Biophysical Characteristics of Lands Abandoned after Tin Mining

Bunvong THAIUTSA* and Virat TANPIBAL**

Abstract

Tin mining has been carried out in Thailand for more than five hundred years. The lands abandoned after mining account for a total area of over 70,000 ha, mostly in the South. The study sites of this investigation were located in the Takuapa district of Phangnga province. The original vegetation type consisted of tropical rainforest with an annual rainfall of 3,615mm and 200 rainy days a year. The soil texture was characterized by sandy loam with a pH of 4.7 and 1.52% soil organic matter. Such biophysical characteristics as vegetation, soil, and water associated with the duration of the period after mining were analyzed.

The results showed that plant succession, soil properties, and water quality varied with the years after the land had been abandoned. There were 55 families of 99 species which naturally regenerated on the 1-20 years old mine-spoiled lands originally occupied by moist evergreen forest. Grasses were found to be pioneer species followed by shrubs and trees. Maximum above-ground biomass was recorded in the 20-year-old site (38 ton/ha), while such production was too low to be traced in the first year plot. Both the physical and chemical soil properties were affected by mining, especially the availability of macronutrients due to the sandy soil texture together with the low pH and CEC values. Heavy metal concentration in the water collected from mining ponds with different age classes was also affected by mining, and it tended to decrease with the increase of the age of the mining-ponds. With the exception of Cd and Pb, the concentrations of Cu, Hg, and Zn did not exceed the drinking-water standards set by the MOPH and WHO. However, the consumption of water collected from mining ponds younger than three years old should be avoided. Information gained from these findings is useful for mine land reclamation and utilization, especially from the reforestation point of view.

Introduction

Tin had played a major role in the economic development of Thailand before the price crisis in 1985. It was of prime importance both in terms of ore production and concession area. The Department of Mineral Resources reported that the annual production of tin in concentrate in 1984 was 29,978 metric tons, of which 18,332 tons were exported as tin metal. About 70,000 hectares of land, equivalent to 0.13% of the country's land area were underlain by mining concessions. Most of the tin mining areas are located on the west coast of the Malayan Peninsula, the Phangnga province in particular. With the exception of off-shore mining, 12.5% of the tin mining concession areas in Thailand are located in this province.

Although tin mining played an important role in the past, it also brought some detrimental problems

Presented at the International Symposium on "the Rehabilitation of Degraded Forest Lands in the Tropics"-Technical Approach, Tsukuba, Ibaraki, Japan, 17 September 1992, held by Tropical Agriculture Research Center (TARC).

* Department of Silviculture
Faculty of Forestry, Kasetsart University, Bangkok 10903, Thailand

** Division of Soil and Water Conservation
Department of Land Development, Bangkok 10900, Thailand

of environmental deterioration to the nation. The overburden materials consisting of soil and unmineralized rocks are stripped off during site preparation for ore extraction. Bare soil subjected to heavy rainfall of over 3,600mm and 200 rainy days per year undergoes different types of serious erosion. Thus, the losses involve not only the original soil itself, but also plant nutrients. The washed out materials may become part of the stream load. Mine tailing has been a principal source of river pollution in the Philippines (Pantastico and Metra, 1982). Deposited downstream in lower flatlands, mine waste causes siltation and toxicity of heavy metals, acids, alkalis, and inorganic salts that makes agricultural production impossible. Several investigators reported that unfavorable conditions of soil spoiled by mining affected the structure, texture, density, acidity, fertility, and microbial activities (Schafer and Nielsen, 1978; Smith *et al*., 1971; Vijarnsorn, 1982).

Tanpibal (1979) studied the texture of abandoned soils at Takuapa in southern Thailand and found that the percentage of sand component increased from 64% before tin mining up to 92% after mining. On the other hand, the percentages of silt and clay decreased as a result of mining from13% and 23% to 3% and 5%, respectively, changing the soil textural class from sandy clay loam to sand. Thaiutsa and Rungruangsilp (1990) also considered that the levels of soil organic matter, phosphorus, potassium, calcium, magnesium, and cation exchange capacity affected by tin mining were "very low".

