

## Chapter 2

### The study village

#### 2.1 Introduction

The mountainous area of Northern Thailand is home to ethnically diverse groups, many of whom have been living in the area for several hundred years or more, the Karen, Lua and H' Tin in particular. Others, e.g., Hmong, Lisu, Lahu, Yao and Akha, have recently arrived from neighboring countries and settled in Northern Thailand since the 1950's (Kunstadter, 1978). All of these minority groups are generally referred to as traditional shifting cultivators who practice slash and burn cultivation for major staple crops such as upland rice, maize and other traditional crops and vegetables or some cash crop for supplement income which used to include opium (Kunstadter and Chapman, 1978; Grandstaff, 1980 and ONCB-UNFDAC, 1983). With long term assistance from external agencies and government programs, which has significantly improved road access into the mountains, many highland communities, former opium growers in particular, have shifted their production systems to alternative land use with intensive cash crops. Remote villages above 1,000 m were relocated to lower elevation where development supports and services could be accessible. Resettlement projects (Nikhom Chao Khao) were implemented in early 1960s, and the evaluation of department has shifted to participatory in late 1980s and remains to be adopted up to now. At present, mountain villages have all become sedentary, movement of whole communities is

become very rare and production systems were more intensive forms of permanent agriculture with much restricted rotation.

In Tee Cha, the study village, external development pressure has been relatively small, inconsistent and temporary. Nevertheless, traditional shifting cultivation has been under many pressures and the production system has been reduced to shorter rotation with the overall maximum cycle of cropping in the 7th years.

Within the general framework of land use changes, land degradation and sustainable land management (Brookfield *et. al.*, 2002; IBSRAM and Hurni, 1996), field survey and village appraisal were conducted in order to gain better understanding of land use changes in the study village. The objectives of the field survey and village appraisal were to describe land use change in the village and examine how the community manages the shifting cultivation in reduced cycle.

## **2.2 Materials and Methods**

The village was taken as the administration unit of the local administration office in Sob Moei district of Mae Hong Son province (Figure 2.1, 2.2, 2.3 and 2.4). Historically, the village was traced back as far as possible with village elders as key informants in order to find out the change and resettlement patterns which are related to the village's cultural practice relating to shifting cultivation.

Several different approaches were undertaken to conduct village survey, collect secondary and primary data and carry out the analysis of the data. At village level, a landscape approach was adopted to identify the existing land use system and the changes from 1937 when the village had split out from the original site at Ban Poo Kaew. Field walk, key informant interview and land use survey was adopted.

### **2.2.1 Village Survey and Key Informant Interview**

Secondary data were collected and compiled from various sources for baseline village information. These include population statistics from district office, Tambon administration office and village files, climate data from Meteorological station in Mae Sariang. As the existing climate data were obtained from lowland condition, a simple rain gauge and thermometer were set up in the village from 2003 to record daily data of rainfall and maximum and minimum temperature.

The socio-economic data were obtained from secondary sources, key informants and household interviews. Household income data were compiled from household record available at the District office and Tambon administration office. Past development

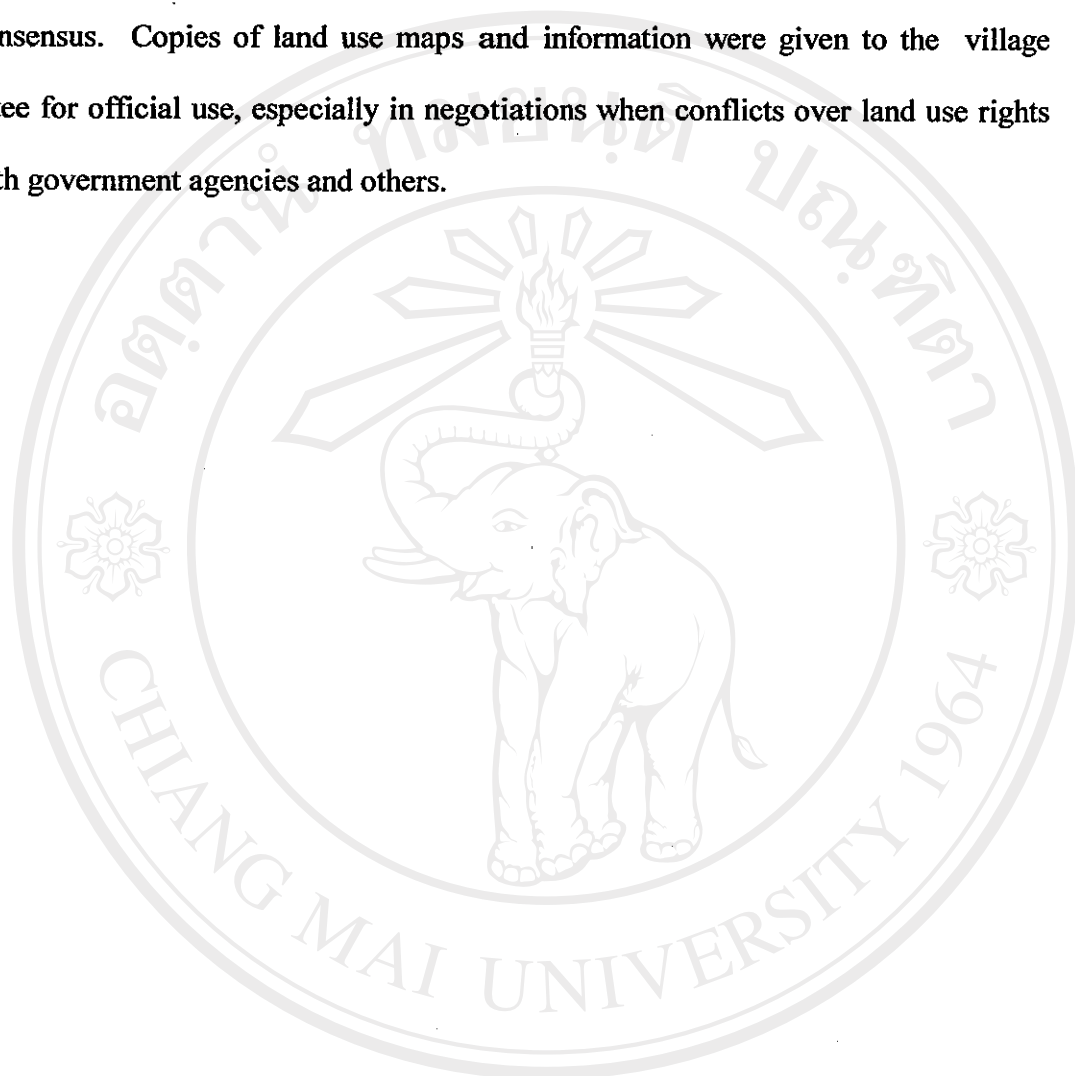
activities, infrastructure development (road construction) installment of village water supply and establishment of rice bank were obtained from village meeting and key informants from local community local authorities and development agencies in the area.

### **2.2.2 Land Use Survey and mapping**

Village map with scale 1:10,000 was prepared from military topographic map (1:50,000) for field use. A general land use was identified with key villagers using a 3-dimensional topographic model as tool for mapping (Tam-Kim-Yong, 1990). This information was then transferred to village map with 1:10,000 for ground check. Ground check was carried out with GPS to confirm and adjust land use in the village landscape. Some 2-3 key farmers assisted in field survey and mapping of existing land use. A sketch map of land use in 1999 and some preliminary land use data were also available during the implementation of CARE project on natural resource. These were further verified and incorporated for presentation in this thesis.

Historical land use and settlements were obtained from key informants interview and focus group discussion. A 3-dimensional model was extended to cover the past settlement sites around the present village boundary. A couple of the old people over 80 years old in the village were invited to participate in the interviewing and village group discussion. From their memory, resettlement sites and shifting cultivation fields were located on the 3-dimension model. These were then ground checked and marked on the map according to topography and land marks. From these exercises, past land use and village settlement maps were produced and revised with the key informants. The results

