairs unbranched or few branches ... 4

4. Head with extensive patterns ... *An. algeriensis*

    - Head with less extensive markings ... *An. claviger*

5. Siphon modified for piercing ... *Cq. richiardii*

    - Not modified ... 6

6. Siphon without pecten spines/hairs ... *Or. pulcripalpis*

    - Siphon with pecten spines/hairs ... 7

7. Siphon with at least 3 pairs of siphonal hairs ... (*Culex*) ... 8

    - Siphon with 1 pair of siphonal hairs ... 0

8. Siphon long and slender (>6 x length:breadth); thorax and abdomen covered in minute spines ... *Cx. territans*

    - Siphon index <6 l:b; no spines ... 9

9. Siphon with 3-5 pairs of hairs; most basal tuft with >6 branches ... *Cx. modestus*

    - Siphon with 4-5 pairs; most basal tuft with 4 branches ... *Cx. pipiens/torrentium*

10. Siphon with paired hairs arising midway on siphon ... (*Aedes*) ... 11

    - Siphon with paired hairs arising at base of siphon ... (*Culiseta*) ... 19

11. Antennae smooth; hairs on abdomen star-shaped ... *Ae. geniculatus*

    - Antennae with spines; hairs not star-shaped ... 12

12. Siphon with 3-4 pairs of dorsal hairs ... *Ae. rusticus*

    - Siphon without dorsal hairs ... 13

13. Last 1 or 2 pecten spines widely spaced

    i) Anal papillae as long as siphon ... *Ae. cinereus*

    ii) Anal papillae usually much shorter ... *Ae. vexans*

    - Last spines of pecten not widely spaced ... 14

14. Anal papillae 3 times longer than saddle ... *Ae. sticticus*

    - Anal papillae <2x length of saddle ... 15

15. Saddle completely encircles anal segment ... *Ae. punctor*

    - Saddle does not completely encircle anal segment ... 16

16. >45 comb scales .... *Ae. detritus*
    - <45 comb scales 17
17. 1 or 2 pre-cratal hairs .... *Ae. caspius, Ae. dorsalis*
    - >5 pre-cratal hairs 18
18. 6 pre-cratal hairs .... *Ae. flavescens*
    - No more than 5 pre-cratal hairs .... *Ae. cantans/annulipes*
19. Pecten with some spines hair like .... *Cs. annulata/subochrea/alaskaensis*
    - Pecten composed entirely of strong spines 20
20. Antennae smooth .... *Cs. longiareolata*
    - Antennae with small spines .... *Cs. morsitans/litorea/fumipennis*

