

URBANIZATION AND ITS EFFECTS ON THE ECOLOGY OF MOSQUITOES IN MACAU, SOUTHEAST ASIA

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ABSTRACT. Recent urbanization in Macau has resulted in the precipitous decline to zero in populations of several anopheline vectors of malaria while providing optimal habitat for the population increase in culicines. Of 18 species of mosquitoes reported in Macau in recent years, 15 species are included here. *Culex quinquefasciatus*, *Culex sitiens*, and *Aedes albopictus* were the most abundant species. Notes are provided for *Anopheles sinensis*, *Armigeres magnus*, *Armigeres subalbatus*, *Culex foliatus*, *Culex fuscus*, *Culex infantulus*, *Culex rubithoracis*, *Culex sumatranus*, *Culex tritaeniorhynchus*, *Mansonia uniformis*, *Toxorhynchites splendens*, and *Tripteroides* sp.

INTRODUCTION

Macau consists geographically of a peninsula of land connected to a larger island area of mainland China as well as 2 smaller islands that are connected to the peninsula by either 2 road bridges or a causeway. Malaria is no longer a disease of public health importance in the territory. Even though Kwoh (1948) reported 6 species of anopheline mosquitoes occurring in Macau between 1945 and 1948, and active cases of malaria were discussed by Gonçalves (1952), only *Anopheles sinensis* Wiedemann and *Anopheles tessellatus* Theobald were believed to be present by 1983 (Morais 1984). Urbanization that has taken place in recent years has resulted in the reclamation of all swampy or suitable *Anopheles* larval habitats on the Macau peninsula. The rapid urbanization, however, has created suitable habitats for the development of many other pest mosquito species. This trend is expected to continue to at least 1999, when Macau will become one of the economic zones of mainland China. In the past, studies of mosquitoes in Macau have concerned mainly the vectors of malaria. More recently, a zoological survey conducted by scientists from the Institute of Tropical Science in Portugal during 1988 and 1989 has resulted in more information becoming available on the culicines of Macau (Ramos 1990) along with the preliminary studies made by Easton (1992a, 1992c, 1993).

The Macau region as well as her immediate surroundings in mainland China have long been considered remote in respect to scientific investigations regarding the Oriental fauna, and little information has appeared in the literature. In an early account (Leitão 1923), the mosquito *Stegomyia fasciata* was mentioned as occurring here, so one purpose of the present study was to determine if *Aedes aegypti* (Linn.) still occurs here. A second objective was to identify other representatives of the culicidae because a sizable num-

ber of species (70) were identified previously in the neighboring colony of Hong Kong (Chau 1982).

MATERIALS AND METHODS

Adult mosquitoes were collected from March through September 1991 on Taipa Island with a New Jersey light trap (NJLT) (Hausherr's Machine Works, Toms River, NJ) equipped with a 25-W frosted bulb as an attractant. The trap was placed on the University of Macau campus. Window collections were made during the same period with a battery-powered aspirator that was also used for biting collections of female mosquitoes attracted to a human volunteer. Larval collections were made with a standard enamelled dipper (0.47 liter) with an extendable handle to search fish ponds, irrigation ditches, or cisterns. A soup ladle with the inside of the spatula end painted white was used to sample water collections that were too shallow for the dipper. Phytotelmata examined for mosquito larvae included the leaves of *Nepenthes mirabilis* pitcher plants that grow vinelike in ravines on granite slopes along hiking trails on both the islands of Taipa and Coloane in Macau. The water content of 10 leaves/plant was sampled monthly from January 1990 to April 1991. Larvae from pitcher plant leaves were allowed to develop to maturity in the laboratory in artificial containers of similar size as the leaves. Standard mosquito breeders (Bioquip Products, Santa Monica, CA) were used to rear larvae collected from water sources other than pitcher plant leaves. Immatures and adults were identified with the manual by Chau (1982) for the Hong Kong mosquito fauna, assuming that these 2 areas share many similar faunal elements.

