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DISTRIBUTION OF ANOPHELINE MOSQUITOES IN NORTHERN AUSTRALIA

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ABSTRACT. Using carbon-dioxide-baited light traps and larval sampling, anopheline mosquitoes were collected from 620 sites in northern Australia. Twelve species were recorded. *Anopheles annulipes s. l.* (335 sites), *An. bancroftii* (181 sites), *An. meraukensis* (162 sites), *An. farauti s. s.* (133 sites), *An. farauti* 3 (93 sites), *An. amictus* (93 sites), *An. hilli* (88 sites), *An. novaguinensis* (70 sites), and *An. farauti* 2 (67 sites) were common and widespread throughout the region, while *An. powelli* (5 sites), *An. stigmaticus* (2 sites), and *An. colledgei* (1 site) were rarely collected. At the time of the surveys the distribution of these species was not limited by the availability of oviposition sites.

INTRODUCTION

The distribution of the *Anopheles* in northern Australia has not been widely studied since the mid-1940s. At that time there was considerable interest in the genus because of the increased threat of malaria transmission in the region due to infected troops returning from combat areas in the Southwest Pacific. Lee and Woodhill (1944) compiled the first comprehensive taxonomic study of the genus for the Australasian region and Mackerras (1947) reported on the vectors and potential vectors on the Australian mainland. O'Gower (1958) summarized the early records on the distribution of the anophelines in the Northern Territory and listed the suspected malaria vectors, as *Plasmodium vivax* Grassi was endemic in the region until 1962.

More recently, records of anophelines from Cape York Peninsula (Marks 1980), the Darwin area (Russell and Whelan 1986) and the Torres Strait islands (Foley et al. 1991) have been reported. Sweeney et al. (1990) and Cooper et al. (1995) studied the distribution of *Anopheles farauti* 1, 2, and 3 on Cape York Peninsula and in the Northern Territory, respectively.

In the course of surveying northern Australia for members of the *An. farauti* complex (Sweeney et al. 1990, Cooper et al. 1995), a comprehensive and extensive set of data was obtained on the distribution of other *Anopheles.* Reported here are the distributions of *Anopheles* species collected during 7 surveys conducted between 1985 and 1991.

MATERIALS AND METHODS

The surveys were conducted at the end of each wet season (April–May) when stable oviposition sites would be plentiful and mosquito densities were expected to be high. Northern Queensland was surveyed in 1985, 1986, and 1991, the Gulf of Carpentaria in 1987, and Northern Territory in 1988, 1989, and 1990.

Survey area: The coastal region of northern Australia between the longitudes 128° and 146°30′E and up to 300 km inland was surveyed. This region is characterized by coastal plains varying from 50 to 100 km in width except on the eastern coast of Cape York Peninsula and northern Queensland, where the mountains of the Great Dividing Range run close to the coast. These coastal plains are drained by numerous large river systems which run to the sea from an inland plateau region (300 m) in the Northern Territory, and from the mountains of the Great Diving Range (500 m) in northern Queensland.

The climate of the region is monsoonal with distinct wet and dry seasons. The former is between December and March, when about 90% of the region's rainfall occurs. The average annual rainfall is 1,200–1,600 mm per annum (p.a.) for coastal areas while inland areas are drier, receiving 800–1,200 mm p.a. As a result of the wet season much of the coastal plain is inundated with flood waters which drain away in the early months of the dry season.

There are few all-weather roads throughout the survey area and, due to flooding, parts of the region were inaccessible at the time of these surveys. The surveys were conducted using 4-wheel-drive land vehicles where possible, and helicopters to access the more remote and isolated areas.

Survey methods: Locations from which anopheline collections were made (collection sites) were selected with the aim of sampling as widely as possible from the major land forms and vegetation types occurring in the survey region. Adult collections were made using battery-powered, carbon-dioxide-baited light traps (Rohe and Fall 1979). Traps were set in the evening and retrieved the following morning. Collected mosquitoes were immobilized with chloroform or by freezing. Anophelines were separated from culicines and then further identified using the keys of Lee and Woodhill (1944).

