รายงานวนศาสตร์วิจัย

FOREST RESEARCH BULLETIN

เล่มที่ ๔๔ NUMBER 44

กันยายน ๒๕๑๙ SEPTEMBER 1976

วิวัฒนาการของการใช้ที่ดินป่าไม้เขตร้อนทางเหนือของประเทศไทย

TROPICAL FOREST LAND-USE EVOLUTION / NORTHERN THAILAND

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เรื่องย่อ

การศึกษาและสำรวจวิวัฒนาการของสภาพที่ดินป่าไม้เขตร้อนทางเหนือของประเทศไทย ได้ดำเนินการในท้องที่ป่าบริเวณนิคมชาวเขาดอยเชียงดาว จังหวัดเชียงใหม่ มีความมุ่งหมายเพื่อ ๑) รวบรวมแผนที่ของการเปลี่ยนแปลงของที่ดินป่าไม้เป็นระยะ ๆ เพื่อคำนวณหาเนื้อที่และสภาพที่เปลี่ยนแปลงไป ซึ่งอาจจะใช้เป็นพื้นฐานในการทำนายแนวโน้มของสภาพป่าไม้ในบริเวณนี้ และบริเวณใกล้เคียงในโอกาสต่อไป ๒) เพื่อประเมินผลการใช้ remote sensing ในการแปลภาพและปรับปรุงแผนที่การใช้ประโยชน์ที่ดินให้ทันสมัย ๓) เพื่อประยุกต์โมเดลทางคณิตศาสตร์วิเคราะห์ปัญหาการเปลี่ยนแปลงทั้งในทางสภาพรูปร่าง เนื้อที่ เป็นระยะไป

การวิเคราะห์ได้ดำเนินการแปลภาพและทำแผนที่จากภาพถ่ายทางอากาศในช่วงระยะเวลาต่าง ๆ ดังนี้ ๒๔๙๗, ๒๕๐๔, ๒๕๑๑ และ ๒๕๑๕ การเปลี่ยนแปลงของสภาพป่าทั้งในทางสภาพและเนื้อที่หาได้จากการเปรียบเทียบเนื้อที่ของสภาพการใช้ประโยชน์ที่ดินเป็นคู่ ๆ ไป นอกจากนั้นแล้วภาพถ่ายจากดาวเทียม ขาวดำ และcolor composites นำมาใช้ในการเปรียบเทียบการเปลี่ยนแปลงและการแปลภาพเพื่อจัดแบ่งสภาพการใช้ประโยชน์พื้นที่ดินด้วย

จากการศึกษาครั้งนี้ได้ทราบว่าพื้นที่ป่าดิบเขาและป่าเบญจพรรณที่มีไม้สักได้ถูกแผ้วถางลงอย่างหนักในช่วงระยะเวลา ๑๘ ปี คือ ในปี ๒๔๙๗ มีเนื้อที่ ๖๑,๙๓๑ และ ๑๔,๔๘๘ ไร่ ในปี ๒๕๑๕ เหลือเนื้อที่ป่าดังกล่าว ๓๓,๒๒๕ และ ๖,๗๐๖ ไร่ ตามลำดับ (—๓.๕๒ % ต่อปี และ —๔.๗๖ ต่อปี) ป่าชนิดอื่น ๆ ก็มีแนวโน้มในการลดลงเช่นเดียวกัน คือป่าเต็งรัง จาก ๕๘,๕๐๐ ไร่ ในปี ๒๔๙๗ ลดลงเหลือ ๔๖,๑๘๑ ไร่ ในปี ๒๕๑๕ (—๑.๓๒ % ต่อปี) ป่าเต็งรังผสมไม้สนจาก ๕,๑๕๐ ไร่ ในปี ๒๔๙๗ ลดลงเหลือ ๓,๓๒๕ ไร่ ในปี ๒๕๑๕ (—๒.๔๖ % ต่อปี) ส่วนป่าดิบแล้งจากปี ๒๔๙๗ มีเนื้อที่ ๕,๕๐๐ ไร่ ลดลงเหลือ ๓,๓๘๕ ไร่ ในปี ๒๕๑๕ (—๒.๗๒ % ต่อปี) เมื่อคิดถัวเฉลี่ยแล้วอัตราการลดลงของพื้นที่ป่าประมาณ —๒.๕๗ % ต่อปี พื้นที่ป่าทั้งหมดในบริเวณนี้จากปี ๒๔๙๗ ถึง ๒๕๑๕ (๑๘ ปี) ลดลงประมาณ ๓๗ %.

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INTRODUCTION

Remote sensing including conventional photography of earth resources from aircraft and setellites can acquire large quantities of data of significant value to forest managers. Imagery is readily available as a result of the Earth Resources Technology Satellite -1 and 2 (ERTS-1 and 2) orbited on July 23, 1973 and ERTS-2 just orbited. This type of imagery provide a range of textural definition among different forest land uses. Feature identification must be made on the basis of spectral characteristics which are best obtained from the use of multispectral sensing devices. Multispectral imagery from space can be used to classify forest types, watershed cover, grassland types, areas of shifting cultivation, and areas of plantation. Each produces different imagery characteristics in each spectral band and will, thereby, exhibit a unique signature comprised of the total of information present in each band. These characteristic signatures will enable a delineation of forest land uses from the imagery. Ground data are necessary to evaluate the effectiveness and accuracy of using orbiting satellite imagery.

Recent advance in remote sensing techniques, particularly multiband sensing, may stimulate an increase in the use of remote survey techniques from space. The use of space-craft, with the capacity for repetitive global coverage and simultaneous large area coverage, can provide data in a quantity never before available. Remote sinsing techniques assist in the management of natural resources through the large scale inventory of species composition and volume.

A satellite sensing system by which large areas of the land could be surveyed in their entirety on one image and which could provide world-wide coverage with a relative small number of images, would be extremly valuable as a data collection tool. Furthermore, the dynamic nature of forestry requires not a simple static evaluation, but also a continual updating of conditions. In addition, remote sensing is one of the rapidly advancing techniques that makes it possible to deal more effectively with large ecosystems. Remote sensing will aid in applying the results of intensive ecological research on small areas to planning and management of large political units, townships, countries or states, whole natural units; watershed, tropical rain forests or even ocean basins. The possibilities of obtaining unique ecological information from airborne or orbiting satellite continue to be an interesting and exciting project.

BACKGROUND

The study area called "Nikom Doi Chiang-Dao" is situated in Chiang-Dao district, Chiang-Mai province in northern Thailand between the latidude 19° 12′ and 19° 20′ N longitude 98° 45′ and 98° 59′ E. It is situated about 67 kilometers north of Chiang-Mai city. The study area comprises 360 square kilometers; of this 206 sq km. was selected for the use by the Department of Public Welfare's Hill Tribe Division as the Nikom, hill tribe settlement. The eastern boundary of the study area is the winding course of the Ping river and the border in the southwest and west is predominantly the Mae-Taeng and Khun Noi rivers.

The vegetation types covering the study area can be classified into five categories based on the composition of the forest, elevation and slope as follows: Hill evergreen forest, dry evergreen forest, mixed deciduous forest with teak, dry dipterocarp forest and dry dipterocarp forest with pine.

Most of northern Thailand is subjected to shifting cultivation. It is estimated that about 2,090,500 hectares of watershed area have been cleared and burned, mostly by the hill tribes living on the mountainous area in the north. The study area have long been heavily devastated for shifting cultivation, a primitive form of agriculture. To determine the potentialities of this area an integrated survey was carried out in 1970 by a team from the School of Forestry, Kasetsart University. This recent study states that 20 percent or 3772 hectares and 6 percent or 1542 hectares of the study area are under swidden farming and permanent agriculture respectively. Natural resource planning is further complicated by the lack of accurate natural resources resources information. Statistical data obtained from this study may be worth-while to be used in the future.

