CURRENT INSECTICIDE RESISTANCE PATTERNS IN MOSQUITO VECTORS IN THAILAND

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Abstract. Chemical pesticides are still commonly used in Thailand for control of agricultural pests and disease vectors. Organophosphates, carbamates and synthetic pyrethroids are commonly used for agricultural purposes, whereas synthetic pyrethroids have become more popular and predominate for public health use. The genetic selection of insecticide resistance (whether physiological, biochemical or behavioral) in pests and disease vectors has been extensively reported worldwide (Brown and Pal, 1971). The long-term intensive use of chemical pesticides to control insect pests and disease vectors is often cited as the reason behind the development of insecticide resistance in insect populations. Unfortunately, reliable information on vector resistance patterns to pesticides in Thailand is sparse because of a remarkable shortage of carefully controlled, systematic studies. This review gathers useful information on what is presently known about disease vector resistance to chemical pesticides in Thailand and provides some possible management strategies when serious insecticide resistance occurs.

INTRODUCTION

Over the 20th century, insecticides of natural and synthetic origins have increased in importance and overall volume of uses as agricultural and public health needs have demanded. Years of routine use have led in some cases to high levels of chemical resistance by certain pests and disease vectors (Georghiou and Saito, 1983).

Resistance can be broadly defined as"the developed ability in a strain of insects to tolerate doses of insecticides which prove lethal to the majority of individuals in a normal population of the same species" (WHO, 1975). This ability is brought about by selection of individuals in a population with a genetically inheritable capacity to withstand insecticides, and not due to the action of the insecticide on a given individual insect. Therefore, the development of resistance is dependent on genetic variability already present in a target population or spontaneously arising during the period of selection (Oppenoorth, 1984). Development of physiological resistance by mosquitos, the most important group of medically important arthropods, was first reported in 1947 when *Aedes. taeniorhynchus* was shown to be resistant to DDT in Florida after only 4 years of use (Brown, 1986). The following 40 years of intensive use of organic insecticides to control insect pests and disease vectors has led to the extensive selection of insecticide resistance in more than 450 species (Georghiou, 1986). Resistance to insecticides has been reported in over 500 species of arthropods, including at least 109 mosquito species found resistant to organochlorines, primarily DDT and dieldrin (Roberts and Andre, 1994).

There are 2 principal types of responses to insecticides, one is physiological and the other is behavioral (avoidance). Physiological resistance, sometimes referred to as biochemical resistance, is the ability of mosquito to survive the effect of insecticide by mechanisms such as detoxifying enzymes. Behavioral avoidance is the ability of a mosquito to avoid the insecticide-treated surface by either direct contact irritancy or noncontact repellency or the combination of both, referred to as excito-repellency (Chareonviriyaphap *et al,* 1997).

Common resistance mechanisms in arthropods include: reduced sensitivity of altered acetylcholinesterases to organophosphates and carbamates; the *kdr* (knockdown resistance) insensitivity to DDT and pyrethroids; reduced neuronal sensitivity to chlorinated cyclodienes; increased metabolism by hydrolysis of organophosphates, carbamates and pyrethroids; increased activity of mixed function oxidases in DDT,

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organophosphate, carbamate and pyrethroid resistance; enhanced metabolism by glutathion-*S*-transferase in DDT and organophosphate resistance; enhanced metabolism by DDT-ase; and reduced cuticular penetration of DDT, organophosphate, carbamate, pyrethroids and chlorinated cyclodienes (Kerkut and Gilbert, 1985; Georghiou, 1986). An arthropod may possess more than one mechanism at work to avoid the adverse effects of various toxic compounds.

VECTOR-TRANSMITTED DISEASES IN THAILAND

Despite years of vector control and public health activities, several vector-borne diseases remain major health threats in Thailand, principally malaria, dengue fever and dengue hemorrhagic fever (DHF), lymphatic filariasis and Japanese encephalitis. All are transmitted by various species of mosquitos, some of which are capable of conveying more than one pathogen. The distribution of these important endemic vector-borne diseases in Thailand is presented in Fig 1. Malaria and lymphatic filariasis are more prevalent along the borders of eastern Myanmar, western Cambodia and northern Malaysia borders. All 4 dengue virus serotypes are widespread throughout the country, while Japanese encephalitis occurs mainly in the rice-growing areas of Thailand (Rattanarithikul and Panthusiri, 1994). Table 1 lists mosquito species known or suspected to act as important vectors of diseases in Thailand.

