ESTIMATION OF AGRICULTURE-FORESTRY TRANSITION MATRICES FROM AERIAL PHOTOGRAPHS*

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The difficulties associated with improving forest management practices on land held by farmers and other small landowners have been well documented. In North Carolina roughly four-fifths of all forest area is to be found in such holdings. To evaluate alternative strategies for improving land management, it is important to have information concerning the rates of change in land use on existing units. Aerial photographs provide a valuable source of this information, especially when flights have been made over an area at regular intervals extending back over several decades. In general, such regularity of aerial photo flights does exist for the continental United States. This article describes the use of such photographic data to construct land-use transition matrices.

THE STUDY AREA

The area analyzed in this study is the Dial Creek watershed, a 3,384 acre tract of typical Piedmont Plateau land located in northeastern Durham County and southeastern Person County. The watershed is approximately five miles long (north-south) and one and one-half miles wide. It represents a geographic entity where land-use practices are considered typical for the Piedmont. There has been increasing interest in the use of a drainage basin such as this as a logical and efficient basic unit of ecosystem [1].

Twenty-seven private landowners were identified in the watershed. Of these, 37 percent owned units smaller than 100 acres, 33 percent owned units of 100-199 acres and 30 percent held units larger than 200 acres. In general, topography is flat to gently rolling in the eastern half where most of the agricultural activity takes place. The western half is mainly gently rolling to rolling with only occasional steep slopes. Most non-forest use in this section consists of pasture land.

The soils of the Dial Creek watershed can be classified into groups based on their geologic parent material. The most common soils, occupying approximately 75 percent of the area, are considered among the best piedmont soils for the production of tobacco [4].

The second category of soils is composed of those derived from "Carolina Slate," mainly fine-grained volcanic and sedimentary rocks. The major agricultural uses for these slate belt soils are small grains and pasture.

The upland forest areas of the watershed may be divided into three major forest types [3]. These are: (1) loblolly-shortleaf pine, (2) oak-pine, and (3) oak-hickory. The three economically important species of pine found in the area are loblolly, shortleaf and Virginia pine. Soft hardwoods including yellow poplar, sweetgum and blackgum are the most abundant hardwood species that are of commercial importance.

SAMPLING METHOD

The measurement of land-use changes in the Dial Creek watershed between 1940 and 1970 was used

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based on intensive sampling from aerial photographs. Four sets of photographs are available for the watershed from flights in October 1940, March 1951, December 1959, and May 1970. Data are thus available on land use during the 1940, 1950,[1] 1959 and 1970 crop years. Intervals between flights are roughly three periods of a decade each.

A systematic sampling design was utilized, beginning with the 1970 flight, using a scale of 1:12,000. The seven photographs required for complete coverage were laid out and the watershed boundary delineated by grease pencil. Graph paper with four squares to the inch was placed over the photographs. At the corners of each square a pin hole was punched through the paper and the photograph. This procedure was followed for the entire area within the watershed and represented the establishment of four sample points per square inch. A total of 607 permanent sample points were obtained, each point representing approximately 5.74 acres. Each sample location was circled for easy identification and assigned a number.

LAND-USE CLASSIFICATION

The 1970 land use of each sample point was determined from extensive ground observation in conjunction with photographic interpretation. Each sample location was classified into one of the following seven land uses: (1) Pine Forest Type, (2) Pine-Hardwood Forest Type, (3) Hardwood Forest Type, (4) Cropland, (5) Pasture, (6) Idle, or (7) Miscellaneous. The definition of each land-use class is given below.

Pine Forest Type - A forest area currently occupied by trees of pine species, in pure or almost pure stands.

Pine-Hardwood Forest Type - A forest area currently occupied by trees of pine and hardwood species in mixture.

Hardwood Forest Type - A forest area currently occupied by trees of hardwood species, in pure or almost pure stands.

Cropland - Land currently under cultivation, or land that shows visual evidence of cultivation within the past two years, but does not qualify as any other land use.

Pasture - Land currently utilized for grazing purposes, including improved and unimproved pasture, but excluding forest areas used for grazing.

Idle - Land currently showing no visual evidence of use as cropland or pasture within the past two years, but lacking adequate stocking of forest trees to be considered as in forest use.

Miscellaneous - Land that currently does not qualify for any of the above land-use classes. Includes primarily roads, water, farmsteads, residence, and powerline rights-of-way.

THREE-DECADE CHANGES

Following the 1970 land-use classification, each of the 607 sample points was located on the other three sets of photographs and re-examined for change. In this manner, each point was classified as to land use for the crop years 1970, 1959, 1950, and 1940. Estimated land use in 1940 is compared with that in 1970 in Table 1.

