Classification of Timberland Productivity in Northwestern California Using Landsat, Topographic, and Ecological Data

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ABSTRACT: The United States Forest Service has recently undertaken several projects nationwide to examine techniques for mapping forest lands having three levels of productivity. Prime timberland is capable of producing 85 or more cubic feet of wood per acre year, non-prime timberland produces between 50 and 84 cubic feet of wood, and non-forest land produces less than 50 cubic feet. The purpose of this project was to evaluate the potential of Landsat derived vegetation classes, topographic data, and ecologically defined geographic zones for classifying and mapping forest land productivity over very large areas.

Two northwestern California sites were designated as study areas. Each area comprised over 2.2 million acres. The land area was classified into the three productivity classes using a statistically based linear model. Variables input to the model were assembled into a computerized grid-cell geographic data base to produce production class maps as well as tabular summaries of acreage per class.

Terrain aspect, derived from digital topographic data, was the variable having the highest correlation with productivity. Eco-zone and Landsat vegetation cover variables were ranked next. Elevation and slope percent ranked last, and were marginally significant to the models at the 0.05 level of probability.

Final classification maps provided a visual indication of the geographic distribution and extent of each productivity class. Acreage summaries gave a quantitative view of the proportion of land area in each class. The accuracy of the classification was considered acceptable because it was in general agreement with previous sample surveys.

The combination of vegetation cover data, obtained from Landsat, with topographic data and ecological zone information proved to be a cost effective method for inventorying and mapping forest land productivity.

INTRODUCTION

Federal, state, and local agencies have been mapping prime agricultural lands for several years, and most of this work has focused on the identification of lands for production of cattle and crops. Recently the United States Forest Service has undertaken several projects nationwide to examine techniques for mapping forest land units having various levels of productivity. Three productivity classes were chosen: (1) *prime* timberland, capable of producing 85 or more cubic feet of wood per acre per year; (2) *non-prime* timberland, producing between 50 and 84 cubic feet of wood; and 3) *non-forest* land, producing less than 50 cubic feet of wood.

The purpose of this project was to evaluate the potential of combining Landsat, topographic, and ecological zone data for classifying and mapping forest land productivity over areas in excess of two million acres. Specific objectives were to

- Develop a georeferenced data base for mapping timberland productivity.
- Develop and apply Linear Stepwise Discriminant Analysis (LSDA) models for classifying prime, non-prime, and non-forest land.
- Assess the accuracy of the models in predicting the three categories of forest land productivity.

PHOTOGRAMMETRIC ENGINEERING AND REMOTE SENSING,
Vol. 51, No. 11, November 1985, pp. 1745-1752.

0099-1112/85/5111-1745$02.25/0

BACKGROUND

Forest managers and researchers have used site index (the height of trees of a given species and of a given age) as a reliable measure of forest land productivity for many years (Spurr and Barnes, 1973). Site index is an expensive and inconvenient variable to measure for large land areas because the job requires field crews and sample surveys.

Aerial photographs have been used in previous studies to estimate productivity based on vegetation, topography, and soils (Choate, 1961). Photographs have greatly reduced the survey time needed when compared to ground sampling techniques, yet inventory continues to be labor intensive for large areas. Of special interest to this project was the digital data provided by the Landsat series of satellites.

Previous research indicated that spectal reflectance patterns, developed from Landsat data through computer classification, would provide vegetation cover information over large areas at lower cost than using aerial photographs (Fox *et al.*, 1983). The joint utility of Landsat and digital topographic data for estimating timberland productivity has been shown in recent research; however, the correlation between unclassified spectral data and productivity was shown to be weak (Tom and Miller, 1980). With this result in mind, it was decided to use classified Landsat data in order to compress the unclassified spectral data set from approximately 60 digital values in four channels to only 14 to 15 classes of land cover. Previous experience indicated that information critical to mapping levels of productivity would probably be contained in the classified data (Fox *et al.*, 1983).

Preliminary investigation and previous research (Zinke, 1961) indicated that soil series and class of parent material were not correlated with productivity in the two study areas. Therefore, it was decided that the survey would be completed without using soils data.