OBJECTIVES

The primary objectives of this study are:

1. To compile sequential forest / agriculture land use map todetermine change in gross forest land use and to utilize them in predicting future land use developments in the study area.

2. To determine the validity of remote sensing for making and updating forest / agriculture land use maps.

3. To integrate historical land use data in mathematical, geographical models of the study area with current satellite land use maps and biological features to predict future spatial and temporal forest land use patterns.

GENERAL APPROACH

The historical photo-interpretation was performed on multidate photographs of the study area to classify and map the forest and agriculture land use and to determine its dynamic change. The photographs were assembled and interpreted by conventional methods for the site to provide a basis for extending the interpretation of the forest land use "change maps."

The research has been undertaken to evaluate the utility of ERTS types of systems for providing the data necessary for local and provincial programs. Emphasis is given to their use in forest and agriculture land use mapping and planning in northern Thailand, and the identification of critical sites, such as shifting cultivation and cultural resource areas.

RESULTS

Forest Depletion

The PLANMAP phase 3 computer program was used to compute gross land use totals and net changes by overlaying the land use data planes of 1954 with 1966, 1966 with 1968, 1968 with 1972, and for the overall period of 1954 with 1972. The computation process yielded changes in land-use for each of 36,000 of 1 hectare cells between each of the time periods indicated. For, example, a 1 hectare cell in land-use i as of 1954 was detected to evolve into land-use j as of 1966 or to remain unchanged. The program yielded the total area of each land-use and net changes, transition summaries and probabilities for the conversion of each land-use to each other land-use, and other related statistical data.

The greatest time interval between dates of the available land-use planes was from 1954 to 1972 or 18 years. Comparision of area measurements for each land-use between these two extreme dates provides an initial estimate of evolution of land-use pattern in the study site (Table 1.).

TABLE 1. GENERALIZED LAND-USE EVOLUTION IN NIKOM DOI CHIANG-DAO SITE BETWEEN 1954 AND 1972.

Type of land-use	Area in sq. km. 1954	1972	Change in Area	Change in Percentage (18 yrs.). %	Change in Percentage (Yearly) %
1. Hill Evergreen Forest	99.09	53.16	-45.93	-46	-3.52
2. Mixed Deciduous Forest with Teak	24.78	10.73	-14.05	-57	-4.76
3. Dry Dipterocarp Forest	93.60	73.89	-19.71	-21	-1.32
4. Dry Dipterocarp Forest with Pine	8.24	5.32	-2.92	-35	-2.46
5. Dry Evergreen Forest	8.80	5.42	-3.38	-38	-2.72
Subtotal of Forest Types	234.51	148.52	-85.99	-37	2.57
6. Swidden Areas	39.51	103.09	63.58	+161	+5.47
7. Irrigated Rice Fields	15.02	24.70	9.68	+ 64	+2.80
8. Tea Plantations	3.50	16.38	12.88	+368	+8.95
9. Teak Plantations	0.00	0.43	0.43	-	-
All Total	292.54	293.12	+0.58*		

* Discrepancy of the total land use area is due to coding error along the study area boundary.

Yearly percentage rates reported here and throughout the balance of this report are those compound percentage rates which if they operated at the same rate each year on a decreasing or increasing area would produce the gross changes in land-use measured. Total area of each land-use on each of the four dates revealed more clearly the progressive changes in the land-use of the site and the recent acceleration of the rate of forest depletion (Figure 1). Accelerated decreased were evident in all the area forest types. The depletion appeared most significant in the hill evergreen forest and mixed deciduous forest with teak (Figure 1).

The areas of these forest type decreased from 9,909 hectares and 2,478 hectares in 1954 to 5,316 hectares and 1,073 hectares in 1972 respectively. Decreased also occurred in the other forest types, however, the absolute change in area of a given forest type should be tempered (normalized) by the total area of the given forest type present at the end of the depletion cycle. For example, the hill evergreen forest type appears to have been depleted the greatest because a large area of it was present at the beginning of the cycle (-3.52 per annum). Closer examination shows that mixed deciduous forest with teak suffered the greatest depletion of -4.76% per year on a compound annual basis.

Dry dipterocarp forest decreased from 9,360 hectares in 1954 to 7,389 hecteares in 1972 (-1.32% per annum), dry dipterocarp forest with pine from 824 hectares in 1954 to 532 hecteares in 1972 (-2.46 per annum), and dry evergreen forest from 880 hectars in 1954 to 542 hecteares in 1972 (-2.72 per annum). A concomitant increase took place in other competing land uses. Swidden areas, irrigated rice Fields, and tea plantations, increased from 3,951, 1,502 and 350 hectares in 1954 to 10,339, 1089 and 1,650 hectares respectively in 1972 (+5.47%, +2.80%, and +8.95% per annum).

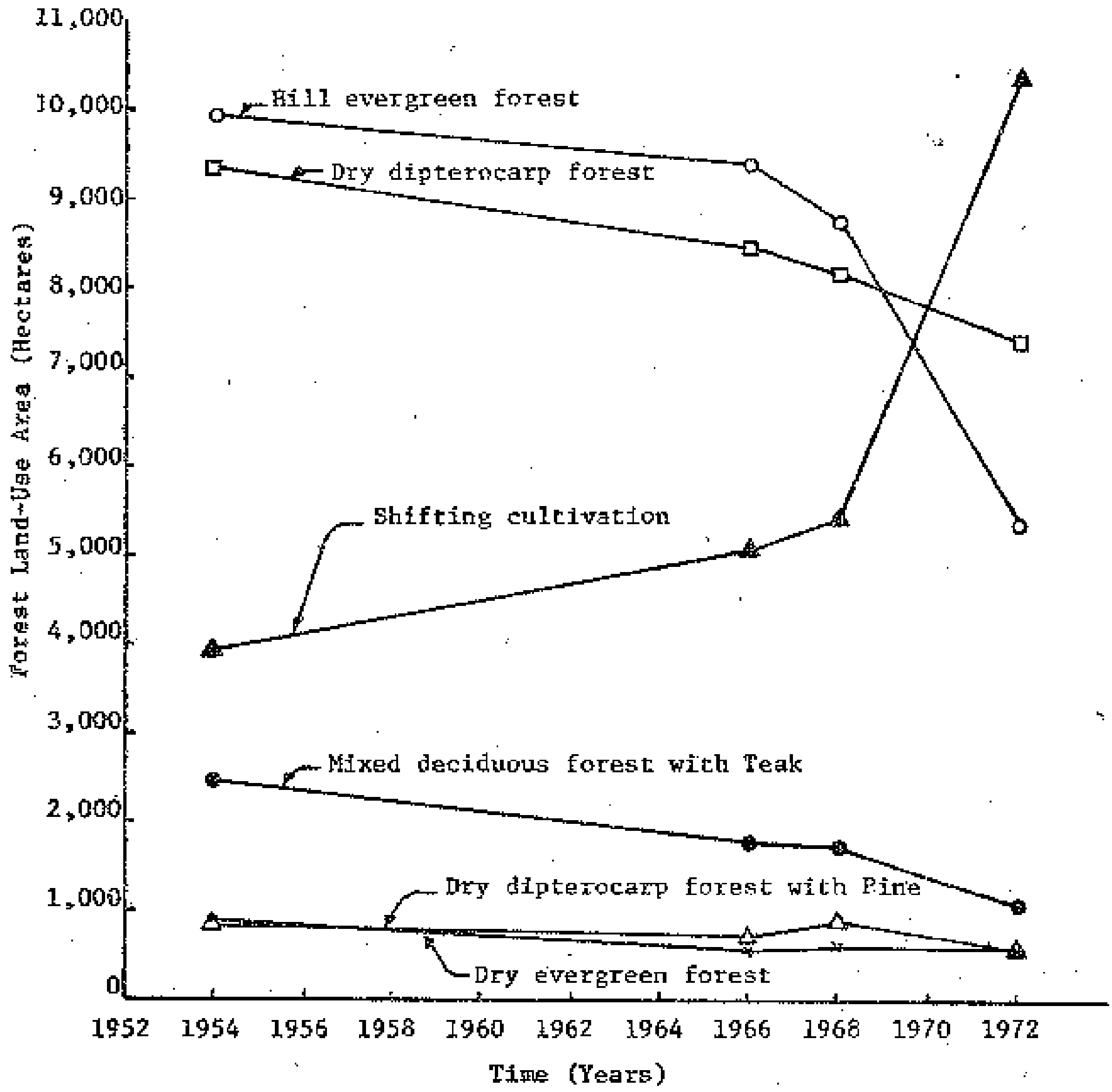

FIGURE 1. FOREST LAND-USE DEPLETION AND THE CONCOMITANT INCREASE IN THE AREA OF SHIFTING CULTIVATION.

