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DEVELOPMENT AND TESTING OF LANDSAT-ASSISTED PROCEDURES FOR COST-EFFECTIVE FOREST MANAGEMENT

USDA, Forest Service
Contract No. 53-3187-2-24

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16. Abstract

The ERIM effort examined the capability of Landsat data to make certain forest management activities on the Clearwater National Forest in Idaho more efficient and/or more effective. One task was designed to evaluate the utility of single-date categorized Landsat data as a source of land cover information for use in assessing elk habitat quality. Landsat data was used to categorize conifer forest on the basis of the percentage crown closure. This information was used to evaluate elk habitat quality on the basis of the ratio of cover to forage. Our preliminary conclusion is that categorized Landsat data can be helpful for assessing current elk habitat quality if the relationships between crown closure and hiding cover can be adequately defined.

Another task was designed to evaluate the utility of merged two-date Landsat data for updating the existing (1972) Clearwater Forest land cover information. Landsat data from 1972 and 1981 were merged, and change images were created. These products indicated where major changes were taking place. These areas could then be examined on aerial photography or in the field to further characterize the nature and magnitude of the change. The 1972 land cover information could be subsequently altered in these changed areas, whereas areas with no change would not have to be re-examined. Our preliminary conclusion is that Landsat change images for stratifying on the basis of change could make updating of data bases more efficient than would be possible without such stratification.

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ERIM staff members making special contributions included Norm Roller, who provided helpful discussions on elk habitat quality. Larry Reed produced the geometrically-corrected two-date Landsat data file, and provided other invaluable assistance. Jim Balcerski was especially helpful in producing various image products which were so important to this study. Nancy Ballard was extremely helpful in preparation of the final report.

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INTRODUCTION

This report discusses work performed on contract 53-3187-2-24 during the period March to September 1982. The work presented here is part of a six-year program between the U.S. Forest Service and the Environmental Research Institute of Michigan (ERIM) to develop, test, and transfer to the Forest Service Landsat-based procedures, algorithms, and products identified as being of potential use to the Forest Service. The efforts conducted by ERIM are funded and administered by the Nationwide Forestry Applications (NFA) Program.

The work reported here was done in cooperation with the Clearwater National Forest and Region I. Two major activities were undertaken: (1) Investigation of the utility of Landsat data for updating land cover information; and (2) Investigation of the utility of Landsat and other data for evaluating elk habitat quality. The initial plan for these activities was based on an NFA project report which analyzed important issues on the Clearwater National Forest (Clark, 1981). This plan was subsequently refined in a meeting between ERIM personnel and NFAP technical monitor Jim Bell in a meeting at ERIM in April 1982. Further changes in these plans were made in a meeting between ERIM, NFAP, and Clearwater National Forest personnel at Orofino, Idaho in late July 1982.

BACKGROUND

Since 1975, ERIM has been working under funding from the U.S. Forest Service to help solve resource management problems on National Forests. Early efforts in 1975-76 concentrated on the assessment of the classification accuracy of forest cover classes obtainable with remotely sensed data of varying degrees of spatial resolution. The test area for the study was the Sam Houston National Forest in Texas.

Work began again in 1978. For the 1978-79 period, ERIM further developed precision Landsat geometric correction software and adapted spatial averaging (BLOB) and change vector analysis (CVA) techniques (originally developed under NASA funding) to estimating changes in forest cover between 1972 and 1975 on the Palouse District of the Clearwater National Forest in Idaho (Thomson, et al., 1980). The Landsat geometric correction software was transferred to the Forest Service Ft. Collins Computer Center.

Focus of the 1979-80 work was Kershaw County, South Carolina. At this stage of the development of change detection techniques, it became clear that automatic change detection procedures showed considerable promise and that, furthermore, Geographic Information System technology could help the Forest Service meet new management objectives. Accordingly, ERIM prepared a five year work plan showing how these technologies could be tested, refined and transferred to the Forest Service. The Kershaw County work concentrated on refinement of automatic change detection and identification procedures, and was the first phase of work under the five year plan (Colwell and Weber, 1981).

In 1980-81, still in keeping with the plan, efforts shifted to the San Juan National Forest in Colorado (Colwell, et al., 1981). The purpose of shifting the test site was to evaluate the change detection procedures, refined by the experience in Kershaw County, in a different forest environment in support of an ongoing effort to develop a forest land management plan. Also, we began refinement of existing Geographic Information System techniques for eventual transfer to the Forest Service.

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IDAHO CHANGE DETECTION

Effective management of the National Forest System's Lands of the U.S. Forest Service depends on an adequate data base of information. Considerable effort is frequently required to construct such a data base, as exemplified by the current Land Management Planning effort in progress on all Forests throughout the country. In areas of considerable change, it is necessary to update this information frequently. Because of increasingly scarce resources and increasing demand for more effective utilization of our National Forest lands, rapid, efficient procedures for updating data bases are required. The objective of the change detection task is to assess the utility of Landsat data for updating data bases.

3.1 BACKGROUND

A basic philosophy we bring to this task is that information should not be thrown away. We do not believe that any components of a data base should be discarded unless better information is available.

Two implications of this point-of-view are that: (1) Landsat data generally should not be the primary source of detailed information in a forest environment if there are superior alternative sources of such information (e.g., aerial photos and field observations); and (2) Landsat data may be most effective if used to assist in updating certain portions of an existing data base.

3.2 APPROACH

In keeping with this perspective on the appropriate use of Landsat data, we decided to determine the utility of Landsat data for updating the 1972* Clearwater National Forest land cover information to 1981 conditions by examining 1972 and 1981 Landsat data in conjunction with

*Although this is generally referred to as 1973 information, since it is based largely on analysis of 1972 aerial photos we will refer to it as 1972 information in this report.

1972 and 1981 aerial photography. The task activities are indicated in Figure 1. It was hypothesized that Landsat data would be able to indicate which portions of the Forest changed appreciably in terms of land cover. Such information would permit the allocation of most subsequent work towards altering the land cover information in the changed areas, rather than allocating uniform effort to the whole Forest, most of which is unchanged from 1972. This prioritization of resources could make updating the land cover information more timely and more efficient in view of the limited resources.

3.2.1 DATA SELECTION

Initial discussions concerning the data base on the Clearwater National Forest indicated that the present land cover information is based largely on analysis of 1972 (1:63,360 black-and-white) aerial photos. An update of the land cover information could be based largely on analysis of 1981 (1:12,000 color) aerial photos but current staff and funding levels apparently preclude that possibility. We chose to determine whether concurrent analysis of Landsat data could make this job more tractable.

We selected Landsat scenes which approximately matched the aerial photographic data of 1972 and 1981. Only one scene (Path 45, Row 27), covering approximately 60% of the Clearwater National Forest, was selected for each date for a demonstration project. The best, most cloud-free Landsat data available were 29 August, 1972 (Scene #1003718030), and 4 July, 1981 (Scene #2235517481). Both scenes are virtually snow-free, but the 1972 scene has some clouds in the southwest corner of the frame.

3.2.2 DATA PREPARATION

In order to analyze Landsat change detection capabilities, we first prepared a geometrically corrected data set. The 1972 Landsat data were geometrically corrected using a set of ground control points and a non-

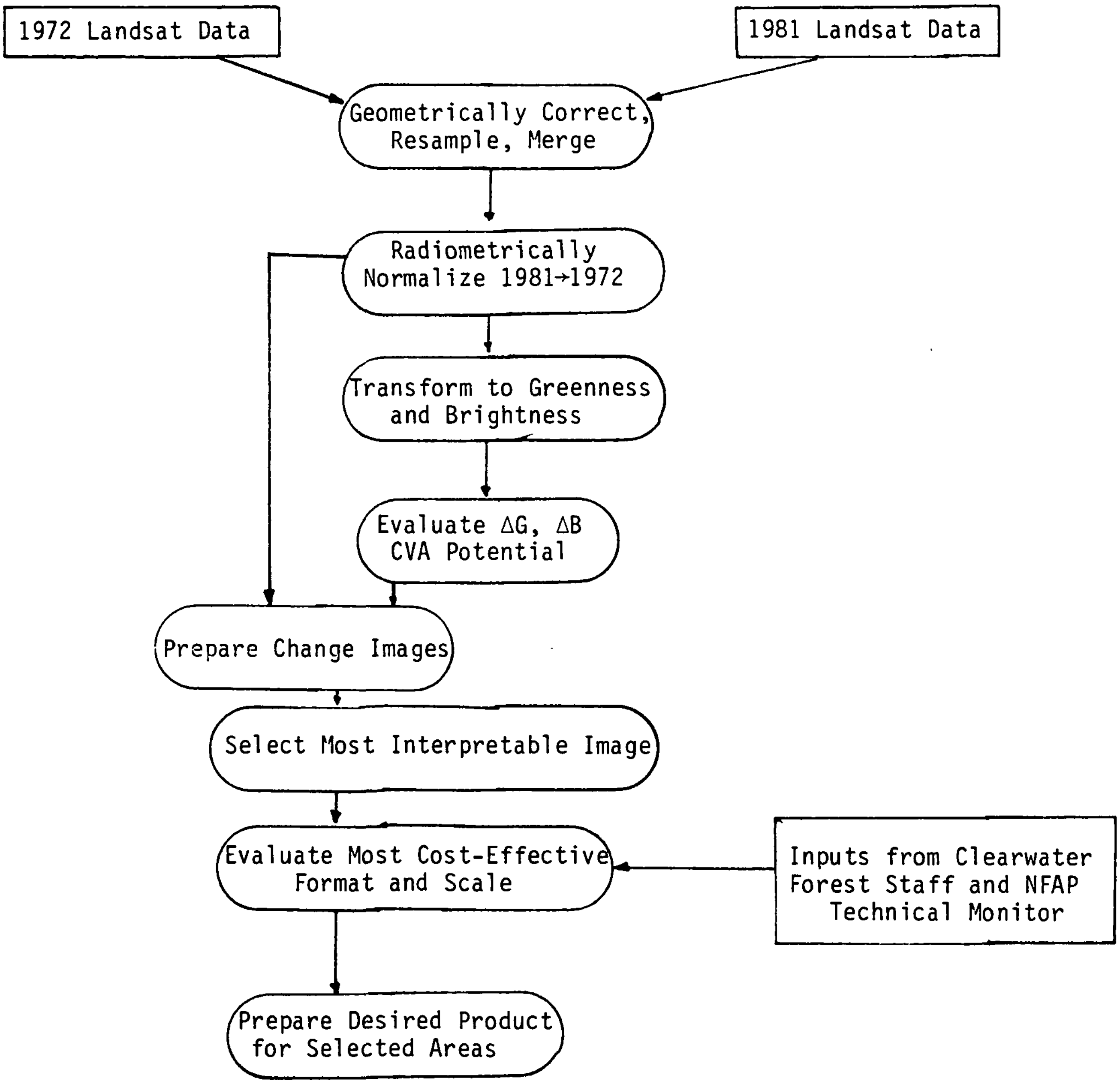

FIGURE 1. FLOW CHART FOR CHANGE DETECTION TASK

linear geometric correction model developed at ERIM. The 1981 Landsat data is an EDIPS "a" tape, which does not contain sufficient information on satellite parameters to implement the ERIM geometric correction model. As of 9/31/82, ERIM has the capability to implement a "reduced-capability geometric correction model on EDIPS "a" tapes. As a result, the 1981 data was corrected to the 1972 data by geometric regression techniques, which are less accurate than the ERIM model. Both scenes were resampled to 50 m pixels in a UTM projection.