Ecological zone maps had been used previously to increase the detail of a Landsat classification (Fox and Mayer, 1981). These zones were defined to represent significant climatic and vegetative regions throughout an area. There was interest in the value of eco-zones for predicting productivity, compared to the value of topographic data and Landsat vegetation classes for making such predictions.

METHODS

This work was performed in two separate study areas (Figure 1) using slightly different data sets for each area. The northern study area (Humboldt County) represents a conifer forest region known to be highly productive, yet containing small regions of non-forest use. The southern area (Mendocino County) contains a greater range of conifer forest productivity and considerable non-forest acreage.

FIG. 1. Location of Humboldt and Mendocino Counties in California.

Both areas are mountainous with elevations ranging from sea level to 7000 feet.

Classifying the productivity of forest land with a linear stepwise discriminant analysis model (LSDA) required the definition of a categorical response variable (productivity classes) and a set of predictor variables (Landsat vegetation classes, ecological zone classes, and topographic variables). The goal of the analysis was to linearly combine the predictor variables to best classify timberland into one of the three productivity classes.

The following predictor variables were made available for use by the discriminant analysis models: vegetation cover as determined from classified Landsat data; elevation, percent slope, and aspect class defined by digital elevation data; and ecological zones (eco-zones) in Humboldt County only, as determined from existing map sources (Fox and Mayer, 1981). These variables were selected for this study based on two criteria: (1) that variables selected were probably highly correlated with productivity based on previous studies; and (2) variables could be obtained from satellite image data, digital elevation data, or published maps rather than from sample surveys or airphoto interpretation. The philosophy was to reduce the cost of the survey.

A supervised Landsat classification of vegetation cover was available for Humboldt County. It was developed for a previous project using guided clustering to select spectral statistics from training areas and a maximum likelihood algorithm for final classification (Fox and Mayer, 1981). This supervised classification of portions of two Landsat scenes (acquisition date: 12 April 1977) contained 14 categories tailored to forest communities including, in two cases, classes of species (Table 1). By contrast, an unsupervised classification was available for Mendocino County (Table 1). The unsupervised analysis was completed as part of a previous statewide land classification project and was based on a resampled mosaic of Landsat scenes obtained in the fall of 1976 (Tosta-Miller and Peterson, 1980). It contained 15 categories of general land cover as well as very generalized forest types such as conifer and broadleaf classes. These two methods of classification provided contrasting data sources and represented vastly different levels of technical work. The supervised classification required five times the effort of the unsupervised classification.

Topography was described by three variables: elevation, percent slope and aspect. These variables were derived from Defense Mapping Agency (DMA) digital terrain data provided by the U.S. Geological Survey (NCIC, undated). Elevation and percent slope were treated as continuous variables while aspect was categorized into eight compass directions: north, northeast, east, southeast, south, southwest, west, and northwest.

Six eco-zones were included in the analysis of Humboldt County only (Figure 2). These zones, developed for a previous project (Fox and Mayer, 1981), were defined to stratify significant changes in forest composition and local climate, and still be generalized enough to form a manageable number

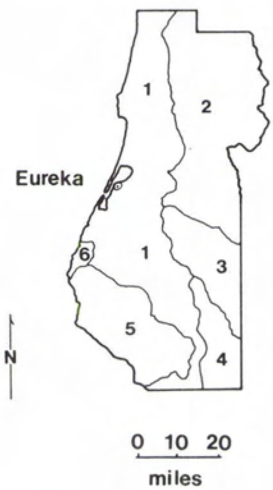

FIG. 2. Locator map for the six eco-zones used in the Humboldt County study area. The names of the zones are (1) Moist Coastal, (2) Moist Interior, (3) Dry Interior, (4) South Interior, (5) South Coast, and (6) Coastal Spruce.

of zones. Coast redwood (*Sequoia sempervirens*) is the major timber species in zone one, the moist coastal zone. The climate is mild. Mean daily maximum temperature during summer is 63°F. Mean daily minimum during winter is 41° F and precipitation is high (40 to 70 inches per year). Zone two, the moist interior, is dominated by Douglas-fir

