HISTORICAL REVIEW OF MOSQUITO CONTROL AS A COMPONENT OF MALARIA ERADICATION PROGRAM IN THE RYUKYU ARCHIPELAGO

Ichiro Miyagi[1,2], Takako Toma[1], Wabyahe LM Malenganisho[1,3] and Miyoko Uza[4]

[1]Laboratory of Medical Zoology, School of Health Science, Faculty of Medicine, University of the Ryukyus, Japan; [2]Research Center of Comprehensive Medicine, Faculty of Medicine University of the Ryukyus, Japan; [3]National Institute for Medical Research, Tanzania; [4]Community Health Nursing, School of Health Science, Faculty of Medicine, University of the Ryukyus, Japan

Abstract. In the Ryukyu Archipelago, where malaria used to be endemic, eradication of the disease was achieved by the year 1962, as a consequential effect of a planned malaria eradication program in the area. This achievement was facilitated by concerted efforts in controlling vector mosquitos and treatment of all detected and presumptive cases of malaria infections. *Anopheles minimus* Theobald and *An. sinensis* Wiedemann were common in all areas endemic for malaria. Knowledge of the biology and bionomics of the mosquitos in malaria endemic areas formed the basis for formulating strategies for the control of vectors and subsequent surveillance activities. Insecticide residual spray, larvivorous fishes and enviromental management were the basic strategies for vector control. The whole program was augmented by an active community participation in all eradication activities.

INTRODUCTION

It is a well-known fact that until 1962 malaria was endemic in some areas of the Ryukyu Archipelago (Shiroma, 1955; Yoshino, 1956; Tanaka *et al,* 1959; Kuroshima, 1960; Yaeyama Health Center, 1962; WHO, 1966; Teruya, 1975; Sakihara, 1979) where it was transmitted mainly by *An. minimus* Theobald and *An. sinensis* Wiedemann. Information on malaria transmission pattern in the Ryukyu Archipelago and its subsequent eradication in the area appears in different scattered published and unpublished literature. As most of this literature is in Japanese language only, its distribution was limited to the Japanese language area. Vector control formed an integral part of the malaria eradication program in the Ryukyu Archipelago. The drastic reduction of anopheline mosquitos in this area was subsequently followed by the reduction of incidence of malaria among the human population. It is therefore considered that vector control through different operations during the program contributed greatly to the eradication of malaria in the Ryukyu Archipelago.

Correspondence : Dr Ichiro Miyagi, Laboratory of Medical Zoology, School of Health Sciences, Faculty of Medicine, University of the Ryukyus, 207 Uehara, Nishihara-cho, Okinawa 903-01, Japan.

Since a great deal of literature concerning malaria and its vectors in this area are in Japanese (Taira *et al,* 1984a,b; Ishigaki City, 1989; Eshita, 1982; Miyara, 1990; Sakihara, 1994) and since the success of malaria eradication in the area was in a greater part contributed by the control of vector mosquitos, we attempt in this paper to review the available, reliable literature on the biology and population dynamics of malaria vector mosquitos in the Ryukyu Archipelago before and after the commencement of the malaria eradication program. We also revised on the recent situation of *An. minimus* in Ishigaki and Miyako Is. We hope this will help in the dissemination of pertinent information which had been difficult to understand by some readers due to the language barrier and limited circulation of the documents.

Geographical features of the Ryukyu Archipelago

The Ryukyu Archipelago consists of a chain of islands extending about 1,000 km southwest from Kyushu Island, Japan (Fig 1). Among them are Okinawa Islands, Miyako Islands and Yaeyama Islands, which are the main focus of this review. The islands enjoy a maritime and subtropical climate which is characterized by high temperature and humidity except the winter season from December to February. The landform of the islands varies greatly depending on the geological features from which they were originally formed. Okinawa and Yaeyama Islands have some mountains and

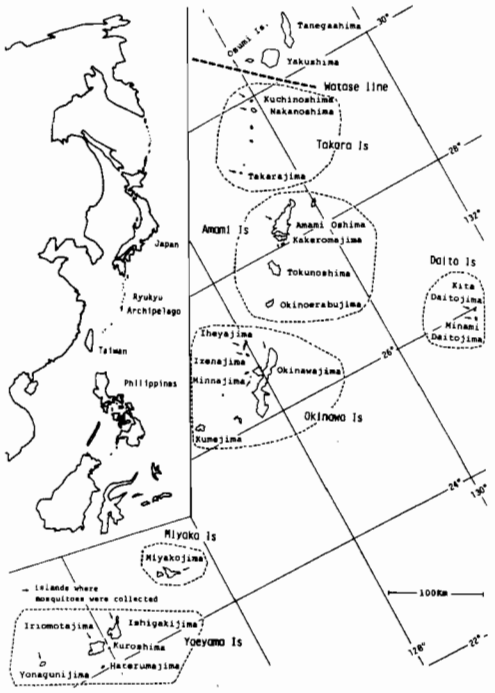


Fig 1– Map of the Ryukyu Archipelago.

hills, while these features are lacking in Miyako Islands. The differences in geomorphological features explain the varied pattern of hydrological features of the land which in turn have direct impact on the breeding habitats of mosquito vectors of malaria. Because of the varied nature of the ecology of mosquito in these islands, each group of islands will be treated separately to review the information on the population dynamics of the malaria vectors and the control activities.