Malaria parasites are only transmitted by *Anopheles* mosquitos. Of the 74 *Anopheles* species recognized in Thailand, only 3 species are considered to be important malaria vectors. These are *Anopheles dirus, Anopheles minimus* and *Anopheles maculatus* (Malaria Division, 1994). All 3 taxa represent individual complexes; of which the respective sibling species are not easily separated from one another (Rattanarithikul and Panthusiri, 1994). *Anopheles dirus* is a forest and forest-fringe inhabiting mosquito, whereas *An. minimus* and *An. maculatus,* are associated with low hill zones and generally have closer contact with humans along the margin of villages. *Anopheles minimus* is commonly found along the quiet edges of slow moving streams and *An. maculatus* is often present at the margin of hilly forest zones, especially in rubber-plantation areas. All 4 human malaria parasites have been reported and can potentially be transmitted by all 3 malaria vectors. *Plasmodium falciparum* and *Plasmodium vivax* are common in Thailand, whereas *Plasmodium malariae* and *Plasmodium ovale* are considered rare occurrences (Rattanarithikul and Panthusiri, 1994).

Dengue is one of the most important arthropod-borne viral diseases in the world and commonly occurs throughout Southeast Asia (Gubler, 1988). Only 2 species of *Aedes* mosquitos, *Aedes aegypti,* an urban species, and *Aedes albopictus,* primarily a rural species, are known to be important dengue virus vectors in Thailand (Rattanarithikul and Panthusiri, 1994). *Aedes aegypti* is more prevalent around human dwellings and is a principal vector in the urban zones, whereas *Ae. albopictus* is considered to be an important vector in the rural areas. For larval habitats, *Ae. aegypti* prefers clean water found in many types of domestic containers inside or near human dwellings, whereas *Ae. albopictus* is more likely to be found in natural containers and outdoor man-made habitats (*eg* tree hole, leaf axils) containing a greater amount of organic debris (Rattanarithikul and Panthusiri, 1994).

Japanese encephalitis is an important mosquito-borne virus in Thailand. A number of different species in the genera *Culex* are responsible for Japanese encephalitis virus (JEV) transmission. The most important naturally infected vector of JEV in Thailand is *Culex tritaeniorhynchus*, followed by slightly less efficient vectors, *Culex fuscocephala, Culex gelidus, Culex vishnui* and *Culex pseudovishnui* (Burke and Leake, 1988). These mosquitos typically breed in pools associated with wet rice cultivation areas throughout the country. JEV transmission normally occurs as periodic epidemics in the rice-growing areas. Pigs are considered to be the major viral amplifying host and can circulate the virus without obvious disease symptoms. Besides pigs, there are several natural vertebrate reservoir hosts that can circulate JEV, primarily *Ardeidae* (egrets, night herons) birds. The potential roles of other animals as reservoir hosts remain unknown.

Lymphatic filariasis is also present in Thailand, consisting of at least 2 distinct species, *Wuchereria bancrofti* and *Brugia malayi* (Phothikasikorn, 1991). *W. bancrofti* is widely distributed along the western Thai-Myanmar border, whereas *B. malayi* is more prevalent in the south and along the Thai-Malaysia border area (Guptavanij and Harinasuta, 1977). The main vectors of *B. malayi* in the south of Thailand are *Mansonia* species, in particular, *Mansonia uniformis*. *Culex quinquefasciatus* is considered to be the principal vector of urban *W. bancrofti*. *Aedes* species such as *Ae. neveus* along with some *Anopheles* species have been implicated as either secondary or possible vectors of lymphatic filariasis in Thailand (Rattanarithikul and Panthusiri, 1994).