In order to radiometrically normalize the two dates of data, radiometric corrections were empirically established. This was accomplished by comparing signatures of unchanged features in the two scenes and determining a regression relationship between the two dates for each channel. These relationships were then used to normalize the 1981 data to the 1972 data. The relationships used are indicated in Table 1.

TABLE 1. COEFFICIENTS FOR RADIOMETRICALLY CORRECTING 1981 DATA TO 1972 DATA

	MSS4	MSS5	MSS6	MSS7
Gain	2.06	1.77	1.65	1.79
Offset	+11.3	+3.3	-1.58	-1.22

Since 1979, ERIM change detection activities have involved development of digital change detection procedures (which we call BLOB/CVA), and comparison with alternative change detection procedures (e.g., Malila, 1980; Colwell and Weber, 1981). Since our original plans were to implement BLOB/CVA on the Clearwater data, we began by implementing the necessary preprocessing.

Before implementing the BLOB/CVA procedure the data must first be transformed from four channels of Landsat data on each of two dates to Brightness and Greenness channels on each date. One approach is to apply the coefficients and offsets developed by Kauth and Thomas (1976).

This method was not used, as those coefficients were developed for an agricultural scene in Illinois and may not be representative of the range of conditions found in the mountainous, forested environment of the Clearwater National Forest. Also, EDIPS data Tasseled Cap coefficients were not available.

The following approach was used to develop a set of coefficients to transform the Idaho data to Brightness and Greenness. Four-band spectral signatures for the cover types present were extracted for each date, and the principal components of each date were determined. Many signatures were taken in the bare soil and bare rock category to ensure that the first principal component of variation would be parallel to the bare soil line. Subsequent analysis proved this had been achieved.

The coefficients of the first two principal components of variation, which we will call Brightness and Greenness, represent over 99% of the variation in the data set. Since the respective coefficients for the two dates were almost identical, they were averaged so that a single set of coefficients could be utilized for both dates. These average coefficients are shown in Table 2. Additional offsets and gains were applied to the Greenness transform to make the Greenness and Brightness scales equivalent.

TABLE 2

COEFFICIENTS USED TO TRANSFORM LANDSAT DATA
TO BRIGHTNESS AND GREENNESS

	PC1 (Brightness)	PC2 (Greenness)
MSS4	.497	-.518
MSS5	.503	-.464
MSS6	.512	.376
MSS7	.487	.612

3.2.3 SPECTRAL INDICATIONS OF CHANGE

During the trip to Orofino in July 1982, a reconnaissance of the study area was conducted which allows for interpretation of some of the features seen on the Landsat imagery, as discussed in the following material. Both on-the-ground field observations and photos were obtained.*

Figures 2 and 3 show the Landsat color IR appearance of the Osier Ridge area on 1972 and 1981, respectively. The low-altitude aerial oblique in Figure 4 was taken at point "a", looking south along the ridge between Laundry Creek and China Creek. A partial cut (foreground) and a clear cut (middle ground) both show a significant amount of non-coniferous green vegetation in the understory. This vegetation may actually make a site in which the overstory has been removed look "greener" than when the overstory is present. As a result, Greenness may be difficult to interpret in trying to detect conifer cutting in this particular situation. Note, however, the considerable shadow cast by the remaining conifers in the partial cut. This shadow is the most distinctive attribute of these conifer stands, and it is manifest in the stand's brightness or albedo. In a similar situation, Colwell (1981) has shown that the relative amount of shadow furnishes a measure of the presence and amount of vegetation. Procedures outlined in that paper may eventually prove applicable to monitoring conifer density in this environment, but development of those procedures is a research topic that was not examined in this investigation. Clear cuts on northwest facing slopes in the background of Figure 4 can be seen to have a darker appearance in the Landsat image (Figure 3) than the southeast facing slopes. This illustration shows the effect of slope and aspect on the Brightness of an area.

*This reconnaissance was conducted in conjunction with and in cooperation with NFAP investigators from the University of California, Berkeley.

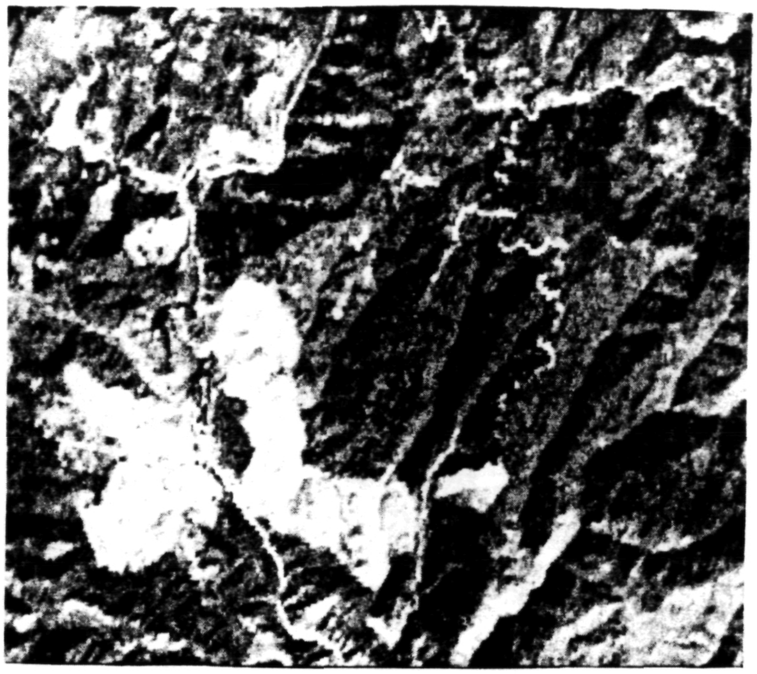

FIGURE 2. 1972 COLOR IR IMAGE OF OSIER RIDGE AREA

FIGURE 3. 1981 COLOR IR IMAGE OF OSIER RIDGE AREA

FIGURE 4. A LOW-ALITUDE AERIAL OBLIQUE TAKEN AT POINT "A" IN FIGURE 3.

FIGURE 5. A LOW-ALTITUDE AERIAL OBLIQUE TAKEN NEAR POINT "B" IN FIGURE 3.

Some of the other non-forested sites have appreciable green vegetation, as indicated by the aerial oblique shown in Figure 5, taken near point "b" (Pollock Ridge) on Figure 3. Figure 5 is a non-forested site, perhaps the result of an historical fire and/or a dry, steep southeast slope that is not favorable to conifer regeneration. It can be seen that such sites do not look significantly different from cut-over areas with understory vegetation.

A number of spectral signatures of Greenness and Brightness for 1972 and 81 were obtained for both changed and for unchanged features. The changes in Greenness and Brightness were then computed and are plotted in Figure 6.

Figure 6 suggests that the change in Brightness is more consistently useful than change in Greenness for this particular data. Some "unchanged" grass/brush features were found to have a greater change in Greenness than some clear cuts, whereas cutting tended to have consistently higher values of change in Brightness than did other features in the scene.

Change in Greenness may have reduced utility for this project for several reasons. One reason for the low utility of Greenness information is that conifer stands in this environment have low Greenness values that are not markedly different from bare soil. Thus, the effect of deforestation or reforestation in the Greenness channel is mainly dependent on understory conditions, including site preparation, and the amount of understory vegetation and its phenological state. The change in Greenness could, therefore, vary from a large positive change to a negative change.

Another reason for the low utility of Greenness information in this environment is the presence of an apparent phenological difference as a result of slightly different acquisition dates for 1972 and 1981 data (late August vs. early July). Although the phenological shift does not affect conifer stands ($\Delta G = 0$), it <u>does</u> affect some understory species