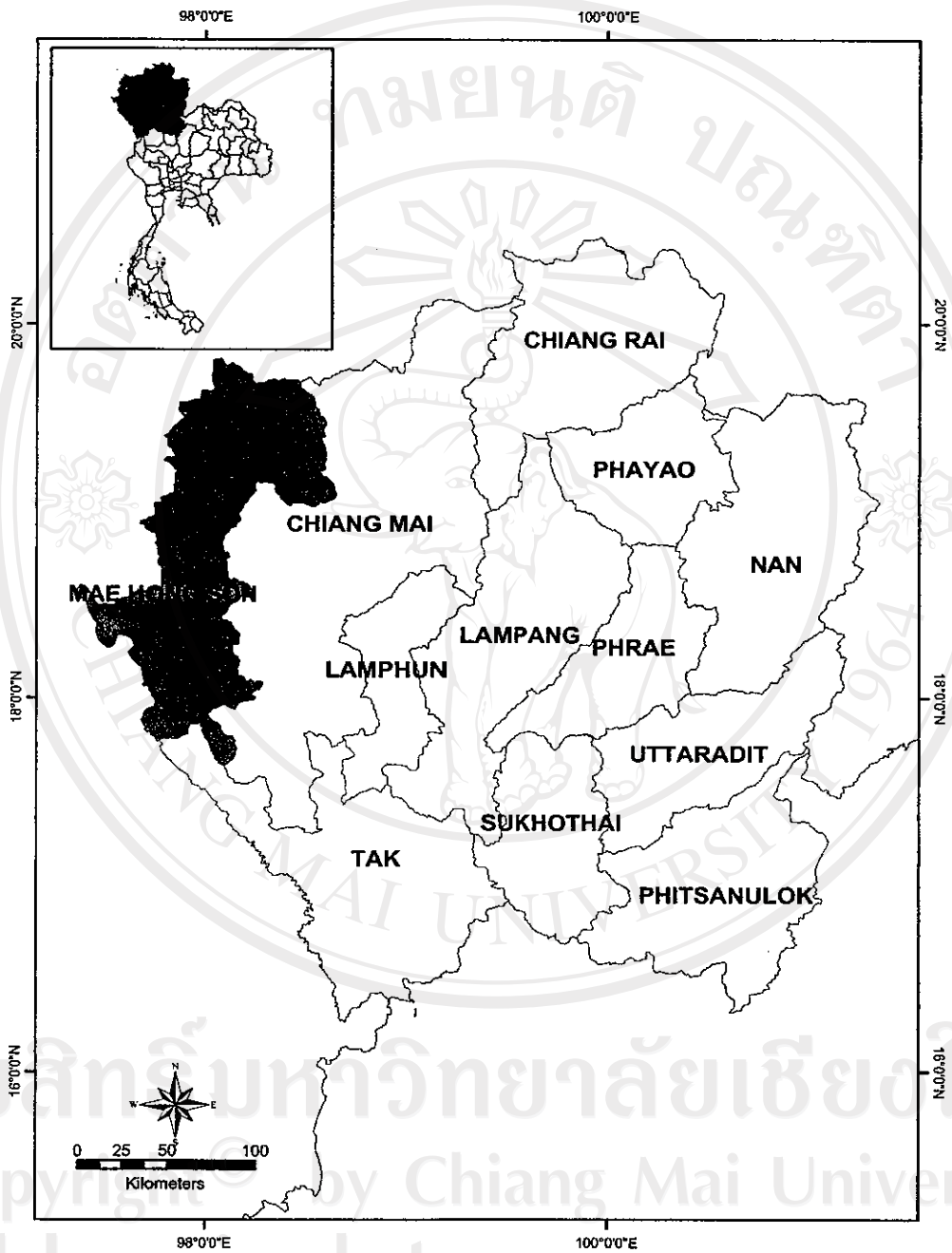
were presented to the community at large in a village meeting to obtain feedback and their consensus. Copies of land use maps and information were given to the village committee for official use, especially in negotiations when conflicts over land use rights arise with government agencies and others.



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**Figure 2.1** Northern Thailand and study site in Mae Hong Son province.

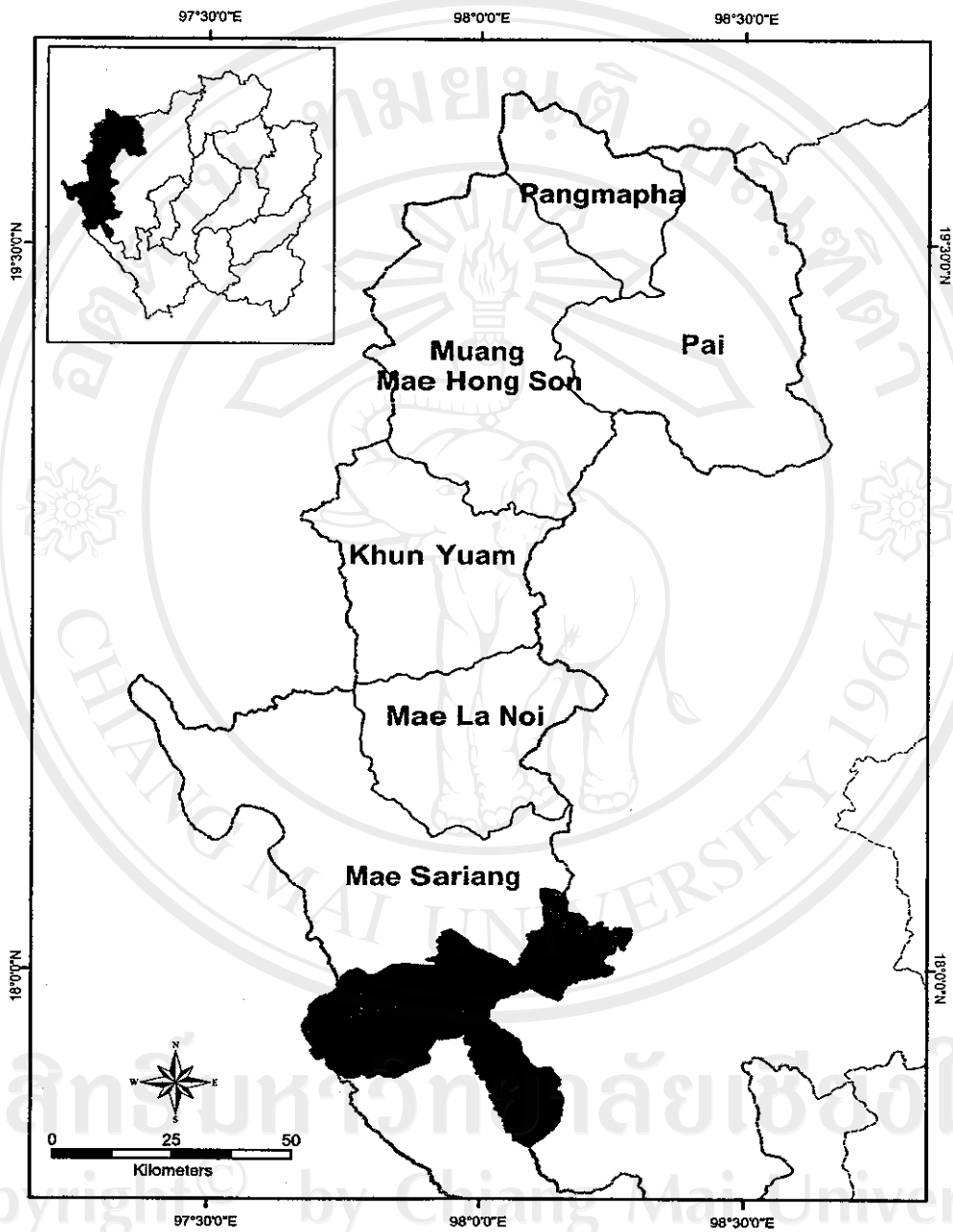


Figure 2.2 Mae Hong Son and district boundary.

