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ECONOMIC RETURNS TO INVESTMENT IN CONTROL OF MIMOSA PIGRA IN THAILAND

ผลตอบแทนทางเศรษฐกิจ ของการลงทุน ในการกำจัด ไมยราบยักษ์ในประเทศไทย

G. LAMAR ROBERT

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Cover Design: The mythical giant Maiyarap.
The Thai name for Mimosa pigra is Maiyarap Yak,
Giant Maiyarap.

PREFACE

Situation

Infestations of Mimosa pigra, a leguminous tree, are found in large areas of Northern Thailand. They are located primarily along roads, canals, rivers and reserviors. It is considered a noxious weed in the area; however, the economic ramifications of the infestations have never been systematically identified and quantified. Consequently it was not clear to what extent and for whom M. pigra was a problem and what measures, if any, should be implemented to control it.

For purposes of this study, "total control" is used to refer to complete elimination of M. pigra in a specified area. The terms "control" and "partial control" are used interchangeably to indicate a level of control which is less than total, i.e., the reduction (but not elimination) of the weed in a specified area. Both total control and partial control can be either temporary or permanent.

M. pigra was first mentioned as being a problem in the Chiang Mai area of northern Thailand in November 1974 during a seminar on aquatic weeds. In March 1978 the first informal seminar dealing exclusively with the M. pigra situation was convened by Saowanee Thamassara of the Royal Irrigation Department (RID).[1] This initial effort was followed by the first formal meeting on M. pigra which was held in Chiang Mai in June 1978. These initial meetings culminated in a request to the U.S. Agency for International Development (U.S.A.I.D.) by the Thai government for assistance in dealing with the M. pigra problem. U.S.A.I D. answered the request with funds to conduct the necessary research, funds which resulted in the present study.

---

[1]Montri Rumakhorn, History of Efforts to Control Mimosa pigra (Bangkok. Kasetsart University, 1980, in Thai), p. 1.

Official government interest in M. pigra is matched by local residents' interest: in the month of December 1980 alone a story relating to M. pigra was the banner headline of the Chiang Mai daily newspaper on two occasions and the subject of a major article on a third.[1]

M. pigra even made Thai national television. A news item on the weed was broadcast nationwide on December 23, 1980, showing the author testing a potential chemical control agent.

As previously noted, M. pigra is found in many countries around the world, but as yet no economic studies have been performed to evaluate its impact. This study provides both a benchmark of quantitative and qualitative data on the economic effect of M. pigra and also can be used as a model for potential future studies in other nations.

Problem

Not enough is known about the benefits and costs of controlling M. pigra in Thailand to determine where the weed should be controlled and, if it is to be controlled, what means of control should be employed.

Objectives

1. Determine where it is appropriate for the Thai government to control M. pigra.

2. Determine where it is appropriate for the private sector to control M. pigra.

3. Determine the most economical control method for each of the various areas where control is indicated.

---

1 Thai News (Chiang Mai), December 2, 1980, December 8, 1980, and December 23, 1980, (in Thai).

Proceedure

After completion of a review of relevant literature, a preliminary survey was made of infested regions in Thailand. Interviews with area residents and government officials were conducted on an informal basis to identify both problems created by M. pigra and also current and potential uses to which the weed is suited. The problems identified (which translate into benefits which would accrue if M. pigra were controlled) and the potential uses of M. pigra (the opportunity costs of controlling the weed) are shown in Figures 1 and 2.

The information gathered during the informal interviews was used to make a rough estimate of the relative economic significance of each of the benefits and opportunity costs. For those of greater economic significance further quantitative investigation was conducted. Others of more minor economic importance were investgated qualitatively only.

The specific methods used in quantitative evaluation varied for each area investigated, ranging from village level surveys conducted throughout the Chiang Mai Valley to interviews with government officials of the Highway Department, Royal Irrigation Department, etc., to data searches in the government's data archives in Bangkok.

Acknowledgements

The work on control of Mimosa pigra has been carried out with financial assistance as well as technical guidance from the International Plant Protection Center, Oregon State University and the University of Florida, from the Ford Foundation and from Chiang Mai University. The author wishes to express his gratitude for this support.

The author wishes to thank Dr. Philips Foster of the University of Maryland for his guidance and counsel, particularly for his two visits to the project during the preparation of this report. The author is very grateful to Professor Chanarong Duangsaat of the Mae Jo Institute of Agricultural Technology who was his assist, mentor, language teacher and friend during the entire period of this project.

The author also wishes to thank Ms. Saowanee Thamassara of the Royal Irrigation Department for her invaluable and unstinting assistance on occasions too numerous to mention.

Professor Punnee Wara-Aswapati of the Geography Department, Chiang Mai University, is responsible for the geographic measurement and mapping of M. pigra in the area. Dr. Martin Gibling, formerly of the Geology Department, Chiang Mai University, conducted the Geological investigation of the impact of M. pigra on rivers and reservoirs. Without the assistance of these two individuals this report would not have been possible.

The author wishes to extend his thanks also to the many other individuals who cheerfully gave their time to answer questions and contribute their own ideas on controlling M. pigra: the government officials, village leaders, farmers and other residents of the Chiang Mai Valley.

Finally, the author whishes to thank Dr. Bob Wack of the U.S. Department of Agriculture, who, in the spring of 1979, took the time to really listen and thus became the first link in the chain of events leading to this report.

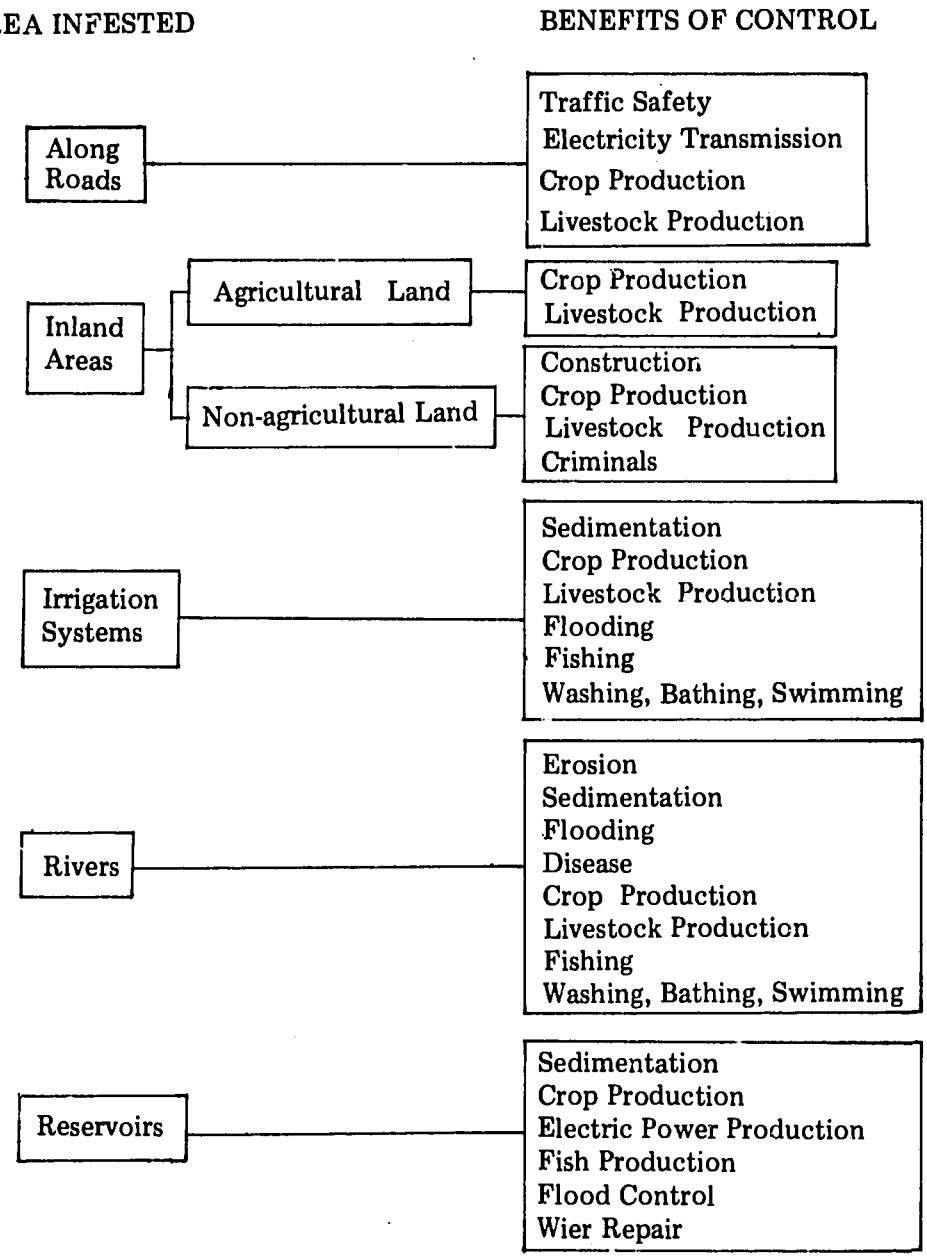
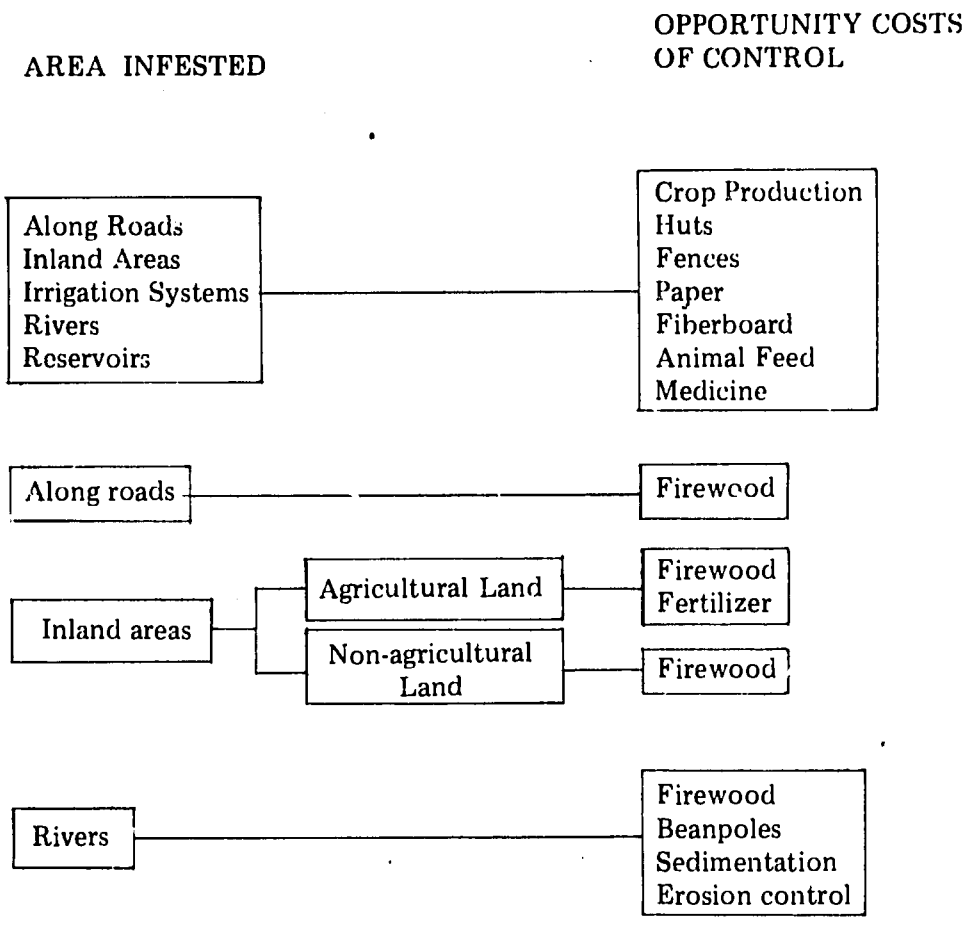


Figure 1. Benefits of Controlling Mimosa pigra.



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PART I
THE NATURE OF THE PROBLEM

Chapter 1. METHODOLOGY

Literature Search

A review of existing literature on Mimosa pigra was conducted in Spanish, English and Thai at libraries at the U.S. State Department, University of Maryland, Oregon State University and Chiang Mai University. In addition, computer searches were made using both the CRIS and AGRICOLA systems. None of these sources located a single instance where a quantitative analysis of the economic impact of M. pigra had been attempted anywhere in the world.

As the weed has been reported on every continent of the globe with the exception of Europe, the lack of economic studies was puzzling. A possible reason for the absence of previous research appeared to be that the infestation in Thailand is relatively much more serious than in other countries. This tentative conclusion was given support by Dr. Kenneth L. S. Harley, Senior Research Scientist and Officer-in-Charge of the Entomology Division of CSRIO, the Australian national research organization. Dr. Harley is currently investigating biological methods of controlling M. pigra. While on a research visit to Thailand to observe the local situation in September 1980 he indicated that the infestation in northern Thailand was by far the most severe he had ever seen. The upshot is that the present study represents the first quantitative research on the economic impact of M. pigra of which the author is aware.

The nature of the major benefits and opportunity costs of controlling M. pigra were identified by means of a preliminary survey of the study area. The survey included aerial and ground inspection of the area as well as unstructured interviews with numerous area residents and government officials.

The major benefits and opportunity costs identified were then quantified using a combination of interviews, special studies, and data searches using semi-structured interview techniques. The heads of each of the three Highway Departments in the study area were interviewed as were the heads of each of the four Royal Irrigation Department (RID) canal systems and the village level leaders responsible for the operation of twenty-one non-government or "traditional"

irrigation systems. In addition, semi-structured interviews were conducted with village headmen at twelve villages (tambons) along the Ping River, approximately ten percent of all villages lying along the Ping in the study area, to get data on river bank farming. Officials of area reservoirs were interviewed using unstructured interview techniques.

In addition to the above, unstructured interviews were conducted with various individuals who either raise animals or are directly involved with the production of livestock such as cattle, dairy cows, chickens and ducks. Various other individuals with knowledge of some aspect of M. pigra were also interviewed, e.g., paper manufacturers, the firm that produced M. pigra fiberboard, etc.

Special Projects

Some aspects of the impact of M. pigra could only be determined by designing and implementing special projects. This study incorporates the results of six major special projects which were completed under the direction and/or guidance of the author.

Mapping

As there had been no previous attempt to quantify the extent and location of M. pigra infestations, a special mapping project was carried out. Using aerial photogrophy, the exact location of M. pigra infestations in a 96 square kilometer section of the Chiang Mai Valley was prepared. This mapping was done by a team of geographers from Chiang Mai University led by Professor Punnee Wara-Aswapati.

Geology

The geological mechanisms through which M. pigra impacts on rivers and reservoirs were only vaguely understood. To fill this knowledge gap, a study of the impact on the geomorphology of area rivers and reservoirs was conducted by Dr. Martin Gibling, then a faculty member of the Geology Department, Chiang Mai University.

Disease

To determine the effect of M. pigra on the incidence of Anopheles minimus mosquitos and thus on the incidence of malaria a team led by Dr. Udom Chitprarop of the Malaria Eradication Headquarters, Chiang Mai, conducted an analysis of the population of A. minimus in the area.

Insects

To determine which insects feed on M. pigra, the anthor, Professor Channarong Duangsaad of Mae Jo Institute of Agricultural Technology and Dr. Ken Harley of CSRIO, Australia, collected specimens on numerous field trips. Taxonomic classification was done by the Entomology Department, Chiang Mai University and by the National Biological Control Research Center, Kasetsart University.

Feed, Fuel

To determine the quantity of M. pigra leaves per unit area of infestation which might be used for animal feed, sample areas were cut and the leaves dried and weighed. Similar methods were used to measure the amount of M' pigra firewood available per unit area. The caloric content of M. pigra firewood was determined using a Bomb Calorimiter at Chiang Mai University.

Analytical Techniques

The analytical techniques employed are derived from several sources, primarily Economic Analysis of Agricultural Projects by J. Price Gittinger (Baltimore Johns Hopkins University Press, 1972), Project Appraisal and Planning for Developing Countries by I. M. D. Little and J. A. Mirlees (New York: Basic Books, 1974), Cost-Benefit Analysis - New and Expanded Edition by E. J. Mishan (New York. Praeger Publishers, 1976), and Eight Preliminary Exercises in Project Analysis by Phillips Foster and Alfred Tieme (College Park, Maryland: Department of Agricultural and Resource Economics, University of Maryland, 1976.

These methodologies were modified as necessary to accomodate the analysis of the impact of M. pigra on the Thai economy. Two facets of that methodology which merit special mention, discounting and shadow pricing, are discussed in detail below.

Discounting

In this report standard discounting proceedures are employed to calculate the present value of benefits and costs of M. pigra control. Discount rates of 15% and 30% are used as these rates effectively bracket the current average rate of return on investment in Thailand.[1] The present values are computed using a ten year time horizon (except as noted) as it is felt that beyond ten years structural changes in the region and development of control methods will probably alter the economic situation sufficiently to require new data on costs and benefits.

---

[1]Based on interviews with area businessmen.

Shadow Pricing

Shadow pricing of components of a project is done when market prices, for whatever reason, do not reflect the true social value of those components. The shadow price is selected to reflect the true social value of the good or service. In evaluating projects in developing countries two key elements frequently require shadow pricing: foreign exchange and labor. Each of these elements is discussed below.

Foreign Exchange. Most developing countries have a "foreign exchange shortage," i.e., they have a greater need for foreign exchange than they have capacity to earn it. In these countries demand for foreign exchange exceeds the supply, yet the official price of foreign exchange is often held down through government regulation. The result is usually a black market in foreign exchange. In such a situation, valuing the foreign exchange component of project at the official government rate of exchange undervalues the foreign exchange component in terms of its real value to the economy.[1]

Chemical methods of controlling M. pigra require a substantial amount of foreign exchange: most herbicides are produced in the United States; most spraying equipment used is of Japanese origin as are the trucks on which the high pressure equipment are to be mounted; and all aircraft used in Thailand are purchased abroad. However, although Thailand could be considered a "developing country" by some definitions, it is not plagued with a critical foreign exchange shortage. In fact, the foreign exchange demand and supply is so well balanced that there is virtually no black market in any hard currency. For this reason, in the following analysis the foreign exchange components of control measures are valued at the official exchange rate and all foreign exchange costs are shown in baht only.

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[1]Phillips Foster and Alfred Thieme, Eight Preliminary Exercises in Project Analysis - A Programmed Learning Approach (College Park, Maryland: Department of Agricultural and Resource Economics, University of Maryland, 1976), p. 27.

Labor. In some developing countries there is a great surplus of labor resulting in high rates of unemployment and underemployment. If this labor is put to constructive use in a project, a shadow price lower than the actual wage rate should be employed in the economic analysis of that project. The shadow price is thus used to reflect the fact that the labor would be making a significantly higher contribution to society than it did before.[1]

In the Chiang Mai Valley, however, there is no significant surplus of unemployed or underemployed labor. This situation is a reflection of the low population growth rate in the area and the relatively high index of cropping intensity. Thus in the following economic analysis actual wage rates are used (with one exception) as they accurately portray the true value of labor both with and without M. pigra control.

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[1] Ibid., p. 23

Chapter 2. THAILAND AND THE CHIANG MAI VALLEY

Thailand

Geography

The Kingdom of Thailand is a constitutional monarchy encompassing an area of 513,520 square kilometers (about three-fourths the size of Texas or approximately as large as Spain) located on the Indo-Chinese Peninsula of Southeast Asia. Thailand extends at its extreme points between 20° 28' N and 5° 36' N, and between 97° 22' E and 105° 38' E. It is bordered on the west and northwest by Burma, on the north and east by Loas, and on the southeast by Cambodia. In the south it shares a common border with Malasia. (Fig. 2-1)

Thailand is divided geographically into four regions: the southern peninsula, the central plains, the northeast and the north. (Fig. 2-2) Politically the Kingdom is divided into 73 Provinces (Changwats), 411 Districts (Amphurs), 3327 Sub-Districts (Tambons) and approximately 50,000 Villages (Mubans).[1]

Of the total area of Thailand, 51.5% is forest and grazing land, 23.2% is farmland. The remainder is unclassified including swamps and lakes. Ninety percent of the farmland is now under cultivation, about three quarters of that being paddy.[2]

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[1]Noel F. Busch, Thailand: An Introduction to Modern Siam (Princeton, N.J.: D. Van Nostrand, 1964), pp. 100-101.

[2]Girgis A. Marzouk, Economic Development and Policies, A Case Study of Thailand (Rotterdam: Rotterdam University Press, 1972), p. 121.

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The climate is tropical, with three distinct seasons: rainy (June-October), cool dry (November-February) and hot dry (March-May). Writing about the climate of the region, Insor said, "heat and humidity are the main features of the climate of Southeast Asia; weather is rarely oppressive, but relaxing, enervating."[1]

Demography

The estimated population of Thailand as of mid-1980 is 47,347,000[2] with a growth rate of 2.3%[3] As of 1970 the ratio of cultivated land to population was 2.2 rai per person,[4] down from 3.0 rai per person in 1960.[5] This reduction is due largely to the rapid rise in population. In Thailand, as in other developing countries, the relatively rapid rise in population is the result of success in controlling the death rate while the birth rate changed little.[6]

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[1]T. Insor, Thailand: A Political, Social and Economic Analysis (London: George Allen and Unwin, 1963), p. 35.

[2]Leela Visaria, Family Planning and Marriage 1979-1980 (Washington, D.C.: Population Reference Bureau, Inc., 1980), no pp.

[3]_____,1979 World Population Data Sheet of the Population Reference Bureau, Inc. (Washington, D.C.: Population Reference Bureau, Inc., April 1979), no pp.

[4]2.54 rai = 1 acre; 6.25 rai = 1 hectare; 1 rai = 1600 meters.

[5]Marzouk, op. cit.

[6]T. H. Silcock, "Summary and Assessment," in Thailand: Social and Economic Studies in Development, T. H. Silcock, ed., (Canberra: Australian Natinoal University Press 1967,

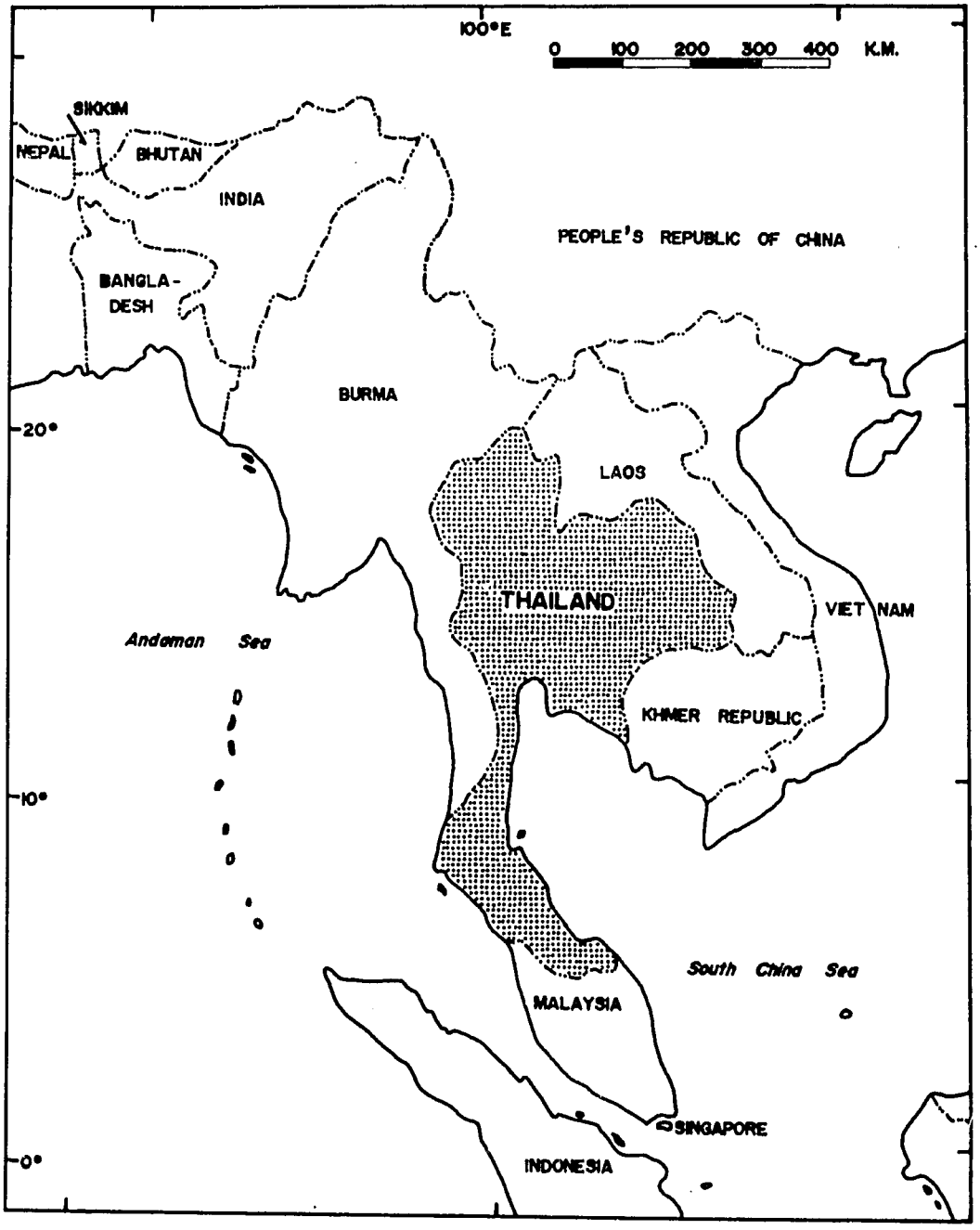

Figure 2-1. Location of Thailand in Southeast Asia.

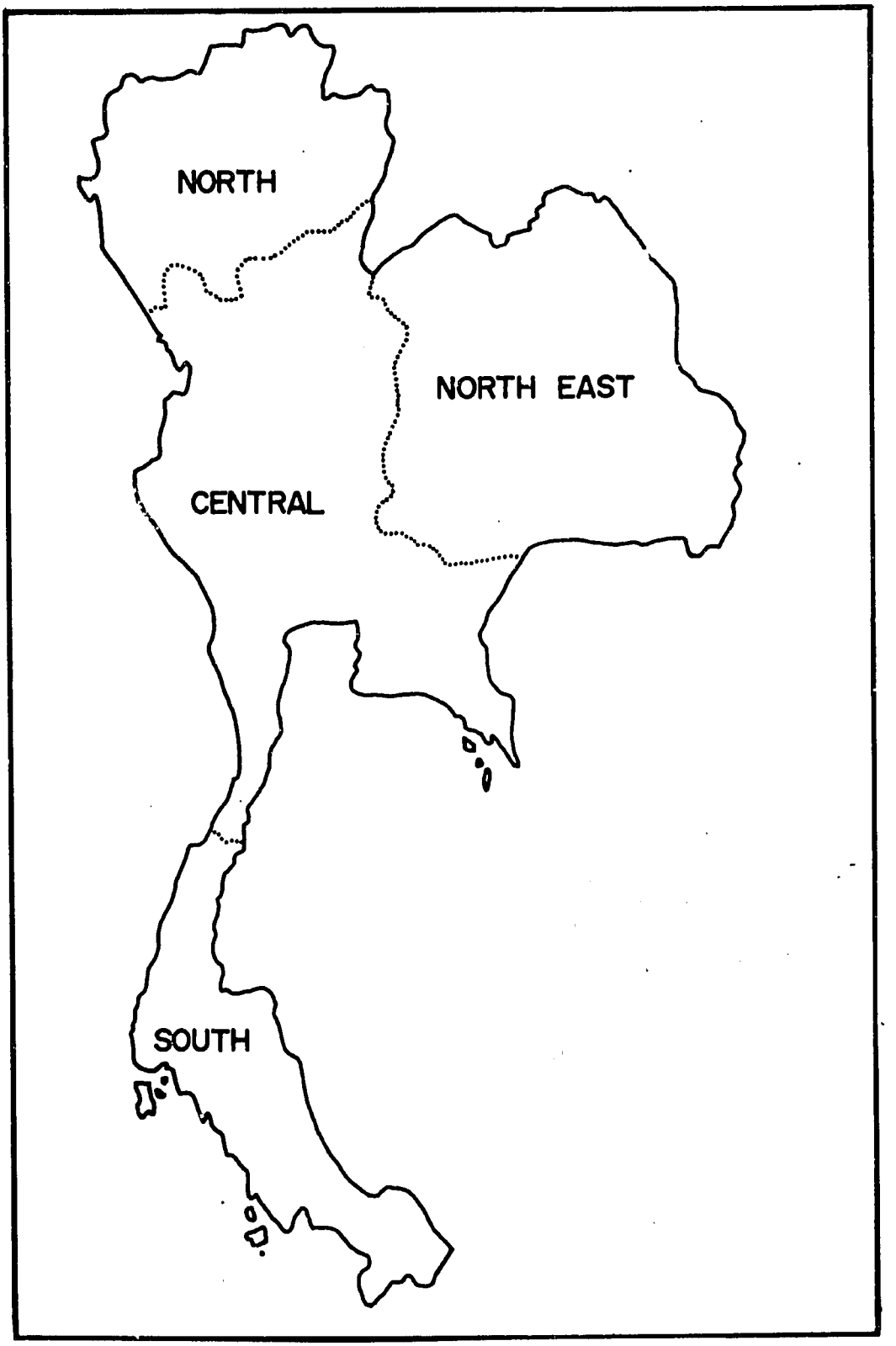

Figure 2-2. The Four Geographic Regions of Thailand.

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The average family size in all parts of Thailand is between five and six persons.[1] (Polygamy has been officially forbidden since 1935 but there is no information on the extent to which the law is followed).[2] The growing population is causing in crasing pressure for production of more food and other agricultural products while nearly all the land suitable for cultivation has been pressed into service[3] and urban centers continue to expand, absorbing prime agricultural land.

Economy

Thiland is primarily an agricultural nation, with 76% of the population dependent on farming for their livelihood.[4] In addition, three-fourths of Thailand's exports originate in agriculture.[5]

Just as the Thai economy is dependent on agriculture, so agriculture is in turn dependent on water. Over most of Thailand it is lack of irrigation water during the dry season and inadequacy of supplemental irrigation during dry spells in the rainy season that limit agricultural production and hinder crop diversifica-

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[1]Gehan Wijeyewardene, "Some Aspects of Rural Life in Thialand," in Thailand: Social and Economic Studies in Development, T. H. Silcock, ed. (Canberra: Australian Natinal University Press, 1967), pp. 65-66.

[2]Ibid., p. 67.

[3]Marzouk, op. cit., p. 155.

[4]_____, The Agricultural Economy of Thailand, ERS - Foreign 321 (Washington, D.C.: U.S. Department of Agriculture, Economic Research Service, January 1972), p. 2.

[5]Ibid., p. 4.

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tion.[1] For those reasons Riparian, flowing water resources are most crucial to the Thai economy.[2]

The supply of water is in turn dependent on the maintenance of watershed. In northeast Thailand maintenance of upland watershed is vital to the economic viability of that region alone. The northern region watershed (which encompasses the Chiang Mai Valley), however, is the key to successful agriculture not only for the nrothern region itself, but also for the crucial "rice bowl" of central Thailand.[3] Thus just as Thailand is considered an agricultural based economy, it could also be considered a water based economy: anything that affects the water supply (such as M. pigra) directly affects the economy of the nation.

The Chiang Mai Valley

Geography

Administratively, Northern Thailand consists of eight Provinces: Chiang Mai Chiangrai, Lampang, Lamphun, Maehongson, Nan, Phayao, and Prae. Geographically, there are five main valleys: Chiang Mai, Chiangrai, Lampang, Nan and Prae. Each valley consists of lowlands (primarily bunded paddy fields), uplands and highlands. Lowlands are generally defined as the areas of nearly level to gently undulating terrain composed of alluvial deposits but not characterized by any special altitude.[4]

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[1] Ibid., p. 15.

[2] _____, Country Development Strategy Statement, FY 1981 - Thailand (Bangkok: U.S.A.I.D. Thailand, U.S. Agency for International Development, January 1979), p. 20.

[3] Ibid.

[4] Jules J. Schotten, "Physiographic, Climatic and Pedological Basis for Irrigated Agriculture in Northern Thailand," in ADC National Seminar Report No. 5, Irrigated Agriculture in Northern Thailand (New York: Agricultural Development Council, 1974), p. 35.

Upland areas are the areas of undulating, rolling or hilly relief. Slopes in these areas range from five to forty degrees. The soils are mainly old alluvial deposits. Highlands are the forest areas, elevated masses of land with relief varying from nearly flat to mountainous with slopes more than forty degrees.[1]

This study concentrates its evaluation efforts on one of the five valleys, the Chiang Mai Valley, for three primary reasons: because the Valley has a heavy M. pigra infestation, because the Valley makes a very significant agricultural/economic contribution to the economy of Thailand, and because by using the same regional boundaries as the Multiple Cropping Project (MCP) of Chiang Mai University, results of this study can be more easily integrated with other research projects.

The Chiang Mai Valley, which includes portions of Chiang Mai and Lamphun Provinces, (Fig. 2-3) ,covers an area of about 1500 square kilometers; [2] it is approximately 110 kilometers long by 30 kilometers wide at its widest point.[3] (Fig. 2-4)

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[1]Kanok Rerkasem, Sorghum: A Potential Crop in Cropping Systems in the North (Chiang Mai : Multiple Cropping Project, Faculty of Agriculture, Chiang Mai University, 1980), pp. 2-3.

[2]Aree Wiboonpongse, An Economic Analysis of Ground water Use in Northern Thailand (Vancouver: CCSEAS 9th Annual Conference at the University of Brittish Columbia, November 1979), p. 4.

[3]Benchavan Tongsiri, Pichit Lerttamrab and Alan R. Thodey, Agricultural Economics Report No. 5 - Agro-economic Characteristics of the Chiang Mai Valley, 1972-1973 (Chiang Mai: Faculty of Agriculture, Chiang Mai University, January 1975), p. 1.

Soils in the Chiang Mai Valley are derived from alluvial deposits and classed as old alluvials (found along the edges of the Valley) and semi-recent and recent alluvials (scattered along the rivers). All soils are similar in their detailed characteristics.[1]

The average annual rainfall (1951-1976) is 1218 mm., with wide variation from year to year. The average annual minimum daily temperature is 23°C, with the lowest (11°C) occuring in January. The average annual maximum daily temperature is 32°C, with the highest (37°C) occuring in March and April.[2]

Demography

The total population of the Chiang Mai Valley is approximately one million (about one inhabitant per rai). Eighty-five percent of the population lives in rural areas. Of these, sixty-eight percent live in households that possess some land. The urban dwellers are concentrated in the two largest cities in the Valley, Chiang Mai (population 93,000 in 1973) and Lamphun (population 12,000 in 1973).[3]

The rate of population growth in the Chiang Mai Valley compares favorably with the 2.3% growth rate of the country as a whole. The growth rate for Chiang Mai Province is 1.29% and for Lamphun Province 1.08%.[4]

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[1]Wiboonpongse, op. cit., p. 5.

[2]Ibid., p. 4.

[3]Tongsiri, op. cit., p. 1.

[4]Phrek Gypmantasiri, et. al., An Interdisciplinary Perspective of Cropping Systems in the Chiang Mai Valley: Key Questions for Research (Chiang Mai: Multiple Cropping Project, Faculty of Agriculture, Chiang Mai University, June 1980), p. 68.