Points are plotted for determinations shown in Table 15 for 1954, 1966, 1968, and 1972.

A total of 8,599 hectares of forest land disappeared between 1954 and 1972 or about 37 percent of the forest area present in 1954. Assuming that almost all of the site of 360 sq. km. was forested at a date some what earlier than 1954, the forest cover present in 1972 constitutes approximately 41.26 %, of its original area indicating a total depletion at 58.74 % by 1972.

Markov Chain Models of Land-Use Evolution in the Nikom Doi Chiang-Dao Site

The PLANMAP* analysis of the landscape data planes in land-scape model allowed cell by cell comparison of changing land-use for each consecutive pair of dates. This yielded land-use transition summary tables and probability transition matrices for each pairing of dates. The land-use summary tables show the total numbers of land cells in a specific land-use which changed to each of other possible land-use or remained unchanged for the specific pair of dates. The probability transition matrices indicate the probability that a specific land-use will be changed to each other land-use or remain unchanged based upon the transition summary table statistics for given pair of dates.

The Markov Chain model (Ashby, 1971) was developed to simulate land-use evolution by applying a probability transition matrix to a given summary table of land-uses. The land-use changes computed between a pair of dates provided the probability Pjk for the Nimom Doi Chiang-Dao site to change from land-use type j to land-use type k, or to remain in

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* PLANMAP is a 7 phase computer software package for manipulating, overlaying, and analyzing map data recorded in a cellular fashion.

the same land-use over the date period. The transformational diagram of land-use evolution can be expressed in terms of systematic land-use transformational diagram (Figure 2). The probability transition matrix $P = (P_{jk})$, and the stochastic row vector $V = (V_j)$, represented the distribution of the proportions of the area of the site given by the land-use type $j = 1, 2 \ldots 9$, adding up to 100 % of the total area for time $t = 0, 1, 2 \ldots$.

The computer program PREDICT* was used to predict the potential change of forest land-use in the study area using the Markov Chain approach. The 9 by 9 element (for all nine possible land uses) probability transition matrix $P = (P_{jk})$ was multiplied by the stochastic row vector $V = (V_j)$. The stochastic row vector is the initial land-use tabulations for the earlier of the pair dates yielding the probability transition matrix, i.e. 1968 for 1968/1972 (Table 2, 3, 4, and 5).

Twenty-five 4-year simulation time periods of predict were set up to predict the amount of each of the nine land-uses for future century using each pair of date available. The future amounts of each land-use were predicted for each of the nine land-use types. The total area of the five forest types for each future four year interval were summed and compared to the future evolution of the area of shifting cultivation.

The complete models of the future of each of the nine individual land-uses of the site based on the 1968/1972 data planes clearly shows the limitations of attempting to interpret long term future trends from such model (Figure 3).

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* PREDICT is a computer package, written in Fortran IV for CDC 6400, to simulate possible change succession of natural resources.

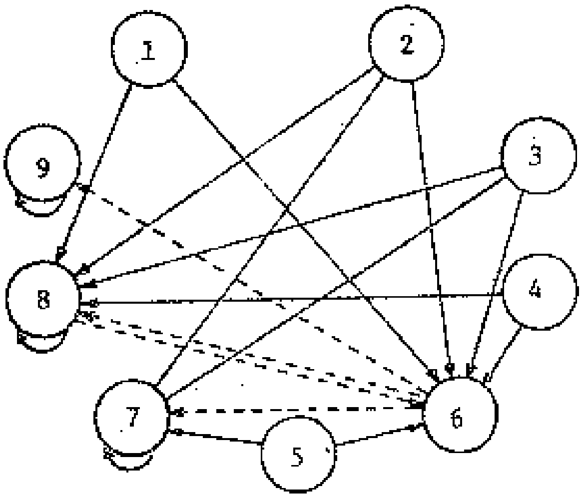

FIGURE 2. FOREST TRANSFORMATIONAL DIAGRAM OF THE MARKOV MODEL OF LAND-USE EVOLUTION.

◯ represent forest type.

◡ represent steady or stable state.

⟶ represent a pathway of possible changes. The head of the arrow indicates the direction of event.

--→ represents occurrence of less common sequences.

The numbers inside the circles present the index of each forest ecotype as coded earlier for each 1 hectare cell on 4 dates.

① Hill Evergreen Forest Type.
② Mixed Deciduous Forest Type with Teak.
③ Dry Dipterocarp Forest.
④ Dry Dipterocarp Forest Type with Pine.
⑤ Dry Evergreen Forest.
⑥ Swidden Area.
⑦ Irrigated Rice Field
⑧ Tea Plantation.
⑨ Teak Plantation.

TABLE 2. LAND-USE TRANSITIONS BETWEEN 1954 AND 1966.

(a) Transformational summary table for the 1954 land-use transformed to another land-use in 1966. Number in the matrix indicate the number of hectares converted.

1966 Land Use

1954 Land Use Code		CODE 1	CODE 2	CODE 3	CODE 4	CODE 5	CODE 6	CODE 7	CODE 8	CODE 9
HILL EVERGREEN FOREST	(1)	6743	49	112	221	33	2257	75	408	0
MIXED DECIDUOUS FOREST WITH TEAK	(2)	57	1564	47	1	7	496	4	302	0
DRY DIPTEROCARP FOREST	(3)	125	99	7391	147	1	919	449	50	0
DRY DIPTEROCARP FOREST WITH PINE	(4)	219	0	257	304	0	65	0	0	0
DRY EVERGREEN FOREST	(5)	66	12	84	0	392	157	5	167	0
SWIDDEN AREAS (ACTIVE AND OLD CLEARING)	(6)	2702	25	95	51	41	1174	27	412	0
IRRIGATED RICE FIELD	(7)	0	14	175	0	0	14	1176	0	0
TEA PLANTATION	(8)	67	0	26	0	99	2	0	154	0
TEAK PLANTATION	(9)	0	0	0	0	0	0	0	0	0

(b) Probability transition matrix for the 1954 land-use transformed to another land-use in 1966. Numbers in the table are the fraction (probability) of the particular area which converted.

1966 Land Use

1954 Land Use Code		CODE 1	CODE 2	CODE 3	CODE 4	CODE 5	CODE 6	CODE 7	CODE 8	CODE 9
HILL EVERGREEN FOREST	(1)	.6854	.0050	.0114	.0225	.0034	.2294	.0015	.0415	0.0000
MIXED DECIDUOUS FOREST WITH TEAK	(2)	.0230	.6512	.0190	.0004	.0028	.2002	.0016	.1219	0.0000
DRY DIPTEROCARP FOREST	(3)	.0134	.0108	.8052	.0160	.0001	.1001	.0489	.0054	0.0000
DRY DIPTEROCARP FOREST WITH PINE	(4)	.2661	0.0000	.2880	.3694	0.0000	.0765	0.0000	0.0000	0.0000
DRY EVERGREEN FOREST	(5)	.0765	.0159	.0973	0.0000	.4542	.1587	.0058	.1935	0.0000
SWIDDEN AREAS (ACTIVE AND OLD CLEARING)	(6)	.5380	.0064	.0243	.0079	.0105	.3005	.0069	.1055	0.0000
IRRIGATED RICE FIELD	(7)	0.0000	.0102	.1271	0.0000	0.0000	.0102	.8526	0.0000	0.0000
TEA PLANTATION	(8)	.1925	0.0000	.0747	0.0000	.2845	.0057	0.0000	.4425	0.0000
TEAK PLANTATION	(9)	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

TABLE 3. LAND-USE TRANSITIONS BETWEEN 1966 AND 1968.