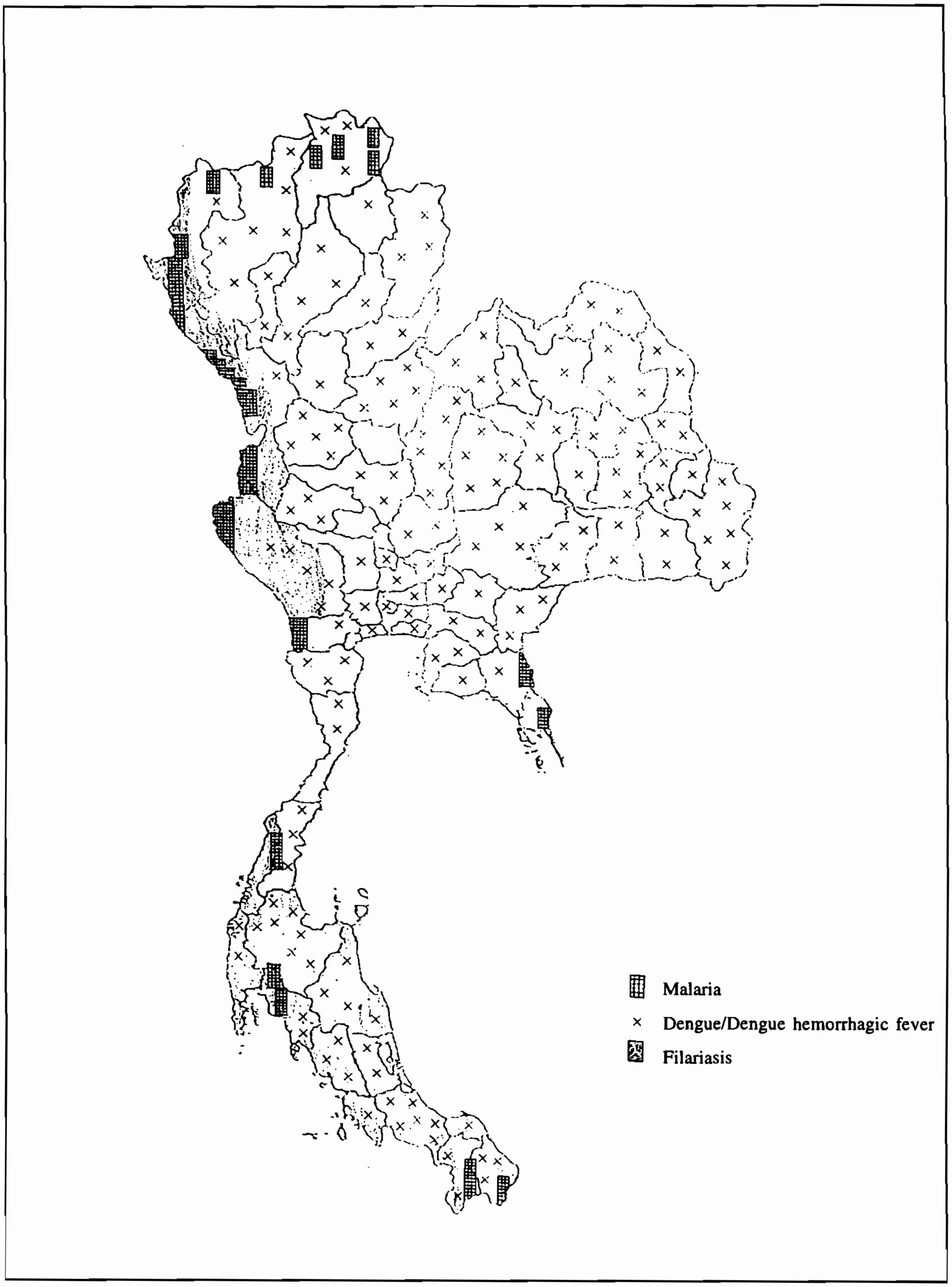

Fig 1–Distribution of malaria, DF/DHF and filariasis in 1997 in Thailand.

Table 1
Confirmed, secondary and suspected vectors of human diseases in Thailand.