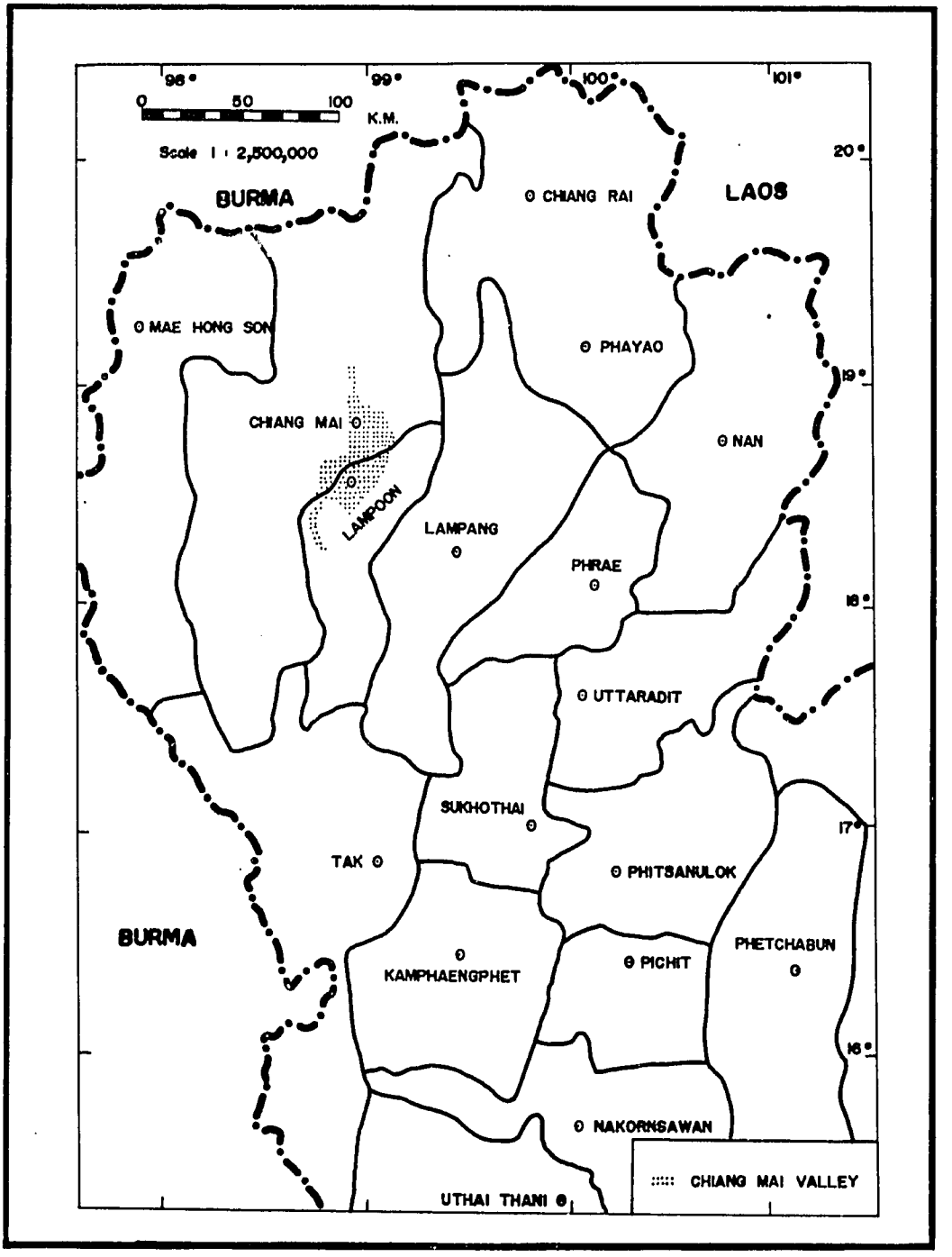

Figure 2-3. Location of the Chiang Mai Valley in the Northern Region of Thailand.

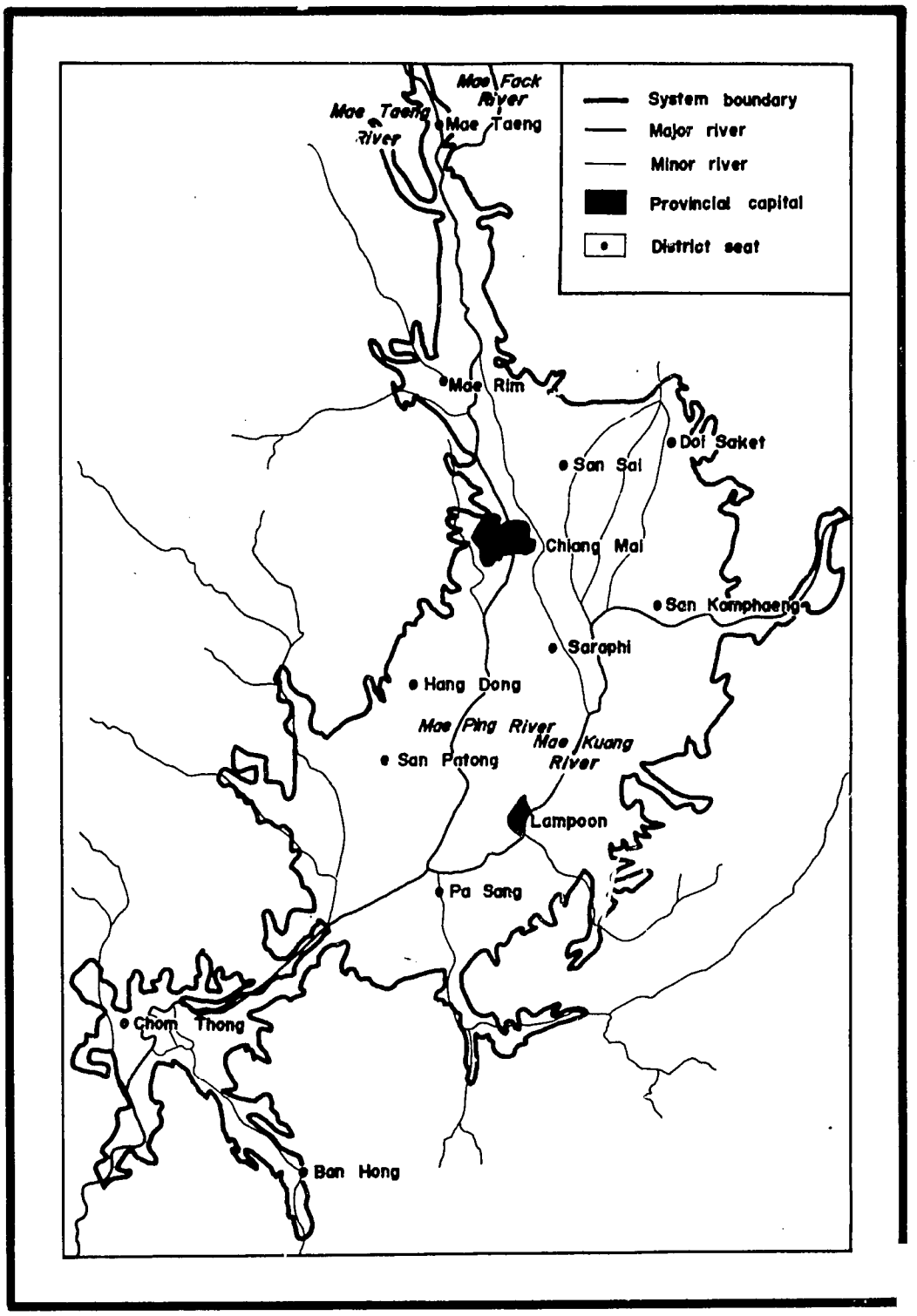

Figure 2-4. Boundaries of the Chiang Mai Valley.

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Economy

The Valley is primarily an agricultural region with only a small industrial sector. The primary non-agricultural industry is tourism: Chiang Mai is known as the "Rose of the North," famous for beautiful scenery and beautiful women.

Of the total valley area, seventy-five percent is paddy land, the balance being divided among a variety of non-rice crops and fruit trees.[1]

Agriculture

The measure of cropping intensity, the "cropping index," is traditionally defined as the number of crops grown on the same piece of land in one year x 100. The average cropping index over the entire valley was estimated to be 163 in 1978.[2] Single cropping, usually wet season rice, is practiced in areas with no dry season water supply. Double and triple cropping is found virtually exclusively in areas served by irrigation systems or other sources of water, with the most intensive cropping occuring in villages with supplemental groundwater or areas near the head of government operated irrigation system.[3] Fig. 2-5 shows the cropping intensity patterns in the valley. Over 80% of the paddy land is irrigated.[4] There are more than twenty cropping patterns practiced in the Valley,[5] with variation of second crops (and third, if any) from year to year a common practice. The major crop in the Valley is glutinous rice, planted by nearly every farm household during the rainy season. Major crops which commonly follow the glutinous rice

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[1] Ibid., p. 1.

[2] Ibid., p. 15.

[3] Wiboonpongse, op. cit., p. 5.

[4] Gymantasiri, op. cit., p. 15

[5] Ibid., p. 47

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crop include chinese cabbage, cucumbers, garlic, mungbeans, non-glutinous rice, peanuts, soybeans, sweet corn, tobacco and tomatoes. [1]

The average farm size in the Valley is about 8.8 rai; in many cases one family's holding is made up of several parcels of land which can be scattered quite far apart.[2] About half the farmers in the Valley own all of the land they farm. This group accounts for 47.4% of the total land area. 27% of the farmers own part of the land they farm and rent the rest from others; this group cultivates 31.6% of the population, those who are solely tenant farmers, cultivate the remaining 21% of the land area. [3]

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[1] Ibid., pp. 61-65

[2] Ibid., p. 23.

[3] Ibid., p. 29.

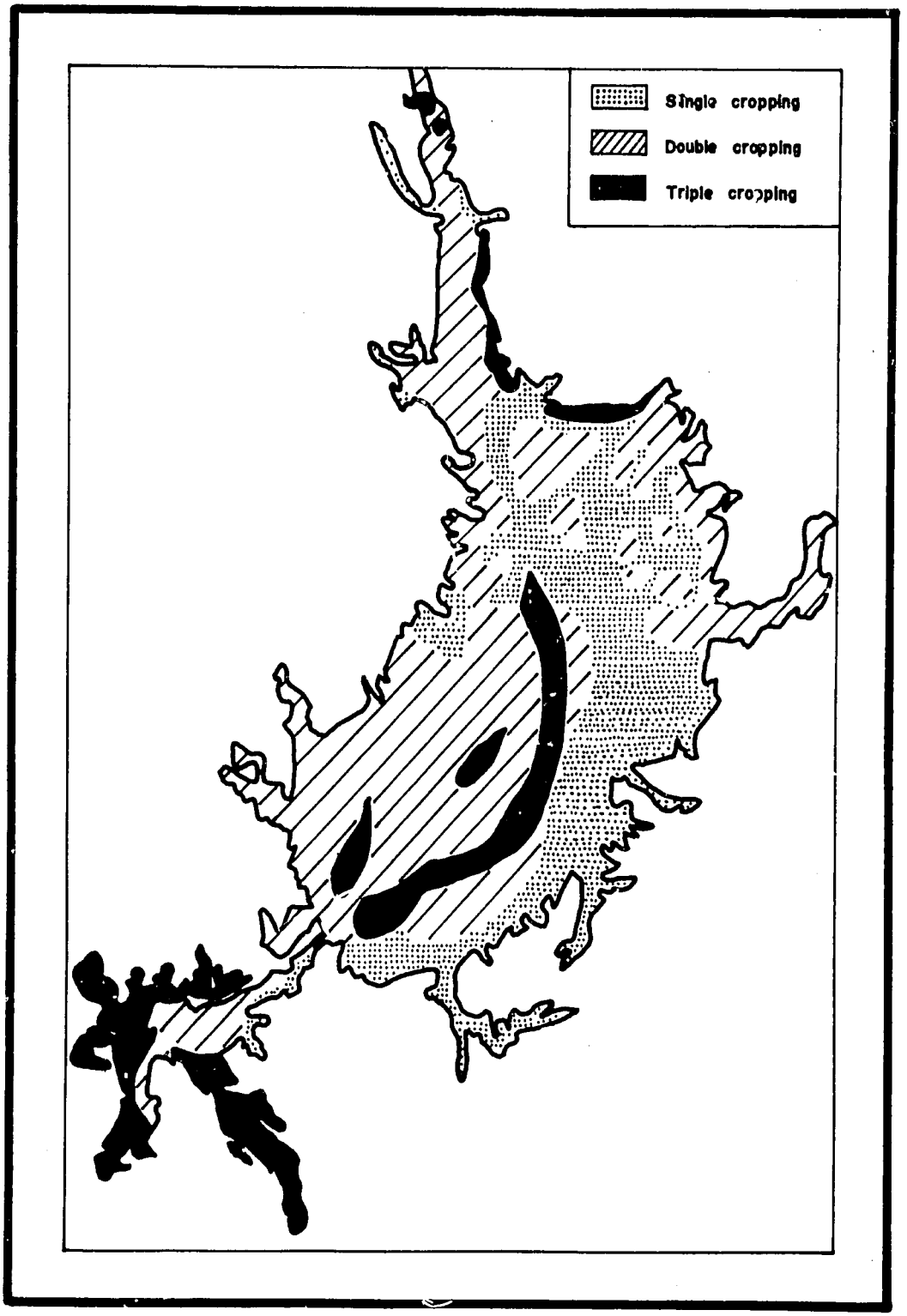

Figure 2-5. Cropping Intensity in the Chiang Mai Valley.

Source: Gypmantasiri, op. cit., p. 22.

Chapter 3. MIMOSA PIGRA LINNAEUS

Taxonomic Classification

Mimosa pigra L., in English known variously as the Giant Sensitive Plant,[1] the Thorny Sensitive Plant,[2] or just plain Mimosa[3] is one of the more than 400 species of the leguminous genus Mimosa.[4] It is a member of the Order Rosales, Family Leguminosae.[5] In Texas M. pigra in represented by two varieties, M. pigra berlandieri (gray) and M. pigra pigra.[6]

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[1] I. L. Miller, L. Nemestothy and S. E. Pickering, Mimosa pigra in the Northern Territory (Northern Territory, Australia: Division of Primary Industry, Department of Industrial d-Development, August 1978, mimeo), p. 2.

[2] P. Wanichantakul and S. Chinawong, "Some Aspects of the Biology of Mimosa pigra in Northern Thailand," in Proceedings of tne Sevènth Conference of the Asian-Pacific Weed Science Society November 26-30, 1979 (Sydney, Australia: The confeernce, 1979), p. 381.

[3] I. L. Miller, L. Nemestothy, and S. E. Pickering, loc. cit.

[4] L. J. Bottimer, "Bruchidae Associated with Mimosa with the Description of a New Species," The Canadian Entomologist, Vol. 101, (November 1969), p. 1188.

[5] J. Abriles and J. Negri Manual de Malezas en el Peru, Communes en Cana ole Azucar (Lima: May and Baker, Ltd., Cooperative Agraria de Produccion Casagrande, Ltd., a No. 32, 1973), p. 100.

[6] B. Turner, "New Names for Texas Leguminosae," Field and Laboratory, Vol. XXIV (January to October 1956), p. 15.

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Physical and Biological Characteristics

General Characteristics

M. pigra is an erect perennial shrub/tree which grows from seed. The full grown height of mature M. pigra plants has been reported to range from a minimum of 0.8 meters[1] up to a maximum of five meters.[2] In Thailand plants reaching over seven meters have been observed by the author, although the average height is closer to five meters. Prefering humid, moist areas,[3] the plant usually grows in dense thickets along river and canal banks as well as in other inland areas where sufficient water is available. They can survive on mountain-sides where water is less abundant, but their growth is relatively stunted (two meters being a large plant in the mountains of Thailand) and they seldom form thickets.

Leaves and Stems

Leaves are bipinnate and are made up of a central stem 20 to 25 cm. long, each composed of numerous fine sensitive leaflets which fold up when touched and at nightfall. The rate at which the leaves fold up when touched is usually slower than that of either M. pudica or M. invisa (two other species of Mimosa also present in Thailand). Older leaves tend to fold more slowly than younger leaves on the same plant.

Root System

The root system of M. pigra is extensive and fast growing. New plants 2-3 cm. in height have a taproot two to four times the height of the plant above ground. In mature plants 3-5 meters tall the taproot is one to two meters long, and the diameter of the root system can be up to seven meters or more. Nodules characteristic of leguminous plants are present on the root hairs.

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[1] Abriles and Negri, loc. cit.

[2] Wanichantakul and Chinawong, loc. cit.

[3] Rafael Castaneda, Plantas del Magdalena, II (Flora de la Isla de Salamanca) Primera Parte (Bogota: Instituto de Ciencias Naturales, 1971), p. 114.

Flowers

Flowers are fluffy balls mauve to pink in color and 10 to 20 mm. in diameter. Stems are short and flowers have 8-10 white stamens and green, oblong hairy ovaries.[1] The flowering cycle (January-December) is shown in Fig. 3-1

Fruit

Seed pods are 3-8 cm. long, one cm. wide, densely bristly. Mature pods are medium to dark brown in color. Pods are divided into an average of 20 segments, each segment containing a single olive green seed 4-6 mm. by 2 mm. in size. The seeds are protected by a very hard seed coat.

Seed Production

Although M. pigra flowers to a greater or lesser extent nearly all year round, the majority of fruit is set between May and August, with the bulk of the seeds maturing by the end of December. During the active seed production period, however, the plant is extremely prolific. The average number of seeds on 2-3 meter trees counted in August was 42,010.56.[2] Under favorable conditions, e.g., ample water supply, a single tree can produce 95,000 seeds per year.
Under favorable conditions, e.g., ample water supply, a single tree can produce 95,000 seeds per year.[3]

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[1] Ibid.

[2] Chanarong Duangsaad, et. al., A Study of Seed Production of Mimosa pigra L. (Chiang Mai: Mae Jo Institute of Technology, in Thai, no pp.).

[3] Wanichanantkul and Chinawong, loc. cit.

Germination

Various factors affect the rate of germination of M. pigra. Seeds do not germinate at all at temperatures below 10° C (50° F)[1] which may account for the absence of M. pigra in temperate zones of the world. Other experiments have produced the following results:

1) Seeds submurged under 0, 2.5, 5, 10, and 20 cm. of water showed germination rates which were not significantly different from one another although seeds germinating under more than a centimeter or so of water are not able to survive.[2]

2) Seeds planted at different soil depths showed very different germination rates:

Surface	- 57.75%	germination
6 cm. deep	- 12.30%	germination
8 cm. deep	- 0.0%	germination[3]

3) Planting in various types of soil had only limited effect on germination rates:

Sand	- 48.75%	germination
Sandy Clay	- 48.20%	germination
Clay	- 45.72%	germination
Laterite	- 39.08%	germination[4]

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[1]Jerdsri Bhanthumnavin, Factors Affecting Germination of Seed of Mimosa pigra Linn. (Abstract of unpublished Master's thesis, Faculty of Science, Kasetsart University, Bangkok, 1977), p. 1.

[2]Ibid., p. 3.

[3]Ibid. p. 2.

[4]Ibid., p. 3.

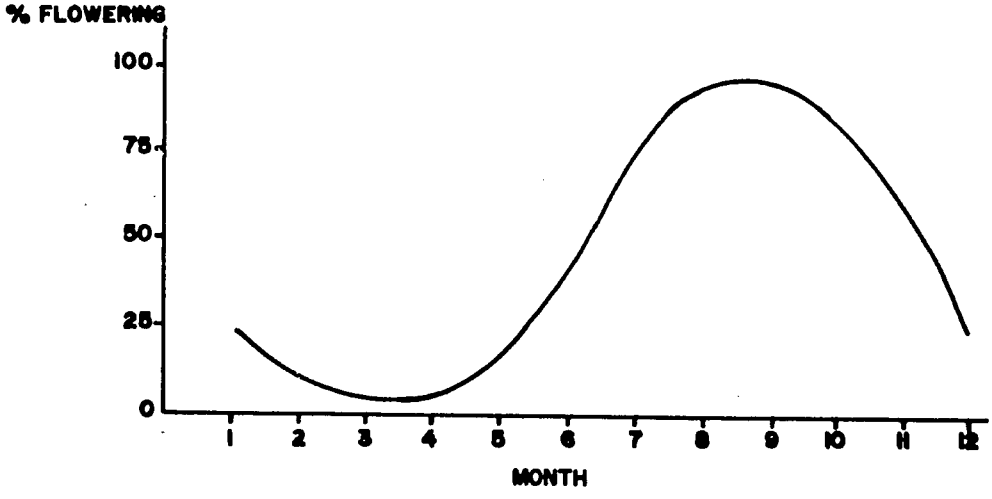

Figure 3-1. The Annual Flowering Cycle of M. pigra in Thailand.

Source: Kittipong, 1980, op. cit., p. 21.

Various authorities differ on the period of viability of M. pigra seeds. Wanichantantakul and Chinawong found a drop in viability from 97% for one month old seeds to 67% for seeds stored for twelve months.[1] Dr. Vichien Pusawang, a plant physiologist in the Department of Horticulture, Chiang Mai University, has found seeds stored under ambient conditions to be viable after two and a half year.[2] Others state that seeds may remain viable for up to 10 years.[3] There are, however, indications that seeds submurged in water two years or more cannot germinate.[4]

Various methods, including boiling seeds in water, soaking them in acid solutions and pricking them with scisors all act to hasten germination. Although no controlled experiments have been conducted, it is common knowledge among farmers that burning fields of M. pigra increases germination.

Growth Rate

M. pigra can grow to a height of one meter or more in three months under well watered conditions and can begin producing seeds after six months,[5] although the first year the number of flowers will be small, with a rapid increase in inflorescence the second and subsequent years.[6] The results of one rate of growth study are shown in Table 3-1. Plants were grown in pots of unspecified size so effects of possible stunting of root growth on height, if any, are unknown.

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[1] Wanichanantakul and Chinawong, loc. cit.

[2] Interview with Vichien Pusawang, Faculty of Agriculture, Chiang Mai University, September 18, 1980.

[3] Miller, Nemestothy, and Pickering, loc. cit., p. 5

[4] _____, Maiyarap Yak [Mimosa pigra] (Bangkok: Weed Control Research and Experiment Division, Department of Irrigation, 1978, in Thai), p. 2.

[5] Duangsaat, et. al., op. cit.

[6] Pytoon Kittipong, Maiyarap Yak [Mimosa pigra] (Bangkok: Thai Department of Agriculture, 1980, in Thai), p. 3.

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Climax Species

M. pigra gives many preliminary indications of being a climax species wherever it has become well established in Thailand. It is intollerant of shade and thus does not establish itself well where taller vegetation such as broadleaf trees are common, but in more open areas it appears at first glance to be a virtual monoculture. However, on closer examination many other plants are often found to be coexisting with the M. pigra. It serves as a trellis for several vine species (including its cousin, Mimosa invisa), and it is even overtopped by some species of reed. In fact, it appears that the longer a stand of M. pigra is left unmolested, the more different species are able to compete with it successfully. As these other species increase in density they gradually shade out more and more of the M. pigra. Finally, M. pigra loses its position as the dominant form and "normal" succession occurs.

Distribution

World-Wide

Apparently native to Central and South America, M. pigra has managed to infest every continent of the world but Europe. (Fig. 3-2) Europe's unique position may end soon, however: four to five kilograms of M. pigra seed were shipped from Thailand to Saudi Arabia in 1980.[2]

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[1] I. L. Miller and S. E. Pickering, Mimosa pigra - A Noxious Weed (Northern Territory, Australia: Division of Primary Industry, Department of Industrial Development (Agdex 647), July 1978), no pp.

[2] Interview with Surapong Sugunnasil, Managing Director, Contec Concrete Co., Ltd., Chiang Mai, November 17, 1980.

Table 3-1. Height of M. pigra grown in pots.

Days since germination	Average plant height (cm.)
30	25.8 ± 0.5
90	97.1 ± 16.2
150	244.1 ± 18.3
210	274.5 ± 35.4
270	301.0 ± 20.6
360	335.1 ± 15.9

Source: P. Wanichanantakul and S. Chinawong, "Some Aspects of the Biology of Mimosa pigra in Northern Thailand," Proceeding 7th Asian-Pacific Weed Science Society Conference, 1979, p. 382.

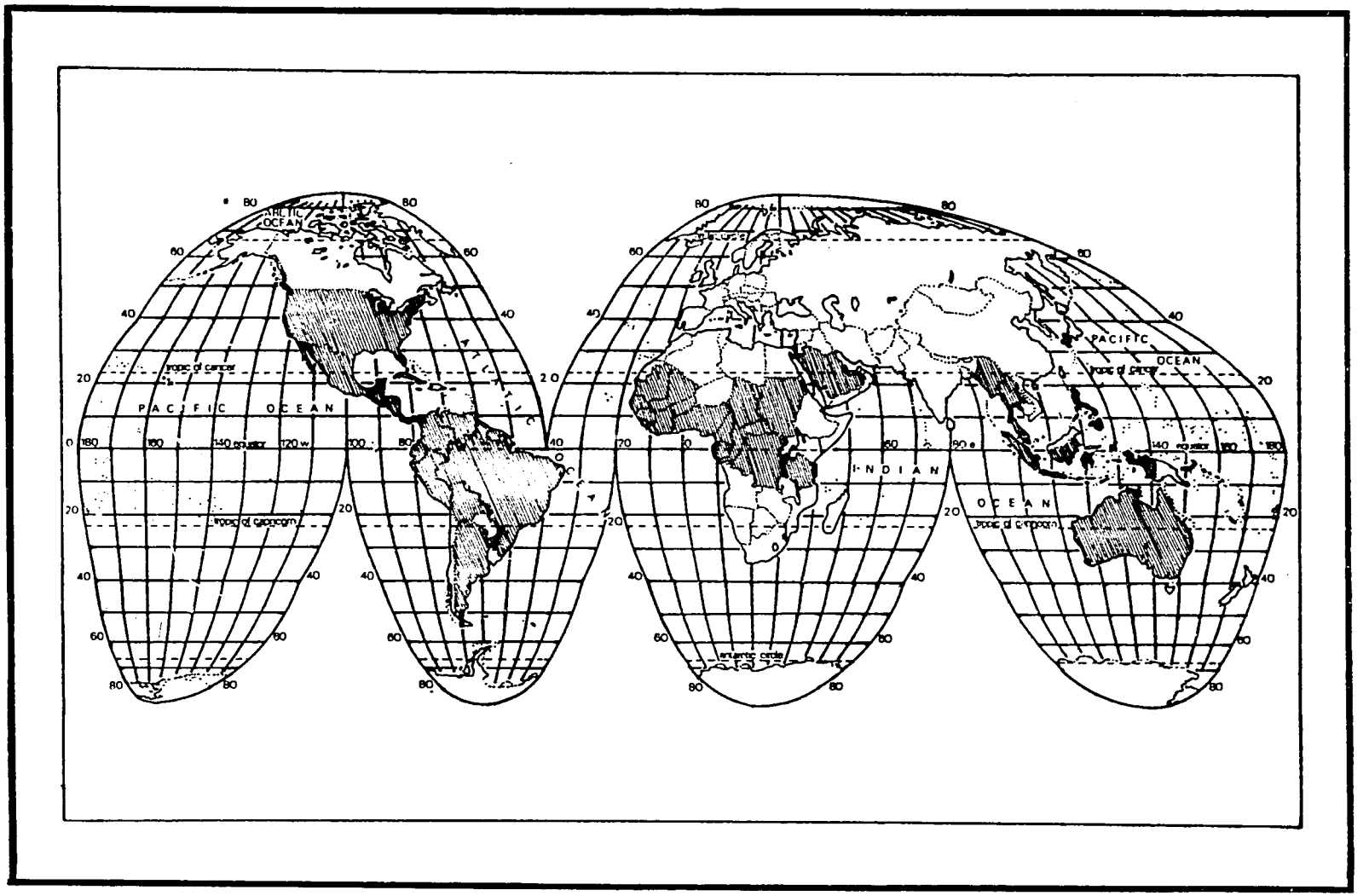

Figure 3-2. Distribution of M. pigra Worldwide by Country.

Protocols Pest Plants

Figure 3-2. (Cont.)

Sources for World Map:

U.S. - Fred B. Jones, Flora of the Texas Coastal Bend (Corpus Christi, Texas: Mission Press, 1975), p. 86.

Argentina - Interview with Dale Habeck, Entomologist, University of Florida, March 31, 1981.

Bolivia - Interview with Ken Harley, Senior Research Scientist, CSRIO, Australia Sep 23, 1980.

Brazil - Letter from John A. Winder, Officer in Charge, CSRIO Brazil, Parana, Brazil, March 4, 1980.

Peru Abriles and Negri, op. cit.

Colombia - Letter from Jerry D. Doll, Extension Weed Scientist, Department of Agronomy, University of Wisconsin, Madison, Wisconsin, January 29, 1980.

Ghana, Sudan, Nigeria, Tanzania, French Equatorial Africa (Gabon, middle Congo, Ubangi-Shari, Chad) - Irvine, F. K., Woody Plants of Ghana with Special Reference to Their Uses (London: Oxford University Press, 1961), p. 346.

West Tropical Africa - J. Hutchinson and J. M. Dalziel, Flora of West Tropical Africa, Second Edition Vol. I, Part 2 (London: Crown Agents for Overseas Governments and Administrations, 1958), p. 495.

Philippines - Ludivina S. de Padua, Gregorio C. Lugod and Jan V. Pancho Handbook on Philippine Medicinal Plants, Vol. 1, (Los Banos, Philippines: Documentation and Information Section, Office of the Director of Research, University of the Philippines at Los Banos, September 1977), p. 39.

Indonesia - Miller, Nemestothy and Pickering, op. cit., p. 3.

Laos and Burma - Interview with Saowanee Thamassara, Weed Control Laboratory Branch, Royal Irrigation Department of Thailand, September 23, 1980.

Central America - Standley, P. C., "Flora of the Loncetilla Valley, Honduras," in Field Museum of Natural History, Pub. 283, Botanical Series Vol. X, Jan. 15, 1931, pp. 213-214.

Ecuador, Guyana, Surinam, French Guiana - Interview with Dale Habeck, Entomologist, University of Florida, Gainsville, Florida, February 22, 1982.

Saudi Arabia - Interview with Surapong Sugunnasil, Managing Director, Contec Concrete Co., Ltd., Chiang Mai, November 12, 1980.

M. pigra is known by many different names in different regions of the world:

Colombia -- zarza,[1] domidera, sensitiva, espino[2]
Costa Rica -- Zarza[3]
El Salvador -- zarza, dormilona[4]
Guatemala -- sinverguenza[5]
Mexico -- choveno,[6] vergonzosa[7]
Panama---espina de vaca[8]
Peru -- una de gato[9]

The name for M. pigra in Thai is Maiyarap Yak. The name Maiyarap comes from the Ramakien, the Thai version of the Indian Ramayana. According to the mythology of the Ramakien, Maiyarap was the imortal King of the Underworld. In Thai Yak means giant.

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[1]Castaneda, loc. cit., p. 114.

[2]Leopoldo Morales, et. al., Algunas Malezas de Potreros Tropicales Manual de Assistencia, No. 19 (Bogota: CIAT, Universidad Nacional de Colombia, July 1974), p. 176.

[3]P. C. Standley, "Flora of the Locetilla Valley, Honduras," Field Museum of Natural History, Pub. 283, Botanical Series Vol. 10 (Chicago: Field Museum of Natural History, January 15, 1931), p. 214.

[4]Ibid.

[5]Ibid.

[6]P. C. Standley, Trees and Shrubs of Mexico (Washington, D. C. : Smithsonian Institution, 1961), p. 362.

[7]Jorge Nieto and Omar Agudis, "Combate de la Zarza con Herbicida," Agricultural Technica en Mexico, No. 10, (1960), p. 21.

[8]P. C. Standley, 1961, loc. cit.

[9]Abriles and Negri, loc. cit., p. 100.

[10]Ray A. Olsson, The Ramakien - A Prose Translation of the Thai Version of the Ramayana (Bangkok: Askorn Sampan, 1968), pp. 181-192.

Thailand

M. pigra was orginally introduced into Thailand from Indonesia in 1947. It was first planted in Amphur Mae Taeng where it was used as a ground cover to improve soil quality, and to help prevent bank erosion

Presently M. pigra is growing in 20 of the 73 provinces of Thailand, with the heaviest concentrations in the northern region.(Fig. 3-3)

Means of Distribution

M. pigra infestations in Thailand are spread primarily by two river-related vectors: water and sand. Seed pod sections, each containing a single seed, are released when mature by the mother plant. The seed pod sections do not float on the air, so in the absence of a strong wind, they fall near the base of the tree where they grew. As many of the trees grow. at the edge of or actually in rivers the seed pod sections often fall onto the surface of the water.

Experiments performed by the author have shown that seed pod sections can float for more than a week in still water. Thus seed pod sections which fall on the surface of the river can be carried long distances by the river currents. In addition, the period when most seeds mature and fall from their trees coincides with the rainy season, when the width of rivers is greatest and the current is strongest, thus speeding seed distribution.

Some of the seeds floating on the surface of the water in their seed pod sections lodge along the edge of the river downstream from the parent plant or float into irrigation systems and lodge along irrigation canal banks. (The period of maximum seed release also coincides with the period of maximum irrigation activity.) Seeds lodging along river and canal banks are thus in an ideal situation to survive if they germinate: an ample water supply and fertile soil.

Other seeds are knocked from their pod sections and fall to the bottom of the river. If these seeds germinated underwater they could not survive. However, due to their hard seed coat, many do not germinate immediately. Then when the rainy season ends and the level of water in the river falls, those seeds which fell to the bottom are now on the surface of the moist, rich soil of the exposed river bottom. Those are the seeds that grow into M. pigra "islands" in the middle of rivers: the seeds germinate in the dry seasons and grow so rapidly that by the time the river rises during the following rainy season they are usually tall enough to extend above the water and survive.

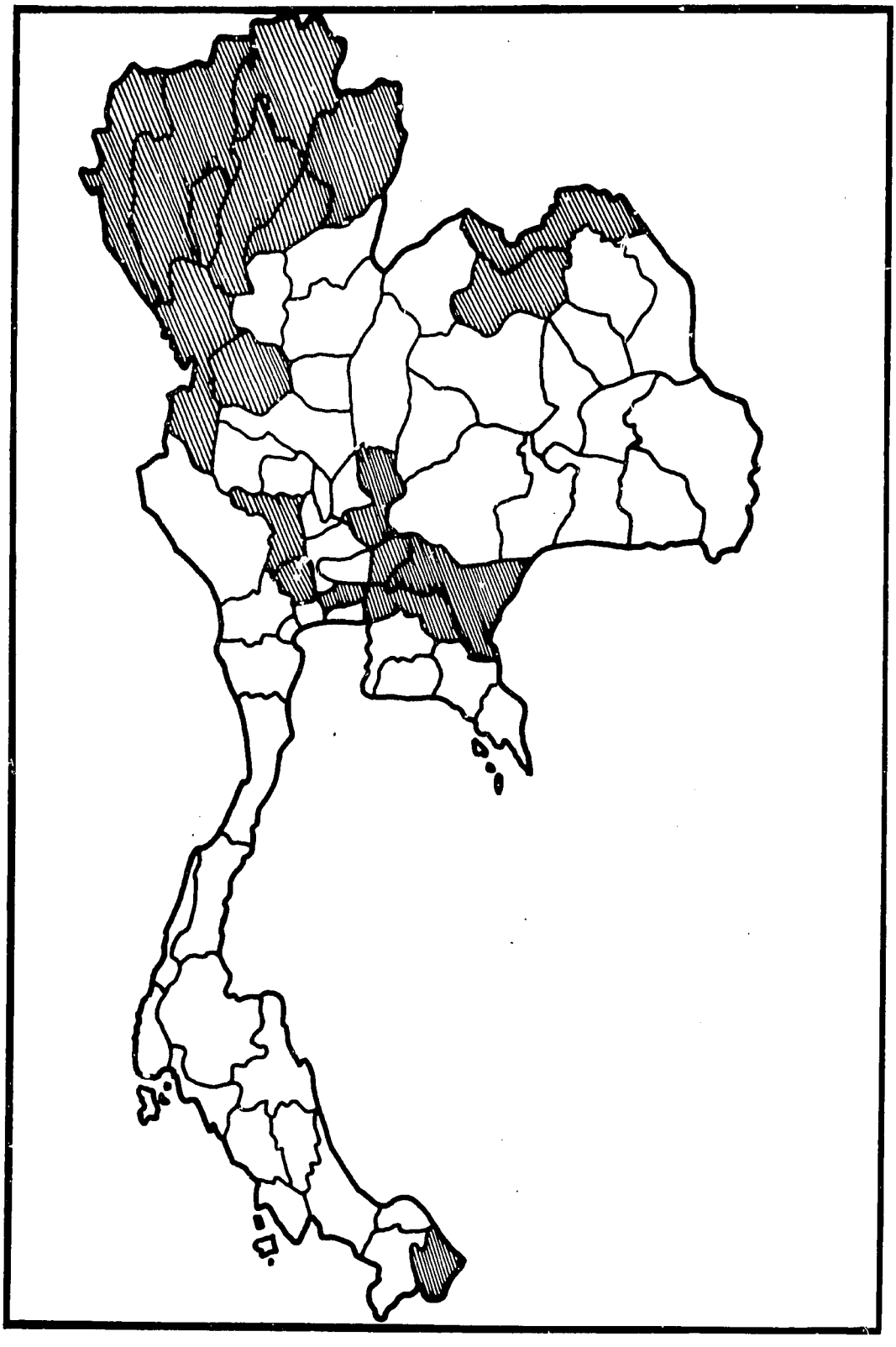

Figure 3-3. Distribution of M. pigra in Thailand by Province (Changwat)

Both the seeds that germinate while lodged along river banks and those which germinate during the dry season on exposed river bottoms are usually a distance downstream from their parent plant. They then mature and produce seeds of their own, spreading the infestation further downstream with each annual repitition of the cycle.