(a) Transformational summary table for the 1966 land-use transformed to another land-use in 1968. Numbers in the matrix indicate the number of hectares converted.

1968 Land Use

1966 Land Use Code		CODE 1	CODE 2	CODE 3	CODE 4	CODE 5	CODE 6	CODE 7	CODE 8	CODE 9
HILL EVERGREEN FOREST	(1)	6247	27	48	502	55	2075	8	634	0
MIXED DECIDUOUS FOREST WITH TEAK	(2)	65	1219	117	10	45	278	5	25	0
DRY DIPTEROCARP FOREST	(3)	27	67	7271	197	2	518	118	13	0
DRY DIPTEROCARP FOREST WITH PINE	(4)	217	0	150	208	0	49	0	0	0
DRY EVERGREEN FOREST	(5)	12	3	7	6	366	155	5	52	0
SWIDDEN AREAS (ACTIVE AND OLD CLEARING)	(6)	1601	292	606	72	99	2076	27	299	0
IRRIGATED RICE FIELD	(7)	20	3	178	0	10	8	1796	5	0
TEA PLANTATION	(8)	554	109	15	0	60	252	0	523	0
TEAK PLANTATION	(9)	0	0	0	0	0	0	0	0	0

(b) Probability transition matrix for the 1966 land-use transformed to another land-use in 1968. Numbers in the table are the fraction (probability) of the particular area which converted.

1968 Land Use

1966 Land Use Code		CODE 1	CODE 2	CODE 3	CODE 4	CODE 5	CODE 6	CODE 7	CODE 8	CODE 9
HILL EVERGREEN FOREST	(1)	.6651	.0029	.0047	.0522	.0059	.2209	.0009	.0675	0.0000
MIXED DECIDUOUS FOREST WITH TEAK	(2)	.0369	.6916	.0664	.0057	.0261	.1577	.0017	.0142	0.0000
DRY DIPTEROCARP FOREST	(3)	.0035	.0082	.8857	.0240	.0002	.0626	.0144	.0010	0.0000
DRY DIPTEROCARP FOREST WITH PINE	(4)	.3062	0.0000	.2131	.4091	0.0000	.0696	0.0000	0.0000	0.0000
DRY EVERGREEN FOREST	(5)	.0208	.0052	.0122	0.0000	.5972	.2591	.0052	.0903	0.0000
SWIDDEN AREAS (ACTIVE AND OLD CLEARING)	(6)	.3162	.0577	.1197	.0142	.0179	.4100	.0053	.0591	0.0000
IRRIGATED RICE FIELD	(7)	.0099	.0015	.0881	0.0000	.0050	.0040	.8891	.0025	0.0000
TEA PLANTATION	(8)	.5517	.0730	.0100	0.0000	.0402	.1689	0.0000	.3503	0.0000
TEAK PLANTATION	(9)	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

TABLE 4. LAND-USE TRANSITIONS BETWEEN 1968 AND 1972.

(a) Transformational summary table for the 1968 land-use transformed to another land-use in 1972. Numbers in the matrix indicate the number of hectares converted.

1972 Land Use

	1968 Land Use Code	CODE 1	CODE 2	CODE 3	CODE 4	CODE 5	CODE 6	CODE 7	CODE 8	CODE 9
HILL EVERGREEN FOREST	1	3695	5	61	279	167	3917	58	549	0
MIXED DECIDUOUS FOREST WITH TEAK	2	41	764	46	0	0	702	55	152	0
DRY DIPTEROCARP FOREST	3	14	57	6525	33	39	1505	366	60	9
DRY DIPTEROCARP FOREST WITH PINE	4	311	11	186	196	0	167	0	0	0
DRY EVERGREEN FOREST	5	145	27	2	0	151	167	0	126	0
SWIDDEN AREAS (ACTIVE AND OLD CLEARING)	6	695	179	499	24	174	5407	70	523	34
IRRIGATED RICE FIELD	7	1	0	50	0	11	19	1951	0	0
TEA PLANTATION	8	414	30	20	0	0	625	4	458	0
TEAK PLANTATION	9	0	0	0	0	0	0	0	0	0

(b) Probability transition matrix for the 1968 land-use transformed to another land use in 1972. Numbers in the table are the fraction (probability) of the particular area which converted.

1972 Land Use

	1968 Land Use Code	CODE 1	CODE 2	CODE 3	CODE 4	CODE 5	CODE 6	CODE 7	CODE 8	CODE 9
HILL EVERGREEN FOREST	1	.4242	.0006	.0070	.0520	.0192	.4497	.0044	.0659	0.0000
MIXED DECIDUOUS FOREST WITH TEAK	2	.0238	.4442	.0267	0.0000	0.0000	.4081	.0203	.0767	0.0000
DRY DIPTEROCARP FOREST	3	.0017	.0068	.7742	.0039	.0046	.1548	.0458	.0071	.0011
DRY DIPTEROCARP FOREST WITH PINE	4	.3571	.0126	.2135	.2250	0.0000	.1917	0.0000	0.0000	0.0000
DRY EVERGREEN FOREST	5	.2385	.0444	.0033	0.0000	.2484	.2747	0.0000	.1908	0.0000
SWIDDEN AREAS (ACTIVE AND OLD CLEARING)	6	.1284	.0331	.0922	.0044	.0322	.6296	.0146	.0597	.0063
IRRIGATED RICE FIELD	7	.0005	0.0000	.0249	0.0000	.0055	.0094	.9597	0.0000	0.0000
TEA PLANTATION	8	.2669	.0193	.0129	0.0000	0.0000	.4030	.0026	.2955	0.0000
TEAK PLANTATION	9	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

TABLE 5. LAND-USE TRANSITIONS BETWEEN 1954 AND 1972.

(a) Transformational summary table for the 1954 land-use transformed to another land-use in 1972. Numbers in the matrix indicate the number of hectares converted.

1972 Land Use

	1954 Land Use Code	CODE 1	CODE 2	CODE 3	CODE 4	CODE 5	CODE 6	CODE 7	CODE 8	CODE 9
HILL EVERGREEN FOREST	1	3778	22	127	545	198	4881	46	442	2
MIXED DECIDUOUS FOREST WITH TEAK	2	141	972	29	0	0	982	45	311	0
DRY DIPTEROCARP FOREST	3	192	40	6798	39	31	1458	657	75	37
DRY DIPTEROCARP FOREST WITH PINE	4	272	2	232	137	0	238	0	0	0
DRY EVERGREEN FOREST	5	161	15	57	0	257	226	3	147	5
SWIDDEN AREAS (ACTIVE AND OLD CLEARING)	6	705	11	46	15	48	2409	19	575	0
IRRIGATED RICE FIELD	7	1	5	69	0	0	7	1527	0	0
TEA PLANTATION	8	114	0	11	0	0	127	0	102	0
TEAK PLANTATION	9	0	0	0	0	0	0	0	0	0

(b) Probability transition matrix for the 1954 land-use transformed to another land-use in 1972. Numbers in the table are the fraction (probability) of the particular area which converted.