Source

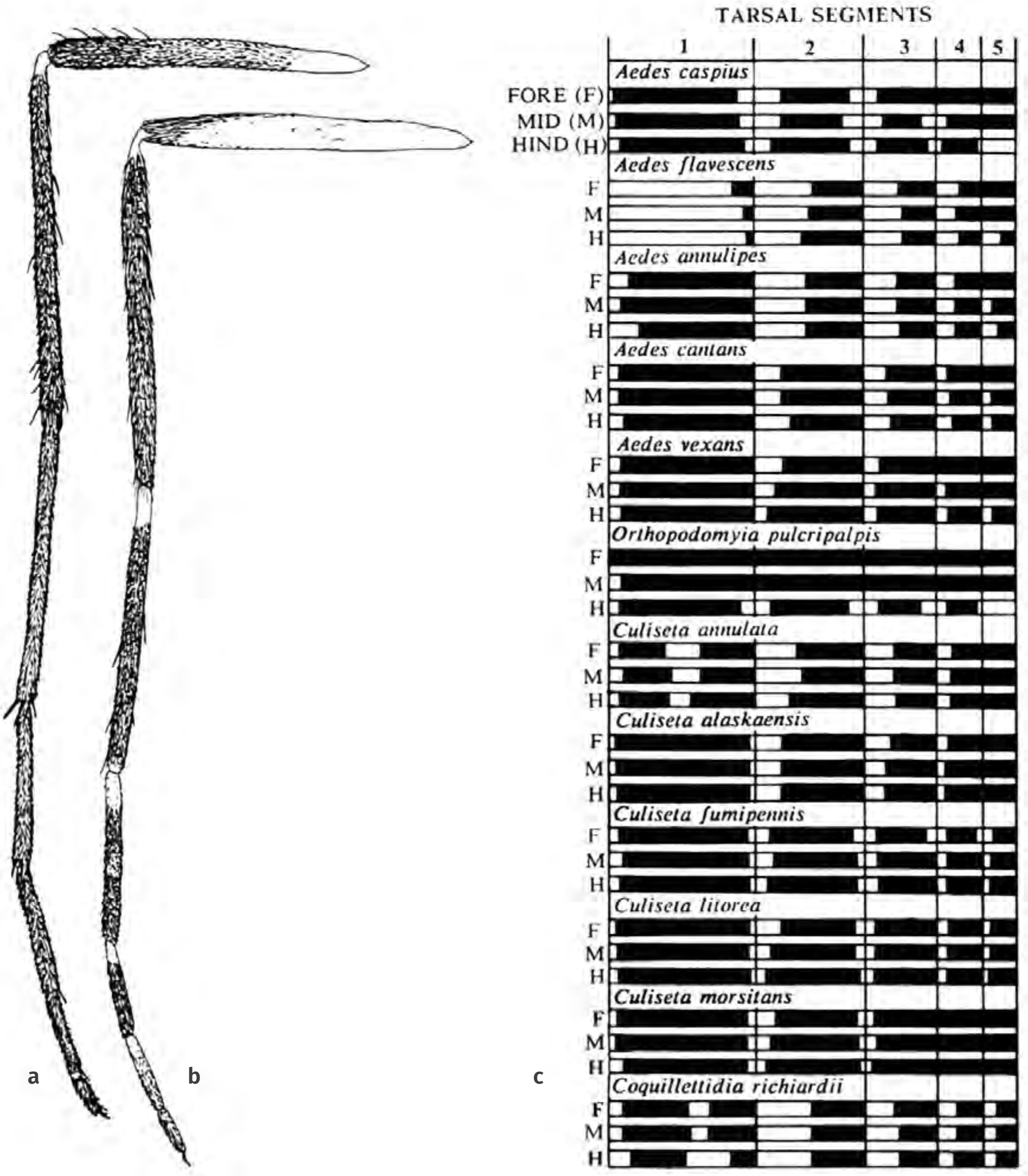
Medlock, J.M. (2015) Impact of the creation, expansion and management of English wetlands on mosquitoes (Diptera: Culicidae). PhD Thesis. University of Bristol.

Further reading

Cranston, P.S., Ramsdale, C.D., Snow, K.R. and White, G.B. (1987) *Adults, Larvae and Pupae of British Mosquitoes (Culicidae): A Key.* Freshwater Biological Association, Ambleside, UK.