Distribution of malaria vectors in the Ryukyu Archipelago

As shown inTable 1, eight species of anopheline mosquitos have been recorded in the Ryukyu Archipelago (Toma and Miyagi, 1986). Four of these species are potential vectors of malaria. These include *Anopheles sinensis, An. lesteri* Baisas and Hu, *An. minimus* and *An. saperoi* Bohart and Ingram. *Anopheles sinensis* and *An. lesteri* are natural vectors of *Plasmodium vivax.* They are widely distributed throughout south-eastern Asia to northern part of Japan. *Anopheles sinensis* and *An. lesteri* are morphologically so similar that they are often treated together as the *Anopheles sinensis* complex.

Table 1

Distribution of *Anopheles* mosquitos occurring in the Ryukyu Archipelago.

Species	Ryukyu Archipelago																Oriental region (incl Taiwan)	Palaearctic Japan
	Nakano Is	Takara Is	Kuchino Is	Amami Is	Tokuno Is	Okinawa Is	Iheya Is	Izena Is	Kume Is	Miyako Is	Ishigaki Is	Iriomote Is	Kuro Is	Yonaguni Is	Kita Daito Is	Minami Daito Is		
An. bengalensis				•	•												+	
l. japonicus	•	•																+
s. saperoi						•												
s. ohamai											?	•						
sinensis	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	+	+
lesteri				•		•	•				•	•		•			+	+
minimus										•	•	•		?			+	
tesselatus						•					•	•					+	

•, + : *Anopheles* spp present
(Based on the data by Toma and Miyagi, 1986)

Anopheles minimus is a well-known vector of *falciparum* malaria. It is widely distributed from south-eastern Asia to as far as Miyako Island which appears to be the northern geographical limit of this species. The larval habitats of *An. sinensis* complex are mainly fallows and rice fields, while *An. minimus* usually breeds along the banks of unpolluted streams.

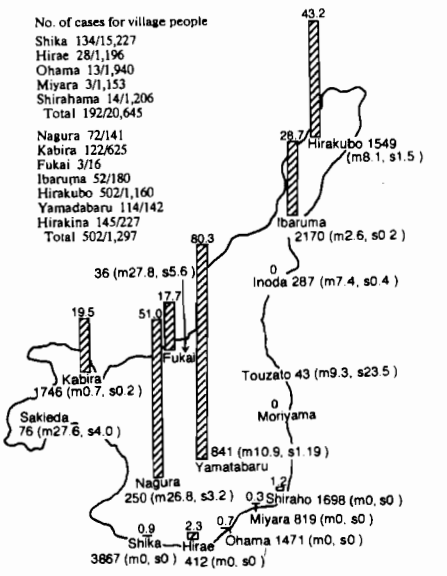
Anopheles saperoi is usually found in the hill forests. It is believed to comprise two subspecies, *An. s. ohamai* Ohama and *An. s. saperoi* (Tanaka *et al*, 1979; Toma and Miyagi, 1986). The two subspecies are geographically isolated; the former is endemic in Ishigaki and Iriomote islands while the latter is confined to the mountainous areas of northern part of Okinawa Island (Table 1). Like *An. minimus*, *An. saperoi* usually breeds along the margins of clean water streams.

Situation of malaria and vector mosquitos before DDT residual spray

Ishigaki Island. Ishigaki Island belongs to a group of 15 islands collectively known as Yaeyama Islands. Some of these islands are inhabited. The inhabited islands include Ishigaki (222.46 km^2), Iriomote (289.27 km^2), and 11 other small islands such as Hatoma (0.96 km^2), Kuro (10.02 km^2), Aragusuku (1.76 km^2), Hateruma (1.75 km^2), Yonaguni (28.8 km^2), Kohama (7.81 km^2) and Taketomi (5.42 km^2). Fig 2 shows the number of *Anopheles* larvae collected in different localities in Ishigaki Island between the years 1938 and 1942. The histograms in the figure show the incidence of malaria cases in 1942. During this period, Shika, Hirae, Ohama, Miyara and Shiraho were considered non-malarious because very few cases of malaria were reported. Correspondingly, no *Anopheles* mosquito was collected in these areas during the same period (Yoshino, 1956). In Ohama Village, for example, among the 1471 mosquito larvae collected, neither *An. minimus* nor *An. sinensis* larvae were found. Conversely, there were many malaria cases in areas such as Nagura (51.0%) and Yamatabaru (80.3%), which also had abundant larvae of *An. minimus* and *An. sinensis*.

Table 2 shows the results of the surveys for anopheline mosquitos carried out in Ishigaki Island 1946-1947 (Ohama, 1947; Miyara, 1990). It was the period when the socioeconomic condition was adversely affected by the effects of World War II. During this period, malaria cases increased tremendously. Insecticides had not yet been used for the control of vector mosquitos. In a survey carried out in nine different localities of Ishigaki Island during this period, a total of 2,463 mosquito larvae was collected in 140 habitats out of which 28.5% were *An. minimus* and 13.2% were *An. s. ohamai*. Table 3 shows the results of the surveys for adult mosquitos done in 1947 (Ohama, 1947; Miyara, 1990). In Ishigaki Island, a total of 194 *An. sinensis* mosquitos was obtained in 19 surveys carried out in 10 places of cow sheds and one stable. *Anopheles sinensis* was very abundant in these animal sheds. In human dwellings, mosquito surveys were carried out nine times. During these surveys 12 adults of *An. minimus* and only two of *An. sinensis* were found. The implication of these findings was that *An. minimus* rather than *An. sinensis* was common in human dwellings.