Joint Probabilities

The joint distribution of the 607 sample points among the seven land-use classes for 1940 and 1970 is shown in Table 2. In this two-way classification each cell represents one of the 49 possible land use combinations. Any given cell contains two numbers. The number in parentheses represents the number of sample points falling in the row classification in 1940 and the column classification in 1970. The decimal number is the proportion of the total sample points in that cell and represents the estimated joint probability that any given point will have the designated uses in the two sample-years, representing an interval of 30 years.

Table 2 also provides for an estimate of acreage in each land-use class for 1940 and 1970. The proportion in each row total multiplied by the acreage of the watershed gives an estimate of land use in 1940. Using the column totals and the watershed acreage, an estimate of the 1970 land-use pattern is obtained.

An indication of the trend in land-use changes can be found by comparing the probability of each joint occurrence, p_{ij}, with its transpose, p_{ji}. The probability may be much greater for a sample point to shift from class "i" in 1940 to class "j" in 1970 than for a change from class "j" in 1940 to class "i" in 1970. For example, the probability of an observation being in Pine Type in 1940 and Hardwood Type in 1970 is .08 as shown in Table 2. The transpose of this occurrence would be the probability of an observation being in Hardwood Type in 1940 and Pine Type in 1970. This probability is shown as .00. Thus, one can conclude that between 1940 and 1970 any change between these two classes is from Pine Type to Hardwood Type.

[1] Since March 1951 is too early to identify land uses for the 1951 crop year this set of photos is identified as representing the 1950 crop year in the remainder of the paper.

Table 1. LAND USE IN DIAL CREEK WATERSHED, 1940 AND 1970[a]

Land-use class	1940		1970	
	Acres	Percent	Acres	Percent
Forestry:				
Pine	1,115	33.0	596	17.6
Pine-hardwood	613	18.1	613	18.1
Hardwood	535	15.8	1,121	33.1
	2,263	66.9	2,330	68.8
Agriculture:				
Cropland	769	22.7	535	15.8
Pasture	95	2.8	195	5.8
	864	25.5	730	21.6
Other:				
Idle	123	3.6	162	4.8
Miscellaneous	134	4.0	162	4.8
	257	7.6	324	9.6
Total Watershed area	3,384	100.0	3,384	100.0

[a]Based on distribution of 607 sample points.

Conditional Probabilities

In examining land-use changes in this study the starting point is taken to be 1940. The movement of each sample point from its classified use in 1940 to its final use in 1970 is of most importance. If the probability of a sample point being in a given state in 1970 depends on its starting state in 1940, this probability is said to be conditional. Conditional probabilities are valid in this study since it is assumed that the initial (1940) land use is known and the 1970 land-use probability is being estimated given the known initial state.

Conditional probabilities can be estimated from the joint probability distribution given in Table 2. The relationship between joint and conditional probabilities can be represented as follows:

Joint: $P(C_{40} = i, C_{70} = j) = P_{ij}$

Conditional: $P(C_{70} = j \mid C_{40} = i) = P_{j|i}$

$$P(C_{40} = i, C_{70} = j) = P(C_{40} = i) \cdot P(C_{70} = j \mid C_{40} = i)$$

$$P(C_{70} = j \mid C_{40} = i) = \frac{P(C_{40} = i, C_{70} = j)}{P(C_{40} = i)} = p_{j|i}$$

where:

$$\sum_j p_{j|i} = 1$$

Each conditional probability, $p_{j|i}$, is simply the number of observations in the j^{th} cell divided by the i^{th} row total of Table 2. As an example, the conditional probabilities of Pine Type in 1940 are the number of observations in each 1970 land-use class divided by the row total. Table 3 gives the conditional probabilities for all land-use classes for the period 1940 to 1970 in matrix form. The construction and use of this type of matrix, also known as a Markov chain, is described by Judge and Swanson [2]. Each entry along the diagonal from the upper left to the lower right is the probability that a sample point will remain in the same land-use class between 1940 and 1970. The closer each diagonal element is to 1.00, the stronger the tendency to resist change.

Each row of Table 3 must sum to 1.00 and represents the land-use probabilities for 1970, given the land-use class in 1940. For example, the table shows that the probability that a site in Pine Type in 1940 will still be in Pine Type in 1970 is only .36. This means that there is a .64 probability of a 1940 Pine Type site being in some other land-use class in 1970. The probabilities associated with these other possible land uses are given in Table 3.