A wide range of water bodies throughout the survey area were inspected for anopheline larvae.

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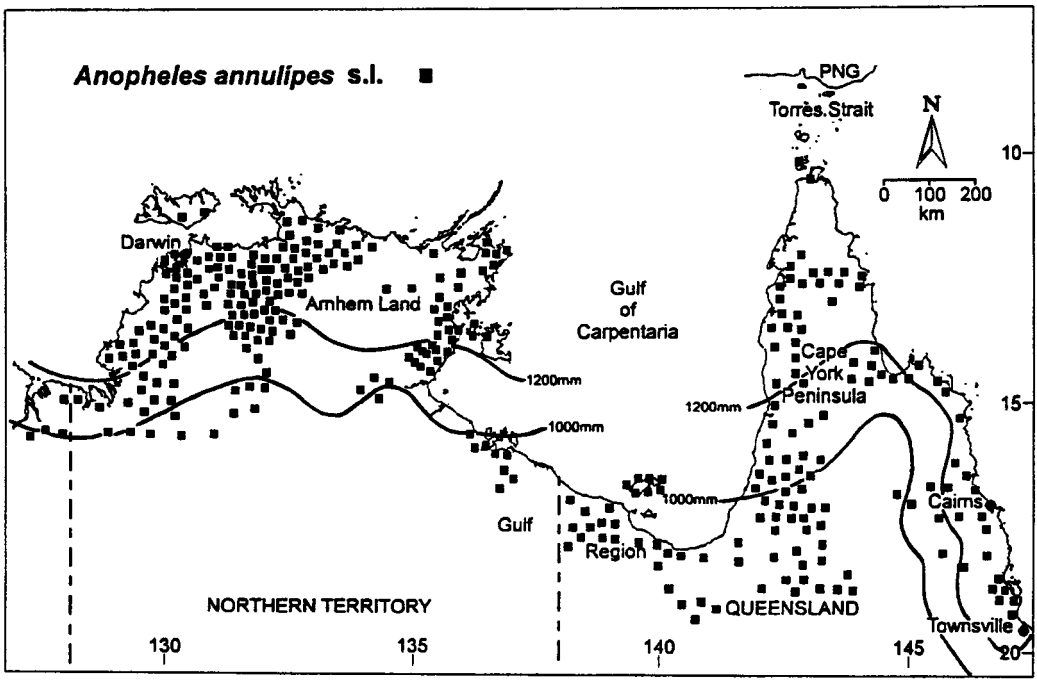

Fig. 1. Distribution of *Anopheles annulipes s. l.* in northern Australia.

Where present a sample of larvae were taken using a standard larval dipper (Clarke Mosquito Control Products Roselle, IL, USA); these were pipetted into 500-ml plastic containers for transporting to a base camp where they were reared to adults in site water on a diet of powdered goldfish food. As they emerged the adults were handled as discussed above. The particulars of each larval collection site were recorded, indicating the type of habitat, size, degree of shading, presence of plant matter (emergent, algae), and condition of the water (still/running, fresh/stagnant) and in the case of saline sites the concentration of salts was measured as parts per thousand using a salinity meter (model 33, Yellow Springs Instruments Co., Inc., Yellow Springs, OH, USA).

Further identification of the isomorphic members of the *An. farauti* complex was carried out using allozyme electrophoresis and DNA probes as described by Mahon (1984) and Cooper et al. (1991).

RESULTS AND DISCUSSION

Anopheline mosquitoes were collected from 620 sites throughout the survey area. Of these, 427 (68.9%) were larval collections and 193 (31.1%) were adult trap collections.

Twelve species of *Anopheles* were identified in the region. The following 9 were common and widespread: *Anopheles annulipes s. l., Anopheles bancroftii* Giles, *Anopheles meraukensis* Venhuis, *Anopheles farauti* Laveran (*s. s.* = *An. farauti* 1, Hii et al. 1993), *Anopheles farauti* 2, *Anopheles farauti* 3, *Anopheles amictus* Edwards, *Anopheles hilli* Woodhill and Lee, and *Anopheles novaguinensis* Venhuis. Three species, *Anopheles powelli* Lee, *Anopheles stigmaticus* Skuse, and *Anopheles colledgei* Marks, were uncommon and had more restricted ranges.