Successional development of vegetation on such abandoned lands is a time-consuming process (Thaiutsa, 1985). The future productivity of mine lands may dependent partly on self-sustaining reclaimed plant communities. The findings on natural regeneration of Casuarina equisetifolia on mine tailings showed that the stand density decreased with the age of the trees or the number of years after the mine had been abandoned, from 7,700 trees/ha at 2 years of age to 42 trees/ha at 20 years of age (Thaiutsa and Tanpibal, 1987). However, the maximum aboveground biomass productivity of this species was observed at the age of 12 years, namely 254.52 ton/ha from a stand density of 1,169 trees/ha (Thaiutsa, 1990). Some heavy metals in the water collected from mining ponds were studied by Chetanachan (1989).

The objective of this paper is to investigate some biophysical characteristics of the lands abandoned after mining, especially vegetation, soil, and water. Information gained is expected to be useful for mineland reclamation and utilization.

Study sites and procedures

Field investigations were carried out at the Takuapa district of Phangnga province, located between 8°50' N latitude and 98°10' E longitude, in southern Thailand. The area is characterized by the presence of valley flatlands. Prior to mining the original land use type consisted of tropical rainforest dominated by such commercial tree species as *Dipterocarpus alatus, Fragraea fragrans, Hopea odorata, Intsia palembanica, and Mesua ferrea* with rattan, bamboos, and climbers as undergrowth. The major climatic data were as follows: 3,615mm rainfall with 200 rainy days a year, 26.8°C mean temperature, and 83% relative humidity. Original soil texture was characterized by sandy loam with a pH of 4.7 and a content of 1.52% organic matter.

The biophysical characteristics investigated in this study included plant succession, aboveground biomass productivity, soil properties, and heavy metals in the water collected from mining ponds. Vegetation and soil samples were collected from 5 age classes of mine tailings including 1, 5, 10, 15 and 20 years after tin mining. Each age class of such land form was categorized into 3 zones, namely, gravel mound, sandy zone, and massive zone, accounting for about 7%, 70% and 13% of tin-mined lands, while the remaining 10% was covered by a mining pond (Fig. 1). Water used for heavy metal analysis was collected from the pond under mining (0 year) and old mining ponds 1, 3, 5, 7, 15 and 20 years of age.

Results and discussion

Plant succession

The findings revealed that there were 14, 36, 40, 39, and 63 species undergoing natural regeneration on mine tailings 1, 5, 10, 15 and 20 years of age, respectively. Most pioneer species found on the first year spoiled site were light-demanding grasses. Percentage of grass cover decreased with the increase of the

