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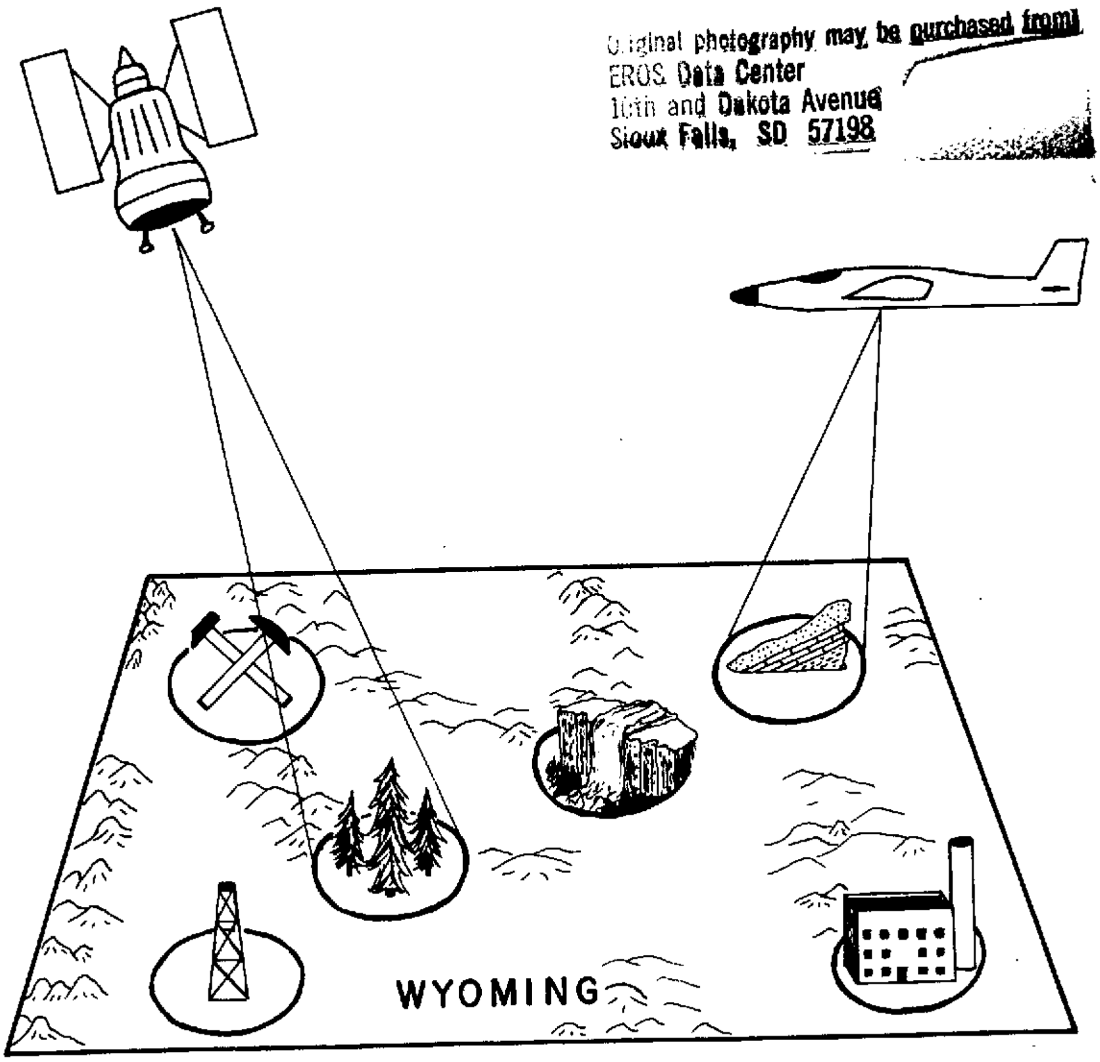

