Use of Topographic and Climatological Models in a Geographical Data Base to Improve Landsat MSS Classification for Olympic National Park

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ABSTRACT: An unsupervised computer classification of vegetation/landcover of Olympic National Park and surrounding environs was initially carried out using four bands of Landsat MSS data. The primary objective of the project was to derive a level of landcover classifications useful for park management applications while maintaining an acceptably high level of classification accuracy. Initially, nine generalized vegetation/landcover classes were derived. Overall classification accuracy was 91.7 percent. In an attempt to refine the level of classification, a geographic information system (GIS) approach was employed. Topographic data and watershed boundaries (inferred precipitation/temperature) data were registered with the Landsat MSS data. The resultant boolean operations yielded 21 vegetation/landcover classes while maintaining the same level of classification accuracy. The final classification provided much better identification and location of the major forest types within the park at the same high level of accuracy, and these met the project objective. This classification could now become inputs into a GIS system to help provide answers to park management coupled with other ancillary data programs such as fire management.

INTRODUCTION

DURING THE LAST DECADE, computer aided classification of Landsat MSS digital data for wildland resource inventories of large areas has been demonstrated to be a generally useful technique. In order to maintain acceptably high levels of accuracy, most of these projects were limited to applications where only the higher levels of classification hierarchies, such as level I or II (Anderson *et al.*, 1976), were required. However, many resources management applications require determinations at lower levels in classification hierarchies, and past studies indicated that attempts at more refined Landsat classification resulted in accuracies dropping below acceptable levels (Aldrich, 1979).

One approach in attempting to overcome these limitations is to use Landsat data from different seasons. As a general rule, multitemporal data sets improve Landsat vegatation classifications (Aldrich, 1979), but careful selection of image dates is important because separations are usually related to plant phenology. The use of accurately registered multitemporal data sets for Big Thicket National Preserve was useful in producing a more refined and accurate vegetation classification (Cibula and Nyquist, 1986). However, in some situations the spectral/spatial limitations of Landsat data cannot be overcome by multitemporal data sets. For example, in mountainous terrain, shadowing caused by lower sun angles during fall, winter, or spring obscures large areas where clear distinctions between conifers and hardwoods could otherwise have been made.

More recently, the geographic information system (GIS) classification approaches, in which Landsat, topographic, and other data in digital formats are geographically referenced to a common base, are being applied. Classification accuracies for nine forest site index classes were improved from 43 percent to 97 percent when 15 variables, in addition to the four Landsat MSS bands, were incorporated into a digital data base (Tom and Miller, 1980). Miller and Shasby (1982) describe how digital terrain data that operated with either subjective or quantitative classification criteria were incorporated with Landsat data to refine classification results for two different projects.

This article describes how the GIS approach using digital terrain data, geographical/climatological models, and Landsat data refined the level of vegetation/landcover classification for Olympic National Park while maintaining high levels of classification accuracy. The Olympic project was one of four cooperative projects between the National Park Service/Denver Service Center and NASA/NSTL Earth Resources Laboratory and was initiated in 1977 and completed during 1979. Subsequently, other investigators has reported on the use of similar techniques, e.g., Fleming and Hoffer (1979), Hoffer *et al.* (1979); Strahler *et al.* (1978), Woodcock *et al.* (1980), Shasby *et al.* (1981), and Hutchinson (1982). However, this study differs in that, in addition to topographic data, general precipitation differences were inferred from watershed delineations.

DESCRIPTION OF STUDY AREA

Olympic National Park, comprising some 800,000 acres, is located on the Olympic peninsula in the western portion of the state of Washington (Figure 1). The Olympic Mountain Range is the dominant feature of the park. Elevation ranges from sea level to the 2421 metre (7,965 foot) summit of Mount Olympus.

Geologically the Olympics are new montains with rugged, rocky, and angular peaks. The range is cut by a number of deep valleys, formed by rivers which flow to the nearby ocean. Glaciers as well as snow cover the highest elevations year round.

When the moisture-laden air moving eastward off the Pacific Ocean meets the mountainous barrier, it cools rapidly and heavy precipitation results. Consequently, the Hoh Valley and the western slopes of Mount Olympus are the wettest locations in the continental United States with 5 metres (200 inches) of precipitation per year. On the eastern side of the Olympics, only 65 kilometres (40 miles) distant from Mount Olympus at Sequim, Washington, there is precipitation of less than half a metre (17 inches) per year. This is the result of being in the rain shadow of these mountains.

Only within the last 25 years have the forest communities of Olympic National Park been studied to any extent (see, for example, Fonda (1967, 1969, 1974), Fonda and Bliss (1969), Franklin and Dyrness (1973)). The temperate rain forest reaches its maximum growth and development in the westward sloping valleys of the Quinault, Queets, Hoh, and Bogachiel Rivers.

