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Mosquito Ecology, and Management of Mosquitoes and People

by Erik Kiviat

Mosquitoes occur almost throughout the biosphere, with the exceptions of the open seas, polar environments, and the driest deserts.[4] There are 57 species of mosquitoes in New York, 169 in the U.S. and Canada, and about 3500 world-wide.[17,18,42,48] Window screens, synthetic repellents and insecticides, and the loss of more than half the wetlands in our country have greatly reduced the impacts of mosquitoes and the diseases they transmit. This is one of the most salient differences between the U.S. and the less-developed regions of the world. Conquest of infectious diseases may be illusory,[39] however; if we do not understand the ecology of the human-mosquito relationship, we will be vulnerable to the potentially devastating social and environmental impacts of an increase in mosquito-transmitted disease with its accompanying mosquito control efforts.

Mosquitoes (Fig. 1) are inextricably associated with wetlands and waters, ranging from the 1000-square-kilometer marsh to the 100-square-centimeter, rain-filled hoofprint. Many wetland habitats, however, are not important mosquito-producers, and many mosquitoes do not come from habitats we ordinarily consider wetlands. Mosquitoes lay their eggs on the water surface or on surfaces that will be flooded at higher water levels. These intermittent-flooding habitats include the exposed bottoms of woodland pools in fall, the surface of irregularly flooded high salt marsh, and the inside walls of treeholes and other natural or artificial containers. Eggs hatch quickly after they are laid in permanent waters, or following flooding in temporary habitats. The larva or wriggler is aquatic and has four developmental stages. Larvae of different species forage on or near the bottom or at the surface, but most swim to the water surface to breathe air (a few species attach themselves to aquatic plants as a source of oxygen). Larvae generally filter their food from the water, ingesting live bacteria, microscopic algae and animals, and particles of detritus (dead organic matter). A few species are predaceous on other insects and crustacea. Different mosquito species undergo winter dormancy as eggs, larvae, or adults.[42,43] There may be one or multiple generations each year.

Standing water must persist for at least several days in order to produce adult mosquitoes, although larval development may

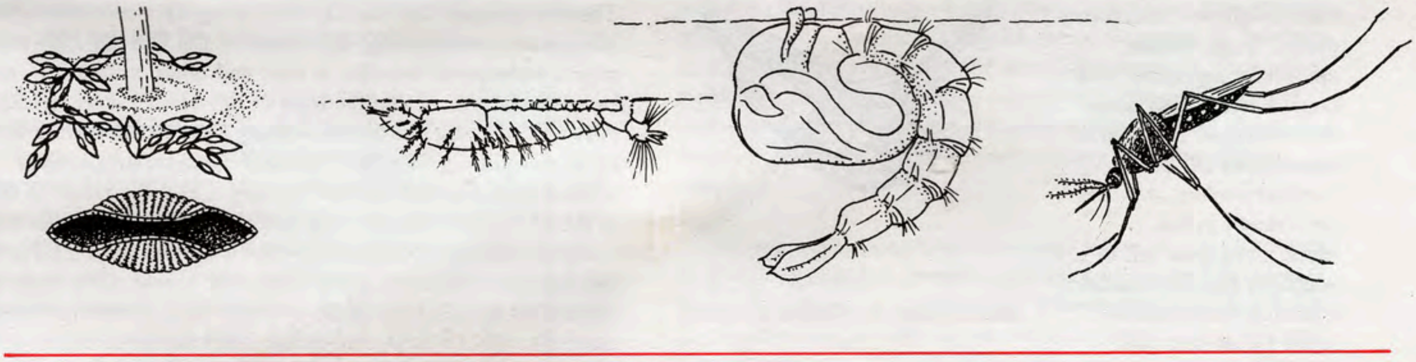


Fig. 1. Life history of the mosquito *Anopheles quadrimaculatus*, a vector of human malaria: 1. Eggs (one enlarged), 2. Fourth stage larva, 3. Pupa, 4. Adult female (not to scale).

take weeks or months if temperatures are low or food scarce. The fully grown larva molts and becomes a pupa that does not feed but can swim vigorously when disturbed. The adult emerges from the pupa and leaves the water. Adult males feed on plant juices, especially flower nectar.[11] Adult females take nectar and some can lay eggs without a blood meal, but many species either require a blood meal to lay eggs or require blood to lay more than a small number of eggs. Depending on the mosquito species, the blood may come from amphibians, reptiles, birds, lower mammals, or humans, and some species do not take blood at all. Mosquitoes are attracted to a variety of chemical and physical stimuli from their hosts, chiefly moisture, warmth, carbon dioxide, lactic acid, and certain other body chemicals; the attractiveness of human hosts is affected by clothing and skin colors, age, sex, the menstrual cycle in women, health, skin chemistry, and the availability of alternative hosts.[6,7,40] Some adult mosquitoes stay within 100 m of the larval habitat, whereas other species may disperse many kilometers and bite humans well away from wetlands.