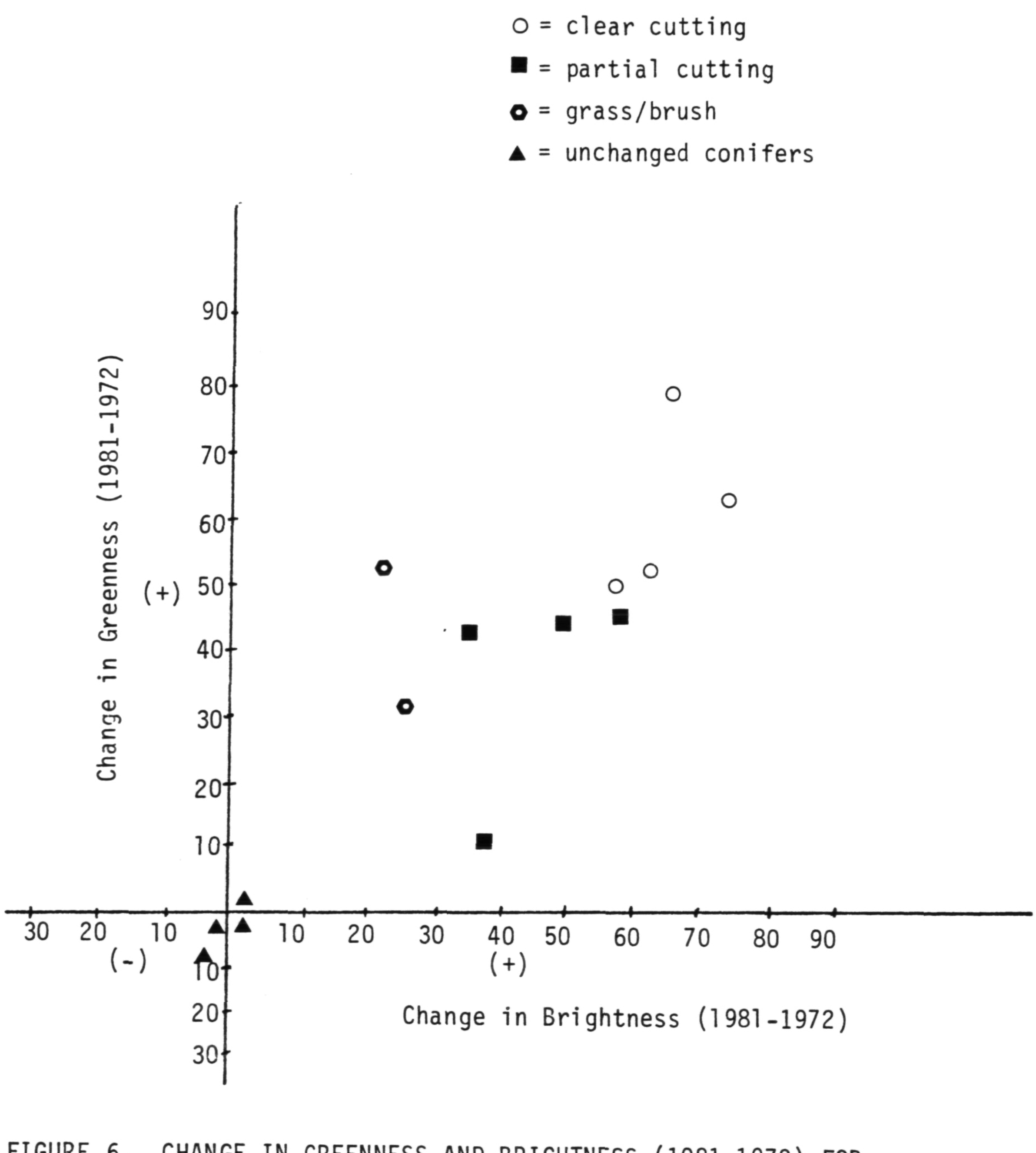

FIGURE 6. CHANGE IN GREENNESS AND BRIGHTNESS (1981-1972) FOR SELECTED FEATURES.

(especially grasses and other annuals) which have significant response in the Greenness channel. The result is that where the understory is the dominant feature (e.g., recent clear cuts or poor [non-forested] sites), the 1981 data tends to have greater Greenness values. This phenomenon is apparently largely due to grasses and other annuals being green on July 4, 1981 and being less green (senescent) on August 29, 1972. We observed this phenomenon even in areas where the 1981 aerial photos show very little tree cover (<10%), so the phenomenon is not due to reforestation. The same phenomenon was also observed on grass rangeland adjacent to the Forest.

Because of the foregoing difficulties in interpretation of Greenness information, change detection efforts for this project have concentrated on interpretation of Brightness information. Analysis of selected signatures has shown that both clear cuts and partial cuts produce an increase in Brightness from 1972-1981. Clear cuts tend to have a greater increase in Brightness than partial cuts, a finding which is consistent with the shadowing caused by confier cover.

As a result of the variable and potentially very large changes in Greenness on both changed and unchanged areas, use of a digital CVA procedure based on change in Greenness and Brightness for detection of change was considered inappropriate for this project. Changes which are unimportant for forest management (e.g., due to phenological differences) have potentially large change vectors ($\Delta G^2 + \Delta B^2$) which might be quantitatively indistinguishable from real change using CVA*. Accordingly, we decided it was more appropriate (as well as less costly) to

*These results appear to be consistent with a previous project on the Clearwater Forest (Thomson, et al., 1979), in which deforestation was characterized mainly by an increase in Brightness, which could be associated with a positive or negative change in Greenness. Greenness information was not as ambiguous in the previous project, apparently because there was phenological similarity between the two acquisition dates.

examine the utility of change images, particularly those based on changes in Brightness. A qualitative indication of change was also considered more appropriate because imperfect scene registration between an EDIPS (1981) and non-EDIPS (1972) tape could produce quantitatively inaccurate indications of change using BLOB/CVA. Qualitative analysis of a variety of change images is discussed in the following section.

3.2.4 CHANGE IMAGES

Several of the types of change images that were examined are shown in Figures 7 through 12. Some of the characteristics of those change images are described in the following material. Figure 7 displays the changes in Brightness from 1972 to 1981. The areas that were cut between 1972 and 1981 are the brightest features (largest positive change) in the image, as expected. A color image of this information is shown in Figure 8, with 1981 Brightness color coded red and 1972 Brightness color coded cyan.

Figure 9 is an image showing the change in Greenness from 1972 to 1981. It can be seen that many of the areas cut prior to 1972 have a greater positive change in Greenness than many of the recent (post-1972) clear cuts.

Figure 10 is an image prepared by color coding the change in Brightness (1982-1971) as red and the change in Greenness as cyan. Areas with a large positive change in both Greenness and Brightness appear white, whereas areas of no change (mainly conifer forest) appear black. Areas characterized mainly by a change in Brightness are red, and areas characterized mainly by a change in Greenness are cyan.

Because of the slope/aspect effect on Brightness, we hypothesized that some relative measure of change in Brightness might be more interpretable than an absolute change in Brightness. As one test of this hypothesis, we examined a normalized Brightness difference transformation, B_2-B_1/B_2+B_1. This transformation might be appropriate to use

FIGURE 7. CHANGE IN BRIGHTNESS (1981-1972) White is high positive change and black is low or negative change.

FIGURE 9. CHANGE IN GREENNESS (1981-1972) White is high positive change and black is low or negative change.

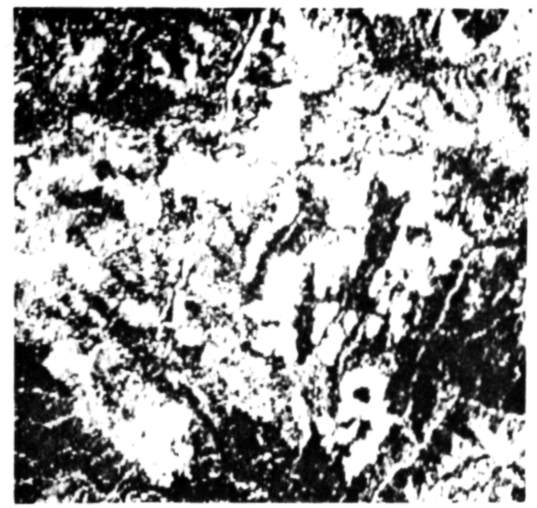

FIGURE 11. NORMALIZED BRIGHTNESS DIFFERENCE. (B_2-B_1/B_2+B_1). White is high positive change and black is low or negative change.

FIGURE 8. TWO-DATE BRIGHTNESS IMAGE
(1981 Brightness=red; 1972 Brightness=cyan)

FIGURE 10. CHANGE IN GREENNESS AND BRIGHTNESS. (ΔBrightness=red; ΔGreenness=cyan).

FIGURE 12. TWO-DATE MSS5 IMAGE
(1981 MSS5=red; 1972 MSS5=cyan)

if a digital change detection algorithm were required. However, for purposes of this project, it is anticipated that visual interpretation can be used. A normalized Brightness difference image (Figure 11) does not seem markedly different from the change in Brightness image (Figure 7) and since the human brain can account for some of the variations in Brightness due to slope and aspect, perfect normalization of these variations may not be crucial.

The above approaches were compared with another approach which has proven to be successful in other applications. This approach is to interpret change on the basis of differences in MSS5 on the two dates. Although in theory such a procedure has less information than some of the other procedures examined, it has the advantage of simplicity and of being easily understood. And since the digital signal levels in all bands are negatively correlated with stand density for these predominantly conifer stands, addition of information to that present in MSS5 was not considered especially helpful. In fact, addition of a third channel appeared to make interpretation of a three-color false color change image more difficult.

Following the example of operational Canadian procedures we color coded the early (1972) MSS5 channel blue and green (cyan), and the later (1981) MSS5 channel red (Figure 12). This procedure resulted in loss of vegetation (e.g., logging) appearing red and gain of vegetation (e.g., increasing grass and shrub cover on clear cuts) appearing cyan. The intensity of the red color is related to the intensity of logging. Clear cuts tend to be a brighter red than partial (selective) cuts. Features that had no change appear in shades of gray (a mixture of all three primary colors), from black to white. Thus the change image looks much like a familiar panchromatic image, except for areas of change.

The resulting change MSS5 image was compared with other forms of change images, and for this particular application, the MSS5 change image appeared to be as useful as any of the other images. Because of

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the high degree of interpretability associated with the MSS5 change image, we recommend it be used in this environment as a guide to where changes are taking place.

A similar result has been obtained by Canadian scientists who compared the utility of a change in Greenness to a change in MSS5 values for assessing deforestation in New Brunswick (Banner and Lynham, 1981). They found that the MSS5 change image was more effective because regrowth of a herbaceous layer affected the Greenness measure and thus became a potential source of confusion.

3.3 RESULTS

All of the change images that we generated were shown to Clearwater Forest staff members in a meeting at Orofino, Idaho in July of 1982. The consensus of the staff members seemed to be that the MSS5 change image with 1972 MSS5 color coded cyan and 1981 MSS5 color coded red was as good as or better than the alternatives.

It was then necessary to determine the most desirable format of that product. A 1:24,000 MSS5 change image transparency was prepared for the Osier Ridge Quadrangle and was shown to the Clearwater Forest staff. Such a product could be directly overlayed over a 7-1/2' Quad Sheet Topographic map or orthophoto to interpret directly where changes had occurred. However, transparencies at such a large scale are also relatively expensive to produce. This situation is due to the necessity of filming the Landsat data at a large enough scale so that 1:24,000 products can be prepared, and also due to the relatively high cost of producing the transparencies. Since both filming and preparation of transparencies have fixed costs independent of scale, producing products at large scale results in large costs per unit area.

An alternative to use of large scale transparent overlays was thus discussed with Clearwater staff members. The alternative discussed was smaller scale hard copy images. Such images could be used in conjunction with a zoom-transfer scope to transfer areas of change from the small scale change image to the larger scale of the desired map or othophoto. The result should be relatively lower cost per unit area.

A copy of an MSS5 change image (scale = 1:125,000) of a portion of the Clearwater National Forest was left with the Forest staff in Orofino. It was suggested that the staff examine the utility of such an image for producing information in conjunction with a zoom transfer scope.

NFAP Technical Monitor Jim Bell indicated that he would investigate the feasibility of the Clearwater staff gaining access to the zoom-transfer scope presently residing in Moscow at the University of Idaho. Clearwater staff members were encouraged to determine what was the smallest scale change image that they could effectively work with, since producing products at the smallest scale would result in the lowest cost per unit area. Clearwater staff members were also encouraged to make a determination of the utility of the change information, and to estimate the cost per unit area of acquiring such information by alternative procedures.