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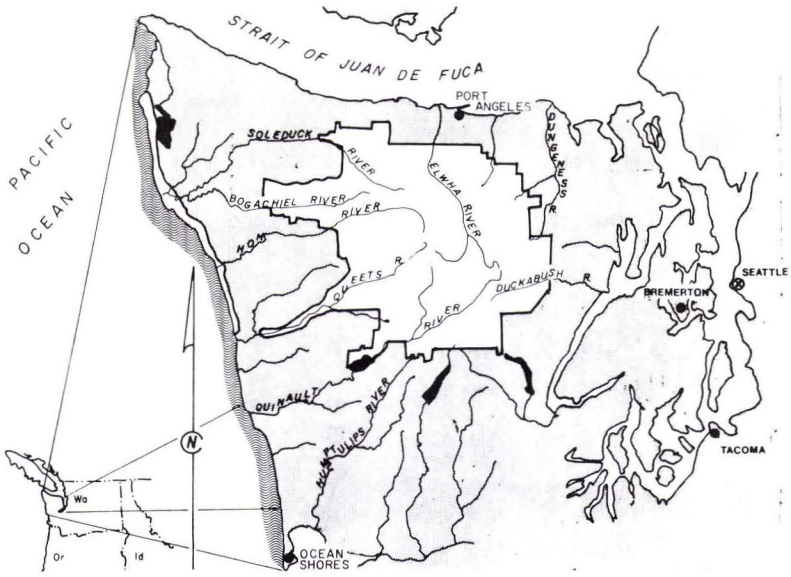

FIG. 1. Location of the study area. Olympic National Park consists of two discrete sections. The interior is the larger and includes parts of the watersheds of the major drainage systems. The coastal portion has as its entire western boundary, the Pacific Ocean. Both sections are shown as white in the landmass portions of this figure.

This forest in Olympic National Park represents one of the world's few temperate rain forests. In these western valleys, this forest is primarily composed of immense stands of western hemlock (*Tsuga heterophylla* (Raf.) Sarg.), Sitka Spruce (*Picea sitchensis* (Bong.) Carr), western red cedar (*Thuja plicata* Donn ex D. Don), and big leaf maple (*Acer macrophyllum* Pursh). Due to the almost continual moisture, branches, tree trunks, and even portions of the log littered forest floor are draped with clubmosses and lichens. These forests form ectomycorrhizae and as observed by Smith (1949), *Cortinarius* is one of the more important mycorrhizal associates.

At higher elevations (about 300 metres, 900 feet) Douglas fir and western hemlock dominate the forest community. Proceeding upward in elevation, one encounters a mountain forest of Pacific silver fir (*Abies amabilis* (Dougl.) Forbes), western white pine (*Pinus monticola* Dougl.) Douglas fir (*Pseudotsuga menziesii* (Mirb.) France), and western hemlock between 600 and 1000 metres (2000 to 3500 feet). This fir/pine/hemlock forest is gradually replaced by the sub-alpine forests of Pacific silver fir.

On the drier eastern slopes of the Olympics, species stratification changes markedly. The Sitka spruce, western red cedar community of the western slopes is replaced on the eastern slopes by a forest dominated by Douglas fir and western hemlock. At higher eastern elevations, silver fir predominates. Douglas fir and western hemlock are the major species of the mid elevations and are found from the eastern slopes of the Olympics to the Puget Sound. At low to mid elevations, where disturbances have removed the conifer forests, these forests are initially replaced with hardwood forests such as red alder (*Alnus rubra*. Bong).

METHODOLOGY

Four Landsat frames [1169-18375 (1/8/73), 2471-18205 (5/7/76), 5465-17490 (7/27/76), and 1781-18272 (9/12/72)] were chosen to be representative of each season in Olympic National Park. Because this area experiences few relatively cloud-free days per year, the seasonal data set selected was the only cloud free data set available for the study area. Natural color 1:24,000-scale aerial photographs taken by the Washington State Department of Natural Resources and flown in July and August 1976 were also available for use in the study.

Computer processing of the Landsat data was accomplished through the use of Earth Resources Laboratory Applications Software—ELAS (Graham *et al.*, 1980). The various overlays specifically used in this project have been briefly described by Cibula (1981).

All Landsat data were classified using SRCH, a module for an unsupervised spectral signature development, and MAXL, a module for maximum likelihood classification. The classifications were screened by both NPS and NASA personnel. In the January data, the classification was dominated by shadow areas as the sun had an elevation of only 19° at the time of the Landsat pass. To a lesser extent, shadowed areas were also prominent in the September data. In the May data, extensive areas of snow cover were still present and covered all the alpine meadow areas as well as being present in the forested areas at higher elevations. This analysis showed that the July data represented the best data to attempt a classification of the major land cover types to be found within the park. Although snow cover still was present at higher elevations, many of the meadow areas were now clear of snow. The July data were selected for further analysis.