Larval habitats are diverse;[38] two are illustrated in Figs. 2-3. All must hold water for at least several days, and provide shelter from strong currents or wave action, abundant food particles, and a degree of freedom from predators. Small fishes of many species, among them mosquitofish (*Gambusia affinis*), killifishes (Fundulidae), topminnows (Cyprinodontidae), and minnows (Cyprinidae), are effective predators on mosquito larvae and under some circumstances are able to regulate mosquito populations. Waters lacking fish (e.g. intermittent woodland pools, treeholes, artificial containers such as old tires), and sectors of aquatic habitats with restricted access by fish (dense vegetation or debris), are thus favorable for mosquitoes. Some of these habitats serve as refuges from predatory fish for other small animals, including many invertebrates and amphibian larvae.

Mosquitoes in the Ecosystem

The sheer abundance of mosquito larvae and adults in some habitats forces consideration of the role of mosquitoes in food webs. That mosquito larvae and adults, often in large numbers, are the prey of many kinds of animals[31,32] does not necessarily mean that these species control mosquito numbers but it suggests that mosquitoes are an important food source to many of their predators. Among these are a variety of bats, swallows, shorebirds, ducks, frogs, fishes, spiders, dragonflies, true bugs, beetles, and other invertebrates. Salt marsh mosquitoes (*Aedes taeniorhynchus, A. sollicitans*) in the black mangrove belt of southern Florida constitute a crucial food base for small fishes and their predators the larger fishes and wading birds (including the endangered wood stork *Mycteria americana*).[30] The large numbers of mosquitoes emerging from woodland pools in the Northeast must export significant quantities of nutrients from these habitats, and may be among the factors that slow the filling of the pools with organic matter from fallen tree leaves. Animals that eat nectar often pollinate their host plants by carrying pollen grains from flower to flower. Mosquitoes are important pollinators of certain orchids.[26,48] Bloodsucking parasites often transmit microorganisms that cause disease. Both the diseases transmitted and the removal of blood *per se* can affect individuals and populations of the host species. Not surprisingly, mosquitoes and other bloodsucking arthropods can play a role in regulating host populations. Deaths resulting directly from the bites of very large numbers of mosquitoes and other biting flies are known; this is rare in humans but occasionally serious for livestock. Mosquito-borne human diseases, however, are common in large portions of the world where they are partly responsible for "underdevelopment," and some of these diseases have been significant locally and historically in the U.S.

Backswimmer eating mosquito larva

Disease

Worldwide, malaria is the most important of many mosquito-transmitted diseases, and has intensely influenced human genetics[20,51] and history.[12] There are about 200-300 million new cases and 2-3 million deaths each year.[39] There were half a million cases of indigenous malaria (acquired from local mosquitoes) annually in the U.S. as recently as the early 1900s.[39] The last New York cases may have occurred near Poughkeepsie.[35] Malaria remained common into the 1930s in the southeastern U.S.,[21] and past mid-century in eastern and southern Europe.[8] The *Anopheles* mosquitoes (Fig. 1) that transmit the protozoa causing human malarias are still present in the U.S., and there have been small outbreaks (up to 30 cases), mainly in California, during the 1980s-90s.[39,50] Persons entering or returning to the U.S. with malaria infections acquired in other countries, a common occurrence, occasionally infect local mosquitoes. The dynamics of the disease system are such, however, that transmission is not sustained because of the small numbers of infected humans, low vector (disease-transmitting animal) populations, and reduced human-vector contact.

Yellow fever and dengue are two viral diseases transmitted by mosquitoes; both were prominent in the southern U.S. and yellow fever once caused epidemics as far north as Boston. Dengue occurred in small outbreaks in Texas in the 1980s. There is concern that the daytime-biting tiger mosquito (*Aedes albopictus*), accidentally introduced to the U.S. in 1985 and now a widespread breeder in tires and other containers, may become a vector of dengue here as in Asia.[29,44] Eastern equine encephalitis (EEE) virus has already been isolated from the tiger mosquito in Florida.[44] Several mosquito-transmitted viruses cause encephalitis in humans. EEE, the rarest of these in the U.S., builds up in wild bird populations under certain environmental conditions; the virus is spread among birds by one mosquito (*Culiseta melanura*), and occasionally from birds to humans by other mosquito species. Mosquito-borne diseases currently affect few people in the U.S., but there is potential for larger outbreaks that would be costly in dollars and human suffering. Despite the effectiveness of mosquitoes as vectors of dozens of other viral diseases, epidemiological and laboratory

Fig. 2. Portion of an intermittent woodland pool in spring: 1. Mosquito larvae (*Aedes vexans*) hanging from surface film, 2. Cyclopoid copepod, 3. Backswimmer (*Notonecta*), 4. Beetle larva (Dytiscidae) eating mosquito, 5. Dragonfly nymph, 6. Water flea (*Daphnia*), 7. Spotted salamander larva (*Ambystoma maculatum*), 8. Common duckweed (*Lemna minor*), 9. Yellow water crowfoot (*Ranunculus flabellaris*) (not to scale).

evidence indicates that mosquitoes are not transmitting the virus that causes AIDS.