As of this writing Clearwater staff members have made preliminary conclusions regarding desired scale and format of change images. Hard copy MSS5 change images at a scale of 1:125,000 are the desired product (J. Bell, personal communication). Such a product has been produced for all of the Clearwater Forest covered by Path 45, Row 27, and has been sent to Orofino.

4
ELK HABITAT SUITABILITY

The second major task of this project is to demonstrate procedures by which a data base of relevant information can be manipulated to make assessments of site suitability. In particular we have chosen to examine capabilities to assess suitability for elk habitat. The overall strategy for this task is shown in Figure 13.

In a previous project, point-specific indications of elk habitat quality were generated (Colwell, et al., 1982). In this project, we propose to produce area-specific indications of elk habitat quality for selected elk habitat evaluation units. The results will be compared with independent estimates of habitat quality based on field observations made by Clearwater Forest staff.

The test sites for evaluation of various elk habitat assessment procedures are on the Elizabeth Lake and Osier Ridge 7-1/2 Quadrangles. The Elizabeth Lake Quadrangle is known to contain some of the best elk habitat in the Clearwater National Forest. It is known that some of the Osier Ridge Quadrangle has been subjected to recent logging, with possible negative effects on elk habitat quality. Thus, the Elizabeth Lake and Osier Ridge Quadrangles are expected to contain a significant range of values of habitat quality.

4.1 BACKGROUND

The basic information which will be used to assess elk habitat quality is vegetation density and roads. As noted in USDA Handbook No. 553 ("Wildlife Habitats in Managed Forests"), two of the assumptions that provide a foundation for habitat management are: (1) "habitat suitability can be judged by the ratio of cover areas to forage areas and their size and arrangement in time and space;" and (2) "Roads left open to vehicular traffic will adversely affect use of the area by elk."

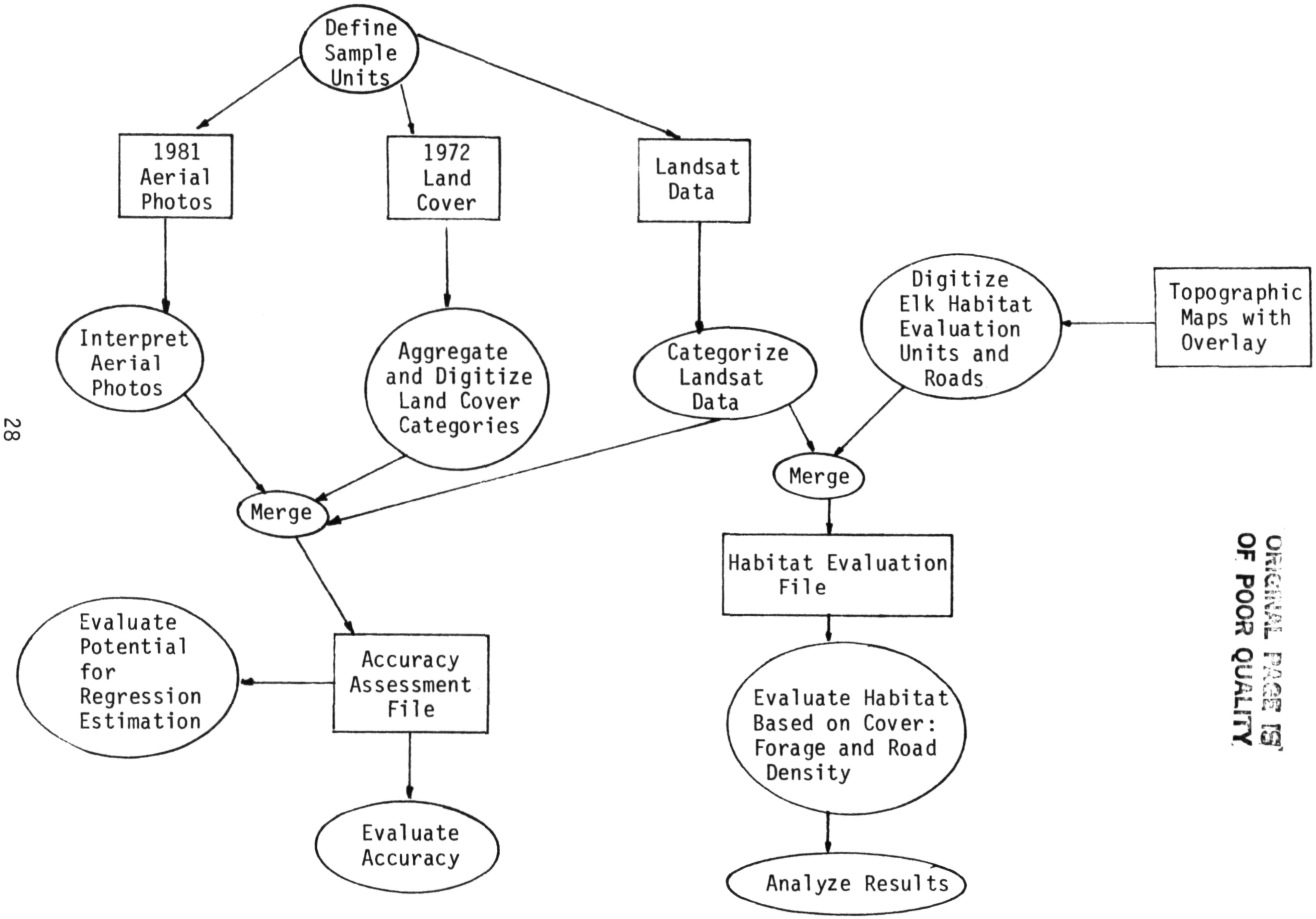

FIGURE 13. FLOW CHART FOR HABITAT EVALUATION TASK

USDA Handbook No. 553 notes that "optimum habitat for deer and elk requires hiding cover." The Handbook defines hiding cover as "vegetation capable of hiding 90 percent of a standing adult deer or elk from the view of a human at a distance equal to or less than 61 meters (200 ft)."

Techniques for directly evaluating hiding cover in this way are costly and time-consuming. Alternative procedures for assessing cover are inferential and are based on canopy closure or average proportions of photointerpreted categories.

As a result of discussions with Clearwater National Forest personnel in July of 1982, it was learned that a great deal of time and energy and wildlife expertise had gone into the development of a model for evaluating elk habitat. This model is currently being used for elk habitat evaluation and, with minor modification, probably will continue to be used for the conceivable future. Although there was interest on the part of Clearwater staff members in evaluating different approaches to assessing elk habitat quality, that would be a research activity, with little or no potential to impact Forest management in the near future.

A more pressing issue with more potential for impact in the short term was discovered. It was learned that existing land cover type information based on interpretation of 1972 black-and-white 1:63,360 panchromatic photos had been found to be only 60-70% accurate (Dan Davis, personal communication). Use of such a data base of land cover for evaluation of elk habitat quality was found to have several serious disadvantages. The most obvious disadvantage is that the land cover labels are inaccurate a significant portion of the time. Another disadvantage is that the land cover information is based on 1972 photos, and hence may not represent current conditions. Although there is reasonably current (1981) large scale (1:12,000) color photography available for the Clearwater Forest, present staffing limitations and commitments preclude interpretation of this photography.

Another problem mentioned with the current land cover information for evaluation of elk habitat quality is that there is important variation within polygons identified as a particular land cover type. For example, small openings within a larger polygon composed principally of mature timber were not identified in the existing land cover map. Although such small openings are of little concern for management of stands for timber, such openings can have significant effects on quality of elk habitat and on the evaluation of the quality of that habitat using the accepted elk habitat model.

An additional problem in using the present land cover information to assess elk habitat quality is that hiding cover is not directly available but must be inferred as a proportion of the various land cover photointerpretation categories (Leege, 1982). Although such a procedure may provide valid average statistics over a large area, there is no guarantee of accuracy on a local or site-specific basis. A more direct way of actually mapping hiding cover would be preferred (Lyon, personal communication).

It became clear that better, more current land cover information would have more immediate impact on management of elk in the Clearwater National Forest than would research into an alternative elk habitat quality model. Considering the uncertainty of NFA Program funding for long-term remote sensing R&D projects, it was decided that the activity with potential for immediate use should take precedence over a long-term research activity. Accordingly, a dialogue was begun to determine whether ERIM could make a contribution to the current desire for better land cover information for evaluation of elk habitat quality.

It was explained to the Clearwater Forest staff that ERIM generally considers Landsat data to be more useful for stratification, for updating existing data bases, and for monitoring changing conditions, than it is as an independent source of very accurate land cover information, particularly for small (e.g., 1-5 acre) areas. It was also explained that in a previous activity in the San Juan National Forest we found that spatial smoothing of Landsat data (effectively degrading the Landsat resolution) apparently improved the classification accuracy of forest stand units (Colwell, et al., 1981). In other words, producing the most accurate stand labels is not necessarily consistent with detecting and labeling small patches.

However, in view of the perceived importance of better land cover information for elk habitat evaluation, it was believed that an effort in this area should be initiated. It was agreed that this effort should be designed to map only a few categories of land cover that would be of value to wildlife managers, and also possibly to timber managers. Therefore, we decided to map forest categories on the basis of crown closure, rather than species composition. It was felt that Landsat would be more successful at mapping crown closure than species composition, and crown closure is a more important parameter for evaluation of elk habitat (and timber) quality.

4.2 APPROACH

For the present elk habitat quality model, forest land types are evaluated as forage or cover. One of the simpler ways of distinguishing between areas of forage and cover is on the basis of crown closure. For example, Isaacsen and Leckenby (1980) suggest that areas that are primarily forage have crown closures less than 10%, whereas areas of primarily hiding cover are characterized by having crown closure of 10% or more. Agriculture Handbook 556 suggests that thermal cover for elk is partially characterized by having canopy closure exceeding 70%. We decided to categorize the Landsat data into these three categories (forage hiding cover, and thermal cover), as well as water.

For purposes of this project, we chose to evaluate the Landsat categorized results on specific elk habitat evaluation units on the

Osier Ridge and Elizabeth Lake 7-1/2' Quadrangles. Boundaries for these habitat units were furnished by Dan Davis, Wildlife Biologist on the Clearwater National Forest staff.

For assessing elk habitat quality, more information than the proportion of cover to food is generally used. Of particular importance in this regard is the linear amount of roads present, by type of road. Therefore, we digitized the current road network (as designated by Dan Davis) and merged it with the Landsat image file.

In an attempt to evaluate the quality of the Landsat categorized data, we decided to compare the Landsat categorizations on selected sample units with photointerpreted classification using 1981 color photos. An alternative source of land cover information (based on 1972 photo interpretation) was also compared.