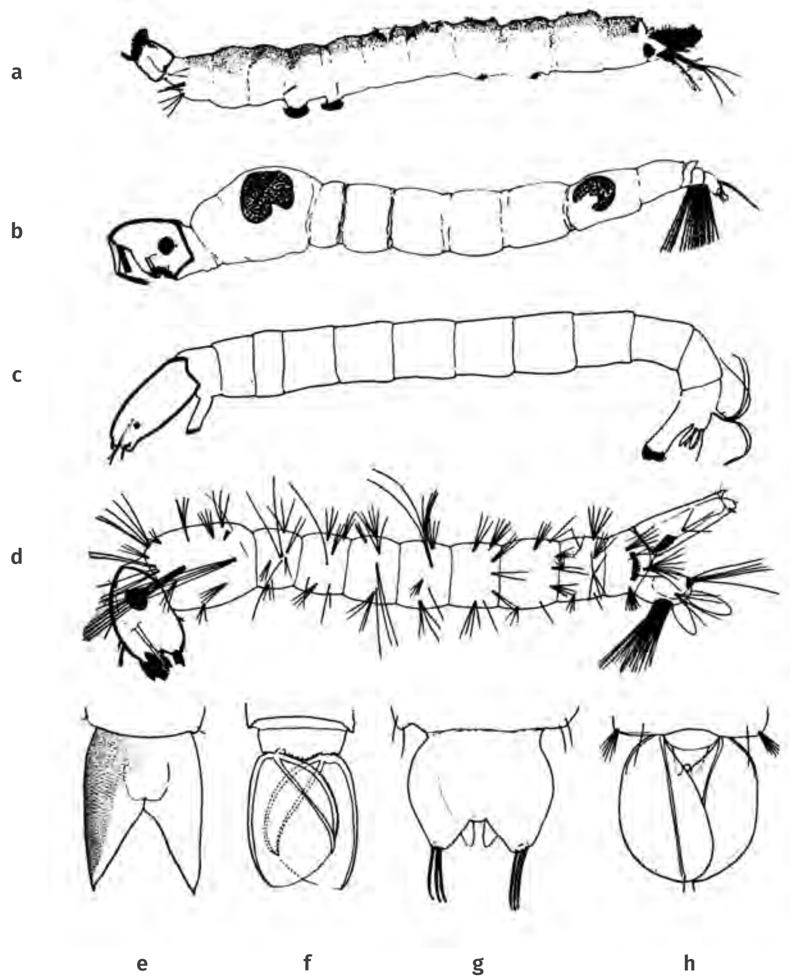
Snow, K.R. (1990). *Naturalists' Handbook 14: Mosquitoes.* Slough: The Richmond Publishing Co. Ltd.

Appendix VII – Identification of some British mosquitoes according to tarsal patterns