The second means of seed dispursal is sand. Much of the riverbank area in the Chiang Mai Valley is composed of a meter or so of topsoil underlaid with a layer of sand many meters thick. Sand from the river bed is removed either by hand or by using large mechanical suction devices and sold. The primary customers for the sand are firms engaged in building construction or road construction/repair. With a few minor exceptions, those industries do not care if there are M. pigra seeds present in the sand they purchase or not, so sand suppliers choose the easiest, closest source of sand: usually river bottoms. (Sand may be removed from rivers without paying royalty - only government permission is required. Then when a new building is constructed or a new road built the construction activity effectively spreads M. pigra from river banks to other areas often many kilometers distant.

In addition to the independent spreading done by water and sand alone, the two vectors work together in cyclical fashion to spread the infestation further and faster: seeds travel from one river site to a construction area or roadway. From there they make their way into another as yet uninfested river, starting the cycle again.

A prime example of this mutual assistance between sand and water is the case of Doi Intanon mountain and the surrounding irrigated valley area. In 1972 the area had absolutely no M. pigra. Then a new road going up the mountain was constructed. No effort was made to use sand free of M. pigra seeds, and the weed sprouted along the new road. The new road is close to the Mae Klang river (which in 1972 was completely free of M. pigra). Today, M. pigra has established itself not only along the new road but also in the Mae Klang River and the irrigation systems which draw their water from the Mae Klang.

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PART II

BENEFITS OF CONTROLLING
MIMOSA PIGRA

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Chapter 4. ALONG ROADS

Definition

For purposes of this study "along roads" is defined to be that area adjacent to roads maintained by highway department crews. It begins at the edge of the road surface and extends away from the road for varying distances; the exact width of the area depends on the classification of the road.

Nature of the Infestation

Qualitative Description

M. pigra can be found along most paved roads in the Chiang Mai Valley. Density of infestation varies from clumps of a few trees to groups of many hundreds of trees extending over tens of meters to virtually uninterrupted thickets going on for a kilometer or more.

Height of individual trees varies from new sprouts a few inches tall to mature trees three to five meters tall. Normally trees do not exceed three meters as all vegetation in areas along roads is cut at least once a year by highway department crews; however, in some areas where roadside maintenance is not carried out according to schedule trees grow to full height, in some locations nearly reaching the tops of utility poles. The rate of growth along roads is relatively high as roadside drainage ditches provide an above average supply of water.

Width of infestations (measuring perpendicular to the edge of the road surface) varies from about two meters up to the point where roadside infestations merge with infestations on non-agricultural land extending inland for tens of meters.

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Quantitative Description

Present extent. There are approximately 882 kilometers (km.) of roads in Chiang Mai Province. Of this total approximately 79.9 km. (48.7%) of minor roads, 113.5 (35.7%) of intermediate roads, and 70 km. (17.5%) of minor roads are infested with M. pigra. Infestations along roads in the Chiang Mai Valley are limited to Chiang Mai Province where the total maintained area along roads is 11,900 rai. Of this total, 5,116 rai or 43% is infested with M. pigra. (Table 4-1) As yet neither Lamphun District nor Ban Hong District, the two Districts in Lamphun Province which lie within the Chiang Mai Valley have any infested roadways.[1] Lamphun and Ban Hong are the two Districts which are farthest south in the Chiang Mai Valley, and also farthest away from Mae Taeng District in the north of the valley, the initial point of infestation in Thailand.

Potential Extent. As noted above, highway department crews regularly cut all vegetation along rights of way along roads so M. pigra does not usually have the opportunity to reach its full potential in these areas. If areas along roads were not maintained, M. pigra infestations would quickly expand right up the very edge of the pavement and branches would extend up to a meter or more out over the surface of the road. Density of the infestations would increase to equal that in other areas where M. pigra is not now controlled, i.e., it would become a virtually impenetrable thicket along those sections of road where it is now present. Infestations along roads are usually spread by seed pod sections floating along drainage ditches as well as sand containing M. pigra seeds being used in road construction or road repair rather than by flowing river water.

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[1] Interviews with Bhunjun Nithiuthy, Director of Chiang Mai Highway Department Section 2, December 17, 1980, Pyroj Sirpirm, Director of Chiang Mai Highway Department Section 1, December 18, 1980; and Thim Sittiwang, Assistant Director of Lamphun Highway Department, December 16, 1980.

Table 4-1. Incidence of M. pigra Infestation Along Roads in the Chiang Mai Valley

Classification of road	Length of roads (km)	Width of maintained right of way (both sides-meters)	Total maintained area (rai)	Total area infested with M. pigra (rai)
Major	164	70	7175	3494
Intermediate	318	20	3975	1491
Minor	400	3	750	131
TOTAL	882	—	11,900	5116

Source: Interviews with Bhunjun Nithiuthy, Director, Chiang Mai Highway Department, Section 2, December 17, 1980; Pyroj Sirpirm, Director, Chiang Mai Highway Department, Section 1, December 18, 1980; and Thim Sittiwang, Assistant Director, Lamphun Highway Department, December 26, 1980.

Nature of the Benefits

Traffic Safety

If M. pigra were not controlled along highway rights of way serious safety hazards would result. The major hazards are described below. Economic values of safety benefits are not calculated as attempts at quantification would be pure speculation due to insufficient data, but the value of these benefits is assumed to be very significant.

Visibility. With M. pigra trees growing to the edge of roadways, the vision of vehicle drivers would be restricted. The problem would be particularly dangerous at curves and intersections, and could greatly increase the traffic accident rate.

Traffic Signs. Roadside traffic signs such as stop signs, signs warning of approaching intersections, curves, etc., would be totally obscured if M. pigra were not controlled. As with visibility problems, the result would, in all probability, be an increase in traffic accidents.

Bicycles and Motorcycles. Bicycles and motorcycles constitute about half the vehicles on the roads of the Chiang Mai Valley. As bicycles are human powered and the average motorcycle is only in the small 70-90 cc. class, both types of vehicles travel at speeds considerably slower than that of the cars and trucks with which they share the highways. The informal and unwritten "rules of the road" in Thailand state that the slower bicycles and motorcycles must move to the side of the road to allow cars and trucks to pass. With M. pigra growing to the edges of the roads and overhanging branches effectively reducing the width of each lane by a meter or more, there would be inadequate room for bicycles and motorcycles to make way for cars and trucks as they now do. Again, this situation would certainly tend to increase the accident rate.

Electricity Transmission

Control of M. pigra along roads would benefit the Electricity Generating Authority of Thailand (EGAT) by reducing the cost of electricity transmission in two areas: erection of new utility poles and maintenance of existing poles and power lines.

Utility Pole Erection. In the Chiang Mai Valley an average of 300 new utility poles are erected each month. Poles are erected along roads at the outer edge of the area maintained by the highway department. The installation cost (labor and

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equipment exclusive of the cost of the poles and power lines themselves) is ฿ 100 per pole if the pole is erected in an area free of M. pigra.[1] Where there is an infestation of M. pigra the average cost per pole increases by 20% to ฿ 120, an increase of ฿ 20 per pole. Approximately 30% of all poles are erected in areas infested with M. pigra.[2]

If all current control efforts along roads were halted, virtually all areas where utility poles are erected would soon become infested with the weed. The annual benefit of current control efforts is therefore the savings per pole erected in uninfested areas (฿ 20) times the number of poles erected yearly in uninfested areas (2520), a total of ฿ 50,400.

Total control of M. pigra along roads, i.e., complete elimination of the weed, would result in an annual benefit of ฿ 72,000: every one of the 3,600 poles erected annualy would be erected in uninfested areas at a saving of ฿ 20 per pole.

Utility Pole and Power Line Maintenance. Benefits would be realized in the area of pole repair as well. Utility poles in the Chiang Mai Valley are made almost exclusively of concrete so replacement of poles is extremely infrequent. Weather severe enough to damage power lines is virtually unknown,[3] so storm damage to power lines is rare. In addition, the low level of air polution in the area means that corrosion damage to the all aluminum powerlines is minimal. The upshot is that the average interval between repairs on any single pole is ten years.[4]

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[1]Twenty baht (฿ 20) equals approximately $ 1 U.S.

[2]Interview with Kassaem Moolajongkorn, Electricity Generating Authority of Thailand, Division 1, January 6, 1980.

[3]Gypmantasiri, op. cit., p. 114.

[4]Moolajongkorn, op. cit.

When repairs are carried out, the average time per repair per pole is 30 minutes. If the repair crew is working in an area infested with M. pigra, the average time per repair doubles to one hour. The typical repair crew consists of three to four men each earning an average wage of ฿ 23.81 per hour.[1] Thus using the average of 3.5 men per crew, the additional cost of repairs to one pole due exclusively to M. pigra is ฿ 41.67. Based on one repair every ten years, the average annual cost is ฿ 4.167 per pole. (Calculation: 3.5 men/crew x 0.5 hours extra per repair in infested areas x ฿ 23.81/hour/man ÷ 1 repair each 10 years = ฿ 4.167 per pole per year.) There are approximately 9,800 utility poles along roads in Chiang Mai Province.[2]

Crop Production

Crop Production could be affected adversely by M. pigra growing uncontrolled along roads in that the weed is a potential alternate host for crop-damaging insects. Normally insects have a "favorite" plant (primary host) on which they prefer to feed, however, if this plant is not available, some insects are capable of feeding on a less preferred plant species. The less preferred plant is known as the alternate host of that insect.

The major ramification of an alternate host is the effect on the population of the insect. To quote H. H. Ross, "in the case of insects feeding on a definite species of plant host, this latter may become defoliated, and it is necessary for the species to adopt a new host or to have its numbers reduced to the carrying capacity of the original host." [3]

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[1]Interview with Praphant Khowsuwan, Electricity Generating Authority of Thailand, Division 1, January 13, 1980.

[2]Moolajongkorn, op. cit. The approximate number of poles was calculated by dividing the 882 km. of roads in Chiang Mai Province by the average 90 meters between poles. Lamphun Province was excluded from the calculation as it has no M. pigra infestations along roads at this time.

[3]Herbert H. Ross, A Textbook of Entomology, 3rd Edition (New York: John Wiley and Sons, Inc., 1965), p. 460.

Preliminary research has shown M. pigra to be an alternate host for a variety of crop damaging insects (Fig. 4-1). Thus, for example, in the hot season after the rice and soybean crops have been harvested, the populations of stink bugs, leaf hoppers, and aphids would normally die back to minimal numbers. However, with the introduction of M. pigra these insects can transfer themselves to that weed and continue to thrive. Then when rice is planted again the following rainy season large numbers of these insect pests will be available to transfer back to their primary host, attacking the new rice plants.

M. pigra is potentially a very important alternate host as it remains green year round, even during the hot dry season when most crops have been harvested, many annual plant species have died, and many perennials have shed their leaves. Unfortunately, a quantitative evaluation of the economic impact of M. pigra as an alternate host would require two years or more of study by a trained entomologist and even an educated guess of the value of controlling the weed is beyond the capacity of this study given the present state of research into the problem.

Livestock Production

Benefits would also be forthcoming in the area of livestock production if M. pigra were controlled along roads. To understand the nature of this benefit, a brief description of the livestock situation in northern Thailand is necessary.

The Chiang Mai Valley is a very fertile region with quite high crop yields per rai and considerable double and even triple cropping. As a result, the opportunity cost of raising cattle and water buffalo on land which could be producing crops is so great as to virtually preclude the practice. An extensive search throughout the Valley located only one case of cropland being used exclusively for grazing cattle. In this one instance the landowner was a wealthy farmer who used only 35 of his 1000 rai of land for cattle, the rest being planted to various crops.

Water is the chief limiting factor in agricultural production in the Valley. During the cool and hot seasons even in most irrigated areas there is insufficient water for farmers to plant their entire acreage. During these seasons there is considerable fallowed cropland area which can be used for cattle and water buffalo grazing. During the rainy season, however, water is plentiful almost everywhere and virtually all arable land is planted. Thus during the rainy season a major source of grazing land is no longer available: the fields left idle during the cool and hot seasons are now all planted, primarily to glutinous rice. The need for

INSECT	PRIMARY (CROP) HOSTS
Leaf hopper	Rice Soybeans
Stink bug	Rice Soybeans
Aphid	Rice Soybeans
Coffee borer	Coffee Rice Soybeans
Moth (Family Lycaenidae Subfamily Theclinae)	Legumes and other crops

Figure 4-1. Partial List of Crop Damaging Insects for which M. pigra is an Alternate Host.

Note: Research in this area is in the very preliminary stages, hence this list is far from complete. As yet even specific insect species have not been identified.

Source: Interview with Chanarong Duangsaad, Projessor of Entomology, Mae Jo Institute of Agricultural Technology, January 10, 1981.

grazing land during the rainy season is currently being filled in part by roadside rights of way, the areas along roads maintained by the highway department. However, the 5116 rai along roads infested with M. pigra[1] is rendered unavailable to cattle and water buffalo.

During the rainy season grass grows faster and lusher than during other times of the year. Even so, the average ruminant requires about forur rai of unimproved pasture during this season, e.g., the kind of pasture found along roads.[2] Thus during the rainy season when the supply of grazing land is lowest, the uninfested areas along roads represent sufficient pasture for approximately 1969 head of cattle and/or water buffalo. (Calculation: 6784 rai along roads uninfested with M. pigra ÷ 4 rai per animal = 1696 animals.)

In actual practice, however, the fact that 43% of roadside areas are infested with M. pigra does not currently impose a significant economic burden on livestock production. This is due to the fact that the 6784 rai of roadside area uninfested with M. pigra is now utilized by grazing animals to only about one tenth of its carrying capacity. Thus the total current demand for roadside pasture area is approximately 678 rai. This figure of 678 rai therefore represents the amount of additional pasture which would be required if all areas along roads were rendered unavailable by M. pigra.

The most readily available source of 678 additional rai of pasture would be land currently used to grow crops. Thus the value of the roadside pasture would be the value of the 678 rai of cropland which would have to be converted to pasture if livestock production were to be maintained at current levels. The average value of crops produced in the rainy season (the season when pasture is limited) is ฿ 683 per rai.[4]

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[1]Nithiuthy; Sirpirm Sittiwang, op. cit.

[2]Interview with Nirandhorn Photikanon, Department of Animal Husbandry, Faculty of Agriculture, Chiang Mai University, December 30, 1980.

[3]Estimate based on personal observations of the author.

[4]Derived from Rapeepun Jaisaard, Multiple Cropping Project Agricultural Economics Report No. 13: Results of Farm Household Modeling in the Chiang Mai Valley (Chiang Mai: Faculty of Agriculture, Chiang Mai University, June 1981), p. 32.

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As noted previously, if all current M. pigra control efforts were halted, virtually all roadside areas would soon become infested. Thus the annual value of current control proceedures is ฿683 per rai times the 678 rai currently utilized, a total of ฿463,074. Because current control efforts already provide a weed-free area greater than that demanded for pasture, complete elimination of M. pigra along roads (total control) would not increase the total benefit to livestock production.

Summary of Benefits

Benefits to M. pigra control along roads is summarized in Table 4-2.

Table 4-2. Summary of Annual Benefits of Controlling M. pigra Along Roads

Nature of the benefits	Value of benefits with current control efforts (Baht)	Value of benefits with total control (Baht)
Traffic Safety	(a, b)	(a, b)
Utility Pole Erection	50,400	72,000
Utility Pole Maintenance	2,859	4,084
Crop Production	(a)	(a)
Livestock Production	463,074	463,074
TOTAL	516,333	539,158

Notes: (a) Economic value could not be estimated due to lack of data.
(b) Value assumed to be very substantial.

Source: As described in text.

Chapter 5. INLAND AREAS

Definition

Inland areas are defined to include all land areas exclusive of land along roads, irrigation canals and river banks. For purposes of this study, inland areas are divided into two categories: agricultural land and non-agricultural land.

Agricultural Land

Definition

Agricultural land encompasses all inland areas currently under cultivation or used primarily for raising livestock or fowl. It includes rice paddies, vegetable gardens and orchards as well as animal pastureland. Land fallowed twelve months or more is excluded from this category.

Nature of the Infestation

Qualitative Description. In rainfed agricultural areas with only tubewell or dug well irrigation, i.e., areas with no irrigation from river fed canals, M. pigra is practically non-existant. Where it does occur in those areas it usually appears as only a few isolated trees growing along the bunds of fields. The economic significance of M. pigra in those areas is so minimal as to be disregarded in an economic analysis of the impact of the weed. This portion of the study will, therefore, focus primarily on areas irrigated by Royal Irrigation Department (RID) and traditional irrigation systems. (Fig. 5-1)

In irrigated areas served by river fed canals some M. pigra does actually grow in the fields themselves as well as on the bunds. However, generally the infestations are limited to the plots immediately adjacent to the servicing canal. In addition, there is some infestation of plots located adjacent to M. pigra infested roadways. (Fig. 5-2) The source of the infestations are seeds from the infested canal or road which float into the plots with irrigation or rain water. It is apparently a combination of two factors that prevents seeds from travelling

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beyond the plot closest to the source of seed. The first factor is that water flows relatively slowly through flooded fields, thus floating seeds do not move rapidly or forcefully. The second factor is that the stalks of the crops themselves act as a barrier to floating seeds, thus impeding their forward progress. The two factors combine to insure that practically no M. pigra seeds spread to other fields.

Densities in infested plots where the weed does appear range from one or two plants per square meter up to several dozen. The size of individual plants in these fields is usually quite small, rarely exceeding 20 cm. and virtually never over 50 cm. in height. The plants don't grown any larger (the average size is about 10 cm.) due to a lack of growing time and/or a lack of moisture. In triple cropped areas the fallow period between completion of one harvest and the next planting, a matter of a few weeks at most, is too short to allow significant M. pigra growth. In double cropped areas the fallow period can be two to three months; however, the fallow period occurs at the height of the hot-dry season. Thus any residual moisture left from the second crop is quickly lost, and a combination of lack of growing time and moisture preclude large M. pigra plants. In areas which receive irrigation only in the rainy season the fallow period between crops is much longer, but the extended fallow period coincides with the cool dry and hot dry seasons so lack of moisture inhibits weed growth.

Quantitative Description. Present extent. As noted above, agricultural land abutting infested canals or roads will be the most likely to be infested; however, the infestation will be limited in almost all cases to the bunded plot immediately adjacent to the source of the infestation. The average size of a plot is one ngan. (One ngan is equal to one quarter of a rai or 400 square meters.) Thus for each 20 linear meters of agricultural land which is adjacent to an infested canal or road there will be approximately 400 square meters of agricultural land infested with M. pigra. (This calculation assumes plots are square 20 x 20 meter areas.)

There have been no previous attempts to quantify the total area of agricultural land infested with M. pigra. As infestations in agricultural land are not of significant economic importance (as explained below), the large expenditure of time and money necessary to conduct such a detailed survey was deemed not to be a suitable use of limited research resources. However, to achieve a very rough estimate, the length of infested roads (882 km.) and canals (2913 km.) was multiplied by 20 meters. This gives a total infested agricultural land area of 47,438 rai.[1]

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[1]Details on infestations in canals will be found in Chapter 6.

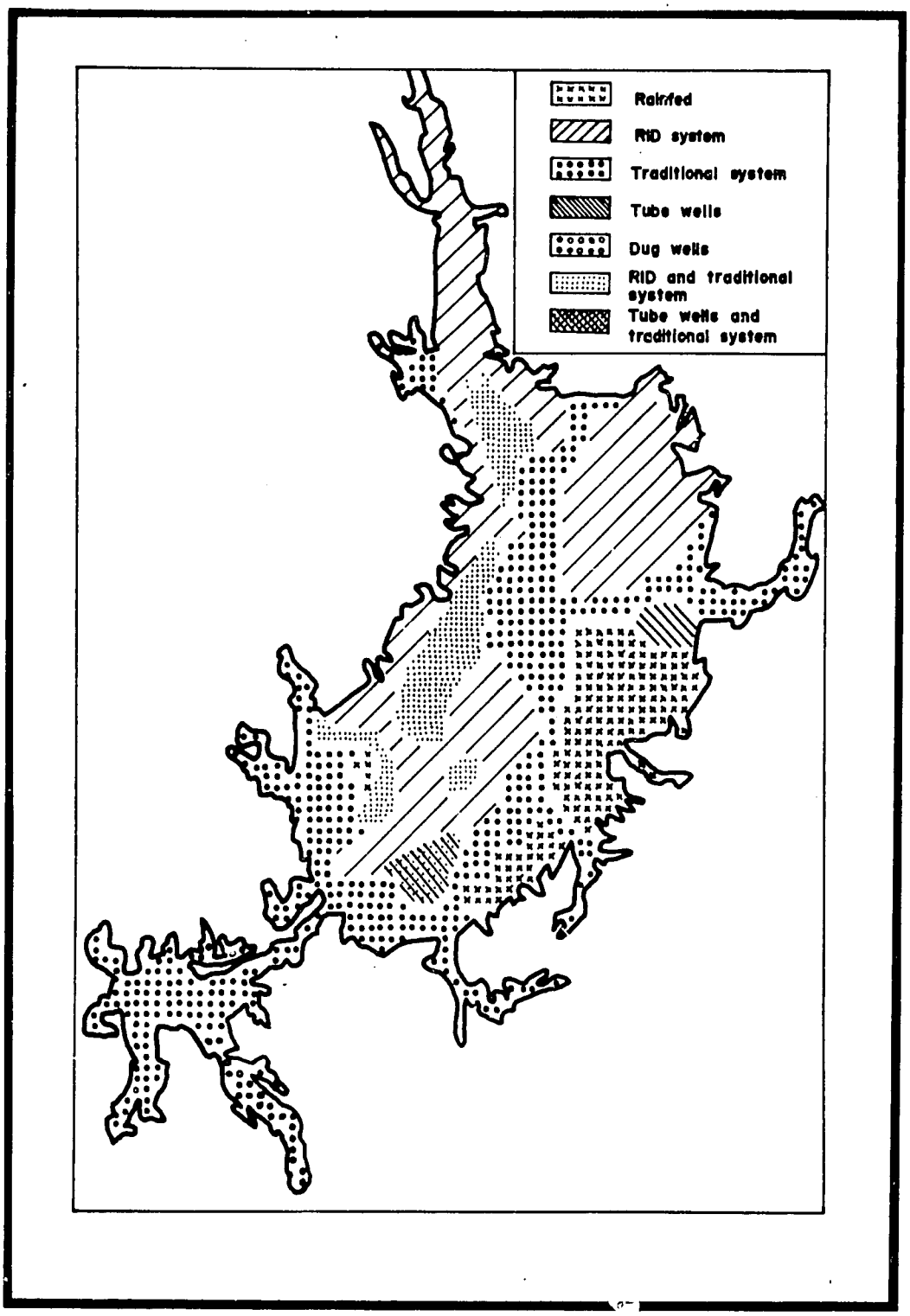

Figure 5-1. Sources of Irrigation in the Chiang Mai Valley.

Source: Gypmantasiri, et. al., op. cit., p. 16.

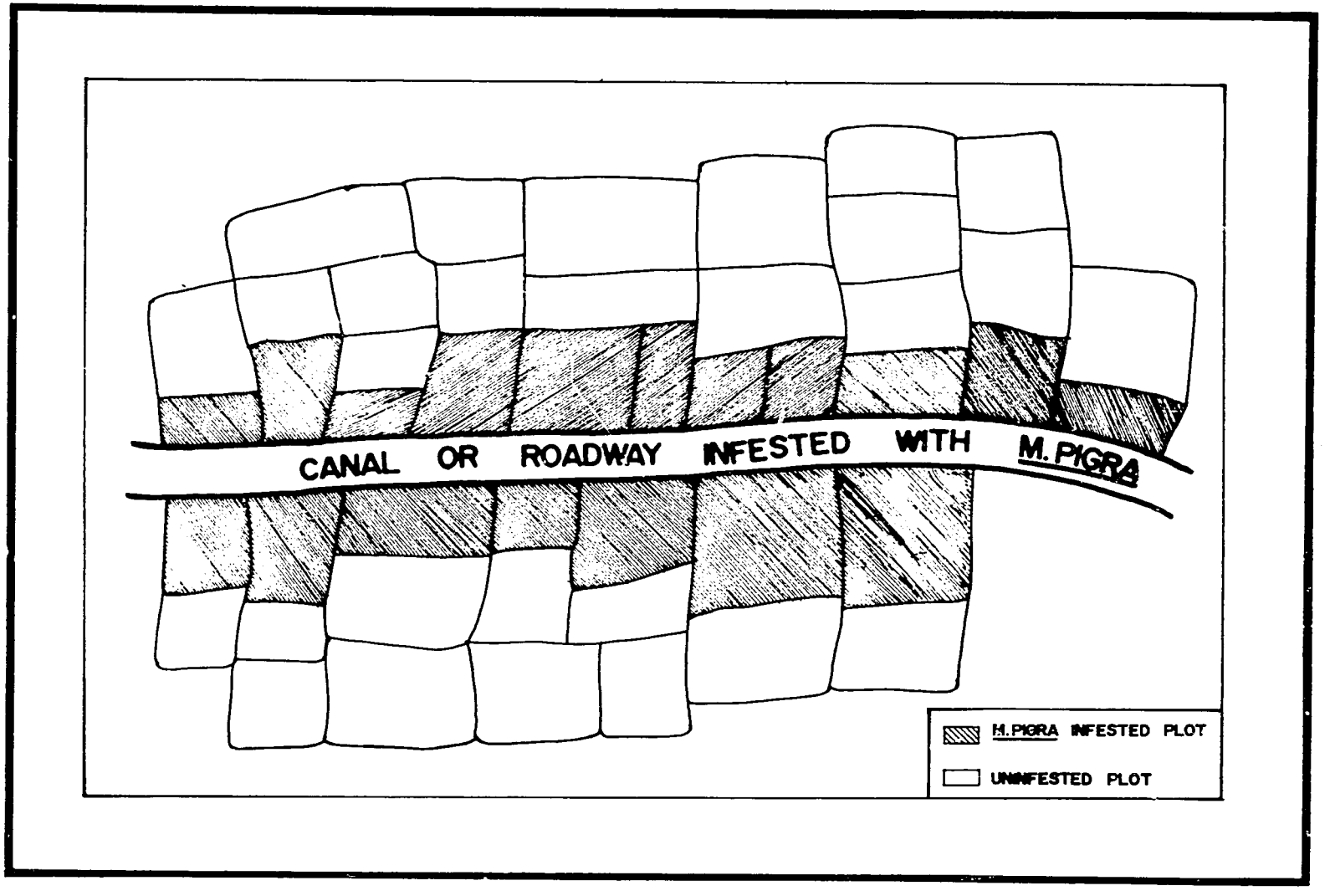

Figure 5-2. Typical Pattern of M. pigra Infestations in Agricultural Areas.

Photographs Not Digitized

Potential extent. Assuming ceteris paribus in other relevant areas, e.g., the amount of M. pigra infestations along canals and roads, no change in the quantity of agricultural land areas infested with the weed is anticipated. The combination of frequent cultivation and/or lack of water during fallow periods prevents M. pigra plants growing in fields from maturing and producing seeds. Thus the weed is effectively restricted to fields close to an external source of seed (the infested canal, river or road). Conversely, if the extent of infestation along canals, rivers, or roads expanded beyond present levels, a proportional increase in the quantity of agricultural land infested with the weed could be anticipated. The increase in infestations in agricultural areas would, however, still be limited to the plots immediately adjacent to the canal, river, or road from which the seeds came.

Nature of the Benefits

Crop Production. There are two areas in which crop production could potentially be affected by M. pigra: yield per acre and total are planted. In the course of numerous interviews with village leaders and individual farmers, it was unanimously reported that the relatively small amount of the weed that maks its way into fields has virtually no impact on either yield or area planted as present control proceedures achieve nearly total control. Plate 17 graphically attests to the fact that farmers do not regard M. pigra as a problem of any consequence vis a vis crop production. The plate shows the weed growing in a low, swampy area of a field - a portion not suitable for cultivation. Note that the trees are mature and producing seeds - which the next rain will wash into the field itself. But the relatively small amount of work required to remove the trees and thus prevent the spread of seeds is not considered by the farmer to be a worthwhile effort. As B. A. Auld has correctly observed, "weeds of roadsides and paddock margins do not necessarily pose a threat to well managed pastures and crops."[1]

Livestock Production. Dairy Cattle. Raising dairy cattle in the Chiang Mai Valley is exclusively a part-time occupation: dairy "herds" almost never exceed five animals. As noted previously, agricultural land is extremely valuable, so each herd is maintained on as little land as possible. The average total area for five cows is between one half and one rai. Feed for the cows which consists primarily of fresh grass and Leucaena spp. leaves is brought to the animals in their small "pasture" area rather than allowing the animals to forage for themselves. Because the cows are raised in such a small area, they effectively control all vegetation -

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[1]B. A. Auld, "Guidelines for Mapping Assessments of Agricultural Weed Problems," PANS, Vol. 24, No. 1, March 1978, p. 68.

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including M. pigra - growing in that area.[1] Thus M. pigra growing in agricultural land has no impact on the dairy industry. Much of the fresh grass brought to cows is harvested from areas along roads. (See chapter 4.)

Fowl. There are many types of fowl raised in the Chiang Mai Valley including chickens, ducks, geese and turkeys. The latter two are not raised in economically significant numbers, being kept primarily for the enjoyment of their owners. They are generally only slaughtered for special occasions to meet the very limited seasonal demands of resident foreigners, e.g., Thanksgiving and Christmas. As only chickens and ducks are raised in significant volume, analysis of the impact of M. pigra was limited to those two types of fowl.

A small number of large scale chicken producers with flocks numbering in the tens of thousands of birds provide the bulk of the chickens and eggs produced in the Valley. All their birds, both layers and those raised for meat, are maintained in large, modern, hygienic chicken houses. As the flocks of these large scale producers never leave their chicken houses until they are to be slaughtered, the presence or absence of M. pigra in the vicinity has no impact whatever on chicken or egg production. Note: the presence of M. pigra could however, raise the cost of the initial construction of the chicken houses. This situation is covered in the second part of this chapter which deals with the effect of the weed on construction.

As with chickens, the great majority of ducks in the Valley are produced by large-scale duck ranchers who maintain flocks of several thousand birds. Although ducks are not kept in enclosed structures as are chickens, they are maintained in relatively small, fenced-in areas where food (primarily commercial duck rations) is provided for them. Again the high value of land results in the duck enclosures being as small as practicable. Within these fenced areas the ducks consume virtually all indigenous vegetation. Any plant which does manage to sprout within the area, be it ordinary grass or M. pigra, is quickly devoured. Thus there is no impact of M. pigra on duck production as the birds themselves provide a natural method of keeping the weed under complete control.

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[1]Interviews with Virat Promberd, Coordinator of the Chiang Mai Dairy Farming Promotion Organization of Thailand, and Preecha Kunama, Extension Promotion Officer, Chiang Mai Dairy Farming Promotion Organization of Thailand, March 23, 1981.

Other Livestock. In addition to the types of livestock mentioned above, other types of animals raised in the Valley include goats, sheep, and horses. None of these are raised in economically significant quantities, hence no attempt was made to quantify the impact of M. pigra on their production. The value of the impact, if any, is assumed to be minimal.

Non-agricultural Land

Definition

Included in the category of non-agricultural land are areas which have never been cultivated as well as land that has been more or less permanently taken out of cultivation. Land which is fallowed between crops (but not longer than twelve months) is not included in this category, but rather is considered to be agricultural land.

Nature of the Infestation

Qualitative Description. Dense, tall (3 to 6 meter) stands of M. pigra cover many tracts of land in and around urban areas in the Valley. Infestations are particularly plentiful in the vicinity of Chiang Mai City, the largest urban center in the area. These tracts of infested land are almost exclusively agricultural land which has been taken out of crop production and left idle. The percent of the total area covered by the weed varies significantly from place to place. In drier areas with little ground moisture the infestations may amount to only a few isolated clumps of trees. On more well watered plots the weed can cover the entire area, virtually preventing direct sunlight from reaching the ground.

As there is normally no effort made to control the weed the height and density of infestations is usually near species maximum for the soil and water conditions of each site. Only sporadic and random harvesting of M. pigra trees from these areas for fuel (see Chapter 8) prevents the weed from reaching its full potential.

The reason these tracts of land are removed from agricultural production in the first place is that land values in the Chiang Mai Valley have been rising rapidly relative to other areas in Thailand and also relative to prices of other goods and services. Farm land is purchased as an investment by non-farmers who then leave the land idle while they wait for further price increases or prepare to build new houses, shops, hotels, etc., on the land. These tracts of idle farm land are known locally as "speculators' land."

Quantitative Description. Present extent. The majority of non-agricutiural land infested with M. pigra lies in and around Chiang Mai City as noted above. Using 1976 aerial photographs, Punnee Wara-Aswapati and Rungarun Phikulnoi have made detailed measurements of the amount of area infested with M. pigra in a 96 square kilometer section of the Valley which encompasses all of Chiang Mai City. The total infested non-agricultural land area measured 13.56 square kilometers (8475 rai). (Fig. 5-3) [1] Based on personal observation, it is estimated that the surveyed area includes approximately 75% of all non-agricultural land infested with M. pigra in the Chiang Mai Valley. Thus the estimated total of infested non-agricultural land in the Valley is 18 square kilometers (11,250 rai).

It is important to mention that land speculation is not the only reason agricultural land is taken out of crop production although it is by far the principal cause in the Chiang Mai Valley. For example, in the Lampang Valley, which is located about 100 km. to the east and south of the Chiang Mai Valley, vast tracts of unirrigated land amounting to many thousands of rai have been taken out of production. Much of this land, especially that abutting the M. pigra-infested Wang River, has been taken over by the weed. In the Lampang area the land was abadoned not because real estate prices were rising but rather because the land is owned by absentee landlords and only rented to tenant farmers. Because of this land tenure situation, when tenant farmers found they could make a better living at non-agricultural occupations, they simple abandoned farming. Landlords could not raise the prevailing agricultural wage level sufficiently to attract farmers to return due to the relatively low productivity of the land in the area. Land productivity there is low primarily due to a lack of irrigation water. The upshot is that many former farms are simply left idle, and M. pigra, left unmolested, rapidly expands to cover the idle land.

Potential Extent. As there is virtually no effort currently being made to control the growth of M. pigra on non-agricutlural land, the extent of the infestation is not expected to increase. The only potential source of increase would be an increase in the rate at which agricultural land is taken out of production and left idle relative to the rate at which idle land is cleared for construction of buildings or roads.

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[1] Adapted from Punnee Wara-Asswapati and Rungarun Phikulnoi, A Study of Mimosa pigra in Muang Chiang Mai District (Chiang Mai: Geology Department, Faculty of Social Science, Chiang Mai University, February 1981, in Thai), p. 3.