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16. Abstract

The application of ERTS-1 imagery to vegetation mapping and identification was tested and confirmed by field checking. ERTS-1 imagery interpretation and density contour mapping allows definition of minute vegetation features and estimation of vegetative biomass and species composition. Large- and small-scale vegetation maps were constructed for test areas in the Laramie Basin and Laramie mountains of Wyoming. Vegetative features reflecting grazing intensity, moisture availability, changes within the growing season, cutting of hay crops, and plant community constituents in forest and grassland are discussed and illustrated. Theoretical considerations of scattering, sun angle, slope and instrument aperture upon image and map resolution were investigated. Future suggestions for applications of ERTS data to vegetative analyses are included.

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Figure 2. Technical Report Standard Title Page

# VEGETATION ANALYSIS IN THE LARAMIE BASIN, WYOMING FROM ERTS-1 IMAGERY

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# EVALUATION OF ERTS-1 IMAGERY FOR SMALL-SCALE VEGETATION MAPPING IN THE LARAMIE BASIN, WYOMING

The area under consideration lies south of Rock River, Wyoming, east of the Medicine Bow Mountains, north of Laramie, and west of Sybille Creek canyon (Fig. 1). A vegetation map of the Laramie Basin test area was constructed from ERTS-image interpretations in order to test the utility of the ERTS imagery for mapping and analysis of range vegetation (Fig. 2). Image 1029-17148, bands 5 (Fig. 3), and 7 (Fig. 4) were used in the interpretation. The image interpretation was supplemented by an isodensity contour map (Fig. 5) of the band 5 image.

The isodensitracer used in constructing the density contour map was adjusted to show alkali areas, grasslands and floodplain vegetation on the basis of film density ranges which represent reflected radiance levels, and which, in turn, correspond to vegetation cover. Infrared band 7 was compared to band 5 for confirmation of interpretation, and bodies of water were identified from band 7.

No comprehensive vegetation maps have been made for the Laramie Basin. The Soil Conservation Service analyzes range conditions for ranchers, but such investigations are very limited. It is hoped that a vegetation map compiled from ERTS imagery, general as it may be, will be useful in assessment of resources, land use, and change.

The lack of an existing vegetation map and the few phytogeographical studies available for the Laramie Basin leave much to be desired in the way of refererence data for photointerpretive mapping of vegetation in this area. However, certain vegetation stands and their distributions are known and can be sought on the ERTS imagery.