Alternative Control Techniques

Some modern mosquito control still involves the spraying of broad-spectrum insecticides, such as malathion and pyrethroids, to kill adult mosquitoes (adulticiding). Malathion is highly toxic to beneficial insects and fish, and can be injurious to birds and mammals although outright mortality seems rare. Pyrethroids have generally low toxicity to mammals, but under certain conditions can be toxic to fish, frogs, predatory mites, honey bees, aquatic insects, and many other insects.[46] Because mosquito larval populations are subject to natural regulation by predatory fishes and invertebrates, non-target toxicity is a substantial concern. Light oils, similar to those used as "dormant oil" for controlling horticultural pests, are still used as mosquito larvicides. These are less phytotoxic (toxic to plants), but can still kill non-target animals.

There are compelling reasons to reduce the use of broad-spectrum (i.e. toxic to many kinds of organisms) insecticides: development of genetic resistance by mosquitoes to hard pesticides; cost and difficulty of organizing effective spraying operations in less-developed countries where many of the world's most serious vector-borne disease problems exist; acute and chronic toxicity to humans; accidental poisoning of honeybees and other domestic animals; toxicity to wild animals including insect pollinators (e.g. bees, butterflies, moths, hover flies, beetles) and fish; and mortality of insects that prey on mosquitoes.[14] Many techniques hold promise for narrowly targeting mosquitoes and other arthropod vectors in ways that have fewer side effects on humans and other non-target organisms.

Because most activities aimed at reducing mosquito numbers take place in and near wetlands, and because wetlands are hotspots of native biological diversity and other ecological values, there is a great potential for conflict between mosquito management and wetland conservation. Historically, toxicants such as DDT and Paris green (a mixture of arsenic and copper compounds) were used in large quantities to kill mosquitoes. These insecticides indiscriminately poisoned other animals; DDT and other organochlorine insecticides caused population crashes in bald eagle, peregrine falcon, osprey, and other birds. Furthermore, in many places mosquitoes have evolved resistance to DDT and certain other broad-spectrum insecticides. Heavy fuel oils were spread on waters to poison mosquito larvae; they often killed fish, amphibian larvae, and other insects. Heavy oils and Paris green were also phytotoxic. In addition, the hydrology of vast areas of wetlands was severely altered to either reduce the hydroperiod (duration of flooding) to less than that necessary for larval development, or to allow predatory fishes access to larval habitats. Mosquito control coupled with agricultural expansion eliminated half the area of wetlands in the U.S. and degraded many of the remaining wetlands.

Fortunately, two least-toxic larvicides are now in widespread use; methoprene is a growth-regulating hormone that disrupts larval development, and *Bacillus thuringiensis israelensis* (Bti) is a bacterium that kills larvae when ingested with food particles. Methoprene and Bti affect a few other groups of flies, but are nontoxic or relatively so to other animals and plants. So far, no evidence of evolved resistance to these materials has been found in mosquitoes.

Botanical larvicides are also promising. Neem,[58] wormseed,[52] and marigold[28] could be grown and prepared for local use in less-developed countries or rural areas with little cash or labor input. Some botanicals may be adaptable to large scale commercial production, but companies may be reluctant to invest in the multimillion dollar process of licensing a pesticide for use in the U.S. unless the product can be patented.

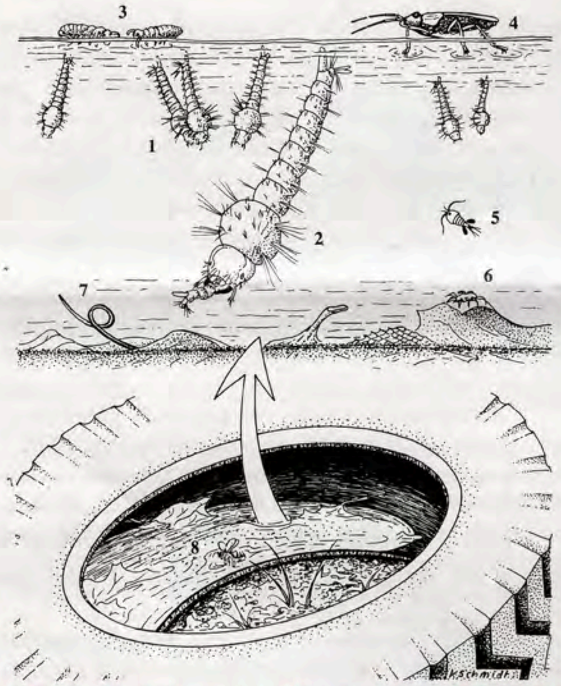


Fig. 3. Automobile tire casing: 1. Mosquito larvae (*Aedes*), 2. Larva of predaceous mosquito *Toxorhynchites*, 3. Springtails (Collembola), 4. Water treader (*Mesovelia*), 5. Cyclopoid copepod, 6. Water mite, 7. Nematode, 8. Dead bee (not to scale).