RESULTS AND DISCUSSION

Culex quinquefasciatus Say, the southern house mosquito, is considered the most abundant spe-

cies in the territory (Table 1). It inhabits all domiciles or buildings in Macau that are not centrally air conditioned. It is the most important species biting man in dwellings during periods of twilight, being able readily to enter dwellings not properly screened. The author noted a somewhat similar situation in Guangzhou on mainland China (Easton and Au Yeung 1986) where living conditions are somewhat more primitive. In Macau, where buildings are equipped with window air-conditioning units, *Cx. quinquefasciatus* can enter apartments with the opening of a window or door. At times when a window is opened, a newly hatched passerine bird can be found on the window ledge, having apparently fallen from a nearby nesting site. Buildings on the University campus provided with window air-conditioning units provide corners and crevices that tree sparrows, *Passer montanus*, can use for their nesting sites (Viney and Phillipps 1983). Buildings illuminated at night by artificial light attract insects (Easton 1992b) that can serve as food for passerine birds and their young during early morning hours. These observations suggest that *Cx. quinquefasciatus* adults rest during daylight hours in cracks and crevices on the outsides of buildings, where they are near their food source, *P. montanus*. Otherwise, these mosquitoes would not be available to enter a domicile as spontaneously with the opening of a window, particularly in flats that are 11–12 stories above the ground. Mosquitoes also can enter a lift or elevator on the ground floor, if the doors open to the outside, and then gain access to apartments in upper levels by riding with the passengers in the lift.

In the spring, levels of humidity inside of domiciles are very high because building construction materials do not insulate the flats from the 70–90% RH levels that persist at sea level in the Pearl River estuary. Adults of this species therefore can survive indoors for longer periods than would be expected of mosquitoes entering heated or centrally air-conditioned domiciles in other areas where relative humidity is lower. House plants that grow in water indoors also can serve as a source for *Cx. quinquefasciatus*, hence water in plant containers needs frequent replacement.

The accumulation of waste water from sources of building construction in Macau has increased the potential habitats of this species. The reclamation of land from the sea presently underway and expected to continue until 1999, when Macau will become a special economic zone of mainland China, also increases potential habitats for this species. Along the Baia da Praia Grande on the Macau peninsula, plans are currently underway to reclaim saline water from the Pearl River delta and establish fresh water reservoirs.

Table 1. New Jersey light trap (NJLT) vs. window (WIN) collections of mosquitoes from Taipa Island, Macau, Southeast Asia, during 1991.

Species	March		April		May		June		August		September	
	NJLT	WIN	NJLT	WIN	NJLT	WIN	NJLT	WIN	NJLT	WIN	NJLT	WIN
<i>Culex quinquefasciatus</i>	2.83/5.0 ¹	0.56/0.40	1.8/2.2	0.53/1.4	0.03/0.03	0.03/0.10	0.03/0.30	0.03/0.10	0.03/0.30	0.03/0.30	0/0.36	0/0.13
<i>Culex sitiens</i>	0/1.2	2.0/2.0	1.6/3.5	2.1/3.6	1.8/1.7	0.16/0.10	0/0.06	0.16/0.10	0/0.06	0/0.06	0/0.13	0.20/0.03
<i>Aedes albopictus</i>	0.03/0	0/0.03	0.03/0	0/0.03	0/0.03	0.03/0	0.06/0.06	0.03/0	0.06/0.06	0.06/0.06	0.20/0.03	
<i>Armigeres subalbatus</i>	0/0.03	0/0.03	0/0.03	0/0.03	0/0.03							
<i>Anopheles sinensis</i>												
<i>Mansonia uniformis</i>				0/0.06						0/0.03		

¹ Number of mosquitoes (male/female)/trap night/month.

Until these depressions are filled with fresh water and stocked with predatory fish, the site will support mosquito breeding.

Culex sitiens Wiedemann (116 males, 243 females attracted to NJLT) was the second most abundant mosquito collected. Apparently ranging throughout the Oriental region, it is considered a brackish water species of coastal marshes in Hong Kong (Chau 1982) and may bite humans at night some distance away from the sea. Adults attracted to the Cultural Centre windows or the NJLT in this study could have been attracted from Coloane Island (1–2 km distant), as larvae had been collected from rock crevices near the sea near Ka-Ho village. This mosquito may now inhabit the water-logged mangrove forest near Taipa Island where a land barrier recently has been constructed as a portion of a reclamation project. This measure now isolates the mangrove trees from receiving flushes of saline water from the estuary. The presence of appreciable numbers of this species on windows of the University Cultural Centre (Table 1) during early morning hours but not on windows at other parts of the campus suggests that they were attracted to a colony of nesting *P. montanus* sparrows that were living behind a nearby air-conditioning unit. Murphy (1990) briefly mentioned this mosquito transmitting *Plasmodium juxtannucleare* bird malaria in the vicinity of mangrove forests in Singapore.