It was decided to implement an assessment of accuracy in such a way that the concept of Landsat/photo regression estimation of the amount of land in the various categories could also be shown. This demonstration was considered especially important for this task for two reasons: (1) It has been found previously that such regression estimation is an effective way of using Landsat categorized results even when the Landsat results are biased; and (2) regression estimation is an effective way of producing precise statistics over large units such as an entire forest, as well as smaller units (e.g., a Ranger District) where photo and/or field sampling alone may produce undesirably imprecise results.

Alternative land cover information available to us (the vegetation type map from 1972 USFS photointerpretation and the 1981 photointerpretation to be done for this project by Bob Spencer) is defined partly on the basis of crown closure, with four classes defined: (1) 0-9%, (2) 10-39%, (3) 40-69%, and (4) 70-100%. We aggregated these categories for comparison with Landsat recognized categories in the following way:

(1) 0-9% = forage
(2) 10-69% = hiding cover
(3) 70-100%= thermal cover

An additional category on the 1972 land cover type map is Non-Commercial Forest (NCF). According to J. Bell (NFAP/Houston) this category is stands with greater than 10% crown closure with less than 20 cu ft mean annual increment." For purposes of this project, all NCF from the land cover maps was assigned to the 10-69% crown closure category.

All Non-stocked areas on the type map were assigned to the 0-9% category. Lakes were assigned to a category of their own.

4.3 RESULTS

Supervised signatures of the desired cover types were obtained from a Landsat file containing six 7-1/2' Quadrangles. A plot of these signatures for the 1981 Landsat data in MSS7 vs MSS5 data space is shown in Figure 14. It can be seen that the main difference between the cover classes is their overall albedo, as was indicated earlier.

The supervised signatures were used to categorize the Landsat data of a six Quadrangle test area. The results for a portion of the test area in the Elizabeth Lake Quadrangle (Figure 15) are shown in Figure 16. The area in the box was an area used to assess classification accuracy, as discussed in the following section.

4.3.1 CLASSIFICATION ACCURACY

A preliminary estimate of the classification accuracy was obtained by comparing the Landsat classification with our interpretation of the same cover classes on the 1981 1:12,000 color photography. The accuracy assessment was done on five 1 km^2 sampling units chosen so as to represent a range of conditions from primarily non-stocked to primarily well-stocked land. For comparison with existing information we computed the area of corresponding categories derived from the existing (1972) USFS

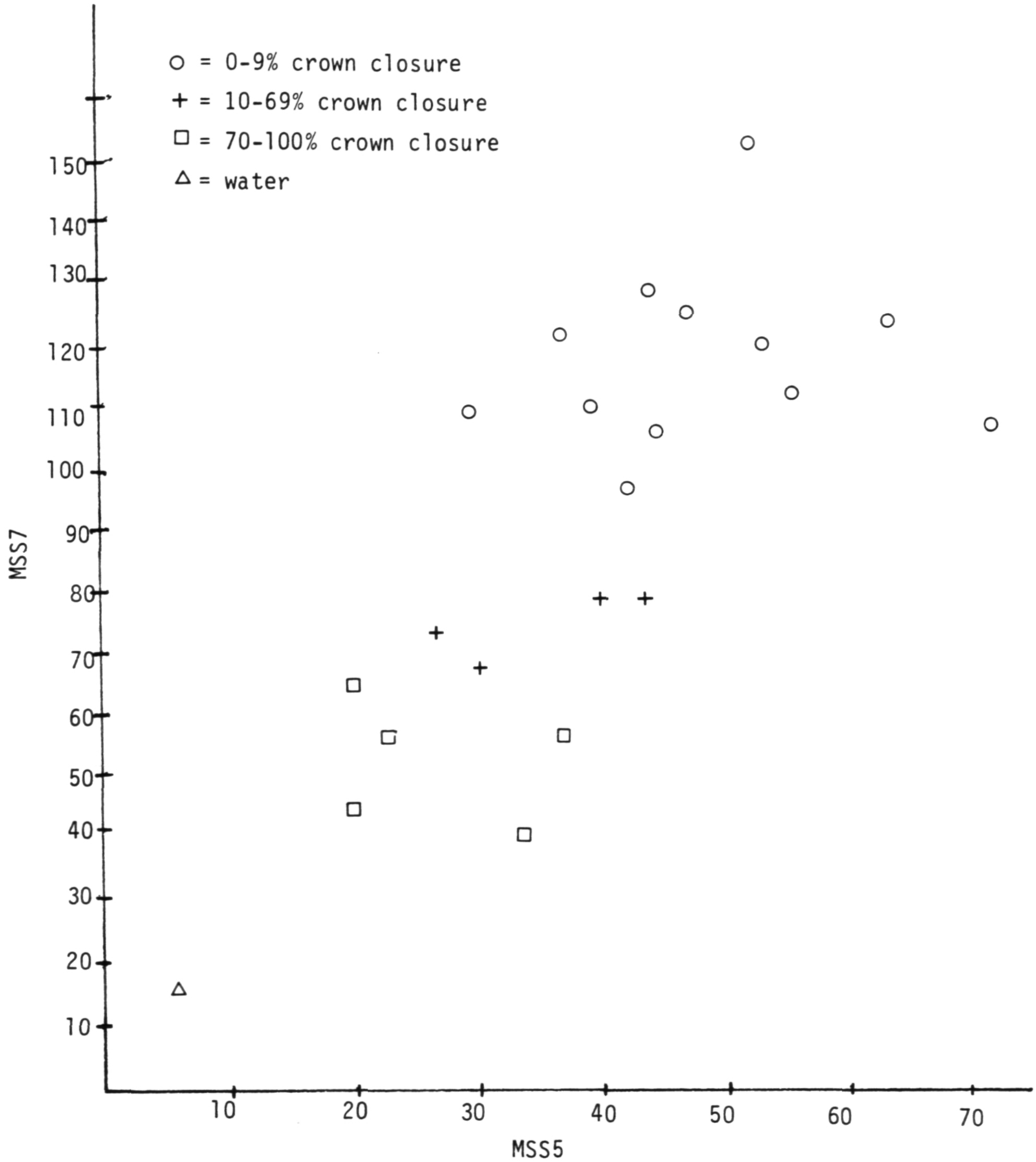

FIGURE 14. PLOT OF MEAN VALUES OF SUPERVISED SIGNATURES USED IN CLASSIFYING 1981 LANDSAT DATA

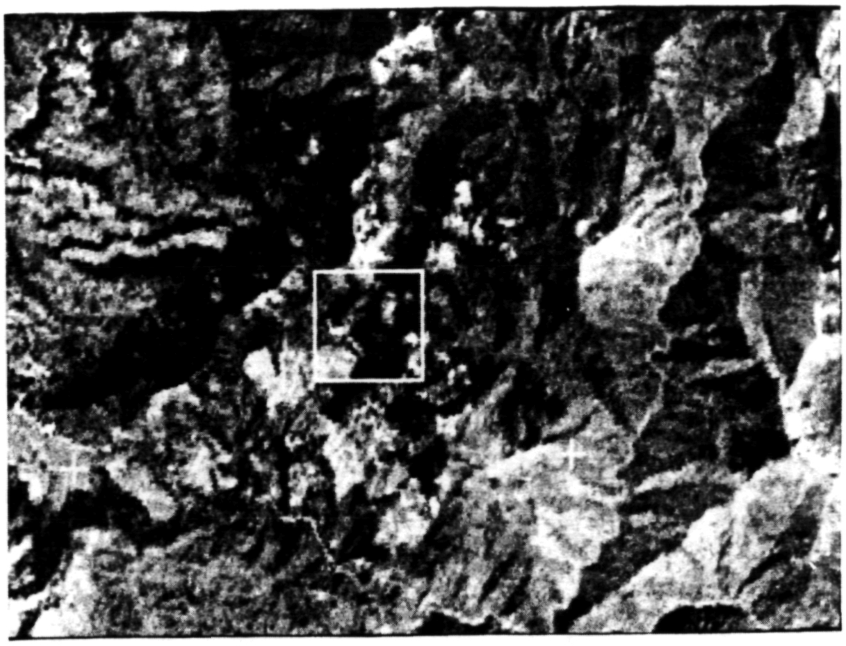

FIGURE 15. 1981 LANDSAT COLOR IR IMAGE OF ELIZABETH LAKE TEST AREA

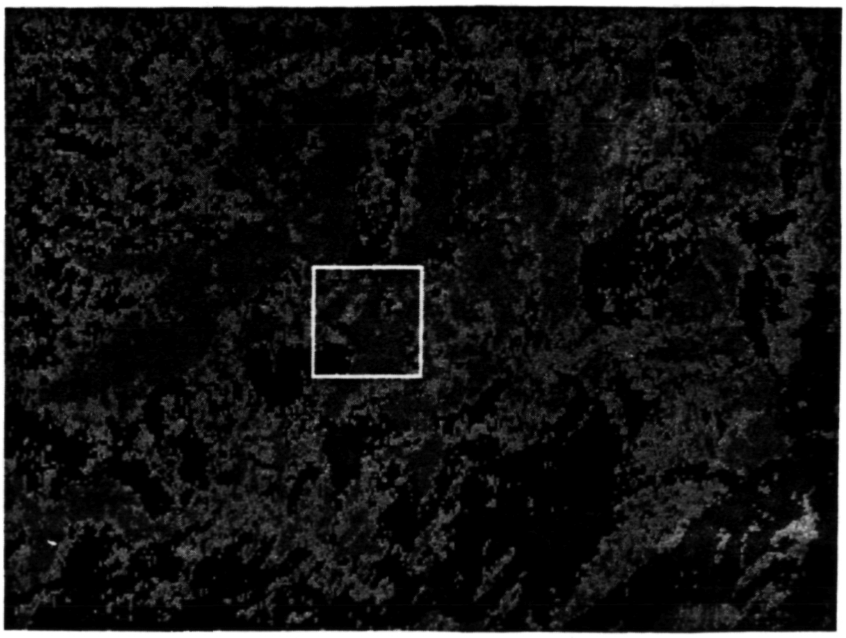

FIGURE 16. 1981 LANDSAT CATEGORIZED IMAGE OF ELIZABETH LAKE TEST AREA. (Red = 0-9%; Light Green = 10-69%; Dark Green = 70-100%; blue = water)

land cover information. The 1972 land cover information for the test area shown in the box in Figure 15 is illustrated in Figure 17. The classification tests results are shown in Table 3.