Iriomote Island and nearby Islands. The central part of Iriomote Island is covered with mountainous forests. The villages are located in the periphery of the island and all were endemic for malaria. Both *An. minimus* and *An. sinensis* were found in Iriomote Island and Yonaguni Island during the larval surveys from 1938 to 1942 (Fig 3). For example, among the 189 mosquito larvae collected in Amitori area,



* The bars for each locality show incidence (%) of malaria cases for 1942.

Adjacent to the name of locality is the total number of mosquito collected and the numbesr in parenthesis the percenlages of *An. minimus* (m) and *An. sinensis* (s) for all mosquito larvae collected.

Based on the data by Yoshino (1956).

Fig 2– Results of larval survey (1938-1942) and incidence of malaria in Ishigaki Island (1942).

Table 2

Results of anopheline larval surveys in Ishigaki Island (1946-1947).

Locality	No. breeding habitats surveyed	Number (and %) of mosquito larvae collected			Total
		An. sinensis	*An. minimus*	*An. s. ohamai*	
Ishigaki	24	324 (92.3)	16 (4.6)	11 (3.1)	351
Ohama	19	353 (90.3)	38 (9.7)	0 (0.0)	391
Nagura	30	251 (48.7)	262 (50.9)	2 (0.4)	515
Yarabu	8	123 (70.3)	0 (0.0)	52 (29.7)	175
Kabira	13	79 (39.9)	119 (60.1)	0 (0.0)	198
Fukai	18	139 (39.9)	154 (44.2)	55 (15.8)	348
Sukubaru	10	60 (28.3)	66 (31.1)	86 (40.6)	212
Inoda	8	21 (14.8)	31 (21.8)	90 (63.4)	142
Hirakubo	10	25 (19.1)	16 (12.2)	30 (16.8)	131
Total	140	1,435 (58.3)	702 (28.5)	326 (13.2)	2,463

(Base on the data by Ohama, 1947 and Miyara, 1990)

Table 3

Results of surveys for anopheline mosquitos (adults) in Ishigaki Island in 1947.

Locality	Animal sheds*				Human dwellings				Farms				Caves				Forest			
	survey	s	m	oh	survey	s	m	oh	survey	s	m	oh	survey	s	m	oh	survey	s	m	oh
Ishigaki	1	9	0	0									1	0	0	0				
Ohama	2	18	5	0	2	0	5	0												
Nagura	2	72	0	0	2	0	4	0												
Yarabu	1	0	0	0					1	0	0	0	1	0	0	0				
Kabira	1	4	0	0	1	0	0	0									1	0	0	0
Fukai	2	78	2	0	1	1	1	0												
Sukubaru									1	0	10	0								
Inoda	1	1	2	0	1	1	1	0												
Hirakubo	2	12	1	0	2	0	1	0												
Total	19	194	10	0	9	2	12	0	2	0	10	0	2	0	0	0	1	0	0	0

*10 cow sheds, 1 stable. s : *An. sinensis*; m : *An. minimus*; oh : *An. saperoi ohamai.*
(Based on the data by Ohama, 1947 and Miyara, 1990)

0.5% were *An. minimus* and 3.2% were *An. sinensis*. The incidence of malaria in this area was 16.7% in 1942 (Yoshino, 1956).

The nearby small islands except Yonaguni Island had very few cases of malaria. It was considered that the reported cases of malaria in these islands were probably those brought in from Ishigaki and Iriomote Islands. Correspondingly, no vectors of malaria were found in these islands except in Yonaguni and Kohama Islands. Yonaguni Island was an endemic area and inmatures of *An. minimus*

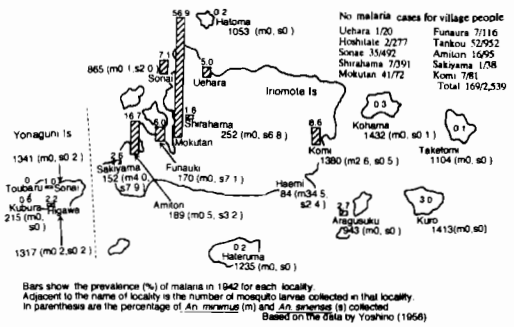


Fig 3– Results of the larval surveys in Iriomote Island, Yonaguni Island and other nearby islets (1938-1942).

and *An. sinensis* were commonly found in 1934 and 1938 to 1942 (Miyara and Nakazato, 1936; Yoshino, 1956).