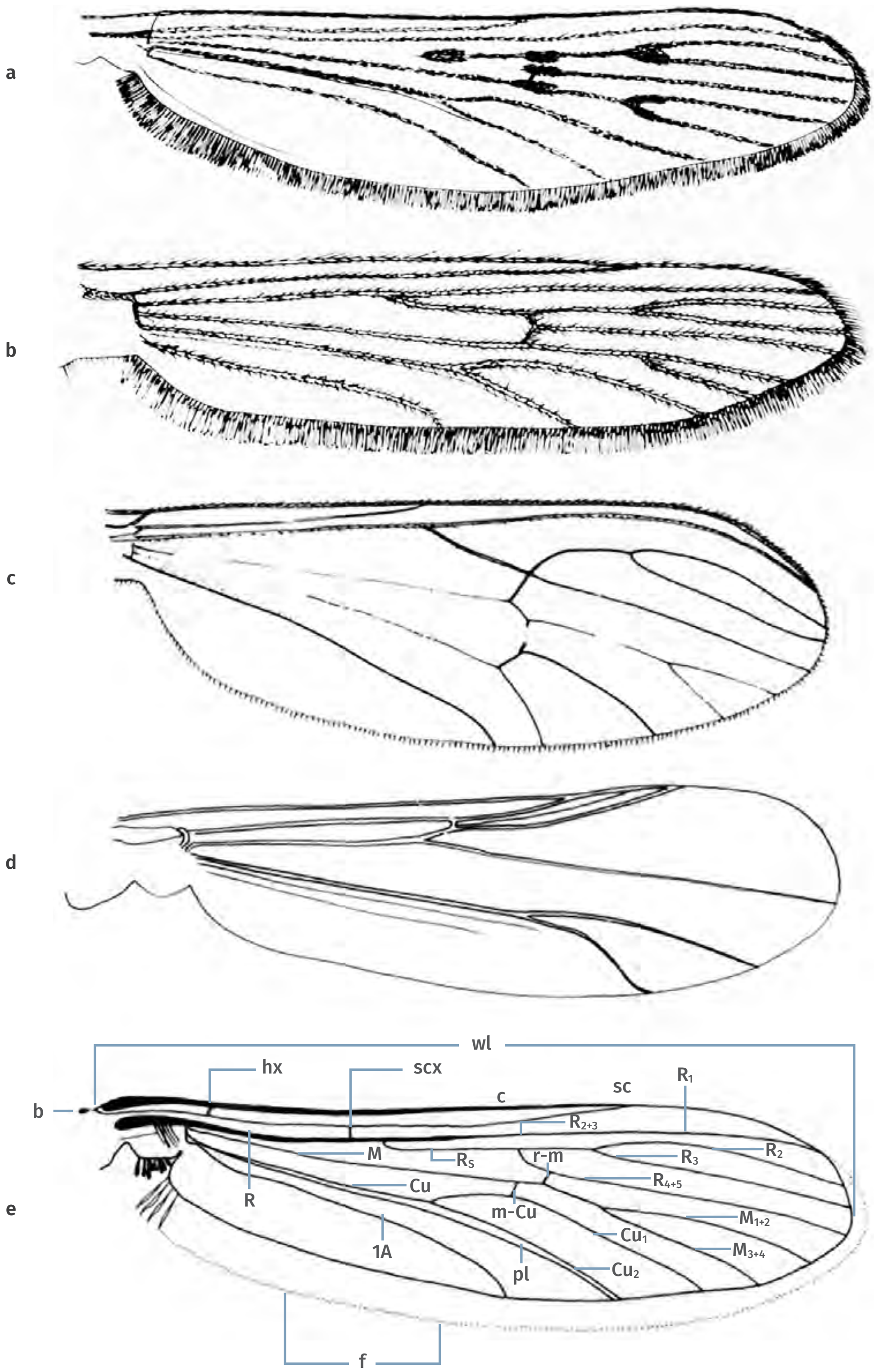
Tarsal patterns: a- *without rings (Ae. geniculatus)*, b- *with rings below joints (Ae. vexans)*, c- *tabular presentation of relative band widths of different culicine species. Image courtesy of the Freshwater Biological Association.*

Appendix VIII – Comparison of aquatic larvae and adult wing patterns of mosquitoes with morphologically similar fly taxa



Larvae: a- *Dixidae*, b- *Chaoboridae*, c- *Chironomidae (Tanypodinae)*, d- *Culicidae (Culicinae)*. *Pupal terminal segment of:* e- *Dixidae:* f- *Chaoboridae*, g- *Chironomidae (Orthocladiinae)*, h- *Culicidae. Image courtesy of the Freshwater Biological Association.*

Appendix VIII – Comparison of aquatic larvae and adult wing patterns of mosquitoes with morphologically similar fly taxa *(cont'd)*



Wing venation: a- *Culicidae* (Anopheles maculipennis *s.l.*), b- *Chaoboridae (Chaoborus crystallinus)*, c- *Dixidae (Dixa aestivalis)*, d- *Chironomidae (Pseudosmittia sp.)*; e- *Culicidae (generalised)* 1A- *anal vein*, b- *basicosta*, c- *costal vein*, Cu_x- *Cubital veins*, f- *fringe of scales*, hx- *humeral cross vein*, M_x- *Medial veins*, m-mCu- *mediocubital cross-vein*, pl- *plical fold*, r- *remigium*, R_x- *Radial veins*, R_s- *Radial stem*, r-m- *radio medial cross-vein*, sc- *subcostal vein*, scx- *subcostal cross- vein*, wl- *wing length. Image courtesy of the Freshwater Biological Association.*

Appendix IX – Data sheets for mosquito reporting

PUBLIC HEALTH ENGLAND MOSQUITO RECORDING SCHEME - DATA FORM

Please complete the following form and send this along with any mosquitoes collected to the address provided below.