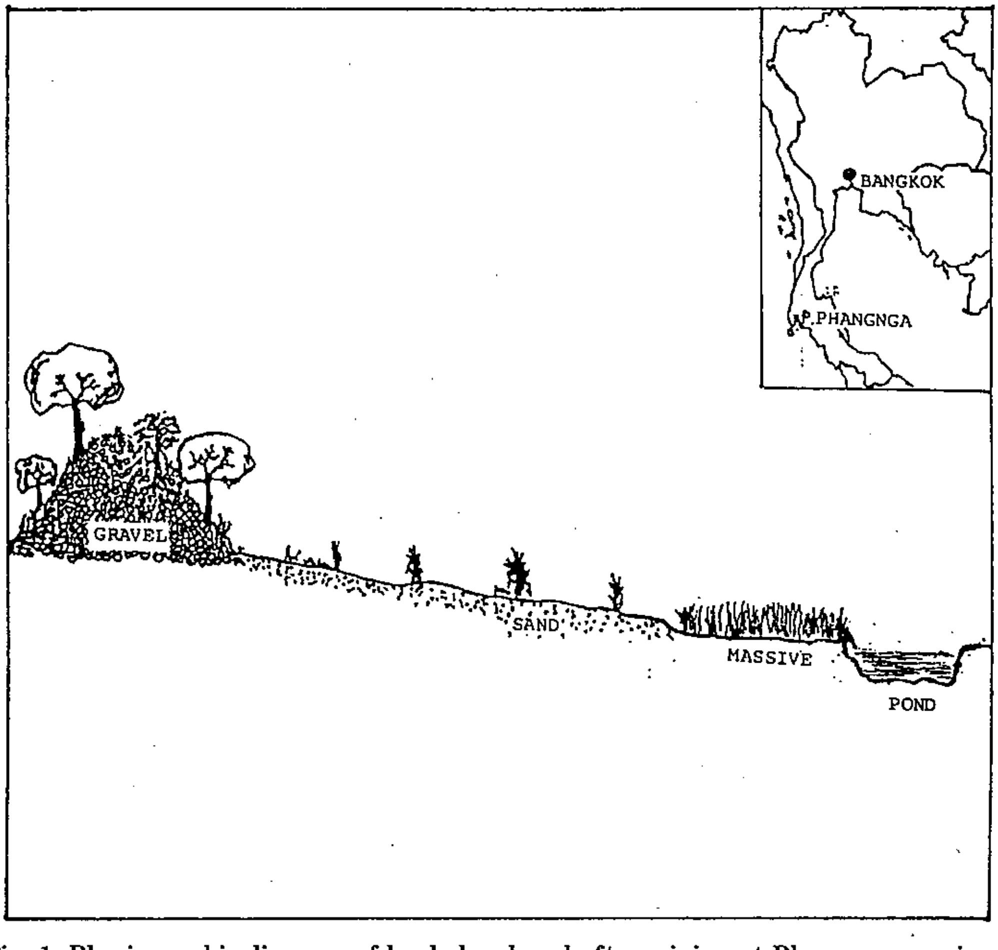

Fig. 1 Physiographic diagram of land abandoned after mining at Phangnga province.

period after mining. In the first-year site, grass species accounted for 50% of the total vegetation species. Such figures decreased to 31, 23, 23 and 19% in the sites abandoned after 5, 10, 15 and 20 years, respectively. The outstanding grasses were *Imperata cylindrica, Cytrococcum accrescens, Chrysopogon aciculatus, Phragmites australis, Saccharum spontaneum*, and *Carex indica*. *Gleichenia linearis* was common on the massive zone.

With the exception of ferns and climbers, *Eupatorium odoratum* and *Melastoma malabathricum* were the pioneer woody plants. Such forest tree species as *Macaranga denticulata, Alstonia macrophylla, Trema angustifolia, Schoepfia fragrans* and *Eurya acuminata* appeared after the two shrubs. Generally speaking, very few woody plants grow on sites younger than five years after mining. Figure 2 shows another aspect of species composition, monocots *vs* dicots and woody plants *vs* non-woody plants. The trend of dicots was similar to that of woody plants, while monocots and non-woody plants showed similar trends. The number of species of monocots and non-woody plants were greater than those of dicots and woody plants only on the tailing sites younger than two years old.

The current findings are in agreement with the results of Saxena (1978) who reported that the successional status of the vegetation depended largely on the pattern of the topography. The uneven surface of the mine spoil affected the natural regeneration. Within a given age class of abandoned land, trees appeared on gravel mound several years earlier than on sandy and massive zones, mainly due to the soil conditions suitable for seedling establishment and plant growth. Hermann (1978) mentioned that reforestation by direct seeding would fail if the following three basic requirements were not met: an adequate supply of viable seeds, a suitable seedbed for germination, and a compatible environment for germination and seedling establishment. As in the case of reforestation by seeding, natural regeneration on abandoned lands after tin mining also requires these basic factors. As a result, tree establishment proceeds well on