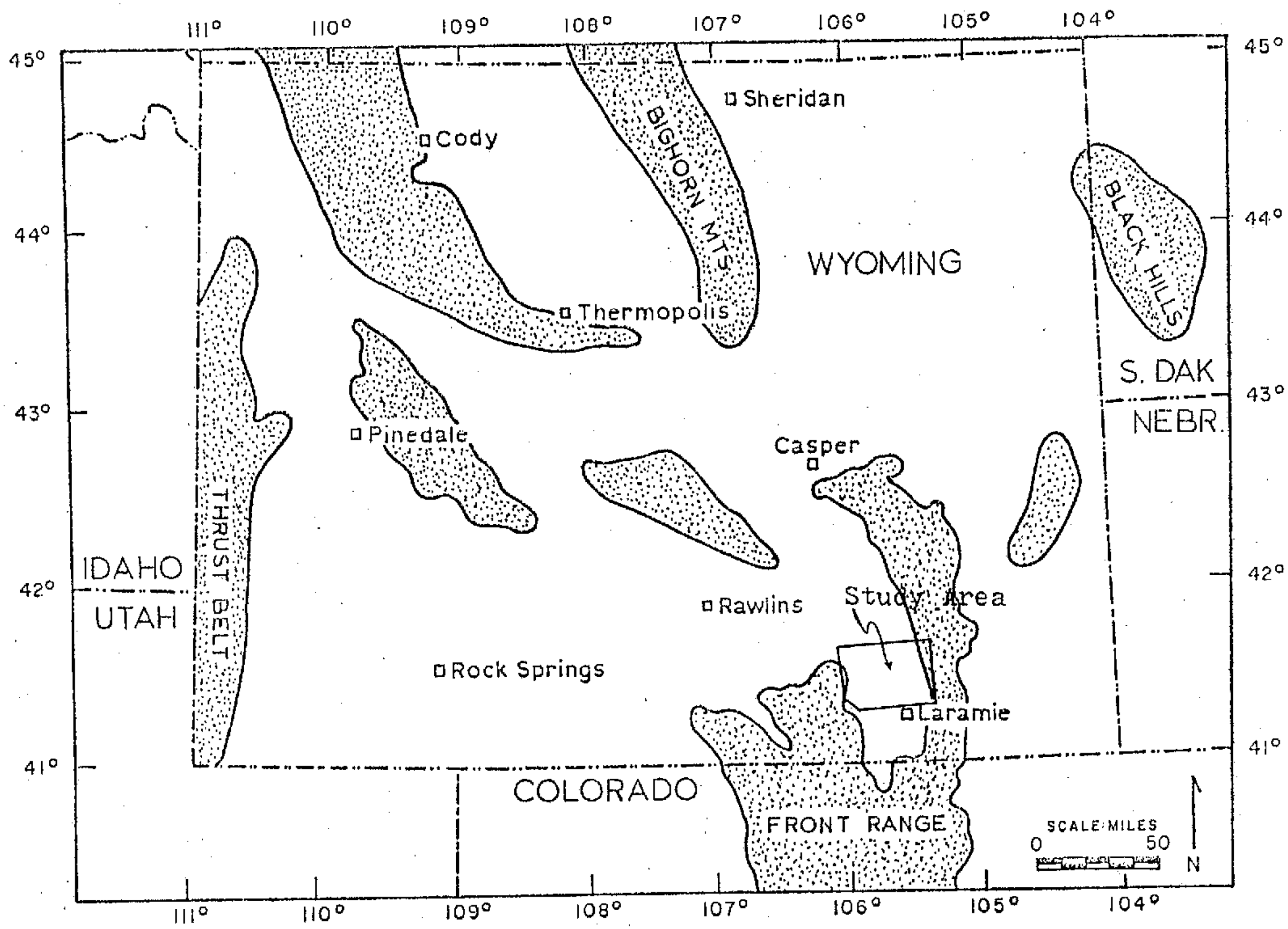



Figure 1. Index map for the Laramie Basin study area.

## INDEX TO FIGURE 2

VEGETATION MAP OF THE LARAMIE BASIN STUDY AREA

The scale is approximately 1:210,000.

The Laramie and Little Laramie Rivers have a confluence in the south-central portion of the map. Cooper Lake was dry during imaging. Dotted lines indicate indefinite boundaries. The same zone divided by a solid line indicates a change towards the next radiance, but not enough to warrant a different classification. The black, numbered lines indicate the 10,000 meter universal

| | | |
|---|---|---|
| 1 | Zone I. | Mostly alkaline areas. The plant community would be expected to consist mostly of halophytes. |
| 2 | Zone II. | Areas of alkalinity and/or light grassland. |
| 3 | Zone III. | Grassland of light cover; typical basin |
| 4 | Zone IV. | Grasslands and brush lands associated with floodplain areas. |
| 5 | Zone V. | Same as above, but lush vegetation is indicated. |
| 6 | Zone VI. | Wet hay meadows, irrigated, possibly areas of shallow standing water. |
| 7 | Zone VII. | Same as above, but darker in red band (No. 5). |
| 8 | Zone VIII. | Bodies of water. |
| 9 | Zone IX. | Stands of conifers, aspen and heavy brush. |
| 10 | Zone X. | Vegetation growing on the Casper Limestone Formation, mostly mountain mahogany, grasses, sagebrush, and scattered conifers. Further information on Zone X is found in the following discussion on the Laramie Range study area. |

