# Data sources for the Anopheles-model package

Tom Smith with inputs from Derek Charlwood and Nakul Chitnis

The main source for vector bionomics data is the MAP repository, documented by Massey et al. (1).

## Additional data

Substantial additional data were included in a supplementary database. This includes publications that are not included in the MAP repository, because they did not meet one or other inclusion criterion. These include some very old, and some very recent publications (2-26). A considerable number of additional publications included relate to *An. albimanus* for which there is a substantial literature poorly represented in the MAP repository. The additional data also comprise measures (especially the sac rate, and biting rhythms see below) which were not routinely extracted by Massey et al. (1).

## Post processing

Most of the entomological parameters can be extracted from the format used by MAP, but additional issues arise with:

### Biting rhythms

African data on biting rhythms have recently been compiled by Shepherd-Smith(27). There is no comprehensive database of the biting rhythms for non-African sites, though the MAP files can be searched for publications containing biting rhythms. Biting rhythms were extracted from a convenience sample of publications giving rhythms for a subset of vectors of particular interest (13, 20, 22, 24, 28-33). This is by no means a comprehensive collection of the data that are out there.

### Gonotrophic cycle length

Part of the MAP database is the results of studies of gonotrophic cycle length. There seem to be various methods for estimating cycle length in the papers in this collection. These are:

1. Keeping fed mosquitoes to see how long it takes for them to lay eggs (as recommended by WHO(34)). This was carried out by (18, 26, 35-43)
2. Mark-recapture(25, 39, 42, 44-50)
3. Cross-correlations in time of biting densities (51)
4. There are also some publications where I can’t easily find a .pdf so I don’t know what method was used (52-54) or where the method is not described (55)
5. Sac rate (as described in (56) and applied also in (24, 56-60)
6. Kulkarni et al (2006)(61) and Tchuinkum et al(62) have used the fed:gravid ratio from resting mosquitoes to roughly estimate the duration of the cycle. The Kulkarni et al (2006)(61) analysis gave values of 1:1.4 (low altitude) and 1:4.5 (high altitude) for *An. arabiensis* in Tanzania, translating these into estimates of 2-3 days and 5-6 days.

If the use of the fed:gravid ratio is valid, then of course there are far more data out there that could be used so it would be possible to obtain estimates of gonotrophic cycle length for many more situations. There are 106 studies in the MAP database for which the fed:gravid ratio is available, corresponding to 30 different Anopheles taxa. Only 22 taxa have gonotrophic cycle lengths estimated by other methods.

The logic of the fed:gravid approach is best explained in Tchuinkum et al(62). Assuming negligible mortality while resting and that a whole annual cycle is representatively sampled), the proportion f = fed/(total-unfed), the duration of the cycle should be u = 1/f. This ignores mortality of resting mosquitoes, but if we assume daily survival while resting of p<1, and u is an integer then:

which is equivalent to:

We can consider the extreme case of assuming all the mortality is at the resting stage, and use this to estimate p from the parous rate, as: . This this leads to an equation for u as a function of the parous rate and f:

Feeding in some ‘reasonable’ numbers into this, we get:

|  |  |  |  |
| --- | --- | --- | --- |
|  | M |  |  |
| 0.6 | 0.8 | 1.67 | 1.75 |
| 0.5 | 0.8 | 2.00 | 2.12 |
| 0.4 | 0.8 | 2.50 | 2.68 |
| 0.3 | 0.8 | 3.33 | 3.61 |
| 0.2 | 0.8 | 5.00 | 5.47 |
| 0.1 | 0.8 | 10.00 | 11.05 |
| 0.6 | 0.6 | 1.67 | 1.86 |
| 0.5 | 0.6 | 2.00 | 2.29 |
| 0.4 | 0.6 | 2.50 | 2.93 |
| 0.3 | 0.6 | 3.33 | 4.00 |
| 0.2 | 0.6 | 5.00 | 6.13 |
| 0.1 | 0.6 | 10.00 | 12.51 |

This suggests that even assigning all the mortality to the resting stage doesn’t make much difference, and so could be a reasonable estimate of the duration of the cycle (applicable even if the parous rate has not been determined). However this ignores the phenomenon of delay before attempting to refeed, which forms the basis of your formula for the use of the sac rate (as described in (56) where we proposed (using the notation of (63)). Conversely the use of the sac rate ignores the possibility that the mosquitoes might rest for more than 48 hours before oviposition.

