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JAPANESE *AEDES ALBOPICTUS* AMONG FOUR MOSQUITO SPECIES REACHING NEW ZEALAND IN USED TIRES

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ABSTRACT. Since a 1988–89 survey of northern New Zealand revealed no additions to the known mosquito fauna, this country's used tire importations have much increased. Relevant entomological quarantine was thus monitored in a November 1992–January 1993 Auckland project, during which almost ⅓ of 8,549 casings from Japan proved wet on inspection. In this study and at 2 South Island ports afterwards, 5 vessels from Japan and one from Australia were found to have brought in mosquito-infested used tires. Live *Aedes albopictus* (all larval instars, pupae, and adults) and *Aedes japonicus,* and dead *Tripteroides bambusa* were discovered in shipments from Japan (3 interceptions each in the first 2 cases, and one in the 3rd). Live *Tripteroides tasmaniensis* were recorded from the Australian cargo. One of the *Ae. albopictus* arrivals was followed by an apprehended introduction at an Auckland importer's premises.

INTRODUCTION

New Zealand (NZ) lacks all significant vector-borne diseases of humans, and pest mosquito problems are localized and quite trifling by comparison with those of most other countries. Only 14 resident species of Culicidae are known, and potential larval habitats are notably underutilized (Laird 1990). Three exotics, *Culex* (*Cx.*) *quinquefasciatus* Say, *Aedes* (*Finlaya*) *notoscriptus* (Skuse) and *Aedes* (*Halaedes*) *australis* (Erichson) were first reported here in 1848, 1920, and 1962, respectively. Ongoing surveillance, including the 1988–89 Northern Mosquito Survey (Laird 1990), has not revealed additional establishments.

Lately, however, the rapidly developing international trade in used tires, which has occasioned widespread detected importations of live mosquitoes and actual establishments in several countries, has caused concern that NZ might be invaded by the cold-hardy Japanese strains of *Aedes* (*Stegomyia*) *albopictus* (Skuse) (the Asian tiger mosquito) central to this problem. During 1989–91, New Zealand's annual used tire imports (all sources) averaged slightly more than a quarter of a million but in 1991–92 jumped from 260,876 to 414,486 (data from NZ Ministry of Commerce). Up to 21 countries were involved in the trade over this period. However, Japan was the largest single source throughout, supplying an annual average of 217,267 tires (85.8% of the total from all sources) in 1989–91, and 391,373 (96.8% of the total) in 1991–92.

Quarantine responsibilities regarding imports reaching NZ by sea or air lie with the Ministry of Agriculture and Fisheries (MAF), from which there was hearsay evidence in 1992 that mosquito larvae had recently been noticed during inspections of newly unloaded wet tires at Auckland. Because of the health implications of this, Central Auckland Health District Community Services/Auckland Area Health Board (CAHDCS/AAHB) designated a team of 4 to explore the question via a search for Culicidae in a proportion of the load of all containerized consignments of used tires reaching local importers during a project starting on November 16, 1992, and ending "soon after any discovery of mosquitoes". This paper reports and analyzes the results achieved.

METHODOLOGY

One of us (L.C.) handled overall organization, M.L. provided entomological advice, R.C.T. arranged necessary purchasing and operational/liaison details, and R.S. was in daily charge of both monitoring and recording incoming consignments. Two data recording forms were devised, the first outlining each inspected container's history and the 2nd detailing mosquito or other biological samples secured. All concerned were familiarized with the required collecting and preservation procedures. The need to remain vigilant throughout every inspection was urged in the light of the experience of Craven et al. (1988) whose infestation rate for wet and dry Asian used tires sampled at USA ports was only 6.8 mosquito-positive casings per 10,000.

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The agreed routine for CAHDCS/AAHB inspection was for MAF to notify R.S. on the morning of each day when shipping containers were to be opened and unloaded under official scrutiny at an importer's premises. In practice, though, unloading was sometimes in progress or completed before she could attend. She was thus occasionally absent when the doors were unsealed. This had implications for the desired random selection of 10% (*ca.* 70) of tires from the different sectors of a tightly packed load.