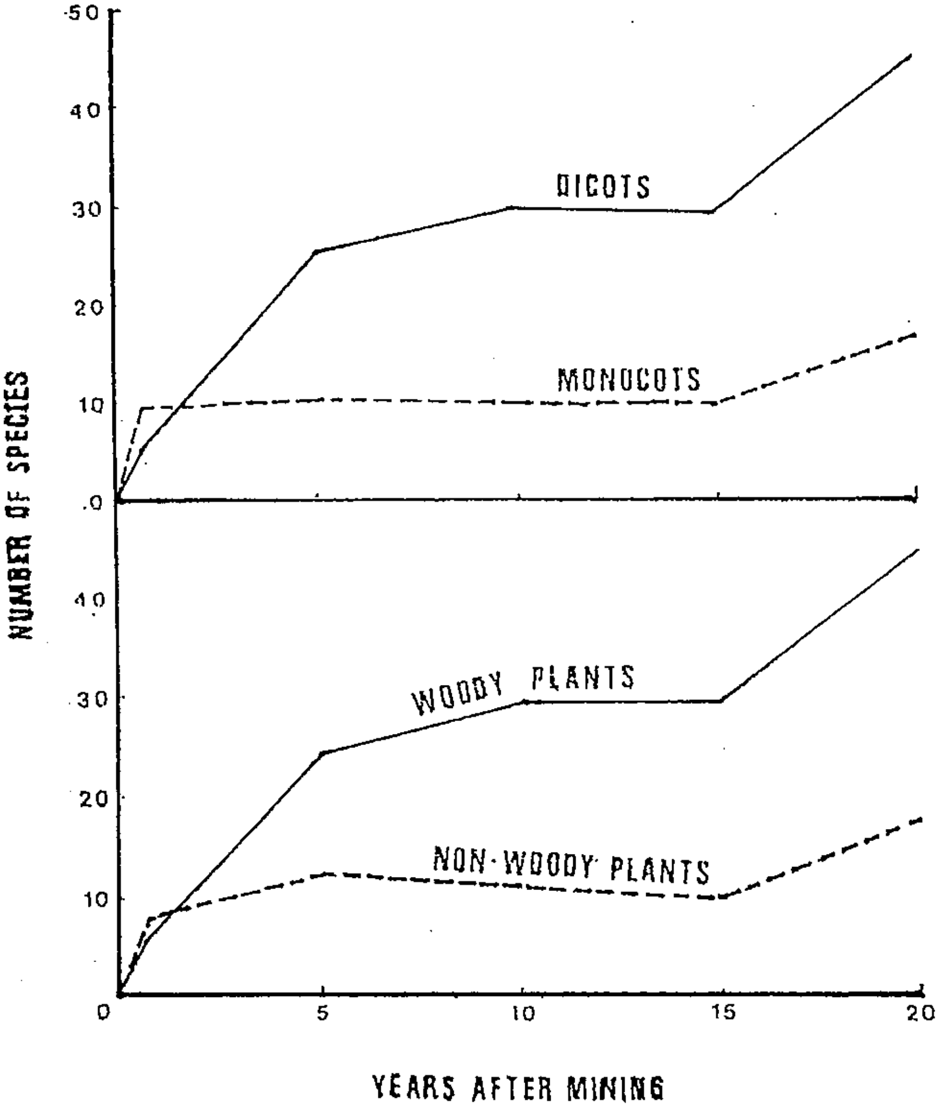

Fig. 2 Number of revegetation species in relation to age classes of mine tailings.

gravel mound in comparison to the sandy and massive zones, especially in the early stage of successional development.

Aboveground biomass productivity

Aboveground biomass productivity measured on an oven-dry weight basis showed that the biomass of the one-year-old site was negligible. Dry matter production on the tailings 5, 10, 15 and 20 years after mining was 14,219, 24,283 and 37,996 kg/ha respectively. It was clear that the amounts of aboveground biomass increased with the increase of the ages of abandoned lands, due to the soil build-up process. Thus, future productivity of mine lands depends on the formation of soils after mining that promotes plant succession and sustains productive communities.

As a result of the soil conditions, the aboveground biomass of this study site also varied with the physiographic zonation of the mine tailings. Maximum oven-dry weights were recorded for the gravel mound, followed by the massive zone and sandy zone in all the age classes (Table 1). Average biomass productivity of the gravel mound was about 3 times higher than that of the massive zone, and 5 times in comparison to the sandy zone. Besides the soil characteristics, considerable differences in the dry matter production among these zones could be accounted for through the species composition of each site. Most of the vegetation types grown on gravel mound consisted of trees and shrubs, while those found on massive and sandy zones belonged to the families Gramineae and Cyperaceae.

Table 1 Aboveground biomass productivity (ton/ha) in relation to topographic zones and the number of years after the mines were abandoned

Zonation	Year				Total
	5	10	15	20	
Gravel	6.35	16.58	24.36	23.00	17.57
Massive	5.85	5.75	5.85	7.84	6.32
Sandy	2.02	1.95	2.71	7.16	3.46
Total	14.22	24.28	32.92	38.00	27.35

Soil properties

Both physical and chemical characteristics of the soils collected from gravel mounds, sandy zones, and massive zones abandoned 1, 5, 10, 15, and 20 years after tin mining in southern Thailand were found to be affected by this type of external treatment. A general summary is given in Table 2. The abnormality of the soil texture may be at the origin of the degradation of other properties. Soil texture in general was characterized by sandy loam with more than 60% of sand particles, especially during the first 10 years after mining due to the presence of fine particles leaching out during the mining processes.