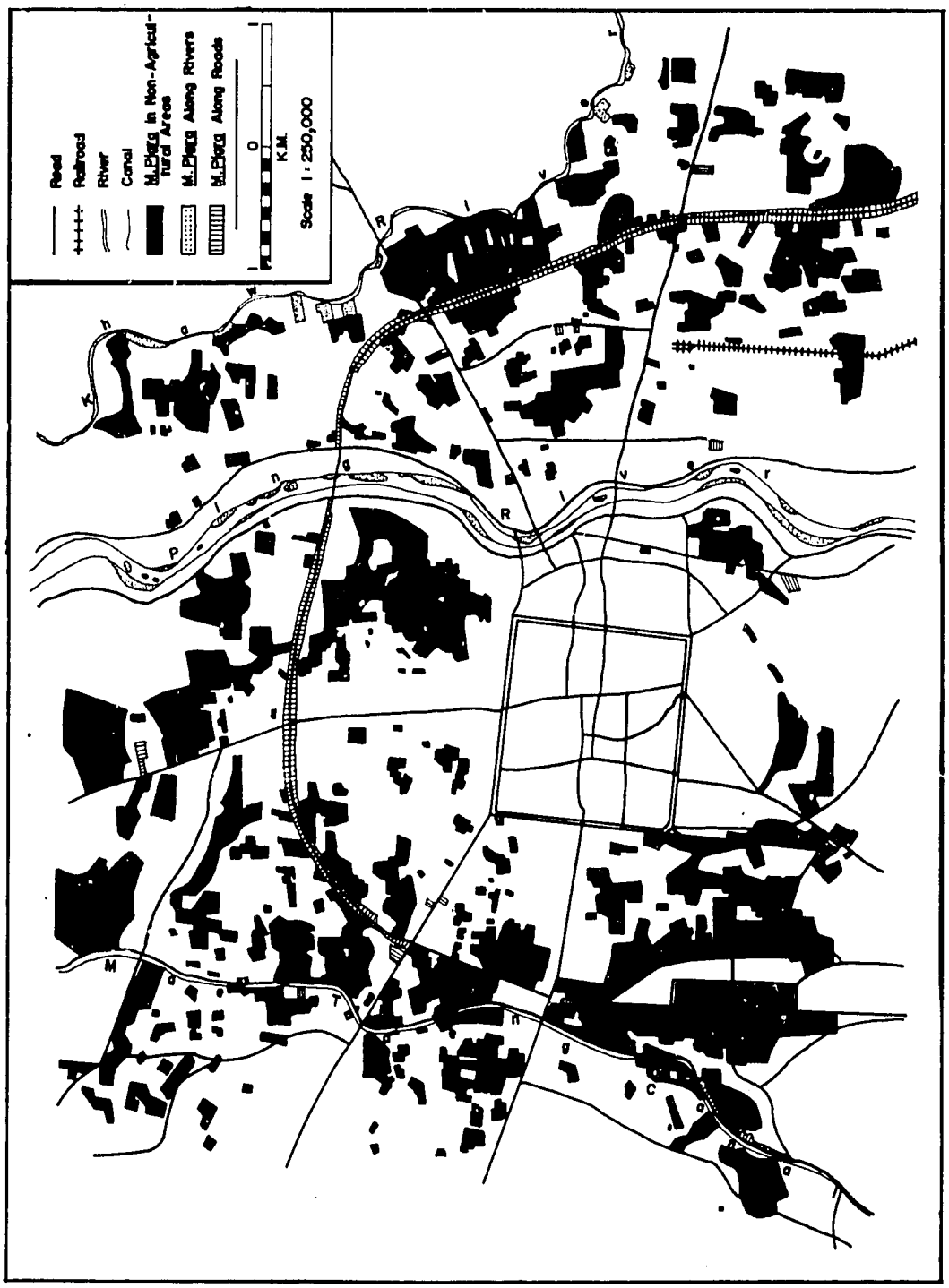

Figure 5-3. Location of M. pigra Infestations in the Chiang Mai City Area.

Source: Adapted from a map prepared by Punnee Wara-Aswapati and Rungarun Phikulnoi, Geography Department, Chiang Mai University, using 1976 Aerial Photographs.

Construction. Before a new structure is built or a new road constructed in an area infested with M. pigra the construction site must first be cleared of the weed. If M. pigra were not controlled, e.g., if it were not removed from the construction site, no construction would be possible. Thus for the consturction industry the value of controlling M. pigra is equivalent to the additional cost of site preparation incurred due to the presence of the weed.

To ascertain the value to the construction industry of controlling M. pigra, unstructured interviews were conducted with individuals engaged in various classes of construciton activity: private home construction, small scale commercial construction, large scale commercial construction and road construction. Results of those interviews are summarized in Table 5-1. As the table shows, the benefits to the construction industry range from minor to nonexistant.

Another minor problem created by M. pigra is that when cement is mixed from sand containing M. pigra seeds, the seeds tend to imbibe water and explode before the cement is set, causing surface pock-marks.[1] In interviews with construction firms in the area, only one reported this phenomenon, and then only as a minor irritant. He solved the problem by obtaining sand from a weed-free area. Thus in total the benefits to the construction industry of controlling M. pigra are so small as to be considered economically insignificant.

Crop production. As noted in Chapter 4, M. pigra is an alternate host for an as yet undetermined number of crop-damaging insect species. Infestations of the weed in non-agricultural areas represent a potentially significant breeding ground for those insects. However, as previously discussed, there is insufficient information available to estimate the value of M. pigra control to crop production.

Livestock Production. As was noted in Chapter 4, there is an acute shortage of grazing land for cattle and water buffalo during the rainy season. Although there is seldom any formal agreement between landowner and livestock raiser, non-agricultural land which is lying idle has traditionally been used as free pasture for these animals. When M. pigra infests a plot of idle land it renders the area

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[1] Letter from C. Parker, ODA Tropical Weed Specialist, Weed Research Organization, Oxford, England, January 28, 1980.

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unavailable to livestock. Non-agricultural areas are, however, used for grazing to only about one third of their potential capacity.[1] Thus the presence of M. pigra in non-agricultural areas does not currently impose a significant economic burden on livestock production. In addition, as the extent of the infestation of the weed in these areas is not likely to increase, there is little potential for the weed becoming an economic burden in the forseeable future.

Criminals. Perhaps the least obvious benefit of controlling M. pigra in non-agricultural areas is that to do so would deny criminals the sanctuary the weed currently provides. Narcotics sellers and users, robbers and others of that ilk establish hideouts and stash their booty deep in thickets of M. pigra where the chances of their being discovered by law enforcement officials is remote.[2]

Due to lack of available statistical information on criminal activities, this benefit of controlling M. pigra was not evaluated quantitatively; however, given the ingenuity of the criminal mind in such matters, if the sanctuary of M. pigra thickets were denied them, the overall crime rate would in all probability not decline perceptibly.

Summary of Benefits

Benefits of controlling M. pigra in inland areas is summarized in Table 5-2.

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[1]Estimate based on personal observations of the author.

[2]Kittipong, op. cit., pp. 10-11.

Table 5-1. Benefits of Controlling M. pigra in Non-agricultural Land: Construction

Type construction	Average total construction cost	Average additional construction cost due to M. pigra (per square meter)	Additional cost as a percentage of total construction cost
Private home	฿ 750,000	฿ 0.875	0.00023%
Small commercial structure	5,000,000	0.34	0.000068%
Large commercial structure	25,000,000	0.0	0.0%
Road building	4,000,000 per km.	0.0	0.0%

Source: Unstructured interviews with individuals engaged in various classes of construction activity.

Table 5-2. Summary of Annual Benefits of Controlling M. pigra in Inland Areas

Nature of the benefits	Value of benefits with current control efforts (Baht)	Value of benefits with total control (Baht)
AGRICULTURAL LAND		
Crop Production	(a)	(a)
Livestock Production	(a)	(a)
NON-AGRICULTURAL LAND		
Construction	(a)	(a)
Crop Production	(b)	(b)
Livestock Production	(a)	(a)
Criminals	(a)	(a)
TOTAL	-------	-------

Notes: (a) Benefits not calculated - assumed to be minimal.
(b) Economic value could not be estimated due to lack of data.

Source: As described in text.

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Chapter 6. IRRIGATION SYSTEMS

Definition

Irrigation systems are a series of canals used to transport water from rivers to farmers' fields and orchards. There are two major types of irrigation systems in the Chiang Mai Valley: systems owned and operated by the Roayal Irrigation Department (RID) of the Ministry of Agriculture and what are known as "traditional" irrigation systems which are owned and operated entirely by the users of the systems, i.e., the farmers.

There are four RID irrigation projects in the Valley. (Fig. 6-1) Each of the RID systems is composed of a wier across a major river, one or more head regulators, one or more main canals and a series of up to 23 latteral canals. Main canals and latterals are lined (sides and bottom) with concrete along those portions where erosion would be a problem. The RID systems serve as feeder sources for some of the traditional systems. (Fig. 6-2)

Traditional irrigation systems are more numerous (1980 separate systems) and more extensive in terms of area serviced (603,041 rai served by traditional systems versus 325,000 rai served by RID systems).[1] (Fig. 6-3) Of the 1980 traditional systems, only 706 have permanent head regulators.[2]

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[1]Peter Kung, "A Review of River Basins and Irrigation Systems in Northern Thailand," ADC National Seminar Report No. 5: Irrigated Agriculture in Northern Thailand, March 17-19, 1974, Manu Seetisarn and Luanne B. Thodey, eds. (Chiang Mai: Faculty of Agriculture, Chiang Mai University, undated), p. 55.

[2]Gypmantasiri, et. al., op. cit., p. 18.

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The primary differences between RID and traditional systems are in the scale of operation, methods used in construction and maintenance, source of funding and control over water distribution decisions. Traditional systems are small compared to RID systems, and each individual system serves a relatively smaller agricultural area. Whereas RID wiers are of concrete, traditional systems are typically made of bamboo stakes driven into the river bottom. These bamboo wiers require extensive, usually semi-annual, maintenance. There are a few traditional systems which make use of rock-filled cribwiers. RID projects are funded through government revenues and maintained by government employees; traditional systems are built and maintained by the water users themselves. Each season RID officials at each system confer with local water users. Then the RID officials decide when, where, and how much water will be released into each RID canal. For each traditional system a local individual is selected by the farm community to manage that system's water distribution in consultation with the water users who selected him.

Even with both traditional and RID systems, however, there is never enough water to satisfy fully the desires of all water users. This is due both to the limitations of the irrigation facilities themselves as well as to the fact that only at the height of the rainy season does rainfall exceed evapotranspiration.[1]

The availability of irrigation water is vital to the maintenance of current levels of agricultural production.

Nature of the Infestation

RID Systems

Qualitative Description. *M. pigra* can be found along both main canals and along latterals of all RID systems. However, due to regular maintenance, which includes clear cutting vegetation on either side of the canals to a width of about ten meters, individual plants generally do not exceed two meters in height and average about half that. In most locations infestations range from small clumps of a few trees to thickets which can extend up to a hundred meters or more.

[1]Benchavan Tongsiri, Pichit Lerttamrab and Alan R. Thodey, Multiple Cropping Project Agricultural Economics Report No. 5: Agro-Economic Characteristics of the Chiang Mai Valley, 1972-1973 (Chiang Mai: Faculty of Agriculture, Chiang Mai University, January 1975), p. 1.

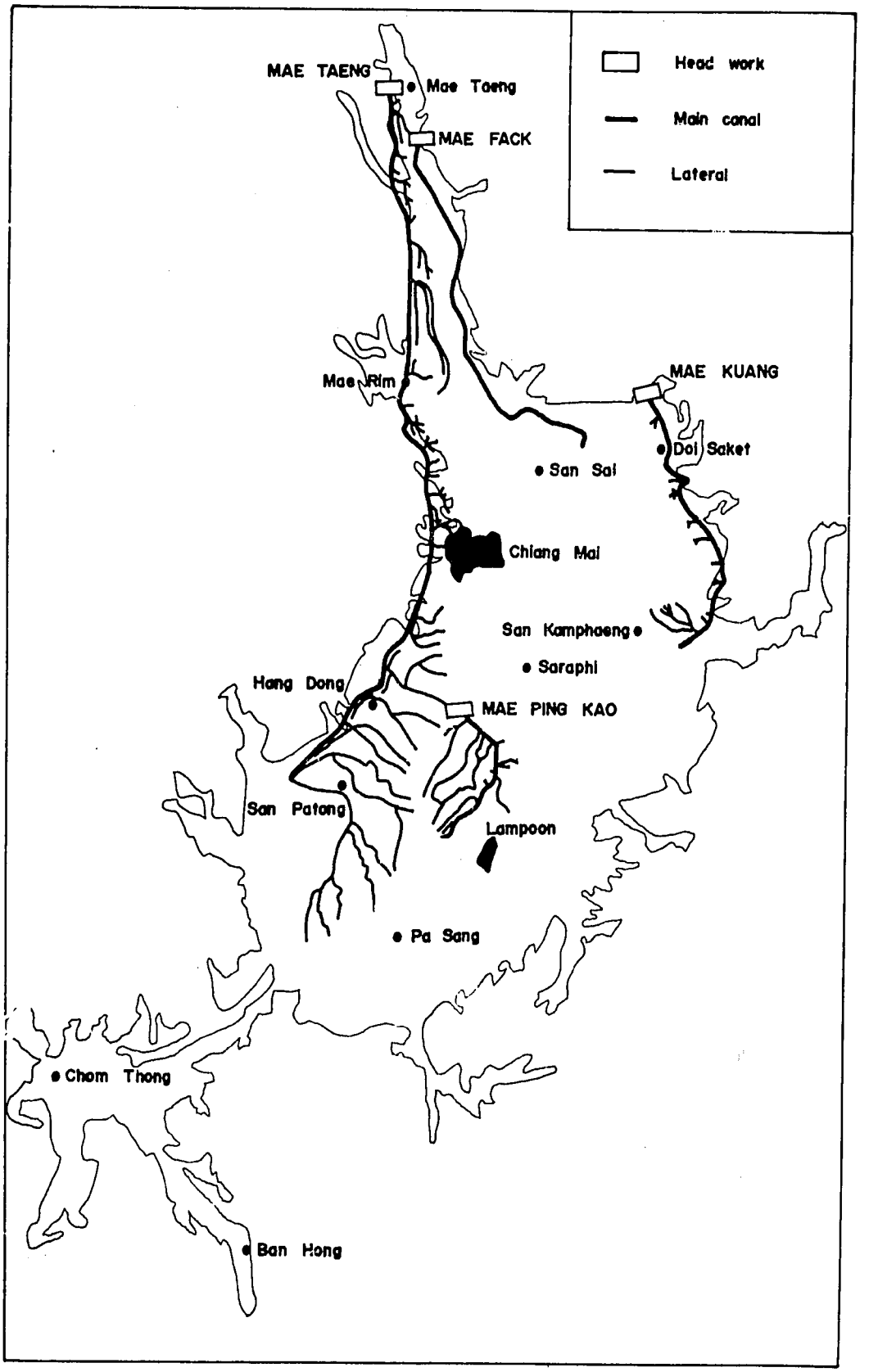

Figure 6-1. Location of Royal Irrigation Department Irrigation Systems in the Chiang Mai Valley.

Source: Gypmantasiri, et. al., op. cit., p. 19.

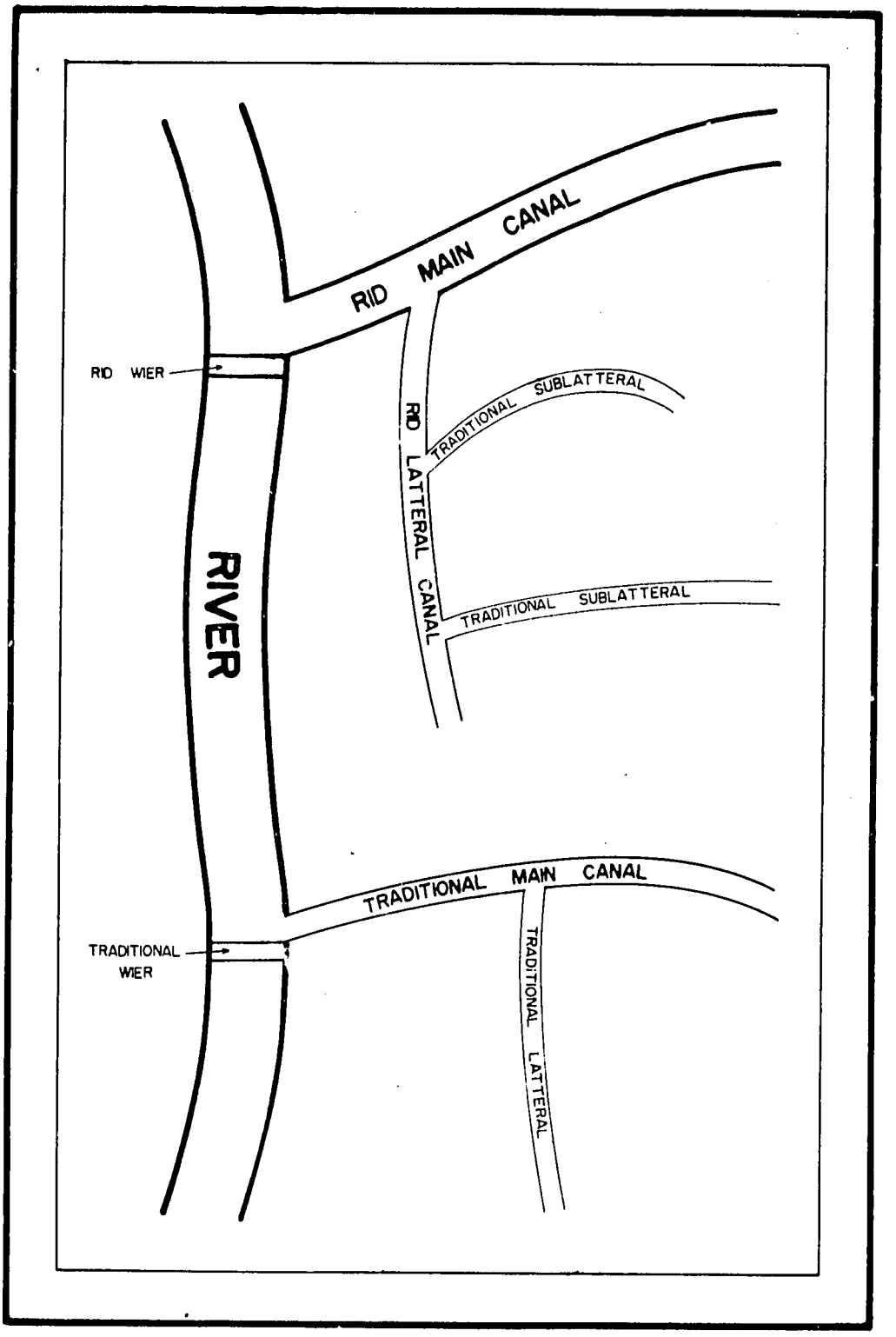

Figure 6-2. Typical Pattern of Royal Irrigation Department and Traditional Irrigation Systems.

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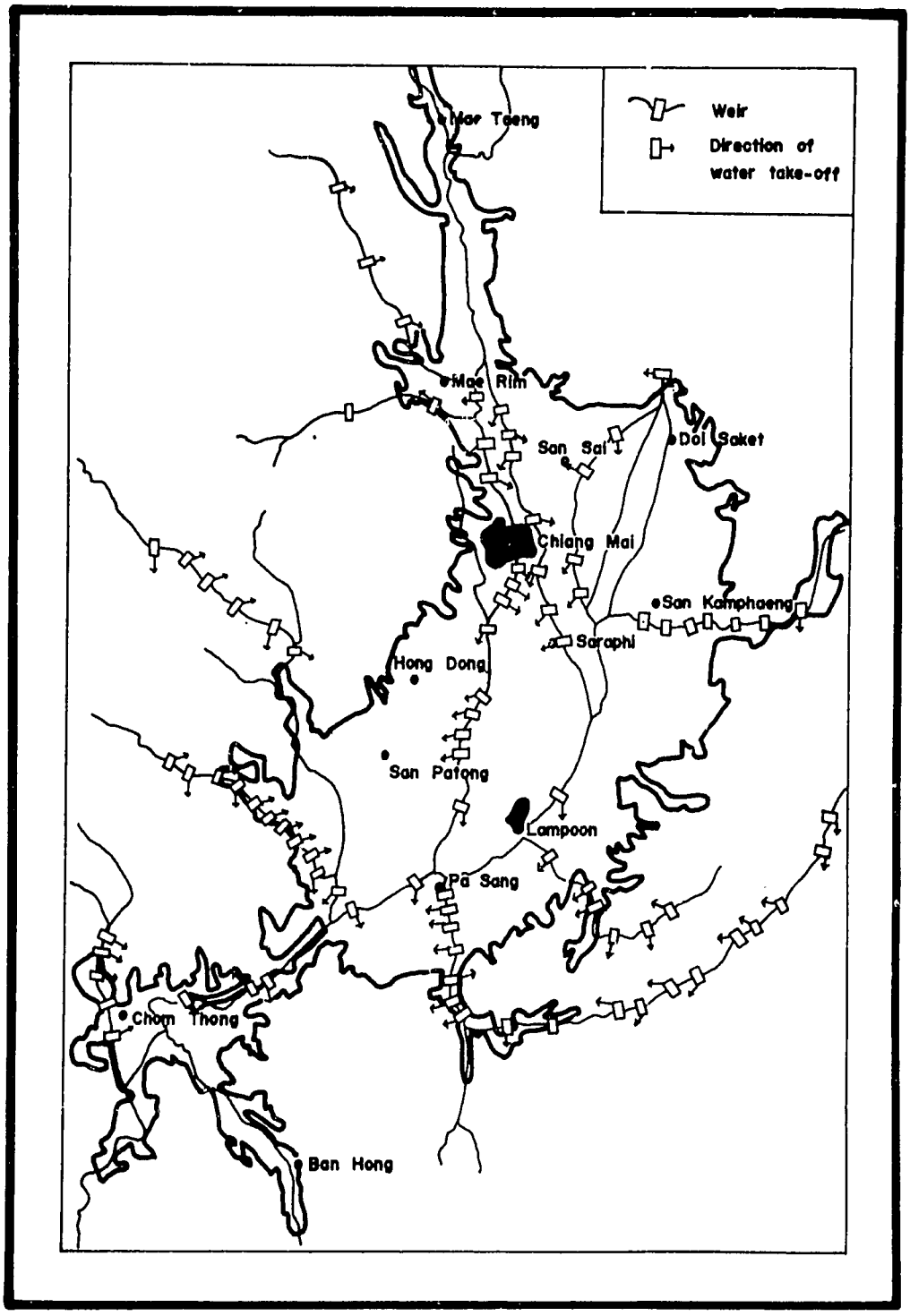

Figure 6-3. Location of Principle Traditional Irrigation Systems in the Chiang Mai Valley.

Source: Gypmantasiri, et. al., op. cit., p. 17.

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Width of infestations (measured perpendicular to the bank of the canal) range from a meter or two up to the full ten meter width (main canals) maintained by RID personnel. The width of infestations is limited to this ten meter band in most instances because almost the entire length of the canal is bordered on one side by agricultural land actively under cultivation and on the other side either by more agricultural land or by a road running paralled to the canal. Almost no M. pigra has been found growing in any of the canals of the RID systems, i.e., the weed is limited to the banks of the canals in almost all instances, and only one case of a single M. pigra plant growing between cracks in the cement wall of a canal has been observed.

Quantitative Description. Present Extent. Approximately 31.4 km. (20%) of the total 152 km. of main canals and 256.5 km. (48%) of the 535.9 km. of latterals are infested with M. pigra.[1] (Table 6-1)

Vegetation along main canals is controlled to a width of 20 meters (10 meters each side) while the width for latterals and sublatterals is 10 meters (5 each side). Multiplying these widths by the length of canals infested with M. pigra yields the toal infested area along canals: 1996 rai. (Calculation: 31.4 km. x 20 m. plus 256.5 km x 10 m. = 3,193,000 m^2 or 1966 rai.)

Potential Extent. If RID crews did not regularly maintain the canal systems, M. pigra would rapidly form dense, virtually impenetrable thickets on either side of the canals. In addition, in those sections of the canal systems not lined with concrete M. pigra would also quickly become established in the actual canal channel itself. (It would also become established in the concrete lined sections of the canals, but it would take somewhat longer.) Inside of one year M. pigra would completely choke the canal system blocking virtually all flow of irrigation water.

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[1] Interviews with Warasin Khanthaphanit, Director, Mae Taeng Irrigation Project, December 29, 1980; Payap Tongsung, Assistant Director, Mae Fack Irrigation Project, December 30, 1980; Suwan Sawangjaeng, Director, Mae Kuang Irrigation Project, June 4, 1981; and Surasit Pinyokhan, Assistant Director, Mae Ping Kao Irrigation Project, June 4, 1981.

Traditional Systems

Qualitative Description. Infestations in traditional systems are generally most severe near the river or RID canal from which they receive their water. This is to be expected as the rivers and RID canals are the primary source of M. pigra seeds in traditional sytems. Even at the headworks of traditional systems, however, trees seldom exceed two meters in height and few trees are allowed to reach maturity and produce seeds of their own. This is due to the regular maintenance of the canals by the water users themselves. Maintenance includes cutting down all vegetation including M. pigra, growing along the canals. (Canal maintenance activities are described in detail in Chapter 10.) In addition to regular periodic maintenance farmers throughout the year make it a habit as they walk to and from their fields to cut down vegetation growing along or in canals which would hinder water flow.

Quantitative Description. Present Extent. There are no statistics available on the percentage of traditional irrigation system canals infested with M. pigra. Infact, there are no statistics on the total length of the canals themselves. To arrive at an estimate of these two values, unstructured interviews were conducted with a random sample of village level leaders who oversee the operation of 21 irrigation systems with permanent head regulators (water gates) at various locations throughout the Valley. Multiplying the average length of surveyed systems (6.084 km.) by the number of systems with permanent head regulators (706) yields a total length of 4,295 km. of canals. To this must be added the length of the 1,274 minor irrigation systems which do no have permanent head regulators. Their total ength is estimated by the author to be 191 km. (average length: 0.15 km.). Thus the total length of all traditional systems is approximately 4,486 km.

Based on the survey of village level leaders, an estimated 2,255 km. (52.5%) of systems with head regulators are infested with M. pigra. Virtually 100% of the 191 km. of minor systems are estimated to be infested with the weed as these systems are very short and thus quite close to the servicing (infested) river. Thus a total of approximately 2,446 km. (54.5%) of traditional canals are infested with M. pigra.

Potential Extent. If traditional canal systems were not maintained on a regular basis M. pigra would rapidly sprout in many sections along the canals forming dense thickets. In the area of the canals nearest the servicing river these thickets would be particularly dense. Inside of one year the result would be the virtual total blockage of water flow in the canals.

Table 6-1. RID Irrigation Systems: Present Extent of M. pigra Infestations

Irrigation system	Main Canals: Length infested with M. pigra	Main Canals: Percent of total canal length infested	Lattertals and Sublatterals: Length infested with M. pigra	Lattertals and Sublatterals: Percent of total canal length infested
Mae Taeng	11.2 km.	15%	155 km.	60%
Mae Fack	3.6 km.	10%	5.5 km.	10%
Mae Kuang	2.8 km.	10%	14 km.	10%
Mae Ping Kao	13.8 km.	100%	82 km.	100%
TOTAL	31.4 km.	20%	256.5 km.	48%

Source: Interviews with Warisin Khanthaphanit, Director, Mae Taeng Irrigation Project, December 29, 1980; Payap Tongsung, Assistant Director, Mae Fack Irrigation Project, December 30, 1980 Suwan Sawangjaeng, Director, Mae Kuang Irrigation Project, June 4, 1981; and Surasit Pinykhan, Assistant Director, Mae Ping Kao Irrigation Project, June 4, 1981.

Nature of the Benefits

Sedimentation

If M. pigra were not controlled along canals, irrigated agriculture would virtually cease to exist in one year's time. The immediate cause would be sedimentation buildup in the canals blocking the flow of water. Sediment in canals comes from two sources. The first is sediment entering the canals with river water. Two types of sediment flow in with the river water. The first is bed load sediment which is composed of gravel (defined by geologists to be particles greater than 2 millimeters in diameter) and sand (particles between 64 microns and 2 mm. in diameter). Neither of these is suspended colloidally in the water, but rather they are washed along the bottom of the river by the current. These types of sediment are generally deposited close to the mouth of the canal because the rate of flow of water slows greatly upon entering the canal and there is no longer sufficient water pressure to push much of this heavier material along. The second type of sediment is suspension load. This is composed of silt (4 to 64 microns in diameter) and clay (less than 4 microns in diameter). These types of sediment are actually held in colloidal suspension in the water. Some suspension load sediment is deposited in canals, but the majority flows into the fields where significant quantities are deposited.

The second source of sediment is material washed from the the banks of the canals themselves either by the flow of water in the canal or rain falling on the canal banks. The composition of this sediment depends on the nature of the material making up the banks of the canal and varies from gravel to clay. The sand and gravel washed from banks tends to lie in the canal immediately below the bank from which it came. The smaller particles (silt and clay) normally enter suspension and are deposited in the fields or washed back into the river.

During fallow periods when little or no irrigation water is present in the canals, M. pigra sprouts in the beds of the canals themselves as well as along the banks of the anals. If these trees are not removed from the canals, when the irrigation water again begins to flow the stems of the M. pigra growing in and along the canals would act as an obstruction slowing the flow of irrigation water. Because the water would flow more slowly, more suspended sediment would settle out and accumulate on the bottom of the canals rather than in the fields. In addition, the stems of the weed would act as a barrier to debris floating in the canals such as tree branches, leaves, etc. This debris trapped by the weed would itself become an additional obstruction to water flow and would also help to full in the canal. Thus sedimentation is the primary mechanism by which uncontrolled M. pigra growth would eliminate irrigated agriculture.

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As the primary economic benefit of controlling M. pigra vis a vis sedimentation is that water will continue to flow in the canals and the primary use of water is irrigating crops, the economic benefits accruing in the area of sedimentation are considered to be subsumed uner the benefits of crop production and are not calculated separately.

Flooding

The same mechanism by which uncontrolled M. pigra could hinder the flow of water in canals, i.e., by acting as an obstruction to water flow in the canal, could theoretically cause flooding as well. The M. pigra, acting as a wier, would cause the canal water to back up behind it thus raising the water level. At some point the water level would exceed the height of the canal banks and flooding would result. In reality this situation would not occur because the M. pigra induced sedimentation would effectively prevent water from entering the canal. With no water flowing in there could be no backup of water behind a M. pigra wier and thus no flooding. In addition, in all RID irrigation systems and all the major traditional systems water flow from the river into the canals is regulated by a water gate. Thus even if water did enter the mouth of the canal, the flow of water into the irrigation system itself could be reduced to whatever level was necessary to preclude flooding. Thus there would be no economic benefit in the area of flood control to a program of M. pigra control along canals.

Crop Production

If M. pigra were not controlled in canals, as noted, irrigation systems would cease to function. If irrigation systems ceased to operate, agricultural production and thus net agricultural income per rai in presently irrigated areas would fall to approximately the level in currently non-irrigated areas. In addition, there would be changes in the level of non-farm employment in those areas which lost their irrigation systems due to M. pigra. The value of those changes is quantified as follows.

The average annual net income per rai in presently irrigated areas is ฿ 2,893. For non-irrigated areas it is ฿ 1,411.[1] Thus the reduction of income from agriculture on a per rai basis would be ฿ 1,752. (Note: this analysis attributes the entire reduction in income to loss of irrigation water. Data which would allow

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[1]Adapted from Tongsiri, op. cit., p. 51 and adjusted for inflation to 1980 values using_____, The New Economic Wave: Problems and Solutions (Bangkok Faculty of Social Science, Thammasat University, 1981, in Thai), p. 38.

the isolation of returns to land, labor, capital and water individually are unfortunately unavailable. As irrigated agriculture is relatively more labor and capital intensive than non-irrigated, the true return to irrigation water may be lower.) The average farm size in irrigated areas is 6.96 rai (compared to 11.72 rai in non-irrigated areas) [1] so the average reduction in annual agricultural income per family in currently irrigated areas if the canals ceased to function would be ฿ 12,194. (Calculation: 6.96 rai/family x ฿ 1,752 loss/year/family = ฿ 12,194.)

To get a valid estimate of the effect of the loss of irrigation it is necessary to consider non-farm employment as well. Farmers in currently non-irrigated areas spend less time farming and more time engaged in non-farm income producing activities. As a result of this allocation of time, the average annual non-farm income in irrigated areas is ฿ 5,815 per family versus ฿ 12,065 for non-irrigated areas.[2] If M. pigra destroys all irrigated agriculture, those families in formerly irrigated areas could be expected to seek additional non-farm income. This study assumes that after the canals cease to function all families in formerly irrigated areas would be able to earn the same amount of income from non-farm activities as families currently in non-irrigated areas, i.e., ฿ 12,065 per year, an increase over their current non-farm income of ฿ 6,250. Note: this probably slightly overstates the actual earning capacity of families in formerly irrigated areas; however, due to lack of data a more accurate estimate is not possible. In addition this overestimate of non-farm earnings tends to cancel the overestimate of agricultural losses as noted above.)

The total change in annual income per family in formerly irrigated areas is thus a loss of ฿ 12,194 in agricultural income and a gain of ฿ 6,250 in non-farm income for a net loss of ฿ 5,944. There are approximately 80,819 farm families in currently irrigated areas in the Valley [3] so the total annual benefit of current M. pigra control efforts is ฿ 480,388,136. (Calculation: 80,819 families x ฿ 5,944/family = ฿ 480,388,136.) As current control efforts effectively prevent

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[1] Adapted from Tongsiri op. cit. p. 81.

[2] Adapted from Tongsiri, op. cit., p. 52, and adjusted for inflation to 1980 values using. _, the New Economic Wave, op. cit.

[3] Estimate based on 937,500 rai in the Valley (1,500 square kilometers) x 75% of the Valley in paddy x 80% of paddy irrigated ÷ 6.96 rai per irrigated farm = 80,819 families.

the weed from disrupting the flow of irrigation water, total control would not increase benefits in the area of crop production.

Livestock Production

In traditional irrigation systems no more than a meter or so of land is cleared on either side of the canal. This small strip of land is not wide enough for raising livestock. In RID systems, on the other hand, canal banks are maintained to a width of ten and five meters on either side (main canals and latterals respectively). This maintenance includes cutting all vegetation including M. pigra. (Details of this method of controlling the weed are found in Chapter 10.) Thus the banks of RID canals represent a suitable area for grazing livestock comperable to the pasture areas along roads described in Chapter 4. The total available pasture area along RID canals is 5,249 rai. (Calculation: 152 km. of main canal x 20 meters plus 535.9 km. of latterals and sublatterals x 10 meters = 8.3984 km^2 or 5,249 rai.)

Based on personal observation, it appears that canal bank pasture is used to only one tenth of capacity, thus the total pasture area demanded along canal banks is approximately one tenth of the total area available, i.e., 525 rai. As with areas along roads, if M. pigra were not controlled, the banks of all RID canals would soon become infested with the weed. If M. pigra were not controlled and grazing land along canal banks were lost, the most readily available source of replacement pasture would be cropland. (Pasture along roads and along canal banks are not substitutes as they are geographically too widely separated.) The value of rainy season use of cropland as pasture (computed in Chapter 4) is ฿ 683 per rai, so the annual benefit of present control measures along canals is 525 rai times ฿ 683 per rai, a total of ฿ 358,575.

As current M. pigra control efforts already provide a weed - free area greater than that demanded for pasture, total control of M. pigra along canals would not increase the annual benefit to livestock production.

A second interaction between canals and livestock is the matter of drinking water for the animals. All livestock require water and canals would appear to be a handy source of water: animals could go to them to drink or (in the case of the water buffalo) to wallow. The actual use of canals for these purposes is, however, extremely limited. Due to the proximity of traditional irrigation canals to planted fields (there is normally only a narrow strip about a meter wide between the canals and the cropped fields) livestock watering is limited as the animals would endanger the crops. Of course when there are no crops planted there would be no danger, but then there would also be no water in the canals. In the case of RID canals use is limited because the banks of the canals immediately adjacent to the water are usually too steep for animals to climb down to get at the water.

There are many other sources of water available for livestock including a multitude of wells and small streams so even if the canals did become inaccessable due to M. pigra infestation the few animals now using the canals would not suffer for lack of water. In addition, if the weed were not controlled there would be no water in the canals for the livestock to use even if they were to gain access though the M. pigra. The upshot is that the impact of the weed on watering livestock would not be economically significant.

Fishing

In the Valley fishing is almost exclusively a leisure time activity for youngsters. Young children (mostly boys) enjoy dangling a hook and line in the larger canals. There is virtually no commercial fishing in the canals with the possible exception of a few enterprising youths trying to hawk their meager catch of four to six inch fish. Thus if M. pigra were to infest the canals, the primary fishing loss would be the value of fishing as a recreational activity for young boys. This benefit has not been calculated.

Washing, Bathing, Swimming

In locations where villagers' houses are located close to large canals, particularly those of the RID systems, steps of ladders are erected against the walls of the canals to allow access to the water. Women climb down these ladders to use the canal water for washing clothes. Both men and women bathe themselves in the canals, somehow managing to perform their entire ablution routine while modestly clad in a wraparound cloth (full length sarong for women, a shorter version for men). Young children enjoy swimming in the canals with girls wearing shorts and t-shirts, boys dressed in birthday suits until about age seven or eight after which age shorts or underpants are de riguer. As noted previously, there are other sources of water available which could be used for washing and bathing. Thus if M. pigra closed the canals, the impact would be negligible (although would-be swimmers might choose to disagree).