Anopheles annulipes s. l. (Fig. 1) was collected from 335 sites (252 larval and 83 adult) and was the most abundant and widespread of all anophelines recorded from the region. This species occurs throughout Australia and is believed to consist of 10 sibling species (Booth and Bryan 1986). Green (1972) identified species D as occurring in northwestern Australia on the western edge of the survey area. Booth and Bryan (1986) identified 2 species as occurring in the northern part of the Northern Territory and another species from northern Queensland. It is possible that the distribution shown here may represent that of a number of sibling species. This may also be indicated by the range of different climatic types over which *An. annulipes s. l.* was found, it being common throughout the wetter areas of the survey region (>1,200 mm p.a.) as well as the drier inland regions (<1,000 mm p.a.). On the coast the larvae of this species were found on 7 occasions in brackish water with salinities up to 16 ppt.

Anopheles bancroftii (Fig. 2) was collected from 181 sites (77 larval and 104 adult) mainly in higher rainfall areas (>1,200 mm p.a.). On Cape York Peninsula it was collected along the western and eastern coastlines; however, it was never found in

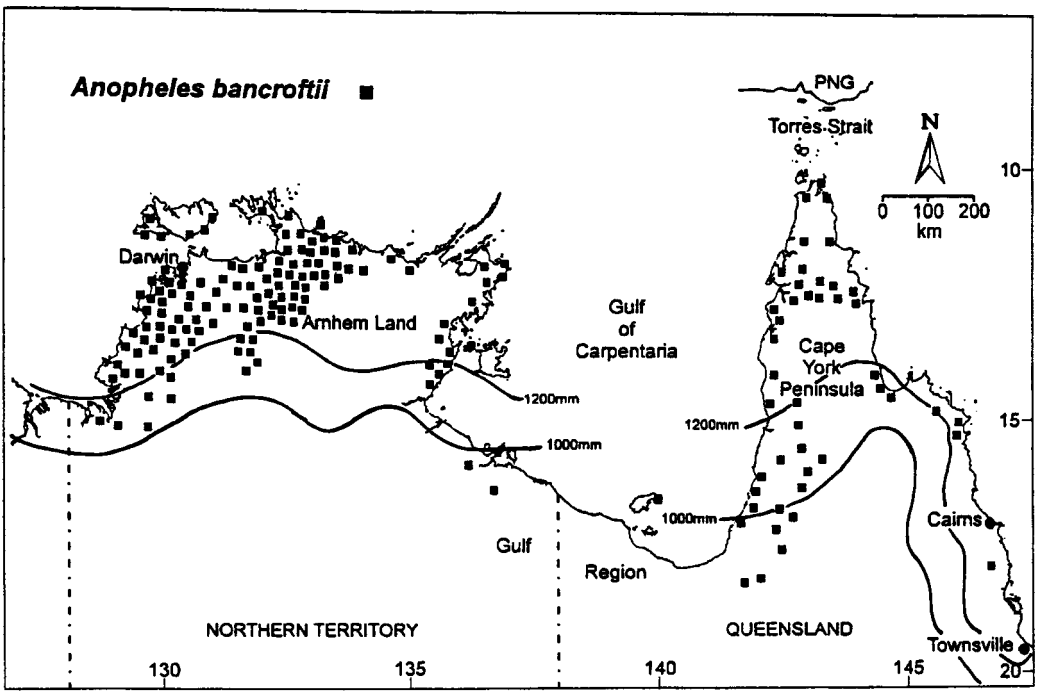

Fig. 2. Distribution of *Anopheles bancroftii* in northern Australia.

large numbers (1–10/trap/night). This species was uncommon in the Gulf region. In the 1989 and 1990 surveys of the Northern Territory, *An. bancroftii* was found to be common, and at a number of locations occurred in high densities (>1,000/trap/night). It is an aggressive biter, feeding at night and during the day in shaded locations, and in some areas constituted a serious pest problem at the time of these surveys.