TABLE 3. SUMMARY OF CLASSIFICATION PROPORTIONS PER SAMPLING UNIT FOR 1981 LANDSAT AND FOR 1972 LAND COVER RELATIVE TO 1981 PHOTOINTERPRETATION

Sample Unit	1981 P.I. (assumed correct)	Landsat	1972 P.I.
0-9% Crown Closure			
1	2	5	4
2	17	15	5
3	10	13	0
4	7	15	0
*5	51	52	37
	87	100	46
Bias		+15%	-47%
10-69% Crown Closure			
1	34	30	33
2	29	30	30
3	2	14	28
4	2	12	17
*5	19	15	3
	86	101	111
Bias		+17%	+29%
70-100% Crown Closure			
1	64	65	63
2	54	55	75
3	84	72	69
4	91	74	83
*5	30	33	60
	323	299	340
Bias		-7%	+5%

* = sampling unit with change from 1972 to 1981.

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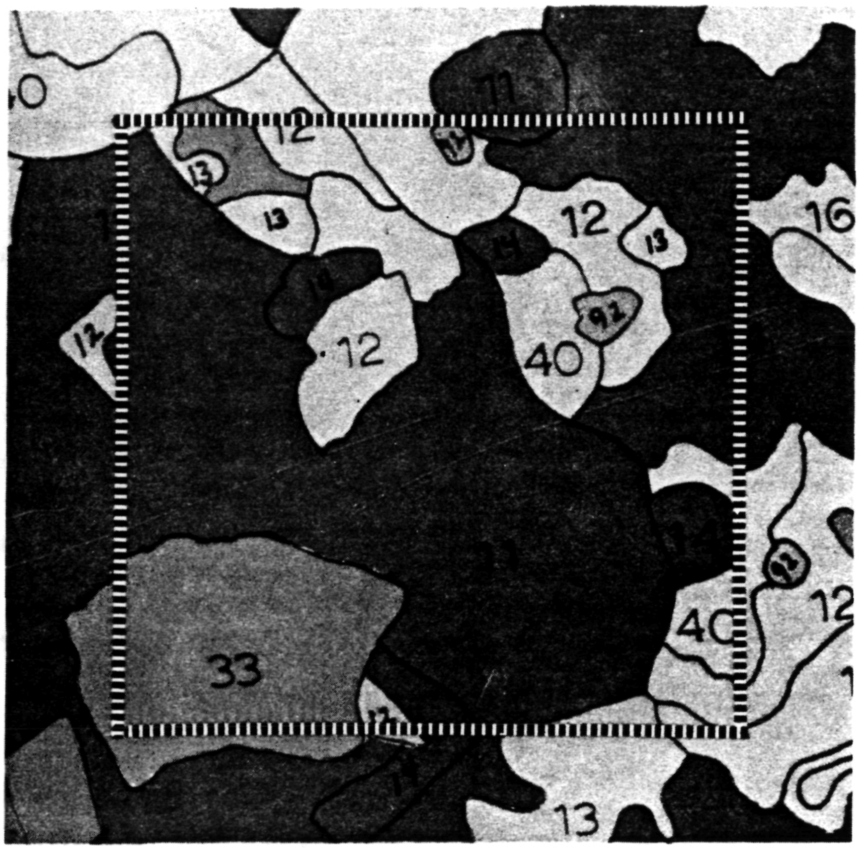

FIGURE 17. 1972 LAND COVER INFORMATION FOR ELIZABETH LAKE TEST AREA

= 0-9% canopy closure

= 10-69% canopy closure

= 70-100% canopy closure

= water

Although no statistically rigorous estimate of the classification accuracy can be obtained from this small, subjective sample, one estimate of performance is the difference between the amount of each category recognized by the computer and that determined by photo interpretation, divided by the amount determined by photo interpretation. This is a measure of misclassification by Landsat. This measure is shown in column 3 of Table 3.

A more complete assessment of accuracy will be possible if it is based on a comparison of Landsat results with the photointerpretation done by Bob Spencer on all of the Elizabeth Lake and Osier Ridge Quadrangles using the 1981 color photography. However, it is suggested that undue emphasis should not be placed on rigorous accuracy assessment of this particular classification map, since no pretense is made that this is the best (most accurate) or most appropriate classification that could be produced. Rather, we believe that more emphasis should be placed on assessing the feasibility and desirability of the Clearwater Forest using the kind of categories produced in this classification for various management tasks, including: (1) wildlife habitat evaluation (e.g., for estimation of cover to forage ratios); and (2) for estimation of areal extent of various forest stocking classes (e.g., by regression estimation). If such applications appear feasible and desirable, a formal accuracy assessment of the best possible classification map (with categories specifically designed for a particular application) would be appropriate.

It is anticipated that classification accuracy could be improved by several procedures. For example, a procedure that was found to be helpful previously was BLOB spectral-spatial clustering of the Landsat data prior to classification (Colwell, et al., 1981). A more primitive but more easily implemented form of smoothing of the data was investigated. The categorized data was smoothed (post-classification smoothing) using a 3 x 3 pixel window. If 6 or more of the surrounding pixels are classified as a particular class which is different from the central pixel, the central pixel is altered to be classified like the majority of its neighbors. The resulting classification of a portion of the area is shown in Figure 18. It can be seen that recognition occurs in more homogeneous blocks, which may be appropriate for timber management. Some small openings that are significant for wildlife may be lost, however. Spectral-spatial clustering prior to classification may produce satisfactory results for both timber and wildlife (Colwell, et al., 1981). Detailed evaluation of a variety of smoothing functions may be warranted in the future.

We also believe that a classification performed on Landsat data collected when the grass and vegetation understory are less green (e.g., in late Spring or early Fall) would reduce some spectral confusion, especially between the 0-9% and 10-69% cover classes. Use of Landsat-D Thematic Mapper data with improved spectral and spatial resolution might also improve classification accuracy. And use of topographic information from digital terrain tapes has been found to increase classification accuracy (Hoffer, 1978; Colwell, 1981). These issues were not studied as a part of this project.

An estimate of the utility of the unsmoothed Landsat categorization was made by comparing its misclassification with the corresponding figures obtained from the land cover information which is based on interpretation of 1972 1:63,360 black-and-white panchromatic photography. The misclassification estimate for the 1972 land cover information is shown in column 4 of Table 3.

The 1972 land cover information could be in error for a variety of reasons. One possible reason is the difficulty of making accurate interpretations from the small scale panchromatic photography. Our limited attempts to do such interpretation showed that significant errors could be made.

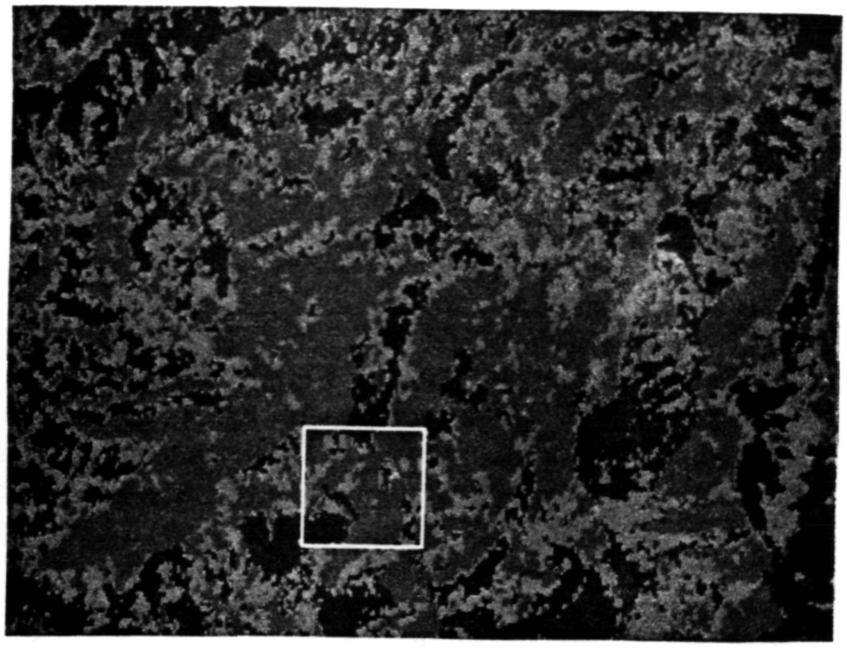

FIGURE 18. POST-CLASSIFICATION SMOOTHING OF FIGURE 16. (Red = 0-9%; Light Green = 10-69%; Dark Green = 70-100%; blue = water)

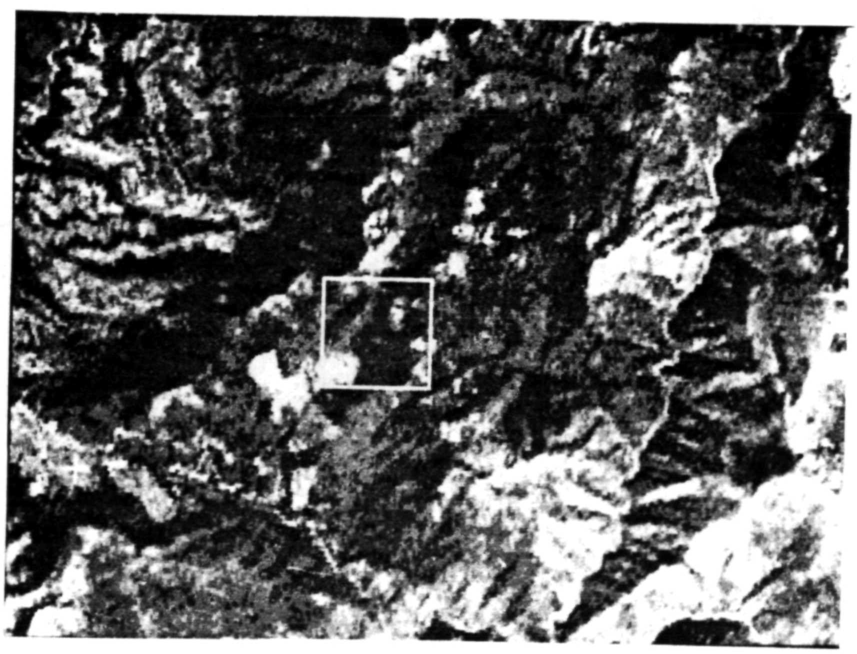

FIGURE 19. CHANGE IMAGE OF ELIZABETH LAKE TEST AREA (1981 MSS5 = red; 1972 MSS5 = cyan)

Another possible reason for apparent misclassification is the procedure for aggregating the 1972 USFS cover categories (Figure 17) into the 1981 categories. Particularly troublesome in this regard was the "Non-Commercial Forest" category, which was allocated to 10-69% cover. The 1981 aerial photography showed that some of this area was virtually devoid of timber and should be assigned to 0-9% cover. Wildlife managers would encounter the same problem in deciding to which category NCF should be assigned.