Aedes albopictus (Skuse), even though collected uncommonly by the NJLT, is nevertheless a very common mosquito in wooded areas of Macau. On Taipa Island, biting rates of mosquitoes attracted to the lower legs of a human volunteer averaged 8–10 females/min over a ½-h period during one late afternoon in August. Because *Ae. albopictus* often is found in wooded areas, it is not considered an urban mosquito on the Macau peninsula. It often bites humans during late afternoons in late summer and can be bothersome to tourists who visit the hiking trails on Taipa (Trilho da Taipa Grande) or Coloane (Trilho da Coloane Grande). The resident Chinese are only occasionally observed hiking in Macau on these trails, so blood meals needed for reproduction of this mosquito probably are obtained from diurnal avifauna or reptiles. Breeding has been observed in waste (Lixo) containers that have been erected along the trails. Even though the openings of these containers are on the sides near the top, rainwater can accumulate if the containers are not emptied on a regular basis, and there is generally ample organic matter present to serve as larval food.

Larvae of *Ae. albopictus* also have been found in rain gutters that line the trails or are constructed along roadways on both islands. There

are no spring-fed streams on the island of Taipa, but rainwater can accumulate in man-made dams at higher levels and constantly flows to lower levels before emptying into the Pearl River estuary. During heavy rains, if gutters are not provided, serious erosion and mudfalls can occur, but when these gutters are semi-clogged with organic matter, such as small twigs or leaves, the pools created can also serve as larval habitats.

Discarded automobile and truck tires often are moved from Macau across the border to mainland China. When these tires are left lying in old fields that are partly shaded by tall grasses or shrubs, they serve as a mosquito breeding source. Tires lying in the open sun do not contain live mosquitoes because summer temperatures greater than 35°C would soon exceed the upper limit of the mosquito's temperature tolerance. The beneficial mosquito *Toxorhynchites splendens* (Wiedemann) has been found occupying rubber tires (1 larva, 1 pupa, August 27, 1991) in an old field near Hac-Sa village on Coloane island. Larvae of *Ae. albopictus* were found in the same tire and most likely constituted part of the food source of the predatory species. These predatory larvae, however, require 1½–2 months to mature whereas *Ae. albopictus* larvae probably can mature in 6–7 days. In Macau, *Toxorhynchites* mosquitoes prefer habitats that contain appreciable organic matter, such as a tree-hole site, so their use in biological control for *Ae. albopictus* is limited when the latter are found in abandoned tin cans or in rain gutters where high summer temperatures (35°C) evaporate sources of rainwater after a few days. The tree-hole habitat in Macau is somewhat limited for mosquito development; the author has located very few sites that contain water for any appreciable period. The upper branches of *Ficus macrocarpa*, the Chinese Banyan tree, could provide habitats in areas where the trees are shaded. Other tree species that could provide a tree-hole habitat on the islands have a shorter life span due to termites that eventually kill them. The flame tree, *Delonix regia*, has been planted along roadsides in urban areas and has been observed in Papua New Guinea (E. Easton, unpublished data, 1988) to provide tree-hole sites for *Toxorhynchites* as well as other species, but in Macau the water in their upward-spreading branches soon evaporates in summer due to high daily extreme temperatures. Fig trees (*Ficus* sp.) as well as other species of trees growing in a more densely wooded environment (i.e., Agriculture and Forestry Park, Siac Pai Van) would tend to have less exposure to the sun so that water in tree-hole habitats would tend to persist longer.