Anopheles meraukensis (Fig. 3) was recorded from 162 sites (77 larval and 85 adult) throughout the survey area and was widespread and common in the wetter areas (>1,200 mm p.a.) of the Northern Territory and Cape York Peninsula. It was absent from the drier (<1,000 mm p.a.) areas of the Gulf region. During the 1989 survey it was recorded in fairly high densities (50–100/trap/night) in parts of the Northern Territory and since it readily attacked man it was a problem at the time of this survey. It was not collected from the islands of the Torres Strait during 1991; however, it has been found there on other occasions (Foley et al. 1991).

The distribution of *Anopheles farauti s. s., An. farauti* 2, and *An. farauti* 3 is discussed in detail elsewhere (Sweeney et al. 1990, Cooper et al. 1995). All 3 species preferred the wetter areas (>1,200 mm p.a.) of northern Australia (Fig. 4). *Anopheles farauti s. s.* was common along the coastline in northern Queensland and the Northern Territory and *An. farauti* 2 was collected more often in Queensland (50 sites) than in the Northern Territory (17 sites), while *An. farauti* 3 was more common in the Northern Territory (74 sites) than in northern Queensland (19 sites). None of these species were collected from the Gulf area during the 1987 survey, and the southern limit on the west coast of Cape York Peninsula was 14°15′S. Kay (1985) recorded *An. farauti s. l.* at Kowanyama (15°30′S) during the wet season of 1975; however, only 25 specimens were collected despite extensive sampling. The 1991 survey located *An. farauti s. s.* 2 and 3 as far south as 18°30′S on the east coast of northern Queensland. Marks et al. (1980) recorded 3 collections of *An. farauti s. l.* from Townsville (19°15′S), the last being in 1980. In each case only a few specimens were collected.

In the 1991 survey *An. farauti s. s.* was found throughout the islands of the Torres Strait. Similar findings were made by Foley et al. (1991), and it has been recorded on the adjacent coastline of Papua New Guinea (PNG) (R. D. Cooper, unpublished data). *Anopheles farauti* 2 and 3 have also been recorded in PNG (R. D. Cooper, unpublished. data); however, except for records of *An. farauti* 2 on 2 islands at the tip of Cape York (Foley et al. 1991) neither species has been found in the Torres Strait.

Anopheles amictus (Fig. 5) was collected from 93 sites (79 larval and 14 adult) across northern Australia. It was not found on the east coast of northern Queensland or the northern half of Cape York Peninsula, although it has been recorded in these areas previously (Marks 1980). *Anopheles amictus* was abundant and widespread throughout the eastern and southern parts of the Gulf of Car-