Integrated Management

Surveillance of mosquito populations and monitoring of weather and other environmental conditions allow prediction of nuisance populations of biting adults and potential outbreaks of encephalitis and other diseases. Good surveillance programs also facilitate finer targeting of problematic mosquito species and populations. Integrated vector control or integrated mosquito management are forms of integrated pest management (IPM); they emphasize attention to the natural history of vectors, detailed surveillance, concern about human safety and non-target organisms, preventive measures, multiple control methods, non-pesticidal techniques, the use of least-toxic pesticides only when (and in the amounts) needed, and cost effectiveness.[59] IPM uses an explicit schedule of thresholds for further monitoring, education, and control actions. Larviciding is more efficient and environmentally safer than adulticiding; some mosquito biologists consider adulticiding a last resort or an indication of management errors. Bti, methoprene, and similar least-toxic larvicides should play an important role in mosquito control.

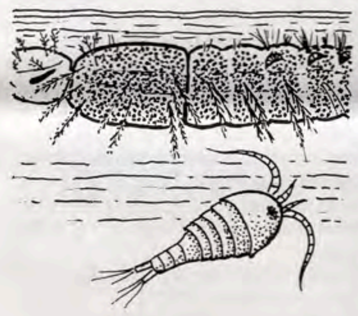
Mosquito surveillance is both disease- and nuisance-oriented, but most actual control efforts in the U.S. are geared to reduce nuisance mosquitoes. In order to maintain public trust and be cost-effective, mosquito management should explicitly address nuisance and disease as different though interrelated problems. Annual expenditures of U.S. and Canadian mosquito control agencies are more than $150 million[48] and single counties in the southern states may have mosquito control budgets exceeding $2 million. Expenditures by individual home owners for insecticides, insect electrocutors, etc., are also substantial. Some consumers are exploited by the manufacturers of questionable technology; electronic repelling devices independently tested to date do not work,[24] and insect electrocutors ("bug zappers") have a limited effect on mosquitoes[45] but kill many night-flying pollinators and predators, adults of valuable aquatic insects, and probably rare insects as well.

Some important pest mosquitoes use abandoned automobile tires, plastic buckets, wading pools, bird baths, toys, empty bottles, clogged gutters and storm drains, and wheel ruts in soft soils from construction equipment, log skidders, and farm vehicles. Elimination (or frequent drainage) of artificial habitats is a mosquito control tactic that has little negative environmental impact. We need low-cost technologies and efficient markets for recycling tires, plastic buckets, and other artificial containers. Better soil management in real estate development, forestry, and agriculture can also help eliminate nuisance and vector mosquitoes. Less artificial larval habitat means less need for insecticides. Pest mosquitoes can breed in wetlands that have been constructed for wildlife habitat and for stormwater and wastewater treatment;[25,53] these systems should be designed and managed to reduce mosquito production.

Hydrologic Manipulation

Another type of "source reduction" involves the alteration of hydrological or vegetational conditions in larval habitats in wetlands and lakes. Many historic and modern water management techniques are ecologically crude: for example, clearing of aquatic or riparian vegetation from lake shallows and stream banks; large-scale, deep drainage of inland wetlands; and grid ditching of tidal marshes. The last comprises the excavation of ditches at regular intervals across an entire marsh. Grid ditching affected 90% of the tidal marshes from Virginia to Maine by 1938.[5] Many ditched areas were not even larval mosquito habitats.[5] Although the subject is controversial,[15,49] among other impacts grid ditching has been reported to increase forbs (broad-leaved herbs) and shrubs at the expense of marsh grasses; decrease densities of mollusks, crustaceans, spiders, mites, leafhoppers, and beetles; eliminate wigeongrass (*Ruppia maritima*) from pools; degrade habitat for ducks and muskrats; and interfere with salt hay harvest.[5] Ditching can improve larval habitat for horse flies and deer flies (Tabanidae) by lowering the marsh surface.[15] Clapper rails avoid nesting near shrubby ditch banks because predatory crows use shrubs for hunting perches.[57] Tidal marshes, despite their superficial monotony, are complex and variable ecosystems and like the rest of nature should be managed with understanding rather than massive trial-and-error. The impacts on native biological diversity and other wetland functions should be assessed individually for each wetland before a health emergency or the economic impact of mosquitoes impels hydrologic alteration; this would have prevented, for example, a county mosquito control agency ditching a nontidal wetland supporting the endangered bog turtle in New York in 1981.

Newer, more focused, ditching techniques for reducing numbers of tidal marsh mosquitoes include open marsh water management (OMWM),[33] tidal irrigation,[23] and runneling.[16] These involve selective ditching to connect the irregularly-flooded breeding pools of the high marsh to low marsh creeks, affording access to mosquito-eating fish and altering the habitats in other ways that are unfavorable to mosquitoes. Some modern ditching machinery sprays the excavated sediments in a thin layer across the marsh rather than making discrete spoil ridges. The new techniques cause less gross change in marsh vegetation and bird populations than traditional grid ditching, but salt marshes that have not been previously altered should not be subjected to OMWM without compelling evidence of a mosquito health hazard.[33] Because the irregularly flooded high salt marsh is (in its natural condition) a refuge from fish predation and a physically and chemically harsh environment, I expect even the most careful selective ditching will eliminate animals (other than mosquitoes) that are vulnerable to increased predation or competition.