Diseases	Vectors	References
Malaria	Main vector *(Anopheles)*	
	1. *An. dirus*	(Rosenberg *et al*, 1990)
	2. *An. minimus*	(Harrison, 1980)
	3. *An. maculatus*	(Malaria Division, 1995)
	Secondary vectors	
	1. *An. sundaicus*	(Scanlon *et al*, 1968)
	2. *An. aconitus*	(Gould *et al*, 1967)
	3. *An. psuedowillmori*	(Green *et al*, 1991)
	Suspected vectors	
	1. *An. barbirostris*	(Harrison and Scanlon, 1975)
	2. *An. philippinensis*	(Rosenberg *et al*, 1990)
	3. *An. campestris*	(Malaria Division, 1995)
	4. *An. culicifacies*	(Harrison, 1980)
Dengue	Main vector *(Aedes)*	
(Type 1-4)	1. *Ae. aegypti*	(Watts *et al*, 1987)
	2. *Ae. albopictus*	(Gould *et al*, 1968, 1970; Chan *et al*, 1971)
Japanese encephalitis	Main vector *(Culex)*	
	1. *Cx. tritaeniorhynchus*	(Gould *et al*, 1974)
	2. *Cx. gelidus*	(Gould *et al*, 1974)
	3. *Cx. fuscocephala*	(Gould *et al*, 1974)
	4. *Cx. pseudovishnui*	(Mourya *et al*, 1991)
	5. *Cx. vishnui*	(Gould *et al*, 1974)
Lymphatic filariasis	Several *Anopheles, Aedes, Mansonia,* and *Culex* mosquitos	(Rattanarithikul and Panthuiri, 1994)

INSECTICIDES USED IN PUBLIC HEALTH AND OTHER SECTORS IN THAILAND

In Thailand, many chemical compounds, including organochlorines, organophosphates, carbamates, synthetic pyrethroids and so-called biorational pesticides, have been used in both agricultural practices and public health control programs. This review concentrates on public health insecticide usage and their impact on disease vectors. For years, DDT was used for malaria control as an indoor residual spray in Thailand. DDT was withdrawn for all agricultural uses beginning 1983 and has been decreasing overtime for malaria control use (Table 2). Although, DDT importation was stopped in 1995, remaining stocks of DDT were still be used in some malaria problem areas of Thailand. The reasons for the removal of DDT from malaria control in Thailand was because of reported vector resistance and perceived adverse impact on the environment. However, the true impact of DDT on mosquito vectors in terms of behavioral effects and disease transmission remain poorly studied. Synthetic pyrethroids (*eg*. permethrin and deltamethrin) are the current insecticides of choice for malaria control in Thailand. These pyrethroids have been used for the impregnation of bed nets and/or as indoor residual house spray in many parts of the country. Temephos (Abate®), an organophosphate, is regularly used in containers for the control of *Ae. aegypti* larvae. Ultra-low-volume (ULV) applications of fenitrothion and malathion are used during the peak period of adult *Aedes* populations, especially during the rainy seasons (June to November each year). *Bacillus thuringiensis israelensis (Bti)*, a safe and commonly used biopesticide, is being used for the control of *Ae. aegypti* larvae in indoor containers. Types of compounds, currently used in public health control programs in Thailand, are presented in Table 3.

Thailand remains principally an agricultural country. Rice, along with several tropical products such as palm, rubber and oranges, represent major commercial and export crops. Many of these crop-growing areas (*ie*, rice fields, rubber plantations and palm) are also suitable habitats for various disease vectors. To control the wide variety of crop pests and disease vectors, several major groups of pesticides are being used concurrently. Quantity and cost value of insecticides imported to Thailand each year from 1978-1997 are relatively high, reaching a peak in 1996 with 14,398 imported tons, costing an estimated 1.57 billion baht (US$=62 million based on the old rate of 1US$=25 Baht) seen in Table 4. Table 5 illustrates yearly quantity (in tons) of pesticides by classes imported for use in Thailand from 1985 to 1997. Overall, use of organophosphates and synthetic pyrethroids has been increasing over time, along with some carbamates, as the pesticides of choice compared to organochlorines.

CURRENT RESISTANT STATUS OF MOSQUITO VECTORS IN THAILAND

Arthropod-borne diseases are an ever increasing cause of death and suffering worldwide. Thailand is endemic for several serious vector-borne diseases, including malaria, dengue fever and DHF, lymphatic filariasis and Japanese encephalitis. Increases in human population and demographic movement of the people in many parts of the country have led to great deforestation, irrigation and urbanization. Many of these environmental changes have favored conditions for increasing vector transmission of diseases. Past efforts to control these diseases in Thailand have focused on the routine use of chemical insecticides. In the malaria control program, the application of indoor residual insecticides to control *Anopheles* mosquitos has become less acceptable to local people and vector resistance to many commonly applied pesticides is now regarded as a major impediment to disease control. Resistance in some disease vectors has been documented with several major groups of pesticides and the present knowledge of vector resistance to chemical insecticides are shown in Table 6.