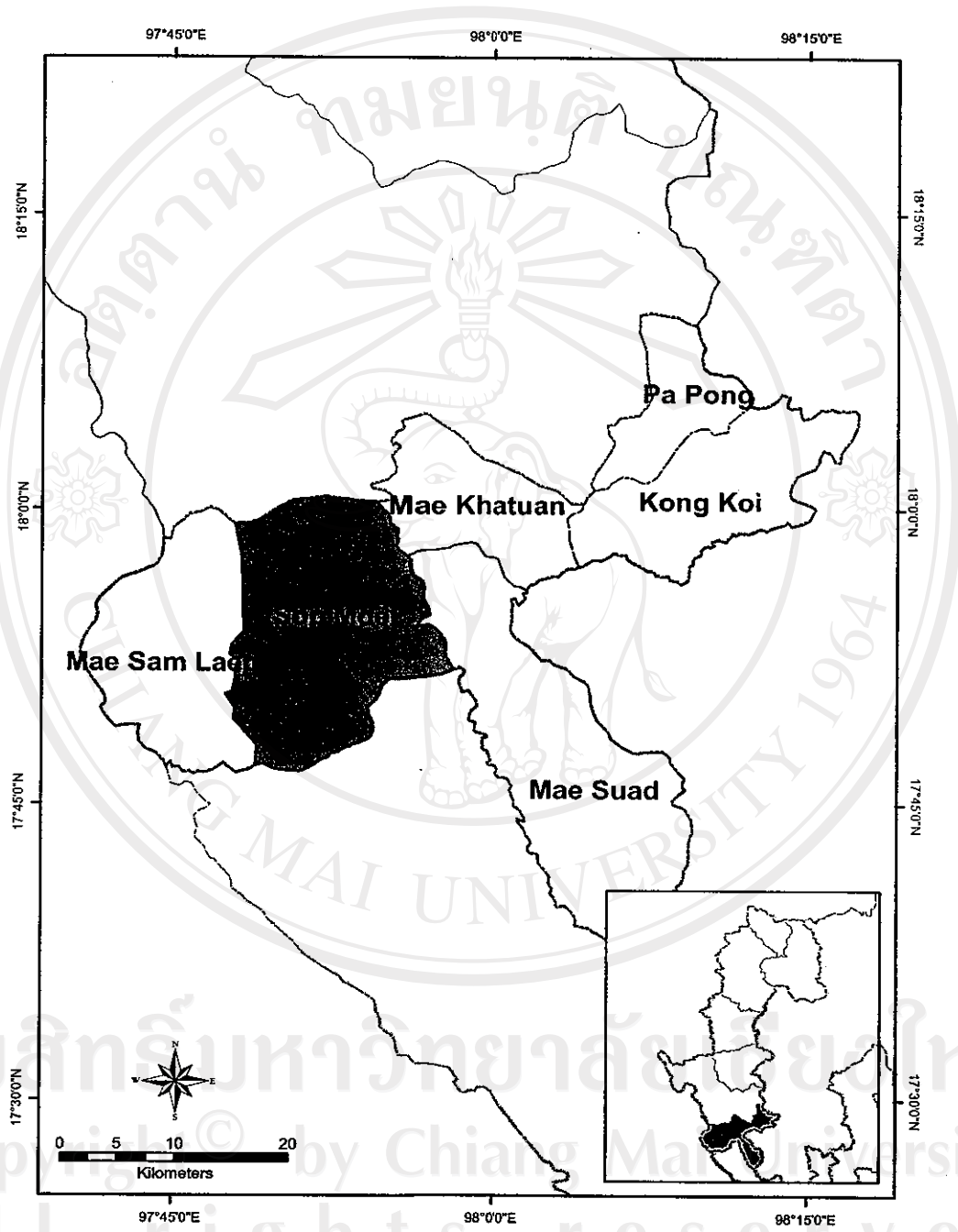
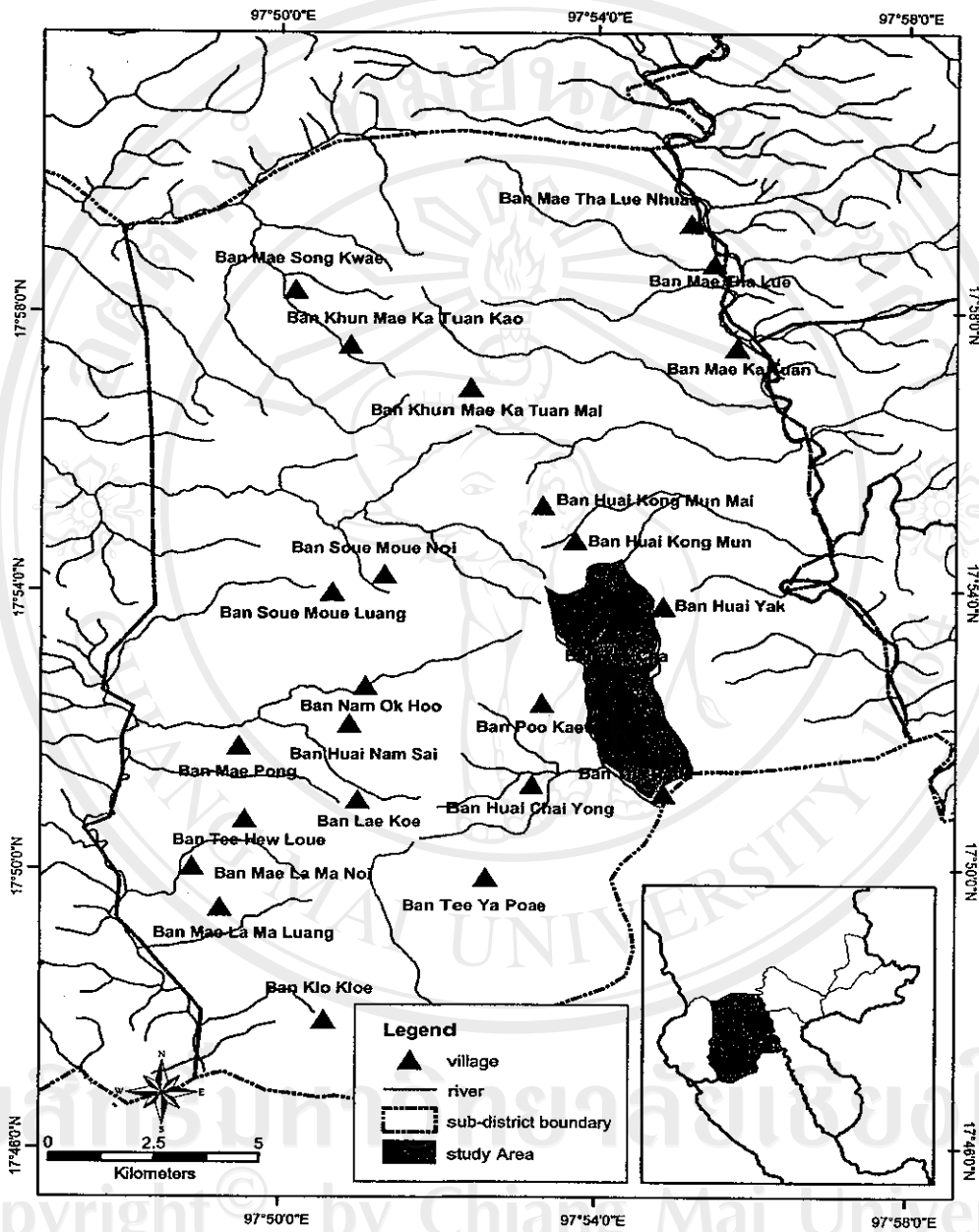


Figure 2.3 Sop Moei district and sub-district boundary.





**Figure 2.4** Study site, Tee Cha, and other highland villages in Sop Moei sub-district, Mae Hong Son province.

## 2.3 Results

### 2.3.1 Climate

The climate of Mae Sariang (in 1994-2003) is described by an annual mean temperature of 26.3<sup>0</sup>C and annual rainfall of 1,196 mm per year (Meteorological station in Mae Sariang) (Figure 2.5). The climate in Tee Cha (700 m MSL), with slightly more annual rainfall at 1,204 mm and about 5 °C lower minimum temperature, is somewhat different from Mae Sariang (500 m MSL) (Figure 2.6). The rainy season in Tee Cha starts in early May when farmers have already sown upland rice in shifting cultivation and finished at the end of September or early October depending on year to year variation. During the rice harvest, air temperature drops quickly below 15<sup>0</sup>C in November with the coldest months in January and February. The hottest month occurs in April when temperature rises to a maximum of 41.2<sup>0</sup>C. Burning of swidden field generally decided during this time to avoid accidental fire and escape early rain.

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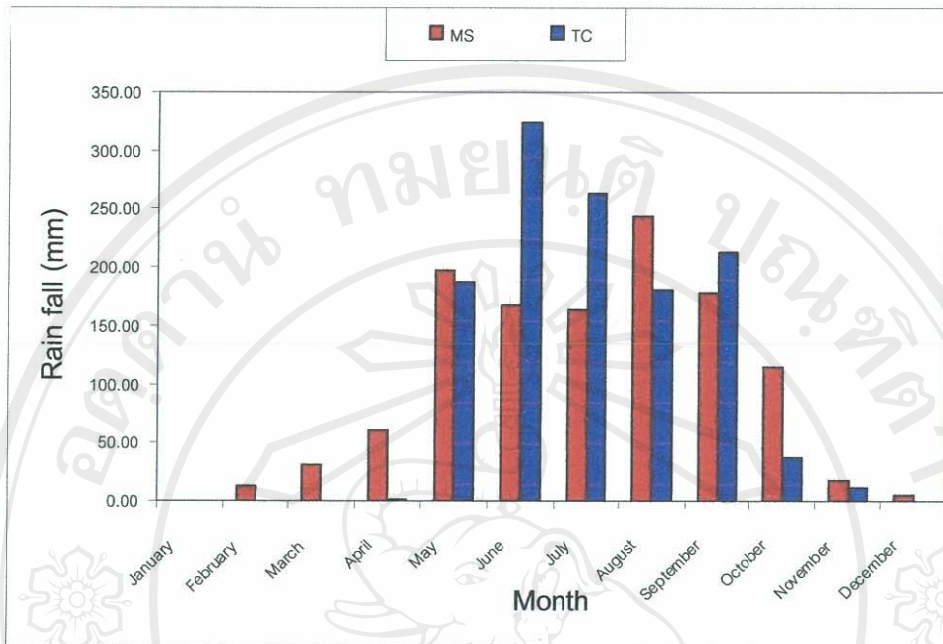


Figure 2.5 Rainfall distribution in Tee Cha (2003-05) and Mae Sariang (1994-2003)