This is resolved by treating the duration of the resting stage as a separate quantity () (60) that can be estimated as . The average duration of the full oviposition cycle is then estimated by:

The inputs to the Anopheles package should thus be and (with the constraint that ). Values of the former are obtained either as a temperature-dependent function (various publications have estimated this), or as . Where the sac rate ( is available, can be determined from the above equation. Alternatively it is obtained from any of methods a-d.

takes real values, but the model is discrete time, with one-day time steps. Effectively this means that we are simulating a Poisson mixture of discrete values (this is broadly supported by published distributions for (38)).

### Estimates of the proportions of mosquitoes resting indoors

Publications with exit trap data (according to MAP)

Mnzava, A.E., Rwegoshora, R.T., Wilkes, T.J., Tanner, M. and Curtis, C.F. (1995). Anopheles arabiensis and An. gambiae chromosomal inversion polymorphism, feeding and resting behaviour in relation to insecticide house-spraying in Tanzania. Medical and Veterinary Entomology, 9(3):316-24 7548951

Sreehari, U., Razdan, R.K., Mittal, P.K., Ansari, M.A., Rizvi, M.M. and Dash, A.P. (2007). Impact of Olyset nets on malaria transmission in India. Journal of Vector Borne Diseases, 44(2):137-44 17722868

Akogbeto, M., Padonou, G.G., Bankole, H.S., Gazard, D.K. and Gbedjissi, G.L. (2011). Dramatic Decrease in Malaria Transmission after Large-Scale Indoor Residual Spraying with Bendiocarb in Benin, an Area of High Resistance of Anopheles gambiae to Pyrethroids. American Journal of Tropical Medicine and Hygiene, 85(4):586-593 21976555

Sachs, P., Diaz Rodriguez, G.A., Briceno, I., King, R., Achee, N.L. and Grieco, J.P. (2013). Comparison of experimental hut entrance and exit behavior between Anopheles darlingi from the Cayo District, Belize, and Zungarococha, Peru. Journal of the American Mosquito Control Association, 29(4):319-327 24551964

## References

1. Massey NC, Garrod G, Wiebe A, Henry AJ, Huang Z, Moyes CL, et al. A global bionomic database for the dominant vectors of human malaria. Sci Data. 2016;3:160014.

2. Charlwood JD, Nenhep S, Sovannaroth S, Morgan JC, Hemingway J, Chitnis N, et al. 'Nature or nurture': survival rate, oviposition interval, and possible gonotrophic discordance among South East Asian anophelines. Malar J. 2016;15(1):356.

3. Chatterjee S, Chandra G. Role of Anopheles subpictus as a Primary Vector of Malaria in an area in India. Jpn J Trop Med Hyg. 2000;28(3):177-81.

4. Charlwood JD, Birley MH, Dagoro H, Paru R, Holmes PR. Assessing Survival Rates of Anopheles-Farauti (Diptera, Culicidae) from Papua-New-Guinea. Journal of Animal Ecology. 1985;54(3):1003-16.

5. Charlwood JD, Graves PM, Alpers MP. The ecology of the Anopheles punctulatus group of mosquitoes from Papua New Guinea: a review of recent work. PNG Med J. 1986;29(1):19-26.

6. Charlwood JD. Survival rate variation of Anopheles farauti (Diptera: Culicidae) between neighboring villages in coastal Papua New Guinea. J Med Entomol. 1986;23(4):361-5.

7. Dev V, Phookan S, Sharma VP, Anand SP. Physiographic and entomologic risk factors of malaria in Assam, India. Am J Trop Med Hyg. 2004;71(4):451-6.

8. Elyazar IR, Sinka ME, Gething PW, Tarmidzi SN, Surya A, Kusriastuti R, et al. The distribution and bionomics of anopheles malaria vector mosquitoes in Indonesia. Adv Parasitol. 2013;83:173-266.

9. Graves PM, Burkot TR, Saul AJ, Hayes RJ, Carter R. Estimation of Anopheline Survival Rate, Vectorial Capacity and Mosquito Infection Probability from Malaria Vector Infection- Rates in Villages Near Madang, Papua-New-Guinea. Journal Of Applied Ecology. 1990;27(1):134-47.

10. Gunasekaran K, Jambulingam P, Das PK. Distribution of indoor-resting Anopheles fluviatilis in human dwellings and its implication on indoor residual spray. Indian J Malariol. 1995;32(1):42-6.