Fungus-infected mosquito larva and the copepod alternate host

Biological Control

Small fishes, especially the mosquitofish (*Gambusia affinis*), have been introduced to control mosquito larvae in nontidal habitats.[1] Larvivorous fishes are used worldwide, and this form of biological control probably long predated modern knowledge of mosquito life history and the role of mosquitoes as disease vectors. In the U.S., there is a compulsion to introduce fishes of any kind to previously fish-less natural and artificial ponds, and an introduced fish species in a pond is likely to spread to other waters. Introduced fishes have been detrimental to the populations of many frogs and salamanders that depend on fish-less waters for their own larval habitats. Introduction of the mosquitofish in experimental pools reduced invertebrate populations thus causing blooms of plankton algae and a variety of chemical and physical changes.[34] Larvivorous fishes, however, probably have little if any negative impact in artificial mosquito larval habitats such as rice paddies and cisterns. Edible larvivorous fish may be used,[14] allowing humans to turn mosquito production to their advantage.

Many other organisms have been used empirically or experimentally for biocontrol of mosquitoes.[9] Mammals and birds, even if concentrated by artificial roost or nest boxes, probably rarely control mosquitoes. Some of the smaller predators and parasites of mosquito larvae are much more promising. Fungi, protozoa, nematodes, copepods, tadpole shrimp, dragonflies, and even the predatory mosquito *Toxorhynchites* have been used successfully in the laboratory or in field trials.

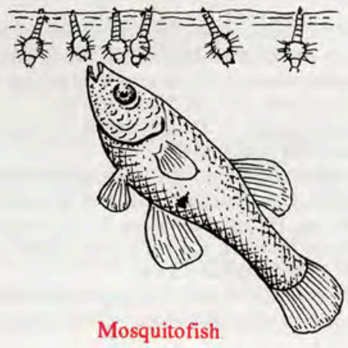
Much additional research and development is needed but a variety of biocontrol agents will eventually become part of the mosquito management "toolkit."

Protection from Biting

Repellents are an important part of both modern and traditional mosquito management. There are hundreds if not thousands of natural products with some degree of mosquito repellency.[14,36] Some plants (e.g. sandalwood, sweet flag, patchouli, annatto, anise, basil[27,37]) have been widely used as cosmetics, adornments, odorants, or flavorings, practices I believe owe their origin partly to insect repellency. After the discovery of DEET, the most widely used synthetic repellent, work on herbal repellents was abandoned for decades but is receiving renewed interest because of concern over the toxicity of DEET to humans,[3,47] and the need for more effective repellents for ticks[14] and other arthropod vectors. Several commercial herbal mixtures are effective against mosquitoes but may require larger amounts or more frequent application than synthetic repellents. Recently, a preparation of neem in coconut oil was reported effective and long-lasting.[56] Unfortunately, much of the literature about herbal repellents does not report the traditional methods of collection, preparation, and use of these materials, which can be the key to understanding their effectiveness.[14]

Window screens can prevent mosquito bites, but may have limited utility in less-developed regions because of cost, need for maintenance, reduction of ventilation, and inability to protect people outdoors or in houses lacking tight walls, floors, and roofs. A great many other "appropriate technologies"[14] are employed, although many are not fully recognised as protection against insects.[37] In traditional and modern lifeways, homes are sited away from wetlands and in breezy locations; low-stature vegetation is maintained around areas used for living, working, or recreation; protective clothing is worn; smoky fires are maintained indoors or outdoors; and outdoor activity times are adjusted.[19,37] Similar procedures are recommended in military manuals and camping handbooks.[13,22] Planning and zoning agencies, which often steer construction away from hazards such as floodplains and steep slopes, could limit development near types of wetlands that are potential disease or nuisance foci;[2] this would reduce insecticide use and would have other ecological benefits.

Besides mosquitoes, other arthropods of medical importance include black flies, deer and horse flies, stable flies, biting midges ("no-see-ums"), sand flies, a few kinds of true bugs, and a number of ticks. Most are true flies (Diptera) and most are partly or largely associated with larval habitats in waters, wetlands, or moist organic matter. Since the eradication of malaria (and the reduction of most potentially dangerous

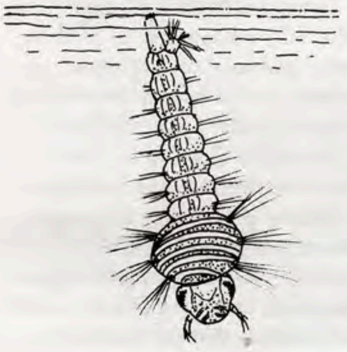


Mosquitofish

vertebrates) in the U.S., we have been unusually free of environmental hazards. The explosion of Lyme disease as a public health hazard in scarcely more than a decade, however, is forcing people to reevaluate their behavior outdoors in suburban, rural, and wilderness areas. This phenomenon should make us aware of the extent to which human cultures and individual behavior worldwide and throughout history and prehistory have adapted to bloodsucking invertebrates.[37]

