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Review

Flight distance of mosquitoes (Culicidae): A metadata analysis to support the management of barrier zones around rewetted and newly constructed wetlands

Piet F.M. Verdonschot[a,b,*], Anna A. Besse-Lototskaya[a]

[a] Alterra Wageningen UR, Department of Freshwater Ecology, P.O. Box 47, 6700 AA Wageningen, The Netherlands
[b] University of Amsterdam, Institute for Biodiversity and Ecosystem Dynamics (IBED), P.O. Box 94248, 1090 GE Amsterdam, The Netherlands

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A B S T R A C T

Society responds to changes in climate and land use via mitigation measures, including rainwater retention and storage in rewetted and newly constructed wetlands. Humans living close to these wetlands express concerns about future mosquito nuisance situations, and request the necessary distance between human occupation and wetlands to avoid such problems. Wetland managers need to know the distance required, as well as the type of management needed for such buffer or barrier zones. Here we performed an extensive literature survey to collect quantitative information on mosquito flight distance and the relevant environmental conditions. Mosquitoes have an average maximum flight distance of between 50 m and 50 km, depending on the species. Long-distance or migratory flights are strongly related to species ecological preferences and physiology, are survived by few specimens, and do not relate to nuisance situations. Nuisance-related or non-oriented flights are also species-specific and cover much shorter distances-between 25 m and 6 km for the 23 species analyzed. Based on these results, we made regression-based estimations of the percentages of the population that cross certain distances. A 90% reduction in breeding site population density would require minimal distances of 56 m for *Anopheles saperoi* and 8.6 km for *Anopheles sinensis*, and much greater distances for *Aedes vexans*, *Culex quinquefasciatus*, and *Culiseta morsitans*. Little useful information was available regarding the environmental conditions under which non-oriented flights took place. Qualitatively, the review showed that flight capacity was influenced by landscape structure, meteorological conditions (temperature, humidity, and illumination), and species physiology (energy available for flight). Overall, our findings suggest that predictions regarding the construction of barrier zones around breeding sites can be made based on mosquito and host density and human nuisance perception, and that barrier zone usefulness strongly depends on the mosquito species involved. Additional quantitative research is needed to better document the non-oriented dispersal patterns of the mosquitoes that populate rewetted and newly constructed wetlands, and the effects of vegetation types in barrier zones on mosquito densities.

Contents

* Corresponding author at: Alterra Wageningen UR, Department of Freshwater Ecology, P.O. Box 47, 6700AA Wageningen, The Netherlands. Tel.: +31 317 48 65 52; fax: +31 317 41 90 00.
E-mail address: piet.verdonschot@wur.nl (P.F.M. Verdonschot).

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Introduction

With climate change in Europe, temperatures will rise, winters will become wetter, and summers will become more dynamic, with longer drought periods and short but heavy rain-storms (IPCC, 2007). Society's response will include mitigation measures to retain and store rainwater in non-saturated soil, temporary basins, or depressions in the landscape. These measures will increase the number of shallow temporary surface waters, such as water storage basins, rewetted areas, marshes, and swamps. Humans living near such rewetted or newly wet areas are increasingly expressing concerns about future mosquito nuisance situations. These concerns raise questions regarding the distance that mosquitoes fly to find their hosts. Such information will help determine the distance needed between human occupation and the surface waters that may potentially act as mosquito breeding sites, as well as direct the management of this intermediate area, often termed the barrier zone.

Service (1997) reviewed the dispersal and migration of mosquitoes and distinguished three dispersal types. The first is unintentional dispersal on human transportation, which is best illustrated by mosquito travel on airplanes from one continent to another (for review, see Smith and Carter, 1984). The second is wind-assisted long-distance dispersal, referring to passive migration that occurs when swarms of emerging mosquitoes drift far away from their breeding sites (Provost, 1952). This activity is strongly influenced by wind speed and direction, and passive dispersal is mostly down-wind (Bailey et al., 1965). Both types are defined here as types of (unintentional) migration. The third dispersal type comprises shorter daily flights in search of hosts, nectar (food), mates, oviposition, and resting sites/shelter. This non-oriented and host-seeking-related dispersal is intentional and most important in dealing with nuisance situations.