WITHIN-DECADE CHANGES

As indicated above, the 607 sample points were examined and classified by land use type, not only

Table 2. DISTRIBUTION OF 607 SAMPLE POINTS AND ESTIMATED JOINT PROBABILITIES FOR SEVEN LAND-USE CLASSES IN DIAL CREEK WATERSHED, 1940 AND 1970[a]

Land use in 1940	Land use in 1970							
	Forestry			Agriculture		Other		
	Pine	Pine-hardwood	Hardwood	Cropland	Pasture	Idle	Miscellaneous	Total
Forestry:								
Pine	.1186 (72)	.0857 (52)	.0840 (51)	.0165 (10)	.0082 (5)	.0099 (6)	.0066 (4)	.3295 (200)
Pine-hardwood	.0198 (12)	.0675 (41)	.0840 (51)	.0033 (2)	.0016 (1)	.0049 (3)	.0000 (0)	.1812 (110)
Hardwood	.0000 (0)	.0016 (1)	.1532 (93)	.0033 (2)	.0000 (0)	.0000 (0)	.0000 (0)	.1582 (96)
Agriculture:								
Cropland	.0247 (15)	.0099 (6)	.0066 (4)	.1236 (75)	.0329 (20)	.0264 (16)	.0033 (2)	.2273 (138)
Pasture	.0033 (2)	.0049 (3)	.0016 (1)	.0049 (3)	.0099 (6)	.0000 (0)	.0033 (2)	.0280 (17)
Other:								
Idle	.0099 (6)	.0115 (7)	.0016 (1)	.0049 (3)	.0049 (3)	.0033 (2)	.0000 (0)	.0363 (22)
Miscellaneous	.0000 (0)	.0000 (0)	.0000 (0)	.0016 (1)	.0000 (0)	.0033 (2)	.0346 (21)	.0395 (24)
Total	.1762 (107)	.1812 (110)	.3311 (201)	.1582 (96)	.0577 (35)	.0478 (29)	.0478 (29)	1.00 (607)

[a]Numbers in parentheses indicate the number of sample points falling in the cell.

Table 3. CONDITIONAL TRANSITION PROBABILITY MATRIX, 1940-1970

Land use in 1940	Land use in 1970						
	Forestry			Agriculture		Other	
	Pine	Pine-hardwood	Hardwood	Cropland	Pasture	Idle	Miscellaneous
Forestry:							
Pine	.36	.26	.25	.05	.03	.03	.02
Pine-hardwood	.11	.37	.46	.02	.01	.03	.00
Hardwood	.00	.01	.97	.02	.00	.00	.00
Agriculture:							
Cropland	.11	.04	.03	.56	.14	.11	.01
Pasture	.12	.18	.05	.18	.35	.00	.12
Other:							
Idle	.27	.32	.04	.14	.14	.09	.00
Miscellaneous	.00	.00	.00	.04	.00	.08	.88

for 1940 and 1970 but also for 1950 and 1959. It is therefore possible to construct conditional probability matrices covering shorter time intervals. Tables 4, 5, and 6 give the probabilities of change in use between the years 1940 and 1950, 1950 and 1959, and between the years 1959 and 1970, respectively. These shorter intervals provide information concerning the time periods in which land-use change was occurring. The most stable forest use was hardwood where the probability that land in that use at the beginning of the period would remain so was .98, 1.00 and .97 for the three periods (see Tables 4-6). The decreasing probabilities associated with pine, .74, .70, and .66, respectively, are an indication that current management practices of the landowners are tending toward a reduction of their most profitable forest type.

To provide approximate measures of decade-to-decade changes, the off-diagonal elements of Table 5 must be increased by 1/9 to allow for the

Table 4. CONDITIONAL TRANSITION PROBABILITY MATRIX, 1940-1950

Land use in 1940	Land use in 1950						
	Forestry			Agriculture		Other	
	Pine	Pine-hardwood	Hardwood	Cropland	Pasture	Idle	Miscellaneous
Forestry:							
Pine	.74	.18	.04	.02	.01	.01	.00
Pine-hardwood	.05	.81	.12	.00	.00	.02	.00
Hardwood	.00	.02	.98	.00	.00	.00	.00
Agriculture:							
Cropland	.06	.02	.00	.76	.06	.09	.01
Pasture	.00	.06	.00	.29	.59	.06	.00
Other:							
Idle	.32	.13	.00	.23	.00	.32	.00
Miscellaneous	.00	.04	.00	.00	.00	.00	.96

