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INTEGRATED CONTROL OF THE DENGUE VECTOR *AEDES AEGYPTI* IN LIU-CHIU VILLAGE, PING-TUNG COUNTY, TAIWAN

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ABSTRACT. Because of an inadequate supply of potable water, villagers of Small Liu-Chiu Isle, Ping-Tung County, Taiwan, store water in containers supporting a large population of *Aedes aegypti.* In 1989–96, integrated control measures against *Ae. aegypti* were implemented on the basis of community participation. These measures included release of mosquito larvivorous fish in the drinking water storage facilities, application of larvicides to the water storage facilities in vegetable gardens, removal of discarded and unused containers and tires, improvement of household water storage facilities, and increase of potable water supply. Before implementation of the integrated control measures in 1988, 74% of the water-containing vessels were water storage facilities, and 24% of those were infested by *Ae. aegypti.* In 1989, the Breteau index for the entire island, indicating the average distribution density for larval *Ae. aegypti,* was 53.9, as compared to an index of 1.2 in 1996. In 4 villages located at the southwest and middle of the island, *Ae. aegypti* nearly became extinct because of the enthusiastic participation of the community. Before the implementation of integrated control, *Ae. aegypti* was the dominant species in containers both inside and outside the household, but after the integrated control, *Aedes albopictus* became predominant outside.

KEY WORDS Larvivorous fish, community participation, public health education, Breteau index, *Aedes albopictus, Aedes aegypti*

INTRODUCTION

Liu-Chiu Village, Ping-Tung County, also known as Small Liu-Chiu Isle, is a small islet located southwest of Taiwan about 15 km from Tung-Kang Cheng, Ping-Tung County. Because of the lack of fresh water supplies, villagers store water in containers, of which most are infested with mosquito vectors of dengue fever. This condition caused an outbreak of type II dengue fever in June 1981 with 80% of the island population contracting the disease (Hsien et al. 1982). Data from Lin et al. (1986) showed that the Breteau index for *Aedes aegypti* (L.) larval distribution density was 73.0. Despite this, when the government tried to improve the water supply by upgrading the under-the-sea water supply pipe in 1981, villagers still believed the supply was insufficient and continued to store water in various containers. Thus, the problem of the breeding of *Ae. aegypti* in water container remained. In 1988, Wei and Hsu surveyed mosquito larvae in water containers. They found that cement tanks, steel drums, and pottery jars had a high level of mosquito larvae with a container index ranging from 35 to 22%. They also observed that *Ae. aegypti* was the dominant species both inside and outside the house. Lien et al. (1989) also reported similar observations in Taiwan and Small Liu-Chiu Isle. In December 1987, the 1st epidemic of dengue fever, with 1,387 cases, occurred in Tung-Kang Cheng, Ping-Tung County (Ko 1989). Patients infected with dengue virus from the Philippines were suspected of initiating the epidemic. Small Liu-Chiu Isle is located near the Philippines, where fishermen visit frequently and may be infected with dengue fever. To prevent the recurrence of dengue epidemics and to prevent the occurrence of hemorrhagic dengue, a large-scale integrated vector control program was carried out on Small Liu-Chiu Isle between 1989 and 1996. This paper reports the strategy and the effectiveness of such control programs. These include surveys for the willingness of the residents to participate, types of containers examined, mosquito larval habitats, and applications of larvivorous fish or larvicides. Different types of public health education program were also provided.

MATERIALS AND METHODS

Control area

The control program was conducted in Small Liu-Chiu Isle, located at 22°19′48″N, 120°21′55″E, and 15 km southwest of Tung-Kang and 33 km southeast of Kao-Hsiung. The island measures 4 km from north to south and 2 km from east to west, with an area of 6.8 km^2. The mean annual temperature on the island is 24.5°C and annual precipitation is 2,000 mm, with the rainy season lasting from May to August. There are 8 villages in this island (Fig. 1). The villages of Penfu, Chungfu, and Yufu are located in the northeast, Shanfu, Shangfu, and Tafu are in the middle, and Tanfu and Nanfu are in the southwest. Proportions of households and populations in each of the 3 areas are shown in Fig. 2.