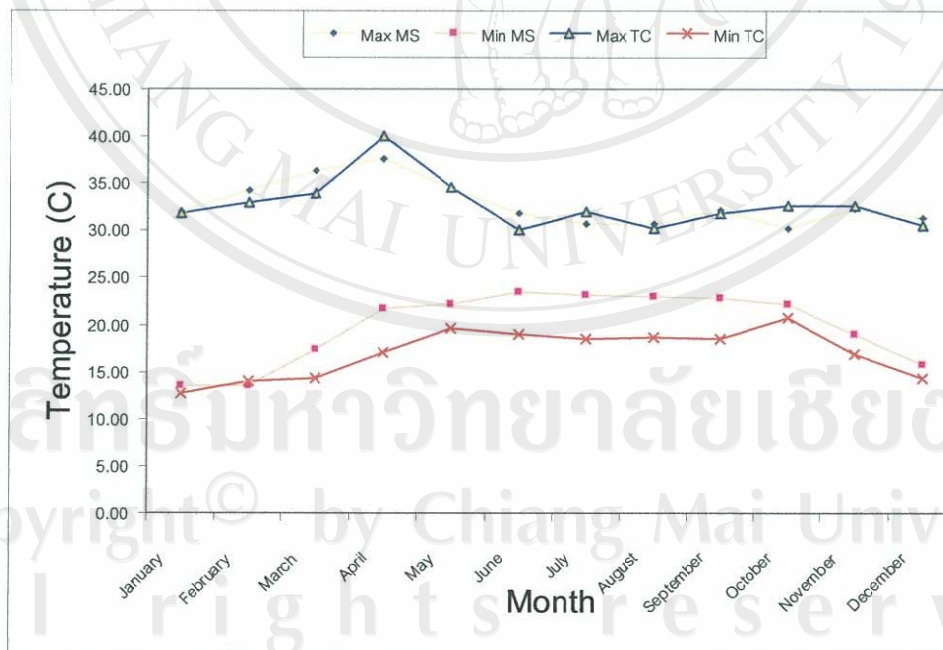


Figure 2.6 Monthly temperatures in Tee Cha (2003-05) and Mae Sariang (1994-2003)

### 2.3.2 Soil

The soil in Tee Cha is sandy loam texture with good drainage property. Soil depth varies from 0.5- >1.5 m depending on field topography. Rill erosion may be observed on steep slopes but landslide occurs only in small patches outside shifting cultivation area. Soils are generally poor with low pH, average 5.16. Soil samples collected from every fallow regrowth in year 2002 (Appendix A), Nitrogen content varies slightly between 0.29-0.43 % with fairly wide variation in other nutrients; Phosphorus 3.07-15.15 ppm (Bray II, Wanatabe and Olsen, 1962), Potassium 90.33-214.33 ppm, Calcium 0.19-4.19 me 100g soil<sup>-1</sup> and Magnesium 0.27-0.99 me 100g soil<sup>-1</sup> (Jackson, 1967).

### 2.3.3 Water

Agriculture in Tee Cha is basically rain fed. Supplement irrigation is available for paddy with small ditches connected to natural waterways. Shortage of water for domestic use is common in dry season especially during March to May. A concrete tank was built to regulate water supply for domestic use. The water is generally clean. Although a bit muddy after heavy rains, it clears up after 3-5 hours. Those farmers who are well off economically own 200 liter metal tanks to store clean water for daily use. Domestic water, supplied from the village stream, is carried to all households by PVC pipes.

### 2.3.4 Population and Migration

Village elders reported that their people had lived in this neighbourhood for more than 200 years. Eight households moved from a nearby village of Ban Poo Kaew to settle in the present site around 1950, when the village population numbered about 30 people (Table 2.1). Formal population survey was begun in 1987. By 2005 the village population had increased to 157 persons. In addition to the natural growth, people move in and out of the village according to the Karen marriage tradition (see next section). Illegal migrants from Myanmar, who are also ethnic Karen, have also married women in these border villages. So far, there was only one case in Tee Cha, because a communal sanction against the practice, in order to reduce pressure on limited land available for shifting cultivation as well as difficulties relating to official status on citizenship of the immigrants and their children.

**Table 2.1** Population and households in Tee Cha village.

Year	Number of Household	Population (persons)			Sources
		Male	Female	Total	
Before 1950	8	-	-	>30	Key informant interview (2001)
1967	13	-	-	50-60	Key informant interview (2001)
1980	18	-	-	>100	Key informant interview (2001)
1987	26	66	38	104	Key informant interview (2001)
1992	28	64	64	128	Key informant interview (2001)
1995	31	57	80	137	CARE(1995)
2000	37	72	70	142	Field interview (2001)
2001	39	75	72	147	Field interview (2001)
2002	44	88	69	157	TAO (2002)
2004	51	-	-	161	Household interview (2004)
2005	51	83	72	157	Household interview (2005)

### 2.3.5 Social Organization, Kinships and Community Networks.

Social organization of the Pwo Karen community in Tee Cha is dominated by kinship networks. Labour is the determinant in upland rice production and exchange labour is organized strongly within the kin group. Family with small kinship network would be at a disadvantage. The kinship networks is also extended beyond the village through marriages. As the Karen follows matrilineal line as the social rule, the new couple would normally move to join the bride's family after marriage and live with in the parental household for 3-5 years before moving out to build their own household. The youngest daughter in the family has obligation to take care parents when they are old and could not work in the field. This is connecting to pattern of land inheritance, within and between the family within and between the villages. However, land is not owned out



right by individuals and households. Redistribution of unused land in shifting cultivation will be illustrated later in section 2.3.9.

Pwo Karen in Tee Cha is also influence strongly by customary rules and spiritual beliefs in organizing and allocation land for upland rice production. Formerly, the natural leader (Ran Ku) plays dual roles in both village administration as well as conducting ceremonial rituals. With respect to shifting cultivation, Ran Ku would make decision on field selection for land clearing and opening ceremonies for land preparation and planting of upland rice. The Ran Ku would have to decide on land allocation to member households in the village. Which field would be planted first before the opening rain starts. With influence from government administration, traditional social and administrative system changed and the administrative role of Ran Ku decline greatly. As the respect elder, Ran Ku has become senior adviser to village administrative committee.

With strong government policies on social integration and permanent settlement back in 1970s, granting of "Thai Citizenship" was attached to village registration. Without village registration, the ethnic minorities would remain "illegal migrants" and have been facing great difficulties in obtaining government support and services (health, education and finance), movement and many others. In the process of village registration, village committee would have to be appointed in order with local administration authorities. Literate young and educated people in the village have taken the task because of their communication skill and broader world new.

At present, Tee Cha has become a core village representing Poo Kaew and Huai Yak as Seattleite villages. Village headman is rotating between the three villages with representative from each village as committee (Figure 2.7.).

In the year 1997, the Thai government established the Local Administration Organization (LAO), as a formal institution for local government. Tee Cha village belongs the Tambon Sop Moei (sub-district). The first head of Tambon administration organization is Mr. Payad and the members from Tee Cha village are Mr. Docare Naetoo and Ms. Chamaipon Kapzo Mr. Thongdee Savadteesa is member of Tambon administration officer in between 2001-2004.



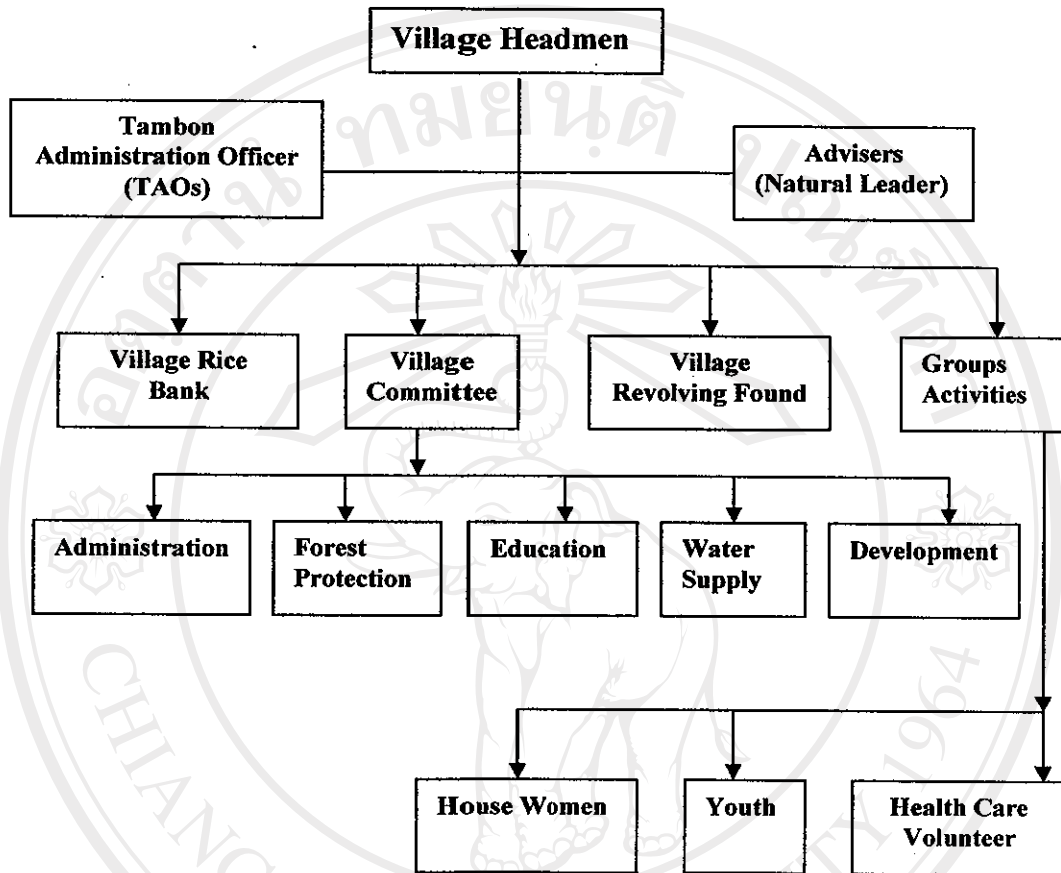


Figure 2.7 Village administrative organization.

source: key informant interview 2002.