RESULTS

Voyage data and wet/dry status of tires on reception: During the project 37 shipping containers were monitored. One had been taken aboard at Pusan, S. Korea, and another (with tires from Stuttgart) at Rotterdam, The Netherlands. The remaining 35 had originated from Japanese ports. These constituted 94.6% of the total closely conforming to Japan's yearly share of the trade for 1992. Fifty percent had been shipped from Yokohama, 17% from Kobe, 10% from Nagoya, and 7% each from Tokyo and Moji. Except for Moji, which is in northern Kyushu on Shimonoseki Strait, these cities are in southcentral Honshu. The port of origin was unclear for the remaining 9%. Some voyages were direct, taking as little as 15 days. Others included brief calls at intermediate ports in Japan, Pusan, Hong Kong, and Kelang (Moluccas, Indonesia). The duration of the trip to Auckland thus ranged up to 22 days. Individual aboard-to-discharge time for shipping containers averaged 18 days. Offloading until delivery (unopened) in an Auckland industrial suburb took a further 1–18 days (mean = 6). Forty percent were delivered within 4 days, and 28% in from 9 to 18 days. The lengthier periods in wharf storage reflected the Christmas/New Year's component of New Zealand's main summer holiday period. Once received by their importers, 66% of the containers were emptied of tires on the day of delivery, the rest usually the next day.

Although the NZ Department (now Ministry) of Health had been specifying since 1987 that *clean and dry* used tires be shipped to importers, 24 (64.9%) of the 37 monitored containers held wet tires (the 2 from S. Korea and The Netherlands/Germany did not). By "wet tires" we mean any exhibiting any quantity of water. Old watermarks were not counted because Craven et al. (1988) reported: "No eggs hatched from the flooded debris from 2,213 tires with watermarks."

Our incidence of wet tires per container ranged from 2 (2.8%) out of 72 inspected, to 802 (88.9%) out of 902. Individual tires usually held less than 1 liter of (nonsaline) water, ranging from 100 to 500 ml. Of the 9,749 tires examined during the project, 2,655 (27.2%) were wet. This incidence rose to 31.1% when the 1,200 non-Japanese tires were excluded. None of the 37 containers monitored had structural damage permitting entry of either rainwater or seawater, so all arriving wet tires must either have been in that state when packed in Japan or have acquired a trifling water content due to en route condensation.

Mosquito findings: Random sampling of wet tires proved negative for mosquitoes or other macroscopic organisms until almost 2 months after the project began. Then, on January 13, 1993, Culicidae (*Ae. albopictus*) were discovered in and around a 20-ft. container brought to a warehouse in the Auckland suburb of Mt. Roskill on the previous day. It had been hoisted aboard the ship *Hua Yuan Kou* at Nagoya on December 9, 1992, after being filled with tires (possibly in Tokyo where the exporter's office was located, or perhaps elsewhere) at least a day or so earlier. After calling at Yokohama next day, the vessel sailed directly to Auckland, arriving on December 27, when the container was off-loaded. It was not delivered to the importer for another 16 days, having been in transit for at least 35 days.

Although R. Syme had been notified that the *Hua Yuan Kou* container was to be unsealed and emptied on the afternoon of January 12, 1993, she found that unloading had been completed that morning. Eighty tires, all of them wet, were then inspected and found negative for Culicidae. Next morning, after searching 160 more wet casings, she discovered a single live 4th instar mosquito larva in the 4,168th tire of the project. This was preserved in 70% alcohol, and with extra assistance, all wet tires examined on the previous day were searched again and the rest of the consignment was inspected. Twenty-three of the load's 802 wet tires (the largest number recorded from any single container during the project, constituting 88.9% of the 902 casings present) harbored 46 live larvae and 6 pupae, and in one instance a sodden female. The number of immatures per tire ranged from one (in 3 instances, twice a 4th instar and once a pupa) to 7 (in 2 instances, the first involving 2 4th-instar larvae, 2 3rds and 3 2nds; and the 2nd, one 4th-instar, three 3rds, one 2nd, one 1st and a pupa). All were identified by M.L. as *Ae. albopictus,* and examples were sent to M.M. who confirmed the identification. From now on *all* wet tires were routinely searched.

During the reinforced search on January 13, 2 or 3 unfamiliar mosquitoes were noticed in flight about the now-empty container by a university graduate student, Gene Browne. He reported them as being black with silvery-white leg bands

Fig. 1. Mt. Roskill survey participants being briefed and allocated search areas by R. C. Thornton, January 19, 1993.

and prominent thoracic stripes. The only resident NZ mosquito that is blackish with white markings is the long-ago introduced (presumably from Australia or New Caledonia) *Ae. notoscriptus.* Although a diurnal indoor intruder in Auckland (Graham 1929), its white ornamentation is far fainter than Browne's description indicated. None of the live mosquitoes were captured, but the alcohol-preserved example already mentioned (from its poor state, an unsuccessful emergence) agreed with the description of *Ae. albopictus* in such taxonomic characters as remained evident. Prior to closing the entire warehouse, preparatory to spraying with deltamethrin and dichlorvos, the importer had the emptied container trucked away to another location where it was disinsected with permethrin on January 14. No dead adults could be found afterwards.