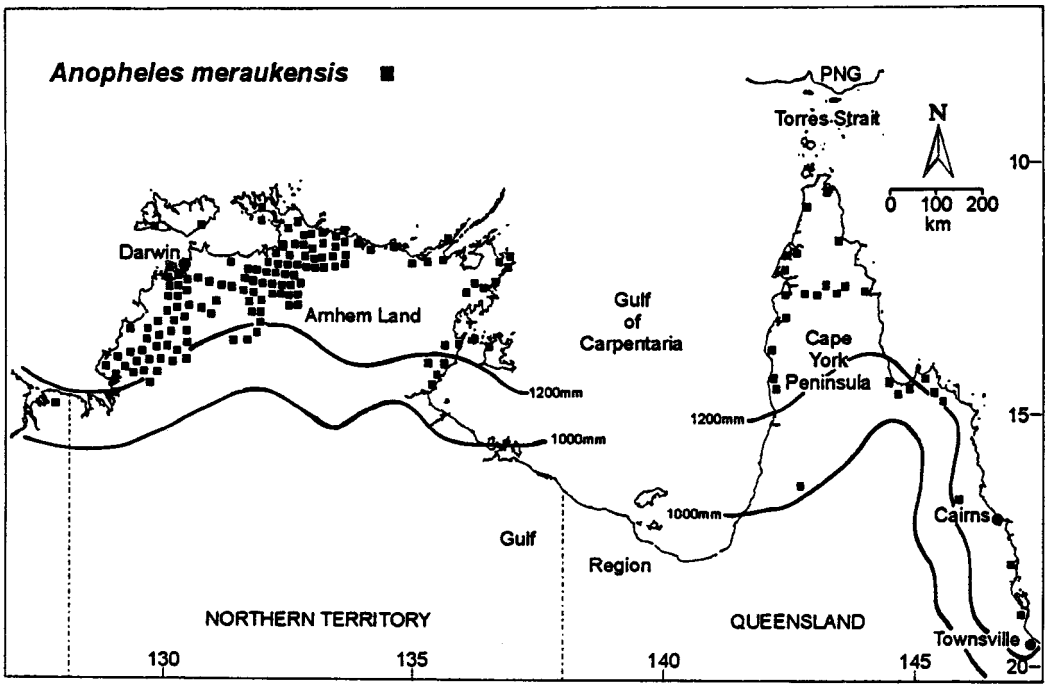

Fig. 3. Distribution of *Anopheles meraukensis* in northern Australia.

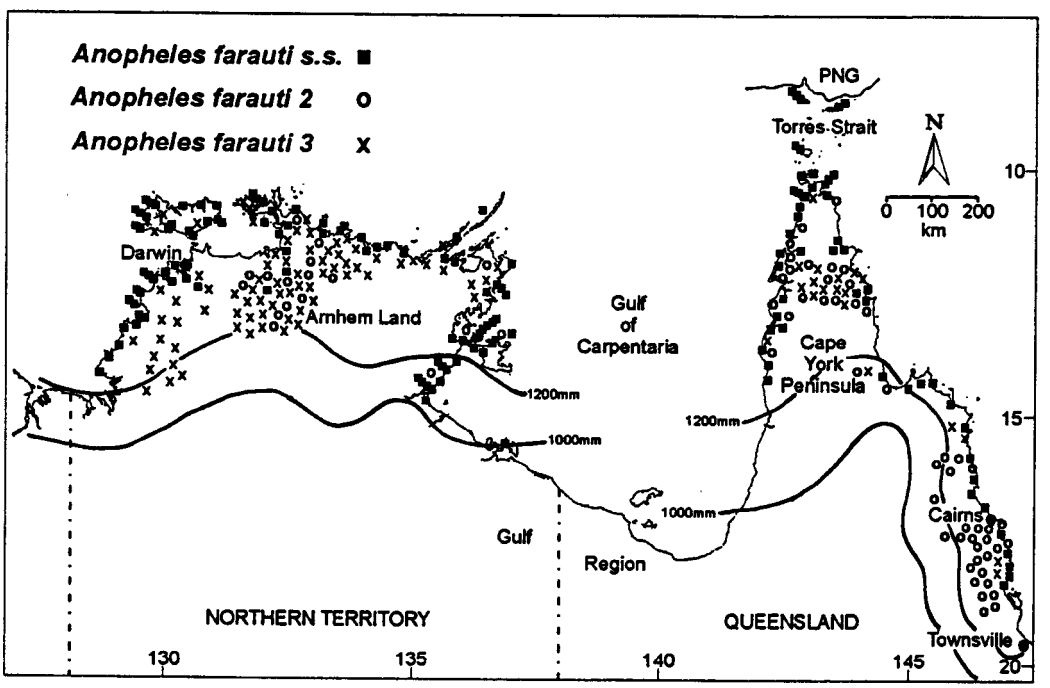

Fig. 4. Distribution of *Anopheles farauti s. s., An. farauti* 2, and *An. farauti* 3 in northern Australia.