In Thailand, information on vector resistance to insecticides is limited due to a remarkable shortage of comprehensive and carefully designed studies. This paper provides some useful background

Table 2
Quantity (tons) of DDT imported for use in Thailand for agricultural and public health purposes.

Year	Agricultural use (tons)		Public health use (tons)	
	AI	Formulation	AI	Formulation
1977	227	859	1,350	1,800
1978	597	1,683	999	1,322
1979	300	953	570	1,484
1980	378	1,487	390	520
1981	83	264	225	720
1982	14	36	594	986
1983	Banned	Banned	345	460
1984			522	696
1985			399	600
1986			485	647
1987			468	623
1988			387	516
1989			414	552
1990			492	656
1991			430	574
1992			418	557
1993			346	462
1994			254	339
1995*			161	215

AI = Active ingredient; *Stop purchasing

Table 3
Historical use of chemical insecticides used in mosquito control programs in Thailand.

Class of compounds	Name of pesticides	Use	Date-present
1. Organochlorine	DDT	Malaria	1949
2. Organophosphate	Temephos	Dengue	1950
		Malaria	unknown[a]
	Fenitrothion	Malaria	1983[a]
		Dengue	unknown
	Malathion	Dengue	unknown
3. Carbamate	Propoxur	Dengue	unknown[b]
	Pirimiphosmethyl	Dengue	1990[a]
	Bendiocarb	Malaria	unknown[a]
4. Pyrethroids	Permethrin	Malaria	1992
	Deltamethrin	Malaria	1994
	Lambda-cyhalothrin	Malaria	1990[a]
	Etofenprox	Malaria	1991[a]
5. Biopesticide	*Bacillus thuringiensis*	Dengue	1990[a]
	isrealensis (Bti)	Malaria	1989[a]
	Bacillus sphearicus	Dengue	1986[a]
	(Bs)	Malaria	1986[a]

a = small scale
b = indoor use

Table 4
Quantity and approximate value of all insecticides imported for use in Thailand from 1978-1997.

Year	Quantity (tons)*	Value (million baht)
1978	10,809	514
1979	10,571	679
1980	10,045	785
1981	6,625	792
1982	5,588	692
1983	6,718	631
1984	8,233	884
1985	7,284	855
1986	8,299	928
1987	6,673	765
1988	8,034	1,137
1989	9,068	1,206
1990	9,356	1,472
1991	7,233	1,244
1992	7,903	1,386
1993	7,330	1,193
1994	7,708	1,150
1995	7,708	1,644
1996	14,398	1,570
1997	12,151	1,761

*organochlorines, organophosphates, carbamates, synthetic pyrethroids and insect growth inhibitors

Table 5
Yearly quantity (tons) of pesticides by class imported for use in Thailand.

Years	Organochlorines (tons)	Organophosphates (tons)	Cabamates (tons)	Synthetic pyrethroids (tons)
1985	622	4,190	917	132
1986	510	4,492	1,060	161
1987	835	5,381	998	133
1988	624	5,463	1,550	226
1989	-	-	-	-
1990	-	-	-	-
1991	-	-	-	-
1992	-	-	-	-
1993	444	4,814	1,386	314
1994	462	5,352	967	348
1995	697	6,157	1,605	409
1996	657	6,231	1,232	231
1997	543	6,123	1,231	342

- Not available

information on the status of insecticide resistance. DDT has been used in malaria control for decades as a safe and effective insecticide with a long residual life. For many years, chemical companies have been developing synthetic pyrethroid pesticides as alternatives or replacements for DDT. These synthetic pyrethroids have shown great promise for insect control due to their fairly low mammalian toxicity and outstanding potency at low doses that rapidly immobilize and kill insects (Prasittisuk, 1994). However, overtime, physiological resistance to these compounds has been detected in numerous arthropods, including *Anopheles* species (WHO, 1992; Malaria Division, 1985-1998). Increasing resistance to pyrethroids is of particular concern because Thailand has been extensively using synthetic pyrethroids, such as permethrin and deltamethrin for malaria control.