Consultations now took place among all concerned with the CAHDCS/AAHB project, including a representative of the Ministry of Health, Wellington. The meeting considered Hawaiian estimates that 10 days after release the mean distance traveled by laboratory-reared *Ae. albopictus* was only 104 m, with very few dispersing beyond 183 m (Bonnet and Worcester 1946). At the temperatures then prevailing in Auckland, *ca.* 24°C, the larval life of a cold-hardy Japanese strain of this species occupies 7–10 days, following 2–3 days from oviposition to hatching (Udaka 1959). Allowing for the possible escape of fertilized and perhaps autogenous females of *Ae. albopictus* from the Mt. Roskill warehouse on January 12 at the container's opening, it appeared feasible for early instar larvae to be developing within, but probably no further than, a 200-m radius from the building a week later. It was decided that a larval habitat survey and control operation covering that zone would be conducted on January 19. Following a training session for 4 parties of 2, each provided with a detailed aerial photograph (Fig. 1), this operation located 78 water-holding artificial containers within the search perimeter. No natural containers were found, the area being devoted to mixed light industry margined by residential streets. It also has a large school complex with extensive grounds, where the day's finest collection of wet artificial containers proved to be the groundsman's trash dump.

Various discarded drums, cans and tires there contained abundant immatures of Auckland's 2 commonest summer mosquitoes, the indigenous *Culex* (*Cx.*) *pervigilans* Bergroth and the exotic *Ae. notoscriptus.* The exotic *Cx. quinquefasciatus* was also found twice. Mixed infestations of the first 2 species accounted for 20% of the 45 mosquito-positive larval habitats discovered during the exercise, when all container-type larval habitats sampled were rendered useless to Culicidae by oiling where it was not practicable to destroy them. The incidence of utilization of artificial containers by associated *Cx. pervigilans* and *Ae. notoscriptus* at Mt. Roskill (57.7% of 78) was slightly lower than the 1988–89 figure for the Northern Mosquito Survey (65% of 1,493; Laird 1990).

As media reports followed the first (January 20) Ministry of Health press release, Firestone Tire and Rubber Co of NZ Ltd. (which manufactures automobile tires and does not import used ones) quickly circulated a relevant flier (Fig. 2) to their agents. The resultant publicity elicited suspected Asian tiger mosquitoes from various sources. Predictably, these comprised *Ae. notoscriptus* adults, but also blepharocerid and mycetophilid midges and the common NZ cranefly *Macromastix dichroithorax* Alexander (the long maxillary palps of which, characteristic of the Tipulidae/Tipulinae, resemble a proboscis).

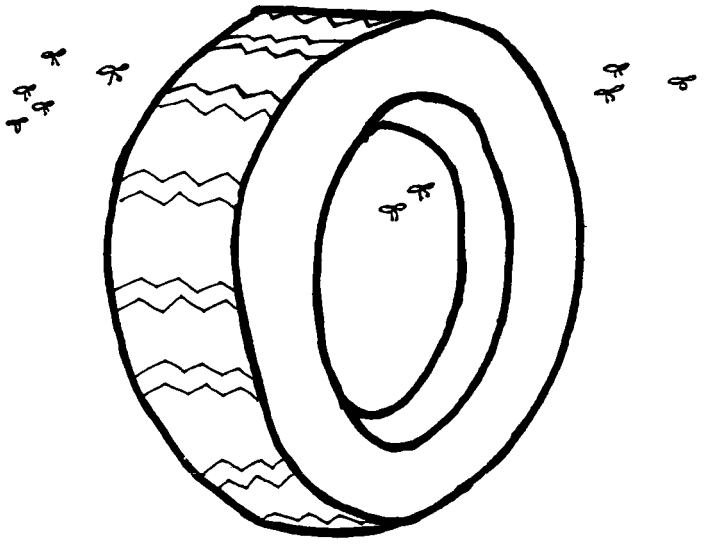
On January 22 more live mosquito larvae were discovered in a tire consignment brought from Yokohama by the *Tai Ping Kou,* from which a 40-ft. container had been landed at Auckland on

THIS WEEK

BUY ANY IMPORTED ASIAN USED TYRE

AND WE'LL GIVE YOU

MORE THAN YOU BARGAINED FOR!