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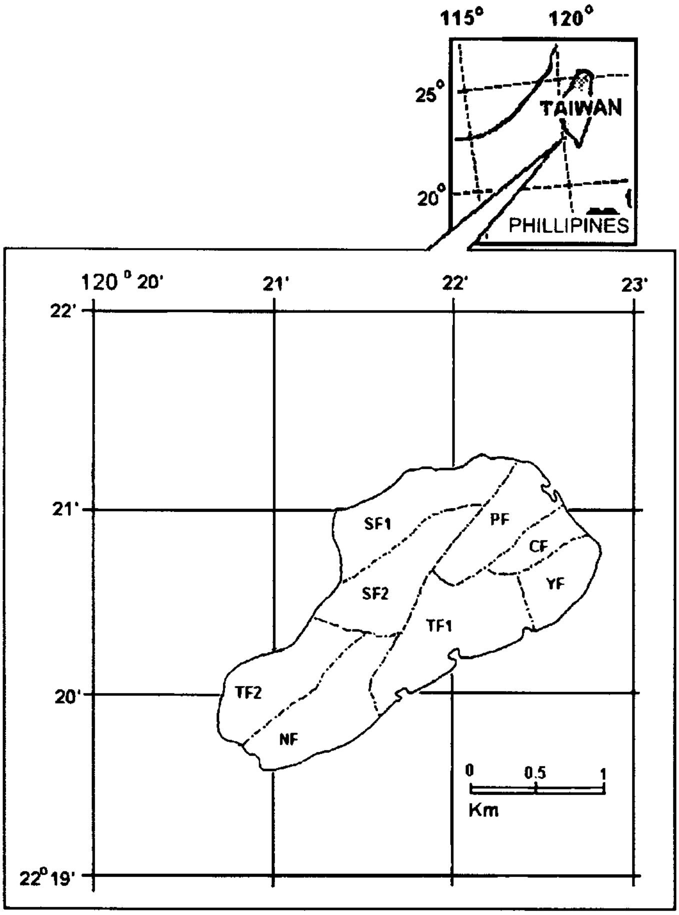

Fig. 1. Map of the Small Liu-Chiu Isle. The northeastern area includes the villages of Penfu (PF), Chungfu (CF), and Yufu (YF). The middle area includes Shanfu (SF1), Shangfu (SF2), and Tafu (TF1). The southwestern area includes Nanfu (NF) and Tienfu (TF2).

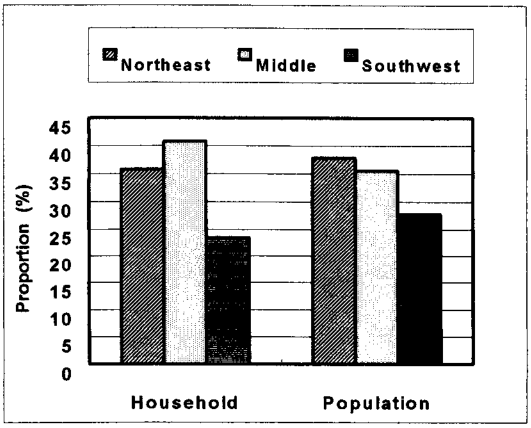

Fig. 2. Distribution of households and populations in 3 areas of Small Liu-Chiu Isle.

People on this island practice fishing as a way of life. They commute to the outside via ferry. No rice is cultivated on the island but vegetable gardens are maintained next to households. Albizzia is cultivated on the island. The public water supply is inadequate in quantity and is turned off frequently. People store water in containers for drinking and other household uses, thus providing habitat for *Ae. aegypti* and *Aedes albopictus* (Skuse).

Investigation of breeding habitats for *Ae. aegypti*

Survey of water containers: A survey was conducted in 1989 by grade and middle school teachers, who performed the survey after school by visits to every household. During these visits, they recorded the number and types of water storage containers.