The Landsat data were geographically referenced to the UTM system by picking control points identifiable in the data and on topographic maps (road intersections, confluences of streams, etc.). Next, the data were resampled to a 50 by 50-metre cell size using a nearest neighbor approach. The resultant data file had an RMS error of ± 60 metres. All ancillary files used in subsequent data base operations were also referenced to UTM coordinates and resampled to 50- by 50-metre cells.

Sites for each of the 29 SRCH-derived spectral classes of the classification were selected for field visitation. Five to 25 sites were chosen for each class, depending upon the extent of the particular spectral class in the park and also to account for topographic variability within spectral classes. Spectrally homogeneous areas at least 4 hectares (10 acres) in size that were close to landmarks which could be recognized easily in the field were the criteria for selection of field sampling sites. The use of these criteria would provide some assurance that field teams could accurately locate the selected sample sites in the field (Joyce, 1978).

The UTM coordinates of the center point of each sample site were derived from the georeferenced classified data and located

TABLE 1. FOREST CANOPY TYPES IN SPECTRAL CLASS THREE*

Plot	Sitka Spruce	Western Hemlock	Western Red Cedar	Mountain Hemlock	Pacific Silver Fir	Alaska Cedar	Aspect	Elev.(m)	Slope	Western White Pine
3-8				35	50		S	1128	31°	
3-7				25	15	15	E	963	10°	
3-9				20	50	10	S	823	13°	
3-6		30	30		15		E	158	3°	25
3-5		30	25		5		flat	146	0°	25
3-13	5	35	20				W	73	4°	
3-14	15	35	30				flat	24	0°	

*These numbers relate to percentages in the upper canopy for each species. Also, the order of individual plots in this table is such that similar major canopy types are consecutive. Note that, where western red cedar and western hemlock occur together, the elevations were not above 158 m (520 feet) whereas, the occurance of silver fir was not observed as a major overstory dominant below 823 m (2700 feet).

TABLE 2. SUMMARY OF FIELD DATA FOR FRAME 5465-17490

SPECTRAL CLASS	DESCRIPTION
1.	Water
2.	Lowland alder
3.	Coastal forest, hemlock, western red cedar, and western white pine; some areas of regeneration; high elevation silver fir
4.	Lowland alder or vine maple with some conifer as an understory component
5.	Lowland and high elevation rocks and bare areas
6.	Coastal forest, hemlock, and Sitka spruce; some areas of regeneration
7.	Water with some areas of kelp beds just off coast (*Macrocystis*)
8.	South slopes, mid- and low-elevation hemlock, and douglas fir
9.	Low elevation grasses and pastures
10.	Similar to 8; second growth Douglas fir in Skokomish
11.	Beach, sand, wet gravel, driftwood
12.	Low- and mid-elevation, old growth Sitka spruce, hemlock, Douglas fir
13.	Lowland alder, some areas mixed with young Douglas fir also being present
14.	Low- and mid-elevation, disturbed, bare, and grass
15.	Low- (but not flatland) and mid-elevation hemlock and Douglas fir
16.	Mid-elevation forest, old growth Pacific silver fir, some hemlock, and Douglas fir
17.	Beach and high elevation bare areas
18.	Lowland alder
19.	Lowland disturbed, with alder
20.	Lowland clearcuts and high elevation bare areas; some gravel in streambeds
21.	Shadows; some water
22.	Mid-elevation, old growth forest, north and northwest aspects
23.	Low- to mid-elevation forests, primarily Sitka spruce, and hemlock; some areas of Douglas fir at mid-elevations
24.	Low elevation clearcuts
25.	Lowland alder and other hardwoods
26.	Clearcuts and bare areas
27.	Snow, ice, glaciers
28.	Some water, shadows
29.	Beaches and bare areas that are wet

on USGS 1:62,500-scale topographic maps. These mapped points were then plotted on the aerial photographs using a Zoom Transfer Scope. Both the aerial photographs and maps were used to locate sites in the field. Some field teams collected data on the ground for sites close to roads or trails, while other teams used a helicopter to reach the more inaccessable areas and collected data while hovering over the site.

Ground reference forms and field sampling techniques were similar to those used in an earlier project at Big Thicket National Preserve (Cibula and Nyquist, 1986). This approach used a modified Braun-Blanquet technique in which ocular estimates of relative canopy coverage for dominant species in each canopy layer are recorded. Henderson (1979) has shown that ocular

VISUAL DATA ONLY

TABLE 3. GROUPING OF 29 SPECTRAL CLASSES INTO NINE COVER GROUPS

Group	Spectral Classes Included	Description
1	1, 7, 21, 28	Water, also some forest areas in deep shadows
2	11, 17, 29	Beach, wet sand, driftwood, moderately dark inert materials; includes high elevation bare areas
3	27	Snow, ice, glaciers
4	5, 20, 24, 26	Inert, clearcuts, some high bare areas
5	9	Pasture, other grasslands
6	3, 6, 14, 23	Coastal forest, hemlock, sitka spruce, some areas of regeneration
7	8, 10, 12, 15, 16, 22	Interior coniferous forest
8	4	Lowland hardwood (alder) with strong conifer understory
9	2, 13, 18, 19, 25	Hardwood, some with hardwood/conifer mix

estimates of species distribution provide comparable data in less time when compared to plot sampling techniques. Color photographs were also taken at the sites, and print(s) of each site were later incorporated with the ground truth forms.