1972 Land Use

	1954 Land Use Code	CODE 1	CODE 2	CODE 3	CODE 4	CODE 5	CODE 6	CODE 7	CODE 8	CODE 9
HILL EVERGREEN FOREST	1	.3842	.0022	.0129	.0549	.0201	.4964	.0041	.0450	.0002
MIXED DECIDUOUS FOREST WITH TEAK	2	.0569	.3923	.0117	0.0000	0.0000	.3963	.0174	.1255	0.0000
DRY DIPTEROCARP FOREST	3	.0711	.0052	.7571	.0042	.0034	.1559	.0712	.0079	.0041
DRY DIPTEROCARP FOREST WITH PINE	4	.2697	.0024	.2819	.1665	0.0000	.2795	0.0000	0.0000	0.0000
DRY EVERGREEN FOREST	5	.1855	.0173	.0656	0.0000	.2957	.2691	.0035	.1642	.0055
SWIDDEN AREAS (ACTIVE AND OLD CLEARING)	6	.2010	.0029	.0118	.0053	.0125	.6167	.0049	.1472	0.0000
IRRIGATED RICE FIELD	7	.0007	.0021	.0495	0.0000	0.0000	.0007	.9472	0.0000	0.0000
TEA PLANTATION	8	.3276	0.0000	.0516	0.0000	0.0000	.3677	0.0000	.2931	0.0000
TEAK PLANTATION	9	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

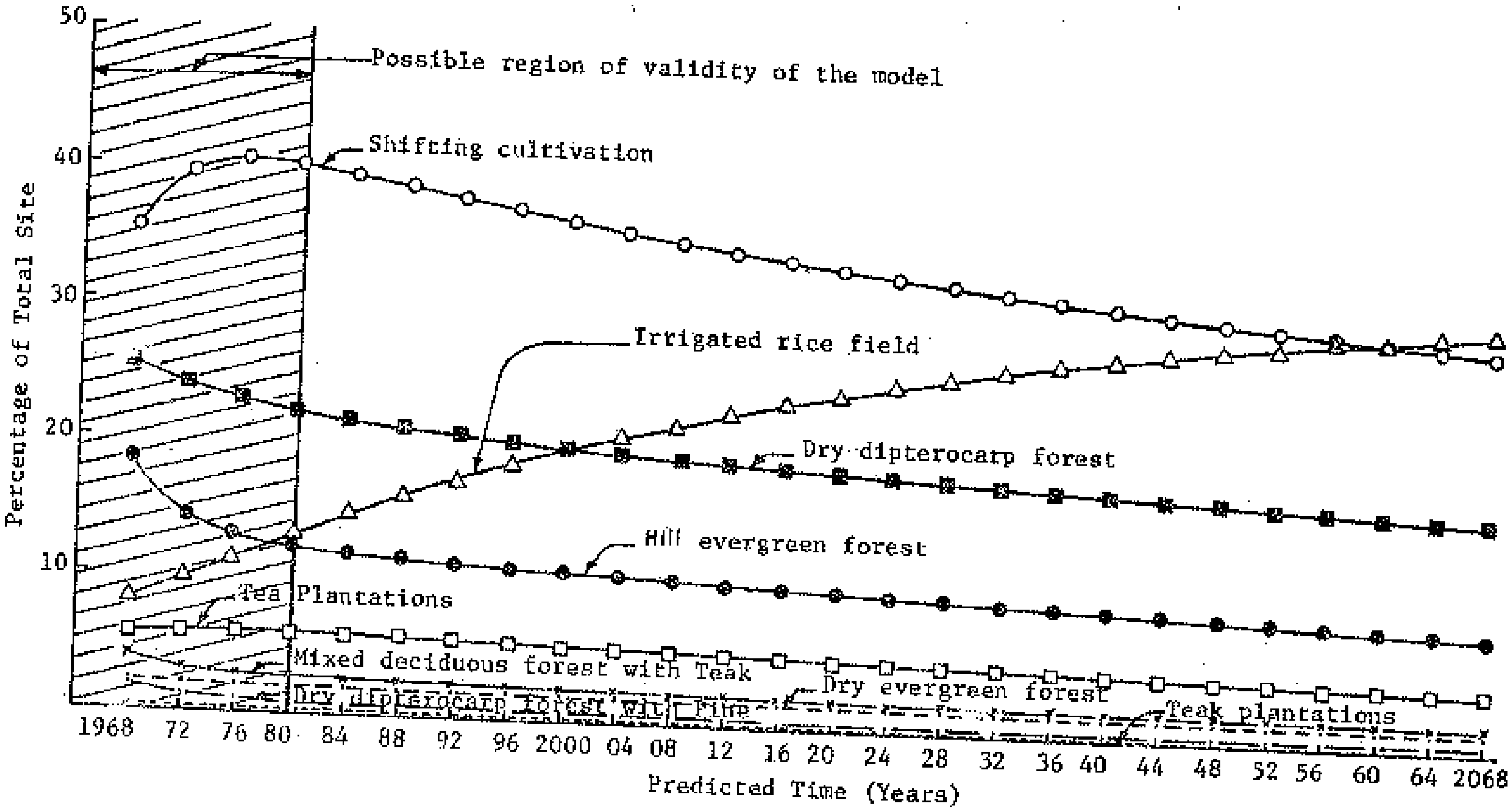

FIGURE 3. PREDICTED AREAS OF EACH OF THE 9 POSSIBLE LAND-USES BASED UPON THE CHANGES BETWEEN 1968 and 1972. No limits have been placed on the possible growth of any land-use relative to any other. A proposed region of validity of the modeled results is shown ending in approximately 1980.

This simplistic model predicts a marked continuous future increase in the percentage of the 360 sq. km. site devoted to irrigated rice. Clearly there are limits of topography and available water which will make this prediction impossible. Future improvement in this stochastic modeling process should account for the upper boundaries on the amount a given land-uses which are imposed by independent variables such as topography, water availability, etc. Some preliminary steps toward collecting the data required to impose these practical limitations in the modeling process on each land-use, such as the upper bounds on shifting cultivation by slope or the conceivable irrigable area for irrigated rice are reviewed in the following section.

The predicted future tendency for an increased area of shifting cultivation followed by a gradual decline (Figure 3) appear reasonable. Eventually almost of all remaining forest land will be consumed by shifting cultivation yielding on upper boundary for this uncontrolled land-use then it would be replaced by other of the more stable land-use (i.g. tea or teak plantations)

Sensitivity Analysis

The initial step in preparing a more specific, deterministic land-use model to predict the future land-use of each landscape cell on a spatial basis were undertaken. The general approach to preparing such a spatial land-use model treats the past, current, or change in land-use of a cell (e.g. 1 hectare) as the dependent variable and other characteristics of the cell (e.g. slope) as the independent variable. Subsequently a multivariate approach will be undertaken to account for the possible interrelationships in the multiple, idependent variables.

Such a model would predict the future evolution of the land use of a cell based upon it current land-use and other physio-biological characteristics. The trends toward change of land-use of a cell from one state to another would be obtained from examination of the past change in land-use of all cells present in the area relative to their suite of individual physio-biological characteristics.

Only a preliminary examination was completed of the relationship between a given land-use or change in land-use and the independent variables of slope, aspect, and elevation. It was intended that cellular maps of the distance-to-drainage and distance-to-trails and other cultural features would be similarly correlated based upon the drainage and cultural features data planes described earlier. More recently several additional maps of the test site including the geology and potential natural vegetation have been obtained and could be similarly correlated. Unfortunately time has circumvented these analyses at present but it appears that the work will be continued and completed.