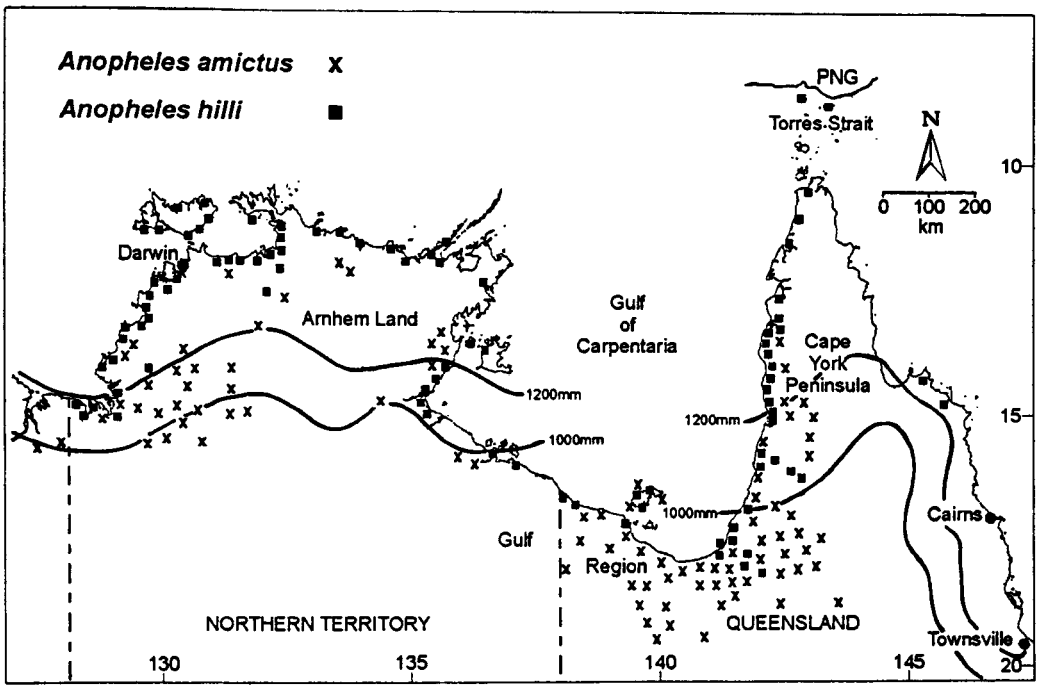

Fig. 5. Distribution of *Anopheles amictus* and *An. hilli* in northern Australia.

pentaria extending up to 100 km inland. This species was scattered throughout the western coast of the Gulf, westward into Arnhem Land, and south of Darwin. It was commonly found coastally and inland in the far southwestern part of the survey area. However, throughout its range adults were never collected in large numbers (<5/trap/night).

Anopheles hilli (Fig. 5) was collected from 88 sites (43 larval and 45 adult), primarily coastal. It was common along the west coast of Cape York Peninsula and the coastline of the Northern Territory. This species will utilize brackish and saline water for larval development and in the current surveys *An. hilli* larvae were found on 16 occasions in sites with salinities of 15–35 ppt. This species was also found in freshwater sites up to 150 km inland.

Anopheles novaguinensis (Fig. 6) was collected from 70 sites (47 larval and 23 adult) predominantly in wetter regions (>1,200 mm p.a.). It occurred on Cape York, but was not common. It was not found in the drier areas of the Gulf region, but was widespread and fairly common in the northern and western parts of the Northern Territory. Throughout its range *An. novaguinensis* was never collected in large numbers (<10/trap/night). It was not recorded on the islands of the Torres Strait during the 1991 survey but has been collected previously from 2 islands close to the tip of Cape York (Foley et al. 1991).

Anopheles powelli (Fig. 6) was collected from 5 sites (1 larval and 4 adult) in the Northern Territory. Marks (1980) has also found it in northern Queensland. In this survey, the larvae were found in association with *An. novaguinensis.*

Anopheles stigmaticus (probably the northern brown form of Marks 1956) (Fig. 6) was collected as larvae on 2 occasions from small ground pools containing clear water with sandy bottoms. Both sites were on the east coast of Queensland between Cairns and Townsville. This form is only known from the coastal region of northern Queensland (Marks 1956, 1980).

Anopheles colledgei (Fig. 6) was found at one location, a high rainfall (>3,000 mm p.a.) area south of Cairns. Larvae were collected from clean, fresh water pools and backwaters, in a creek flowing through rain forest. The type locality of *An. colledgei* is just north of this site (Marks 1956) and its range appears to be restricted to the wetter rain forest areas on the east coast of northern Queensland.