Data for all sites that related to a specific spectral class were analyzed in detail to determine interrelationships between topographic features and the community types represented (Table 1). This was done for all spectral classes where there appeared to be a variation in the community type represented.

These data became the basis by which the 29 spectral classes were named (Table 2), and eventually these data were also an important part in developing the relationships used to refine the classification through the use of digital topographic data.

The results of this analysis did show that there was considerable overlap among spectral classes for different forest types, which is to be expected as this park is an area of great topographic relief. The field data and spectral plots were used to aggregate 29 spectral classes into nine broad land cover groups. Table 3 gives a description of these classes. The nine groups in Table 3 represent what the project particpants believed to be the best land-cover classification that could be achieved directly from these data.

Examination of the field data (see Table 1) as well as data obtained from independent field studies by the NPS and Dr. Jan Henderson (personal communication) strongly suggested that land-cover identification would significantly improve by stratifying topography and precipitation/climate regimes. DMA digital terrain data obtained from a U.S. Geological Survey (USGS) National Cartographic Information Center (NCIC) were registered to the UTM data base. Measures of elevation, slope, and aspect were derived from these data. Seven different wa-

TABLE 4. MATRIX MODELS FOR THE SEVEN DISCRETE GEOGRAPHIC/CLIMATOLOGICAL REGIONS IN OLYMPIC NATIONAL PARK AND ENVIRONS FOR ONE OF THE NINE GENERAL LAND-COVER CATEGORIES (GROUP 7, TABLE 3). THE GENERAL LAND-COVER GROUP IS REASSIGNED TO MORE SPECIFIC LAND-COVER CATEGORIES BASED ON THE WATERSHED, ELEVATION, AND ASPECT CHARACTERISTICS FOR A GIVEN PIXEL. FOR EXAMPLE, IF GROUP 7 (INTERIOR CONIFER FOREST) OCCURS IN PRECIPITATION MODEL 1 (SOLEDUCK) AND OCCURS ON NORTH ASPECTS AND ALSO OCCURS AT ELEVATIONS FROM 0 TO 152 METERS (0 TO 500 FT), THEN THIS GROUP BECOMES LAND-COVER CLASS 14 (LOWLAND WESTERN HEMLOCK, SITKA SPRUCE).

OLYMPIC NATIONAL PARK LANDSAT CLASSIFICATION

MATRIX MODELS USED TO OPERATE ON NINE GROUP LAND COVER CLASSIFICATION TO PRODUCE 21 GROUP CLASSIFICATION

ASPECT

ELEVATION	O	N	NE	E	SE	S	SW	W	NW
0–500	14	14	14	14	14	14	14	14	14
500–1000	13	13	13	13	13	13	13	13	13
1000–1500	13	13	13	13	13	13	13	13	13
1500–2000	12	12	12	13	13	13	13	13	13
2000–2500	12	12	12	12	13	13	13	13	12
2500–3000	12	12	12	12	12	13	13	12	12
3000–3500	12	12	12	12	12	12	12	12	12
3500–4000	12	11	11	12	12	12	12	12	12
4000–4500	11	11	11	11	12	12	12	12	11
>4500	11	11	11	11	11	11	11	11	11

MODEL 1 SOLEDUCK

ASPECT

ELEVATION	O	N	NE	E	SE	S	SW	W	NW
0–1000	13	13	13	13	13	13	13	13	13
1000–2000	13	13	13	13	13	13	13	13	13
2000–2500	13	12	12	13	13	13	13	13	13
2500–3000	12	12	12	12	13	13	13	13	12
3000–3500	12	12	12	12	12	13	13	12	12
3500–4000	12	11	11	12	12	12	12	12	12
4000–4500	11	11	11	11	12	12	12	12	11
>4500	11	11	11	11	11	11	11	11	11

MODEL 2 ELWHA

ASPECT

ELEVATION	O	N	NE	E	SE	S	SW	W	NW
0–2000	13	13	13	13	13	13	13	13	13
2000–2500	13	13	13	13	13	13	13	13	13
2500–3000	13	12	13	13	13	13	13	13	13
3000–3500	12	12	12	12	13	13	13	13	12
3500–4000	12	12	12	12	12	13	13	13	12
4000–4500	12	11	11	12	12	13	13	13	12
4500–4700	11	11	11	11	11	13	13	13	11
>4700	11	11	11	11	11	11	11	11	11