Yet another possible reason for apparent misclassification of the 1972 land cover information is change which occurred between 1972 and 1981. Analysis of a Landsat change image and 1981 photographs indicated that only sample unit #5 (with an asterisk) had any significant change (see Figure 19). If we examine only this sampling unit, we can see from Table 3 that 1981 Landsat categorization gives a much better representation of current cover conditions than the existing (1972) USFS land cover data base.

The Landsat misclassification figures in Table 3 could also be called "bias". It is not at all surprising that there is some bias in the Landsat categorization. This situation has been seen many times previously (e.g., Colwell, 1978; Latham, 1981), but bias does not preclude effective utilization of Landsat data, as discussed in the following section.

4.3.2 REGRESSION ESTIMATION

Landsat categorization with greater bias than found in this study has been shown to be useful for making estimates of amount of resource features. One way in which this can be accomplished is by regression estimation using Landsat data in conjunction with samples of photo or field data. Regression estimation allows Landsat data to be bias-corrected and hence to be useful in reducing imprecision in statistical estimates. Regression estimation can be represented by the formula:

$$\hat{Y}_{pop} = N[\bar{y}_n + b(\bar{X}_N - \bar{x}_n)]$$

where: (1) $\hat{Y}_{pop}$ is the estimate of the population total over the whole area of interest; (2) $\bar{y}$ and $\bar{x}$ are photo and Landsat average values from a random sample of n sampling units; (3) b is the slope of the linear regression line between y and x; and (4) $\bar{X}$ is the Landsat average value of the entire area (N potential sampling units).

The increased precision achievable with regression estimation might be helpful to Clearwater Forest personnel in two ways. If it is desired to reduce the cost of producing statistical estimates of the entire Forest, regression estimation may furnish a procedure for achieving this objective. Previous investigations have shown Landsat/photo regression estimation to be more cost-effective than random sampling for achieving a given precision of the estimate (e.g., Latham, 1981).

Alternatively, if more precise local estimates (e.g., Ranger District) are needed, regression estimation could allow this to be achieved with no increase in number of photo or field sampling units. This application of Landsat data is currently being investigated by the U.S. Department of Agriculture for producing more precise county and Crop Reporting District estimates of crop area with no increase in field sampling.

The keys to the utility of Landsat categorized data for either of the above purposes are: (a) the degree of correlation between Landsat categorization and the photo or field enumeration; and (2) the relative cost of the Landsat and photo or field enumeration. This situation is shown graphically in Figure 20. From this figure it can be seen that if the correlation is high, even modest cost ratios (photo/Landsat) will result in regression estimation being more cost-effective.

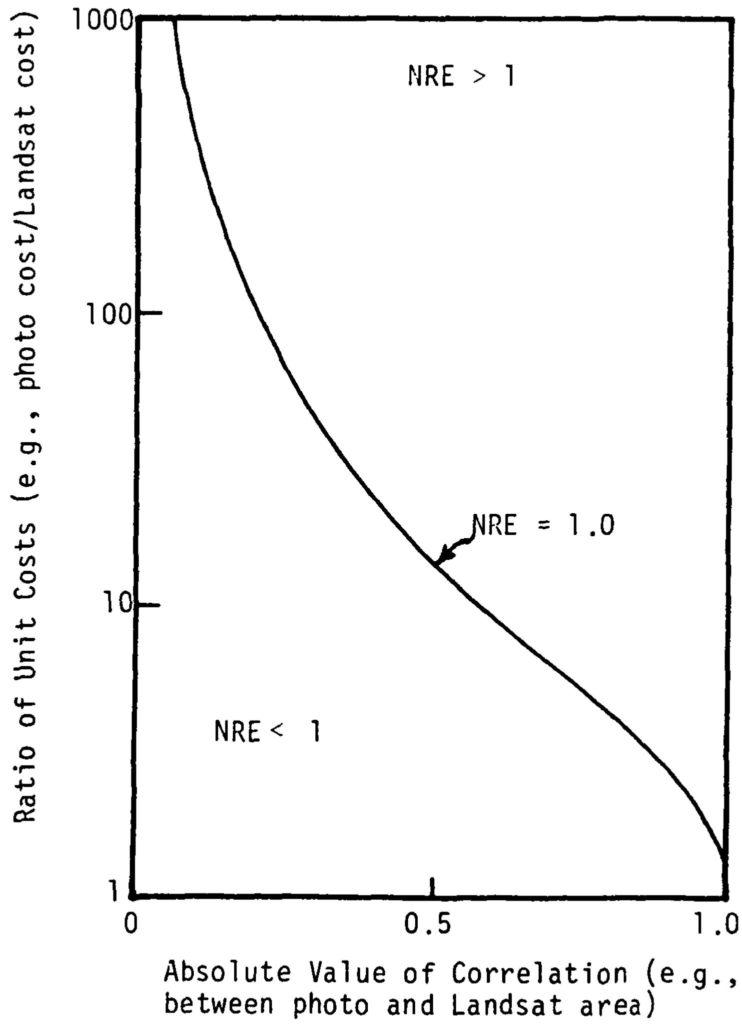

FIGURE 20. NET RELATIVE EFFICIENCY (NRE) OF REGRESSION ESTIMATION VS. SINGLE SAMPLING (After Jessen, 1978).

Alternatively, even if the correlation is low, high cost ratios can make regression estimation more cost-effective. For a cost ratio of 10, a correlation of approximately 0.6 would be required for regression estimation to be more cost-effective. Irrespective of cost, a regression estimate will always be a more precise estimate if there is any correlation ($R \neq 0$), with the increase in precision approximately equal to $1/1-R^2$.

The exact utility of regression estimation cannot be determined for the Clearwater National Forest, because a random photo sample was not obtained. However, some indication of the potential utility of Landsat data can be obtained from analysis of the correlation between Landsat and photo estimates for the three cover categories. The correlations are .98, .91, and .99 for 0-9%, 10-69%, and 70-100%, respectively. These figures probably exaggerate the degree of correlation because the sampling units were non-randomly chosen so as to get a large range of proportions of each cover type.

It is difficult to determine valid cost ratios from this project, both because the project was not done in an operational mode, and also because it is not clear how to allocate fixed costs that contribute to more than one activity. Our estimate is that the photo/Landsat cost ratio is probably greater than 10. In a previous project (Latham, 1981) we estimated a field measurement/Landsat cost ratio of approximately 200. A more rigorous analysis of correlation and cost ratios would be required before determination of the true cost-effectiveness of regression estimation using Landsat data in northern Idaho could be made.

4.3.3 HABITAT EVALUATION

The ultimate goal of the activity discussed in this chapter has been to make improved estimates of elk habitat quality by use of an improved data base. That aspect of the activity is discussed in this section.

We chose to use a simplified form of the habitat quality model. In particular we chose to examine just the cover/forage ratio and the road density. This is the procedure used in a recent elk habitat evaluation in Oregon (Bright, 1982).

We analyzed all of the elk habitat evaluation units (as furnished by Dan Davis) which were entirely enclosed within either the Elizabeth Lake or Osier Ridge Quadrangles. Habitat evaluation unit boundaries and road networks were digitized and merged with the Landsat categorized file. Hiding cover was assumed to be forest with $\geq$ 10% crown closure. The amount of hiding cover and the length of road by road type was then calculated by computer for each of the four habitat evaluation units. The results are shown in Table 4.

TABLE 4. PROPORTION OF HIDING COVER, LENGTH OF ROADS AND AREA OF HABITAT UNITS

Habitat Unit	Area (km^2)	Hiding Cover (%)	Main Road (km)	Secondary Roads (km)
EL1	25.6	80	0	0
OR1	29.5	46	4.6	23.3
OR2	9.2	57	5.6	0
OR3	17.2	53	11.6	0

For each habitat unit, we computed reductions in effective habitat area based on the presence of roads and based on deviations from the optimum cover to forage proportions. The effect of roads (Potential Use/Roads) was determined using the relationships in Agriculture Handbook 553 (adapted from Perry and Overly, see Figure 21). An additive relationship for effects of different kinds of roads was