Summary of Benefits

Benefits to control of M. pigra in irrigation systems are summarized in Table 6-2.

Table 6-2. Summary of Annual Benefits of Controlling M. pigra in Irrigation Systems.

Nautre of the benefits	Value of benefits with current control efforts (Baht)	Value of benefits with total control (Baht)
Sedimentation	(a)	(a)
Crop Production	480,388,136	480,388,136
Livestock Production	358,575	358,575
Flooding	0	0
Fishing	(b)	(b)
Washing, Bathing, Swimming	(b)	(b)
TOTAL	480,746,711	480,746,711

Notes: (a) Benefits assumed to be subsumed under other categories of benefits.
(b) Benefits not calculated - assumed to be minimul.

Source: As described in text.

Chapter 7. RIVERS

Definition

The term river as used in this study refers to the actual river itself plus the banks including land immediately adjacent to the normal high level the water reaches during the rainy season. The principle river in the Valley, and the one on which this study concentrates, is the Ping River; other rivers include the Mae Taeng, Mae Fack and Mae Kuang. (Fig. 2-4)

Nature of the Infestation

Qualitative Description

The tallest (up to seven meters plus) and largest diameter (over 25 cm. circumfrence) M. pigra trees infesting the Valley are found along rivers. Rivers in the Valley are all of the meandering type, i.e., they do not follow a straight course but rather curve back and forth in a series of bends. With very few exceptions, M. pigra grows in significant quantities only on the deposition (inner) side of these bends. (Fig 5-3) Infestations range from a few widely spaced trees to dense thickets which extend up to several hundred meters along the edge of the river and which are up to one hundred and fifty meters wide.

Lack of seeds is not a factor in determining the degree of infestation along rivers: as the seed pod sections float on the water then eventually sink to the bottom, the entire bed of M. pigra infested rivers from shore to shore is a virtual M. pigra seed bank. In the dry seasons (cool and hot) when the water level in rivers falls, M. pigra sprouts on the exposed river bottom. When the rainy season again raises the water level many of the new plants growing in the shallower areas, i.e., the deposition bank, are able to survive and grow. At the height of the rainy season the trees may be standing in water more than two meters deep.

Quantitative Description

Present Extent. The amount of M. pigra infestation was measured over an 9.4 kilometer segment of the Ping River using aerial photographs taken in 1976, the most recent available for detailed analysis. Over this measured segment, 11,875 rai were significantly infested with the weed, an average of 1,263 rai per kilometer.[1] The measured segment appears to be representative of the river as a whole; thus there are an estimated 117,459 infested rai along the 93 kilometers of the Ping River which is within the Valley.

Potential Extent. There are no written records of when M. pigra first entered the Ping River and started moving south toward Chiang Mai City, although it is generally acknowledged by local residents that the weed reached the city in significant quantities about 1970. The only available measurements of the rate of increase of the infestation were made specifically for this report by a team of fourth year geography students supervised by Punnee Wara-Asawapati of the Geography Department, Chiang Mai University. They used measurements of the extent of infestation shown in aerial photographs taken in 1976 and 1979 along a 9.4 kilometer section of the Ping River where it flows through Chiang Mai City. Over that three year period the infested area increased by only 6.25 rai. Thus the degree of infestation along the Ping River appears to have nearly reached its asymptotic limit.

The Chiang Mai Valley river systems are inherently geologically unstable. The high ratio of bed load to suspension load in the river water is indicative of frequent sand bar formation and moving channels.[2] Thus even when the weed reaches its maximum in terms of total area infested along a given section of river, shifts in the river channel itself over time could be expected to change the location of M. pigra infestations but not the quantity.

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[1] Wara-Asawapati and Pigulnoi, op. cit.

[2] Interview with Dr. Martin Gibling, Geology Department, Faculty of Sciences, Chiang Mai University, December 10, 1980.

Nature of the Benefits

Sedimentation

Sedimentation refers to the buildup of material at the bottom and along the banks of rivers. M. pigra alters the normal pattern of river sedimentation in two major aspects: it changes both the quantity and the composition of sediment deposited. Three of M. pigra's attributes are responsible for these alterations namely,. the plant's rapid growth rate, its flood resistance and its extensive root system.

In the dry season when the level of water in Valley rivers falls several meters, large tracts of river bottom and sand bar are exposed. M. pigra sprouts in these areas, and, because of the weed's rapid growth rate, plants may reach a height of a meter or more before the next rainy season again raises the river water level. Because of their flood tollerance and extensive root system, plants which extend 50 cm. or so above the rainy season water level have a good chance of surviving.

Plants which sprout on the deposition side of bends in the river have a definite advantage over plants sprouting elsewhere due to the natural geological and hydrological characteristics of rivers. First, on the deposition side of bends the river bottom is normally higher (the rainy season water level is more shallow) than other parts of the river due to normal sedimentation. Because it is higher, river bottom on the deposition side is exposed first as the water level drops after the rainy season. That allows M. pigra seeds in those area to sprout sooner. In addition, again because the river bottom is higher, the deposition side is the last to be flooded when the rainy season again commences. The upshot is that M. pigra on the deposition side has a significantly longer growing season in which to reach a height sufficient to survive the rainy season high water level. Another advantage afforded M. pigra growing on the deposition side is that the river flow is normally slower there than in other parts of the river, thus plants on that side are less likely to be washed away by the strong rainy season currents. For these reasons the vast majority of plants which survive the rainy season are those which grow on the deposition side

During the rainy season plants standing in the water act as baffles, reducing the velocity of water passing through them. Because the water flow is slowed markedly, the amount of sediment deposited in M. pigra infested areas is greatly increased. In addition, those trees growing in the water sprout additional roots along the underwater segments of their trunks. These advantitious roots serve to slow the flow of water, increasing the amount of sediment deposited still further. Another factor is that material already deposited is stabilized, i.e., kept from

washing away, by the extensive root system of the weed. It is estimated that approximately 75% of sediment deposited along the Ping River is due to the presence of M. pigra.[1]

M. pigra increases sedimentation through a cyclical process. The initial infestation of the weed in an area along a river increases sedimentation in that area during the rainy season. The additional sediment raises the level of the river bottom slightly in the infested area. That higher river bottom provides opportunity for additional weed growth during the following dry seasons: the newly raised river bottom is exposed to the air sooner and remains exposed longer before again being inundated during the rainy season. Thus during the second rainy season following the incursion of M. pigra there are additional plants to further increase the amount of sedimentation deposited. This additional sediment provides opportunity for still more plants to grow during the next dry seasons, etc. The result of this cyclical process is a series of concentric rings of M. pigra centered on the initial point of infestation with the oldest plants in the center of the circle, and the youngest in the outermost ring, an effect somewhat analogous to annual growth rings in trees. (Fig. 7-1)

In dry seasons the presence of M. pigra increases the amount of sediment retained in an area by reducing the normal dispursal of sediment deposited during the previous rainy season. On river bottoms and sand bars which are exposed to the air during the dry seasons the roots of the weed and its litter help to prevent wind and rain erosion of deposited material. In addition, the shade provided by the tree itself and, perhaps more importantly, by its litter, help keep the underlying soil moist thus preventing drying and cracking. Parched, cracked soil is more susceptible to both rain and wind erosion.

Not only is the amount of sediment deposited increased, but the composition of the sediment itself is altered as well. Suspension load material, i.e., fine sand, silt and clay, is usually not deposited as sediment but rather the majority of this material is washed out to sea. However, in areas where the river flow is slowed due to M. pigra large amounts of this material are deposited as sediment.

Sedimentation in rivers is not in and of itself an economic problem. It is, however, the immediate cause of other situations which have definite economic implications in the areas of bank erosion and river bottom crop production which are discussed below.

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[1] Martin Gibling, The Influence of Mimosa pigra on River Sedimentation in the Chiang Mai Area (Chiang Mai: Department of Geology, Faculty of Science, Chiang Mai University, May 1981), p. 2.

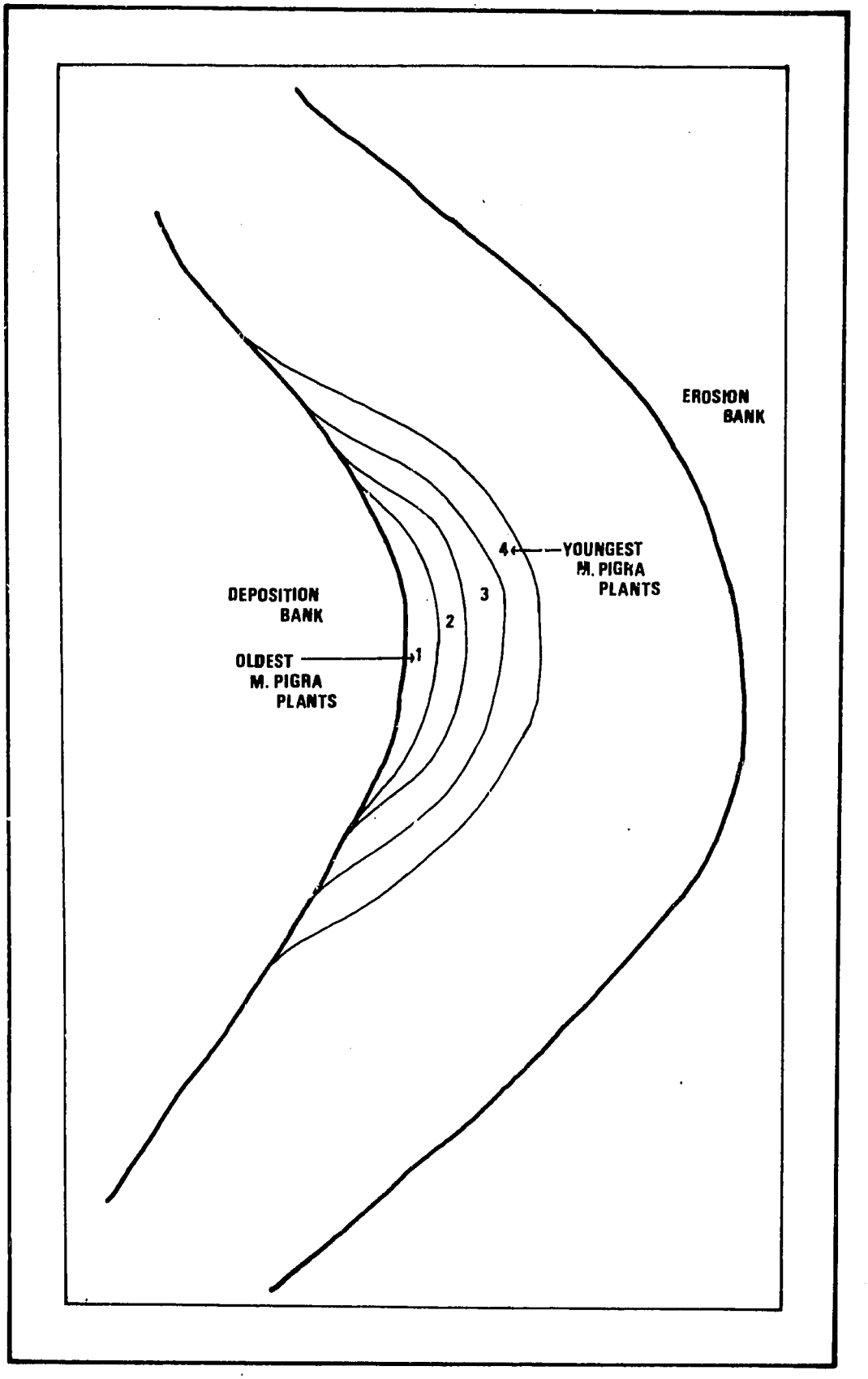

Figure 7-1. Typical Cyclical Pattern of M. pigra Infestation Expansion in Rivers.

Erosion

There is a layer up to several meters thick of sand and gravel underlying the river basins. Because the underlying strata is not cohesive, the erosion of river banks, a normal geological process in any river system, is particularly rapid in Valley rivers. It should be noted, however, that river bank composition is not uniform throughout the Chiang Mai Valley or even along any one of the Valley rivers. Some banks are composed of primarily sand and gravel with only a thin layer of silt and clay whereas other banks consist of rock or sand and gravel mixed with a fair amount of highly cohesive clay. As would be expected, the former is much more susceptible to erosion than the latter.[1]

M. pigra infestations along the deposition side of river bends accelerate the normal erosion process on the opposite bank. The increased sediment deposited where the M. pigra is growing deflects the flow of the river current more directly into the opposite (erosion) side of the river. In addition, as the increased sediment tends to reduce the cross-sectional area of the river channal, the current in response flows more swiftly which also increases erosion. (Fig. 7-2)

Over an 9.4 kilometer section of the Ping River between 1976 and 1979 approximately 8.8 rai of land along the river were lost to erosion.[2] As 75% of river sedimentation is due to M. pigra, it is assumed that the same percentage of erosion is also due to the weed. Thus 6.6 rai were lost due to M. pigra over the measured section, an annual loss of 2.3 rai per year per kilometer. Riverbank land is valued at ฿ 2;893 per rai, the annual return to irrigated agricultural production (see Ch. 6). Thus the annual value of the benefit which would be realized if M. pigra were controlled along rivers in terms of reduced bank erosion ฿ 6,654 per kilometer or ฿ 618,813 for the entire 93 kilometers.

Flooding

As described above, M. pigra plants standing in rivers act as a baffle reducing the water flow velocity in their immediate vicinity. This would appear to indicate that the infestations act as a partial wier which would have the effect of backing up the river above them. In addition, M. pigra induced sedimentation would appear to reduce channel volume which would tend to back up river flow still

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[1] Ibid.

[2] Measurements were made using aerial photographs by a team of fourth year geography students under the supervision of Punnee Wara-Aswapati of the Geography Department, Faculty of Humanities, Chiang Mai University.

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further. Taken together, these two forms of obstruction of water flow seem to indicate that the weed would cause increased flooding during the rainy season.[1]

Although M. pigra was introduced into Thailand in 1947 it has only become a major factor in the Ping River at Chiang Mai City since about 1970. If infestations of the weed did in fact increase flooding, the frequency and severity of flooding near the city would be expected to have increased since that date. No such increase has occurred. Data on the high water level of the river each year measured at a site just north of Chiang Mai City for the fourteen year period prior to the advent of major infestations (1957-1970) and the past ten years (1971-1980) were compared. Flooding occurred in eight of fourteen years in the former period but in only five of ten years in the latter.[2] By direct inspection it appears that the incidence of flooding has actually decreased slightly since the advent of M. pigra; however, analysis of the data using ordinary least squares techniques indicates no statistically significant difference between the two periods at the 0.01 level of confidence. (Appendix 1) Thus M. pigra apparently has no effect on flooding.

Why flooding has not increased is not immediately evident. One possible factor is the thick layer of sand and gravel underlying most of the rivers. This material is more or less easily eroded, so where M. pigra restricts the width of the river there may be larger than usual quantities of river bed material washed away i.e., the river digs itself a deeper channel. That is, by increasing the channel depth the river compensates for the M. pigra induced reduction in channel width. Whatever the mechanism, the upshot is that flooding has not increased since the advent of M. pigra so there is no benefit to be gained in this area by controlling the weed.

Rate of Colonization

Over the approximately thirty years since M. pigra was introduced into Thailand the weed has spread to nearly every potential infestation site in the Chiang Mai Valley. It can even be found along the mountain road leading to Phuping Palace, the King of Thailand's residence on Doi Suthep Mountain.

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[1] Martin Gibling, 1981, op. cit.

[2] _____, Thailand Hydrological Yearbook: Water Year 1957 through Water year 1980, Vols. 5-23 (Bangkok: Hydrology Section, Royal Irrigation Department, 1958-1981), p. 2 (each volume).

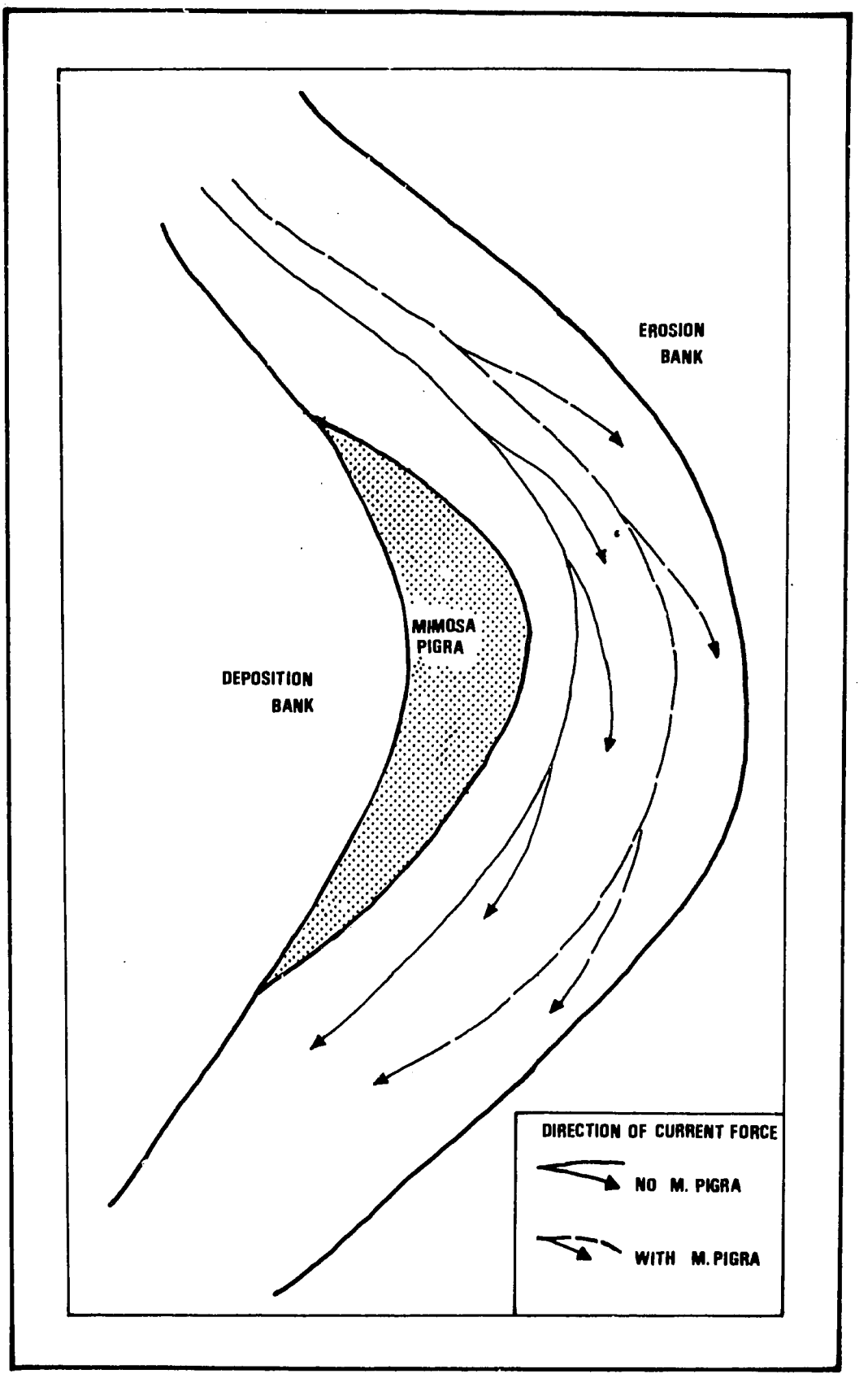

Figure 7-2. Method by which M. pigra Affects Erosion in Rivers.

The primary vector responsible for this colonization is rivers: seed pod sections float on the water surface for long periods, spreading the weed far downstream. In addition, river bottom sand containing M. pigra seeds is transported to other locations thus spreading the weed overland. However, as the weed has already colonized nearly all sitable locations within the Valley, in that area the rate of increase of the weed population is very low. Thus although rivers are the primary colonization vector, the economic benefits within the Chiang Mai Valley of controlling the weed along rivers vis a vis reduced colonization within the Valley would not be significant: the damage has already been done.

Looking beyond the boundaries of the Valley, however, a different picture emerges: it appears that in many provinces of Thailand M. pigra infestations are increasing at a rapid rate. Considering that each mature tree can produce tens of thousands of seeds per year this situation is, although very disturbing, not surprising.

Based on the level of benefits which would accrue to control of M. pigra in the Chiang Mai Valley alone, it is clear that reducing the rate of colonization of the weed in other areas of Thailand would result in very significant benefits indeed. Quantification of these benefits for the entire Kingdom would require a separate analysis of each region of potential infestation individually as each would be effected somewhat differently. For example, in the Chiang Mai Valley M. pigra does not affect duck raising as in the Valley this enterprise is a highly land extensive activity. In parts of the central region of Thailand, however, duck raising is relatively quite land intensive. If M. pigra were to colonize that region, the ducks would not be able to control the weed as they do in the Valley and the weed would take over large tracts of duck raising land. The impact of that loss of duck raising land would be economically significant. Suck a detailed analysis of each region of the country is beyond the scope of this study. The fact that the specific nature of the benefits would differ from region to region does not negate the importance of those benefits. In fact, based on the personal observations of the author, it is estimated that controlling the colonization of M. pigra in currently uninfested areas is probably the single most significant economic benefit to controlling M. pigra along rivers.

Disease

Malaria is transmitted to humans through the bite of various species of Anopheles mosquito. Since restrictions have been placed on the use of the insec-

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ticide DDT, formerly the keystone in mosquito control programs, there has been a general resurgence of malaria in Asia as well as other parts of the world.[1]

Of the several species of Anopheles mosquito which can transmit malaria, one species, Anopheles minimus, requires relatively still, clean water in which to lay its eggs. (Other species require stagnant water for egg laying.) It is this egg laying characteristic of A. Minimus that seemed to indicate a connection with M. pigra: by slowing the water flow in large sections of rivers M. pigra appears to provide additional suitable egg laying areas, a situation which would tend to increase the A. minimus population and thus the incidence of malaria.

On the other hand, M. pigra infestations also tend to shade out and prevent the growth of emergent aquatic weeds. When female A. minimus mosquitos lay their eggs they usually do so while grasping the stems of emergent aquatic weeds. Thus M. pigra seems to deny the insects their customary egg laying perch. This would appear to indicate that M. pigra would tend to reduce the A. minimus population. The value of shading emergent weeds is demonstrated by a practice employed in India before the introduction of DDT (pre 1940) to reduce the population of A. minimus. There thorny bushes were planted along the edge of stream banks where the branches of the bushes would extend out over the water, shading out and killing emergent aquatic weeds. (The species of thorny bush recommended was not M. pigra.)[2]

The upshot is that M. pigra brings two forces to bear on A. minimus: one which potentially causes an increase in population, the other a reduction. To determine which factor, if either, predominates, Dr. Udom Chitpraprop of the Malaria Eradication Headquarters, Chiang Mai, undertook to determine if the A. Minimus population was higher or lower than average in areas infested with M. pigra than in unifested areas. His experiment found no difference in mosquito populations between infested and uninfested areas. Thus M. pigra is

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[1]Susan Super, "Malaria Makes a Comeback," in Agenda - Agency for International Development (Washington, D.C.: United States Agency for International Development, January/February 1980), p. 10.

[2]K B. Williamson, ' Naturalistic Methods of Anophelene Control, " in Malariology - A comprehensive Survey of All Aspects of this group of Diseases from a Global Standpoint, Vol. II, Mark F. Boyd, ed. (Philadelphia: W.B. Saunders Co., 1949), pp. 1365-1366.

apparently not a factor in the incidence of malaria.[1] Dr. Chitprarop also stated that there are no other diseases whose vectors might be affected by M. pigra infestation either on land or water.[2] Thus there are no economic benefits to M. pigra control in terms of disease reduction.

Crop Production

During the dry seasons when the river level falls, some farmers living in villages adjacent to the river plant crops along river banks and on exposed river bottom. Virtually all of the river bottom area planted to crops is infested with M. pigra. (In some areas an exceptionally deep river channel and steep banks prevents M. pigra from gaining a foothold. However, the same combination of deep channel and steep banks also precludes river bank bottom cropping in those areas.)

To ascertain the effects of the weed on river bottom farming semi-structured interviews were conducted with the leaders of twelve villages located along the Ping River. The leaders of those villages reported that M. pigra impacted adversely on river bottom crop production in three areas: soil preparation time, weeding time and yield per rai. They reported no beneficial effects of the weed on crop production.

The time required to prepare river bank soil for planting is increased because in addition to normal soil preparation activities M. pigra must be removed by cutting and/or digging. There are two "categories" of the weed which must be removed: the new seedlings which sprout as the river level recedes and the nearly year old trees which grew up on the river bottom following the previous year's harvest. The latter can be up to several meters tall.

The average total soil prepartion time (including M. pigra removal) is 22.1 man/days per rai. Village leaders estimated that 11.7 man/days of that total are due exclusively to M. pigra. At an imputed agricultural wage rate of ฿ 30 per day, the extra 11.7 man/days represents an additional soil preparation cost of ฿ 351 per rai. The combined total area planted by the 136 village groups (tambons)

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[1] Interview with Dr. Udom Chitprarop, M.D., M.P.H., Malaria Eradication Headquarters, Chiang Mai, May 1,1980.

[2] Ibid., November 27, 1980.

located along the 93 kilometers of the Ping River is estimated to be 8,463 rai.[1] Thus the total additional cost of soil preparation due to M. pigra is ฿ 2,970,513 per year for the 93 km. of the Ping River studied.

As noted previously, river bottoms are virtual M. pigra seed banks; where crops are planted along rivers the weed usually sprouts in profusion throughout the growing season. The current average weeding time, based on the results of the survey of village level leaders, is 40.6 man/days per rai versus an estimated 15.1 man/days if there were no M. pigra, an increase of 25.5 man/days per rai. At an imputed agricultural wage rate of ฿ 30 per day, the 25.5 man/days per rai represent an additional weeding cost of ฿ 765 per rai. Thus the total additional weeding cost due to M. pigra for the 8,463 rai planted along the Ping is ฿ 6,474,195 per year.

Total yield per rai is also reduced by M. pigra. The reduction is due primarily to competition between the weed and crops for vital nutrients. Specific crops planted vary from area to area along the river and include cabbage, cauliflower, corn, cucumbers, eggplant, garlic, lettuce, long beans, onions, peanuts, pepper, potato, pumpkin, snow peas, sweet potato, and tobacco. The value of the average yield per rai is ฿ 3,565. Village leaders estimated that if there were no M. pigra, the value of the yield would be ฿ 4,687, an increase of 31.5% or ฿ 1,122 per rai. Thus the total annual loss for the 8,463 rai planted is ฿ 9,495,486.

Combining the value of the increased soil preparation time, increased weeding time and decreased yield gives the total annual benefit which would accrue if the weed were controlled: ฿ 18,940,194.

Livestock Production

M. pigra would appear to affect the cost of livestock production in that the weed seems to block the animals' access to the water's edge. This is not a significant economic problem for two reasons. First, most villages located close to rivers have many alternate sources of water such as shallow wells, farm ponds and streams Second, as M. pigra grows in significant quantities only on the deposition side of bends in the river, animals can usually easily walk around the more densely infested areas to reach the water. Thus there is no significant economic benefit to M. pigra control vis a vis livestock production.

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[1] Based on an average 0.0889 rai planted per household as determined by village level survey, an average 140 households per village (Gypmantasiri, et. al., op. cit., p. 33) and an estimated average five villages per village group (tambon).

Fishing

As previously noted, there is virtually no commercial fishing in the Valley. There are, however, a number of individuals who engage in fishing for their own consumption. M. pigra appears to affect this activity in two ways: by blocking the fisherman's access to the water's edge and, as the weed grows in the water itself, by reducing the available fishing area. Observation of fishing activities and interviews with fishermen has shown neither factor to be a significant economic problem.

Serious weed infestations occur only on the deposition side of bends in the river so fishermen, like livestock, can easily go around the denser parts, a minor inconvenience at most. Thus access to the edge of the river is no problem.

As to the availability of fishing area, there is very little fishing activity in the rainy season as this is the period of peak demand for agricultural labor. In addition, during the rainy season the river current is usually too swift for net casting, the most popular method of river fishing. Most fishing occurs in the dry seasons when the river levels are lower, river currents are more gentle and agricultural labor demands are lower.

In the rainy season M. pigra plants standing in the water do in fact block large areas of river surface. In the dry seasons, however, the river level falls leaving the M. pigra plants growing on dry river bottom land where they do not affect the potential fishing area. Thus when the fishing is in progress, the weed is not a problem. In fact, M. pigra may actually help increase the size and quantity of fish available in the dry seasons by providing a rainy season sanctuary among the M. pigra stems where smaller fish can hide from their natural enemies such as birds, snakes, frogs and larger fish. Unfortunately, time and budget limitations precluded pursuing this question further.

Washing, Bathing, Swimming

Washing clothes, bathing and swimming are common practices in Valley rivers. As with fishing, each of these activities is dependent on access to the river's edge. Again, as with fishing, the nature of M. pigra infestations usually allows easy skirting of the deser thickets so there is no significant access problem. Swimming requires open water in addition to access to the river's edge. However, swimming is only engaged in during the dry seasons due to the swift rainy season curents. Thus, in the dry seasons when children want to swim the lowered river level has left the M. pigra growing on the land and the swimming area is not reduced by the weed at all. Thus for none of these three activities would control of M. pigra result in a significant economic benefit.

Summary of Benefits

Benefits to control of M. pigra along rivers are summarized in Table 7-1.

Table 7-1. Summary of Annual Benefits of Controlling M. pigra Along Rivers[a]

Nature of the benefits	Value of benefits with total control (baht)
Sedimentation	(b)
Erosion	618,813
Flooding	0
Rate of Colonization	(c)
Disease	0
Crop Production	18,940,194
Livestock Production	(d)
Fishing	(d)
Washing, Bathing, Swimming	(d)
TOTAL	19,559,007

Notes: (a) Data for the 93 kilometers of the Ping River which lie within the Chiang Mai Valley.

(b) Sedimentation benefits subsumed under other categories of benefits.

(c) Value could not be estimated due to lack of data, but benefits assumed to be very substantial.

(d) Value not calculated - assumed to be minimal.

Source: As described in text.

Chapter 8. RESERVOIRS

Definition

A reservoir is a body of water often formed by building a dam across a river. The river flow backs up behind the dam, raising the water level and creating a lake or pond. Water in the lake can then be released as needed. Within the Chiang Mai Valley there are curently no dam/reservoir systems in operation. However, the Mae Ngat Dam being constructed on the Ngat River, a major tributary of the Ping River in Chiang Mai Province, is nearing completion. For this reason an evaluation of the impact of M. pigra on reservoirs is included in this report.

As the Mae Ngat reservoir is not yet completed, it was necessary to evaluate a reservoir in another location. The Kew Lom reservoir and dam project on the Wang River in the Lampang Valley was selected for this purpose because it is similar in size and construction to the Mae Ngat project and because M. pigra infestation of the Wang River is comperable to that of the Ngat River. Thus throughout this analysis the impact of the weed will be measured using Kew Lom infestation data, but the value of that impact will be evaluated using the projected value of the Mae Ngat project.

The Mae Ngat dam, when completed, will be zone-earthfill type with a height of 59 meters and a crest length of 1,950 meters. Its reservoir is planned for a volume of 256 million cubic meters (retention level volume). [1]

Benefits from the Mae Ngat project are anticipated in many areas including crop production (through increased irrigation), fish production, flood control and reduced cost of wier repair. These are the benefits which would be affected ad-

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1 _____, Mae Ngat Project (Bangkok: Royal Irrigation Department, February 1979, in Thai), p. 6.

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versely if M. pigra were not controlled in the reservoir, i.e., the benefits which would accrue to a program of M. pigra control.

Nature of the Infestation

Qualitative Description

In the Kew Lom reservoir M. pigra infestatons are very dense and individual trees can grow to be quite tall (7 meters plus). Infestations extend along both banks of the reservoir for the majority of its length, and from at or above the rainy season high water line to near the lowest level reached by the reservoir in the hot season. Infestations occur also on virtually all channel bars and other island-like formations which protrude above the water during the hot season.

Quantitative Description

Present Extent. The original surface area of the Kew Lom reservoir measured 12,000 rai. As of 1980, approximately 5,000 rai (41.7%) of that area had become infested with M. pigra.[1]

Potential Extent. In 1972 when the Kew Lom project was completed, the reservoir itself was virtually weed free although the Wang River was rather heavily infested. The observed rate of increase of M. pigra infestation to date and the projected future rate of increase are plotted in Figure 8-1. Based on extrapolation of observed rates of infestation increase, the reservoir will be 90% infested in the year 1997, exactly 25 years from the date of its completion.

The Nature of the Benefits

Sedimentation

The usual cause of the demise of a dam/reservoir system is sedimentation. Deposits of material washed into the reservoir gradually build up, particularly behind the dam. As this occurs, the volume of the reservoir decreases as the reservoir bottom rises until only the volume occupied by the original river remains.

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[1]Interview with Prachak Thimkachana, Director, Operations and Maintenance, Kew Lom Dam and Reservoir Project, February 23, 1981.

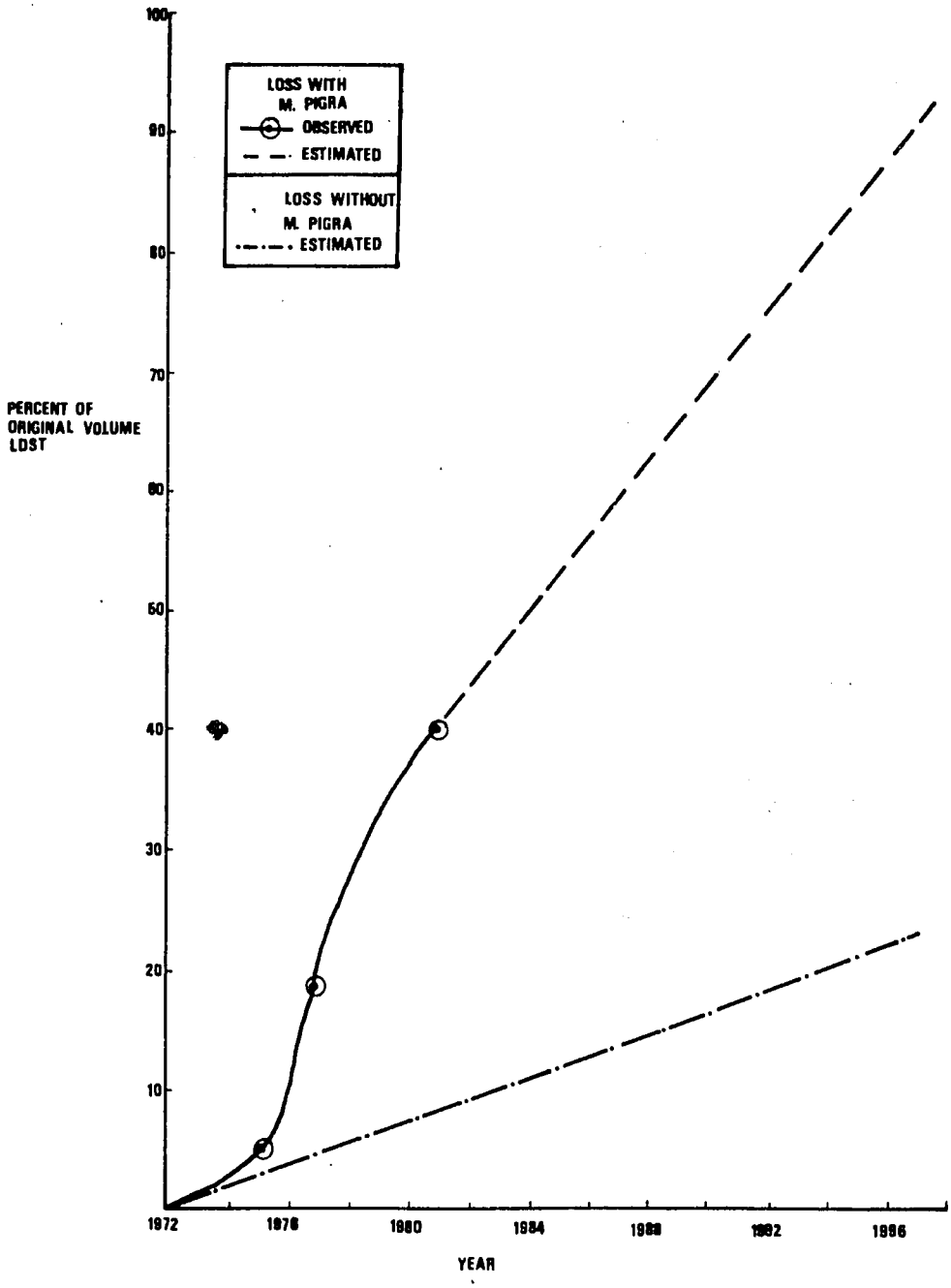

Figure 8-1. Rate of Loss of Original Reservoir Volume With and Without M. pigra: Kew Lom Project.