Table 5. CONDITIONAL TRANSITION PROBABILITY MATRIX, 1950-1959

Land use in 1950	Land use in 1959						
	Forestry			Agriculture		Other	
	Pine	Pine-hardwood	Hardwood	Cropland	Pasture	Idle	Miscellaneous
Forestry:							
Pine	.70	.19	.04	.05	.00	.01	.01
Pine-hardwood	.09	.54	.37	.00	.00	.00	.00
Hardwood	.00	.00	1.00	.00	.00	.00	.00
Agriculture:							
Cropland	.04	.02	.01	.81	.04	.08	.00
Pasture	.00	.05	.00	.00	.58	.32	.05
Other:							
Idle	.24	.08	.00	.40	.00	.28	.00
Miscellaneous	.00	.00	.00	.00	.00	.04	.96

tenth year of the 1950's and the off-diagonal elements of Table 6 must be decreased by 1/11 to adjust from eleven to ten seasons. Using pine as an example, the adjusted probability that use will change in the decade of the 1950's is given by (1.00 – .70) 1.11 = .33 and the probability of no change is .67. The comparable figures for the decade of the 1960's are (1.00 – .66) .91 = .31 as the probability of change and .69 as the probability of no change.

The shift out of pine took place at a somewhat slower rate (.26) during the 1940's than during the 50's and 60's with little difference noted in the latter

Table 6. CONDITIONAL TRANSITION PROBABILITY MATRIX, 1959-1970

Land use in 1959	Land use in 1970						
	Forestry			Agriculture		Other	
	Pine	Pine-hardwood	Hardwood	Cropland	Pasture	Idle	Miscellaneous
Forestry:							
Pine	.66	.15	.10	.04	.01	.04	.00
Pine-hardwood	.04	.73	.13	.03	.03	.03	.01
Hardwood	.01	.00	.97	.01	.00	.00	.01
Agriculture:							
Cropland	.03	.02	.01	.67	.14	.14	.00
Pasture	.00	.00	.00	.18	.70	.06	.06
Other:							
Idle	.20	.24	.08	.32	.04	.12	.00
Miscellaneous	.00	.00	.00	.00	.00	.04	.96

Table 7. CHANGE IN LAND USED FOR PINE FOREST IN DIAL CREEK WATERSHED, 1940 TO 1970[a]

Land shifted to pine			Land shifted from pine		
Acreage	Use in 1940		Use in 1970		Acreage
-	Pine	(no change-401 acres)	Pine		-
67	Pine-Hardwood		Pine-Hardwood		290
0	Hardwood		Hardwood		284
83	Cropland		Cropland		56
11	Pasture		Pasture		28
34	Idle		Idle		34
0	Misc.		Misc.		22
195	Total shift to pine		Total shift out of pine		714

[a]Total acreage in pine: 1940, 1,115 acres; 1970, 596 acres.

two periods (.33 vs .31 after adjustment). Much of this land shifted to pine-hardwood. Conversion of pine-hardwood to hardwood was most rapid during the 1950's.

Land shifted out of cropping uses during the first two decades moved into the idle classification most frequently, followed by pasture and pine, but during the decade of the 1960's the probability that cropland would be used as pasture was as great as that it would lie idle.

The transition matrices are useful in determining total acreages involved in land-use changes and can be obtained directly from Table 2. For any given land-use class, the row probabilities multiplied by the acreage in the watershed (3,384 acres) would indicate the movement from that class between 1940 and 1970. Similarly, the movement to a given land-use class can be estimated by multiplying the column probabilities by the watershed acreage.

Consider the 1,115 acres that were in pine in 1940 as an example (Table 7). By 1970 only 596 acres were still in pine, a net decrease of 519 acres. However, only 401 of the original 1,115 acres were still in pine. The left side of Table 7 shows that 195 acres in other land-use classes in 1940 had moved to pine by 1970. Offsetting this change were 714 acres of 1940 pine that went to other land-use classes in 1970, as shown by the right side of Table 7. Although

the net change was a loss of 519 acres in pine, 909 acres actually underwent land-use change over the thirty-year period.

SUMMARY

Transition matrices are an important research tool for analyzing land use changes. This paper presents a case study of the development of such matrices using aerial photographs as a data base, combined with careful field observations to establish current land-use practices at the selected sample points. Photographic data from flights at well-spaced intervals provide a basis for measuring and evaluating changes in land use. One important aspect of land use change demonstrated by the example is the significance of total movement of acreage among different uses as opposed simply to periodic net acreage change. In the study of which the example given here was a part [5], total movement was an important concern in measuring the hydrologic influence of land use changes.

The applicability of transition matrices to the investigation of problems of environmental quality arising out of shifts from either agricultural or forestry uses to urban uses is also worth mentioning. Conditional probabilities can be quite useful in quantitative analysis of the forces which are responsible for land use changes. Information concerning the relationship between number of sample points and reliability of the estimated probabilities would be valuable.

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