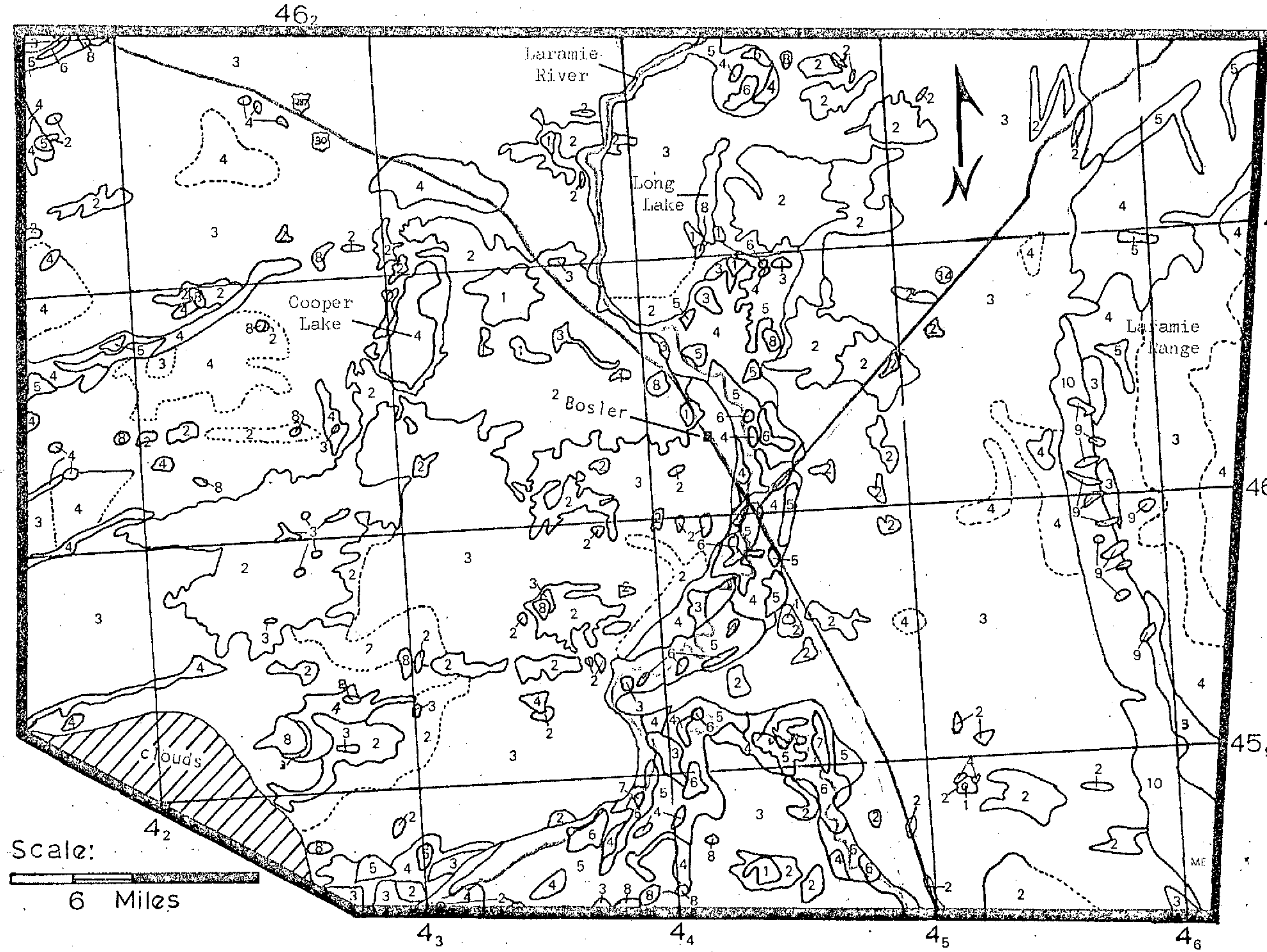



Figure 2: Vegetation Map of Laramie Basin.