Miyako Islands. Miyako Islands consist of eight islands, of which, Miyako Island (158.47 km^2) and Irabu Island (29.03 km^2) are the larger ones. These islands differ in many aspects from those of Yaeyama Islands. From the geomorphological point of view, most of these islands belong to the extensive depression land form and are commonly known as low islands. They are mostly covered by marine terraces and lowlands, and are composed of the Ryukyu limestone. They have residual limy soil. This type of soil has a poor water holding capacity which consequently has a direct effect upon the land water systems. The main sources of water in Miyako Islands are wells and springs from which small streams ramificate. These are the main breeding habitats of *Anopheles* mosquitos in these areas. Fig 4 shows the larvae collected on Miyako Island in 1955 when DDT spray had already started to be used to control malaria vectors. A total of 208 mosquito larvae was collected in Shirakawata area of Hirara City, out of which 68.8% were *An. minimus* and 23.1% were *An. sinensis* (Shiroma, 1955). These results also indicated that anopheline larvae were abundant in these areas. Similar results were also obtained in Nagakita area of Gusukube Town as well as in Kawamitsu and Sugama of Shimoji Town.

Malaria control operations before and after Word War II

Yaeyama Islands. Various measures were carried out to control malaria in Ishigaki and Iriomote Islands before and after World War II (Table 4). In this review, attention is focused on those measures

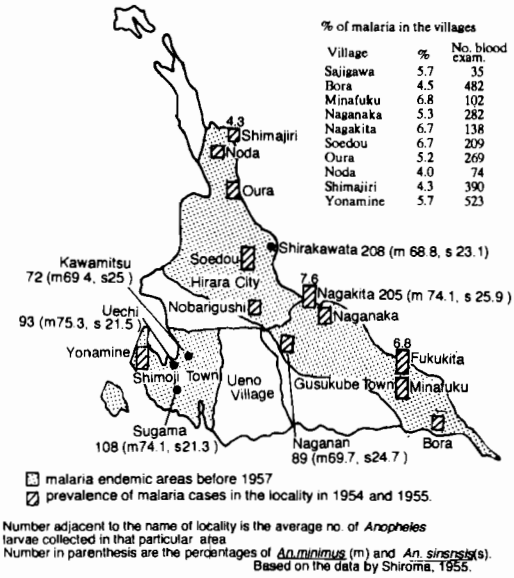


Fig 4– Results of larval surveys in 1955 in the malaria endemic areas of Miyako Is.

aimed at controlling vector mosquitos.

The history of malaria control efforts in Ishigaki and Iriomote Islands can be traced back to 1896. Between the year 1896-1913, malaria control measures centered mainly on control of malaria parasites in the human population. Anti-mosquito measures were not given priority. During the period between 1922-1944 anti-mosquito measures started to be incorporated as additional strategy for controlling malaria in endemic areas. These measures involved cutting of bushes and trees near residential houses, drainage of swamps, burying pools and ponds and introduction of larvivorous fishes (*Gambusia* spp) in the streams. During the same period as shown in Table 4, the number of malaria cases for a year fluctuated between 704 and 2,255 cases (Kuroshima, 1960; Yaeyama Health Center, 1962; Teruya, 1975; Sakihara *et al,* 1994).

In 1945, the period just after the World War II, malaria patients surprisingly increased drastically. From 1947, larval control measures included using organochlorine chemicals such as 10% DDT kerosene solution of 2% Chlorden solution which were sprayed in rice flelds and water pools. The slow releasing chemical application equipment was used to spray larvicides in the rivers and streams. Vector control measures were carried out with parasite control in human population. As a result, both

Table 4

Malaria control operations in Yaeyama Island (1896-1962).

Year	Human population	Malaria cases	Control measures against parasites and vector mosquitos
1896-			**1892-1913**
1913	-	-	**Against parasites** : treatment of clinical cases by quinine.
1922	23,548	1,127	**1922-1944**
1923	26,578	831	**Against parasites** : treatment of parasitemics by quinine and clinical cases by atebrin.
1924	26,881	887	**(major)**
1925	26,418	1,720	**Against mosquito larvae** : cut down bushes and trees around houses in endemic areas, drain
1926	29,241	886	**(minor)** swamps, bury pools of water, introduce Gambusia fishes.
1927	29,991	1,055	1894 Three spp of malaria were identified for the first time by Dr Miura
1928	30,511	1,568	1921 Malaria control office was established in Yaeyama
1929	29,918	2,024	1926 Extension and re-organization of malaria control office
1930	30,126	1,387	
1931	31,621	1,197	
1932	31,546	1,324	
1933	31,646	1,070	**1945-1947**
1934	36,322	1,298	**Against parasites** : treatment of clinical cases with atebrin in endemic areas.
1935	35,992	1,223	1947 Govenment of Yaeyama established by-lows for control
1936	35,456	957	**1947-1954**
1937	35,188	1,303	**Against parasites** : mass chemotherapy and treatment of all clinical and presumptive cases
1938	36,198	2,255	with atebrin in endemic areas.
1939	36,672	1,399	**Against mosquitos** : spray 5% DDT kerosene solution inside houses.
1940	36,979	704	Treat all breeding habitats with 10% DDT dust or 2% chlorden solution
1941	36,137	922	by a slow releasing formulation (drip) method. General clearing of
1942	35,273	930	bushes and cutting of trees within 2 km distance around living houses.
1943	35,276	937	1949 Emigrants from Okinawa and Miyako to Ishigaki Is.
1944	47,553	-	
1945	31,371	16,884	
1946	35,731	9,050	
1947	38,573	6,594	
1948	42,134	799	
1949	43,546	17	**1955-1956**
1950	43,986	35	**Against parasites** : treatment with chloroquine or primaquine for all clinical cases and
1951	46,137	74	parasitemics.
1952	47,471	405	**Against mosquitos** : spray chlorden or DDT kerosene solution into breeding streams and
1953	48,642	1,610	rivers.
1954	42,234	2,039	
1955	47,656	1,865	
1956	48,415	2,211	
1957	47,411	1,730	**1957-1962**
1958	49,240	370	**Against parasites** : treatment of clinical cases with chloroquine or primaquine and mass
1959	49,075	58	**(minor)** chemotherapy with chloroquine in endemic areas.
1960	51,431	4	**Against mosquitos** : DDT residual spray.
1961	51,442	5	**(major)** "Wheeler's plan"
1962	-	0	