11. Gunathilaka N, Denipitiya T, Hapugoda M, Abeyewickreme W, Wickremasinghe R. Determination of the foraging behaviour and blood meal source of malaria vector mosquitoes in Trincomalee District of Sri Lanka using a multiplex real time polymerase chain reaction assay. Malar J. 2016;15:242.

12. Ismail IAH, Notananda V, Schapens J. Studies of Malaria and Responses of Anopheles balabacensis and Anopheles minimus to DDT residual spraying in Thailand. Geneva; 1973 1973. Report No.: WHO/MAL/73.810.

13. Singh N, Mishra AK, Chand SK, Sharma VP. Population dynamics of Anopheles culicifacies and malaria in the tribal area of central India. J Am Mosq Control Assoc. 1999;15(3):283-90.

14. Mahmood F, Reisen WK. Duration of the gonotrophic cycles of Anopheles culifacies Giles and Anopheles stephensi Liston, with observations on reproductive activity and survivorship during winter in Punjab Province, Pakistan. Mosquito News. 1981;41(1):41-50.

15. Ndoen E, Wild C, Dale P, Sipe N, Dale M. Mosquito Longevity, Vector Capacity, and Malaria Incidence in West Timor and Central Java, Indonesia. ISRN Public Health. 2012;2012(Article ID 143863):1-5.

16. Van Bortel W, Chinh VD, Berkvens D, Speybroeck N, Trung HD, Coosemans M. Impact of insecticide-treated nets on wild pyrethroid resistant Anopheles epiroticus population from southern Vietnam tested in experimental huts. Malar J. 2009;8:248.

17. WHARTON RH. The habits of adult mosquitoes in Malaya. I. Observations on anophelines in window-trap huts and at cattle-sheds. Ann Trop Med Parasitol. 1951;45(2):141-54.

18. Mekuria Y, Granados R, Tidwell MA, Williams DC, Wirtz RA, Roberts DR. Malaria transmission potential by Anopheles mosquitoes of Dajabon, Dominican Republic. J Am Mosq Control Assoc. 1991;7(3):456-61.

19. Ricciardi ID. Definicion de los habitos alimentares de anophelinos de Guatemala y Republica Dominicana, por tecnicas de gel-precipitation. Rev Microbiol. 1971;2(3):107-12.

20. Hobbs JH, Sexton JD, St JY, Jacques JR. The biting and resting behavior of Anopheles albimanus in northern Haiti. J Am Mosq Control Assoc. 1986;2(2):150-3.

21. Muirhead-Thomson RC, Mercier EC. Factors in malaria transmission by Anopheles albimanus in Jamaica. II. Ann Trop Med Parasitol. 1952;46(3):201-13.

22. Taylor RT. The ecology of Anopheles albimanus (Wied.) in Haiti. Mosquito News. 1966;26(3):393-7.

23. Bown DN, Rodriguez MH, Arredondo-Jimenez JI, Loyola EG, Rodriguez MC. Intradomiciliary behavior of Anopheles albimanus on the coastal plain of southern Mexico: implications for malaria control. J Am Mosq Control Assoc. 1993;9(3):321-4.

24. Molez JF, Desenfant P, Jacques JR. Bio-ecology of Anopheles albimanus Wiedeman, 1820 (Diptera : Culicidae) in Haiti (Hispaniola). Bulletin de la Societe de Pathologie Exotique. 1998;91(4):334-9.

25. Rodriguez MH, Bown DN, Arredondo-Jimenez JI, Villarreal C, Loyola EG, Frederickson CE. Gonotrophic cycle and survivorship of Anopheles albimanus (Diptera: Culicidae) in southern Mexico. J Med Entomol. 1992;29(3):395-9.

26. Rua GL, Quinones ML, Velez ID, Zuluaga JS, Rojas W, Poveda G, et al. Laboratory estimation of the effects of increasing temperatures on the duration of gonotrophic cycle of Anopheles albimanus (Diptera: Culicidae). Mem Inst Oswaldo Cruz. 2005;100(5):515-20.

27. Sherrard-Smith E, Skarp JE, Beale AD, Fornadel C, Norris LC, Moore SJ, et al. Mosquito feeding behavior and how it influences residual malaria transmission across Africa. Proc Natl Acad Sci U S A. 2019.

28. Ritthison W, Tainchum K, Manguin S, Bangs MJ, Chareonviriyaphap T. Biting patterns and host preference of Anopheles epiroticus in Chang Island, Trat Province, eastern Thailand. J Vector Ecol. 2014;39(2):361-71.