MODEL 3 QUILCENE

ASPECT

ELEVATION	O	N	NE	E	SE	S	SW	W	NW
0–2000	13	13	13	13	13	13	13	13	13
2000–2500	13	13	13	13	13	13	13	13	13
2500–3000	13	12	12	12	13	13	13	13	13
3000–3500	12	12	12	12	12	13	13	13	12
3500–4000	12	11	11	12	12	13	13	13	12
>4000	11	11	11	11	11	11	11	11	11

MODEL 4 HOODSPORT

ASPECT

ELEVATION	O	N	NE	E	SE	S	SW	W	NW
0–1500	13	13	13	13	13	13	13	13	13
1500–2000	13	13	13	13	13	13	13	13	13
2000–2500	13	12	12	13	13	13	13	13	13
2500–3000	12	12	12	12	13	13	13	13	12
3000–3500	12	12	12	12	12	13	13	12	12
3500–4000	12	11	11	11	12	12	12	12	12
>4000	11	11	11	11	11	11	11	11	11

MODEL 5 SHELTON

ASPECT

ELEVATION	O	N	NE	E	SE	S	SW	W	NW
0–500	14	14	14	14	14	14	14	14	14
500–1000	13	13	13	13	13	13	13	13	13
1000–1500	13	12	12	12	13	13	13	13	13
1500–2000	12	12	12	12	12	13	13	13	12
2000–2500	12	12	12	12	12	13	13	12	12
2500–3000	12	12	12	12	12	12	12	12	12
3000–3500	12	11	11	11	12	12	12	12	12
3500–4000	11	11	11	11	11	12	12	12	11
4000–4500	11	11	11	11	11	11	12	11	11
>4500	11	11	11	11	11	11	11	11	11

MODEL 6 QUINAULT

ASPECT

ELEVATION	O	N	NE	E	SE	S	SW	W	NW
0–900	14	14	14	14	14	14	14	14	14
900–1000	13	13	13	13	13	13	13	13	13
1000–2000	13	13	13	13	13	13	13	13	13
2000–2500	12	12	12	12	13	13	13	13	12
2500–2700	12	12	12	12	12	13	13	12	12
2700–3000	12	12	12	12	12	12	12	12	12
3000–3500	12	11	11	12	12	12	12	12	12
3500–4000	11	11	11	11	12	12	12	12	11
>4000	11	11	11	11	11	11	11	11	11

MODEL 7 HOH

IN THE ABOVE MODELS, THE ABSCISSA REPRESENTS THE ASPECT WHILE THE ORDINATE REPRESENTS THE ELEVATION. THE INPUT GROUP FOR THIS TRANSFORMATION WAS GROUP SEVEN (INTERIOR CONIFEROUS FORESTS). THE NUMBERS IN THE MATRIX REPRESENT THE NEW GROUP INPUT CLASS SEVEN BECOMES FOR A SPECIFIC ASPECT, ELEVATION AND MODEL.

THE FOREST TYPES REPRESENTED BY THESE NEW GROUPINGS ARE:

11 SUBALPINE FOREST, SILVER FIR

12 WESTERN HEMLOCK, DOUGLAS FIR, SILVER FIR

13 WESTERN HEMLOCK, DOUGLAS FIR

14 LOWLAND WESTERN HEMLOCK, SITKA SPRUCE

tersheds were identified on USGS maps, each with different precipitation/climate characteristics. The watershed polygons were digitized and registered to the data base (Figure 2).

The Landsat classification groups were subjected to boolean decision tests involving elevation, slope, and aspect in order to refine the nine-land-cover classes described in Table 3. Slope data were used to discriminate water from forested areas in shadow. For example, where spectral classes 1, 7, 21, and 28 (Table 3) occured on slopes greater than 5°, these classes were then classified as shadow instead of water. Group 4 (Table 3) represented bare agricultural fields, recent clear cuts, as well as barren areas of high elevation. These high barren areas were

TABLE 5. 21 GROUP OLYMPIC NATIONAL PARK LAND-COVER CLASSIFICATION

Group	Spectral Classes Included (Table 1)	Description
1	1, 7, 21, and where slope is less than 5°	Water
2	2 below 427 m (1400′)	Hardwoods or hardwood/conifer mix
3	4	Lowland hardwood or hardwood/conifer mix; may include brush or slash also with much conifer in the association
4	5, 20, 24, 26, below 1067 m (3500 feet)	Agricultural fields without vegetation or with very little (24); clearcut areas; slash; clearcuts w/early regeneration (ca 20–30% veg. cover or less); concrete; other inerts (includes some urban)
5	9	Pasture & other grasslands
6	11, 17, 29, below 533 m (1750 feet)	Beach, river gravel, wet sand, driftwood, moderately dark colored inert materials
7	1, 7, 21, and 28, where the slope is greater than 5°	Shadows
8	27	Snow, ice, or glaciers
9	2, 13, 18, 19, 25, above 2400′	Scrub; high elevation hardwood; vine maple and Sitka alder
10	17 and 24, above 533 m (1750 feet)	Alpine meadows (class 24 with sparse vegetation)
11	3, 6, 14, 23, modified as discussed in text to Group 7 (Table III)	Subalpine forest, Silver fir
12	" "	Western hemlock, Douglas fir, Silver fir
13	" "	Western hemlock, Douglas fir
14	" "	Lowland Western hemlock and Sitka spruce
15	3, 6, 14, 23, modified as discussed in text (Group 6)	Coastal hemlock, Cedar; some regeneration of these species in included (41)
16	5, 20, 26, above 1067 m (3500 feet); 17, above 533 (1750 feet)	Bare rock, in mountains
17	9 above 533 m (1750 feet)	High elevation bare areas which have partially regenerated
18	13	Hardwoods with various ratios of hardwood/conifer mix
19	18 Below 427 m	
20	19 (1400 feet)	
21	25	