### 2.3.6 Settlement patterns

Years ago Tee Cha was formally combined with Poo Keaw village with local name referred to as Ban Huai Mae Lamong with a total population of 18 households with abundant land for shifting cultivation with long fallows of 20 years and over (Figure 2.8). On average, 6-8 persons household<sup>-1</sup> and occupied over 2 ha for upland rice with household low yield due to inadequate labour for crop maintenance. Mr. Mu Jae, (>80 years old) one of the village elders, said that the rice yield could vary between 30-60 tang/1 tang of seed, equivalent to 1.85-3.24 ton ha<sup>-1</sup>. About 70 years ago, 8 families decided to move out to started a new village next to shifting cultivation field on the other side of Om Long River, flowing to Huai Chai Yong and meet Yuom River to the south of the village. After some time, a few families moved back to Mae Khatuan (Figure 2.9 and Figure 2.10), the rest of the families remained in Tee Cha under the leadership of Mr. Cho Wa. Villagers still moved regularly and basically fallowed shifting cultivation fields. Their houses were built temporally with bamboo and thatched with leaves. It was not until 1958, when the villagers as a whole decided to settle permanently in the present site (Table 2.2 and Figure 2.9). The decision was made of the basis of site suitability i.e. biophysical, ecological, agriculture and cultural consideration. The site is locating on a relatively flat ridge, surrounded by fallow fields for rotation. It is close to village headwaters and situates above the main stream, "Huai Tee Cha".

**Table 2.2** The household settled and moved of the Tee Cha villager in 1937 – 2004.

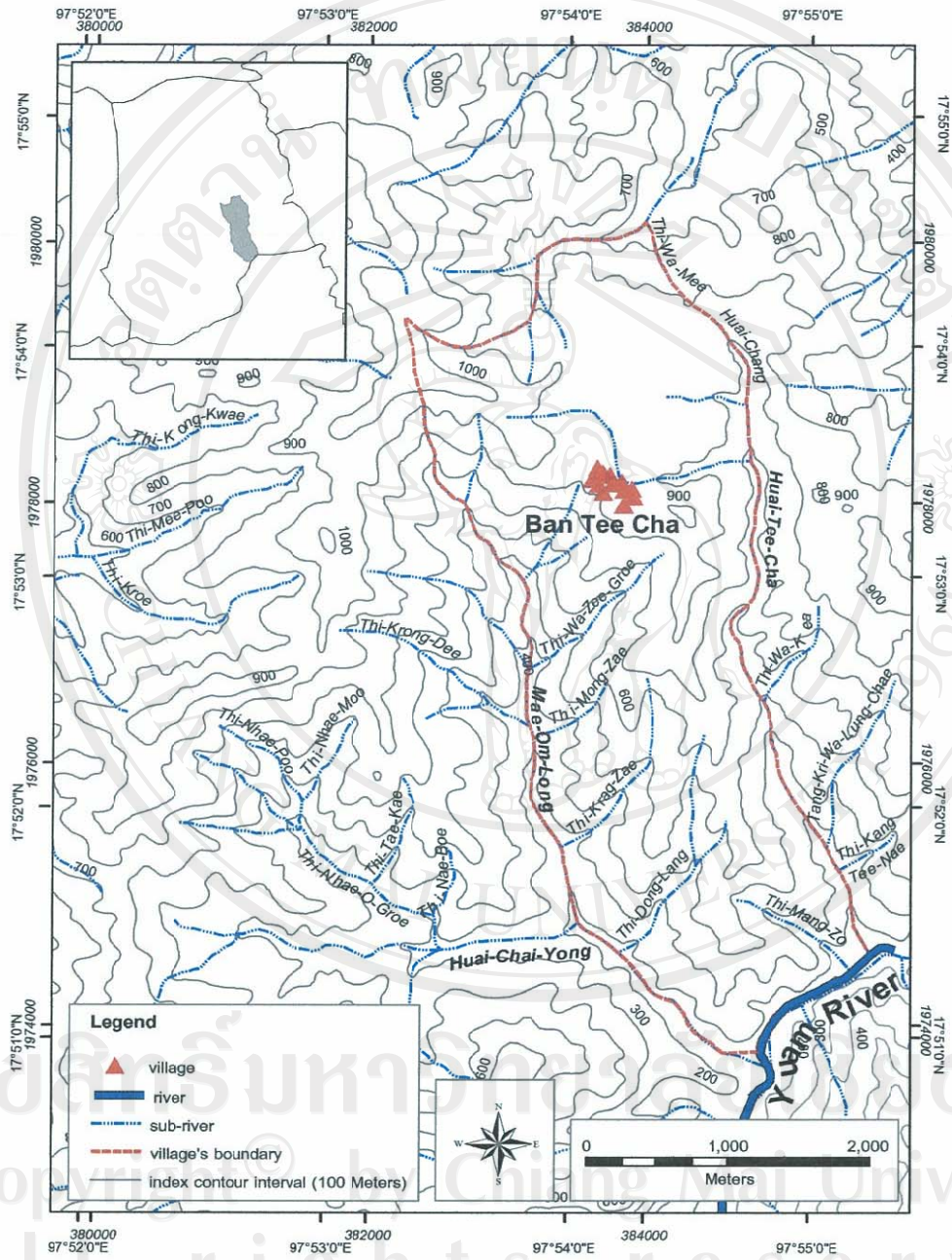
Year	Settlement Site <sup>1</sup>	Number of		Total area of upland rice in shifting cultivation (ha)	Area per household (ha)	Fallow period (years)
		Household	Farmers			
< 1937-1937	Huai Mae La Mong	18	126	969.37	7.69	20+
1938-1941	Tacae Orchard	8	56	-	-	10-20
1942-1944	Decae Paddy	9	63	203.46	7.54	10-20
1945-1947	Khun Huai Kong Moon	5	35	199.54	7.94	10-20
1948-1957	Mae Om long	-	-	-	-	10-15
1958-1980	Tee Cha (now)	8	56	495	6.19	10
1981-1994	Tee Cha (now)	18	123	495	2.75	10
1994-2001	Tee Cha (now)	32	160	495	2.21	7
2002-2004	Tee Cha (now)	35	157	495	2.02	7