PERSON SUBMITTING DATA	
Name of person submitting mosquito(es)	
Company name	
Address	
Telephone number	
Email address	

LOCATION OF COLLECTION	
Date of collection	
Specific location of collection *(grid reference if possible)*	
General location of collection *(nearest village/town/city)*	
Local habitat *(deciduous woodland, coniferous woodland, pasture)*	
Any further information/notes	

Appendix X – Useful contacts

FOR MOSQUITO REPORTING

Public Health England, Medical Entomology, Public Health England, Porton Down, Salisbury SP4 0JG

Email: mosquito@phe.gov.uk

FOR PEST CONTROL

The British Pest Control Association, 4A Mallard Way, Pride Park, Derby DE24 8GX

Email: enquiry@bpca.org.uk

Website: https://bpca.org.uk/

Find a pest controller: +44 (0) 1332 294 288

Appendix XI – NBN Data Providers

The authors are grateful to the Data Providers who submit species records to the NBN (https://nbnatlas.org/). Those who provided data used in the species distribution maps presented in this publication are acknowledged in full below and by the following citation:

NBN Atlas occurrence download at http://nbnatlas.org. Accessed 05 June 2020.

The NBN Trust, Data Providers, and Original Recorders (where identified) bear no responsibility for any further analysis or interpretation of the material, data and information presented.

Biological Records Centre

BIS for Powys & Brecon Beacons National Park

Bristol Regional Environmental Records Centre

Buglife

Cofnod - North Wales Environmental Information Service

Cumbria Biodiversity Data Centre

Dipterists Forum

Environmental Records Information Centre North East

Fife Nature Records Centre

Highland Biological Recording Group

Leicestershire and Rutland Environmental Records Centre

Malcolm Storey

Manx Biological Recording Partnership

Merseyside BioBank

Ministry of Justice

National Trust

Natural England

Natural Resources Wales

NatureSpot

Norfolk Biodiversity Information Service

North East Scotland Biological Records Centre

Nottinghamshire Biological and Geological Records Centre

Rotherham Biological Records Centre

Royal Horticultural Society

Royal Society for the Protection of Birds

Scottish Wildlife Trust

Shropshire Ecological Data Network

South East Wales Biodiversity Records Centre

Staffordshire Ecological Record

Suffolk Biodiversity Information Service

Sussex Biodiversity Records Centre

The Wildlife Information Centre

West Wales Biodiversity Information Centre

Woodmeadow Trust

Yorkshire Wildlife Trust

Wetlands across Britain provide important habitat for wildlife, including a range of invertebrates and many of the mosquito species recorded in Britain. They also generate a wide range of environmental, economic and socio-cultural benefits to people, supporting their health and wellbeing and mitigating the impacts of climate change. This book is designed to provide those working in wetland management, conservation and policy with the information and tools necessary to ensure that wetlands can continue to deliver these many benefits without public and veterinary health issues arising from mosquitoes.

So how can wetland creation, management and expansion be achieved while limiting perceived or actual public health impacts from mosquitoes? To help answer this question, this book gives an overview of the biology, ecology and behaviour of British mosquitoes in wetlands, provides details of strategies for surveying mosquitoes, as well as species-specific details on the kinds of aquatic habitats that support British mosquitoes. It also includes details of the legal frameworks surrounding pest management as relates to mosquitoes and an assessment of the current risks associated with future mosquito-borne disease in the UK.

To support practitioners in preparing evidence-based risk assessments and management plans, a tool for predicting which mosquito species are likely to be found in specific wetland environments is included, alongside guidance on how to survey and manage problematic species. Public perceptions of mosquitoes, best practice for responding to enquiries about mosquitoes, and the history of mosquito research in early 20th Century England are also touched upon.

VALUING NATURE PROGRAMME