Notes on other species: *Aedes aegypti* was not found in Macau during this study. In the neighboring colony of Hong Kong, where *Ae. aegypti*

was reported in the late 1950s, the specimens apparently were discovered on vessels arriving from other countries (Chau 1982). In Macau at present, *Cx. quinquefasciatus* occupies urban habitats in places where *Ae. aegypti* potentially could survive, whereas *Ae. albopictus* is found in similar water catchments in rural areas that are shaded by trees. On the islands, the mosquitoes' food sources could be diurnal lizards (*Calotes* sp.) or birds because the mammals and insectivores on Taipa and Coloane islands are all nocturnal in habit.

Anopheles sinensis (one female, May 10, 1991, NJLT) is believed now to be a relatively uncommon species in Macau because of urbanization. The habitat on the Macau peninsula formerly inhabited by this species (Morais 1984) was reclaimed by 1988. Larvae of this species were collected by the author on the edge of a grassy banked reservoir at Siac Pai Van on Coloane Island, August 1991.

Armigeres magnus (Theobald) commonly inhabits leaves of *Nepenthes mirabilis* where they grow on granite slopes or ravines on Coloane Island (Ramos 1990) or on Taipa Island (Easton 1992b). Larvae were found inhabiting the leaves of this plant during all months of the year, but highest densities were found from September to February with fewer numbers from March to May. During the spring of the year, there are fewer water-containing leaves because newly formed leaves do not open until later summer. In Hong Kong (Chau 1982), *Ar. magnus* is reported also from *N. mirabilis* leaves, but in other areas of the Orient, such as Malaysia, tree holes seem to be preferred as larval habitat.

Armigeres subalbatus (Coquillett) occasionally is attracted to lights from the University buildings at night (Table 1), and larvae occur in polluted waters (Chau 1982). In Hong Kong, it is reported to feed on pigs and cattle as well as on humans.

Culex foliatus Brug. Larvae of this species were collected in a flooded field containing taro plants, *Colocassia esculenta*, near Hac-Sa village on Coloane Island, July 1991. In Hong Kong, Chau (1982) reported larvae of this species living in side pockets of clear streams such as in the Tai Po Kau forest area in the New Territories.

Culex fuscans Wiedemann. Adults are attracted occasionally to windows on the University campus (August 1991). In Hong Kong they live in highly polluted ground water area where they prey as larvae on *Cx. quinquefasciatus*. Ramos (1990) examined larvae collected from a cement tank on Coloane Island in Macau that also contained *Ae. albopictus* and *Culex pallidothorax* Theobald.

Culex infantulus Edwards and *Culex rubi-*

thoracis (Leicester) larvae have been collected from the same site as *Cx. foliatus* above. In Hong Kong *Cx. rubithoracis* commonly inhabits swampy fields or ground pools and ponds containing water hyacinth, *Eichornia crassipes*.

Culex sumatranus Brug inhabits pitcher plant leaves along with *ar. magnus* on Coloane Island (Ramos 1990) and along the Trilho de Taipa Grande hiking trail on Taipa Island (Easton 1992b). Larval abundance in the leaves is lowest during the spring months from March through May and highest during the winter season from September through February. Even though the water volume in the leaves in spring is greater than at other times of the year because spring is the period of the greatest amount of rainfall in Macau, most of the leaves have been produced during late summer of the previous season. New leaves do not open on these plants until July or August, which accounts for the greater numbers of larvae of both *Ar. magnus* and *Cx. sumatranus* during late summer, and by the spring of the following year most of the immatures will have developed. The existence of 1st-instar larvae of *Cx. sumatranus* in the leaves during February as well as in June, long after the leaves have opened the previous seasons, provides evidence that more than one generation of *Cx. sumatranus* can develop per year in one *N. mirabilis* leaf. Larvae reared in the laboratory at temperatures only slightly lower than environmental completed their life cycles in less than 50 days.

Culex tritaeniorhynchus Dyar. One female, September 8, 1991, on windows of the University Cultural Centre. In Hong Kong, Chau (1982) listed this as a common species in ground pools, water hyacinth fields, fish ponds, rice fields, and irrigation ditches where there is emergent vegetation.