Larval density of Ae. aegypti: From April 1988 to December 1996, larval density of *Ae. aegypti* in

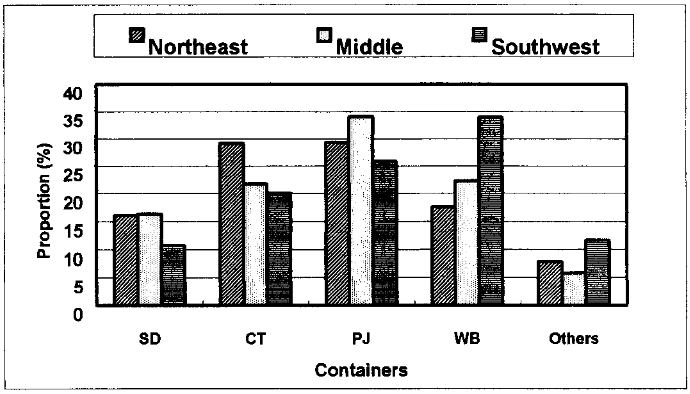

Fig. 3. Distribution of various types of containers in 3 areas of Small Liu-Chi Isle in 1989. SD, steel drum; CT, cement tank; PJ, pottery jars; WB, wooden barrel; others, vases, dishes, and discarded tires.

water storage containers both inside and outside the household was surveyed twice a month for all 8 villages. Simultaneously, public health education was offered to the villagers in a community participation fashion. Data for larval density were collected according to the established WHO (1972) method and expressed as Breteau index or container index. These indices were used to evaluate the efficacy of control measures as well as to make further improvements in the control strategy.

Integrated control of *Ae. aegypti*

Release of larvivorous fish into containers for potable water: Because of insufficient supply of drinking water from the public water system, islanders on Small Liu-Chiu store water in water containers that become breeding sites for *Ae. aegypti.* In the 1989 survey of the islanders' willingness to control *Ae. aegypti,* 32% of the households were found to be willing to try larvivorous fish in their water containers (Wang et al. 1990). Therefore, release of larvivorous fish into the storage containers of potable water was made from 1989 through 1992. In 1989, 5 releases of 17,600 fish were made including introduction of *Gambusia affinis* (Baird and Girard), *Poecilia reticulata* (Peters), *Tilapia mossambica* (Peters), and *Sarotherodon niloticus* (L.); these 4 species were replaced with *Cyprinus carassius* (L.) in 1990 because the latter had a constant availability and strong adaptability. Releases included 3 times in 1990 stocking 12,651 fish, 6 times in 1991 stocking 23,310 fish, and once in 1992 stocking 4,167 fish.

Application of larvicide to watering containers in vegetable gardens: For the control of *Ae. aegypti* in plant watering facilities, larvicides Abate and *Bacillus thuringiensis israelensis* (*Bti*) were used, because the sun would heat up the water to a temperature detrimental to larvivorous fish. Abate (1% temephos granules, American Cyanamid Co., Wayne, NJ) was placed into the containers at a final concentration of 1g per 1,000 liters of water. A total of 83.7 kg of Abate granules was used from 1989 to 1994. Beginning in 1995, *Bti* (200 ITU granule, Abbott Laboratories Co., North Chicago, IL) was applied at the same rate as Abate granules. Both larvicides were applied once every 3 months.

Reduction of abandoned containers or tires: Efforts were also made to reduce sources by the following activities. Information about health issues was given to the villagers through the grade and middle school teachers who performed the household visits after school. Inspectors promptly removed empty bottles, cans, and discarded tires while surveying the mosquito breeding sites. A public health campaign through broadcasting media also urged the islanders to eliminate all types of water-containing vessels from open land and vacant houses. In addition, clean up campaigns in each village or on an island-wide scale were implemented during the schools' winter break.