TABLE 1. PREDICTOR VARIABLES AVAILABLE FOR ANALYSIS

Humboldt County Landsat Vegetation Classes*	Mendocino County Landsat Vegetation Classes**
1. Redwood Forest	1. Conifer Forest
2. Douglas-fir Forest	2. Dominant Conifer/Broadleaf
3. Dominant Douglas-fir/Broadleaf	3. Dominant Broadleaf/Conifer
4. Dominant Broadleaf/Douglas-fir	4. Broadleaf Forest
5. Mixed Conifer Forest	5. Open Conifer
6. Dominant Conifer/Broadleaf	6. Open Broadleaf
7. Broadleaf Forest	7. Brushland
8. Broadleaf Savannah	8. Open Shrub
9. Brush Land	9. Agriculture
10. Dominant Brush/Conifer Regeneration	10. Grassland
11. Agriculture	11. Bare Soil
12. Grassland	12. Rock
13. Bare Soil	13. Water
14. Other	14. Urban
	15. Other
Additional Variables	Additional Variables
15-20 Eco-Zones 1-6	16-23 Aspect Classes 1-8
21-28 Aspect Classes 1-8	24 Percent Slope
29 Percent Slope	25 Elevation (feet)
30 Elevation (feet)	

* Derived from supervised classification of Landsat MSS data.
** Derived from unsupervised classification of Landsat MSS data.

(*Pseudotsuga menziesii*), tanoak (*Lithocarpus densiflorus*), and Pacific madrone (*Arbutus menziesii*). The climate is more extreme than zone one with similar winter (41° F, mean daily minimum) and warmer summer temperatures (95° F, mean daily maximum) than zone one. Rainfall is as high as zone one. Zone three, the dry interior, is dominated by Douglas-fir and California black oak (*Quercus kelloggii*). The climate is characterized by warm summers (95° F), cool winters (35° F) and lower precipitation (52 inches) than zones one and two. Broadleaf species (tanoak and Pacific madrone) dominate the forest cover of zone four, the south interior. Temperatures in zone four are similar to zone three and precipitation is lower (35 inches). Zone five, the south coast, is characterized by Douglas-fir. The climate features wet winters (100 inches) and dry, hot summers (95° F). Zone six, coastal spruce, represents a small area dominated by sitka spruce (*Picea sitchensis*). The climate is mild yet characterized by harsh winter storms bringing high rainfall (100 inches per year). Temperatures are mild, similar to zone one.

The predictor variables (Landsat class, eco-zone, elevation, slope, aspect) were geographically registered and encoded into a grid-cell geographic data base (Smith and Blackwell, 1980). The grid-cell size was 100 metres by 100 metres (2.47 acres). A small training data set consisting of 19,382 grid cells was systematically sampled from both study areas, a total population of 1,855,572 grid cells. This was determined to be the largest sample obtainable, given constraints of time and cost. The sampled data was used to develop the predictive equations of the LSDA model.

The training data set contained the values of the predictor variables and the productivity classes. This information was used to develop the discriminant functions of the LSDA that were used to classify forest productivity throughout the study area. The values of the predictor variables were obtained from the data base for the training data set. Soil-Vegetation maps (U.S. Forest Service, 1961) were registered to the data base to provide forest productivity classes for the training grid cells. Forest productivity classes were not printed on these maps. However, Douglas-fir and Ponderosa Pine (*Pinus ponderosa*) site classes (ranges of site index) were printed in roman numerals for each forest vegetation type identified on these maps. These roman numeral site classes were transformed into forest productivity classes using U.S. Forest Service conversion tables (Table 2).

Discriminant functions were developed from the training data using an IBM 370 computer at the State of California's Teale Data Center with Statistical Analysis System (SAS) software, BMDP program 7M. The predictor variables of Landsat class, eco-zone, elevation, slope, and aspect class were treated differently depending on whether they were categorical or continuous variables. The categorical predictor variables were transformed because the statistical theory used to develop LSDA assumes continuous predictor variables. Landsat class, eco-zone, and aspect class were treated as if each class were a separate variable and coded as zero or one depending on the presence or absence of the class. For example, Landsat class one (redwood forest) was defined as its own variable, having a value of one if the grid cell was in this class and a value of zero if not. This has been shown to be a legitimate way to handle categorical predictor variables in LSDA (Hand, 1981). Percent slope and elevation were not transformed, as they were already continuous variables.