(Based on the data by Kuroshima, 1960, Yaeyama Health Center, 1962, Teruya, 1975 and Sakihara *et al*, 1994).

malaria cases and population of vector mosquitos diminished drastically, indicating success of the integrated intervention measures.

From 1957 to 1962, the strategy for vector control in Ishigaki and Iriomote Islands was principally aimed at adult mosquitos (Table 5). All localities were treated by DDT residual spray. DDT spraying was carried out in the interior of all houses, store barns, animal and vehicle sheds, and all kinds of shelters. The first seven sprays were done thoroughly once every six months in all places which had apopulation of 40,000-44,000 people. The 8th and 9th sprays were done once a year and were focused mainly on areas which had inhabitants of less than 12,000 people, except those of Ishigaki City and Ohama Town. Larval control measures were also carried out, though at a small scale. DDT

Table 5

Control measures carried out against mosquitos in Yaeyama Island (1957-1962).

Anti-mosquitos operations by "Wheeler's plan":	
Chemical and method :	DDT residual spray.
Area sprayed:	All localities of Ishigaki Island and Iriomote Island.
Structures sprayed:	5% DDT suspension prepared from 75% DDT wettable powder were sprayed in structures of rough construction with porous materials such as straws, cement, stones, etc.
	5% DDT kerosene solution were sprayed on structures of non-porous, smooth or hard surfaces and bed nets, boats and automotive vehicles were sprayed.
	10% DDT dust were sprayed in open spaces between ground and first floor of living houses.
Amount of insecticide:	2g of DDT per m^2.
Interval of spray:	Once in 6 or 12 months.
Spray coverange:	91-98.5% of habitats, structures and materials, etc.

Spraying schedule

Spray	Period	No of people receiving service
(In Ihigaki and Iriomote except Yonaguni and other isolated islands)		
1st	August 1957 - February 1958	44,582
2nd	March 1958-August 1958	43,638
3rd	September 1958-February 1959	41,083
4th	March 1959-August 1959	41,034
5th	September 1959-January 1960	40,660
6th	February 1960-July 1960	41,501
7th	August 1960-January 1961	43,254
(In Iriomote and Ishigaki Island except the urban areas of Ishigaki City and Ohama Town)		
8th	1961	11,872
9th	1962	11,872

(Based on the data by WHO, 1966)

and chlorden were exclusively used in breeding habitats such as stream-bed pools, and where breeding of vectors occurred (WHO, 1966).

Miyako Islands

Malaria control measures in Miyako Islands were mainly similar to those of Yaeyama Islands (Tables 6 and 7). However, during the period between 1957-1960, DDT spraying was done selectively in Miyako Islands, focusing on endemic areas only (Tanaka *et al,* 1959; WHO, 1966; Shimozato 1973; Eshita, 1982).

Table 6

Malaria control operations in Miyako Island (1827-1962).

Year	Population of human	No. of malaria cases	Control measures against parasites and vector mosquitos
1927	58,187	1,301	**1927-1947**
1928	60,153	1,456	**Against parasites (major)** : treatment of clinical cases and parasitemics using quinine. From 1938, atebrin and plasmohin were also used.
1929	61,158	437	
1930	61,298	211	**Against mosquito larvae (minor)** : environmental management by clearing ditches and streams. Introduction of Gambusia fish into breeding habitats.
1931	62,903	165	
1932	62,950	174	1927 Malaria control office was established in Miyako.
1933	63,806	223	
1934	66,985	231	
1935	67,276	371	
1936	65,581	464	
1937	60,016	459	**1948-1956**
1938	70,668	1,792	**Against parasites (minor)** : treatment of all clinical cases with atebrin.
1939	68,518	1,253	
1940	68,700	564	**Against mosquito larvae (major)** : spray 5% DDT kerosene solution into ponds and rice fields: later changed to 10% DDT dust.
1941	64,418	917	
1942	-	1,135	Frequency of spray: once per week in spring and summer. Twice per month during autumn and winter seasons.
1943	-	1,435	
1944	50,799	-	Amount of spray : 2.1-5.5g of insecticide per 100 m^2.
1945	58,675	-	
1946	60,000	7,985	
1947	70,259	46,231	
1948	72,000	10,590	
1949	73,000	616	
1950	74,612	206	
1951	-	67	**1957-1960**
1952	-	123	**Against parasites (minor)** : mass chemotherapy in endemic areas using chloroquine and treatment of all clinical cases with chloroquine or primaquine.
1953	75,685	50	
1954	76,236	500	**Against adult mosquitos (major)** : spray DDT inside houses and animal sheds in endemic areas. "Wheeler's plan"
1955	77,645	313	
1956	76,460	124	
1957	76,542	66	
1958	-	12	
1959	-	1	
1960	72,339	0	

In 1927 the first office to organize malaria control activities in Miyako Island was established.