Source: Adapted from Interview with Prachak Thimkachana, op. cit., and_____, Kew Lom Project Construction Report, op. cit.

Thus dam/reservoir systems are not expected to last indefinitely: the Kew Lom project was initially planned to have a useful life of 100 years.[1]

As was the case with rivers, the rate of sediment buildup increases markedly in reservoirs when M. pigra infestations are present. The specific mechanisms by which this increase in sedimentation rate is brought about are the same for both rivers and reservoirs. These mechanisms were described in detail in Chapter 7 and will not be repeated here except to note that in the case of reservoirs the normal sediment storage area directly above (behind) the dam is ineffective in containing the M. pigra generated sedimentation. Whereas the sediment storage area holds material which would otherwise back up immediately behind the dam itself, M. pigra generated sediment is deposited all along the reservoir and not primarily just at the dam.

A direct measure of the amount of sedimentation which has occurred in a reservoir infested with M. pigra (and thus a method of measuring the reduction in reservoir volume) is the amount of reservoir surface area covered by the weed. The area infested with M. pigra can be used as a measure of volume reduction in this way because the weed can grow only on ground which is not inundated for at least a portion of the year. Thus the presence of the weed indicates that sediment has built up in that area to the point where the reservoir bottom is above water part of the year. For example, the fact that 41.7% of the Kew Lom reservoir has become infested indicates that sedimentation has occurred to the point that 41.7% of the original reservoir volume has been lost.

The estimate that the Kew Lom reservoir will be 90% infested (which means for practical purposes it will have ceased to exist) in 25 years from completion of construction means that an average of 4% of the volume of the reservoir will be lost to sedimentation each year. The originally projected useful life of 100 years anticipated a loss of only 1% per year. M. pigra in reservoirs thus causes a four fold increase in the rate of sedimentation/reduction of reservoir volume from 1% to 4% per year. (These estimates assume a constant rate of sedimentation).

Sedimentation in a reservoir does not represent an economic loss in and of itself. It is rather the means by which other benefits, e.g., crop production, fish production, etc., are reduced. For this reason, as was done in the analysis of rivers in the previous chapter, the benefits of M. pigra control vis a vis sedimentation will not be calculated separately but rather will be considered to be subsumed under other benefits.

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[1] _____, Kew Lom Project Construction Report (Bangkok: Royal Irrigation Department, undated, in Thai), no pp.

Crop Production

The benefits derived from a reservoir are, as noted above, directly related to the volume of the reservoir. In the analysis of crop production and all other reservoir benefits, a directly proportional relationship between level of benefits and reservoir volume will be assumed, e.g., a 4% reduction in reservoir volume in one year would mean a 4% reduction in annual crop production benefits from that reservoir. (The data are not available which would be necessary to make more precise estimates.)

If there were no M. pigra in the reservoir, the value of benefits would be reduced by approximately 1% per year due to normal sedimentation. If M. pigra were allowed to grow unchecked the value of benefits would be reduced by 4% per year due to the higher rate of sedimentation. The difference between the two is the reduction in value of benefits each year attributable to M. pigra, i.e., the value of benefits which would accrue if M. pigra were controlled in reservoirs.

The largest single area of benefits which is expected to be realized when the Mae Ngat system is completed is increased crop production made possible by increased availability of irrigation water. The value of irrigation water in terms of crop production is ฿ 519 million per year.[1] Without M. pigra infestation this value would be reduced by 1% (฿ 5.29 million) each year over the 100 year life of the project. For example, the value the first year the project is completed would be ฿ 529 million. After one year it would be reduced to ฿ 523.71 million; after two, to ฿ 518.42 million, etc. If M. pigra were allowed to grow uncontrolled in the reservoir, the value would be reduced by 4% (21.16 million) per year for 25 years at which time the reservoir would have virtually ceased to exist. For example, the value the first year the project is completed would be 529 million, but then after one year with M. pigra infestation it would be reduced to ฿ 507.84 million; after two, ฿ 497.26 million, etc.

The difference in the value remaining each year is the benefit which would accrue to a program of M. pigra control. Thus in terms of crop production the benefits of M. pigra control would be zero the year the project is completed, ฿ 15.87 million after one year (฿ 523.71 million less ฿ 507.84 million) and ฿ 21.16 million after two years. A partial tabulation of benefits to crop production is shown in Table 8-1.

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1 _____, Report on Economic Analysis: Mae Ngat Project, Ampoe Mae Taeng, Changwat Chiang Mai (Bangkok: Project Economic Study Branch, Project Planning Division, Royal Irrigation Department, December 1979, in Thai), p. 5-5.

Table 8-1. Benefits of Controlling M. pigra in Reservoirs (Mae Ngat Project): Crop Production[a]

Year[b]	Annual value of electric power production if no M. pigra (millions)	Annual value of electric power production with uncontrolled M. pigra (millions)	Value of annual loss due to M. pigra (Annual benefit of M. pigra control) (millions)
0	฿ 529.00	฿ 529.00	฿ 0.00
1	523.71	507.84	15.87
2	518.42	486.68	31.74
3	513.13	465.52	47.61
---	---------	---------	---------
24	402.04	21.16	380.88
25	396.75	0.00	396.75
26	391.46	0.00	391.46
....	---------	-------	--------
99	5.29	0.00	5.29
100	0.00	0.00	0.00

Notes: (a) Partial tabulation.
(b) Years from completion of the Mae Ngat Project.

Source: As described in text.

Electric Power Production

The Mae Ngat project is projected to produce 24.5 million kilowatt-hours of electricity per year.[1] Based on a value of ฿ 0.70 per kilowatt-hour,[2] that represents a value of ฿ 17,150,000 per year.

Based on the same assumptions employed to evaluate crop production benefits, if there were no M. pigra in the reservoir the quantity of electricity produced would decrease by 1% per year. If M. pigra were present and not controlled the electricity generated would be reduced by 4% per year. A partial tabulation of benefits to electricity production is shown in Table 8-2.

Fish Production

It is anticipated that the completed reservoir would be used as a site for aquaculture development and freshwater fish culture. The initial annual value of these activities is expected to be ฿ 415,000 per year.[3] A partial tabulation of benefits, using annual value reduction rates of 1% without M. pigra and 4% with uncontrolled M. pigra as described above, is shown in Table 8-3.

Flood Control

The completed dam and reservoir project will be able to mitigate flood damage resulting from the Ngat and Ping Rivers overflowing their banks following the torrential downpours of the rainy season. (The Ping River has overflowed its banks 13 times in the past 24 years.)[4] The excess water flow will be contained by the reservoir and released through the dam at a more moderate rate. The value of this flood control is estimated to be ฿ 6.6 million per year.[5] A partial tabulation

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1 _____, Mae Ngat Project, op. cit., p. 9.

2 Lowest per kilowatt-hour charge in Chiang Mai Province.

3 _____, Report on Economic Analysis, Mae Ngat Project, Ampoe Mae Taeng, Changwat Chiang Mai, op. cit., p. 5-5 and , Mae Ngat Project op. cit., p 6.

4 _____, Thailand Hydrological Yearbook: Water Year 1957 to Water Year 1980, op. cit.

5 _____, Report on Economic Analysis: Mae Ngat Project, Ampoe Mae Taeng, Changwat Chiang Mai, op. cit., p. 5-6.

of benefits, using annual value reduction rates of 1% without M. pigra and 4% with uncontrolled M. pigra as described above, is shown in Table 8-4.

Wier Repair

The final benefit of the Mae Ngat project will be the reduction of expenditures for repair of traditional irrigation system wiers. All wiers generally require annual repairs and/or maintenance checks at least once a year. With the completion of the project several wiers would be replaced entirely by the dam and reservoir system. Others would require less frequent and/or less extensive repairs as the flow of the Ngat and Ping Rivers would be more moderate year round. The punnishment meted out to wiers by the very strong rainy season river flow would be reduced. The value of wier repair which will be no longer necessary is estimated to be ฿ 302,726 per year.[1] A partial tabulation of benefits, using annual value reduction rates of 1% without M. pigra and 4% with uncontrolled M. pigra as described avove, is shown in Table 8-5.

Summary of Benefits

A partial tabulation of benefits to M. pigra control in the Mae Ngat Project reservoir vis a vis crop production, electric power production, fish production, flood control and wier repair is shown in Table 8-6.

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[1] Ibid.

Table 8-2 Benefits of Controlling M. pigra in Reservoirs (Mae Ngat Project): Electric Power Production [a]

Year[b]	Annual value of electric power production if no M. pigra (millions)	Annual value of electric power production with uncontrolled M. pigra (millions)	Value of annual loss due to M. pigra (Annual benefit of M. pigra control) (millions)
0	฿ 17.15	฿ 17.15	฿ 0.0
1	16.98	16.46	0.52
2	16.81	15.78	1.03
3	16.64	15.09	1.55
----	-------	--------	-------
24	13.03	0.69	12.34
25	12.86	0.0	12.34
26	12.69	0.0	12.69
---	-------	----	-------
99	0.17	0.0	0.17
100	0.0	0.0	0.0

Notes: (a) Partial tabulation.
(b) Years from completion of the Mae Ngat Project.

Source. As described in text.

Tabel 8-3. Benefits of Controlling M. pigra in Reservoirs (Mae Ngat Project): Fish Production[a]

Year[b]	Annual value of fish production if no M. pigra	Annual value of fish production with uncontrolled M. pigra	Value of annual loss due to M. pigra (Annual benefit of M. pigra control)
0	฿ 415,000	฿ 415,000	฿ 0
1	410,850	398,400	12,450
2	406,700	381,800	25,900
3	402550	365,200	37,350
----	----------	----------	----------
24	315,400	16,600	298,800
25	311,250	0	311,250
26	307,100	0	307,250
----	----------	----------	----------
99	4,150	0	4,150
100	0	0	0

Notes: (a) Partial tabulation.
(b) Years from completion of the Mae Ngat Project.

Source: As described in text.

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Table 8-4 Benefits of Controlling M. pigra in Reservoirs (Mae Ngat Project): Flood Control[a]

Year[b]	Annual value of flood control if no M. pigra	Annual value of flood control with uncontrolled M. pigra	Value of annual loss due to M. pigra (Annual benefit of M. pigra control)
0	฿ 6,600,000	฿ 6,600,000	฿ 0
1	6,534,000	6,336,000	198,000
2	6,468,000	6,072,000	396,000
3	6,402,000	5,808,000	594,000
---	---	---	---
24	5,106,000	264,000	4,752,000
25	4,950,000	0	4,950,000
26	4,884,000	0	4,884,000
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99	66,000	0	66,000
100	0	0	0

Notes: (a). Partial tabulation.
(b) Years from completion of the Mae Ngat Project.

Source: As described in text.

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Table 8-5. Benefits of Controlling M. pigra in Reservoirs (Mae Ngat Project): Wier Rapair [a]

Year[b]	Annual value of reduced wier repair if no M. pigra	Annual value of reduced iwer repair with uncontrolled M. pigra	Value of annual loss due to M. pigra (Annual benefit of M. pigra control)
0	฿ 302,726	฿ 302,726	฿ 0
1	299,699	290,617	9,082
2	296,671	278,508	18,163
3	293,644	266,399	27,245
----	----------	----------	----------
24	230,072	12,109	217,963
25	227,045	0	277,045
26	224,017	0	224,017
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99	3,027	0	3,027
100	0	0	0

Notes: (a) Partial tabulation.
(b) Years from completion of the Mae Ngat Project.

Source: As described in text.

Table 8-6. Summary of Benefits of Controlling M. pigra in Reservoirs (Mae Ngat Project)[a]

Year [b]	Annual value of benefits (millions)
1	฿ 16.61
2	33.21
3	49.82
---	---------
24	398.49
25	415.10
26	409.57
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99	5.53
100	0.0

Notes: (a) Partial tabulation.
(b) Years from completion of the Mae Ngat Project.

Source: As described in text.

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PART III

COSTS OF CONTROLLING MIMOSA PIGRA

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Chapter 9. OPPORTUNITY COSTS

Definition

The opportunity cost of some good or service is its worth in the next best alternate use. Following that definition, the opportunity cost of controlling M. pigra is the value of the next most valuable use to which the weed would be put if it were not controlled, e.g., firewood.

A correllary to the above definition is that if M. pigra could be used in a given application but in fact is not so used, e.g., animal feed, no opportunity cost would be incurred if the weed were controlled.

In this chapter various current and potential uses of M. pigra and described. Potential uses which are not currently economically significant are included to provide guidance to policy makers and others regarding possible future applications of the weed. Where M. pigra is currently controlled two opportunity cost figures are presented for each current use category: the opportunity cost incurred due to present control efforts and the opportunity cost which would be incurred if the weed were totally controlled. This parallels the "benefits with current control efforts - benefits with complete control" format used in Section II of this report.

Current Uses

Firewood

M. pigra is currently harvested in significant quantities for use as firewood from only two locations: from along rivers and from non-agricultural areas. If current control efforts along roads were halted, the weed would also be harvested from that area. The opportunity cost of controlling the weed in each of those areas is described below.

Rivers. To determine the amount of M. pigra harvested for fuel along the 93 kilometers of the Ping River which lie within the Valley, semi-structured interviews were conducted with a representative sample of leaders of village groups

(tambon) located adjacent to the River. Twelve village groups were surveyed, approximately ten percent of the total number of riverside villages. Based on these interviews it is estimated that 12.8% of all fuel used by villages located adjacent to the Ping River is M. pigra.

The quantity of firewood used by riverside villages was computed by comparing the caloric content of M. pigra with that of charcoal. One kilogram of M. pigra firewood yields 4.31 Calories (4.31 kilocalories or 4,310 calories) versus 5.06 Calories per kilogram of charcoal.[1] The average household uses 37.5 kilograms (three baskets) of charcoal per month or 450 kilograms per year if they use exclusively charcoal fuel.[2] The annual caloric requirement per household is thus 2,277 Calories which translates into 528 kilograms of M. pigra firewood. As 12.8% of fuel used by households in riverside villages is M. pigra, the total amount of weed used for firewood annually is 6,438,385 kilograms. (Calculation: 140 households per village x 5 villages per village group (tambon) x 136 riverside village groups x 528 kg/household x 12.8% = 6,438,385 kg.)

The average price of charcoal is ฿ 2 per kilogram (฿ 25 per 12.5 kilogram basket). On a caloric basis, charcoal is worth ฿ 0.395 per Calorie. As M. pigra is a lower quality fuel, burning more rapidly, less evenly and less cleanly than charcoal, it is estimated that on a caloric basis M. pigra is worth approximately 75% as much as charcoal, i.e., ฿ 0.296 per Calorie. (There is so little M. pigra firewood offered for sale that its market price has not yet been established.) At that price, the 6,438,385 kilograms of M. pigra firewood used is worth ฿ 8,213,834. (Calculation: 6,438,385 kg x 4.31 Cal/kg x ฿ 0.296/Cal = ฿ 8,213,834.)

Because there are currently no M. pigra control efforts along rivers, there are currently no opportunity costs incurred. If the weed were totally controlled, however, the opportunity cost would be the full value of the weed presently used for firewood, i.e., ฿ 8,213,834.

Non-agricultural Land. There are, as previously indicated, approximately 8,475 rai of non-agricultural land infested with M. pigra. Based on personal observation it is estimated that roughly ten percent of the M. pigra in these areas which is suitable for firewood is actually used for that purpose.

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[1] Measurements made by the author using a Bomb Calorimeter.

[2] Unstructured interviews with area charcoal users.

To quantify the amount of M. pigra used for firewood, the average yield of M. pigra fuel in non-agricultural areas was determined. This was done by cutting, drying and weighing the M. pigra firewood from representative four square meter grids in weed-infested areas. Total dry weight of firewood averaged 8.2 kg per four square meter or 3,280 kg. per rai.[1] The average age of the firewood-size trees was about 2.5 years, thus the potential annual yield is approximately 1,312 kg. per rai. As only ten percent of the firewood available on the 8,475 infested rai is harvested, the totaal amount of M. pigra used for firewood is 1,111,920 kg. per year. As households using exclusively M. pigra firewood use 528 kg. per year, it is estimated that the equivalent of 2,106 households use M. pigra fuel harvested from non-agricultural areas.

Using the value of B 1.65 per kilogram of M. pigra calculated above, the total amount of M. pigra harvested from non-agricultural areas annually is worth ฿ 1,834,668. As is the case along rivers, there are currently no efforts to control M. pigra in non-agricultural areas, hence no opportunity cost. However, if the weed were totally controlled, the opportunity cost would be ฿ 1,834,688 per year.

Along Roads. Current efforts have virtually precluded the harvesting of M. pigra along roads: the trees just don't get large enough in most areas before they are cut down by highway crews. If control efforts were halted, firewood size trees would be available on virtually the entire 11,900 rai of roadside areas. As areas along most roads are less densly populated than non-agricultural areas (which are primarily urban) and people are loath to walk more than a few hundred meters to harvest the weed, it is estimated that the rate of harvesting M. pigra along roads for use as fuel would be about one tenth that in non-agricultural areas, i.e., 119 rai would be used. Thus it is estimated that a total of 390,320 kilograms of M. pigra worth ฿ 644,028 would be harvested along roads if the weed were not controlled. (Calculation: 119 rai x 3,280 kg/rai = 390,320 kg.) This is the estimated opportunity cost of current control efforts (and of total control).

Agricultural Land. When M. pigra is allowed to grow in agricultural land to firewood size this implies that the land is no longer under active cultivation. By definition the area has then become non-agricultural land, hence there can be no opportunity cost vis a vis firewood in agricultural areas.

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[1] Experiment conducted by the author.

Irrigation Systems. As with roads, current control efforts in irrigation systems have resulted in almost no M. pigra being harvested from along canals. If current control efforts were halted, virtually all canals would quickly become filled with sediment due to M. pigra. However, as the irrigation systems would no longer by functioning to bring water to the fields, farmers would most probably plant crops along the former canals, clearing out unwanted vegetation, e.g., M. pigra, in the process. Thus along canals neither present control efforts nor complete control of the weed would result in any opportunity cost.

Reservoirs. Based on observations of the Kew Lom reservoir, it has been determined that the minimal amount of M. pigra harvested for fuel from reservoirs is not economically significant.

Beanpoles

Another use to which M. pigra is put by farmers is for poles on which climbing beans and peas can grow. The number of poles required per rai of crops and the length of those poles varies considerably from one type of bean or pea to another. For example, long beans require about 200 two meter poles per rai whereas snowpeas need twice that number but each pole is only 1.5 meters in length.

The vast majority of M. pigra bean poles used are harvested from along rivers No other area which is close enough to the farmers' fields can provide a sufficient quantity of M. pigra. In one village it was reported that even along the Ping River there was too little M. pigra to use it for both beanpoles and firewood. In that instance firewood was considered the more valuable commodity so beanpoles were made of bamboo, the traditional beanpole material.

Based on the results of semi-structured interviews with leaders of villages located along the Ping River it is estimated that a total of 290 rai of climbing beans and peas is planted by farmers in villages adjacent to the Ping using M. pigra for beanpoles.

It requires an average of 3.7 days to harvest sufficient M. pigra beanpoles for each rai of crops. At an imputed agricultural wage rate of ฿ 30 per day, the value of M. pigra beanpoles used in the Valley is ฿ 32,190 per year, the opportunity cost that would be incurred if M. pigra were totally controlled along the Ping River. As there are now no M. pigra control measures along rivers in agricultural areas there is currently no opportunity cost incurred.

Sediment

As noted previously, the presence of M. pigra is responsible for approximately 75% of the sediment deposited along rivers infested with the weed. Along one kilometer and a half section of the Ping River where it flows through the northern part of Chiang Mai City an estimated 100,000 cubic meters of sediment have been deposited. This deposition occurred over roughly the past ten years, i.e., since M. pigra infestations along the Ping River reached the city.[1] During the dry season of 1981 two local firms using bulldozers, payloaders, and a steady stream of dumptrucks removed that sediment from the river and trucked it elsewhere for use as landfill. The market value of that landfill, exclusive of transportation costs, is ฿ 3 per cubic meter.[2]

Prior to the incursion of M. pigra, there was never enough sediment deposited along the river to make large scale removal profitable, hence the entire value of the sediment removed, ฿ 300,000, can be attributed to the presence of the weed. Presumably, if the weed is not controlled in another ten years sediment will again build up to previous levels. Thus the opportunity cost which would be incurred if the weed were controlled along that kilometer and a half section, calculated on an annual basis, would be ฿ 30,000 per year.

For only approximately twenty kilometers along the Ping River - ten kilometers north and ten south of Chiang Mai City - is removal of M. pigra induced sediment profitable. Beyond that distance transportation costs to urban sites where the fill would be used becomes prohibitive.[3] If it is assumed that there are 100,000 cubic meters of sediment along each kilometer and a half of river, which preliminary surveys have indicated is the case, the sediment as yet not removed from the remaining 18.5 kilometers near Chiang Mai City represent a potential ฿ 1,233,333 worth of landfill. If this sediment is in fact removed, and it is likely that at least part of it will be, the opportunity cost of controlling M. pigra would rise proportionately.

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[1] Interview with Wanchai Boonyasurat, Undersecretary of Chiang Mai Municipality, June 11, 1981.

[2] Interview with Jirakhak Sonmance, Manager, Siam Square Construction Company, Chiang Mai, (one of the two firms that removed the sediment), June 11. 1981.

[3] Interview with Prasong, Srikunmontri Owner and Manager, Prasong Transport Company, Chiang Mai (the second firm which removed sediment from the river), june 12, 1981.

As to reservoirs, sediment deposited there does not represent eighter a current or a potential opportunity cost under any forseeable circumstances. Reservoirs are usually located so far from urban centers (the Mae Ngat project is approximately 40 kilometers from Chiang Mai City) that transportation costs make if impractical for commercial firms to remove the sediment for use in urban projects.

Crop Production

Insect damage of crops is a relatively serious problem for several crops grown in the Valley: insects reduce both the quantity and quality of yields. M. pigra, by providing potentially suitable perching places for insectivorous birds, may help to reduce the level of insect damage.

Determination of whether there is in fact a reduction of insect damage to crops due to the presence of M. pigra would require extended study by ornithologists, entomologists and plant production specialists which is beyond the scope of this study. For this reason the economic value of this opportunity cost could not be determined.

Potential Uses

Erosion Control

In irrigation canals erosion is primarily the result of three natural forces: sheet (runoff) erosion, splash erosion (the erosion caused by individual raindrops impacting the soil) and the undercutting effect of the flow of irrigation water acting on the walls of the canals. In most canal systems none of these forces causes serious erosion problems in other than a few isolated locations for two reasons.

The first reason erosion is not a problem is that canals are usually built in area where soils are relatively fertile. In addition to this natural fertility, rich river sediment deposited in the beds of canals is removed during periodic canal maintenance and shovelled onto the canal banks, further increasing soil fertility. As would be expected in areas with highly fertile soil, there is an abundance of vegetation of various types growing along almost all canal banks. This vegetation effectively brunts the force of both sheet and splash erosion.

The second reason erosion is not a problem is that irrigation water, particularly in traditional systems, flows relatively slowly, so it doesn't usually have appreciable undercutting effect on canal banks. M. pigra could help control what undercutting does occur, but the cure would be worse than the disease: as undercutting occurs primarily below the water level, to be effective, the weed would

have to be allowed to grow actually in the bed of the canal. That would both impede the flow of the water and increase sedimentation, two highly undesirable effects.

Thus the presence or absence of M. pigra along canals does not materially affect erosion rates, hence control of the weed would not result in any opportunity cost.

In rivers, also, M. pigra is not a significant factor in erosion control. That is the case because the weed grows almost exclusively along the deposition side of river bends. The deposition side of a river is not normally subject to erosion; on the contrary, as its name implies, even in the absence of M. pigra the deposition side is subject to sedimentation buildup rather than erosion. The upshot is again that no opportunity cost would be incurred if the weed were controlled.

Huts

A use for which M. pigra would, at first glance, appear well suited is in the construction of the numerous small huts farmers erect near their fields to provide temporary shelter. Thicker stems of the weed would seem to be ideal for the framework of these grass-thatched structures. In fact, not a single instance of M. pigra being used for that purpose was found. Farmers questioned stated that it is not used because M. pigra wood is too soft and rots to quickly. They all used either bamboo or some other locally available (but more rot resistant) wood for their hut frames. Thus control of M. pigra represents no opportunity cost vis a vis hut construction.

Fences

In a very few locations, primarily in areas near rivers, M. pigra is occasionally cut for use in building temporary rail-type fences around planted fields to keep cattle and water buffalo out. The reason it is not used more extensively for this purpose is, again, that the wood rots too quickly. Bamboo is the usual material of choice for these light duty fences.

One individual has devised another type of M. pigra fence. He has a closely spaced hedge of M. pigra trees growing four deep which he planted all around his property to keep out unwanted intruders. In summary, however, so little of the weed is used for fences, either the cut or the living varieties, that the opportunity costs of controlling M. pigra would be economically insignificant.

Fertilizer

As M. pigra is a nitrogen fixing legume, it could, theoretically, increase yields if used as a fallow period cover crop. In practice no such increase is realized. In

most of the fields where the weed does appear it is plowed under while still too young to fix significant quantities of nitrogen: for the first few weeks newly sprouted legumes are in fact net users rather than net producers of fixed nitrogen. In the few cases where the weed is allowed to grow for longer periods, before the next crop is planted the weed is physically removed from the field: either cut down at ground level or dug up and then discarded. As most of the nitrogen fixed by a legume is stored in the plant itself rather than in the soil, removing the plant from the field effectively removes the bulk of the nitrogen it has fixed as well. Thus in neither case would control of the weed result in any opportunity cost.

Animal Feed

There is currently virtually no M. pigra used for animal feed, so control of the weed would involve no opportunity costs. However, recent experiments have shown M. pigra to be a suitable animal feedstock. In fact, it was found to be superior in certain nutritional aspects to Leucaena leucocephala, a closely related legume which is used extensively as an animal feedstock in Thailand. Thus M. pigra has the potential to become a viable alternative to L. leucooephala.

Animal weight gain is usually a good indicator of the nutritional value of a feedstock. A number of feeding trial experiemnts have been performed comparing weight gain of animals on diets which included L. leucocephala versus those on diets in which M. pigra was substituted for the L. leucocephala. These experiments have shown that pigs,[1] chickens,[2] sheep,[3] quail,[4]

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[1]Therdchai Vearashilp B. Phuangphong and S. Ruengpaibul, A Comparison of Leucaena leucocephala and Mimosa pigra L. in Pig Diets (Chiang Mai: Department of Animal Husbandry, Faculty of Agirculture, Chiang Mai University, 1980, mimeo, in Thai), p. 36.

[2]Sornarong Supachawalit, A Comparison of Leucaena leucocephala and Mimosa pigra L. for Inclusion in Broiler Diets (Chiang Mai: Faculty of Agriculture, Chiang Mai University, 1980, mimeo, in Thai), p. 36.

[3]Therdchai Vearasilp, A Comparison of Nutritive Values and Voluntary Intake of Mimosa pigra L. and Leucaena leucocephala in Sheep (Chiang Mai: Department of Animal Husbandry, Faculty of Agriculture, Chiang Mai University, 1980, mimeo, in Thai), p. 4.

[4]N. Tongvittaya, et. al., A Study on Inclusion of Mimosa pigra in Japanese Quail Diets, A Report to the National Converence, Animal Section, Kasetsart University, Bangkok, February 1979 (Bangkok: The Conference, 1979), p. 4.

rabbits[1] and even rats[2] do as well or better on the diets which included M. pigra. The quantity of M. pigra or L. leucocephala in the diets ranged between four and eight percent by dry weight in each of the experiments. The high fiber content of the two feedstocks precludes feeding higher concentrations to non-ruminants.

Chemical analysis of M. pigra and L. leucocephala gives a possible indication of why the former was able to match or exceed the latter in terms of animal weight gain. Although the crude protein content of M. pigra is fractionally lower (23.35% versus 23.64%), it exceeds L. leucoocephala in per unit content of all amino acids but one, mimosine, which M. pigra lacks entirely.[3] It is, in fact, the presence of the non-essential amino acid mimosine in L. leucocephala that limits the percentage of that feedstock in ruminant diets. (Ruminants could digest the high fiber content of both M. pigra and L. leucocephala.) When L. leucocephala is fed in high concentrations, e.g., when it composes more than half the diet of a ruminant for more than six months, it can result in general ill health with loss of tail and rump hairs, excessive salivation (drooling) and poor growth. The direct cause is that the mimosine causes an underproduction of thyroxine by the animal's thyroid gland which results in goiter.[4] Thus M. pigra, with no mimosine content, could theoretically be used in very high concentrations in ruminant diets. To date there have been no feeding trial experiements conducted with ruminants to verify this theory. The lack of experiments is due primarily, according to prospective reserachers, to the relatively greater time and financial requirements of experiments with large animals.

The final factor in evaluating a prospective animal feedstock is its palatability. In the case of M. pigra the numerous sharp thorns, which are an integral part of the leaves, would appear to be a problem. In practice that is not the case. The

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[1] N. Tongvittaya, et. al., A study on Inclusion of Mimosa pigra in Japanese Quail Diets, A Report to the National Conference, Animal Section, Kasetsart University, Bangkok, February 1979 (Bangkok: The Conference, 1979), p. 4.

[2] Manirat Siriwilysagulwong and Therdchai Vearasilp, "Mimosa pigra L. in Rabbit Diets," in Warasan Mae Jo [Mae Jo Journal] Chiang Mai, Vol. 5, No. 3, January 1981, in Thai, p. 44.

[3] Ibid., p. 3.

[4] _____, Leucaena: Promising Forage and Tree Crop for the Tropics (Washington, D. C.: National Academy of Sciences, 1977), pp. 32-33.

author has personally observed cattle on many occasions browsing on M. pigra leaves by choice in areas where various other grasses were equally available. (Plate 28)

To determine the quantity of M. pigra feedstock potentially available, the author, with the assistance of Thawachai Chaitrakunsup and Therdchai Vearasilp of the Faculty of Agriculture, Chiang Mai University, cut, dried and weighed M. pigra leaves from measured test areas. Based on the results of those measurements it appears that if M. pigra were harvested every 45 days (as is currently done with L. leucocephala) it would be possible to obtain eight crops per year for a total of just over 2,000 kg. dry weight of feed per rai. This compares not unfavorably with the 1,920 to 3,200 kg. per rai per year produced by L. leucocephala.[1]

Medicine

In various regions of the world M. pigra is used for medicinal purposes. Most of these uses probably would be called "folk medicine;" that classification, however, does not necessarily imply a lack of efficacy. A few example follow.

(1) In Tanzania the roots are used for snake bite.[2]

(2) An infusion or decoction of the leafy stems is used as a wash for fever, as a mouthwash for toothache and as a remedy for plethoric conditions by the Hausa tribe.[3]

(3) In the region formerly known as French Equatorial Africa an infusion of root scrapings is used for head colds, the liquid being dropped into the nostrils.[4]

(4) In the Sudan it is used by the Zande as a mineral salt plant and in the Kordofan area as an eye medicine.[2]

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[1] Ibid., p. 29.

[2] Irvine, op. cit., p. 346.

[3] Ibid., p. 347.

[4] Ibid., p. 346.

[5] Ibid., 346-347.

(5) In the Philippines a decoction of the entire plant is considered antiasthmatic. A root decoction is given for urinary complaints. The plant is also used as an emeric. Leaf infusions are used for dysentery and kidney trouble. Crushed leaves are rubbed into a paste which has emollient properties. The paste is applied to glandular swellings. The seeds are used as an emeric and also for sore throat and hoarseness.[1]

M. pigra has been growing in Thailand for a relatively short period of time and there is no evidence to date that any of these medicinal properties of the plant have yet been made use of. Thus at present the opportunity cost of control in the area of medicine is nil.

Paper

There is currently no M. pigra being used in the manufacture of paper in Thailand on either an experimental or commercial basis. There are three main reasons for this situation. First, the fibers of M. pigra are too short for even lower grade paper.[2] Second, harvesting the weed is difficult due to its thorns. Finally, sugarcane bagasse, a good paper pulp input, is currently readily available in quantity.

In the future, however, M. pigra my be used in admixture with other longer fiber stock because the demand for paper is increasing while the supply of bagasse is dwindling slowly as more and more of it is burned as a fuel to dry crops. The Siam Kraft Paper Co., Ltd., producers of over half the pulp manufactured in Thailand, indicated that they would look into the feasibility of using M. pigra as a pulp feedstock.[3] However, as no M. pigra is now used in paper manufacture, there would be no opportunity cost incurred if the weed were controlled.

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[1] de Padua, op. cit., p. 39.

[2] Interview with Surapong Sugunnasil, Managing Director, Conec Concrete Co., Ltd., Chiang Mai, November 17, 1980.

[3] Interview with Chanarong Rienjongdee, Sales Technical Service Section, Siam Kraft Paper Co., Ltd., Bangkok, March 11, 1981.

Fiberboard

It is technically possible to manufacture a fiberboard type product using M. pigra. One company, working in cooperation with the Thai Forestry Department, has actually made samples of M. pigra fiberboard, but the product was never put into commercial production.[1]

The main problem with producing fiberboard from M. pigra commercially is that the final product absorbs an unacceptable amount of moisture. To prevent this moisture absorption special additional chemical treatment must be included in the manufacturing process. This extra treatment raises the cost of production to the point where the product is not price competitive.[2]

Perhaps in the future a less costly manufacturing process will be developed; however, as no M. pigra is currently being used in the manufacture of fiberboard, the opportunity cost of control in this area is zero.

Summary of Opportunity Costs

Opportunity costs of controlling M. pigra are summarized in Table 9-1.

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[1] Interview with Anuwat Jitrjruysri, Hang Hun Suan Co., Bangkok, May 22, 1981.

[2] Kittipong, op. cit., p. 8.

Table 9-1. Summary of Annual Opportunity Costs of Controlling M. pigra

Cateogry of area/ Nature of the opportunity costs	Value of opportunity costs with current control efforts (Baht)	Value of opportunity costs with total control (Baht)
Along Roads		
Firewood	644,028	644,028
Non-agricultural Areas		
Firewood	0	1,834,688
Rivers[b]		
Firewood	0	8,213,834
Beanpoles	0	32,190
Sediment	0	30,000
Erosion control	(a)	(a)
Total (rivers)	(a)	8,276,024
All Areas		
Crop Production	(a)	(a)
Huts	0	0
Fences	(a)	(a)
Fertilizer	0	0
Animal feed	0	0
Medicine	0	0
Paper	0	0
Fiberboard	0	0

Notes: (a) Value not calculated - assumed to be minimal.
(b) Data for the 93 kilometers of the Ping River which lie within the Chiang Mai Valley.

Source: As described in text.

Chapter 10. DIRECT COSTS

Definition

Direct costs of controlling M. pigra include the value of all capital and labor expended to control the weed (eliminate or reduce the level of the infestation). There are three potential methods of controlling M. pigra: mechanical, chemical and biological. Currently only mechanical methods are employed on other than a very limited or experimental basis.

Mechanical Control

Definition

Mechanical control includes all control techniques which do not involve the use of any chemical or biological control agents. The three primary mechanical control methods are cutting, digging and burning.

Cutting. Mechanical control by cutting currently involves simply chopping down the trees at or near ground level. The tool usually employed is the sturdy all-purpose knife, about eighteen inches long, found throughout Thailand.

Cutting M. pigra even at ground level, however, usually does not kill the plant. Rather each tree will send up from one to six or more new shoots from the old stump. Each of the new shoots is capable of attaining the height and girth of the parent. If the shoots themselves are subsequently cut, each of the cut shoots will itself put out new shoots. Thus cutting alone as currently practiced does not achieve permanent control.

Although none are currently employed, it appears that an all terrain vehicle (ATV) equipped with a flail mower similar to the attachment used with tractors to cut grass along roads might be a suitable mechanical device for controlling M. pigra along rivers and in reservoirs. If infestations in these areas were cut below the rainy season water level, the majority of the plants would very likely drown. Even the trees which did not drown would have their seed production

reduced considerably. Because of the weed's rapid growth rate, cutting would have to be done either during the rainy season or late in the hot season to achieve success. In either case, the cutting vehicle would have to be able to both float on the water as well as drive along mud flats, hence the need for an ATV.