TABLE 2. THE RELATIONSHIP BETWEEN THE DOUGLAS-FIR AND PONDEROSA PINE SITE CLASSES, PRINTED ON THE SOIL VEGETATION MAPS, AND THE FOREST PRODUCTIVITY CLASSES USED IN THIS STUDY*

Forest Productivity Class	Douglas-Fir Site Classes Included	Ponderosa Pine Site Classes Included
Prime	I, II, III, IV	I, II, III
Non-prime	V	IV, V
Non-forest	(no symbol recorded)	VI, VII

* After pages 2490.6—9. *Forest Service Manual*, Region 5, Supplement 232, May 1980.

Predictor variables were selected by the computer program in a stepwise manner to maximize discrimination between productivity classes. Variables which did not provide statistically significant discrimination at the 0.05 level of probability were not included in the final equations. The discriminant functions, developed from the training data, were used to classify the entire geographical data base into the three productivity classes: prime, non-prime, or non-forest. The VICAR-IBIS software package (Smith and Blackwell, 1980) was used for this step. Finally, thematic maps of each study area were printed from the grid cell data base at 1:100,000 scale by Dynamic Graphics Inc., Berkeley, California.[1]

RESULTS AND DISCUSSION

Seventeen predictor variables were selected for inclusion into the discriminant model for Humboldt County and 18 were selected for Mendocino County. The variables are listed in order of selection by the LSDA stepwise process (Table 3). The selected set of predictor variables in Humboldt County consisted of eight Landsat vegetation classes, four eco-zone classes, four aspect classes, and percent slope. Predictor variables selected for Mendocino County

[1] The mention of a private firm is for clarity and does not imply endorsement.

TABLE 3. PREDICTOR VARIABLES LISTED IN ORDER OF SELECTION AT THE 0.05 PROBABILITY LEVEL FOR THE DISCRIMINANT FUNCTIONS

Humboldt County	Mendocino County
East Aspect	North Aspect
Southeast Aspect	South Aspect
South Aspect	Southwest Aspect
Southwest Aspect	West Aspect
Eco-Zone 1 (Moist Coastal)	Landsat Class Water
Eco-Zone 2 (Moist Interior)	Landsat Class Agriculture
Eco-Zone 5 (South Coast)	Landsat Class Bare Soil
Eco-Zone 6 (Coastal Spruce)	Landsat Class Grassland
Landsat Class Brush	Landsat Class Brushland
Landsat Class Brush/Regeneration	Landsat Class Broadleaf
Landsat Class Broadleaf	Landsat Class Open Conifer
Landsat Class Broadleaf Savannah	Landsat Class Open Broadleaf
Landsat Class Other	Landsat Class Dominant Broadleaf/Conifer
Landsat Class Bare Soil	Landsat Class Dominant Conifer/Broadleaf
Landsat Class Grassland	Landsat Class Conifer
Landsat Class Agriculture	Landsat Class Other
Percent Slope	Percent Slope
	Elevation

included twelve Landsat vegetation classes, four aspect classes, percent slope, and elevation. Landsat vegetation classes were more significant for determining site quality in Mendocino than in Humboldt. The inclusion of eco-zone classes in Humboldt reduced the need for vegetation classes because many of the eco-zone boundaries corresponded to vegetation type boundaries. Aspect class variables were selected first in both counties, reflecting their value in determining these three levels of productivity. The majority of the Landsat classes included in the models were either non-forest or broadleaf forest classes because conifer forest classes were not closely associated with productivity. The presence of broadleaf and non-forest vegetation influenced the model toward predicting a low productivity class. The species specific conifer classes, provided by the Humboldt Landsat classification, did not contribute significantly to the model.

The final classification maps (Figure 3) provide a visual indication of the geographic distribution and extent of each productivity class. These maps also provide a site specific indication of productivity. Area summaries were compiled by county (Table 4) and by county land-use divisions (Table 5).