Prospects

Diseases are ecological systems,[41] and vector-borne disease is controlled at the interface between human ecology and vector ecology. Strategies and tactics of mosquito management need continual diversification because mosquitoes develop resistance to insecticides, insecticide and repellent toxicity to humans and other biota are discovered, the need to conserve wetland values becomes greater as less high-quality wetland remains, and different solutions are needed for different places, times, cultures, pests, and diseases. The future of mosquito control lies in integrated management programs, with statistically valid surveillance, fine-tuned use of repellents, biocontrol, elimination of artificial containers, and least-toxic larvicides. Habitat alteration and pesticide use in wetlands should be compatible with biodiversity functions and other wetland values.[10,54,55] This will be accomplished partly through better understanding of wetland habitats.[38] We need to reduce nuisance mosquito bites and disease transmission with a minimum of impact to wetlands, birds, amphibians, fishes, pollinators, plants, and other organisms. One benefit will be the conservation of species and genetic variants of flora and fauna that are potential sources of even better herbal repellents, larvicides, and biocontrol agents (where would we be if the pool in Israel that yielded Bti had been drained before its discovery?). It is crucial that we prevent major outbreaks of mosquito-borne disease, for example a resurgence of indigenous malaria, that might reverse our society's gradual acceptance of wetlands as a necessary and valuable component of the biosphere.



Parasitic nematode in *Aedes* larva

References Cited

1. **Anonymous**. 1924. The use of fish for mosquito control. International Health Board of the Rockefeller Foundation, New York. 120 p.
2. **Anonymous**. 1991. Mosquito spraying; Balancing the risks: Rare virus vs. pesticides. NYCAP News 2(4):18.
3. **Anonymous**. 1993. Bug off! How to repel biting insects. Consumer Reports 58(7):451-454.
4. **Bagur**, J.D., et al. 1977. Impacts of mosquito control practices; A bibliography. U.S. Fish and Wildlife Service FWS/OBS/76-22, 97 p.
5. **Bourn**, W.S. & C. Cottam. 1950. Some biological effects of ditching tidewater marshes. U.S. Fish and Wildlife Service Research Report 19, 30 p. + folded maps in pocket.
6. **Bowen**, M.F. 1991. The sensory physiology of host-seeking behavior in mosquitoes. Annual Review of Entomology 36:139-158.
7. **Brown**, A.W.A. 1966. The attraction of mosquitoes to hosts. Journal of the American Medical Association 196(3):159-162.
8. **Bruce-Chwatt**, L.J. & J. de Zulueta. 1980. The rise and fall of malaria in Europe; A historico-epidemiological study. Oxford University Press, U.K. 240 p. + plates.
9. **Chapman**, H.C. 1985. Biological control of mosquitoes. American Mosquito Control Association, Fresno, California. 218 p.
10. **Clarke**, J.A., B.A. Harrington, T. Hruby & F.E. Wasserman. 1984. The effect of ditching for mosquito control on salt marsh use by birds in Rowley, Massachusetts. Journal of Field Ornithology 55(2):160-180.
11. **Clements**, A.N. 1992. The biology of mosquitoes, Vol. I: Development, nutrition and reproduction. Chapman & Hall, London. 509 p.
12. **Cloudsley-Thompson**, J.L. 1976. Insects and history. St. Martin's Press, New York. 242 p.
13. **Craighead**, F.C., Jr. & J.J. Craighead. 1956. How to survive on land and sea. Naval Institute Press, Annapolis, Maryland. 366 p.
14. **Curtis**, C.F., ed. 1990. Appropriate technology in vector control. CRC Press, Boca Raton, Florida. 233 p.
15. **Daiber**, F.C. 1982. Animals of the tidal marsh. Van Nostrand Reinhold Company, New York. 422 p.
16. **Dale**, P.E.R., P.T. Dale, K. Hulsman & B.H. Kay. 1993. Runnelling to control saltmarsh mosquitoes: Longterm efficacy and environmental impacts. Journal of the American Mosquito Control Association 9(2):174-181.
17. **Darsie**, R.F., Jr. 1992. Key characters for identifying *Aedes bahamensi* and *Aedes albopictus* in North America, North of Mexico. Journal of the American Mosquito Control Association 8(3):323-324.
18. **Darsie**, R.F., Jr. & R.A. Ward. 1981. Identification and geographical distribution of the mosquitoes of North America, North of Mexico. American Mosquito Control Association, Fresno, California. 313 p.
19. **Dunn**, F.L. 1988. Human factors in arbovirus ecology and control. P. 281-290 in T.P. Monath, ed. The Arboviruses: Epidemiology and Ecology, Vol. I. CRC Press, Boca Raton, Florida.
20. **Edelstein**, S.J. 1986. The sickled cell; From myths to molecules. Harvard University Press, Cambridge, Massachusetts. 197 p.
21. **Faust**, E.C. 1951. The history of malaria in the United States. American Scientist 39:121-130.
22. **Fears**, J.W. 1979. The sportsman's guide to swamp camping. David McKay Company, New York. 274 p.
23. **Fultz**, T.O., Jr. 1978. Mosquito source reduction and present water management regulations in coastal Georgia. Proceedings of the Sixty-Fifth Annual Meeting, New Jersey Mosquito Extermination Association:36-40.
24. **Garcia**, R., B. Des Rochers & W.G. Voigt. 1976. Evaluation of electronic mosquito repellers under laboratory and field conditions. California Vector Views 23(5-6):21-23.
25. **Godfrey**, P.J., E.R. Kaynor, S. Pelczarski & J. Benforado, eds. 1985. Ecological considerations in wetlands treatment of municipal wastewaters. Van Nostrand Reinhold Company, New York. 473 p.
26. **Gorham**, I.R. 1976. Orchid pollination by *Aedes* mosquitoes in Alaska American Midland Naturalist 95(1):208-210.
27. **Grainge**, M. & S. Ahmed. 1988. Handbook of plants with pest-control properties. John Wiley & Sons, New York. 470 p.
28. **Green**, M.M., J.M. Singer, D.J. Sutherland & C.R. Hibben. 1991. Larvicidal activity of *Tagetes minuta* (marigold) toward *Aedes aegypti*. Journal of the American Mosquito Control Association 7(2):282-286.
29. **Hall**, S.S. 1987. The invader. Hippocrates 1(3):36-45.
30. **Heald**, E.J., W.E. Odum & D.C. Tabb. 1974. Mangroves in the estuarine food chain. P. 182-189 in P.J. Gleason, ed. Environments of South Florida: Present and Past. Miami Geological Society Memoir 2, Miami, Florida.
31. **Hinman**, E.H. 1934a. Predators of the Culicidae (mosquitoes). I.-The predators of larvae and pupae, exclusive of fish. Journal of Tropical Medicine and Hygiene 37(9):129-134.
32. **Hinman**, E.H. 1934b. Predators of the Culicidae (mosquitoes). II.-Predators of adult mosquitoes. Journal of Tropical Medicine and Hygiene 37(10):145-150.
33. **Hruby**, T. & W.G. Montgomery. 1988. Open Marsh Water Management for open tidal marshes in the Northeast; A manual of methods. Revised. Massachusetts Audubon Society, Lincoln. Not continuously paginated.
34. **Hurlbert**, S.H., J. Zedler & D. Fairbanks. 1972. Ecosystem alteration by mosquitofish (*Gambusia affinis*) predation. Science 175(4022):639-642.
35. **Jamnback**, H. 1969. Bloodsucking flies and other outdoor nuisance arthropods of New York State. New York State Museum of Science Service Memoir 19, 90 p.
36. **King**, W.V. 1954. Chemicals evaluated as insecticides and repellents at Orlando, Fla. U.S. Department of Agriculture, Agriculture Handbook 69, 397 p.