Figure 3. A portion of ERTS-1 image 1029-17184-5, showing both study areas.

Figure 4. A portion of ERTS-1 image 1029-17184-7, showing both study areas.

Figure 5. A density contour map (from ERTS-1 image 1029-17184-5) of the Laramie Basin study area used for the small-scale vegetation mapping shown in Figure 2.

Figure 3 shows that some vegetation types can be discriminated from the red band alone. Heavily vegetated floodplains are easily separated from drier areas supporting other vegetation types (Fig. 6). Floodplain vegetation shows a variety of contrasting radiance patterns on both bands 5 and 7. These patterns are readily interpreted by comparison of density contour maps derived from ERTS bands 5 and 7. Light-toned areas surrounded by floodplain vegetation may be elevated grassland areas or simply alkaline flats devoid of heavy vegetation cover. Alkaline areas show up distinctly on band 5 but are easily confused with dense mesic vegetation on the infrared bands.

There are no coniferous forests in the area of the preliminary vegetation map. However, in nearby mountain areas, conifers are readily mapped from the imagery because they are relatively dark in both bands 5 and 7 (Fig. 7). Figure 7 also shows clearcut and burned-over areas which can be identified and studied quantitatively. Cloud cover is common in high mountain areas and often obscures large areas of coniferous forest. The Laramie Basin is predominantly a short grass prairie. This grassland exhibits a mottled appearance on the ERTS imagery. In some areas slightly alkaline conditions produce light toned regions on the band 5 imagery. Straight-line tone changes often represent fence lines and corresponding differences in grazing intensities (Fig. 8). Some of the tonal contrasts may reflect differences in species composition of the grassland, especially where grazing pressure affects species composition and vegetative biomass. Figures 8 and 9 show examples of tonal changes at different times of the year. Figures 8 and 9 are from band 5 imagery taken on 21 August, 1972 (No. 1029-17184-5) and 11 July, 1973 (No. 1353-17190-5) respectively. Figure 9 lacks the degree of contrasting tonal change that Figure 8 shows. This seems to indicate that in July 1973, grazing has not yet affected the grassland, and that species are similar in the two areas. The field check results of this are discussed on page 27 of this report.

Figure 6. A portion of ERTS-1 image 1353-17190-5, showing the flood plains of the Laramie and Little Laramie Rivers, in contrast to the drier Laramie Basin, 11 July 1973.

Figure 7. A portion of ERTS-1 image 1353-17190-5 showing some of the clear-cut areas in the Snowy Range, Wyoming, 11 July 1973.

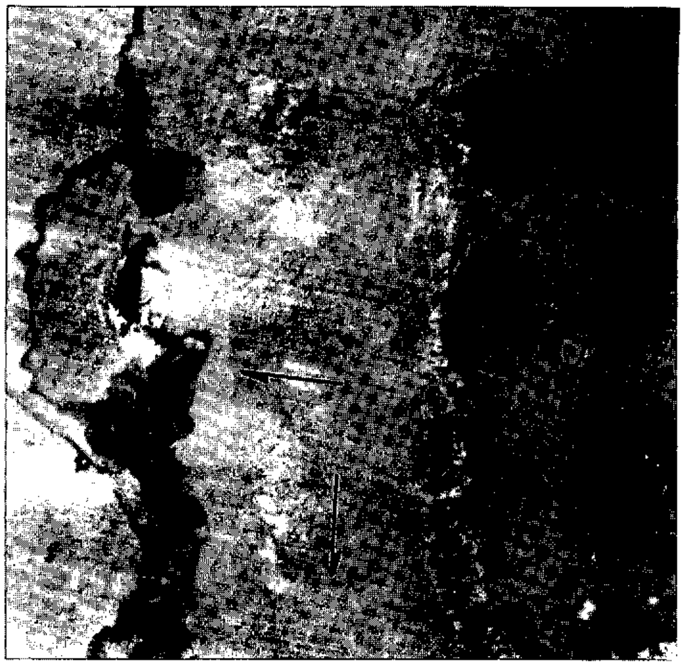


Figure 8. A portion of ERTS-1 image 1029-17184-5, showing tonal changes due to grazing intensity; 21 August 1972. The straight lines (arrow) indicate fence lines.