PLANMAP phase 7 was employed to compare cell by cell the 1954, 1966, 1968, and 1972 land-use and changes in land-use with the slope, aspect, and elevation of the cell. Histograms of the tendency of the distribution of each land-use to correlate with these independent topographic features of the cell features were plotted on the computer line printer and also on microfilm with statistical summaries. The examples show only the distribution histograms (the sensitivity) of 1972 swidden areas versus slope, aspect, and elevation respectively but similar histograms were produced for all land-uses and dates. The example histogram for the sensitivity of shifting cultivation versus elevation (Figure 4) illustrated that in 1972 shifting cultivation was at an average elevation of 1,081.89 meters with one standard deviation ($\pm \sigma$) ranging from 442 to 1738 meters. A second histogram (Figure 5) illustrated that shifting cultivation was practiced at the avarage slope 31 percent with a $\pm \sigma$ range from flat land to the slope of 70 percent. The histogram of swidden areas as a function of aspect (Figure 6) showed that aspect had very little role in determining shifting cultivation practice, probably because in the tropical regions the energy balance of surfaces with respect to aspect are approximately equal.

Comparative results of the tendency of land-use distribution to relate to topography for the four available dates were thus tabulated. Mean elevations of swidden areas, irrigated rice fields, and tea plantations distribution in 1954 were 1232.59, 444.88, and 907.07 meters, whereas in 1972 they were 1081.89, 506.11, and 1161.20 meters respectively. Note that a significant decrease occurred in the mean elevation of shifting cultivation from 1232.59 to 1081.89 meters as it expanded significantly in area during the period. These statistical data indicate that shifting cultivation was expanding predominantly to lower elevations during the time period and its $\pm$ one standard deviation in elevation in 1954 was 250.42 meters but expanded to 333.80 meters in 1972.

The irrigated rice area increased during the overall 18 year time interval in both mean elevation (907.07 to 1,160.20 meters), and slope (16.24 to 18.39%) because almost all lands suitable for paddy fields in lowland had been under use prior to 1954. It appears that check dams for supplying water at higher elevation together with improved cultivation techniques supported conversion of areas of higher elevation and slope to rice paddies. Tea plantations expanded to higher elevations and slopes.

The mean elevations of tea plantations in 1954 and 1972 were 907.07 and 1161.20 meters respectively and the mean slope increased from 30.75 to 33.71 percent.

Forest Depletion Versus Topography

The change in land-use from 1954 to 1966, 1966 to 1968, 1968 to 1972, and for the overall period of 1954 to 1972 were obtained by a cell by cell comparison of land-use data. The examples show only the distribution histograms of 1968 swidden land-use, 1972 swidden land-use and change in swidden land-use for these two dates plotted versus slope. Statistical results for areas which changed in land-use for the period as a function of their slopes and elevations were tabulated (Tables 24 and 25). The example, the histograms for slope illustrated that shifting cultivation was at the average slope of 33.34% in 1968, 33.71% in 1972, and that the changes in shifting cultivation during the period of 1968 to 1972 occurred at a mean slope of 32.15%.

Examination of the results obtained from such an approach show that changes in shifting cultivation occurred preferentially at mean slopes of 32.55, 31.65, and 30.82% for the periods of 1954/1966, 1966/1968, and 1968/1972. Similar interpretations and trends can be seen by examining the preferential mean slopes and elevations for changes in each land-use for the available date periods. These data provide statistical representation of the preference of a given land-use to change to another land-use as a function of topography. This preference is characterized by the distribution function or histogram and by $\pm$ one standard deviation and other statistics of central tendencies. These provide the input data for the development of a higher order MARKOV model to predict future land-use tendencies taking into consideration the restrictions placed upon the evolution of a given land-use by the physio-biological limitations of the site (slope, elevation, drainage, etc.)

Value of ERTS Images in Land-Use Classification

ERTS MSS band 5 imagery was the best single black and white image for first and second level forest and agriculture land-use classification based upon a comparison of accuracy with the land-use classification obtained from the 1972 aerial photography. This imagery resulted in correct identification of 68 percent for forests, 50 percent for swidden areas, and 81 percent for rice fields. ERTS MSS band 7 imagery was inferior to that of band 5 for the land-use classification desired but did have good contrast for land and water discrimination and for mapping drainage patterns. ERTS color IR composite images of multispectral bands 4, 5, and 7 were superior to any of the black and white bands for the forest and agriculture land-use classification sought. This color IR imagery permitted recognition percentages of 68 percent for forest, 60 percent for swidden areas, and 87 percent for rice fields. A similar evaluation of black and white ERTS MSS imagery and color IR composite for land-use mapping has been validated by others.

Experience from interpretation of ERTS color IR composite images at a scale of 1:250,000 revealed that these images were very useful for land-use classification, especially in the determination of location, amount, and distribution of agricultural and forest lands in large areas such as provinces. Nine land-use categories were delineated on the color IR composite images of 1:250,000 scale for the Chiang-Mai province. Open water, streams and rivers, lakes, artificial ponds, and reservoirs are easily delineated. Water bodies as small as 0.25 hectare or 40 meters in diameter were detected. Other land-use categories have specific color-types and color-tones that made it possible to readily delineate them. It was found that when the color IR composite images were photographically enlarged to a scale of 1:125,000 the apparent resolution, color density, and color-tone decreased and interpretation was hampered by the MSS scanning pattern. Consequently, fewer land-use categories can be classified on the enlarged 1:125,000 prints than those of somewhat smaller but more appropriate synoptic scale of 1:250,000.

Value of Digital Imagery Analysis

Unfortunately, digital imagery analysis was not completed in this study. Consequently it is not known whether computer classification or color IR composite image interpretation would be more effective in land-use classification of the study area. Several other studies have indicated that computer classification had certain advantages, namely: 1) more information existed in each digitally recorded image than in the film, 2) the data were less degraded because they had never been transformed to an analog form for display, 3) with digital data it was easier to retrieve and interpret more timely information with precision, and 4) automatic analysis of the image considerably reduced the amount of subjective work done by the analyst.

Value of Computerized Mapping

Computerized mapping is a new technique of machine processing to generate spatial information patterns about the area under study. It can locate and delineate areas of similar characteristics and can display a spatial perspective of the study site or landscape for further use in intensive land-use planning.

Past 20 Years of Land-Use Evolution

Evidence from the summary table and transition probability matrix shows that during the earlier period of 12 years from 1954 to 1966, the compound probability of forest land being converted to shifting cultivation was about 1.50 percent, to paddy fields 0.20 percent, and to tea plantations it was 0.30 percent per annum. From 1966 to 1968 the compound annual probabilities of transformation of forest land to shifting cultivation, paddy field, and tea plantations were 8.00, .30 and 2.00 percent respectively. The percentage of forest converted to tea plantations from 1966 to 1968 was high compared to the 1954/1966 period due to the high demand for tea leaves to supply tea factories in the study area. The increased demand for tea during that period caused a rise in the selling price of the tea and made it one of the most valuable crops of the area. Rising prices and continuing demand for tea prompted people to remove the forest and establish native tea plantations.

Over the most recent period from 1968 to 1972 the compound annual probabilities of forest land-use being changed to shifting cultivation, paddy fields, and tea plantations were 9.65, 0.60 and 1.08 percent respectively. During this period the forest lands were heavily damaged. Political and sociological conditions played an important role in these changes. Three main factors were involved in increasing the rate of conversion of forest land to shifting cultivation during the period.

1) The battle along the Burmese border forced several minority groups, especially the hill tribes, to migrate to the high mountains of Thailand

and to increase the population of those practicing shifting cultivation for their subsistence. 2) During this period new representatives were elected over all the country. These representatives were almost all administrators, they aided the lowland people seeking land for cultivation in the reserved forests and the high mountains. 3) The population explosion of the tribes and indigenous ethnic groups in the area was the most important factor which increased the area of and, more importantly, the rate of conversion to shifting cultivation. This resulted from progress in medicine and hygiene which was supported by the government and eliminated many of the former early causes of death.