Improvement of islanders' water storage containers: Traditionally, the islanders used cement tanks, pottery jars, and steel drums for water storage. These containers lacked tight seals and covers, and thus allowed mosquitoes an easy passage for egg laying in these major breeding sites. Beginning in 1990, islanders were urged to set up stainless steel water towers, which not only have a very large capacity but also provide a tight seal or cover to prevent adult *Ae. aegypti* from entering

RESULTS

Residence visit and survey

Of 2,480 residences visited, a total of 5,533 water-containing devices was found. The results of individual household surveys for water containers are shown in Fig. 3. Among these, 14% (range 11–16%) were steel drums, 23% (20–29%) were cement tanks, 30% (26–34%) were pottery jars, and 24% (18–34%) were wooden barrels and other

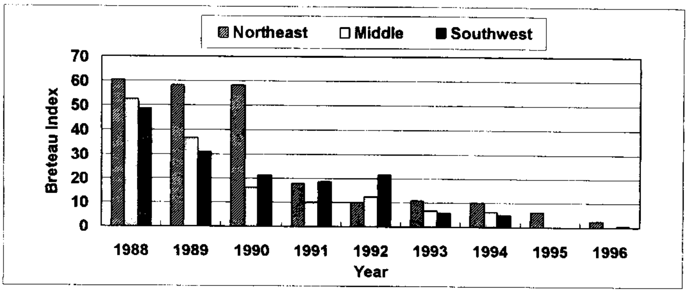

Fig. 4. The average larval density of *Aedes aegypti* observed in 1988 through 1996 in 3 areas of Small Liu-Chiu Isle.

types. One half of these containers were used for storing drinking water, the rest were for washing, cleaning, and plant watering (data not shown). Only less than 1% of the households were willing to destroy their cement tanks or replace them with stainless steel water towers, and 32% were willing to try larvivorous fish in their water containers. These results urged us to rank the release of the larvivorous fish in the drinking water containers as the 1st priority.

Survey of larval density of *Ae. aegypti*

Larval density of *Ae. aegypti* was surveyed for all 8 villages from 1988 to 1996. The results of yearly surveys of larval density of *Ae. aegypti* from 1988 to 1996 are shown in Fig. 4. Before implementing the integrated control, in 1988, the average Breteau index for the entire island reached 54. After the control measures were established, a significant decrease in index was observed at middle and southwestern areas beginning in 1990, and in northeast area in 1991. In 1995, no breeding of *Ae. aegypti* was found in 3 villages in the middle area. In 1996, the average Beateau index of the monthly survey for the whole island declined to 1.2, although a small number of larvae were identified in northeast areas and occasionally were found in the southwest villages from January to November in 1996. However, analysis of the data for December 1996 revealed that *Ae. aegypti* larvae no longer existed in any of the villages (data not shown).

Table 1. Breeding rate of *Aedes aegypti* in various water containers in 1989 and 1996, before and after the integrated mosquito control program (IMCP) was conducted in Small Liu-Chiu Isle.

Container	Before IMPC (1989)		After IMPC (1996)	
	No.	CI (%)[1]	No.	CI (%)
Vase and dishes	45	6.7	14	0
Cement tanks	41	48.7	56	1.8
Plastic drums	27	14.8	236	0.8
Steel drums	129	27.0	83	2.4
Pottery jars	84	32.0	121	1.7
Others[2]	83	9.0	41	0

[1] CI, Number of container with *Aedes* larvae/total number of that type of containers examined.

[2] Containers included vases, dishes, a variety of abandoned containers, and automobile tires.

Breeding containers for dengue vectors

The efficacy of control programs was also evaluated by the breeding rate for *Ae. aegypti* in the various water containers surveyed at the 8 villages. Results are shown in Table 1. Table 1 shows that among 409 containers accounted for, 69% were tanks, jars, and drums for water storage. The breeding rate for *Ae. aegypti* was highest in cement water tanks, followed by pottery jars and steel drums, with an average rate of 24% for all containers in April 1989. For April 1996, a total of 531 containers was inspected, of which 44% were plastic drums. *Aedes aegypti* larvae were found only in the water storage containers, with the highest rate for steel drums and a container index with an average rate of 1.3%. However, inspection of containers (n = 858) eventually showed no larvae breeding in December 1996. This absence of breeding may be attributed to the integrated mosquito control program.