You can choose from any one of three deadly diseases, only this week, and only when you buy a used Asian tyre.

Typhoid, yellow fever or dengue fever can be yours - FREE, and we'll even throw in some larvae.

So come in and see us at any non-Firestone tyre centre and we'll give you a real buzz.

Fig. 2. Flier distributed by a tire company following the initial press release on imports of *Aedes albopictus* to NZ. Reproduced by permission of Firestone Tire and Rubber Co. of NZ Ltd., Auckland.

January 14 after a direct voyage of 16 days. It was delivered to an East Tamaki (South Auckland) importer on January 21, when permethrin was sprayed into its tightly packed mass of 1,290 used tires on unsealing and opening. The doors were closed again pending unloading next morning 24 days after departure from Yokohama. R. Syme inspected 800 tires, 40 of which were wet but lacked Culicidae. On the afternoon of January 22, 100 more tires were examined by an MAF inspector, who discovered live 1st- and 3rd-instar larvae and a pupa in 500 ml of water in the last casing. Unloading was halted immediately. The container was again sprayed with permethrin and closed. As before the mosquitoes proved to be *Ae. albopictus.*

The E. Tamaki container was re-opened on the morning of January 25, with R.S. and 2 Health Protection Officers from South Auckland Health District (SAHD)/AAHB inspecting its remaining tires. Still-living *Ae. albopictus* immatures were recovered from 2 of them, truck tires each holding about a liter of water, bringing the total for the Yokohama container to 29 larvae of all instars and 5 pupae. Dead Culicidae were found in 20 more tires, but samples from only 2 of these were received by M.L. for identification. In one (with *ca.* 100 ml of water) there was a decom-

posing 4th-instar larva of *Ae. albopictus*. The other (with *ca.* 300 ml of water) yielded a long-dead adult female of this species. All told, 340 (26.2%) of the consignment's casings were wet.

On January 27–28, a 200-m-radius survey of artificial containers was undertaken around this importer's premises, yielding 93 water-holding sites of which 60 (64.5%) were mosquito-positive. The percentage of utilization was closely comparable with 1988–89 figures. Of the 37 samples taken from tires, large outdoor accumulations of which were adjacent to the East Tamaki warehouse, a number of those received by M.L. held immatures from more than one tire. The 23 occupied artificial containers other than tires inspected (oil drums, plastic buckets, industrial scrap of various kinds, an upturned canoe, etc.) showed 71% utilization by *Cx. pervigilans*, 50% by *Ae. notoscriptus*, and 25% by both. The 37+ positive tires showed 68.7% utilization by the latter, 62.5% by the former, and 31.3% by both. They also revealed 2 triple utilizations in rejected tires earlier imported from Japan. The 3rd species present was *Ae. albopictus*.

One sample provided 35 3rd- and 4th-instar larvae of *Ae. notoscriptus*, 13 2nd to 4th instars of *Cx. pervigilans*, and a 2nd-instar *Ae. albopictus*. The other held 41 *Ae. notoscriptus* larvae of all instars, 3 3rd and 4th instars of *Cx. pervigilans*, and 2 3rd instars of *Ae. albopictus*. Again, identifications and instar status of the last-mentioned species were confirmed by M.M.[7] Both samples also included pupae of the 2 resident mosquitoes, which have oviposition-to-adult intervals in excess of 2 wk under optimum conditions (Graham 1929; M.L. unpublished data). The presence of these pupae proves that the 2 source tires had been discarded since at least January 13–14, and had therefore been there for a week or more prior to the arrival of the *Ae. albopictus*-infested container.

In consultation with Ministry of Health and MAF Border Services a 500-m-radius larviciding and artificial container destruction operation was now implemented. It was centered upon the point where the infested shipment had been unpacked. The rationale included the rather slow dispersal time for *Ae. albopictus* already considered in the Mt. Roskill operation. Also, most of the extended treatment area was open, grassed, and without clumps of shrubs or trees, which fit well with the evidence of Mori (1979) that a Japanese cold-hardy strain of this species clearly prefers to shelter in vegetation at intervals along a dispersal route; helping to account for a 16-day dispersal of both sexes to only about 200 m. Fortunately, few artificial containers were present.