29. Ndoen E, Wild C, Dale P, Sipe N, Dale M. Dusk to dawn activity patterns of anopheline mosquitoes in West Timor and Java, Indonesia. Southeast Asian J Trop Med Public Health. 2011;42(3):550-61.

30. Dev V. Anopheles minimus: Its bionomics and role in the transmission of malaria in Assam, India. Bulletin of the World Health Organization. 1996;74(1):61-6.

31. Manh CD, Beebe NW, Van VN, Quang TL, Lein CT, Nguyen DV, et al. Vectors and malaria transmission in deforested, rural communities in north-central Vietnam. Malar J. 2010;9:259.

32. Hii JL, Smith T, Mai A, Ibam E, Alpers MP. Comparison between anopheline mosquitoes (Diptera: Culicidae) caught using different methods in a malaria endemic area of Papua New Guinea. Bull Entomol Res. 2000;90(3):211-9.

33. Desenfant P. Rôle et bioécologie de *A. albimanus* (Wiedemann, 1820) vecteur du paludisme en Haiti: Université de Paris-Sud; 1988.

34. Organisation WH. Manual on Practical Entomology in Malaria. Part II: Methods and Techniques. 1975.

35. Manga L, Toto JC, Le Goff G, Brunhes J. The bionomics of Anopheles funestus and its role in malaria transmission in a forested area of southern Cameroon. Trans R Soc Trop Med & Hyg. 1997;91(4):387-8.

36. Ijumba JN, Mosha FW, Lindsay SW. Malaria transmission risk variations derived from different agricultural practices in an irrigated area of northern Tanzania. Med Vet Entomol. 2002;16(1):28-38.

37. Afrane YA, Lawson BW, Githeko AK, Yan GY. Effects of microclimatic changes caused by land use and land cover on duration of gonotrophic cycles of Anopheles gambiae (Diptera : culicidae) in western Kenya highlands. Journal of Medical Entomology. 2005;42(6):974-80.

38. Beier JC. Frequent blood-feeding and restrictive sugar-feeding behavior enhance the malaria vector potential of Anopheles gambiae s.l. and An. funestus (Diptera:Culicidae) in western Kenya. J Med Entomol. 1996;33(4):613-8.

39. Fernandez-Salas I, Rodriguez MH, Roberts DR. Gonotrophic cycle and survivorship of Anopheles pseudopunctipennis (Diptera: Culicidae) in the Tapachula foothills of southern Mexico. J Med Entomol. 1994;31(3):340-7.

40. Mendis C, Jacobsen JL, Gamage-Mendis A, Bule E, Dgedge M, Thompson R, et al. Anopheles arabiensis and An. funestus are equally important vectors of malaria in Matola coastal suburb of Maputo, southern Mozambique. Med Vet Entomol. 2000;14(2):171-80.

41. Ree HI, Hwang UW, Lee IY, Kim TE. Daily survival and human blood index of Anopheles sinensis, the vector species of malaria in Korea. J Am Mosq Control Assoc. 2001;17(1):67-72.

42. Santos RL, Forattini OP, Burattini MN. Laboratory and field observations on duration of gonotrophic cycle of Anopheles albitarsis s.l. (Diptera: Culicidae) in southeastern Brazil. J Med Entomol. 2002;39(6):926-30.

43. Tanga MC, Ngundu WI, Tchouassi PD. Daily survival and human blood index of major malaria vectors associated with oil palm cultivation in Cameroon and their role in malaria transmission. Trop Med Int Health. 2011;16(4):447-57.

44. Birley MH, Charlwood JD. The Effect of Moonlight and Other Factors on the Oviposition Cycle of Malaria Vectors in Madang, Papua-New-Guinea. Annals of Tropical Medicine and Parasitology. 1989;83(4):415-22.

45. Charlwood JD, Graves PM, Birley MH. Capture-Recapture Studies with Mosquitos of the Group of Anopheles-Punctulatus Donitz (Diptera, Culicidae) from Papua- New-Guinea. Bulletin of Entomological Research. 1986;76(2):211-27.

46. Charlwood JD, Graves PM. The effect of permethrin-impregnated bednets on a population of Anopheles farauti in coastal Papua New Guinea. Med Vet Entomol. 1987;1(3):319-27.