(Based on the data by Tanaka *et al,* 1959; WHO, 1966; Shimozato, 1973; Teruya, 1975; Eshita, 1982 and Sakihara *et al,* 1994).

Table 7

Control measures carried out against adult mosquitos in Miyako Island (1957-1960).

Chemical and method :	DDT Residual Spray.
Areas sprayed:	Malaria endemic areas (*ie* Gusukube Town, Hirara City and Shimoji Town)
Structures sprayed:	Interior of living houses: 5% DDT kerosene solution. Kitchens, storage barns and animal sheds, etc: 5% DDT suspension prepared from 75% DDT wettable powder. House floor surfaces: 10% DDT dust.
Frequency of spray:	Once in 6 months or 12 months.
Amount of Insecticide:	2.29 g of DDT per m^2.

(Based on the data by Tanaka *et al,* 1959; WHO, 1966; Shimozato, 1973; Eshita, 1982).

Table 8

Results of the mosquito surveys carried out during and after the period of DDT residual spray.

Yaeyama Islands

Larval collection

January 1961 (After 7th DDT residual spray):
No vector mosquito was collected.

March 1961 : No vector mosquito was collected, same as above.
(last case of malaria was recorded in Ohara, Iriomote Island).

January - December, 1964 : Monthly routine *Anopheles* collections were made (After the 9th DDT residual spray).

Locality	Habitats surveyed	Habitats with *An. minimus* larvae	Total number of larvae collected (range per collection)	
			An. minimus	*An. sinensis*
Ishigaki Island	32	13	315 (0-91)*	6,210 (228-1,206)**
Iriomote Island	22	4		

In total, 20,905 collections by dips were carried out.

* The number of *An. minimus* larvae collected increased during the period February-March and July and December.

** The highest number of *An. sinensis* larvae was recorded in January to June with a decline in May and a rise again in December.

(Based on the data from WHO, 1966)

Results of mosquito surveys during and after the use of DDT residual spray

Yaeyama Islands

Table 8 shows the results of mosquito surveys done during and after the period of DDT residual spray from 1957 to 1962 (WHO, 1966). Records of mosquitos were not available for Ishigaki and Iriomote Islands during this time of residual spraying. There were no regular mosquito surveys during this period. Nevertheless, fragmentary mosquito surveys were carried out in these islands in January (when the 7th spray was done) and in March 1961 when the last malaria case was found at Ohara in Iriomote Island. Apparently no anopheline mosquito was collected during these surveys. From various surveys conducted in 1964 in Ishigaki and Iriomote Islands two years after the termination of DDT residual spray, a total of 315 larvae of *An. minimus* and 6,210 larvae of *An. sinensis* was collected by 20,905 dips during this period (WHO, 1966). In 210 nights from June to December, 1964, only six *An. minimus* and 33 *An. sinensis* were collected by one light-trap in Ishigaki Island and two light-traps in Iriomote Island. These results confirmed the remarkable decrease of malaria vectors, especially *An. minimus*.

Miyako Island. In Miyako Island a larval survey was carried out at 15 potential breeding habitats in 1959. Only a single *An. minimus* larva was collected at Kawamitsu in Shimoji Town. Another survey was carried out in Miyako Island from June to December 1964. During this time only one *An. minimus* was collected by the light trap method in 14 localities (WHO, 1966; Fukumine, 1959). The results of these surveys, like those of Ishigaki Island and Iriomote Island sugested that the malaria vectors were markedly reduced by DDT residual spray.

In 1969, filariasis control campaign was started in Miyako Island. During this campaign, malathion (an organophosphorus compound) was sprayed to

Table 9

Number of Anopheline larvae collected at different streams in Ishigaki and Iriomote Islands (1975-1977).

Date of collection	Locality*	No. of dipping	Anopheline larvae**			
			min	*sin-lest*	*ohama*	Total
Dec 1975	Mt forest	50	38	5	0	43
	Coastal forest	55	0	14	0	14
	Total	105	38	19	0	57
Apr 1976	Mt forest	89 (30)	223 (0)	8 (0)	0 (23)	231 (23)
	Coastal forest	55	0	12	0	12
	Total	144 (30)	223 (0)	20 (0)	0 (23)	243 (23)
Jul-Aug 1976	Mt forest	90 (30)	197 (18)	26 (0)	0 (86)	223 (104)
	Coastal forest	60	0	0	0	0
	Total	150 (30)	197 (18)	26 (0)	0 (86)	223 (104)
Apr 1976	Mt forest	85 (30)	41 (5)	29 (0)	0 (50)	70 (55)
	Coastal forest	60	0	6	0	6
	Total	145 (30)	41 (5)	35 (0)	0 (50)	76 (55)
Oct 1977	Mt forest	30 (30)	20 (26)	9 (0)	0 (9)	29 (55)
Grand total		574 (120)	519 (49)	109 (0)	0 (168)	628 (217)
Average no. per dip			0.9 (0.41)	0.19 (0)	0 (1.4)	1.09 (2)

* Mountain forest: Kawarayama, Noromizu and in Ishigaki
Coastal forest: Yoshihara and Arakawa in Ishigaki Is.