Humboldt County was shown to be 74.7 percent prime forest and 24.5 percent non-forest. The non-prime class was shown to occupy 0.8 percent of the land area, sharply lower than that reported by the 1968 U.S. Forest Survey, which indicated that 12 percent of the land area is non-prime (Oswald, 1968). The non-prime area reported here generally agrees with the published site classes of the sample of grid cells taken from the soil-vegetation maps to develop the discriminant models (1.6 percent non-prime). The 1968 Forest Survey estimate of prime forest land was 14.9 percent lower than the estimate reported here in terms of land area classified and the non-forest area was 5.2 percent lower. Area summaries for Mendocino County agreed well with

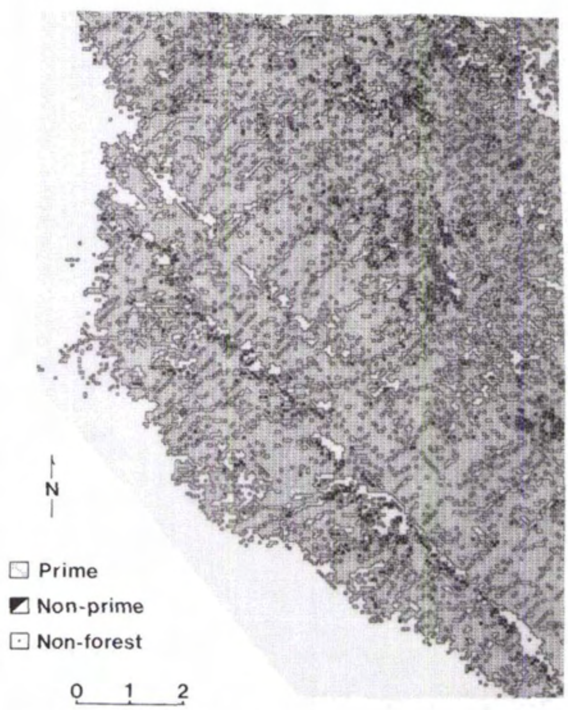

FIG. 3. Forest land productivity map for the south coast portion of Mendocino County.

TABLE 4. TABULAR SUMMARIES OF AREA BY COUNTY

Forest Productivity Class	Humboldt County		Mendocino County	
	Acres	Percent	Acres	Percent
Prime	1,740,142	74.7	805,429	35.7
Non-Prime	17,870	0.8	466,906	20.7
Non-Forest	571,541	24.5	981,374	43.6
Total	2,329,553	100.0	2,253,709	100.0

the Forest Survey (Oswald, 1972). The area of prime forest land reported here was 9.3 percent lower than the Forest Survey estimate; non-prime, 13.3 percent higher; and non-forest, 3.7 percent higher. These discrepancies are acceptable considering differences in the methods used by the U.S. Forest Service and the accuracy of the productivity data used in this study to train the discriminant models.

Site specific accuracy checks were made in both counties using a sample of the training data in Mendocino County and an independent test data set in Humboldt County (Table 6). Overall classification accuracy was reduced mainly by errors in the non-forest productivity class. A large number of non-forest grid cells were classed as prime in both counties. Many of these errors probably occurred because grid cells in the rangeland and agricultural areas on the Soil-Vegetation Maps were defined as non-forest land on those maps (i.e., the ground truth was non-forest). However, these areas did contain small groves of conifer forest, often larger than one grid cell in area. If a forested grid cell (labeled as a non-forest area on a soil-vegetation map) was in a highly productive eco-zone and aspect class, it was probably classed as prime, producing a classification error according to the evaluation rules used here. One might argue that these classifications were truly correct considering that many rangeland areas can become productive forests once trees are allowed to invade.

The cost of the project was $220,000, or 4.8 cents per acre (Table 7). The supervised Landsat classification (Humboldt) was approximately four times more expensive than the unsupervised (Mendocino). Map production and land area summary costs accounted for a third of the project budget. The project had research objectives which included software development that added to the cost of the inventory. An operational project of this scale could be done for approximately $150,000.