Oviposition sites, utilized by the anophelines species found during these surveys, were small ground pools left by receding flood waters or recent rain, or the edges of larger bodies of water such as swamps or flood plain. Some were man- or animal-made, such as wheel ruts, roadside ditches, drains (both earthen and concrete), hoof prints, and wallows. Most sites were temporary, being maintained by wet season rains, and would dry up once the dry season started.

Of the 427 larval sites sampled, 244 (57.2%) sites contained one species only, 126 (29.5%) sites

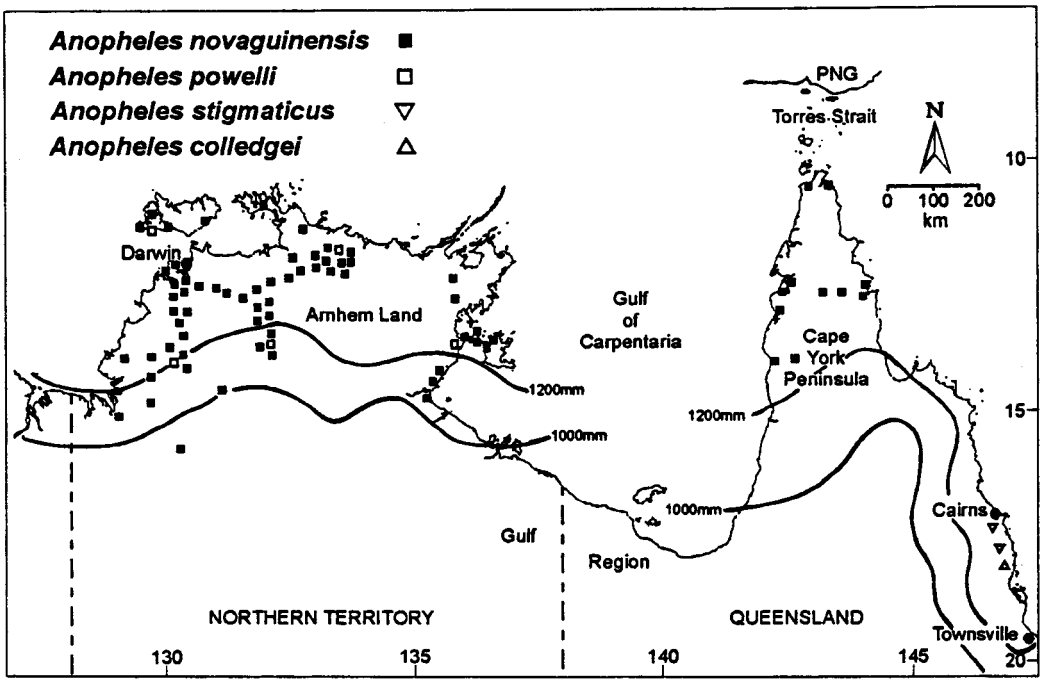

Fig. 6. Distribution of *Anopheles novaguinensis, An. powelli, An. stigmaticus,* and *An. colledgei* in northern Australia.

contained 2 species and 57 (13.3%) sites contained 3–5 species. Table 1 shows the larval associations for the 9 commonly collected species. The larvae of *An. farauti* 2 and 3 were not recorded with *An. amictus,* and *An. farauti* 3 was not found with *An. hilli,* with the other species there appeared to be no preference for one species to be associated with another, and each species was at one time or another found together with one of the other species. The types of larval habitats utilized by the various species are given in Table 2. There appeared to be no preference by any one species for a particular type of larval habitat and characteristics such as the the size, shading, amount, and type of plant material and the condition of the site water did not appear to influence the selection of one particular species for a particular site.