37. **Kiviat**, E. In review. Traditional protection against biting flies. Proceedings INTECOL International Wetlands Conference IV, Columbus, Ohio, September 1992.
38. **Laird**, M. 1988. The natural history of larval mosquito habitats. Academic Press, San Diego. 555 p.
39. **Lederberg**, J., R.E. Shope & S.C. Oaks, Jr., eds. 1992. Emerging infections; Microbial threats to health in the United States. National Academy Press, Washington, DC. 294 p.
40. **Maibach**, H.I., W.A. Skinner, W.G. Strauss & A.A. Khan. 1966. Factors that attract and repel mosquitoes in human skin. Journal of the American Medical Association 196(3):173-176.
41. **Mattingly**, P.F. 1969. The biology of mosquito-borne disease. George Allen and Unwin, London, U.K. 184 p.
42. **Means**, R.G. 1979. Mosquitoes of New York. Part I. The genus *Aedes* Meigen with identification keys to genera of Culicidae. New York State Museum Bulletin 430a, 221 p.
43. **Means**, R.G. 1987. Mosquitoes of New York. Part II. Genera of Culicidae other than *Aedes* occurring in New York. New York State Museum Bulletin 430b, 180 p.
44. **Mitchell**, C.J., M.L. Niebylski, G.C. Smith, N. Karabatsos, D. Martin, J.-P. Mutebi, G.B. Craig, Jr., & M.J. Mahler. 1992. Isolation of eastern equine encephalitis virus from *Aedes albopictus* in Florida. Science 257:526-527.
45. **Nasci**, R.S., C.W. Harris & C.K. Porter. 1983. Failure of an insect electrocuting device to reduce mosquito biting. Mosquito News 43(2):180-184.
46. **Naumann**, K. 1990. Synthetic pyrethroid insecticides: Structures and properties. Springer-Verlag, Berlin. 241 p.
47. **New York State Department of Health**. 1992. Health Advisory; Tick and insect repellents. NYS DOH, Albany. 2 p.
48. **Nielsen**, L.T. 1991. Introduction; Mosquitoes unlimited. Natural History (July):4-6.
49. **Nixon**, S.W. 1982. The ecology of New England high salt marshes: A community profile. U.S. Fish and Wildlife Service FWS/OBS-81/55, 70 p.
50. **Oaks**, S.C., V.S. Mitchell, G.W. Pearson & C.C.J. Carpenter, eds. 1991. Malaria; Obstacles and opportunities. National Academy Press, Washington DC. 309 p.
51. **Phillips**, R.S. 1983. Malaria. Edward Arnold, London, U.K. 60 p.
52. **Quarles**, W. 1992. Botanical pesticides from *Chenopodium*? IPM Practitioner 14(2):1-11.
53. **Reed**, S.C., E.J. Middlebrooks & R.W. Crites. 1988. Natural systems for waste management and treatment. McGraw-Hill Book Company, New York. 308 p.
54. **Resh**, V.H. & S.S. Balling. 1983. Tidal circulation alteration for salt marsh mosquito control. Environmental Management 7(1):79-84.
55. **Roberts**, F. 1993. The Endangered Species Act and vector control legislation: Reconcilable? Journal of the Florida Mosquito Control Association 64(1):40-45.
56. **Sharma**, B.P., M.A. Ansari & R.K. Razdan. 1993. Mosquito repellent action of neem (*Azadirachta indica*) oil. Journal of the American Mosquito Control Association 9(3):359-360.
57. **Shisler**, J.K. & T.L. Schulze. [1977?]. Some aspects of Open Marsh Water Management procedures on clapper rail production. Transactions of the Northeast Section, Wildlife Society 33:101-104.
58. **Vietmeyer**, N.D., et al. 1992. Neem; A tree for solving global problems. National Academy Press, Washington, DC. 127 p.
59. **World Health Organization** Expert Committee on Vector Biology and Control. 1983. Integrated vector control. WHO Technical Report Series 688, WHO, Geneva, Switzerland. 72 p.