( ): Number of larvae collected in Komi and Otomi, Iriomote Is.

** *min: An. minimus, sin-les: An. sinensis* and *An. lesteri, ohama: An. s. ohamai.*

(Based on the data by Miyagi and Toma, 1978)

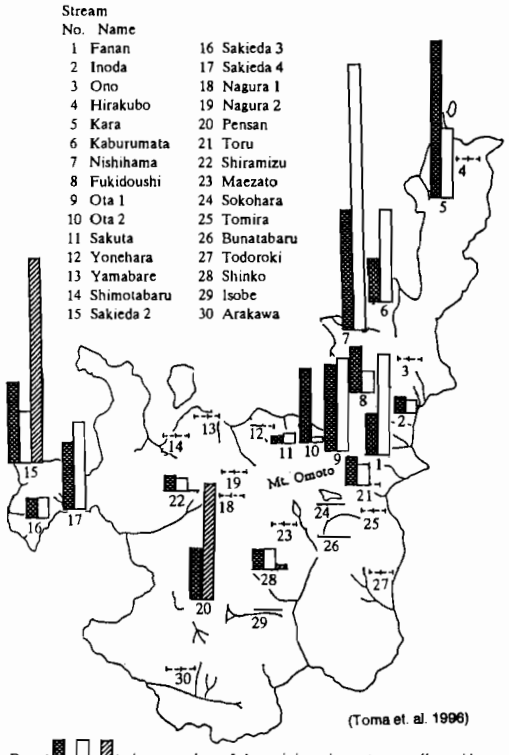
control *Culex quinquefasciatus* the vector of filariasis. A total of 24,456 adult mosquitos was collected during this period using the light trap method in 1977 nights. The proportion of *An. minimus* and *An. sinensis,* was extremely low, being 0.008% and 0.2% respectively (Kishimoto *et al,* 1985).

Recent observations on the mosquito dynamics

Yaeyama Islands. Table 9 shows the results of anopheline mosquito survey in Ishigaki Island and Iriomote Island from 1975 to 1977, that is 13 to 15 years after the use of DDT for residual spray. Larval surveys were carried out in streams of mountainous and coastal forest areas. During this time 519 larvae of *An. minimus* and 109 of *An. sinensis* including *An. lesteri* were collected by 574 dips in Ishigaki Island. In Iriomote Island, 49 *An. minimus* and 168 *An. s. ohamai* larvae were collected by 120 dips. It was evident that the larvae of *An. minimus* in Yaeyama Islands had started to increase (Miyagi and Toma, 1978). Since August, 1990, surveys on the distribution and dynamics of *Anopheles* larvae were reintroduced in Ishigaki Island. Thirty streams were surveyed and about 66.7% of the surveyed streams was incriminated as breeding habitat of anopheline mosquitos. Almost all the larvae collected in the streams were *An. minimus,* and the population increased from July to September and decreased in March (Toma *et al,* 1996). Mosquitos were collected five times from 1977 to 1981 in Yonaguni Island and no *An. minimus* was found but *An. sinensis* was very common (Miyagi and Toma, 1983).

Miyako Islands

Kishimoto *et al* (1985) reported that the relative abundance of *An. minimus* larvae was 0.05-0.54 per dip inGusukube Town and 2.0-6.8 per dip in Shimoji Town in surveys carried out from 1980 to 1983 in 17 streams and springs which were malaria endemic areas before 1957 (Fig 6). Many adults on this species, about 21.0% of 1,954 mosquitos were collected by light trap in Nakazato of Shimoji Town in 1981. Recently, Toma *et al* (1996) studied the abundance and distribution of *An. minimus.* The larvae were collected in only 5 of 23 sites surveyed in 1991 and 5 of 17 sites in 1995 (Fig 7); the relative abundance was apparently low, being 0.04 to 0.14 per dip in 1991 and 0.2 to 1.1 per dip in 1995. *An. minimus* larvae were found and the number collected was 0.04-0.09 larvae per dip. Since the first



Bars (, ,) show number of *An. minimus* immatures collected by 4 persons in 30 minutes in Aug., 1990, Nov., 1990 and Oct., 1991, respectively. Length of the bars indicate 100 immatures.
shows that immature of *An. minimus* was not collected.
The number under the bars show the stream surveyed.

Fig 5– Distribution and abundance of *Anopheles minimus* in 30 streams of Ishigaki Is.

construction of underground dam in 1979, the volume of water in the streams has been reduced significantly. With the rapid reduction of streams, the population of *Anopheles* mosquitos was also reduced.

Okinawa Island

In Okinawa Island about 160,098 people contracted malaria in 1946, the period just after the World War II (Sakihara *et al,* 1994; Teruya, 1975). It was reported that during this period an outbreak of malaria occurred among most of the people who took refuge in the mountains of the northern part of Okinawa Island.