Brackish pools, with salinities as high as 35 ppt, were used by *An. farauti s. s.* and *An. hilli* in 37 and 36% of the larval sites surveyed, respectively. *Anopheles farauti s. s.* and *An. hilli* have adapted to saline conditions (Russell 1979, Sweeney 1987), and tides are known to play a role in the seasonal abundance of *An. hilli* (Roberts 1948, Russell and Whelan 1986). In these surveys it was found that brackish sites were occasionally utilized by *An. annulipes s. l., An. amictus, An. novaguinensis, An. meraukensis,* and *An. bancroftii.*

Larval habitats, utilized by the 9 commonly collected species, were plentiful throughout the survey area following the wet season. It is therefore unlikely that the availability of oviposition sites would be a factor limiting the distribution of any of the species collected. However, the ranges of some spe-

Table 1. Larval associations for 9 anopheline species collected in northern Australia.

	Number of larval collection sites								
Anopheles species	f1	f2	f3	an	am	ba	hi	me	no
farauti 1 (f1)	—								
farauti 2 (f2)	10	—							
farauti 3 (f3)	4	11	—						
annulipes s.l. (an)	8	13	9	—					
amictus (am)	1	0	0	47	—				
bancroftii (ba)	4	8	9	38	10	—			
hilli (hi)	9	2	0	9	11	3	—		
meraukensis (me)	10	8	10	39	2	22	2	—	
novaguinensis (no)	7	4	3	19	3	6	4	11	—

Table 2. Larval habitats utilized by 9 anopheline species in northern Australia.

Type of larval habitat	Anopheline species[1]								
	f1	f2	f3	an	am	ba	hi	me	no
Swamp	10	3	4	14	7	8	7	8	2
Flood plain	1	0	2	11	1	4	0	3	0
Creek (edge)	3	9	5	38	0	11	1	23	15
Lagoon (edge)	8	3	2	40	21	13	9	11	2
Ground pool	14	15	9	94	30	14	14	20	14
Animal wallow	2	2	0	10	3	5	4	4	1
Hoof print	2	3	1	15	11	3	4	3	1
Rock pool	3	1	1	13	4	2	1	1	6
Wheel rut	0	1	0	3	0	1	1	0	1
Drain/ditch	1	3	2	13	2	4	2	4	5
Total	44	40	26	252	79	77	43	77	47
Saline sites	16	0	1	7	2	2	16	2	2

[1] Abbreviations as in Table 1.

cies were restricted: the 3 members of the *An. farauti* complex were rarely found below the 1,200 mm isohyet, while *An. bancroftii, An. meraukensis,* and *An. novaguinensis* were rarely found below the 1,000 mm isohyet. In the distribution of these species, humidity rather than actual rainfall may be important. Roberts (1948) suggested that humidity plays a major role in the distribution and seasonal prevalence of anophelines in northern Queensland, with *An. farauti s. l.* requiring high humidity for its survival and *An. annulipes* and *An. amictus* tolerating lower humidity and drier conditions; our findings support these observations.

O'Gower (1958) reported that in the Northern Territory species occurrence declined in the dry season and only *An. annulipes* could be found throughout the year. Russell and Whelan (1986) showed a similar trend with anophelines in the Darwin area being most abundant in the late wet and early dry periods. As the surveys reported here were conducted at the end of the wet season, when conditions for survival and dispersal would be the most favorable, it is likely that the distributions recorded here are a good indication of the possible ranges of these species. However, the distribution and abundance of these species, in any one year, will be the result of several interacting climatic factors which will depend on the severity of the preceding dry season and the amount and duration of rain occurring during the wet season. As these conditions fluctuate from year to year, so too will the abundance and range of the anopheline species present.

Malaria was last recorded on the Australian mainland in the Northern Territory in 1962, up until this time it commonly occurred throughout parts of Australia north of 19°S (Black 1972). *Anopheles farauti s. l.* and *An. hilli* have been incriminated as vectors in northern Queensland with *An. farauti s. l.* believed to be the primary vector (Mackerras 1947). In the Northern Territory, up until 1962, a low rate of endemic vivax malaria was maintained in the region below 15°S (Black 1972). This region is outside the range recorded here for *An. farauti* 1, 2, and 3. *Anopheles annulipes s. l.* and, to a lesser extent, *An. amictus,* were found to be common in this region. It is possible that these 2 species may have been responsible for the transmission which occurred there, an observation previously made by O'Gower (1958).

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