**Source:** Key informant interview (2001-2004)

**Notes:** 1= As referred by key informant with landmarks or local names







**Figure 2.9** Topography and boundary of rotational shifting cultivation areas of Tee Cha village in 2004.

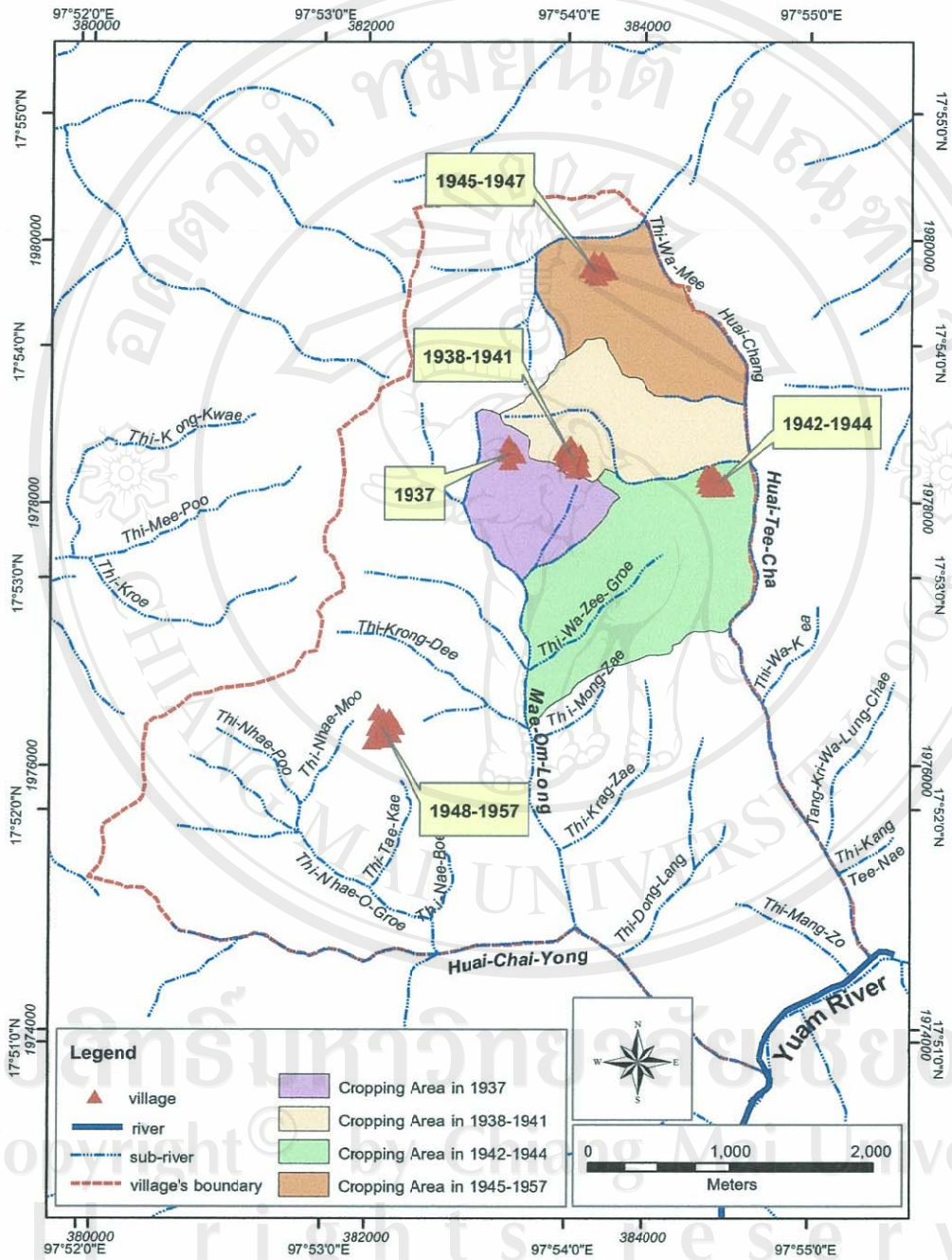
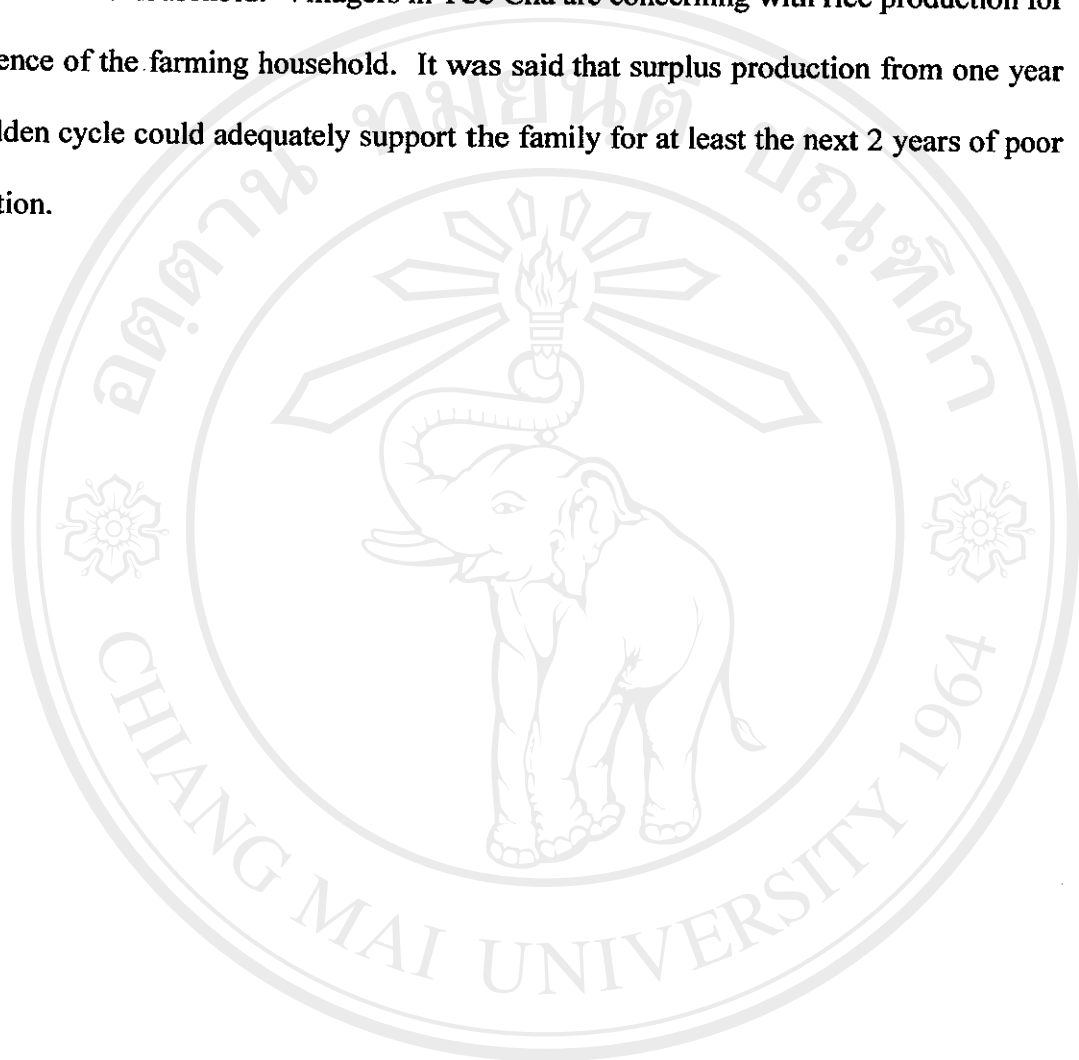


Figure 2.10 Pattern of household settled and village movement in 1937-1957.

### 2.3.7 Source of cash income and livelihood activities

According to Tambon and district statistics, annual income of farmers in Tee Cha was average at 1,500 baht person<sup>-1</sup> year<sup>-1</sup>. This is somewhat below the national average, 101,304 baht person<sup>-1</sup> year<sup>-1</sup> (year 2003). Majority of farming households earn cash income from many activities. Major source of cash income derive from selling fresh (20-30 bath kg<sup>-1</sup>) and dry chili (80-100 baht kg<sup>-1</sup>) (Table 2.3). Wage labours outside the village have significant contribution to household income for the past 3-4 years. More than half of total households in the village have gone out to lowland village in Chom Thong, Hod, Ban Hong and Li districts for Longan picking with high wage at 100-150 baht person<sup>-1</sup> day<sup>-1</sup>. Many households also harvest forest products for selling to outside markets in Mae Katuan and district market in Sop Moei and Mae Sariang. Major products include edible mushroom (e.g. *Astreus hygrometricus* (Pers) Morg and *Auricularia polytricha* (Mont.) Sacc), bee honey, bamboo shoot and bamboo worm. Domesticated and wild fruits may be sold to middlemen who visit to the village regularly. Large animals, cattle, buffaloes including elephants, are earning the majors sources of cash income. Almost all of household have own animals. Small animals, pigs and chickens are a key raised for own consumption and use extensively for spirit offers during the rice growing season and sickness of members in the family. In the past, many households owned elephants for logging activity. As logging activity disappeared, elephants were used as draft animal when road transportation was very poor. The role of elephant in the village is decreasing. Some 2-3 elephants was sold to outside for tracking tour for the past 2 years.

So far, cash income earning activities are somewhat supplement to the overall livelihood of the household. Villagers in Tee Cha are concerning with rice production for subsistence of the farming household. It was said that surplus production from one year of swidden cycle could adequately support the family for at least the next 2 years of poor production.



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**Table 2.3** Livelihood activities of villagers in Tee Cha village

Activity	Number of Households	% of total Hh
Upland rice	35	100.00
Paddy	5	14.30
Chilies	30	85.70
Fruit trees	9	25.70
Sugar cane	3	8.60
Coffee	7	20.00
Swidden crops	35	100.00
Weaving	35	100.00
Basketry	30	85.70
Fishing	30	85.70
Livestock		
• Pigs/ chicken	35	100.00
• Cattle/ buffalo	31	88.60
Elephants	2	5.70
Forest products collected		
• Mushroom	35	100.00
• Bee honey	5	14.30
• Fruit and vegetable	35	100.00
• Bamboo shoot	35	100.00
• Bamboo worm	35	100.00
Wage labour		
• Longan picking	16	45.70
• General wage labour	6	17.10
Small shops	3	8.60

Source: Household interview (2002-2004).

In Table 2.4, only 29 % of total numbers of households in the village were rice surplus and majority of the households (71 %) were minus deficit. The problem of rice deficit may be overcome by many different ways. Borrowing from the village rice bank is common among the deficit household. Mixing source with other root crop such as cassava, yam or job's tear could solve the problem to a large extent. With increasing market opportunity and improvement of infrastructure, buying rice from the outside is becoming common on the past few years.

**Table 2.4** The number of households with enough rice for year-round consumption.

	Number of Household				
	2000	2001	2002	Average	%
Rice enough	12	14	6	10	29.40
Rice not enough	22	20	29	24	70.60
• 1-2 month	3	3	6	4	16.60
• 3-4 months	7	5	5	6	25.00
• 5-6 months	3	6	11	7	29.20
• > 6 months	9	6	7	7	29.20
Total	34	34	35	34	100.00

Source: Household interview (2000-2002)

### 2.3.8 External Supports and Services

Officers from the Department of Public Welfare were posted to the village during 1977-1978 to provide services in agriculture development, health care and education. Many fruit trees and plantation crops such as coffee were introduced. Provisions of seedlings were free of charge. This initial effort has also resulted in establishment of a primary school for formal education in 1981.