A comparison was also made between the larvae of *Ae. aegypti* and *Ae. albopictus* in containers. The proportions of *Ae. aegypti* vs. *Ae. albopictus* in 1988, 1995, and 1996 are shown in Fig. 5. Before integrated control, water container–bred mosquitoes consisted of 65% *Ae. aegypti,* whereas after the integrated control the ratio was down to 22% in the northeastern villages. A similar reduction was also observed in other areas.

DISCUSSION

Studying breeding sites is the most important step for the control of *Ae. aegypti,* a dengue virus vector. The present investigation found that people in Small Liu-Chiu Isle were accustomed to storing water in various containers because of an inadequate supply of potable water. These containers became the primary breeding sites for *Ae. aegypti,*

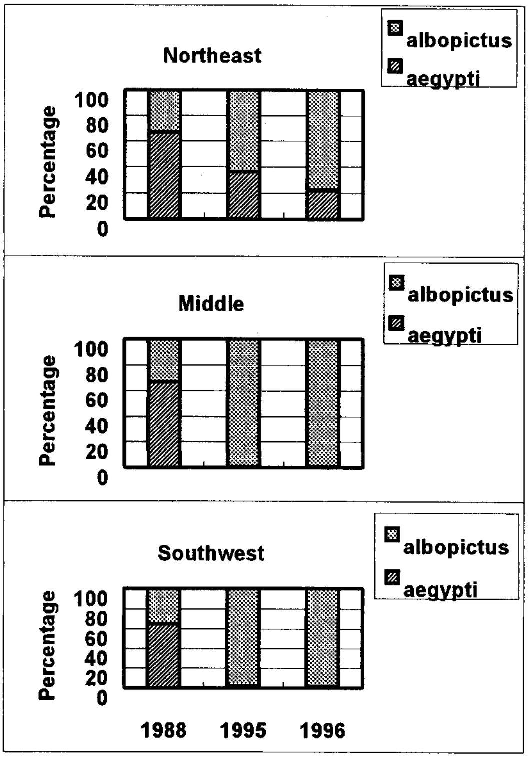

Fig. 5. The percentages of containers infested with larvae of *Aedes aegypti* and *Aedes albopictus* in 3 areas of Small Liu-Chiu Isle in 1988, 1995, and 1996. A reduction in dominance of *Ae. aegypti* was evident.

which was similar to the situation reported by Barker-Hudson et al. (1988) in the tropical islands of Australia. This is different from the situation found in Brazil, Mexico, and the Caribbean, where larvae of *Ae. aegypti* were mainly observed in discarded tires and containers (Nathan and Knudson 1991, Winch et al. 1992, Mazine et al. 1996). In 1988, cement tanks and pottery jars were the major containers with larvae of *Ae. aegypti* on Small Liu-Chiu Isle. The reasons for this might be that these containers were not covered tightly, and they always contained ample water and with a steady temperature. These conditions enhance adult egg-laying activity and the survival rate of mosquito larvae.

Because one half of containers were used to store water for drinking on Small Liu-Chiu Isle, the control strategy for dengue fever vectors was limited. In 1989, after the release of larvivorous fish in household containers of participating villagers, the larval index was significantly lower than that of nonparticipating households (Wang et al. 1990). After that, more and more people participated in the fish release project after some education and persuasion. When a dengue fever outbreak occurred in Chinese coastal provinces in 1980, the disease vector *Ae. aegypti,* breeding mainly in water storing containers in fishing villages, also was controlled by using larvivorous fish (Wu et al. 1987).

Although Abate has a low toxicity to mammals, and our survey indicated that only 1.5% of residents of Small Liu-Chiu Isle accepted Abate, according to Novak (1985), *Bti* was added to treatment program after 1995. A further decline of larval density was observed in 1996. Combining application of 2 larvicides with different modes of action may slow down the development of resistance in *Ae. aegypti* to Abate (Andrande and Modolo 1991).