WHO (1966) reported that *An. sinensis* was the main vector of malaria in an epidemic which occurred in the forests of the northern part of Okinawa Island. However, according to the results of mosquito surveys carried out recently, we now consider that the endemic species *An. s. saperoi* might have

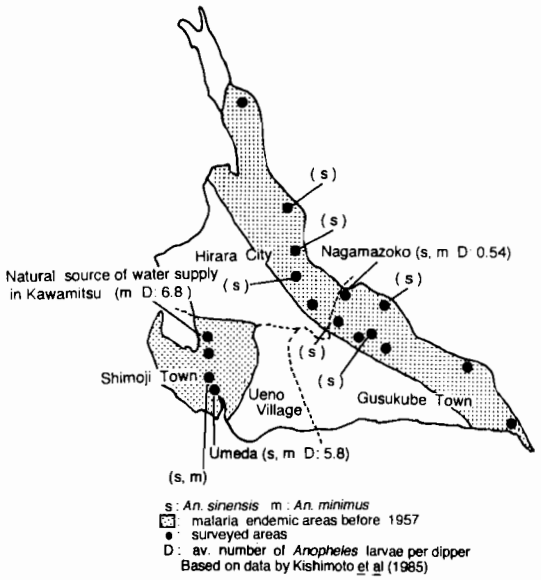


Fig 6– Distribution of malaria vector mosquitos in Miyako Is (Dec 1980; April 1981 and March 1983).

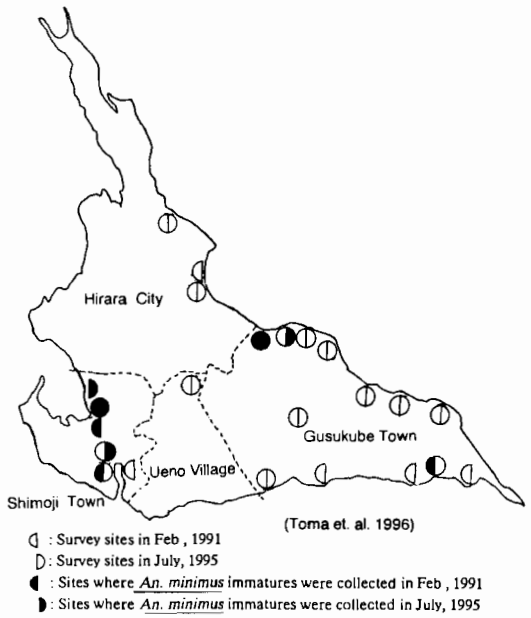


Fig 7– Distribution of *An. minimus* in 23 survey sites of 21 streams in Miyako Is, 1991 and 1995.

played an important role in the transmission of malaria epidemics in 1945-1948. The reason is that many immatures of *An. s. saperoi* and fewer of *An. sinensis* had always been found in the forest streams in all surveys carried out recently (Toma and Miyagi, 1986). This indicates that *An. s. saperoi* is the most abundant species in these areas. Besides this, *An. s. saperoi* has a strong anthropophillic behavior. Female mosquitos of this species are vicious biters of humans especially during the day-time (Toma and Miyagi, 1986). It is now being considered that many people might have been attacked by this mosquito in their hiding places during the World War II. During this period many people were displaced from their homes to escape the fierce battle in the lowlands and were forced to hide in the forests of northern Okinawa where they lived temporarily in small huts. The mass movement of people into forest areas resulted in temporal change of the biological balance between mosquito and hosts. It is most likely that human beings became the main source of blood meals for these day time mosquito biters. In due course malaria parasites were incidentally transmitted throughout the population. Furthermore, *Anopheles saperoi* in Yaeyama Islands (nowadays in treated as subsepecies *An. saperoi ohamai*) was experimentally susceptible to *Plasmodium vivax* (Ohama, 1947).

CONCLUSION

From the above facts we now consider that the main vectors, when malaria was endemic in the Ryukyu Archipelago were *Anopheles sinensis* complex in the open lowland areas of Okinawa Island, and *An. saperoi* in the foot of mountains and forest regions. In Miyako, Ishigaki, Iriomote and Yonaguni Islands, *An. minimus* was the principal vector of tropical malaria (*Plasmodium falciparum*) while *An. sinensis* complex was the main vector of quartan malaria (*Plasmodium vivax).*

All anopheline mosquitos apparently became potential transmitter of malaria, because during the war, there were several displacements of people from their homes. This resulted not only in change of the biological balance in areas where they settled, but also they became exposed to forest mosquitos which consequently changed their feeding behavior. Most of the people suffered high malnutrition and were weak. The consequence of these factors was the observed amplification of malaria cases which apparently were brought about by lack of acquired immunity against malaria infection

among the transmigrants accompanied by severe weakness of their body defense mechanism due to malnutrition.

The most important keys to the success of malaria eradication program in the Ryukyu Archipelago were : (1) the stringent control of anopheline mosquitos using DDT residual spray (which at that time was a new technology introduced by Dr CM Wheeler and popularly became known as "Wheeler's plan"), (2) the excellent active participation of the whole community during the attack phase of the program, and (3) the effective strong willed leadership of Dr S Ohama who was the director of Yaeyama Health Center and an instrumental figure in the planning and implementation of all operational activities in this program of malaria eradication (Kitzmiller, 1982). The combination of these factors enabled the complete extermination of vector mosquitos within a very short period of time before they could develop resistance against insecticides. The effect of these combined efforts was the disruption of malaria transmission cycle in all areas of the Ryukyu Archipelago.

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