The forest depletion has occurred in every forest type. A total of 8,599 hectares of forest land-use disappeared between 1954 and 1972 for a total reduction in forest area of about 37 percent. Forest removal has been most significant in the hill evergreen forest and the mixed deciduous forests because of their fertile soils and commercially valuable tree species. The hill evergreen and mixed deciduous forests decreased from 9,909 and 2,478 hectares in 1954 to 5,316 and 1,073 hectares in 1972 respectively. Dry dipterocarp forest was depleted from 9,360 hectares in 1954 to 7,389 hectares in 1972, whereas dry dipterocarp forest with pine deteriorated from 824 to 532 hectares, and dry evergreen forest from 880 to 542 hectares.

Significant depletion of all forest types took place between 1954 and 1972. However, for the period from 1966 to 1968 the study shows that the areas of dry dipterocarp forest with pine and dry evergreen forest increased from 7.06 and 5.78 to 8.69 and 6.07 hectares respectively. Possibly these small "apparent" increases in forest lands were due to interpretation errors on the aerial photographs. Ground observation of the current regeneration in these areas will be helpful in resolving this anachronism.

Swidden areas, paddy fields, and tea plantations exhibited corresponding conspicuous increases from 3,951, 1,502, and 350 hectares in 1954 to 10,309, 2,470, and 1,638 hectares in 1972 respectively. A small teak plantation had been established in an old clearing area by the end of 1968. The area of teak plantations as measured from the 1972 map was 43 hectares.

Net forest land-use changes have been obtained by a comparison of forest land-uses in 1954 to 1972. Rate of forest depletion is determined based on these data. Forests in the study area were depleted at an average compound annual rate of 3.52 percent for hill evergreen forest, 4.76 percent for mixed deciduous forest with teak, 1.32 percent for dry dipterocarp, 2.46 percent for dry dipterocarp forest with pine, and 2.72 percent for dry evergreen. The overall annual rate of forest depletion in the test area was 2.57 percent, or 603 hectares compounded annually. These statistical data provide the basis for assessing the need for a forest-cover monitoring system for northern Thailand.

The Future of Forest Land-Use Evolution

Logic indicates that the transition probability matrix obtained from the 1968 and 1972 pair of land-use maps most closely represents the current situation and tendency for land-use change. The Markov Chain model was employed to predict the forest land-use evolution in the study area using these most recent successional changes. The time period simulated was 100 years, from 1968 to 2068 (Figure 3). This simulation indicates that from the beginning of the period in 1968 the tendency of shifting cultivation is to gradually increase to a maximum of 40 percent of the total area of the site in 1976, and thereafter, it will begin a gradual decrease to 29 percent in 2068. The potential decrease is accounted for by the fact that eventually all forested areas will be impacted which will automatically decrease the practice of shifting cultivation.

The percentage of the total area of the site in dry dipterocarp, mixed deciduous forest with teak, and dry dipterocarp forest with teak, and dry dipterocarp forest with pine will decrease respectively from 25, 3.7, and 1.9 percent in 1968 to 8.4, 1.9, and .01 percent by 2068. The percentage of hill evergreen forest will sharply decrease from 18.2 percent at the beginning of the period to 12 percent in 1980, after which it will gradually decrease to 8.5 percent by 2068. The simulation shows that the dry evergreen forest is currently the most stable due to the fact that the remainder of this forest area which might be cleared for shifting cultivation is on increasingly steep and inaccessible ground. Information obtained from this simulation is used to envisage what will happen in the future without considering the role of changes in the controlling natural, political and sociological factors. However, these preliminary data are valuable for use in formulating forest management plans and a regional land-use planning program. As new airphoto coverage of the area becomes available, revised land-use maps can be prepared and more up-to-date simulations can be obtained. Should airphotos become available at two to three year intervals in the future a useful analysis of the real impact of forest management practices can be completed using the techniques described. The improved earth imaging satellites of the future coupled together with improved automated image processing systems should provide the spatial data needed to prepare more timely simulations of this type. Satellite imagery will also allow significantly larger sample areas which would be more representative of the total region.

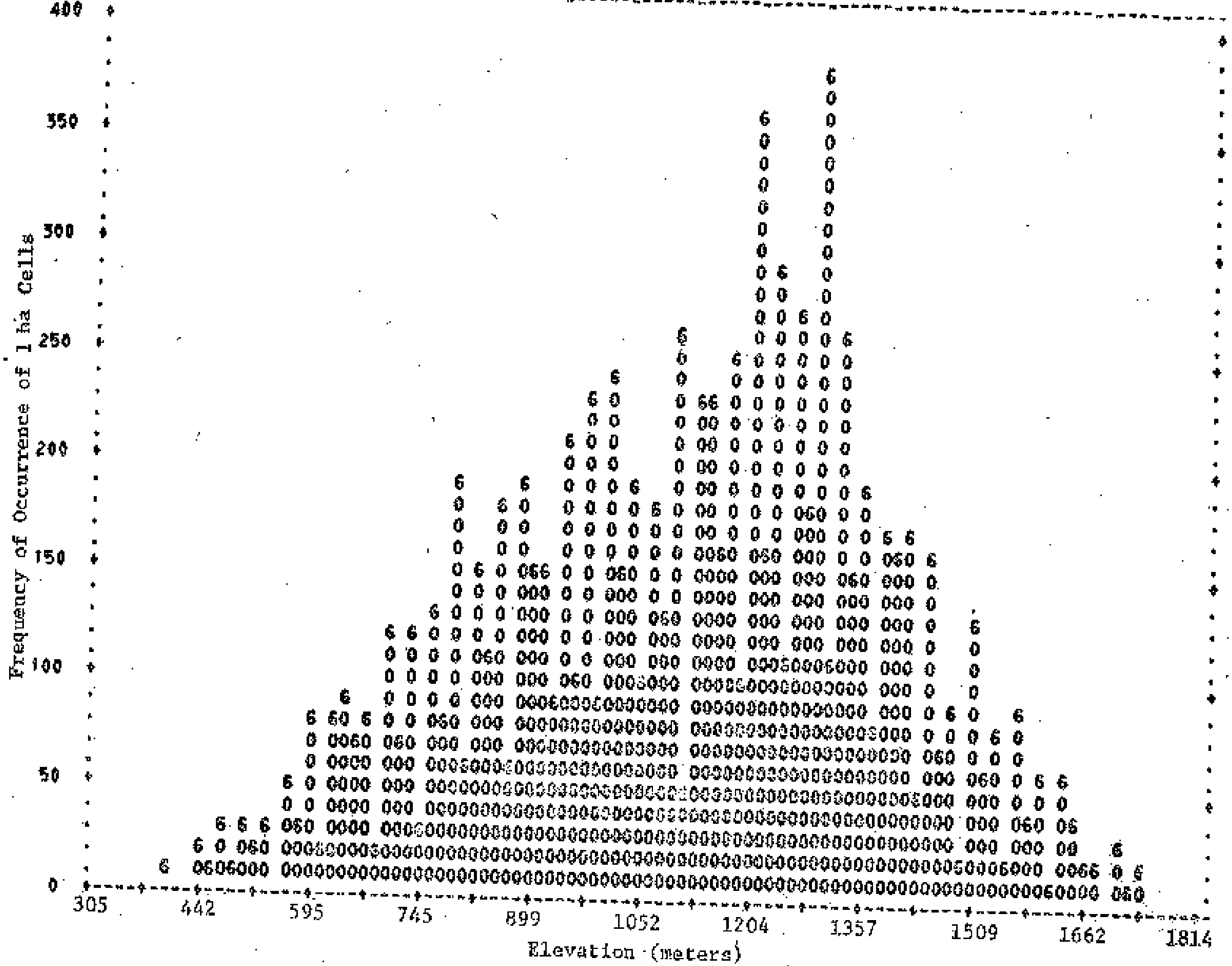

FIGURE 4. DISTRIBUTION OF 1972 SWIDDEN AREAS VERSUS ELEVATION.