In addition to water storage facilities, 28% of water-containing devices in Small Liu-Chiu Isle were in the form of vases, dishes, discarded tires, and various containers, all of which were also breeding sites for *Ae. aegypti.* Our study continued to push for community-supported efforts on source reduction, especially for the vacant houses in the southwestern area of the island. In this area, many discarded containers were left when residents emigrated. After reducing these containers, a significant reduction in the level of *Ae. aegypti* was shown in 1990. During 1991–92, a strategy of source reduction was not successful because of the shortage of manpower; this led to a slight increase of larval density. But thereafter larval density was decreased again because of residents' cooperation. A similar situation was observed in the middle area (Fig. 4). The density of households and populations was highest in the northeastern area (Fig. 2), and here the willingness of residents to participate in our vector control program was lower. Moreover, more tourists usually discarded containers more frequently in northeastern villages. These problems resulted in a slower decrease in larval density in this area.

Stainless steel water towers with tight covers were erected to prevent adult mosquitoes from laying eggs inside. Focks and Chadee (1997) reported that in Trinidad reduction of *Ae. aegypti* was achieved from removal of discarded containers from the environment and improvement of water storage facilities. According to Chan et al. (1993), the 1st government-sponsored integrated control program against the *Ae. aegypti* was implemented in Singapore to control epidemic hemorrhagic dengue fever in 1966. That program consisted of source reduction, education and persuasion, and legislative measures. Later, this kind of program was adapted by Thailand (Sucharit 1993), Malaysia (Lam 1993), Indonesia (Soedarmo 1993), Vietnam (Khin 1993), Brazil (Serufo et al. 1993), and Argentina (Aviles et al. 1997).

The ratio of *Ae. aegypti* to *Ae. albopictus* was examined in Small Liu-Chiu Isle by Wei and Hsu in 1988. Eighty-five percent of mosquito-infested containers were infested by *Ae. aegypti,* with indoor and outdoor infestation rates recorded at 46 and 15%. After the implementation of vector integrated control, our results indicated that *Ae. aegypti* was nearly completely replaced by *Ae. albopictus* except in the northeastern villages. Meanwhile, the average outdoor breeding rate ratio between *Ae. aegypti* and *Ae. albopictus* for the entire island also changed from 75 : 25 to 21 : 79. The replacement of *Ae. aegypti* outdoors by *Ae. albopictus* has been reported by O'Meara et al. (1992) at a cemetery in Florida, and in Mobile, AL, by Hobbes et al. (1991) after the introduction of control measures.

In 1995, we applied α-cypermethrin in 5 villages where many houses were vacant. Because the starting larval density was too low, showing any significant effect was difficult; therefore, the spray of α-cypermethrin was stopped after 1 trial. However, controlling *Ae. aegypti* with malathion by ultra-low volume (ULV) spray also showed poor results in Puerto Rico (Fox and Specht 1988). Chadee (1988) observed that when more than 6% of the houses were unoccupied, control projects seldom succeeded. Our study suggests that source reduction was more effective than adulticide spraying to reduce mosquito populations in areas with many vacant houses. In the last 20 years, dengue has had a drastic resurgence with increased frequency of epidemics and geographic expansion, aided by the overestimation of the usefulness of ULV applications of insecticides (Gubler and Clark 1996)

In the present study, we found that motivating people in a community to participate in integrated control programs was more effective for long-term control of dengue. This program was built on long-term surveys of larval density, release of larvivorous fish, improvement of water storage facilities, source reduction, and larvicide application. As suggested by Lloyd et al. (1994), our program took vector ecology, the subculture of the community, and the cultural background into consideration. This enhanced the cooperation of the islanders. Khin (1993) also stated emphatically that the concept of integrated control must be seeded deeply into the community structure; therefore, we continually educated islanders that mosquito control is everybody's responsibility. The effectiveness of these efforts was shown in the survey of *Ae. aegypti,* which was nearly eradicated. In 1987–88, 6 cases of dengue fever occurred in Small Liu-Chiu Isle; however, no cases have occurred since 1996 even though islanders are still storing water in their houses.

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