Figure 9. A portion of ERTS-1 image 1353-17190-5 showing the same area as in Figure 8. Note the less distinct tonal changes apparent on 11 July 1973.

Reflectance characteristics of various vegetation types were observed qualitatively. Plant absorption in the visible spectrum is due primarily to quantum absorption which is a function of the density of pigments. Thus, absorption in the green and blue bands indicates the amount of pigments present, especially chlorophyll. The chlorophyll content, in turn, can be related to vegetation type, cover, biomass, water availability, leaf area index, available nutrients, etc. Infrared reflectance, which is substantial in many species, is closely related to development of the leaf structure, particularly in the mesophyll layer, as well as to leaf area index and cover, (Gates et al., 1965; Hoffer and Johannsen, 1969; Gates, 1970; and Meyers, 1970). Thus, broad-leaf vegetation in mesic environments, with profuse and well-developed leaves, should exhibit considerable absorption of the visible energy and have high infrared reflectance. This holds true for the Laramie Basin. Drier vegetation shows less visible absorption and less infrared reflectance. Xeric plains vegetation, with its poorer leaf structure development and sparse cover, shows little difference in visible and infrared reflectance.

The effect of water on leaf structure and quantity of vegetation is apparent when comparing crops in dry and irrigated fields and dry plains with wet hay meadows. For example, irrigated crops appear very dark in the visible ERTS-1 bands and extremely light in the infrared, whereas the effect is less pronounced in dry-land crops. An example of this can be seen in Figure 10. Differences in crop species do not affect reflectance variations as severely as does water availability. Similarly, the leaf structure of the wet meadow vegetation is well developed and with a large leaf area index, thus, much visible radiation is absorbed and infrared is reflected. Dry grasslands show little or no difference between infrared and visible reflectances.