The statistical analysis of all the relevant properties showed that there were significant differences between age classes and between zones within age classes. Soil fertility increased with the increase of the time after mining. Areas occupied by sand were found to correspond be the poorest zone based on chemical analyses. The optimal range of organic matter in most mineral soils should range from 1.5 to 2.5%, but the percentage of organic matter of all the zones in the sites younger than 20-year-old was lower than these figures. Other soil nutrients including CEC were also under similar conditions. Besides, too low a soil pH affected the degree of availability of soil nutrients, macroelements, in particular.

Based on the standard classification of the USDA for the soil properties, soils of all zones and age classes showed a very strong acidity and low nutrient concentration, especially in the sandy zone (Table 3). Thus, reclamation for agricultural-based utilization of tin mine lands is not an easy task, since the sandy zone covers the major part of the abandoned lands.

Water quality

Water quality in this study is confined to the concentrations of some heavy metals in water collected from mining ponds 0, 1, 3, 5, 7, 15 and 30 years old. The 0-year-old mining pond is referred to as the pond under mining operation. The results showed that the mean concentrations of Hg, Cd, Pb, Cu, and Zn were 0.80ppb, 0.06ppm, 0.67ppm, 0.23ppm, and 2.33ppm, respectively. With the exception of Pb and Cu, maximum concentrations of Hg, Cd, and Zn were recorded for the 0-year-old mining pond, while the levels of Pb and Cu were found to be maximized in the 1-year-old pond. Details of heavy metal concentrations are given in Table 4.

Data in Table 4 obviously revealed that the metal concentrations decreased with the increase of the age of the mining pond. Based on the levels of heavy metals associated with the age of the mining pond, 2 groups, i.e., mining ponds younger than 3 years old and those older than 3 years old, the Pb, Cu, Cd, and Zn concentrations of water in the mining ponds older than 3 years old were not significant, but they differed from those of the 0-and 1-year-old mining ponds. These significant levels are important for the use of water collected from mining ponds of different age classes for various purposes. The low pH of water together with the high levels of heavy metals may limit the specific use of water. With the exception of Hg, Cu, and Zn for instance, the concentrations of Cd and Pb exceeded the drinking-water standards set up by the World Health Organization and Ministry of Public Health.

Table 2 Soil properties affected by tin mining in different zones with various age classes

Properties	Zone	Year after mining				
		1	5	10	15	20
Sand (%)	Gravel	74.4	69.8	26.5	51.8	45.2
	Sandy	78.1	87.3	87.1	72.4	35.1
	Massive	20.7	45.4	28.9	35.9	6.1
Silt (%)	Gravel	12.8	11.1	24.1	19.1	26.4
	Sandy	12.4	3.6	3.0	12.1	38.6
	Massive	50.6	21.6	32.0	41.4	42.6
Clay (%)	Gravel	12.7	19.1	49.5	29.1	31.5
	Sandy	9.4	9.1	9.9	15.5	26.3
	Massive	28.8	32.9	39.1	22.7	51.4
pH	Gravel	4.9	4.9	4.8	4.9	4.8
	Sandy	4.9	4.9	4.9	5.1	4.9
	Massive	4.9	4.6	4.7	4.8	4.8
Organic matter (%)	Gravel	0.04	1.02	1.23	1.01	3.84
	Sandy	0.03	0.20	0.18	0.91	1.08
	Massive	0.11	0.92	1.27	1.15	1.55
P (ppm)	Gravel	4	2	1	2	12
	Sandy	1	1	2	2	2
	Massive	3	3	3	1	2
K(ppm)	Gravel	43	26	52	36	106
	Sandy	35	12	24	24	24
	Massive	49	18	46	36	25
Ca (ppm)	Gravel	47	59	89	50	111
	Sandy	37	81	42	70	53
	Massive	67	97	70	48	79
Mg (ppm)	Gravel	11	16	41	18	70
	Sandy	7	7	7	19	16
	Massive	24	23	34	17	39
CE (meq/100g)	Gravel	2	2	6	3	7
	Sandy	2	1	1	2	3
	Massive	5	4	5	4	6

Table 3 Zonation ranking of some chemical properties of soil affected by tin mining at Phangnga province (Source: Thaiutsa and Rungruangsilp, 1990)