Malaria vector resistance to insecticides has been monitored, based on the results of standard World Health Organization contact susceptibility tests using discriminating dosages (WHO, 1981a). Tests are regularly conducted by the 5 Regional Malaria Zones, located throughout the country. Results are reported to the Malaria Division, Department of Communicable Disease Control, Ministry of Public Health, Thailand. In 1985, there was no evidence of insecticide resistance in mosquito vectors from any region of Thailand. In 1986, development of physiological resistance to DDT was detected in *An. aconitus* from the north (Table 6) where DDT was commonly used for malaria control. A year later, development of resistance to DDT was found in field collected mosquitos of *An. philippinensis, An. nivipes* and *Anopheles aconitus* from the same northern region. Between 1990 and 1997, the development of physiological resistance to DDT had been detected in all 3 primary malaria vectors, *An. dirus, An. minimus* and *An. maculatus*, mostly from the northern part of Thailand (Table 6; Fig 2). This apparent rise and spread of DDT resistance in these *Anopheles* mosquitos could be attributed to the rapid and increased use of DDT either for malaria control or use of other related organochlorines for agricultural needs. Resistance and inherent environmental problems associated with DDT use resulted in a change to the synthetic pyrethroids for impregnation of bednets and intradomicillary spraying programs beginning in 1992. Unfortunately, development of insecticide resistance to permethrin was shown in a population of *An. minimus* from northern Thailand, approximately 1 year after its introduction into the program (Malaria Division, 1997). In general, malaria vector resistance to DDT and permethrin is more prevalent in areas of the northern Thailand (Fig 2). This might be a reflection of more monitoring of the resistance status by entomology teams in the areas. Furthermore, mosquito population numbers remain quite stable in these northern areas compared to the other parts of the country. Malaria teams in other parts of the country often encounter very low seasonal mosquito populations resulting in incomplete insecticide susceptibility monitoring. Therefore, careful and complete monitoring of *Anopheles* vectors resistant to insecticides, especially synthetic pyrethroids, should be of a major emphasis of public health activities.

Table 6
Development of insecticide resistance in mosquitos vectors in Thailand detected from 1985-1995 (based on WHO standard diagnostic concentrations of insecticides).

Mosquitos	Insecticides	Regions	Locations[a]	Date
An. dirus	DDT (4%)	North	Lampang, Mae Mao, Ban Dong	1995
	DDT (4%)	North	Lampang, Maung, Ban Lang	1995
An. minimus	Permethrin (0.25%)	North	Phrae, Rong Kwang, Huay Rong	1992
An. minimus	DDT (4%)	North	Uttaradit, Ban Khok, Ban Khok	1990
An. maculatus	DDT (4%)	North	Uthaitanee, Ban Rai, Ban Rai	1990
	DDT (4%)	North	Phrae, Rong Kwang,Pai Ton	1994
An. aconitus	DDT (4%)	North	Chiangrai, Chiang Khlong, Vieng	1986
	DDT (4%)	North	Phayao, Pong, Ngim	1986
	DDT (4%)	North	Phayao, Chiang Kham, Rom Yen	1986
	DDT (4%)	North	Chiang Rai, Turng, Hngaoa	1986
	DDT (4%)	North	Chiang Rai, Chiang Khlong, Vieng	1987
	DDT (4%)	North	Phayao, Chiang Kham, Rom Yen	1987
	DDT (4%)	North	Lampang, Tung, Mai Mog	1991
	DDT (4%)	North	Phayao, Chiang Kham, Rom Yen	1991
	DDT (4%)	North	Chieng Rai, Turng, Hngaoa	1991
	DDT (4%)	North	Chiangrai, Chiang Khong, Chiang Khong	1992
	DDT (4%)	North	Chiangrai, Chiang Khong, Vaing	1994
	DDT (4%)	North	Phayao, Chiang Kham, Rom Yen	1995
	DDT (4%)	North	Phayao, Chiang Kham, Rom Yen	1995
An. culicifacies	DDT (4%)	North	Chiang Mai, Chom Tong, Ban Pae	1991
	DDT (4%)	North	Chiang Mai, Chom Tong, Ban Pae	1994
An. nivipes	DDT (4%)	North	Chiang Rai, Thoeng, Hngaoa	1987
	DDT (4%)	North	Nan, Thung Chang, Pou	1987
	DDT (4%)	North	Nan, Sa, Eye La Nai	1987
	DDT (4%)	North	Phrae, Song, Sa Aead	1987
	DDT (4%)	North	Chiang Rai, Thoeng, Hngaoa	1988
	DDT (4%)	North	Phayao, Chaing Kham, Rom Yen	1988
	DDT (4%)	North	Uttaradit, Ta Pa, Nam Mun	1989
	DDT (4%)	North	Chiang Rai, Thoeng, Hngaoa	1989
	DDT (4%)	North	Chiang Rai, Thoeng, Hngaoa	1990
	DDT (4%)	North	Chiang Rai, Thoeng, Hngaoa	1991
	DDT (4%)	North	Chiang Rai, Thoeng, Hngaoa	1992
	DDT (4%)	North	Chiang Rai, Thoeng, Hngaoa	1994
	DDT (4%)	North	Phayao, Chaing Kham, Rom Yen	1994
An. philippinensis	DDT (4%)	North	Chiangrai, Thoeng, Hngaoa	1987
	DDT (4%)	North	Phayao, Chiang Kham, Rom Yen	1987
Ae. aegypti	Malathion	Northeast	Si Sa Ket[b]	1992
	(1.0 ppm)	Northeast	Ubon Ratchathani[b]	1992
	Malathion	Central	Bangkok[b]	1992
	Malathion	Northeast	Udon Thani[b]	1993
	Temephos	Central	Bangkok[b]	1986
	(0.2 ppm)	North	Phayao[b]	1990
	Temephos	Central	Bangkok[b]	1992
	Fenitrothion (0.05 ppm)	North	Lampang[b]	1990
Cx. quinquefasciatus	Malathion (1.0 ppm)	Central	Bangkok[b]	1986
	Malathion	South	Pattani[b]	1991
	Malathion	Central	Ratchaburi[b]	1991
	Malathion	Northeast	Nakhon Ratchasima[b]	1992
	Temephos (0.2 ppm)	Central	Bangkok[b]	1986
	Temephos	Northeast	Nakhon Ratchasima[b]	1992
	Temephos	North	Phitsanulok[b]	1993
	Temephos	Central	Suphan Buri[b]	1995