In 1992, CARE, an international non-government organization, introduced agroforestry as alternative system to traditional shifting cultivation due to shortenings fallow periods (Table 2.5). This continued into the second phase of the project with greater emphasis on forest conservation and watershed protection. The project terminated in 1998. In 1980, a road was constructed through the middle of village for mining activity in near by Tha Reua. There were two trucks, commuting between mining site and Sop Moei. Villagers had access to this transportation with free of charge. The road was very poor and frequently not useable in the middle of wet season. Major road improvement and expansion was carried out in early 2004 by the Army to support assistance activities at refugee camp in Mae La Ma about 15 km from Tee Cha. Paved road is expected with initial budget from local government at a cost of 9 million baht for 7 kms. With road improvement, the influence of outside markets is increasing rapidly. The number of traders visiting the village is increasing. There are those who come to buy chilies, vegetables, honey, mushroom and other forest products as well as sellers of everyday household items. Market information is improving. After the Salaween scandal in 2003, when timber poaching in the Salaween National Park became national news, enforcement of national forest protection and watershed conservation policies are being strengthened. Use of fallow field is supposedly legally prohibited for shifting cultivation, but alternative options have yet to be found. In Tee Cha the enforcement of this law has yet to be made although the village has received repeated official warnings.

**Table 2.5** The development of Tee Cha farmers in 1958 – 2004

Name of organization	Year	Activity
Public Welfare	1977-1978	<ul style="list-style-type: none"> <li>• Agriculture development practice e.g. planting fruit trees, cash crops (coffee).</li> <li>• Primary health care</li> <li>• Education</li> </ul>
CARE project	1992-1998	<ul style="list-style-type: none"> <li>• Agroforestry systems introduced.</li> <li>• Introduction of alternative agriculture practice for permanent farming e.g. extension of hedge rows for soil water conservation methods, planting fruit trees, made the fishpond and construction of the paddy field.</li> </ul>
Thai Army and Local organization	2003-2004	<ul style="list-style-type: none"> <li>• Improve road from Mae katuan in the Sob Moei district to the village.</li> <li>• Building cement tank for domestic water supply.</li> </ul>
Traders	From 2003	<ul style="list-style-type: none"> <li>• Increase visiting from buyers of agriculture and forest products and sellers of consumer items.</li> </ul>

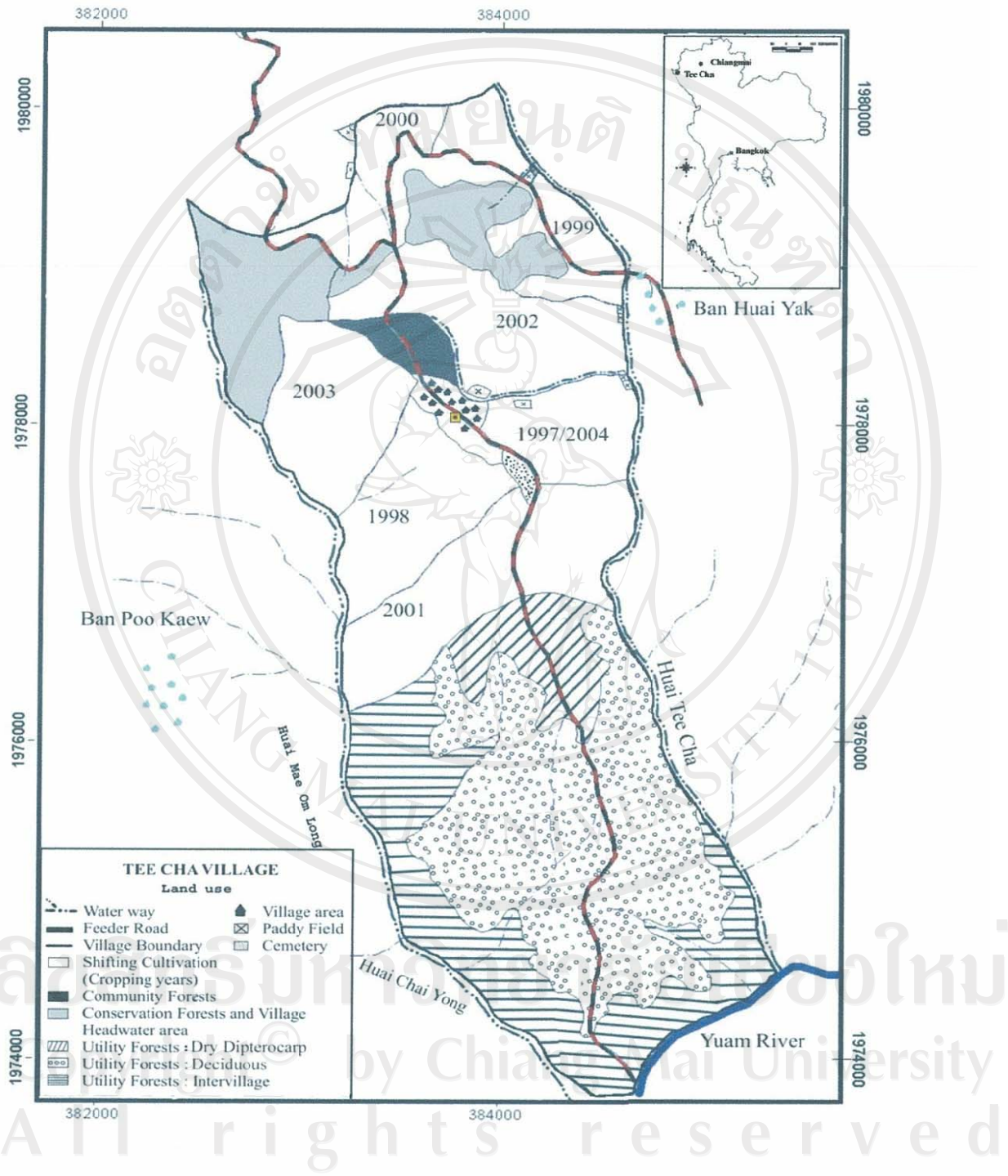
Source: Field interview in 2002-2004, CARE / INRC

### 2.3.9 Land Ownerships and Management for Shifting Cultivation

Despite the diversity of land use in Tee Cha village, shifting cultivation remains the dominant land use and upland rice is the major crop that provides the main household staple food (Figure 2.11 and Table 2.6). Upland paddy and mixed perennial orchards are individually owned properties, shifting cultivation fields are basically communal owned. Under the leadership of natural leader (Ran Ku), the most suitable fallow with production regeneration at the best maturity stage would be suggested for clearing and burning for upland rice. Fields are allocated in a process of land distribution that includes collective discussion. As land is currently limiting, fallow fields have been divided and allocated to the member households in the village for upland rice production (Figure 2.12). The criterion for this allocation is based on occupation and use of the field in the previous cropping cycle, but the land has also to be shared with new households, such as new families just separated from the parental household. Those with land they were not able to use fully, including those who are too old to work or have move out are obliged to have their land redistributed to those who do not have enough. Within one rotational cycle, the number of fields had increased to accommodate new households (Figure 2.13). The evidence of improved market access can also be seen in the current prominence of chili as a cash crop. Equitable distribution of shifting cultivation land for upland rice is traditionally practiced by Pwo Karen and it appears to be a strong tradition.

After harvesting of upland rice, land would be returned to community and opened for community use, e.g. collecting perennial root crops left over in the field, fire-wood, forest product and grazing.





**Figure 2.11** Tee Cha village's land use in 1997-2004.

**Source:** Field survey 1997-2004.

**Table 2.6** The type and area of land use of Pwo Karen in Tee Cha village in 2004

Type of Land Use	Area	
	ha	%
<b>Natural Forests</b>	<b>557.17</b>	<b>51.48</b>
• Conservation Forest and Head water	84.21	7.78
• Community Forest	47.19	4.36
• Utility Forest: Deciduous	374.85	34.63
• Utility Forest: Inter-village	47.45	4.38
• Cemetery	3.47	0.32
<b>Village Site</b>	<b>5.50</b>	<b>0.51</b>
<b>Agriculture Lands</b>	<b>519.68</b>	<b>48.01</b>
• Shifting Cultivation	495.6	45.79
Fallow years 1998	70.61	6.52
Fallow years 1999	57.71	5.33
Fallow years 2000	59.78	5.52
Fallow years 2001	104.43	9.65
Fallow years 2002	86.32	7.98
Fallow years 2003	69.94	6.46
Cropping year 2004	46.81	4.32
• Permanent Fields	16.08	1.49
• Paddy fields, and Fish pond	8.00	0.74
<b>Total Area</b>	<b>1082.35</b>	<b>100.00</b>