delineated using the 1067-m (3500 feet) elevation level for the separation criterion. Analysis of group 5 (pasture and other grasslands) indicated that this group was also representative of high elevation areas that were regenerating following fire. Therefore, the 518-m (1700 feet) elevation level was used to separate regeneration areas from other grasslands.

Similar decision rules were applied to group 7 (interior coniferous forest, Table 3). Aspect, elevation, slope, and precipitation/climate regimes were used to process this group into four more specific coniferous forest types. These boolean decision rules may be envisioned as matrix models involving climatological regimes, elevation, and aspect. The models are given in Table 4.

RESULTS AND DISCUSSION

The new result of these operations yielded a 21-group land-cover classification. Table 5 gives the description for each of these groups. Plate 1 is a color coded map produced from this classification and Figure 3 is a synopsis of the information and rationale used to derive the final vegetation/land-cover classification. Acreage compilations for each class were produced for the coastal and interior units of the park (Table 6).

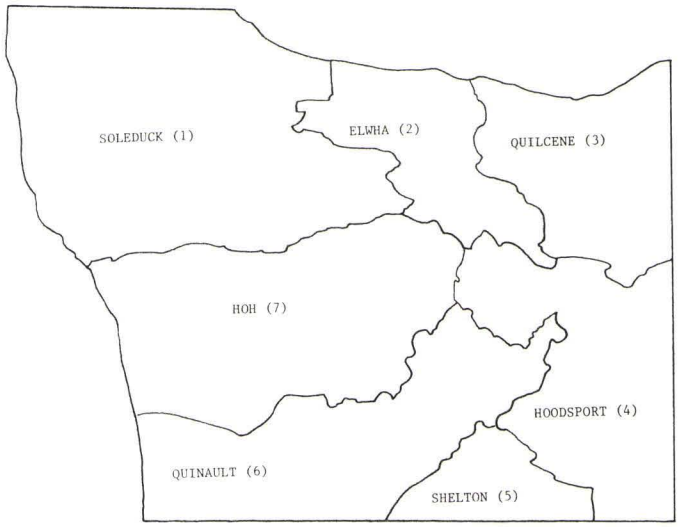

FIG. 2. Geographical/climatological regions used as one data channel in the GIS which was used with other data as described in text to develop the final land-cover classification of Olympic.

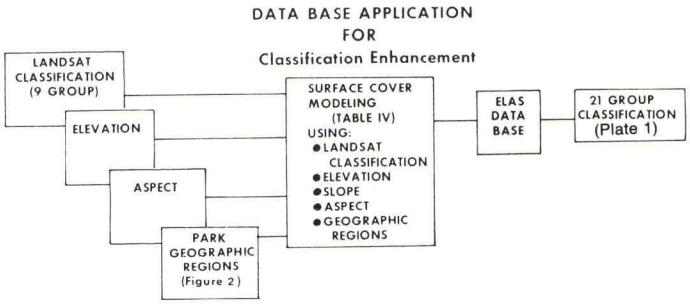

FIG. 3. Synopsis of data base elements and application for classification enhancement to produce final classification (Plate 1) of Olympic National Park.

For field verification, 200 random points were generated for the interior unit of the park while another 100 random points were generated for the coastal unit. For each site, a 15 by 15 matrix was printed with numbered groupings that corresponded to the groupings given for each of the two classifications as previously described (Tables 3 and 5). Each site was also plotted onto 1:62,500-scale USGS maps and onto 1:24,000-scale color aerial photography. Of the 300 randomly chosen sites, 253 were actually visited. Forty-seven sites were not visited because of adverse weather conditions or the field teams' uncertainty about exact location of the site in the field. The unvisited sites were not considered in the accuracy assessment.