On January 27 a container from the ship *Godwit* was being unpacked in the Auckland suburb of Penrose when a live 4th-instar larva was pipetted from *ca.* 200 ml of water in 1 of 404 wet tires (80.1% of this 20-ft. container load of 504). It was subsequently identified by M.M. as *Aedes* (*Finlaya*) *japonicus* (Theobald). The voyage had originated at Kobe on December 28 and after brief calls at Moji, Pusan, Kelang, and Hong Kong, Auckland was reached on January 18. The container was not delivered to its importer for a further 8 days, and another day elapsed before it was opened and unloaded. On top of this overall total of 30 days an unknown length of time must be allowed for surface transport within Japan. Inquiries via NZ Customs revealed that the exporter's address was in Osaka. In southern Honshu, Nakata (1962) found that in the vicinity of Kyoto larvae of *Ae. japonicus* occur even in the coldest month, January.

The *Godwit* had continued her voyage southward on the day of arrival at Auckland. Having alerted the Canterbury Area Health Board (CAHB) to the interception of *Ae. albopictus* in tires from the *Tai Ping Kou* after she had proceeded to Lyttelton (the port of Christchurch, on the east coast of NZ's South Island), the Ministry of Health now conveyed similar advice on the *Godwit*.

On January 29 P.W.H. informed M.L. that live late-instar larvae tentatively identified as *Ae. albopictus* had been found in a tire from the *Godwit*, which had berthed at Lyttelton a week earlier. The container had not been delivered to its importer and opened for another 6 days, its tires then having been in total darkness for *ca.* 30 days. The identity of these live larvae was confirmed by M.L. and M.M. as was that of 2 dead ones of *Tripteroides* (*Tp.*) *bambusa* Yamada from a tire in a 2nd container from the same source. Both containers had been uplifted at Moji. Being based near Moji, M.M. proceeded to investigate the Japanese aspect of this transaction, finding that the tires had been packed by an exporter in Kitakyushu, a large industrial city close to Moji. This exporter sometimes arranged such exports on learning of the availability of stocks of used casings suitable for sale abroad. He indicated that the tires had originated from the immediate vi-

[7] Whose returned material has been lodged in the insect repository of Landcare Research NZ Ltd., Mt. Albert Research Centre (formerly Entomology Division, NZ Department of Scientific and Industrial Research), Auckland. These reference collections now also house the other mosquito specimens secured during our project, plus sets of all larval instars and pupae, of *Aedes albopictus* reared for the purpose by M.M. from 2 strains derived from Seburi, in inland NW Kyushu, and Kabeshima, offshore from northern Saga Prefecture, Kyushu.

cinity of Kitakyushu, volunteering that the NZ purchaser had specified dry tires and that it was his custom to remove water by vacuum pumping. This practice could account for the presence of small residual quantities of water in exported used casings.

The CAHDCS/AAHB monitoring project had ceased on January 29. Two days later MAF began to subject 100% of imported used tires to inspection. On February 15 P.W.H. contacted M.L. on the 2nd South Island finding of relevant imports in a 40-ft. container with about 1,300 tires, nearly all of them wet and holding an estimated total of *ca.* 350 liters of water. They had just reached Lyttelton aboard the *Wellington Maru.* Numerous larvae had been seen, but only 2 late instars were received for identification by M.L. and M.M. They proved to be *Ae. japonicus,* and as in the first instance the exporter's address was in Osaka.

On March 10 there was a further interception at Lyttelton. It involved not Japan but Australia, and a >3-m tire for an earth-moving vehicle. Two such tires from an exporter at Bayswater on the outskirts of Melbourne, Victoria, had been brought from that port in 5½ days aboard the *Canterbury Express.* MAF personnel found that each held *ca.* 8 liters of water. The positive one contained ca. 100 live larvae, 4th instars from which were identified by M.L. as the very distinctive *Tripteroides* (*Polylepidomyia*) *tasmaniensis* (Strickland), one of 3 members of its genus known from the state of Victoria (Dobrotworsky 1965). The determination was subsequently confirmed by Richard C. Russell, University of Sydney and Westmead Hospital, New South Wales, Australia.