[a]In some areas, routine programs for susceptibility testing was not possible due to the shortage of mosquitos.
[b]Information on District not available.

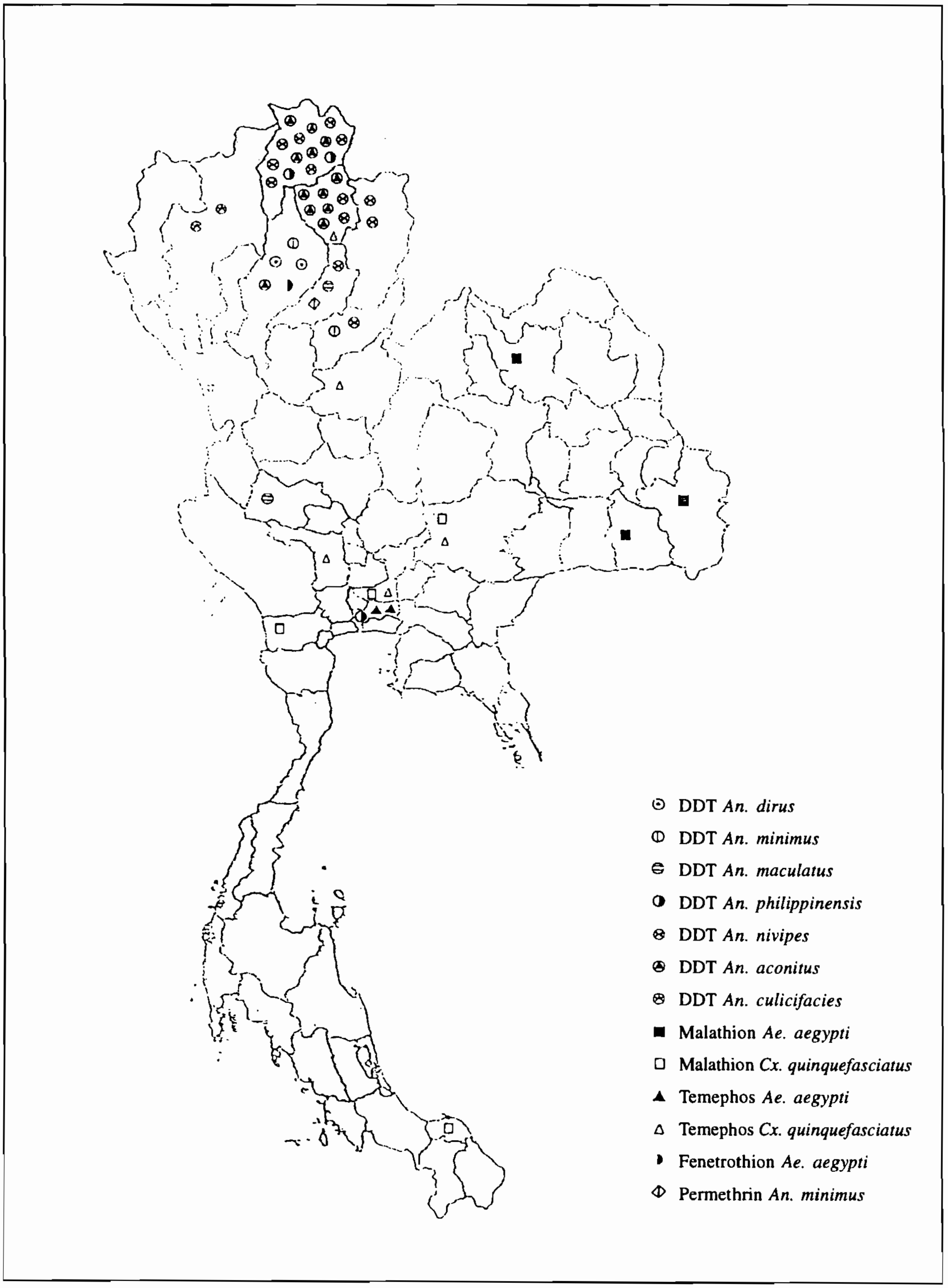

Fig 2–Distribution of mosquito vectors resistance to chemical insecticides in Thailand.

Evidence of resistance to malathion, temephos and fenitrothion in *Ae. aegypti* and *Cx. quinquefasciatus* has been observed, based on data from 1985-1998 the WHO susceptibility tests for larvae (WHO, 1981b). In 1986, there was evidence of the development of resistance to temephos and malathion in Bangkok mosquito strains of *Ae. aegypti* and *Cx. quinquefasciatus*. A few years later, development of physiological resistance to other organophosphates and carbamates was detected in *Ae. aegypti* and *Cx. quinquefasciatus* populations of the south, north, northeast and central parts of the country where those chemicals were commonly used for mosquito control.

Insecticide resistance in mosquito vectors could have arisen from the common use of the same insecticides by other sectors such as agriculture, forestry and from general public health use (operational and household uses). In agriculture, most pesticides are toxic to disease vectors and other insects. Mosquito vectors are normally found resting and breeding in agricultural habitats, where they are exposed to those insecticides. Resistance development might possibly be related to the foraging habits of female in search of bloodmeals. In host seeking behaviors, female mosquitos may spend more time in pesticide treated areas either indoors or outdoors closed to preferred hosts. Additionally, household products, mainly organophosphates, carbamates and synthetic pyrethroids, are commonly used in homes and may be an important cause of insecticide resistance, especially in the house-haunting mosquito, *Ae. aegypti*.