47. Chiang GL, Loong KP, Chan ST, Eng KL, Yap HH. Capture-recapture studies with Anopheles maculatus Theobald (Diptera: Culicidae) the vector of malaria in peninsular Malaysia. Southeast Asian J Trop Med Public Health. 1991;22(4):643-7.

48. Jaal Z, MacDonald WW. A mark-release-recapture experiment with Anopheles lesteri paraliae in northwest Peninsular Malaysia. Ann Trop Med Parasitol. 1992;86(4):419-24.

49. Quinones ML, Lines JD, Thomson MC, Jawara M, Morris J, Greenwood BM. Anopheles gambiae gonotrophic cycle duration, biting and exiting behaviour unaffected by permethrin-impregnated bednets in The Gambia. Med Vet Entomol. 1997;11(1):71-8.

50. Toure YT, Dolo G, Petrarca V, Traore SF, Bouare M, Dao A, et al. Mark-release-recapture experiments with Anopheles gambiae s.l. in Banambani Village, Mali, to determine population size and structure. Med Vet Entomol. 1998;12(1):74-83.

51. Bockarie M, Service MW, Barnish G, Toure Y. Vectorial capacity and entomological inoculation rates of Anopheles gambiae in a high rainfall forested area of southern Sierra Leone. Trop Med Parasitol. 1995;46(3):164-71.

52. Ijumba JN, Mwangi RW, Beier JC. Malaria Transmission Potential of Anopheles Mosquitos in the Mwea-Tebere Irrigation Scheme, Kenya. Medical and Veterinary Entomology. 1990;4(4):425-32.

53. Ameneshewa B, Service MW. Blood-feeding behaviour of Anopheles arabiensis Patton (Diptera: Culicidae) in central Ethiopia. Journal of African Zoology. 1997;111(3):235-45.

54. Hii JL, Birley MH, Kanai L, Foligeli A, Wagner J. Comparative effects of permethrin-impregnated bednets and DDT house spraying on survival rates and oviposition interval of Anopheles farauti No. 1 (Diptera:Culicidae) in Solomon Islands. Ann Trop Med Parasitol. 1995;89(5):521-9.

55. Chandra G. Age composition of incriminated malaria vector in a rural foothills in West Bengal, India. Indian Journal of Medical Research. 2008;127(6):607-9.

56. Charlwood JD, Smith T, Billingsley P, Takken W, Lyimo E, Meuwissen J. Survival and infection probabilities of anthropophagic anophelines from an area of high prevalence of *Plasmodium falciparum* in humans. Bull Entomol Res. 1997;87:445-53.

57. Charlwood JD, Kihonda J, Sama S, Billingsley PF, Hadji H, Verhave JP, et al. The Rise and Fall of Anopheles Arabiensis (Diptera, Culicidae) in A Tanzanian Village. Bulletin of Entomological Research. 1995;85(1):37-44.

58. Charlwood JD, Pinto J, Sousa CA, Ferreira C, Gil V, do Rosario VE. Mating does not affect the biting behaviour of Anopheles gambiae from the islands of Sao Tome and Principe, West Africa. Annals of Tropical Medicine and Parasitology. 2003;97(7):751-6.

59. Charlwood JD, Pinto J, Sousa CA, Ferreira C, Petrarca V, Rosario VD. 'A mate or a meal' - Pre-gravid behaviour of female Anopheles gambiae from the islands of Sao Tome and Principe, West Africa. Malaria Journal. 2003;2.

60. Charlwood JD, Nenhep S, Sovannaroth S, Morgan JC, Hemingway J, Chitnis N, et al. 'Nature or nurture': survival rate, oviposition interval, and possible gonotrophic discordance among South East Asian anophelines. Malaria Journal. 2016;15.

61. Kulkarni MA, Kweka E, Nyale E, Lyatuu E, Mosha FW, Chandramohan D, et al. Entomological evalution of malaria vectors at different altitudes in Hal District, Northeastern Tanzania. Journal of Medical Entomology. 2006;43(3):580-8.

62. Tchuinkam T, Simard F, Lele-Defo E, Tene-Fossog B, Tateng-Ngouateu A, Antonio-Nkondjio C, et al. Bionomics of Anopheline species and malaria transmission dynamics along an altitudinal transect in Western Cameroon. BMC Infect Dis. 2010;10:119.

63. Chitnis N, Smith T, Steketee R. A mathematical model for the dynamics of malaria in mosquitoes feeding on a heterogeneous host population. J Biol Dyn. 2008;2(3):259-85.