Finally, 2 of 5 used tires employed as packaging on the tray of a light truck aboard the *Azalea Ace* proved positive for Culicidae on her August 30 arrival at Dunedin, an east coast port 350 km south of Lyttelton. Each tire and 2 others held *ca.* 1 liter of water, the 5th being dry. P. W. Holder was sent 3 live larvae from one of the tires. Sixteen more were counted in the other but were not collected when all tires were drained and treated with permethrin. The specimens (2 4th instars and one 3rd) were duly identified by M.L. and M.M. as *Ae. japonicus.* The voyage had originated from Yokohama on August 7, and after uplifting the truck at Nagoya 2 days later the ship had called at 2 Honshu ports (Sakai and Kobe) and 3 NZ ones (Auckland, Wellington, and Lyttelton) en route to Dunedin.

DISCUSSION

It is intriguing that some 43% of the tires inspected at Auckland were found negative for mosquitoes in the first 8 wk of the monitoring project, but the remaining 2½ wk produced interceptions of *Ae. albopictus* (twice) and *Ae. japonicus* (once) in consignments shipped from 2 areas of Honshu and one of Kyushu in midwinter. Sharpened alertness from the first discovery onwards was undoubtedly a factor, as it must have been in the ensuing South Island interceptions, when MAF Border Services personnel, after years of random inspections of tires arriving in NZ without a single confirmed mosquito identification, contributed another finding of *Ae. albopictus* and 2 more of *Ae. japonicus* besides a first discovery each of *Tp. bambusa* from Japan and *Tp. tasmaniensis* from Australia! It can only be wondered how long such importations had been proceeding unrecognized.

Significance of mosquito importations to NZ via the used tire trade: Cold-hardy *Ae. albopictus* and *Ae. japonicus,* with 3 interceptions each, were the most important of the potential mosquito immigrants discovered during the brief CAHDCS/AAHB monitoring project and its unanticipated South Island aftermath. The first vector's arbovirus-transmitting propensities are well known (Hawley 1988, Tiger Tales 1992). In respect to *Ae. japonicus,* recent data from Hokkaido (Takashima and Rosen 1989) demonstrate its suitability as a host for Japanese encephalitis virus, which it can transmit efficiently to laboratory animals following oral infection. It can also transmit this virus transovarially to its F_1 larvae, though its significance in natural cycles and overwintering of the pathogen has yet to be studied.

As to purely nuisance significance, being an aggressive biter of mammals, especially humans (Tanaka et al. 1979, Hawley 1988), the Asian tiger mosquito would certainly worsen NZ's prevailing pest mosquito situation if established here. *Tripteroides tasmaniensis* is also a day-biter that readily attacks humans (Lee et al. 1989). Similar dispersal of both species and also of *Ae. japonicus* to that of the introduced *Ae. notoscriptus,* which is already entrenched in various natural container-type larval habitats in NZ native forests (Laird 1990), would likely be accelerated by a distinctively NZ use for old tire casings. For although reuse provides the main business for this country's used tire trade, the more worn casings in imported consignments are often set aside for (sometimes immediate) dispatch to rural purchasers for use as weights on the plastic sheeting covering ensilage piles (Laird 1990). A single such pile is recognizable from afar by its scores to hundreds of tires, heavily utilized by *Cx. pervigilans* and/or *Ae. notoscriptus* but still offering much unutilized larval habitat.

Fast sales of newly imported used casings for

this particular purpose might thus pose the special risk of injecting foreign mosquitoes (as eggs, whether diapausing or not, in dry tires?) into potentially hazardous situations. Subsequently emerging females would have ready access to the blood of domestic stock, farmers, and feral animals, plus immediate recourse to large tire concentrations for oviposition. Focal populations of imported vectors and/or pests could thus be facilitated in remote areas where their arrival might escape notice. Range expansion from such bridgeheads would be promoted by the diversity of containers, both artificial and natural (tree holes, rock holes, leaf axils, etc.) available as larval habitats nearby.

How do Northern Hemisphere mosquitoes survive 5+ wk of darkness between their midwinter and NZ midsummer, with a tropical crossing between?: All Southern Hemisphere destinations for containerized Northern Hemisphere used tires pose any life history stages of mosquitoes with the challenge of an equatorial transit. The first such event for Australasia involving (possibly) cold-hardy *Aedes albopictus* was reported by Kay et al. (1990). It concerned a single 4th-instar larva of the Asian tiger mosquito identified from a wet tire taken from a damaged shipping container on October 3, 1988, at subtropical Brisbane (27°30'S), Australia. Taken aboard at Kobe on August 27, the container was damaged en route. This raised the possibility of its having been vulnerable to entry by *Ae. albopictus* at intermediate ports (Hong Kong and Manila, Philippines). It was thus not possible to state with certainty whether the strain of this species was a cold-hardy or tropical one.