Property	Zone		
	Gravel	Sandy	Massive
pH	VSA	VSA	VSA
Organic Matter	ML	VL	L
P	VL	VL	L
K	L	VL	L
Ca	VL	VL	VL
Mg	VL	VL	VL
CEC	L	VL	L

Remarks: VSA = Very strong acidity
VL= Veru low
ML= Moderately low
L= Low

Table 4 Heavy metal concentrations of water collected from mining ponds of various age classes in Phangnga province

Heavy metal	Age of mining pond (years)						
	0	1	3	5	7	15	30
Hg(ppb)	1.04	0.89	0.82	0.77	0.69	0.72	0.69
Cd(ppm)	0.12	0.09	0.04	0.03	0.03	0.03	0.04
Pb(ppm)	1.40	1.78	0.33	0.34	0.30	0.29	0.26
Cu(ppm)	0.57	0.76	0.07	0.06	0.05	0.05	0.06
Zn(ppm)	5.83	4.80	1.25	1.00	1.07	1.16	1.18
pH	4.95	3.68	5.13	5.05	5.35	5.80	6.10

Remarks: Figures under the same horizontal lines on not different at P. 01

Conclusions

This investigation shows that the successional development of plant communities on mine tailings varied with the topographic zones and duration of the time after the mine was abandoned. The number of vegetation species and the aboveground biomass productivity increased with the increase of the time after the mine was abandoned. The soil properties were also affected by tin mining in the same manner. Due to the differences in the levels of heavy metals between age classes of mining ponds, consumption of water collected from mining ponds younger than three years old should be avoided.

References

1) Chetanachan, P. (1989): Heavy metal concentration in water collected from different age classes of mining ponds at Amphoe Takuapa, Changwat Phangnga. M. S. Thesis (Environmental Science, Kasetsart Univ. 102p.
2) Hermann, R. K. (1978): Seeding. *In*: Regenerating Oregon's forest: A guide for the regeneration forester. Edited by Clearly, C. D. *et al*., Oregon State Univ. Ext. Serv., Corvallis. pp. 148-161.
3) Pantastico, E. B. and Metra, T. M. (1982): Impact of mining and logging on soil resources in some places in the Philippines. *In*: Proc. Int. Symp. Soil, Geology and Landforms: Impact on Land Use Planning in Developing Countries, Bangkok. B 9. 1-9. 8.
4) Saxena, S. K. (1978): Degradation of vegetation in the surface mined area of western Rajasthan. *In*: Ecology and coal resource development, Vol. II. Edited by Wali, M. K. Pergamon Press, New York. pp. 626-633.
5) Schafer, W. M. and Nielsen, G. A. (1978): Soil development and plant succession on 1-to 50-year-old strip mine spoils in southern Montana. *In*: Ecology and coal resource development, Vol. II. Edited by Wali, M. K. Pergamon Press, New York. pp. 541-549.
6) Smith, R. M., Tryon, E. H. and Tyner, E. H. (1971): Soil development on mine spoil. W. Va. Univ. Agric. Exp. Stn. Bull. 604T. 47pp.
7) Tanpibal, V. (1979): Fertilizer levels and nut productivity of cashew planted on mine tailings at Takuapa, Phangnga. Department of Land Development, Bangkok. 25pp.
8) Thaiutsa, B. (1985): Natural regeneration of tin mined lands. Proc. Second Asian Conference on Technology for Rural Development, Kuala Lumpur. 18pp.
9) Thaiutsa, B. and Tanpibal, V. (1987): Natural regeneration of *Casuarina equisetifolia* on mine tailings in southern Thailand. Proc. Asian Seminar "Trees and Mycorrhiza", Kuala Lumpur. pp. 227-240.
10) Thaiutsa, B. (1990): Estimating productivity of *Casuarina equisetifolia* grown on tin-mined lands. *In*: Proc. Second International Casuarina Workshop, Cairo. pp. 94-101.
11) Thaiutsa, B. and Rungruangsilp, C. (1990): Impact of tin mining on soil properties. Thai J. For., 9,

73-82.

12) Vijarnsorn, P. (1982): The ecology of tin mine tailings in peninsular Thailand. *In*: Proc. Int. Symp. Soil, Geology and Landforms: Impact on Land Use Planning in Developing Countries, Bangkok. B 17. 1-17. 18.