MODELLING THE DEMOGRAPHY AND CONTROL OF DISEASE-CARRYING TROPICAL MOSQUITOES IN NORTHERN AUSTRALIA

By

Siobhan Clare de Little

A thesis submitted in fulfilment of the requirements for the degree of

Doctor of Philosophy

Ecology and Evolutionary Biology

University of Adelaide

October 2011

Statement of Originality

I, Siobhan Clare de Little certify that this work contains no material which has been accepted for the award of any other degree or diploma in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text.

I give consent to this copy of my thesis when deposited in the University Library, being made available for loan and photocopying, subject to the provisions of the Copyright Act 1968.

The author acknowledges that copyright of published works contained within this thesis (as listed below*) resides with the copyright holder(s) of those works.
I also give permission for the digital version of my thesis to be made available on the web, via the University's digital research repository, the Library catalogue, the Australasian Digital Theses Program (ADTP) and also through web search engines, unless permission has been granted by the University to restrict access for a period of time.

*DE LITTLE, S. C., BOWMAN, D. M. J. S., WHELAN P. I., BROOK, B. W. & BRADSHAW, C. J. A. 2009. Quantifying the drivers of larval density patterns in two tropical mosquito species to maximize control efficiency. *Environmental Entomology*, 38:4, 1013-1021.

*DE LITTLE, S. C., WILLIAMSON, G. J., BOWMAN, D. M. J. S., WHELAN P. I., BROOK, B. W. & BRADSHAW, C. J. A. 2011. Experimental comparison of aerial larvicides and habitat modification for controlling disease-carrying *Aedes vigilax* mosquitoes. *Pest Management Science* In Press, Accepted 7/09/2011.

Siobhan C. de Little Date

Abstract

Mosquito-borne pathogens constitute a major burden of disease for humans globally, and are predicted to increase in range and incidence given climate change projections based on 21st Century emissions scenarios for greenhouse gases. Understanding the contributions of environmental variation and density feedback to changes in vector population abundance is essential for designing effective control programmes and predicting disease outbreaks in humans. In my thesis I outline a population ecologist's five-step plan for mosquito control, and define the parameters needed to create spatially explicit demographic models of mosquito population dynamics using an example disease-vector system in Darwin, Northern Territory, Australia. My spatio-temporal models of larval abundance treat two important vector species in the Northern Territory: *Aedes vigilax* and *Culex annulirostris*. I show how larval habitats used by the saltwater-influenced breeder *Ae. vigilax* and the obligate freshwater breeder *Cx. annulirostris* are separated both spatially and temporally in a tidally influenced swamp. I identify adult abundance in the previous month as the most important temporal driver of larval densities in both species, providing a clear dynamical link between the two main life phases in mosquito development: the aquatic larval stage and the mobile adult stage. My field experiments show that the main vector control programme in the Northern Territory, aerial larvicide application, is effective at suppressing adult emergence of *Ae. vigilax*, whereas other possible larval control measures such as vegetation removal via burning or slashing are not as effective in this context. My experiments reveal that current larval sampling procedures alone are inadequate for quantifying larval abundance or adult emergence. Further manipulation experiments show that reducing *Ae. vigilax* larval densities results in the emergence of larger adults, and that this relationship between larval density and adult emergence size is tempered by environmental conditions such as changes in nutrient levels across different larval habitats. Mosquito body size is linked to vital rates such as fertility and adult survival that are important determinants of disease transmission probability. My measurements of body size of remotely trapped female *Ae. vigilax* adults reveal evidence for longer survival time since

emergence in larger adults, and together these findings define an important mechanism of density feedback in mosquito populations; competition for resources at the larval stage results in smaller adult emergence sizes, and therefore, lower adult survival and fertility. My block-bootstrapped generalised linear models of a widespread tropical and subtropical disease in Australia – Ross River virus – show that environmental proxies of adult vector abundance, rather than trapped vector abundance data, are the most accurate predictors for the highest priority health statistic: wet season outbreaks of Ross River virus cases. These results demonstrate that quantifying the environmental determinants of variation in larval habitat quality and the subsequent production of adults provides the means to construct models that are likely more accurate for predicting disease transmission than expensive residential vector monitoring systems. Given that low-income tropical developing countries are the hardest hit by mosquito-borne diseases, cost-effective solutions to deal with the current and future burden of mosquito-borne disease are of paramount importance to global human health.

Acknowledgements

All funding for research outlined here was through an Australian Research Council Linkage Grant (LP0667619). The opportunity to undertake this project was thanks entirely to my supervisors Corey Bradshaw, David Bowman and Barry Brook. Thanks in particular to Corey for continually challenging me to learn and develop new quantitative skills, and for his never-ending support and belief in me. Thanks also to David for his unique views on the way the world works and his support.

This project would not have been possible without the tireless and extensive work of Peter Whelan and his team at the Medical Entomology Branch of the Northern Territory Department of Health and Community Services. Some of the data used for this project was part of the $479172 in-kind contribution from the Department of Health and Community services for the Australian Research Council Linkage Grant #LP0667619 (see Appendix I). The contributed datasets include:

i. *Aedes vigilax* and *Culex annulirostris* larval abundance data, water presence data, monthly *Ae. vigilax* and *Cx. annulirostris* adult abundance data and monthly spraying hours data for the Leanyer/Holmes Jungle swamp complex spanning November 2000 to December 2006 (Chapter 2).

ii. Monthly counts of laboratory-confirmed cases of Ross River virus infections in the Darwin region notified to the Northern Territory Centre for Disease Control, and monthly *Ae. vigilax* and *Cx. annulirostris* adult abundance data from 11 locations around Darwin spanning January 1991 to December 2007 (Chapter 5).

Thanks to the staff and admin at both the School for Environmental Research at Charles Darwin University, and the Global Ecology Lab at the University of Adelaide, for their support and help over the years. In particular, I thank Lubomir Bisevac, Grant Williamson and the mosquito experiment volunteer team for their assistance in the field; and Salvador

Herrando-Perez, Steve Delean and Nerissa Haby for their statistical know-how.

A big thank you goes to my family, especially my Mum and Dad, who never stop believing in me and have supported me financially, emotionally, and intellectually throughout the project. Thank you also to all my wonderful friends who have kept me sane over the years, in particular Caroline Lehmann, Kyra Wood, Jane McArthur, Meredith Roberts-Thomson, James Thorpe, Jacinta Mooney, Cameron Anderson, Kara Martin and Lexi Keeton.

Finally, thank you to my boyfriend Julian. Without your support and tolerance I would not have completed this thesis.

“The mosquito’s a clever little bastard. You can track him for days and days until you really get to know him like a friend. He knows you’re there, and you know he’s there. It’s a game of wits. You hate him, then you respect him, then you kill him.”

– Roy Spim, Mosquito Hunter.

Mosquito Hunter’s Sketch, Monty Python’s Flying Circus

Contents