TABLE 5. TABULAR SUMMARIES OF AREA BY COUNTY AND BY LAND-USE DIVISIONS

Classification	Acres	Percent Prime	Percent Non-Prime	Percent Non-Forest
HUMBOLDT COUNTY				
Public Lands				
National Forest	381,161	84.0	0.0	16.0
National Park	84,944	71.5	0.0	28.5
State Parks	55,533	88.3	0.0	11.7
Bureau Land Mgm.	47,572	82.6	0.0	17.4
Indian Reservation	89,679	93.8	0.0	6.2
Total Public	658,889	84.0	0.0	16.0
Private Lands				
Timber Preserve Zone	1,159,003	77.4	0.6	22.0
Other Private	511,661	56.6	2.1	41.3
Total Private	1,670,664	71.0	1.1	27.9
MENDOCINO COUNTY				
Public Lands				
Jackson State Forest	49,836	62.8	1.7	35.5
Other Public	326,469	14.7	51.1	34.2
Total Public	376,305	21.1	44.5	34.4
Private Lands				
Timber Preserve Zone	1,722,923	39.6	16.7	43.7
Other Private	154,481	28.5	7.8	63.7
Total Private	1,877,404	38.7	15.9	45.4

TABLE 6. CONTINGENCY TABLES FOR THE CLASSIFICATION OF INDIVIDUAL GRID CELLS

HUMBOLDT COUNTY (Independent Test Data)

Forest Productivity	Percent Correct*	Number of Cells Classified Into Group: Prime	Non-prime	Non-forest	Total
Prime	90.7	2883	44	250	3177
Non-prime	86.7	8	52	0	60
Non-forest	65.6	178	37	410	625
Total		3069	133	660	3862
Overall accuracy**	86.6% correct				

MENDOCINO COUNTY (Training Data)

Forest Productivity	Percent Correct*	Number of Cells Classified Into Group: Prime	Non-prime	Non-forest	Total
Prime	78.1	3438	265	701	4404
Non-prime	81.8	0	9	2	11
Non-forest	65.4	587	197	1484	2268
Total		4025	471	2187	6683
Overall accuracy**	73.7% correct				

* Relative to errors of omission. Calculated by dividing the number of grid cells classified by LSDA into a particular class by the total number of grid cells actually occurring in that class.

** Calculated by summing correctly classified grid cells in all groups and dividing by the total number of grid cells evaluated.

CONCLUSION

Merging vegetation-cover classes derived from Landsat data, topographic parameters derived from DMA terrain data, and published eco-zone maps into a statistical model effectively produced three land-cover classes for mapping forest productivity. The aspect variable was most highly correlated with productivity. Eco-zone classes contributed to classification accuracy and reduced the number of vegetation cover classes required for prediction of forest productivity classes. Vegetation cover classes were also shown to be significant to the model. The non-forest classes such as grass or brush were more highly correlated with productivity than conifer forest classes. Non-forest classes were provided in equal detail by both the unsupervised Landsat classification and the supervised classification. However, the supervised classification was four times more expensive than the unsupervised. The most valuable contribution from this process is the thematic map. The "in-place" information provided by maps is not available from sample surveys.

TABLE 7. COSTS FOR MAPPING THREE CLASSES OF TIMBERLAND PRODUCTIVITY (U.S. DOLLARS TO THE NEAREST 100)

Salaries		
Landsat Classification		
Humboldt County	28,000	
Mendocino County	4,000	
Discriminant Function Development	53,000	
Thematic Map Production	35,700	
Total Salaries		120,700
Computer Processing		
Landsat Classification		
Humboldt County	10,000	
Mendocino County	7,000	
Discriminant Function Development	12,500	
Thematic Map Production*	28,100	
Total Computer		57,600
Administrative and Travel (total)		41,700
Total Project Cost		220,000
Cost per acre 0.048 (4,583,262 acres in two counties)		

* Includes the cost of developing software.

ACKNOWLEDGMENTS

The financial support of the U.S. Forest Service and the California Department of Forestry under Interagency Agreement No. 3-080-078 is gratefully acknowledged. A special thanks is also given to Dynamic Graphics Inc. of Berkeley, California for the in-kind contribution of software development and map production.

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(Received 23 June 1984; revised and accepted 6 May 1985)

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