Digging. Because of the extensive latteral root system of the weed and its deep taproot, digging up trees using hand tools is not a common practice. Where large areas are to be cleared of M. pigra, e.g., on sites where buildings or roads are to be constructed, bulldozers or similar equipment is usually employed.

Digging does achieve permanent control of those individual plants which are removed; however, if there are seeds remaining in the soil or if new seeds are introduced into the area the infestation will recur and control will be only temporary.

Burning. Burning of standing M. pigra trees is only possible in areas where there is a plentiful supply of ground cover, e.g., dried grass and other weeds, and where there is no danger of the fire spreading to other areas. This method of control is reasonably effective: in Australia burning treatments late in the dry season when the M. pigra was suffering moisture stress achieved an 80% kill. However, the same burning done after the first rain had no effect at all the kill rate was zero.[1]

Burning is not, however without side effects. The heat generated by burning is sufficient to break the seedcoat dormancy of seeds lying in the soil on which the burning occurs.[2] A week or so after an infested area has been burned, the ground is often virtually covered with a green blanket of new M. pigra seedlings.

Costs of Mechanical Control

Along Roads. As noted in Chapter 4, all vegetation along roads is controlled periodically, i.e., cut back to a height of a few inches. This is done using primarily simple hand tools. Areas not infested with M. pigra are cut an average

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[1] Letter, I. L. Miller, Senior Agronomist, Department of Primary Production, Division of Agriculture and Stock, Northern Territory, Australia, May 10 1980.

[2] S. Thamasara and M. Simagrai, Chemical Control of Mimosa pigra L. in Irrigation Systems Using Krenite, paper presented at the Annual Meeting of the Aquatic Plant Management Society, Chatanooga, Tennessee, July 15-18, 1980.

of twice a year. In these M. pigra-free areas one man using a grass whip can clear one half rai per day. At an average salary of ฿ 60 per day per worker, the total annual cost of controlling vegeation is ฿ 240 per rai.

M. pigra infestations, on the other hand, are cut usually only once a year, immediately before the weed sets its seeds. In infested areas one man can clear only 200 square meters per day, so the annual cost of controlling vegetation in M. pigra infested areas is ฿ 480 per rai. The annual cost of current M. pigra control efforts along roads is thus the difference between the cost of vegetation control in unifested areas and the cost of control in infested areas, i.e., ฿ 240 per rai.[1] Mutiplying the per rai cost of ฿ 240 by the 5,116 rai infested with M. pigra along roads yields the total annual cost of current M. pigra control efforts: ฿ 1,227,840.

Inland Areas. Agricultural Land. M. pigra is controlled in agricultural land primarily by two fundamental farming activities which are carried out whether or not M. pigra is present: soil preparation prior to planting and weeding of crops after planting.

Prior to planting nearly every type of crop farmers must first prepare the soil in their fields. This is done either by plowing using animal or mechanical traction or by hand using a mattox-like tool. If the M. pigra in those few fields where it does occur does not exceed 20 cm. or so in height effort required for soil preparation is virtually unchanged by the presence of the weed, i.e., M. pigra control is achieved at no additional cost.

In a few fields the soil remains relatively moist even in the dry seasons. If these moist fields happen to be close to a source of seeds and if the fields are not tripple cropped, then M. pigra can grow taller than 20 cm. during the fallow period. When the weed exceeds this height it cannot easily be plowed under and must be removed by hand. Farmers who have fields which are subject to this excessively tall M. pigra growth are aware of the situation and generally do not allow the weed to grow to its full potential. Instead they pull the young plants by hand while they are still small. The time required to pull M. pigra in these fields averages about 1.1 hours per rai.[2] At an average daily wage rate of ฿ 30, the

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[1] Interview with Boonjun Nithiuthai, op. cit., August 11, 1981.

[2] Unstructured interviews with area farmers.

usual rate for agricultural labor during the planting and harvest periods,[1] it would appear that M. pigra added ฿ 3.3 per infested rai to the cost of soil preparation. However, the M. pigra is pulled during the hot dry season when demands on farmers' time is lowest. The true measure of the value of these M. pigra control efforts is the opportunity cost of the farmers' time. During the hot season the demand for part time labor in rural areas is very low and the cost of transportation to part-time employment in urban areas is usually prohibitively high. Thus the opportunity cost of the small amount of time each farmer spends pulling young M. pigra plants is negligible. In summary, even in the few fields where the weed can grow to over 20 cm. during the fallow period, there is virtually no increase in the cost of soil soil preparation, i.e., no M. pigra control costs.

Turning next to weed cntrol, the author's investigations have shown that M. pigra results in no measureble increase in weeding costs. During the rice growing season, M. pigra cannot germinate and grow in paddy fields as they are flooded to a depth of 10 to 15 cm. Rice is grown in the rainy season which is also the period of maximum M. pigra germination and growth. During the other seasons M. pigra is no more of a problem to farmers than any other weed: normal weeding practices keep it and all other weeds under reasonably complete control. If M. pigra were to disappear overnight from farmers' fields there would be a plethora of other weeds such as Amaranth spp. (pigweed) and Physalisminima (hogweed) to take its place. The upshot is that there is virtually no increase in the cost of weeding, i.e., no M. pigra control costs.

Non-agricultural Land. Costs of mechanical control (cutting) of M. pigra in non-agricultural land depend on the use to which the land is to be put. If the weed is cleared as part of site preparation activities prior to construction, the additional cost of M. pigra control is minimal as noted in Chapter 5. If, however, control of M. pigra is an end in itself, e.g., for esthetic reasons the cost would be comperable to that of control along roads, i.e., ฿ 480 per rai. This cost assumes that, unlike roadside areas, control of other (non-M. pigra) vegetation in non-agricultural land is not required.

Irrigation Systems. Royal Irrigation Department Systems. Vegetation along RID canals is controlled using the same methods as those employed along roads, i.e., hand cutting using grass whips and knives. Two principle factors determine the annual cost of cutting M. pigra: the frequency with which it is cut and the average size of the individual plants being cut. Along RID canals all vegetation, including M. pigra, is cut more frequently than that along roads: an average of ap-

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[1] Jaisaad, op. cit.

proximately three times per year. This higher frequency of cutting tends to increase the annual control costs per rai. However, the more frequent cutting also means that the individual M. pigra plants along RID canals have less time to grow between cuttings and are thus not so tall or so stout as those along roads, so are easier to cut. This tends to decrease the annual per rai control costs. On balance the higher cutting frequency and smaller plant size tend to cancel each other out and the additional cost of vegetation control along RID canals due to M. pigra is approximately the same as that along roads i.e., ฿ 240 per rai per year. Multiplying that ฿ 240 by the 1,996 rai of RID canal banks infested with the weed yeilds the annual cost of current M. pigra control efforts, a total of ฿ 479,040.

Traditional Systems. Maintenance of traditional irrigation systems is carried out from one to three times per year depending on the characteristics of the individual canal system. Each time maintenance is performed, all vegetation along canal banks, including M. pigra, is cut back to a height of a few inches and vegetation growing in the canals themselves is dug up and removed. Maintenance of traditional irrigation systems is done by the water users (farmers) themselves on a voluntary basis, hence there is no directly observable wage rate. For purposes of this analysis, an imputed wage rate of ฿ 30 per day is used. This is the same rate used throughout this study for general farm labor.

Based on interviews with the village level leaders responsible for twenty-one traditional irrigation systems, the average time required to maintain canals without M. pigra infestations is estimated to be 299.1 man/days per kilometer per year. For portions of canals infested with M. pigra the annual maintenance time per kilometer rises to 382.2 man/days, an increase of 83.1 man/days. Thus the annual additional cost per kilometer in infested areas is ฿ 30 times 83.1 man/days, a total of ฿ 2,493. Multiplying this figure by the estimated 2,446 kilometers of traditional canals infested with M. pigra yields the total annual cost of controlling the weed in traditional irrigation systems: ฿ 6,097,878.

Rivers and Reservoirs. Controlling M. pigra by cutting is not feasible along rivers and in reservoirs. Due to the vast areas involved it would not be possible to recruit a sufficiently large labor force to accomplish the task at normal wage rates. Flail mowers (described above) represent a possible but as yet untried mechanical control method.

Summary of Mechanical Control Costs

Costs of mechanical control are summarized in Table 10-1.

Table 10-1 Direct Costs of Mechanical Control of M. pigra

Area	Per unit annual cost of control (Baht)	Total annual cost of control (Baht)
Along Roads[a]	240/rai	1,227,840
Inland Areas		
Agricultural Land	(b)	(b)
Non-agricultural Land	480/rai	(b)
Irrigation Systems[a]	240/rai	479,040
RID Systems		
Traditional Systems	2,493/linear kilometer	6,097,878
Rivers	(c)	(c)
Reservoirs	(c)	(c)

Notes: (a) Cost of present control methods.
(b) Value not calculated - assumed to be minimal.
(c) Mechnaical control not pratcical with present equipment (but see text re flail mowers).

Source: As described in text.

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Chemical Control

Definition

Chemical control includes all control techniques involving the use of chemical agents (herbicides) to kill M. pigra. As chemical control is still largely experimental, much of the data presented here is of a preliminary nature.

Herbicides

Various herbicides have been tested in Thailand and other countries for efficacy in controlling M. pigra. Herbicides which have shown good results include 2, 4, 5-T, dicamba, fosamine and glyphosate.

2, 4, 5-T. Of the four chemicals listed above, 2, 4, 5-T appears to be potentially one of the most effective. In experiments conducted in Mexico infestations of M. pigra to be treated with the herbicide were first burned. Forty-five to sixty days after burning the areas were sprayed with a one percent solution of Esteron 2, 4, 5-T. Twelve months after treatment the level of control was 96% and 98% for areas sprayed forty-five and sixty days after burning respectively.[1] At the present time 2, 4, 5-T is not available for use in Thailand as there is some question about its toxicity to humans.

Dicamba. Dicamba, an auxinic herbicide,[2] is a benzoic acid (2-methyoxy-3, 6-dichlorobenzoic acid)[3] which acts mainly by foliage translocation.[4] It is a

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[1] "Mexican Agricultural Program," in Rockefeller Foundation Annual Report 1959-60 (New York: Rockefeller Foundation, 1960), p. 86.

[2] P. W. Morgan, "Effects of Ethylene Physiology," Herbicides - Physiology, Biochemistry, Ecology, Second Edition, Vol. I, L. J. Audus, ed. (London: Academic Press, 1976), p. 264.

[3] R. C. Brian, "The History and Classification of Herbicides," Herbicides - Physiology, Biochemistry, Ecology, Second Edition, Vol. I, L. J. Audus, ed. (London: Academic Press, 1976), p. 264.

[4] J. P. Shildrick, et. al., "The Principles of Weed Control in Sports Turf and Lawns," Weed Control Handbook, Vol. I Principles, Sixth Edition, J. D. Fryer and R. J. Makepeace, eds. (Oxford: Blackwell Scientific Publications, 1977), p. 13.012.

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selective post-emergent herbicide, commonly used for control of docks in established grassland and for control of bracken.[1]

Introduced by the Vesicol Chemical Corporation (U.S.) in 1965, dicamba is a relatively safe herbicide: the acute oral LD_{50} for rats is 2,900 ÷ 800 mg./kg., the LC_{50} for rainbow trout is 23 mg./l. (96 hours) and for small carp 465 mg./l. (48 hours). It is rapidly degraded in soil: in one test none of the chemical could be detected 300 days after application of 6.7 kg. per hectare. This chemical metabolizes in plants to the herbicidally inactive 2,5-dichloro-3-hydroxy-6 methoxy zybenzoic acid.[2]

In experimental spraying trials performed in the Chiang Mai Valley virtual 100% kill of M. pigra was achieved using a 2,400 ppm solution of dicamba in water and applying approximately 2.5 liters of herbicide per rai. After forty-five days trees averaging over two meters tall were defoliated; branches and trunks were desicated.[3]

The speed with which a herbicide kills the entire M. pigra plant is an important factor in evaluating chemical control agents. When the weed becomes defoliated, which usually occurs within a few weeks of herbicide application, the long thorns (which are an integral part of the leaves) drop off. Without its thorns, the plant's value as firewood rises greatly. Defoliated trees are quickly cut down for use as fuel. If the trees are cut before the root system has had sufficient time to absorb a lethal dose of herbicide, regrowth will occur. Thus the more quickly a herbicide kills the entire plant the more complete control will be. Preventing cutting of defoliated M. pigra for extended periods is not feasible.

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[1] Brian, op. cit. p. 7.

[2] Charles R. Worthing, ed., The Pesticide Manual - A World Compendium (Nottingham, England: The Boots Company, Ltd. 1979), p. 165.

[3] Experiments conducted by Pornphot Srimahachota, Farm Manager, Pornpattana Agriculture Company, in August, 1981. Interview with Pornphot Srimahachota, December 11, 1981.

The price of dicamba in Thailand has not yet been established, but it is expected to be about ฿ 300 per liter.[1]

Fosamine. Fosamine-amonium, an ammonium salt of fosamine (ethyl hydrogen (amoniocarbonyl) phosphate), was introduced by the DuPont Company in 1974 under the trade name Krenite.[2] It is a translocating herbicide effective against many species of woody plants. It does not harm crops or other non-woody plants.

Fosamine rapidly decomposes in soil and may be used on land adjacent to water supplies. It is toxicologically quite safe: the acute oral LD_{50} for the formulated product is 24,000 mg./kg. for rats. The LC_{50} for rainbow trout is greater than 1,000 mg/.l. (96 hours) and for bluegill 670 mg./l. (96 hours).[3]

In experimental trials conducted in the Chiang Mai Valley by the Royal Irrigation Department in 1980 and observed by author, good control of M. pigra was obtained for all plants which were thoroughly sprayed with the chemical. Trees thoroughly covered were completely defoliated within two weeks. Main branches and trunks gradually died, becoming completely dessicated approximately four to five months after spraying. There was apparently little or no translocation of the herbicide outward to unsprayed portions of the plants. If a single branch of a tree was left unsprayed the tree itself usually did not die but rather grew new branches replacing the ones killed by the herbicide. This regrowth began approximately six to eight months after the initial spraying.

The 1980 price of Krenite-S (Krenite with the required quantity of surficant premixed in the formulation) was ฿ 244 per liter.

Glyphosate. Introduced by the Monsanto Company in 1971, the herbicide glyphosate mono (isopropylamine) salt is marketed under the trade name Roundup. It is a non-selective, post-emergent herbicide effective against deep rooted perennials as well as annual and biennial species of grasses, sedges and broadleaf weeds.

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[1] Interview with Pornphot Srimahachota, Farm Manager, Phornpattana Agriculture Company, Chiang Mai, November 1, 1981.

[2] Worthing, op. cit., p. 286.

[3] Ibid.

The acute oral LD_{50} of glyphosate for rats is 4,320 mg./kg.[1] It is non-residual, being completely degraded within a month principally by microorganisms taking it to CO_2, the phosphate moiety being strongly adsorbed to the clay minerals in the soil.[2]

In experiments conducted by the Royal Irrigation Department in 1981 control effectiveness of glyphosate in controlling M. pigra was virtually identical to that of fosamine: rapid defoliation was followed by slow dessication of branches and stems of all thoroughly sprayed trees. However, in the case of glyphosate, all vegetation contacted by the herbicide was also killed along with the M. pigra. Thus glyphosate is suitable as a M. pigra control agent only in areas where complete elimination of all vegetation is not undesirable. The 1980 price of Roundup was ฿ 360 per liter.

Application Methods

Ground Spraying. Ground spraying includes all herbicide application methods which do not involve the use of aircraft. There are two main types of ground spraying equipment available: small knapsack sprayers pumped by hand and larger, motor driven high presure sprayers. Use of both types is discussed below.

Knapsack Sprayers. Knapsack sprayers, with their easy portability and relatively low cost are ideally suited for controlling infestations along traditional irrigation systems. In these areas the short spray range of the knapsack sprayers is not a disadvantage as infestations seldom exceed two meters in depth, the practical limit for this type of equipment used against M. pigra.

High Pressure Sprayers. For infestations along roads, along RID irrigation canals and along rivers high pressure sprayers are most suitable. In these areas the breadth and depth of the infestations require the additional spraying range of high pressure equipment. For roads and RID canals, a high pressure unit mounted on a truck could easily access most M. pigra infestations in those locations by driving

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[1] Worthing, op. cit., p. 292.

[2] A. W. Brown, Ecology of Pesticides (New York: John Wiley and Sons, 1978) p. 381.

along existing roads. If the spraying equipment were mounted on a boat or an all-terain vehicle most infestations along rivers could be accessed. Aerial spray would not be satisfactory in these areas as damage to desirable vegetation would result due to the relatively wide spray pattern.

Aerial Spraying. For controlling M. pigra in reservoirs such as Kew Lom the use of aerial spraying techniques is necessary due to the vast areas involved. In tests of herbicide application conducted by the RID, helicopters have proven to be more efficatious than fixed wing aircraft as the former can fly lower and slower thus obtaining more thorough coverage with a lower spray volume.

Cut, Burn, Spray. For areas where cutting M. pigra is practical and where burning of the infested area can be done safely, a combination of cutting, burning and spraying (using whichever application method is most appropriate) would appear to be a viable alternative to spraying alone. The method consists of cutting down the M. pigra then burning the area to be controlled. Forty-five to sixty days after burning herbicide is applied to the regrowth and new sprouts. There are two advantages to this system: first, the initial cutting followed by a short period of regrowth means that the leaf area of M. pigra to be sprayed will be reduced so less chemical will be required. Second, the burning causes large numbers of M. pigra seeds already in the ground to germinate. Thus in subsequent years, barring the introduction of new seeds, the number of M. pigra plants sprouting will be diminished. This method has not yet been tested in Thailand; hence, due to lack of data on the degree of efficacy of this method it cannot be evaluated economically at the time.

Costs of Chemical Control

In computing the cost of chemical control, for exposition purposes in this report the cost of herbicide is set at ฿ 300 per liter which approximates the average price of chemicals tested.

Herbicide application would have to be repeated periodically if control of M. pigra in a given area is to be maintained. This continuing control effort is necessary for two reasons: first, trees in areas where the weed is not controlled would continue to produce new seeds. These new seeds could be transported to areas where the weed is being controlled. Second, as M. pigra seeds maintain their viability for very long periods of time, seeds already in the soil in controlled areas would continue to germinate for an unknown number of years.

How frequently spraying of an area would have to be repeated to maintain control has not yet been determined as the amount of new growth from seed that would occur in a given period of time is unknown. For exposition purposes it is estimated that one annual spraying would be sufficient. It is expected that the

cost of herbicide application would decrease for second and subsequent sprayings of the same area as new M. pigra trees sprouting after the initial spraying would be relatively smaller in height and fewer in number than the initial infestaiton.

The ideal rate of application for herbicides has not yet been determined definitively. For exposition purposes it is estimated that a rate of 2.5 liters per rai would be sufficient.

Also for exposition purposes and not based on actual measured results, it is estimated that the cost of the second year of chemical control in an area would be approximately 20% of the first year cost. For the third through tenth years the cost is estimated to be 10% of the first year cost. It is felt that extrapolation of costs beyond ten years would not be meaningful due to the lack of actual cost data.

Along Roads. The only method of herbicide application suitable for use along roads is high pressure spraying. Kanpsack sprayers don't have sufficient range to be satisfactory and aerial spraying would result in destruction of desirable roadside trees.

The 1980 cost of controlling the weed using high pressure spraying equipment is estimated to be ฿ 1,105 per rai for the first year. This cost includes chemicals, labor and equipment.[1] The second year cost would be 20% of that figure or ฿ 221 per rai. For the third and subsequent years the cost is estimated to be 10% of the initial cost or ฿ 110.5 per rai. Thus for the 5,116 rai along roads which are infested with M. pigra the first year total cost of chemical control would be ฿ 5,653,180, reducing to ฿ 1,130,636 the second year and to ฿ 565,318 the third and subsequent years.

Inland Areas. Agricultural Land. Chemical control is not practical for controlling M. pigra in agricultural areas. Farmers' planting schedules cannot accomodate delays of serveral weeks or even months while herbicides kill the weeds growing in their fields.

Non-agricultural Land. Chemical control of the weed could be accomplished in non-agricultural areas using high pressure equipment. Cost per rai would

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[1]Based on Cost of Control of Giant Mimosa, paper presented by Pornphot Srimahachota at the 16-18 December 1981 National Seminar on Mimosa pigra (Chaing Mai: The Conference, 1981), no pp. Price is for control of relatively narrow infestations with one inch average stem diameter. Price discounted to 1980 level.

average about ฿ 1,870 per rai.[1] However, in most instances M. pigra would be controlled in non-agricultural land because construction was to commence the site. Delaying further construction activity for a period of months while the herbicide took effect would normally not be practical.

Irrigation Systems. Royal Irrigation Department Systems. Using high pressure equipment, M. pigra along RID canals could be controlled for about the same cost as that along roads, i.e., ฿ 1,105 per rai the first year, ฿ 221 per rai the second year and ฿ 110.5 per rai the third and subsequent years. Thus the total first year cost of controlling M. pigra on the 1,996 infested rai would be ฿ 2,205,580; the second year cost would be ฿ 441,116; and for the third and subsequent years, ฿ 220,558. As along roads, knapsack sprayers lack sufficient range and aerial spraying would kill desirable vegetation so neither of those methods would be suitable.

Traditional Systems. Knapsack sprayers are most appropriate for controlling the weed along traditional irrigation systems. In these areas infestations are less dense than along RID canals, making high pressure equipment unnecessary. In addition, many traditional irrigation canals are not accessible by vehicle, so transportaton of the high pressure gear to the site of infestations would be difficult.

Knapsack sprayers cost approximately ฿ 0.45 per hour of operation (equipment only). It is estimated that a farmer can spray one half kilometer of M. pigra along traditional irrigation canals per hour. Thus the equipment cost is ฿ 0.90 per kilometer.[2] Using an imputed wage rate of ฿ 5 per hour, the total first year cost of M. pigra control in traditional irrigation systems is ฿ 11 per kilometer exclusive of chemicals.

An application rate of 2.5 liters per rai translates into 3.125 liters per kilometer of traditional canal (computed on the basis of a one meter deep infestation on each bank). Cost per kilometer would be ฿ 10.9 for equipment and labor plus B 938 for herbicide for a total first year cost of ฿ 949. This would reduce to

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[1] Ibid. Price is for control of infestations of medium density and 1.5 inch average stem diameter. Price discounted to 1980 level.

[2] Interview with Tavatchai Radanachaless, Agronomy Department, Faculty of Agriculture, Chiang Mai University, November 13, 1981.

฿ 190 per kilometer the second year and to ฿ 95 the third and subsequent years. The total cost of control along the estimated 2,446 infested kilometers of canals is thus ฿ 2,321,254 for the first year, ฿ 464,250 for the second year and ฿ 232,125 for the third and subsequent years.

Rivers. As with roads and RID canals, knapsack sprayers do not have sufficient range for control along rivers, and aerial spraying would destroy desirable vegetation. Thus high pressure spraying is the only effective herbicide application technique available. Because the equipment would have to be mounted on a boat or an all-terrain type vehicle rather than a relatively inexpensive truck, the cost of labor and materials is estimated to be much higher than that for spraying along roads and RID canals: approximately ฿ 2,890 per rai for the first year, ฿ 578 for the second year and ฿ 289 for the third and subsequent years.[1]

Reservoirs. The only way to control M. pigra in reservoirs which are already heavily infested such as Kew Lom is aerial spraying. The area involved is just too large to be effectively covered using high pressure sprayers.

The cost of aerial spraying using a Hiller 124E4 nelicopter depends on the total amount of solution (herbicide plus water) sprayed per rai. The cost at an application rate of 20 liters of solution per rai is ฿ 26, whereas if 40 liters per rai are applied the cost is ฿ 44.5 [2] or an average of approximately ฿ 35 per rai. Assuming a herbicide application rate of 2.5 liters per rai and a cost of ฿ 300 per liter of herbicide, the total cost of aerial application the first year would be ฿ 785 per rai. This would reduce to ฿ 157 per rai the second year and to ฿ 78.5 the third and subsequent years. Thus the total cost for controlling the 5,000 rai of M. pigra in the Kew Lom Reservoir would be ฿ 3,925,000 the first year, ฿ 785,000 the second year and ฿ 392,500 the third and subsequent years.

Summary of Chemical Control Costs

Costs of chemical control of M. pira are summarized in Table 10-2. It should

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[1] Based on Cost of Contral of Giant Mimosa, paper presented by Pornphot Srimahachota, op. cit. Price is for control of very dense infestations with two inch average stem diameter. Price discounted to 1980 level.

[2] Paisan Ratanasatiyon, ed., Chemical Control of Mimosa by Aerial Application (Bangkok: Chemical Weed Control Branch. Entomology and Zoology Division, Agricultural Technology Department, undated [1981] in Thai, p. 18.

Table 10-2. Direct Costs of Chemical Control of M. pigra

Area	Per unit cost of control[a] (Baht	Total cost of control[a] (Baht)
Along Roads	1,105/rai	5,653,180
Inland Areas		
Agricultural land	(b)	(b)
Non-agricultural land	1,870/rai	(c)
Irrigation Systems		
RID Systems	1,105/rai	2,205,580
Traditional Systems	949/linear kilometer	2,321,254
Rivers[d]	2,890/rai	339,456,510
Reservoirs[e]	785/rai	3,925,000

Notes:
(a) Figures are estimated cost of first year of control. Cost of second year of control is estimated to be 20% of first year cost. Third and subsequent years estimated to be 10% of first year costs.
(b) Value not calculated - chemical control generally impractical in these areas.
(c) Value not calculated - control not generally recommended.
(d) Figures are for the 93 kilometers of the Ping River in the Chiang Mai Valley.
(e) Figures are for the Kew Lom Reservoir.

Source: As described in text.

be noted that chemical control cost data is based on extrapolation of very minimal experimental data.

Biological Control

Biological control is defined as "the action of parasites, predators and pathogens in maintaining another organism's density at a lower level than would occur in their absence."[1] Because M. pigra is an exotic (introduced) species in Thailand, however, the natural parasites, predators and pathogens which keep it largely in check in its native habitat are absent. Thus in terms of controlling the weed in Thailand, biological control means the introduction of another exotic organism (or organisms) into that country which either kills, prevents the reproduction of or otherwise reduces the population of M. pigra.

To be acceptable as a biological control agent, the organism, as well as being efficacious in controlling M. pigra, would also have to be species specific. That is, it would have to have a deleterious effect on M. pigra without causing damage to any other desirable species.

The Commonwealth Scientific and Industrial Research Organization (CSRIO) of Australia has fielded a team of scientists in South America to seek just such a biological agent. As of this publication, the team has identified several likely prospects. (Figure 10-3) Determining whether any of these insects are in fact suitable will require additional research and testing for species specificity. Should a species-specific biological control agent be identified, the degree of control that it would be capable of and the speed with which it would attain that level of control is dependent on the nature of the agent and cannot be estimated at this time.

Costs of Biological Control. The cost of biological control will be determined by the nature of the control agent. However, to provide a very rough esti-

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[1]George W. Cox and Michael D. Atkins, Agricultural Ecology - An Analysis of World Food Production Systems (San Francisco: W. H. Freeman and Company, 1979), p. 466.

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mate of the probable cost range, the costs of controlling Pistia stratiotes in Thailand is cited. The average cost of raising and releasing an insect control agent over a 3.5 square kilometer area was ฿ 13.8 per rai.[1]

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[1]Interview with Banpot Napompeth, Director, National Biological Control Reasearch Center, Kasetsart University, Bangkok, December 29, 1981.

Taxonomy	Part of plant attacked: By immature stages	Part of plant attacked: By adults
COLEOPTERA		
Bruchidae		
Acanthoscelides pigricola Kingsolver	Seeds	——
A. Quadridentatus (Schaeffer)	Seeds	——
Chrysomelidae		
Chlamis sp. nr. sidae Monros	Foliage/Stems	Foliage/Stems
Chlamis sp. nr. spinosa Kollar	Foliage/Stems	Foliage/Stems
Cryptocephalinae		
Cryptocephalus sp. nr. Miserabilis Suffarin	Foliage	Foliage
Halticinae		
Syphraea flavipes Jacoby	Roots	Foliage

Figure 10-1. Potential Biological Control Agents for M. pigra

Source: K. L. S. Harley, et. al., Prospects for Biological Control of Mimosa pigra in Australia Paper presented at the International Symposium on Mimosa pigra Management, Chiang Mai, Thailand, February 22 to 26, 1982 (Chiang Mai: The Symposium 1982), pp. 17-18.

PART IV

CONCLUSIONS AND RECOMMENDATIONS

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Chapter 11. CONCLUSIONS AND RECOMMENDATIONS

Conclusions

Analysis

For each category of area infested with M. pigra as described in this report there are two questions to be answered: what is the least expensive means of controlling M. pigra in that area and what are the economic returns to investment in control in that area. The following analysis provides the answers to those questions. Economic analysis is conducted for each area for a ten year period. It is felt that extrapolation of benefits and costs of control beyond a period of ten years would be of limited value due to probable future structural changes in the economy of the region and changes in costs of M. pigra control, e.g., development of new herbicides and/or new application methods. As there are as yet no proven biological control agents available, that method of control is excluded from the analysis.

Along Roads. Method of Control. In areas along roads, the areas adjacent to roads which are maintained by highway department crews, M. pigra can be controlled by two means: mechanical or chemical. To compare the cost of these two means it is necessary to take account of the differences in value of early versus later costs by discounting those costs. The discount rate used in this analysis is 15%. The discounted cost (present value) of chemical control for a ten year period is ฿ 1,503 per rai versus ฿ 1,205 for mechanical control. (Appendix 2) It should be noted here again for emphasis that mechanical and chemical control cost figures used are the additional costs due to M. pigra and not the total cost of vegetation control along roads.

The discounted costs indicate that mechanical control is 20% less expensive than chemical control. However, as noted in Chapter 10, chemical control cost estimates are based on extrapolation of very preliminary cost data so a difference of only 20% is well within the margin of error. Thus until further data becomes available on the costs (and results) of chemical control it is not possible to state definitively whether chemical or mechnical control is the less expensive method for use along roads.

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Economic Returns to Control.. The returns to investment in control of M. pigra along roads, if benefits in terms of traffic safety are excluded, are negative, i.e., the costs of control exceed the benefits each year. The annual direct cost of control (฿ 1,227,840) plus the opportunity costs of firewood foregone (฿ 644,028) total ฿ 1,871,868 which is greater than the economic benefits which are only ฿ 516,333. This would seem to indicate that control of M. pigra along roads is not indicated. However, for reasons of traffic safety as well as other non-economic reasons, control of vegetation (and hence of M. pigra) along roads is required by government directive. Thus even though economic returns to investment in control are negative, the weed should be controlled along roads.

Agricultural Land. Cost of Control. In agricultural land, i.e., inland areas currently under cultivation or used primarily for raising livestock, current agricultural practices effectively control the weed at virtually no additional cost as described in Chapters 5 and 10. Thus there is no requirement for an M. pigra control program per se using either mechanical of chemical methods.

Economic Returns to Control. As there are neither significant economic benefits nor opportunity costs associated with control of M. pigra in agricultural land, the economic returns to a specific program designed to control M. pigra in agricultural land would be nil.

Non-agricultural Land. Method of Control. Non-agricultural land is defined as land which has never been cultivated as well as land that has been more or less permanently taken out of cultivation. In these areas M. pigra could be controlled either mechanically or chemically. Using the same discounting proceedures described in the section "Along Roads" above, the discounted cost (present value) of both methods was computed. (Appendix 3) The difference in cost between mechanical and chemical control discounted over a ten year period is only B 135 per rai or approximately five percent. As was the case with control along roads, due to the relative uncertainty of chemical control costs, with only a five percent margin of difference it is not possible to state definitively at this time whether chemical or mechnical control is the less expensive in non-agricultural land.

Economic Returns to Control. In non-agricultural land there are no economically significant benefits to controlling M. pigra. There are, however, quite significant opportunity costs. In the Chiang Mai Valley, M. pigra firewood valued at ฿ 1,834,688 is harvested each year (approximately ฿ 216 per infested rai). Thus the economic returns to control of the weed would be entirely negative: the annual cost of control would be ฿ 480 per rai per year direct control cost (mechanical control) plus ฿ 216 per rai opportunity cost for a total of ฿ 969. This is the value of the annual net loss per rai which would accure to a program of M. pigra control in non-agricultural land. The total loss if all 11,250 infested rai were controlled would be ฿ 10,901,250 per year.

Irrigation Systems. Royal Irrigation Department Systems - Method of Control. As described in Chapter 10, the costs of mechanical and chemical control of M. pigra in RID systems is virtually identical to the costs of control along roads Thus as shown in Appendix 2 mechanical control is calculated to be 20% less expensive than chemical control over a ten year period. However, a difference of only 20% is, as noted, well within the margin of error in computing chemical costs. Thus until further data becomes available, it is not possible to state definitively whether chemical or mechanical control is the less expensive method for use in RID systems.

Traditional Irrigation Systems - Method of Control. By inspection chemical control can be seen to be less expensive than mechnical control in traditional irrigation systems. The first year cost per linear kilometer of chemical control is ฿ 949 which reduces to ฿ 189.8 the second year and to ฿ 94.9 the third and subsequent years. The per kilometer cost of mechanical control is ฿ 2,493, more than twice the first year chemical control cost. The discounted costs of control over a ten year period points up the disparity dramatically: for mechanical control to be the less expensive method, actual chemical control costs would have to exceed estimates in this report by approximately 865%, an unlikely occurance. (Appendix 4)

Economic Returns to Control. As noted in Chapter 6, the benefits of controlling M. pigra in RID systems and traditional systems cannot be separated. Thus evaluation of economic returns to control of the weed must consider the two types of systems as a unit, comparing the sum of the costs of control in both types of systems with the benefits of irrigation. As mechanical control is marginally the less expensive method in RID systems based on available data and chemical control is the least expensive in traditional systems, the costs of those methods will be used in the evaluation of economic returns.

The direct costs of control the first year are ฿ 479,040 (RID) plus ฿ 2,321,254 (traditional) for a total of ฿ 2,800,294. That figure represents the total cost of control as there are no opportunity costs incurred if M. pigra is controlled in irrigation systems. Benefits each year amount to ฿ 480,746,711.

Computation of an internal rate of return is not possible for irrigation systems as in every year benefits of control exceed costs. A benefit/cost ratio was computed, however, using a discount rate of 30%.(Appendix 4) The benefit/cost ratio at that discount rate computed over a ten year period is 377. A ratio that high is generally considered to be "off the scale" in economic analysis: the economic rate of return to investment in control of M. pigra in irrigation systems is extremely high.

Rivers

Method of Control. As noted in Chapter 10, the only feasible method of controlling M. pigra in rivers is chemical control using high presure spraying equipment.

Economic Returns to Control. Along the 93 kilometers of the Ping River used in this study the cost of control exceeds the value of benefits, exclusive of benefits in terms of reduced rate of colonization of currently uninfested areas. Even in the third and subsequent years of control, when the cost of control is at its lowest value, the direct control costs are ฿ 33,945,651 per year and the opportunity costs are ฿ 8,276,024 for a total cost of ฿ 42,221,675. Benefits each year total only ฿ 19,559,007. Thus the economic returns to control along rivers hinge on the value of the rate of colonization factor - the value of slowing the rate of spread of M. pigra to currently unifested areas.

To provide an indication of the order of magnitude of the situation, to obtain an internal rate of return of 27% the value of benefits in terms of reduced colonization would have to total ฿ 100,000,000 annually, more than five times the value of all other benefits combined. (Appendix 5) Thus the economic returns to control of M. pigra in rivers is negative unless reduced colonization benefits are substantial. Computation of the value of benefits in terms of rate of colonization, as noted in Chapter 7, is beyond the scope of this study. However, it is estimated that reducing the rate of colonization into currently uninfested areas is probably the single most significant economic benefit to controlling the weed along rivers. It is further estimated that the economic returns to control in terms of reduced colonization in infested segments of rivers which are immediately upstream from uninfested segments would be quite high. As noted below, additional research is needed to determine the rate and location of spread of M. pigra infestations, information that would assist in ascertaining where the highest returns to control along rivers would occur.

Reservoirs

Method of Control. Aerial application of herbicides is the only feasible method of controlling M. pigra in heavily infested reservoirs such as Kew Lom.