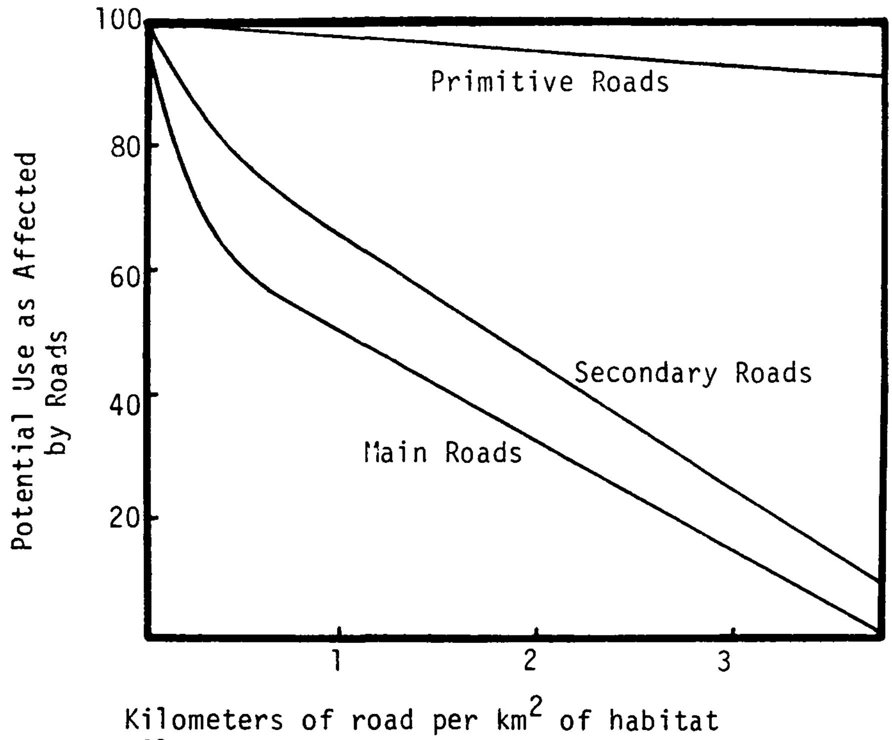

FIGURE 21. POTENTIAL ELK USE AS AFFECTED BY ROAD DENSITY

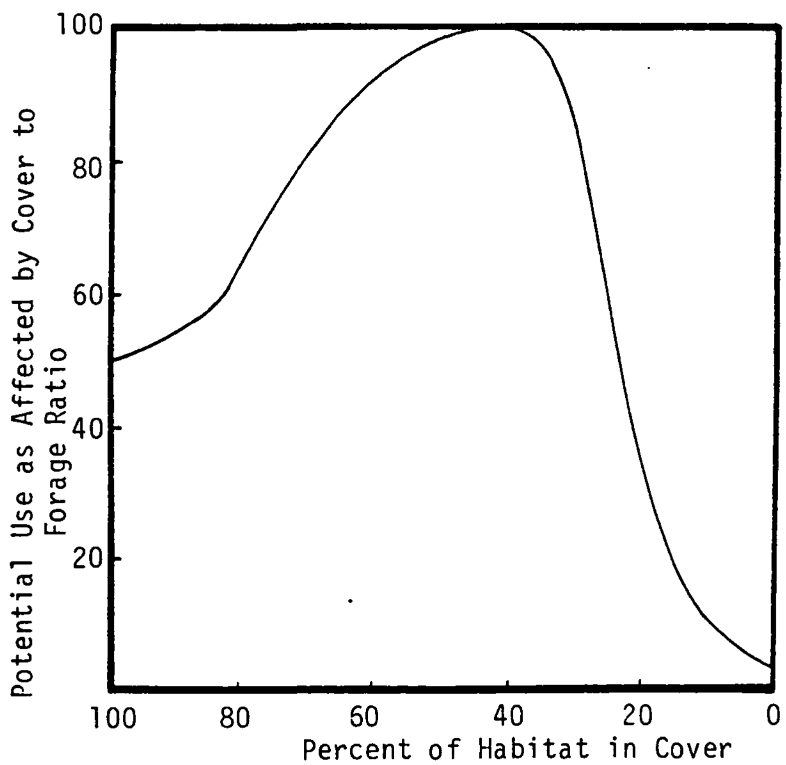

FIGURE 22. POTENTIAL USE AS AFFECTED BY COVER

assumed. That is, the potential as affected by main, secondary, and primitive roads is 100% - U_M - U_S - U_P = E_R.

The effect of deviations from optimum cover to forage proportions (Potential Use/Cover) was determined from the relationship in Leege (1982). In addition, a reduction in habitat potential was computed on the basis of the fraction of the habitat unit that was unusable (Potential Use/Home Range). We assumed water was the only unusable area. The results of evaluating habitat reductions are shown in Table 5.

TABLE 5. POTENTIAL USE (%) OF ELK HABITAT UNITS

	EL1	OR1	OR2	OR3
Potential Use/Home Range	100	100	100	100
Potential Use/Cover	64	100	93	97
Potential Use/Roads	100	56	58	57

The effect of reductions in habitat was assumed to be multiplicative. Therefore the habitat quality model is:

$$\text{Habitat Effectiveness}_{(\%)} = \text{Potential Use}_{HR} \times \text{Potential}_{Cover} \times \text{Potential}_{Roads}$$

Habitat effectiveness was calculated using this model, and the results are shown in Table 6.

TABLE 6. HABITAT EFFECTIVENESS OF HABITAT UNITS

Habitat Unit	Habitat Effectiveness (%)
EL1	64
OR1	56
OR2	54
OR3	55

The results are perhaps surprising considering our expectation that the Elizabeth Lake Quadrangle contains some of the best elk habitat in the Clearwater Forest and that the quality on Osier Ridge was lower. Our results show that the Osier Ridge Habitat Units have values of habitat effectiveness nearly comparable to the Elizabeth Lake Habitat Unit, and the Elizabeth Lake Unit does not have a particularly high value.

The Elizabeth Lake Habitat Unit (EL1) is an area composed mainly of mature timber, with little recent logging. Using our procedure, too much cover (too little food) is indicated for there to be high values of habitat effectiveness, even though there are no roads present to detract from habitat effectiveness.

All of the Osier Ridge Habitat Units, on the other hand, have had considerable recent logging. This logging has resulted in nearly ideal cover to forage ratios using our procedure. The resulting high values of habitat effectiveness due to a favorable cover to forage ratio compensates for the loss of habitat effectiveness due to the presence of roads.

It is hoped that these results can be checked by independent estimates of habitat quality (e.g., by scat counts) that may be furnished by Clearwater Forest personnel. If the results can be verified, it suggests that logging is not incompatible with acceptable long-term elk habitat quality.

One possible source of error in the above habitat assessments is incorrect cover to forage ratios due to inaccuracy in the Landsat data base. Our accuracy assessment units discussed previously suggest that this is not a major source of error. For the four unchanged assessment units, the overall cover to forage ratio from aggregated Landsat classes is 0.89, whereas the corresponding ratio from 1981 photointerpretation is 0.92.

Another source of possible error is that our estimates of amount of cover are not based on proportions of P.I. types, which is the standard procedure. This seems a likely source of significant error, with our estimates of amount of hiding cover based on Landsat expected to be generally too high. We are assuming that the Landsat categories with $\geq$10% crown closure are entirely hiding cover, whereas standard procedures assume each P.I. category is only partially hiding cover. For example, P.I. Type 11 is assumed to be 82% hiding cover, and PI Type 13 is assumed to be 46% hiding cover (see Table I of Leege, 1982). If the Landsat cover categories are assumed to average only 60% hiding cover, the resulting Landsat cover to forage ratio for the Elizabeth Lake Habitat Unit shown in Table 4 would be revised to .6(.8) = .48. This is an almost ideal cover to forage ratio (Figure 22), and would result in a habitat effectiveness for the unit of 98%. Valid use of Landsat estimates of hiding cover for evaluation of habitat quality may be dependent on recalibration of the cover to forage curve to Landsat type estimates of cover.

One other possible source of error in the habitat evaluation we have done is the use of too simple a habitat quality model. Not all of the factors that could be considered or that are considered by present procedures (Leege, 1982) were included in our simplified model. Comparison of results from a simplified model with those of a more complex model is beyond the scope of this project.

5
CONCLUSIONS

Many of the most important conclusions from this project depend on evaluation of materials by the Clearwater Forest Staff. Our preliminary conclusions are contained in the following discussion.

5.1 CHANGE DETECTION

Based on the results of this project, it appears that a rather simple, easily interpreted Landsat change image (based on MSS5 from two dates) can be helpful in updating existing land cover data bases in areas dominated by coniferous forest. Such an image can be used to locate areas of major change, especially reduction in conifer cover due to logging, fire, avalanche, etc. Detailed information on the nature of this change could then be obtained by analysis of aerial photos an/or field observation.

Whether a Landsat change image should be used in the above manner is dictated by a number of factors. One such factor is the relative cost of obtaining change information from a Landsat change image vs the cost of alternative procedures for generating such information. To help in making this comparison we have computed our current operational cost for producing such an image. As per the ERDC cost manual, we have computed the current cost per km^2 for acquiring, geometrically correcting and merging two Landsat scenes and producing 1:125,000 scale change images that would cover an entire Landsat scene. The cost is approximately \$0.25 per km^2. Actual costs would be higher for a smaller area, and costs would be lower if some of the fixed costs (e.g., tape acquisition, geometric correction) were amortized over several tasks (e.g., including digital classification).

Another factor affecting the utility of a Landsat change image is available personnel. In some instances, staffing limitations may preclude generating change information by alternative procedures such as analysis of complete aerial photo coverage. Yet another factor is timeliness. Staffing limitations may make it difficult to generate alternative change information in the desired amount of time.

5.2 HABITAT EVALUATION

Based on the results of this project, it appears that Landsat data has some potential to help produce a data base of very generalized land cover types based mainly on crown closure and/or stocking. Such information might be helpful both for managing timber and for assessing wildlife habitat quality.

Whether Landsat data should be used for this purpose is dependent on several factors. One such factor is the cost of obtaining such information. The current ERIM cost to produce categorized data over an entire Landsat scene is .15 km^2, excluding tape and geometric correction costs.

Another factor affecting the utility of Landsat categorized data is its accuracy relative to an existing or potential land cover data base. In evaluating such accuracy one should consider not only accuracy in labeling particular stands (of primary importance for timber management), but also accuracy in detecting and labeling small openings within a stand (of considerable interest for elk habitat assessment).

An important factor concerning the value of Landsat categorized data for elk habitat evaluation is whether Landsat crown closure/-stocking categories can be related to amount of hiding cover. Landsat categories are based on the vertical perspective, whereas hiding cover is defined on the basis of horizontal line-of-sight. We believe that there is a high correlation between the two parameters much of the time, but we have not demonstrated this fact. If Landsat crown closure categories are to be used in conjunction with current habitat assessment procedures, new curves relating Landsat crown closure proportions on a habitat unit to hiding cover proportions must be developed.

One advantage to using Landsat categorized data is that it comes packaged in a digital data base. Thus, statistics over any area of interest can be easily extracted. In addition, spatial information on size of stands, distance to road, interspersion, and juxtaposition can easily be calculated (e.g., Colwell, et al., 1981).

6
RECOMMENDATIONS

It is recommended that the utility and cost-effectiveness of the material produced as a part of this project be evaluated by Clearwater Forest personnel. Depending on the results of that analysis, we recommend several additional steps.

6.1 CHANGE DETECTION

If the Landsat change image proves to be useful, we suggest that suitable 1972-1981 change images be produced for that part of the Clearwater Forest that was not covered in the scene evaluated for this project. If precisely corrected change images are too expensive, we recommend investigating the utility of color coded EROS (or Canadian) transparencies, which would cost less, but also would be less precisely registerable. If more detailed and more quantitative change information is required from Landsat, we recommend the demonstration of digital change detection and identification procedures such as BLOB/CVA using two scenes collected in late spring or early fall (thereby reducing some vegetation phenological problems) and not using an EDIPS tape, which makes digital registration difficult. Such procedures should be evaluated as a part of an overall survey strategy to produce reliable information (e.g., regression estimation).

6.2 HABITAT EVALUATION

If the accuracy of the Landsat categorization is found to be promising, but not as good as desired, efforts to produce more accurate results should be initiated. Our experience suggests that classification based on spatially smoothed data (e.g., BLOB), and classification assisted by topographic data will both improve categorization accuracy. Landsat D Thematic Mapper data may also improve results, especially for small openings, roads and narrow "buffer belts" of unharvested timber.

With or without improvements in classification accuracy, it seems probable that Landsat data could help produce statistical estimates by regression estimation more precisely and more cheaply than by alternative procedures. This possibility should be explored based on a statistically valid analysis of randomly sampled Landsat and photo sampling units.

The use of Landsat categorized data to assess elk habitat quality will be dependent on establishing relationships between Landsat categorized data and existing data and procedures. One way to explore these relationships is to determine the average amount of hiding cover (as determined by traditional procedures) that is associated with various Landsat categories (e.g., 0-9%, 10-69%, 70-100% crown closure categories). An initial estimate of these relationships could be obtained by computing the amount of PI derived hiding cover for a sampling of Landsat categorized features. The use of interspersion and juxtaposition in the elk habitat model should be explored.

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