Mansonia uniformis (Theobald). One female, September 1, 1991, NJLT. The eggs of this species are laid in clusters on the undersides of floating leaves of aquatic vegetation, and larvae pierce and attach to the stems and roots of water plants. Water hyacinths commonly reach Macau by floating downstream from mainland China when one of the branches of the Pearl River is in flood. When these plants become established in fresh water habitats on the peninsula or on one of the islands, conditions are favorable for the development of *Ma. uniformis*.

Tripteroides sp. Twenty-five or more adults, April 11, 1991, hanging below roof at entrance of horizontal mine shaft flooded with water, Choec-van, Coloane Island. In Hong Kong, *Tripteroides aranoioides* larvae have been reported from bamboo stumps (Chau 1982) and from pitcher plants in West Malaysia (Beaver 1979), but I have not located larval habitats in Macau. The

food source of this species is not known here, but the opening of the mine shaft is shared by 7 species of insectivorous bats (3 species of *Miniopterus*, 2 *Myotis* sp., one *Hipposideros* sp., and one *Rhinolophus* sp.) as well as the nesting violet whistling thrush, *Myiophonus caeruleus*.

Three additional species of *Culex* reported by Ramos (1990) in Macau, namely *Cx. pallidothorax*, *Culex pseudovishnui* Colless, and *Culex vagans* Wied., were not collected in this study.

ACKNOWLEDGMENTS

Much appreciation is given to Chau Gar-Wai, Pest Control officer, and the technicians working in his section of the Urban Services Department, Hong Kong Government, Kowloon, for their help in the identification of certain mosquito species, particularly *Cx. foliatus*, *Cx. infantulus*, and *Cx. rubithoracis*. The author also acknowledges M. F. Ferreira and M. M. Morais, Health Services Department, Macau Government, for local information on mosquito breeding sources.

REFERENCES CITED

- Beaver, R. A. 1979. Fauna and foodwebs of pitcher plants in West Malaysia. *Malayan Nat. J.* 33(1):1-10.
- Chau, G. W. 1982. An illustrated guide to the identification of mosquitoes in Hong Kong. Urban Council, Hong Kong.
- Easton, E. R. 1992a. Selected aspects of environmental health in Macau, pp. 213-224. *In*: B. Taylor, D. Y. Yuan, R. Ramos and W. H. Keong (eds.). Socioeconomic development and quality of life in Macau. Centre of Macau Studies, University of Macau, Instituto Cultural de Macau.
- Easton, E. R. 1992b. 1990 additions to the annotated list of the insects of Macau. *Entomol. News* 103:30-36.
- Easton, E. R. 1992c. Ecological habitats of mosquitoes (Culicidae) in Macau. *Proc. XIX International Congress of Entomology. Abst. XIIC-2,505.*
- Easton, E. R. 1993. Ecological studies regarding man-biting mosquitoes (Diptera: Culicidae) in Macau. *Acta Parasitol. Portug.* 1:42.
- Easton, E. R. and S. S. Au Yeung. 1986. Mosquito captures using a mechanical aspirator and an encephalitis surveillance trap on Guangzhou City, Guangdong Province, People's Republic of China. *J. Am. Mosq. Control Assoc.* 2:92-93.
- Gonçalves, F. I. 1952. Algumas notas sobre o paludismo em Macau. *An. Inst. Med. Trop. (Lisb.)* 9:485-490.
- Kwoh, B. C. S. 1948. A general report of Malaria and mosquito control in Macau during the year 1945-1947. Macau Governo de Macau.
- Leitão, A. D. N. 1923. Aperçu nosologique Macao et les agents transmetteurs de la peste. *Tellurologie et Climatologie Medicales de Macao (Macao Station Climatique).*
- Morais, M. M. 1984. Serviço de Combate ao Sazonismo. Relatório Annual, Direcção dos Serviços de Saúde, Macau.
- Murphy, D. H. 1990. Insects and public health in the mangrove ecosystem, pp. 423-452. *In*: C. L. Ming and P. K. L. Ng (eds.). *Essays in zoology.* Department of Zoology, University of Singapore, Singapore.
- Ramos, H. Da C. 1990. Seven new culicine records from Macau (Diptera, Culicidae). *Bol. Soc. Portug. Entomolog.* 129:325-340.
- Viney, C. and K. Phillipps. 1983. *Birds of Hong Kong.* Government Printer, Hong Kong.