Economic Returns to Control. As benefits of control over the ten year evaluation period exceed costs each year, computation of an internal rate of return to M. pigra control in reservoirs is not possible. However, using a discount rate of 30% a benefit cost ratio of 39 is obtained. (Appendix 6) Although not "off the

Summary of Economic Returns to Control

Economic returns to investment in control of M. pigra in irrigation systems and reservoirs are very high. Economic returns along roads are negative, but overriding non-economic factors (particularly safety considerations) make control mandatory. In agricultural land normal farming activities effectively control the weed: there would be virtually no benefits to a project directed specifically at M. pigra control, only costs, so economic returns to control would be highly negative. In non-agricultural land economic returns to control would be highly negative: opportunity costs as well as direct control costs would be incurred and no benefits would be forthcoming. The possible exception to the above would be if M. pigra is proven to be a significant alternate host for crop destroying insects. In that event control of the weed in non-agricultural land and along roads could result in positive economic returns. In rivers economic returns to control are variable, hinging on the value of reducing the rate of colonization of currently uninfested areas. Economic returns are highly positive along river segments immediately upstream from currently uninfested areas. In river segments far from uninfested areas, where colonization would not be a factor, economic returns to control are negative.

Recommendations

Recommendations on M. pigra Control

Recommendations on controlling M. pigra are as follows:

1) Continue government control efforts along roads. Use either mechanical or chemical control means until more complete data become available on costs of chemical control.

2) No specific program should be implemented to control M. pigra in agricultural land to supplement the control obtained by current farming pracitices.

3) No government effort should be made to control M. pigra in non-agricultural land unless the weed is proven to be a significant alternate host for crop-destroying insects. If control is necessary, either mechanical or chemical means should be used until more complete data become available on costs of chemical control.

4) Continue government control efforts in Royal Irrigation Department irrigation systems. Either mechanical or chemical means should be used until more complete data become available on costs of chemical control.

5) Continue advocating private control in traditional irrigation systems, but recommend switching from mechanical to chemical control.

6) Begin government control efforts in rivers using chemical means. Control should commence at the site of infestations which are immediately upstream from uninfested areas.

7) Begin government control efforts in reservoirs using chemical means.

Recommendations for Further Research

Control Methods. Efforts to evaluate potential herbicides should continue. Longitudinal studies of the results of chemical control in a given location should be accomplished to evaluate the long term degree of control obtained with various chemicals. Costs and results of combination control methods, e.g., cut, burn, spray, should also be researched.

Alternative methods of mechanical control should be investigated. Particularly the feasibility of using flail mowers along roads, RID irrigation canals and along rivers should be evaluated.

The possibility of expanding programs designed to increase public awareness of the severity of problems associated with M. pigra should be investigated, e.g., descriptive posters placed in prominent places in provinces and districts where M. pigra is likely to spread or where it is just beginning to gain a foothold.

The feasibility of implementing laws against large scale sand removal from infested rivers should be evaluated as sand is an important vector in the spread of the weed.

A country-wide survey of the incidence of M. pigra should be accomplished using aerial photography and/or satellite imaging. Repeated periodically, this relatively low cost research could identify trends in spread of the weed and thus suggest where control efforts should be concentrated. This mapping could be supplemented by a village-level M. pigra reporting system whereby farmers in currently uninfested areas would notify authorities of the appearance of new infestations.

Uses. As complete control of M. pigra is not possible in Thailand with existing resources, investigation of potential productive uses of the weed should be encouraged, e.g., use of M. pigra as animal feed.

PLATES

Plate 1. Branches of M. pigra with flowers and seed pods.

Plate 2. Stages of development of M. pigra fruit from buds to mature seeds. Mature seed pods are dark brown.

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Plate 3. A flowering branch of M. pigra.

Plate 4. M. pigra is a prolific seed producer. Mature (dark brown) and immature (light green) seed pods are growing on the same branch.

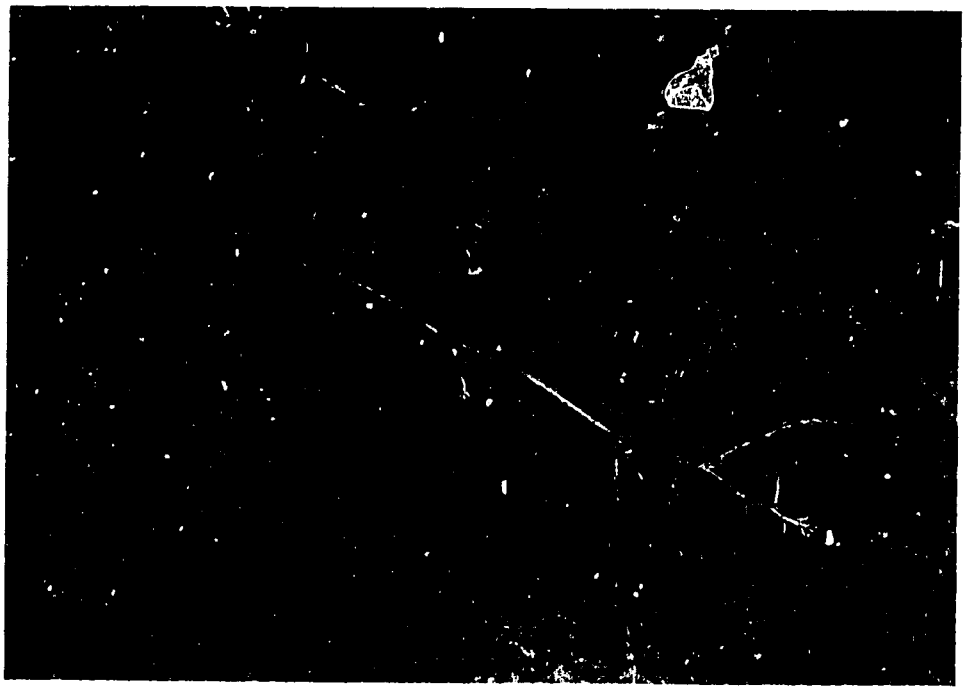

Plate 5. Known as the giant sensitive plant, M. pigra leaflets are normally unfolded.

Plate 6 The same plant with leaves folded after being touched. Leaves also fold each evening, unfurl again at dawn.

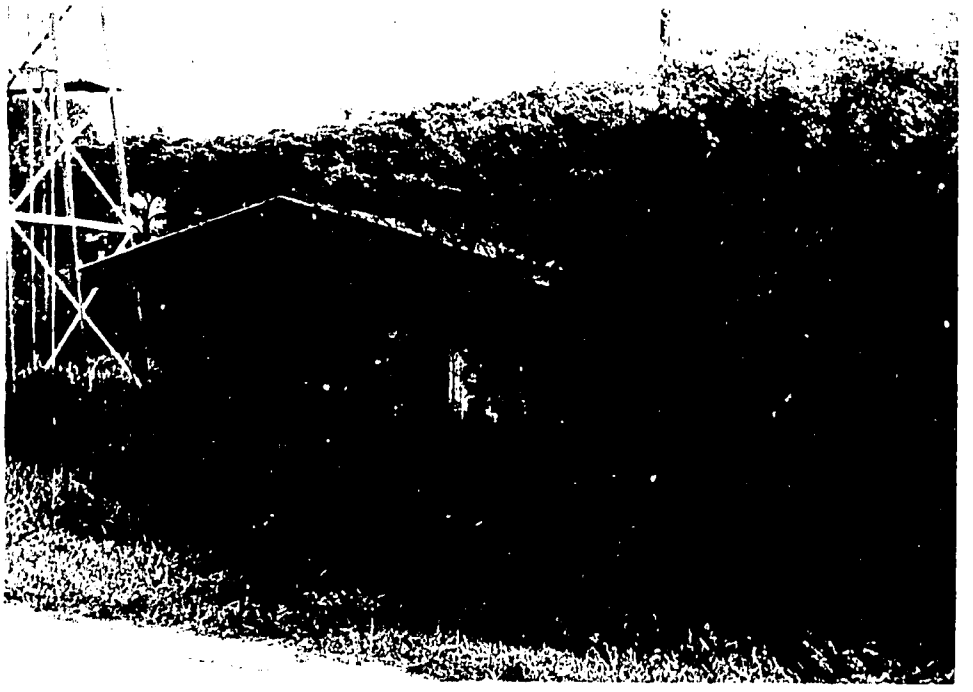

Plate 7. A very fast growing plant, M. pigra on the left side of the building has been cut to ground level. (The green plants on the fence in the left foreground are an unrelated species of vine.)

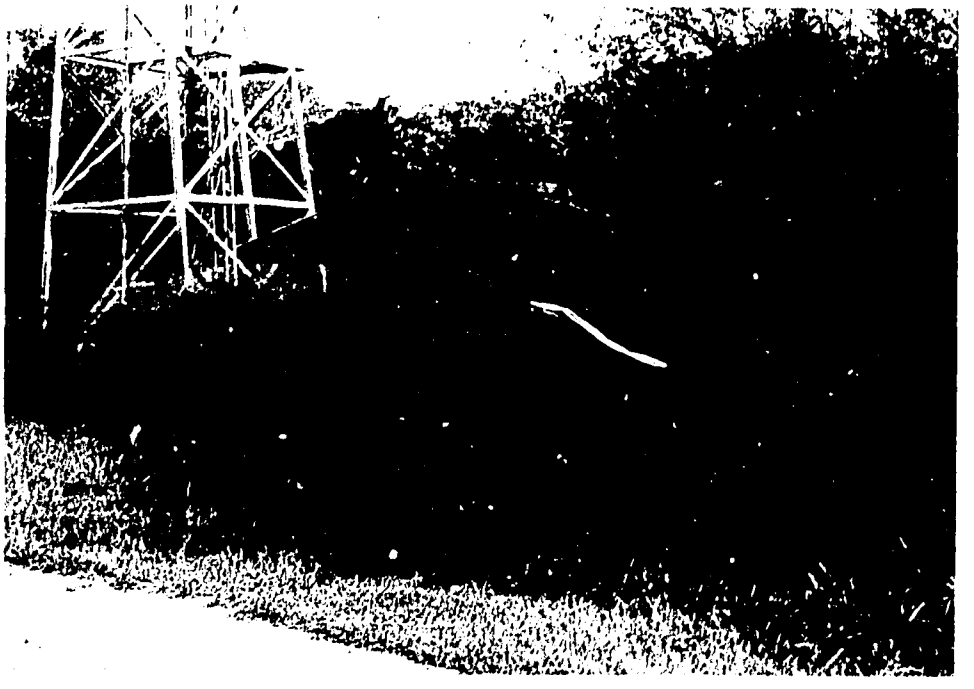

Plate 8. The same building two months later. The M. pigra regrowth is approximately two meters tall.

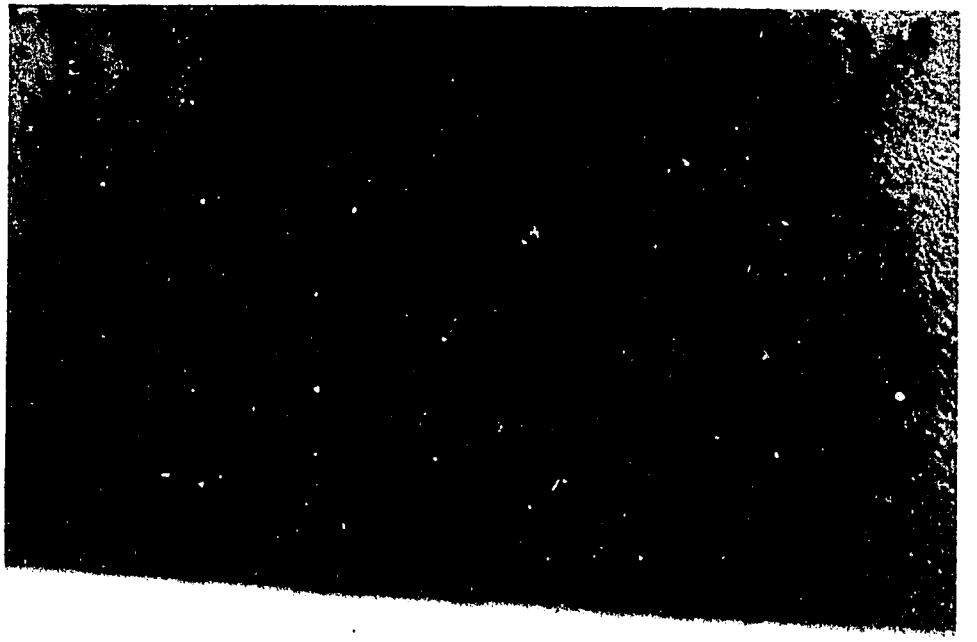

Plate 9. M. pigra is highly flood tollerant. These plants are growing in water nearly two meters deep.

Plate 10. Small scale sand removal from the Ping River. Removing sand containing M. pigra seeds from rivers for use eleswhere increases the rate of colonization.

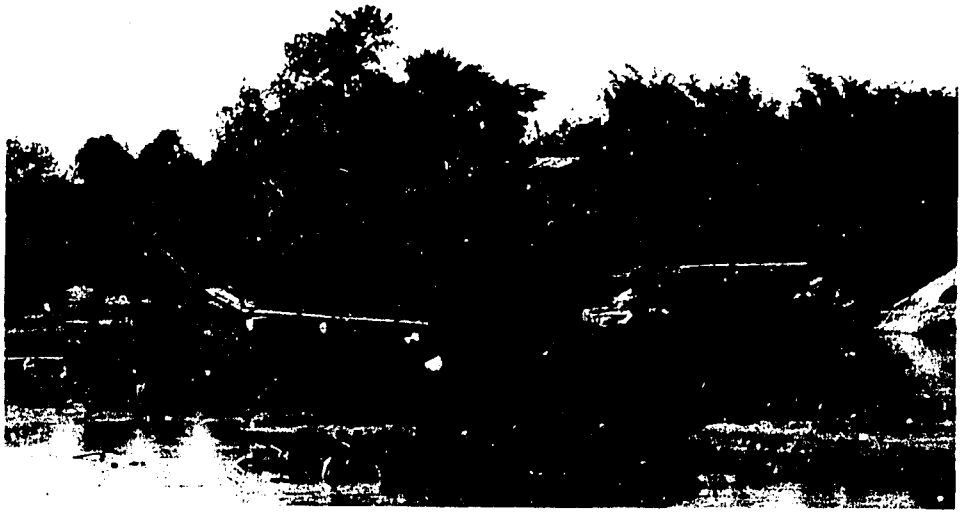

Plate 11. Large scale sand removal from the Ping River using a hydraulic pump.

Plate 12. If allowed to grow uncontrolled along roads M. pigra would create a serious safety problem by obscuring traffic signs and blocking drivers' vision.

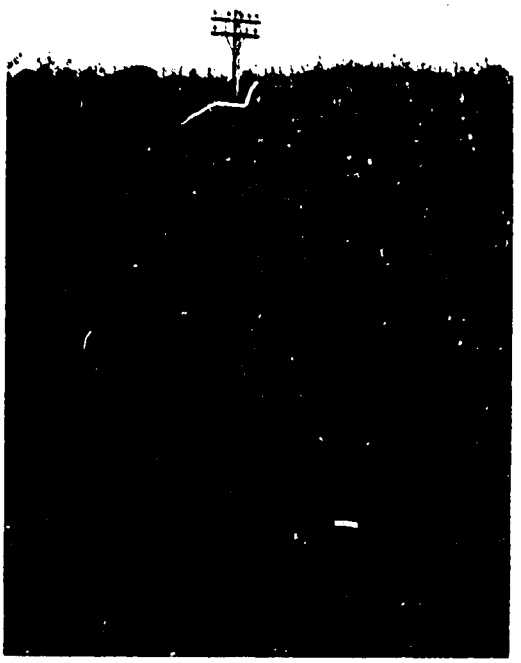

Plate 13. Infestations of M. pigra along roads increases the cost of erection and maintenance of utility poles.

Plate 14. M. pigra is an alternate host for several crop-destroying insects including this species of stink bug.

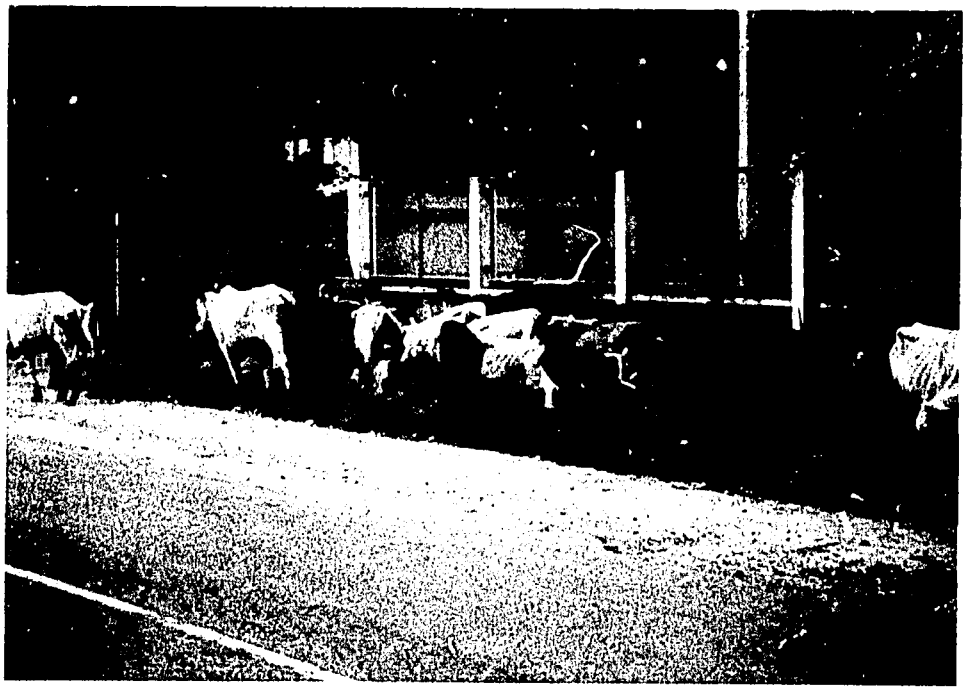

Plate 15. Uncontrolled M. pigra infestations would deny livestock the use of valuable pasture along roads.

Plate 16. In agricultural land M. pigra is not a serious problem. In fields it is seldom able to grow more than a few centimeters high.

Plate 17. The problems created by M. pigra in agricultural land are so inconsequential that these farmers have not even bothered to remove it from a swampy area in the middle of their rice field even though they know the seeds will be dispursed throughout their plot.

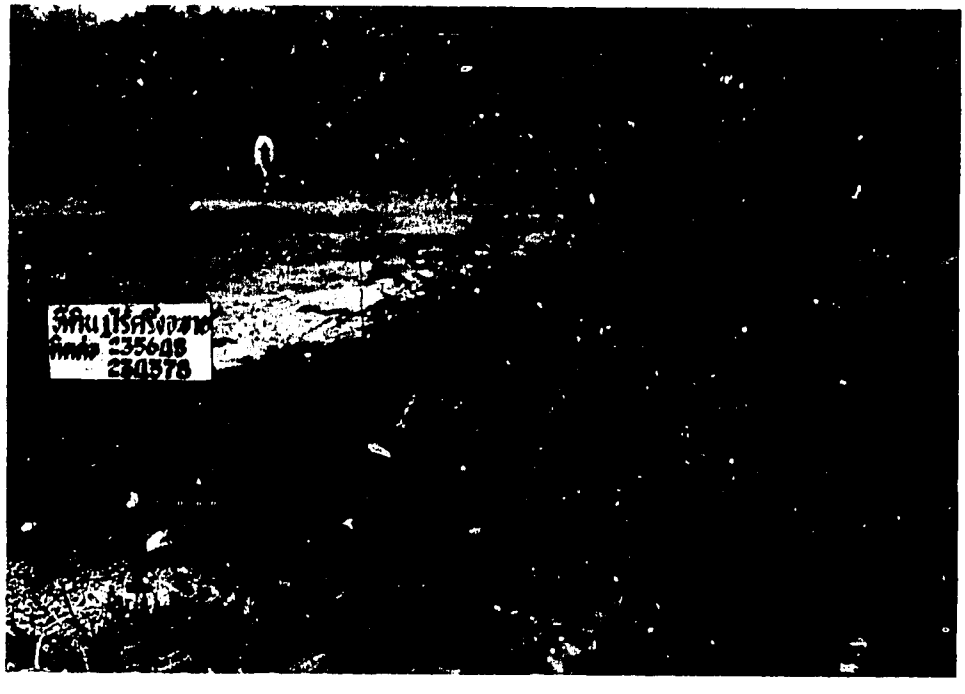

Plate 18. M. pigra frequently grows in non-agricultural land near urban areas. The sign says "Land for Sale."

Plate 19. If left uncontrolled M. pigra would rapidly expand into canals, blocking the flow of irrigation water to farmers' fields.

Plate 20. Uncontrolled M. pigra along the banks of Royal Irrigation Department canals would deny livestock this source of pasture.

Plate 21. M. pigra growing along rivers causes a four fold increase in sedimentation, extending river banks and stabilizing sand bars.

Plate 22. Adventitious roots sprouting from the submerged portions of the trunks of M. pigra plants slow water flow. This is one of the means by which M. pigra increases river and reservoir sedimentation.

Plate 23. This road located on the "outside" (erosion side) of a bend in the Ping River has been washed away due primarily to M. pigra. Infestations of the weed on the "inside" (deposition side) of river bends increase erosion on the opposite bank.

Plate 24. Farmers harvesting peanuts from a river bank plot. M. pigra increases soil preparation and weeding time, decreases yields of river bank agriculture.

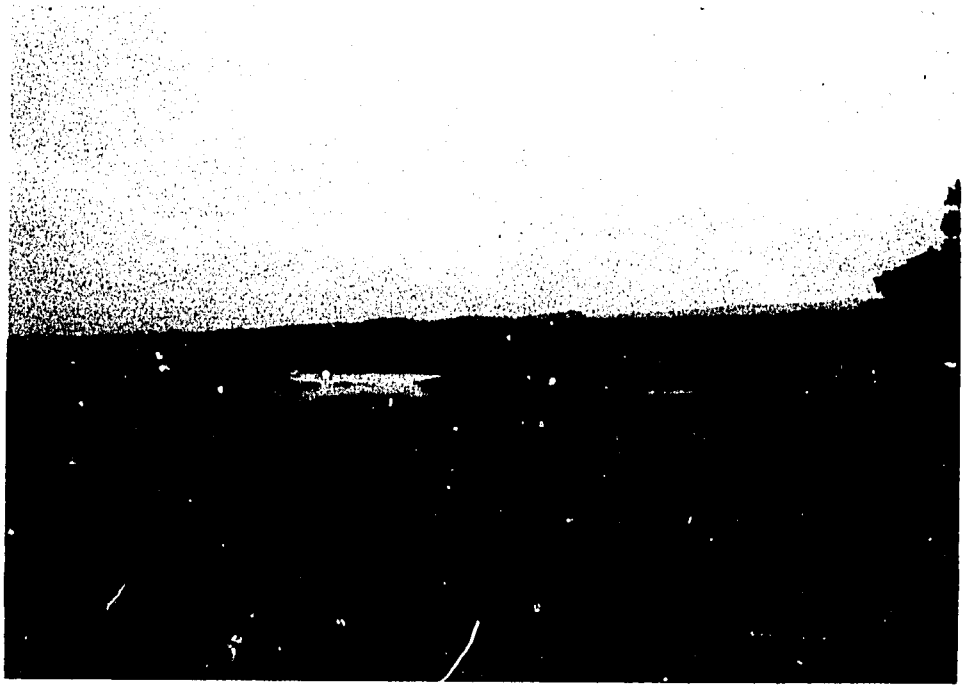

Plate 25. Forty percent of the Kew Lom Reservoir is infested with M. pigra. Eight years ago the area pictured was a wide, open lake.

Plate 26. M. pigra is cut for firewood along rivers and in non-agricultural land.

Plate 27. Where it is particularly abundant some families use exculsively M. pigra firewood.

Plate 28. M. pigra is used to a limited extent for beanpoles instead of bamboo where M. pigra is abundant.

Plate 29. Palatability test. Because M. pigra lacks the amino acid mimosine it is a good potential feed for livestock, particularly ruminants which are able to digest its high fiber content.

Plate 30. M. pigra induced sediment deposited along the Ping River was removed for use as landfill. A by-product of the sediment removal was partial control of the weed.

Plate 31. Application of herbicides using high pressure spraying equipment is an alternative to mechanical control of M. pigra along roads and along Royal Irrigation Deaprtment canals. It is currently the only feasible method of control along rivers.

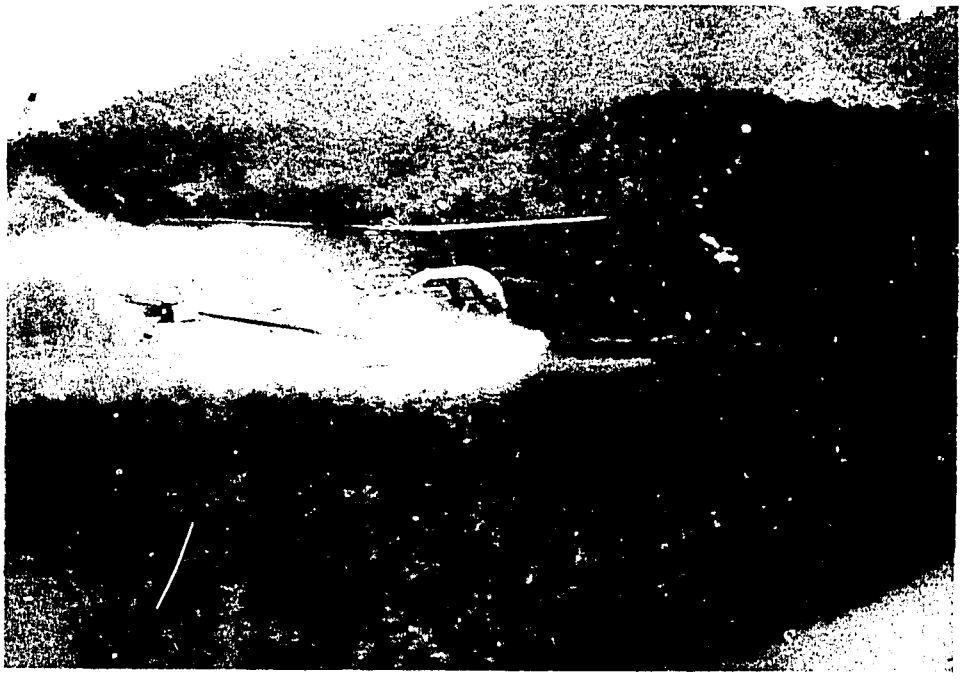

Plate 32. Aerial application of herbicides is the only practical means of controlling M. pigra in reservoirs.

APPENDIXES

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Appendix 1. Incidence of Flooding - Ping River Above Chiang Mai City 1957-1980.

Year	Highest Water Level (Meters Above Sea Level)
1957*	304.61
1958	304.13
1959*	304.49
1960	303.98
1961*	304.51
1962	303.76
1963*	304.65
1964	304.16
1965*	304.76
1966	303.92
1967*	304.62
1968	303.87
1969*	304.51
1970*	304.31
1971*	304.46
1972	303.59
1973*	304.67
1974	304.10
1975*	304.72
1976	303.96
1977*	304.50
1978*	304.48
1979	303.82
1980	304.05

* Water level above flood stage (304.30 meters above sea level)

Source : As described in text.

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Appendix 1. (Cont.)

Calculations

Set A = 1952-1971

$$\bar{X}_A = \frac{\sum X_A}{n_A}$$

$n_A = 15$

$X_A = 4{,}564.74$

$\bar{X}_A = 304.32$

Set B = 1972-1980

$$\bar{X}_B = \frac{\sum X_B}{n_B}$$

$n_B = 9$

$X_B = 2{,}737.89$

$\bar{X}_B = 304.21$

$$\bar{\bar{X}} = \frac{\sum X_A + \sum X_B}{n_A + n_B} = 304.28$$

$$SSA = n_A(\bar{X}_A - \bar{\bar{X}})^2 + n_B(\bar{X}_B - \bar{\bar{X}})^2 = 0.0681$$

$$df_A = k - 1 = 1$$

$$SSW = \sum_A (X_i - \bar{X}_A)^2 + \sum_B (X_i - \bar{X}_B)^2 = 2.7180$$

$$df_W = (n - k) = 22$$

$$\text{Calculated } F = \frac{SSA/df_A}{SSW/df_W} = 0.551214$$

Tabular $F^{0.99}_{22,1} = 7.94$

Appendix 1. (Cont.)

Calc. F $<$ Tab. F: Accept null hypothesis (A and B are subsets of the same group), i.e., there is no statistical difference between them) at the 0.01 level of confidence. This means that the incidence of flooding did not change after the M. pigra infestation occured. Econometric analysis after John Johnoton, Econometric Methods (New York: McGraw - Hill, 1963).

Appendix 2. Disconoted Costs (Present Value) of Mechanical and Chemical Control of M. pigra Along Roads and in Royal Irrigation Department Irrigation Systems

Year	Discount factor (15%)	Annual mechanical control costs per rai (Baht)		Annual Chemical control costs per rai (Baht)	
		Undiscounted	Discounted	Undiscounted	Discounted
1	.870	240	208.8	1,105.0	961.4
2	.756	240	181.4	221.0	167.1
3	.658	240	157.9	110.5	72.7
4	.572	240	137.3	110.5	63.2
5	.497	240	119.3	110.5	54.9
6	.432	240	103.7	110.5	47.7
7	.376	240	90.2	110.5	41.6
8	.327	240	73.5	110.5	36.1
9	.284	240	68.2	110.5	31.4
10	.247	240	59.3	110.5	27.3
TOTAL		2,400	1,204.6	2,210.0	1,503.4

Note: Year end discounting proceedures used.

Source : As described in text.

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Appendix 3. Discounted Costs (Present Value) of Mechanical and Chemical Control of M. pigra in Non-agricultural Land

Year	Discount factor (15%)	Annual mechanical control costs per rai (Baht)		Annual chemical control costs per rai (Baht)	
		Undiscounted	Discounted	Undiscounted	Discounted
1	.870	480	417.6	1,870	1,626.9
2	.756	480	326.8	374	282.7
3	.658	480	315.8	187	123.1
4	.572	480	274.6	187	107.0
5	.497	480	238.6	187	92.9
6	.432	480	207.4	187	80.8
7	.376	480	180.5	187	70.3
8	.327	480	157.0	187	61.2
9	.284	480	136.3	187	53.1
10	.247	480	118.6	187	46.2
TOTAL		4,800	2,409.2	3,740	2,544.2

Note: Year end discounting proceedures used.

Source: As described in text.

Appendix 4. Discounted Costs (Present Value) of Mechanical and Chemical Control of M. pigra in Traditional Irrigation Systems

Year	Discount factor (15%)	Annual mechanical control costs per rai (Baht)		Annual chemical control costs per rai (Baht)	
		Undiscounted	Discounted	Undiscounted	Discounted
1	.870	2,493	2,168.9	949.0	825.6
2	.756	2,493	1,884.7	189.8	143.5
3	.658	2,493	1,640.4	94.9	62.4
4	.572	2,493	1,426.0	94.9	59.3
5	.497	2,493	1,194.1	94.9	47.2
6	.432	2,493	1,077.0	94.9	41.0
7	.376	2,493	937.4	94.9	35.7
8	.327	2,493	815.2	94.9	31.0
9	.284	2,493	708.0	94.9	27.0
10	.247	2,493	615.8	94.9	23.4
TOTAL		24,930	12,467.5	1,518.4	1,291.1

Note: Year end discounting proceedures used.

Source: As described in text.

Appendix 5. Benefit/Cost Batio of Control of M. pigra in Irrigation Systems

Year	1	2	3	4	5
Discount Factor (30%)	.769	.592	.455	.350	.296
Undiscounted costs (Baht)	2,800,294	943,291	711,165	711,165	711,165
Discounted costs (Baht)	2,153,426	558,428	323,580	248,908	191,303
Undiscounted Benefits (Baht)	480,746,711	480,746,711	480,746,711	480,746,711	480,746,711
Discounted Benefits (Baht)	369,694,211	284,602,053	218,739,754	168,261,349	129,320,865

Year	6	7	8	9	10
Discount Factor (30%)	.207	.159	.123	.094	.072
Undiscounted costs (Baht)	711,165	711,165	711,165	711,165	711,165
Discounted costs (Baht)	147,211	113,075	87,473	66,850	51,204
Undiscounted benefits (Baht)	480,746,711	480,746,711	480,746,711	480,746,711	480,746,711
Discounted benefits (Baht)	99,514,569	76,438,727	59,131,845	45,190,191	34,613,763

Appendix 5. (Cont.)

Total discounted costs: ฿ 1,485,507,337

Total discounted benefits: ฿ 3,941,458

$$\text{Benefit/Cost Ratio} = \frac{\text{Total discounted benefits}}{\text{Total discounted costs}}$$

$$= \frac{฿\ 1{,}485{,}507{,}337}{฿\ \ 3{,}941{,}458} = 377$$

Appendix 6. Internal Rate of Return to Control of M. pigra in Rivers.

Year	1	2	3	4	5
Undiscounted costs (Baht)	347,456,510	76,167,326	42,221,675	42,221,675	42,211,675
Undiscounted benefits (Baht)	119,559,007	119,559,007	119,559,007	119,559,007	119,559,007
Net benefits (Baht)	(227,897,503)	43,391,681	77,337,332	77,337,332	77,337,332
Discount Factor (25%)	.800	.640	.512	.410	.328
Discounted benefits (Baht)	(182,318,002)	27,770,676	39,596,714	31,708,306	25,366,645
Discount factor (30%)	.769	.592	.455	.350	.296
Discounted benefits (Baht)	(175,239,338)	25,687,875	35,188,486	27,068,066	20,803,742

Year	6	7	8	9	10
Undiscounted costs (Baht)	42,221,675	42,221,675	42,221,675	42,221,675	42,221,675
Undiscounted benefits (Baht)	119,559,007	119,559,007	119,559,007	119,559,007	119,559,007
Net benefits (Baht)	77,337,332	77,337,332	77,337,332	77,337,332	77,337,332
Disconut factor (25%)	.262	.210	.168	.134	.107
Discounted benefits (Baht)	20,262,381	16,240,840	12,992,672	10,363,202	8,275,095
Discount factor (30%)	.207	.159	.123	.094	.072
Discounted benefits (Baht)	16,008,828	12,296,636	9,512,492	7,269,709	5,568,288

Appendix 6. (Cont.)

Present Value at 25% discount rate: ฿ 10,258,529

Present Value at 30% discount rate: (฿ 15,835,216)

Internal Rate of Return (IRR) Interpolation Formula:

$$\text{Last discount rate which yields a positive present value} + \frac{\text{The present value for the discount rate which yields the lowest positive total present value}}{\text{The sum, without regard to sign, of the above number plus the present value for the discount rate which yielded the first negative total present value}} \times \text{The difference between the two discount rates} = \text{IRR}$$

$$25 + \frac{10{,}258{,}529}{(10{,}258{,}529 + 15{,}835{,}216)} \times (30 - 25) = 26.97$$

Appendix 7. Benefit/Cost Ratio of Control of M. pigra in Reservoirs (Mae Ngat)

Year	1	2	3	4	5
Discount factor (30%)	.769	.592	.455	.350	.269
Undiscounted costs (Baht)	3,925,000	785,000	392,500	392,500	392,500
Discounted costs (Baht)	3,018,325	464,720	178,588	137,375	105,583
Undiscounted benefits (Baht)	16,610,000	33,210,000	49,820,000	62,390,000	82,980,000
Discounted benefits (Baht)	12,733,090	19,660,320	22,668,100	20,900,650	22,321,620

Year	6	7	8	9	10
Discount factor (30%)	.207	.159	.123	.094	.072
Undiscounted costs (Baht)	392,500	392,500	392,500	392,500	392,500
Discunted costs (Baht)	81,248	62,408	48,278	36,895	28,260
Undiscounted benefits (Baht)	99,580,000	116,180,000	132,770,000	149,380,000	165,890,000
Discounted benefits (Baht)	20,613,060	18,472,620	16,330,710	14,041,720	11,950,560

Source: As described in text.

Appendix 7. (Cont.)

Total discounted costs: ฿ 4,161,680

Total discounted benefits: ฿ 163,102,450

$$\text{Benefit/Cost Ratio} = \frac{\text{Total discounted benefits}}{\text{Total discounted costs}}$$

$$= \frac{฿\ 163{,}102{,}450}{฿\ 4{,}161{,}680} = 39$$

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