The next Southern Hemisphere record was from Cape Town (33°56'S), South Africa. It concerned dead immatures of *Ae. albopictus* in a shipment of tires from Tokyo and January/February 1990 live early instar larvae of this species in winter shipments from Osaka and Kobe (the consignment from the latter port had been in transit for at least 35 days). In May 1990 Cornel and Hunt (1991) handled 2 more (2nd-instar) live *Ae. albopictus* larvae received in a shipment from springtime Yokohama. They considered it "unlikely that the eggs would have hatched prior to arrival as the containers are usually sealed and dark inside", suggesting that "agitation of water in the tires, resulting in the submergence of dry non-diapausing eggs while off loading might . . . have induced hatching". Soon afterwards, Jupp and Kemp (1992) reported 3 findings of live mosquito immatures in shipping containers landed at Durban, South Africa (some 4° north of Cape Town), from wintertime Yokohama and Tokyo. Adults reared included *Ae. albopictus, Uranotaenia* sp., and *Ae. aegypti.* The last-mentioned mosquito is indigenous in South Africa but does not occur in Japan, which suggests oviposition by a local mosquito following tire unloading. A similar explanation was suggested by Kay et al. (1990) for the presence of 2 2nd-instar *Cx. quinquefasciatus* larvae in a tire from Japan that they inspected at Brisbane.

All Culicidae intercepted at Auckland, Lyttelton, and Dunedin in arriving used tires had unquestionably come with the shipments in question. Most were alive on discovery, having completed some (and in the case of the *Hua Yuan Kou Ae. albopictus,* all) of their aquatic stages in total darkness maintained for several weeks. How, then, did live examples of all larval instars, pupae, and adults of *Ae. albopictus,* also late instars of *Ae. japonicus,* come to be present in sealed shipping containers transported on (especially) the 4 voyages from midwinter Japan to midsummer NZ?

Many of the tires in the mosquito-positive consignments had clearly been loaded wet; notably, 88.9% for the *Hua Yuan Kou* and most of *ca.* 1,300 for the *Wellington Maru.* This agrees with the South African experiences, with 85% of the tires in one of the northern winter consignments positive for *Ae. albopictus* on arrival at Cape Town having been wet (Cornel and Hunt 1991), and likewise 80% of those in such a Durban shipment (Jupp and Kemp 1992). These figures suggest that the tires had been taken from outside storage dumps freely utilized by mosquitoes. All but one of our leads to Japanese tire exporters failed to reveal where and how shipping containers were actually packed, and the literature is uninformative in this regard. However, our investigations revealed the existence of small to large outdoor tire accumulations in Kyushu; and according to Japanese pest control personnel one of the largest such dumps once caused serious nuisances downwind due to production of mosquitoes from its tires. Those from Kitakyushu included both the Asian tiger mosquito and *Tripteroides bambusa,* which, with others, were collected from tires reaching the USA from Japan (Craven et al. 1988).

The life history stages of *Ae. albopictus* and *Ae. japonicus* that departed from midwinter Japan to reach NZ as live late-instar larvae (and in the first case pupae and adults too) must now be considered. Only one stage, the egg, is possible for the former species in southcentral Honshu, where its pupae are not found after October nor 4th-instar larvae after November (Nakata 1962). Furthermore, in Kyushu northward throughout this mosquito's Japanese range, larvae, pupae, and adults cannot overwinter (Mori et al. 1981). Only eggs do so (Sota and Mogi 1992a). It was suggested by Mori et al. (1981) that autumn-

emerging females lay diapausing eggs in nature. Sota and Mogi (1992b) found such *Ae. albopictus* eggs to survive longer than nondiapausing ones at low humidity.

New Zealand's 2 December departures from Honshu and the December 29 one from Kyushu, and South Africa's 3 in that month and January show the chances of larval or pupal uptake with used tires was virtually nil. And had any surviving autumn females gone aboard, their existence within the shipping containers would have been limited to 5–7 days in the absence of nourishment other than water (Hien 1976). Had even mouse blood been available, it might have been otherwise. *Aedes albopictus* females feed readily from mice (Miyagi 1972). Mice are not unknown in shipping containers, even those passing through the tropics. For when on October 1981 the first-ever such container was craned down to the new lagoon wharf of Funafuti atoll (8°30′S, 179°12′E), Tuvalu, and opened, house mice emerged (Laird 1984). Its load, though, included bulk foodstuffs. Mice would surely find containerized tires far less appealing.