Design and production, Kathy Anne Schmidt. Drawings Copyright©Kathleen A. Schmidt 1994. This article benefitted from a course, discussions, and use of the library at the University of South Carolina International Center for Public Health Research. Eric T. Schreiber (Florida A&M University) provided information for the drawings of biocontrol organisms; we also consulted Chapman.[9] Gretchen Stevens and Laura Pilkington commented on a draft. Donors, organizations, and individuals acknowledged do not necessarily agree with the concepts and opinions expressed in *News from Hudsonia*.

Errata:

The Copyright statement in *News from Hudsonia* 9(3) should have specified the turtle drawings; credit for "Design and production, Kathy Anne Schmidt" was omitted, and credit for the habitat sketch should have read "Kathy Anne Schmidt and Erik Kiviat." Acknowledgment of support for turtle studies was omitted for Mrs. Beatrice Duggan and Dr. James Shields.

Micro-review

Kaufman, L.H. (Illustrated by K. Kaufman.) 1993. Deserts. Peterson Field Guide Coloring Books. Houghton Mifflin Co., Boston. 68 p. and **Pyle**, R.M. (Illustrated by K. Kest.) 1993. Insects. Peterson Field Guide Coloring Books. Houghton Mifflin Co., Boston. 68 p. Both books are delightful and informative.

Hudsonia Projects

Greenway: We are drafting habitat profiles for the *Manual for Identifying Biodiversity Resources in the Hudson River Greenway Corridor*. The manual will be a tool to help planners, conservationists, consultants, and land owners make better use of biological information in land use decisions Please let us know your needs in this arena.

Marine Mammals: We are analyzing data on the marine mammal fauna of the Hudson River. Contact us if you (or someone you know) has seen a sea porpoise, dolphin, or whale in the Hudson, or if you know of literature or news media accounts, photos, or specimens from the Hudson.

* * *

1994 NATURAL HISTORY COURSES

Hudsonia offers one-day, non-credit courses for professionals and amateurs with a strong interest in field science. Most 1994 courses are linked to our *Manual for the Identification of Biodiversity Resources in the Hudson River Greenway Corridor* (in preparation). Call Laura Pilkington, 914-758-1881, for information or registration (payment is required 10 days in advance).

Intermittent Woodland Pools, 7 May, Erik Kiviat
Limestone Ledges, 14 May, Spider Barbour
Tidal Stream Mouths, 21 May, C. Lavett Smith
Capitol District Significant Habitats (Pine Bush), 4 June, Bob Dirig
Grasses and Sedges, 18 June, Jerry C. Jenkins
Hudson Highlands Significant Habitats, 9 July, Spider Barbour
Grasses and Sedges, 23 July, Jerry C. Jenkins
Westchester County Significant Habitats, 13 August, Ken Soltesz
Wetland Delineation, 27 August, Gretchen Stevens
Mid-Hudson Region Significant Habitats, 10 September, Gretchen Stevens
Acidic Crests, 24 September, Spider Barbour
Stream and Wetland Restoration, 1 October, Sven Hoeger

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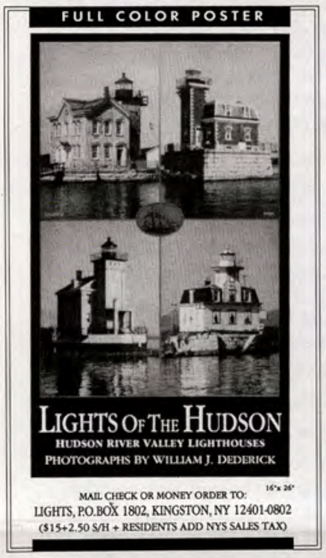

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Erik Kiviat, Executive Director

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