The sites which were field checked were visited by ground teams and by helicopter. As described earlier, the sites were photographed and canopy analyses performed. The data for each site were examined first with respect to the nine group classification and secondly with respect to the 21 group classification. If the site was located at the junction of different land-cover types, each was examined, and assigned a group description. Then the matrices were examined in a 3 by 3 array about the center point (150-meter square area). The group number for the center point was noted, as well as any other group numbers which occurred within the 3 by 3 array. If there was a majority coincidence between the group number obtained in the matrix printout and the group description ascribed to the site on the basis of field analysis, the site was considered correct. If correspondence did not exist, the group classification was considered to be in error. Where the chosen site was located at the junction of different land-cover types, the majority of groups

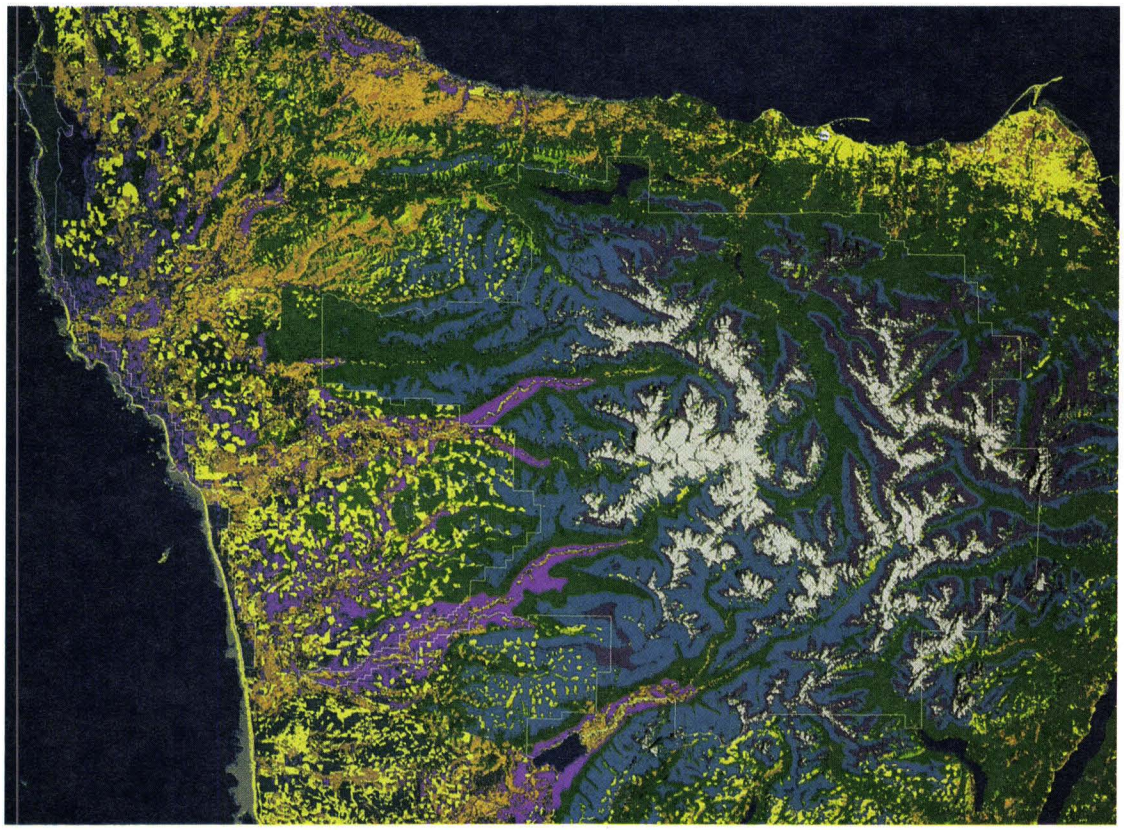

PLATE 1. Color coded land-cover classification for a 21-group land-cover classification of Olympic National Park. The colors depict the major vegetation of units and other land-cover types. The groups are those in Table 4. Color nomenclature is that of the ISCC - NBS (Inter-Society Color Council, 1965; Kelly and Judd, 1976). The park boundary is shown as white.

GROUP	COLOR	DESCRIPTION
1	#183 - dark blue	Water
2	#54 - brownish orange	Hardwoods
3		Lowland hardwood or hardwood conifer mix
4	#87 - moderate yellow	Agricultural fields without much vegetation, clearcut areas
5	#52 - light orange	Pasture and other grasslands
6	#265 - medium gray	Moderately dark colored inert materials
7	#267 - black	Areas in shadow
8	#263 - white	Snow, ice, or glaciers
9	#132- deep yellowish green	High elevation hardwood; scrub
10	#143 - very light green	Alpine meadows
11	#262 - grayish purplish red	Subalpine forests
12	#164 - moderate bluish green	Western hemlock, Douglas fir, Silver fir
13	#132 - deep yellowish green	Western hemlock, Douglas fir
14	#250 - moderate purplish pink	Lowland Western hemlock and Douglas fir
15	#174 - dark greenish blue	Coastal hemlock, cedar
16	#264 - light gray	Bare rock in mountains
17	#162 - very light bluish green	High elevation bare areas which have partially regenerated
18	#53 - moderate orange	Hardwoods with various ratios of hardwood/conifer mix
19	#51 - deep orange	" "
20	#38 - dark reddish orange	" "
21	#40 - strong reddish orange	" "

within the matrix had to consist of these differing land-cover types to be considered correct.