Had any 4th-instar Asian tiger mosquito larvae still surviving in early December Honshu been taken aboard the *Hua Yuan Kou* with adequate food available, they might perhaps have been able to pupate as the ship entered the tropics. And despite the absence of photosynthesis in a totally dark environment, wet tires stored for even a little time in the open before being packed should have offered a diversity of, for example, bacterial and colorless protistan food for detritus-feeding aedines (Laird 1988). Although tropical pupation might thus have been feasible, the survival of the rest of the voyage by any resultant adults would have been problematical. Had food been suboptimal, though, 4th-instar persistence might have extended through arrival and storage in NZ—Mori (1979) notes as many as 58 days larval survival with suboptimal food.

Although these suggested scenarios are loaded with "ifs," all possibilities must be explored to explain the presence of live 2nd- and 3rd-instar *Ae. albopictus* larvae in those 2 Japanese tires discarded at East Tamaki prior to the *Tai Ping Kou* container's unsealing on January 21. Because 3 such larvae were collected from these casings on January 28, initial speculation ranged from interrupted oviposition by an earlier-arrived adult to autogeny. Either case would have fitted the observed larval development time, which in *Ae. albopictus* averages 7–10 days (Udaka 1959). Negative factors would have included the likely unavailability of adequate space for aerial mating above or among tightly packed tires, and the usually low incidence of autogenous females (Mori 1979).

The likeliest solution was thus the loading in Japan of tires (whether wet or dry) containing diapause eggs oviposited by autumn-emerging Asian tiger mosquitoes, and/or long-dried early- to mid-September nondiapausing eggs (Mori et al. 1981). Because most *Ae. albopictus* eggs are oviposited a little above the water surface (as much as 54 mm above, but with a mean of 11.1 mm; Amerasinghe and Alagoda 1984), those laid in stored tires in autumn when Japanese rainfall tends to be low (Sota and Mogi 1992a) might remain unsubmerged until handling began at loading. From then onwards and during the voyage, inevitable movement of any water (including that derived from condensation) in an egg-positive tire could stimulate erratic hatching of diapausing eggs for 30 days or longer (Mori et al. 1981). Moreover, nondiapausing eggs hatch easily when submerged at high temperatures, irrespective of daylength.

The hatching of eggs in either state, spread over much of the journey and during sometimes lengthy storage thereafter, could account for the presence of any or all life-history stages of *Ae. albopictus* at the NZ (or other Southern Hemisphere) opening of containers of used tires packed under Japanese winter conditions. It also suggests a more plausible explanation than autogeny for the January 28 discovery of early instar Asian tiger mosquito larvae at East Tamaki. As regards *Ae. japonicus* and *Tp. bambusa,* the former overwinters as larvae in Japan's southwest (Kamimura 1976); and in northern Kyushu the latter has both eggs and 4th-instar larvae in diapause from early winter onwards (Mori et al. 1985).

Countermeasures to the international dispersal of mosquitoes via the used tire trade: Ideally, were the exportation of used tires to be proscribed internationally in other than "clean and dry" state following steam cleaning (which kills eggs as well as larvae; Craven et al. 1988), there would not be a problem. Neither would there be were methyl bromide fumigation compulsory, either at the sealing of tire-loaded containers for export or on their opening at arrival (the present Australian requirement; AQIS 1991). Since Reiter and Sprenger (1987) pleaded for "urgent discussion at the international level" towards a universally effective solution, the number of USA states infested with cold-hardy *Ae. albopictus* has doubled (Tiger Tales 1992). There have also been additional establishments in Albania (Adhami and Murati 1987), northern Italy (Sabatini et al. 1990, Dalla Pozza and Majori 1992) and Nigeria (Savage et al. 1992), besides apprehended importations to Australia (Kay et al. 1990) and South Africa (Cornel and Hunt 1991, Jupp and Kemp

1992). In the continuing absence of relevant international action and recognizing that the Asian tiger mosquito seems headed for a wider circumglobal presence, NZ took rapid action to update quarantine practice following the January 1993 Auckland interceptions. From February 1 100% of imported used tires became subject to inspection, and pending early finalization of revised quarantine procedures with the authorities of overseas exporting countries, mandatory methyl bromide fumigation of such tires on entry to NZ was instituted in early September (information from MAF and the Ministries of Customs and Health).

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