Sources: Field survey 2002-2004 and Village meeting 2004



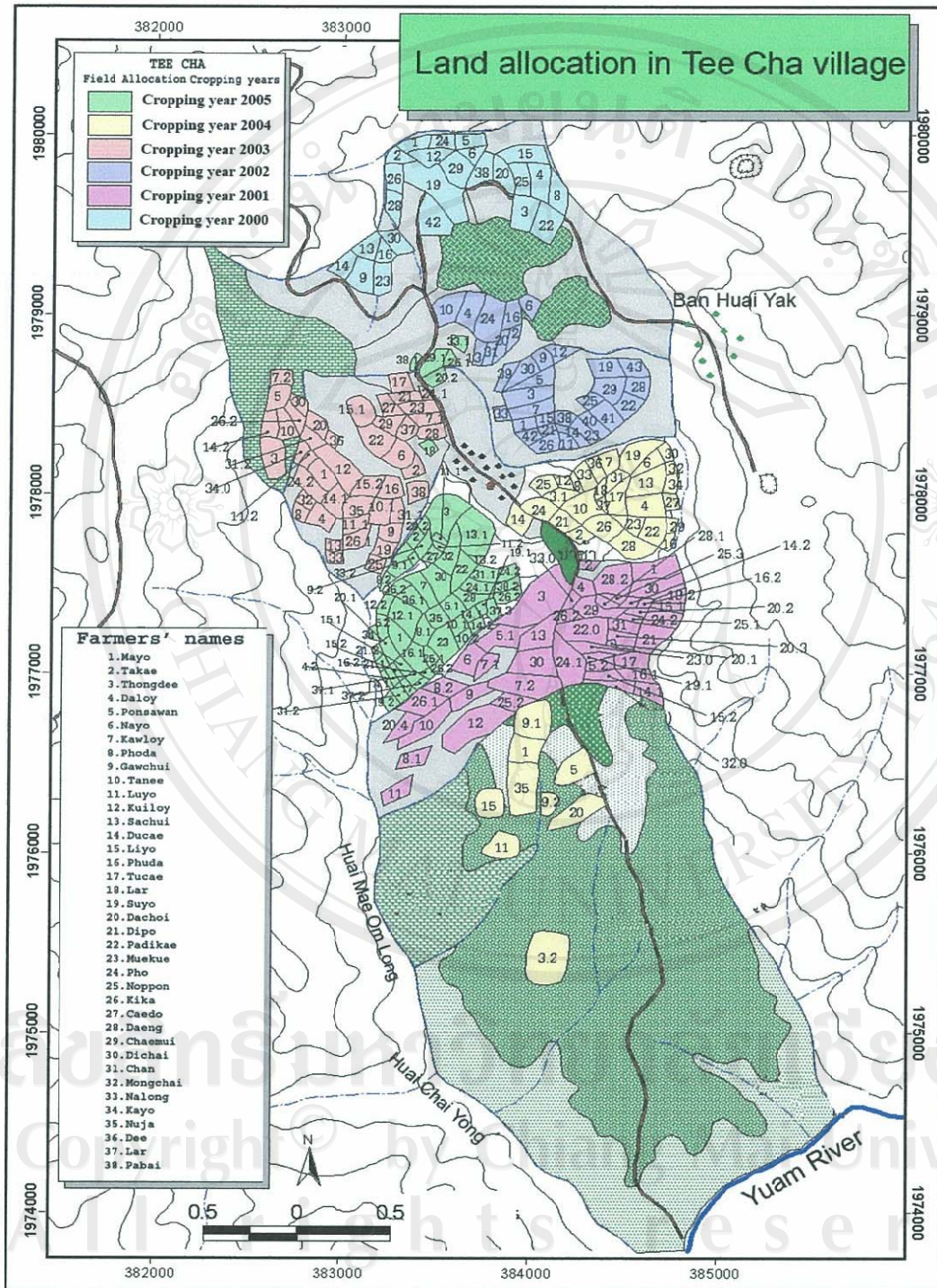
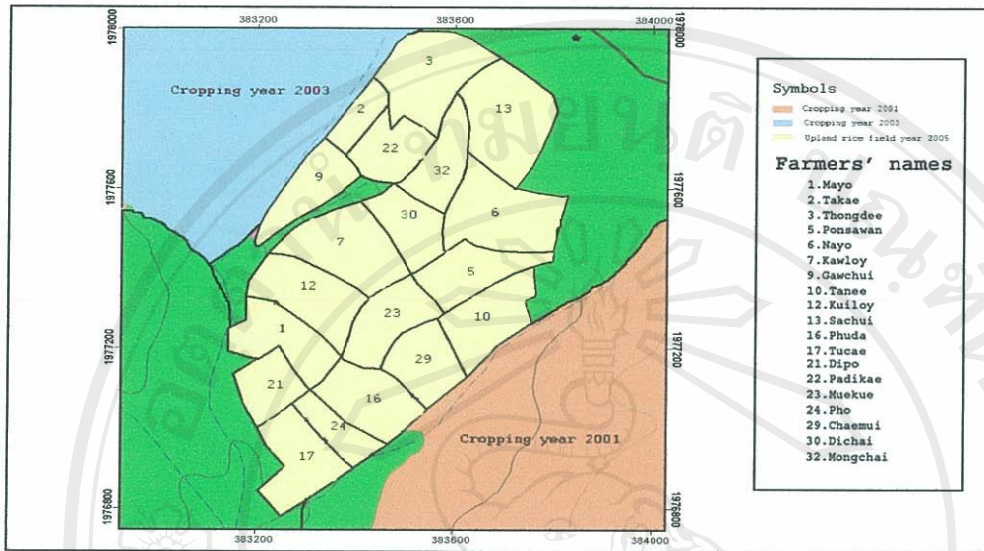
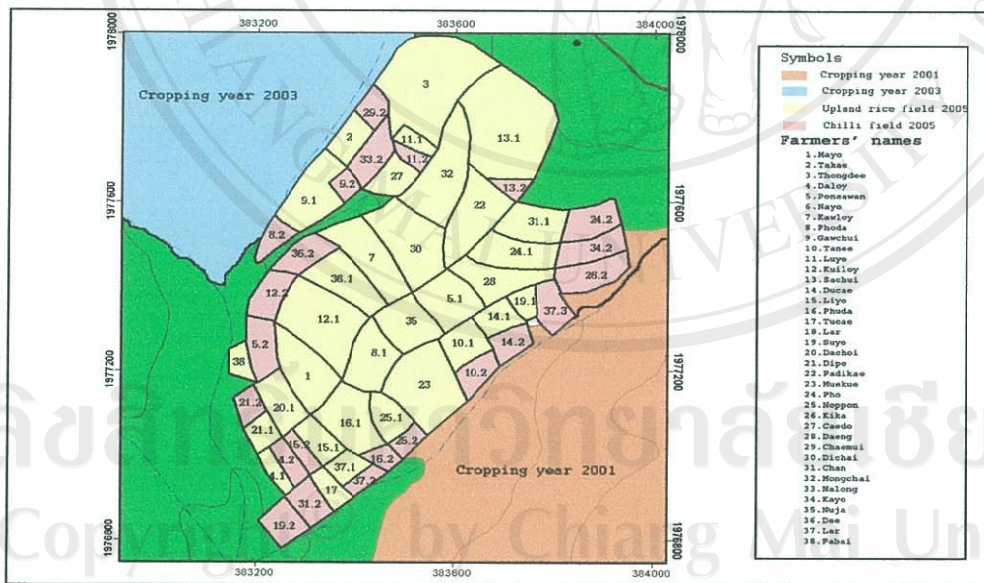


Figure 2.12 Land allocation of farmers in Tee Cha village between years 2000-2005.





(a) Pattern of land occupation for upland rice in 1998



(b) Pattern of land occupation in 2005

Figure 2.13 Pattern of land occupation for upland rice in shifting cultivation.

## 2.4 Discussions

The situations in Tee Cha village have changed greatly in the past few decades. Significant change in land use and management of shifting cultivation due to internal pressure which have been evident prior to the exposure to development, as individual by the splitting up of village, building up of population and to certain extent increasing access to external market and off-farm job opportunities. The government policies had very small contribution to social, economic and land use of the local community in the past. Recently, government rules and regulation have been enforced to protect the existing natural forests and conserve ecological integrity of local watersheds. Although, Tee Cha village is located outside of protected areas, i.e. natural parks and wildlife sanctuary, reforestation activity and legal enforcement to stop shifting cultivation have been imposed on the village and these have direct impact on the existing shifting cultivation where the system are practical with short fallow of overall 7 years cycle.

Recent road improvement is expected to have impact on shifting cultivation and village land use. Market information is impinging strongly on the local community with increasing access and information. On one hand, the force is providing opportunity for local community to increase cash income from various sources. Rapid expansion of market and commercialization would, on the other hand increase farmer' aspirations to intensify production with in many areas turn out to be negative trade off to natural resources biodiversity and watershed as a whole (Allen, 1994 and Ganjanaphan *et. al.*, 2004). Change in land use and management of shifting cultivation may move forward sustainable intensification and these depend to local capacity and ability to cope with the

change (Brookfield *et al.*, 2001). In the next chapter, this argument will be clarified with intensive field study on farmers' management of shifting cultivation in the face of change.

On a broad scale, the organization and management of shifting cultivation remain to be communal decision and arrangement. This is Pwo Karen tradition, as shifting cultivation belongs to community, member households in the village has right to use land for upland rice cultivation but the right will have to be more or less distributed between the member households. As a rule, no one of Karen in community lives without land, the collapse of shifting cultivation may lead to social collapse. This may be one of the reasons why shifting cultivation remains in existence despite the many unfavorable conditions against the system. Can farmers maintain productivity of the shifting cultivation with reduced cycle? Are there any problems and constraints on succession destruction and regeneration of shifting cultivation? Can these be overcome and how? These are the questions that will be dealt with in the subsequent chapters in this thesis.