The results of these analyses are shown in Tables 7 and 8. An overall accuracy of 91.7 percent was obtained for both the 9- and 21-group classifications. Although the overall classification accuracies were the same, the 21-group classification was a significant improvement over the 9-group classification because the more detailed classes impart greater levels of information which are necessary for park management. In short, the 21-group product more closely matches the information needs for park mangement.

The lowest individual group accuracy recorded was 74 percent. As might have been predicted, the major source of error or confusion in both classifications was between the various conifer or hardwood/conifer mixed groups. Any number of factors, such as mixed pixels, inaccuracy of the boolean models, illumination effects, or small differences between some spectral classes, working independently or in concert could have caused

TABLE 6. ACREAGE COMPILATION FOR LAND-COVER CLASSIFICATION OF OLYMPIC NATIONAL PARK, 21-GROUP CLASSIFICATION

Group	Land Cover Description	Interior Portion Area Cov'd (Hectares)	Interior Portion % Of Park Covered	Coastal Portion Area Cov'd (Hectares)	Coastal Portion % of Park Covered
1	Water	2294	0.65	56	0.43
2	Hardwoods or hardwood conifer	840	0.24	341	2.5
3	Hardwood/conifer mix	9924	2.8	1120	8.6
4	Agriculture, clear cuts, other inert	1694	0.48	292	2.2
5	Pasture and other	232	0.07	199	1.5
6	Beach, wet river gravel, other dark inert	435	0.12	257	1.7
7	Shadows	2623	0.7	24	0.19
8	Snow, ice, or glaciers	33743	9.6	—	—
9	Scrub, high elevation hardwood, vine maple	3805	1.1	—	—
10	Alpine meadows	3811	1.1	—	—
11	Subalpine forest	52392	15.	—	—
12	Western hemlock, Douglas fir, Silver fir	109924	31.	—	—
13	Western hemlock, Douglas fir	81891	23.	—	—
14	Lowland Western hemlock and Sitka spruce	8887	2.5	2669	20.
15	Coastal hemlock, Cedar, some regeneration	1959	0.56	7268	56.
16	Bare rock in high mountains	31551	9.0	—	—
17	High elevation bare areas with regeneration	1592	0.45	—	—
18	Hardwood with various admixtures of conifer	739	0.21	74	0.57
19	Hardwood with various admixtures of conifer	73	0.02	38	0.29
20	Hardwood with various admixtures of conifer	139	0.04	245	1.9
21	Hardwood with various admixtures of conifer	1099	0.31	8	0.061
60	Imbedded boundary	1083	0.31	492	3.8
	TOTAL	350738		13088	

TABLE 7. OLYMPIC VERIFICATION MATRIX CLASSIFICATION A(9 GROUPS) TOTAL PARK

	Matrix 1	2	3	4	5	6	7	8	9	No. of Sites Visited
1	100									8
2		92.3					7.7			13
3			100							8
4				100						22
5					83.4				16.6	6
6						89.4	2.1	4.2	4.2	47
7			1.8	3.6		3.6	90.1		1.8	111
8						4.5	9.1	86.3		22
9									100	16

the associated themes to be misclassified. In addition, any classification tends to be a subjective abstraction and subtle differences of a few percent, either real or errors in ocular estimates in canopy coverage of co-dominant species (e.g., silver fir), could result in shifting one closely allied group (e.g., western hemlock/Douglas fir) to another (e.g., western hemlock/Douglas fir/silver fir) in the 21-group classification.

CONCLUSIONS

This study represents one of the first attempts to apply geographic models and topographic data with a computer assisted Landsat classification over an area as topographically and vegetationally diverse as Olympic National Park. It is notable that a high level of accuracy was maintained while the number of land-cover groups was increased from nine to 21.

The results of this project have been useful in a number of ways. Small inadvertent trespass logging incursions into the park were identified from the data and subsequently verified in the field by park personnel. Further boolean operations on data sets were performed to derive National Fire Damage Rating Systems fuel models and potential habitat for the spotted owl, a threatened species. One of the authors (Nyquist) has used the basic methodology developed during this project with more refined precipitation data to produce a highly accurate and more detailed vegetation classification for North Cascades National Park.

TABLE 8. OLYMPIC VERIFICATION MATRIX CLASSIFICATION (21 CLASSES) WHOLE PARK

Fld. Ver.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	Number of Sites Visited
1	100																					8
2		100																				8
3			82.3										5.9	5.9					5.9			17
4				93.8											6.3							16
5					75														2.5			4
6						100																8
7							—															
8								100														8
9									100													2
10										100												1
11											100											15
12			1.9									90.6	7.5									53
13			2.6									7.7	89.7									39
14		13	4.3											74	4.3					4.3		23
15															100							27
16														7.1		92.9						14
17																	100					2
18																		100				3
19																			100			2
20																				100		2
21																					100	1

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