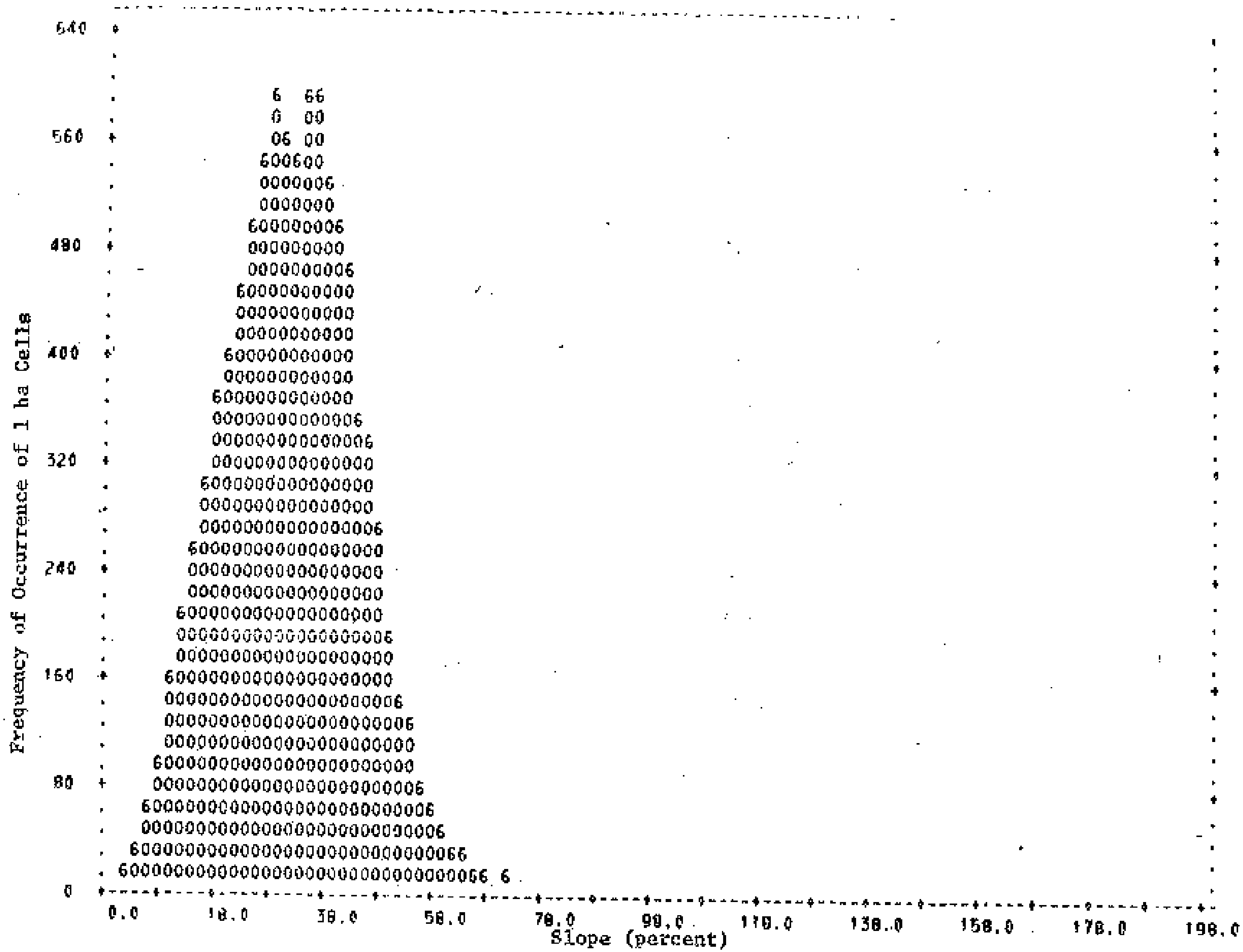

FIGURE 5. DISTRIBUTION OF 1972 SWIDDEN AREAS VERSUS SLOPE.

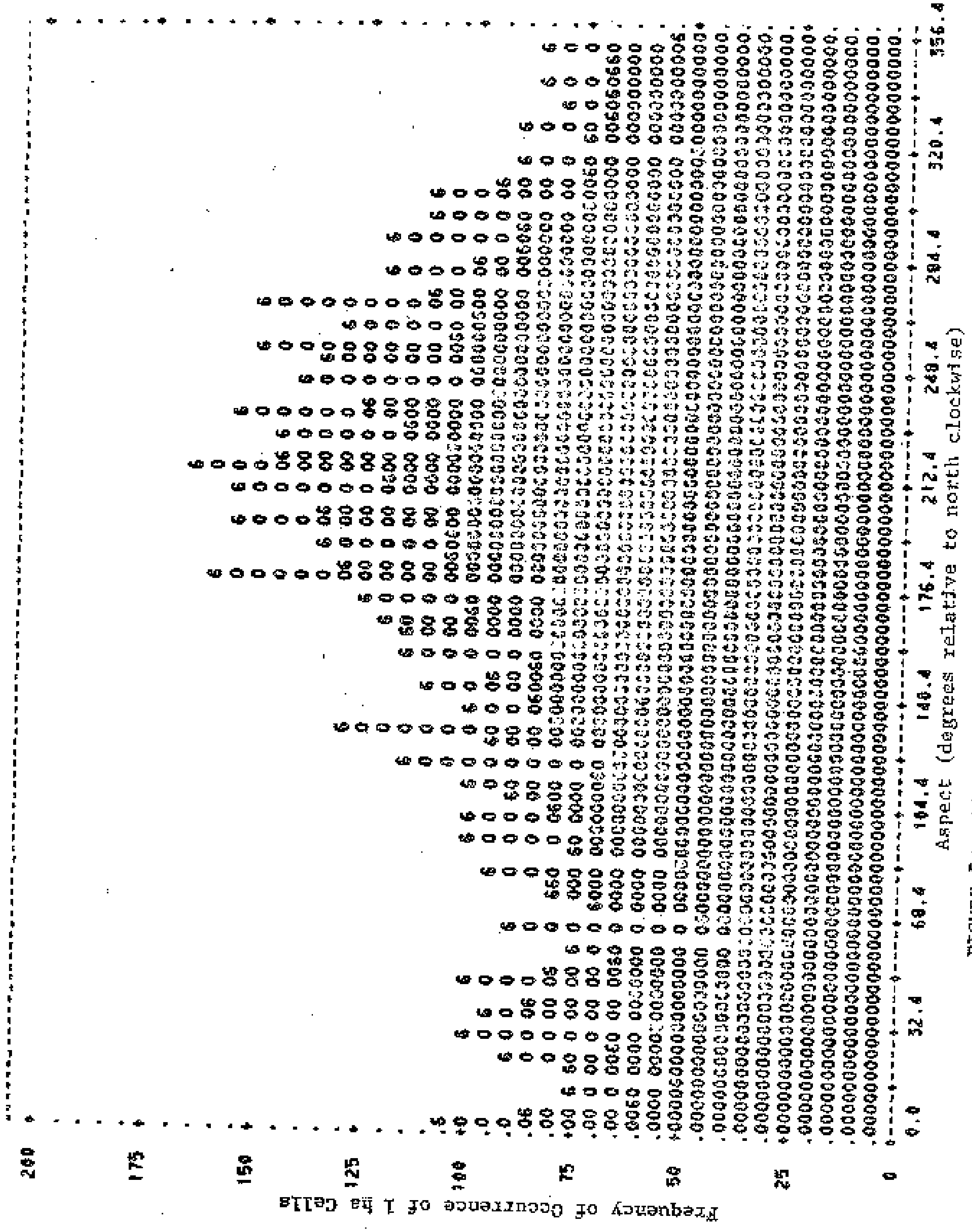

FIGURE 6. DISTRIBUTION OF 1972 SWIDDEN AREAS VERSUS ASPECT.

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