Efforts to control resistance patterns in insects have been proposed to prevent or slow the development of insecticide resistance and to manage the impact of resistance to new insecticides (Brattsten *et al*, 1986). Various countermeasures have been proposed for avoiding the development of insecticide resistance in mosquitos (Georghiou, 1980; Brown, 1981; Leeper *et al*, 1986; Plapp, 1986; Croft, 1990). Methods include varying the doses of insecticide applied, using restricted rather than wide area applications, applying insecticides only when vector-borne transmission occurs, using of less persistent insecticides, rotation of insecticides, and protecting the natural enemies of vectors, all to help minimize the selection pressure from insecticides. Use of an integrated control approach including the application of bacterial toxins and use of biological control organisms has been encouraged (Brown, 1981; WHO, 1986; Roberts and Andre, 1994; Chareonviriyaphap, 1995).

In conclusion, insecticide resistance monitoring should be detected and evaluated as early as possible and should be increased in both periodicity and geographical coverage in Thailand to include as many known vectors as possible. Detection of incipient or operationally unacceptably high levels of physiological resistance will alert public health authorities to take appropriate steps to counter potential reduced control efforts. Moreover, control programs should remain aware of cross-resistance to many related insecticides that may arise from the wide use of the same groups of synthetic compounds against mosquito populations and agricultural pests.

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