In most mosquito species, oogenesis can only be completed when the female takes a blood-meal. Therefore, mosquitoes have developed complex host-seeking behavior to locate and feed on a potential host. This host-seeking dispersal depends on species, season, and host availability. Sutcliffe (1987) recognized three intentional dispersal phases: (1) non-oriented dispersal that enhances the likelihood to encounter stimuli of potential hosts (see also Silver, 2008) or active dispersal according to Provost (1953), (2)) oriented host location, and (3) attraction to a suitable candidate host in the immediate vicinity. The latter two classes relate to appetitive flights for host seeking (Provost, 1953). Appetitive flight behavior is mainly based on thermal stimuli and olfactory stimuli, such as carbon dioxide, lactic acid, octenol, acetone, butanone, and phenolic compounds (Takken, 1991). As wind generates host-odor plumes, appetitive flight is mostly upwind dispersal to increase the chance of encountering stimuli deriving from a host.

The first type of intentional dispersal, the non-oriented dispersal, is based on visual stimuli—such as a row of trees in *Orconectes rusticus* (Schäfer et al., 1997)—and covers the phase during which female mosquitoes actively travel the greatest distances between breeding site, shelter, and host (Sutcliffe, 1987). Overlap between non-oriented dispersal and wind-assisted dispersal or migration is unavoidable. It is generally agreed that non-oriented dispersal predominantly takes place during the first days after emergence (Nayar, 1985), with mark-release experiments indicating that it mostly occurs between 1 and 4 days after release (e.g., Watson et al., 2000). Non-oriented dispersal is directly influenced by environmental factors. These can relate to the local microclimate or meteorological conditions, such as wind velocity (e.g., Bidlingmayer, 1964; Schäfer et al., 1997), humidity, and temperature (e.g., Platt et al., 1957; Lewis and Talor, 1967); illumination levels (such as the shade of rows of trees for *O. rusticus*); wind velocity; local topography and vegetation type (structure); host presence and density; and the availability of suitable oviposition sites.

Non-oriented dispersal is also influenced by species adaptations relating to the physiological status of the female, body size, flight strength, and population density. As non-oriented dispersal serves to find hosts, species host preference affects the distance and direction of dispersal. Ornithophilic species (such as *Culex pipiens pipiens* and *Culiseta morsitans*) disperse in vertical direction toward trees (up to >10 m), higher than species that feed on mammals (such as *Aedes* and *Ochlerotatus*).

Concerning the meteorological conditions, Dow et al. (1965), Bailey et al. (1965), and Reisen and Lothrop (1995) all concluded that non-oriented dispersal is relatively independent of wind direction. The presence of vegetation directly influences the microclimate, causing increased humidity, reduced wind, and tempered temperatures. Therefore, females usually fly close to the ground or just above the top of the vegetation. Microclimatological circumstances can influence flight strength or capacity. A study by Kaufmann and Briegel (2004) distinguished strong (>2 km) and weak flyers (<2 km). Becker et al. (2010) further classified mosquitoes into four groups according to their flight capacity and occurrence: weak flyers, which are urban domestic, snowmelt, and container breeding species that breed and rest close to their hosts' habitats and do not fly long distances (Watson et al., 2000); weak-moderate flyers, which occur in woodlands; moderate-strong flyers, which occur along field and forest edges; strong flyers, which occur in open areas and disperse over long distances (Gillies, 1972; Bidlingmayer, 1975).

The non-oriented dispersal flight range of mosquitoes is most important with respect to potential nuisance situations, and in determining the width and environmental conditions required for barrier zones to prevent adult females from penetrating human occupancies in nuisance-causing quantities. Barrier zones are areas with adverse environmental conditions for adult mosquitoes—such as wind, high temperature, and low humidity, which strongly lower the survival rate (Clements, 1963; Craig et al., 1999). It is typically assumed that open areas act best as barrier zones. It should also be noted that nuisance perception can differ between people, and influences barrier zone management.

The present study performed a literature review, and used the obtained data to quantify the species-specific flight distances of both migration and non-oriented dispersal, as well as the effects of environmental conditions, especially barrier zones. Our results can assist managers in determining the distance needed between human occupation and mosquito species-specific breeding site in order to reduce or avoid nuisance situations. Migration is included in the analyses to improve knowledge of species flight strengths.

Methods

A literature survey was performed to obtain an overview of quantitative data relating to mosquito migration and non-oriented dispersal distances. We used the search terms range or capacity or