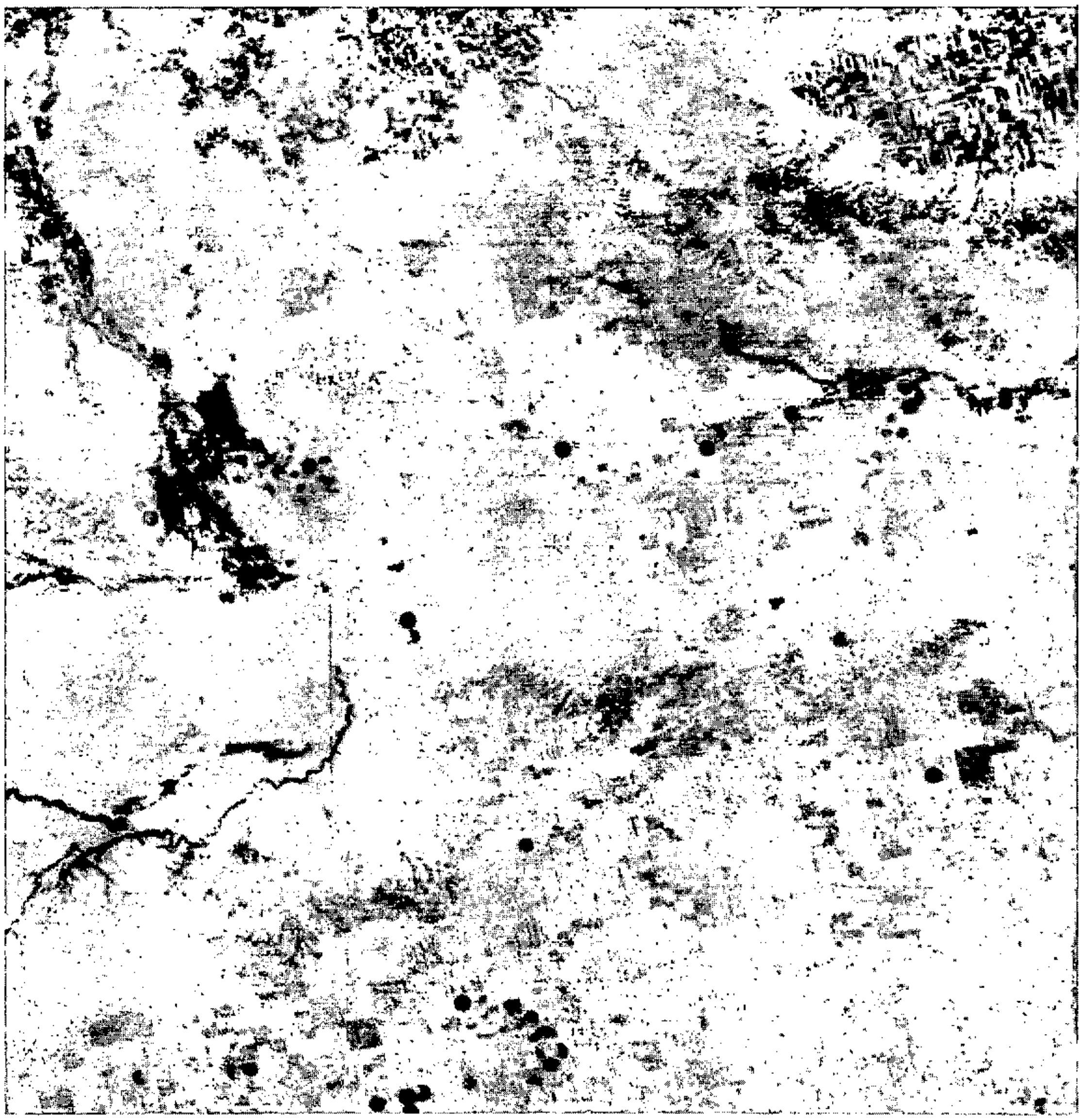


Figure 10. A portion of ERTS-1 image 1353-17132-5, showing the contrast between irrigated and dryland crops in the Chugwater, Wyoming area, 10 July 1973.

The ERTS images are definitely of considerable value in phytogeographical studies. Readily discriminated with a large degree of confidence are deciduous forests, coniferous forests, and floodplain vegetation, irrigated farming, dry-land farming, alkaline areas, and grassland-shrubland.

The two ERTS-1 bands that appear most useful at this time are 5 and 7. Band 4 is very similar to band 5 with regard to vegetation reflectance, whereas band 6, being a combination of deep red and very near infrared, represents a frequency range in which many plants show high absorption in the red and high reflectance in the infrared. As such, band 6 is generally no more effective in vegetation analysis than an average of bands 5 and 7. However, this does not mean that bands 4 and 6 are never important in interpretation. Indeed, their value may be significant in quantitative vegetation analysis.

## EVALUATION OF ERTS IMAGERY FOR LARGE-SCALE VEGETATION MAPPING IN THE LARAMIE RANGE, WYOMING

### Description of the Study Area

The area chosen for study is located in the Laramie Mountains about 8 miles northeast of Laramie, Wyoming. The area is bounded by Rogers Canyon on the north, Sherman Hill on the east, Pilot Hill on the South, and a hogback ridge near Dry Gulch on the west (See Figure 11). The whole area comprises about 21.6 square miles. The site was chosen for its easy access and the availability of low-level color and color infrared photography (Figure 12; from NASA Mission 213, Flight 2, Line 20, Frame 124, Flown 8 Sept. 1972). Another important aspect of this study area is the heterogeneity of the landscape, substrate type, and vegetation type.

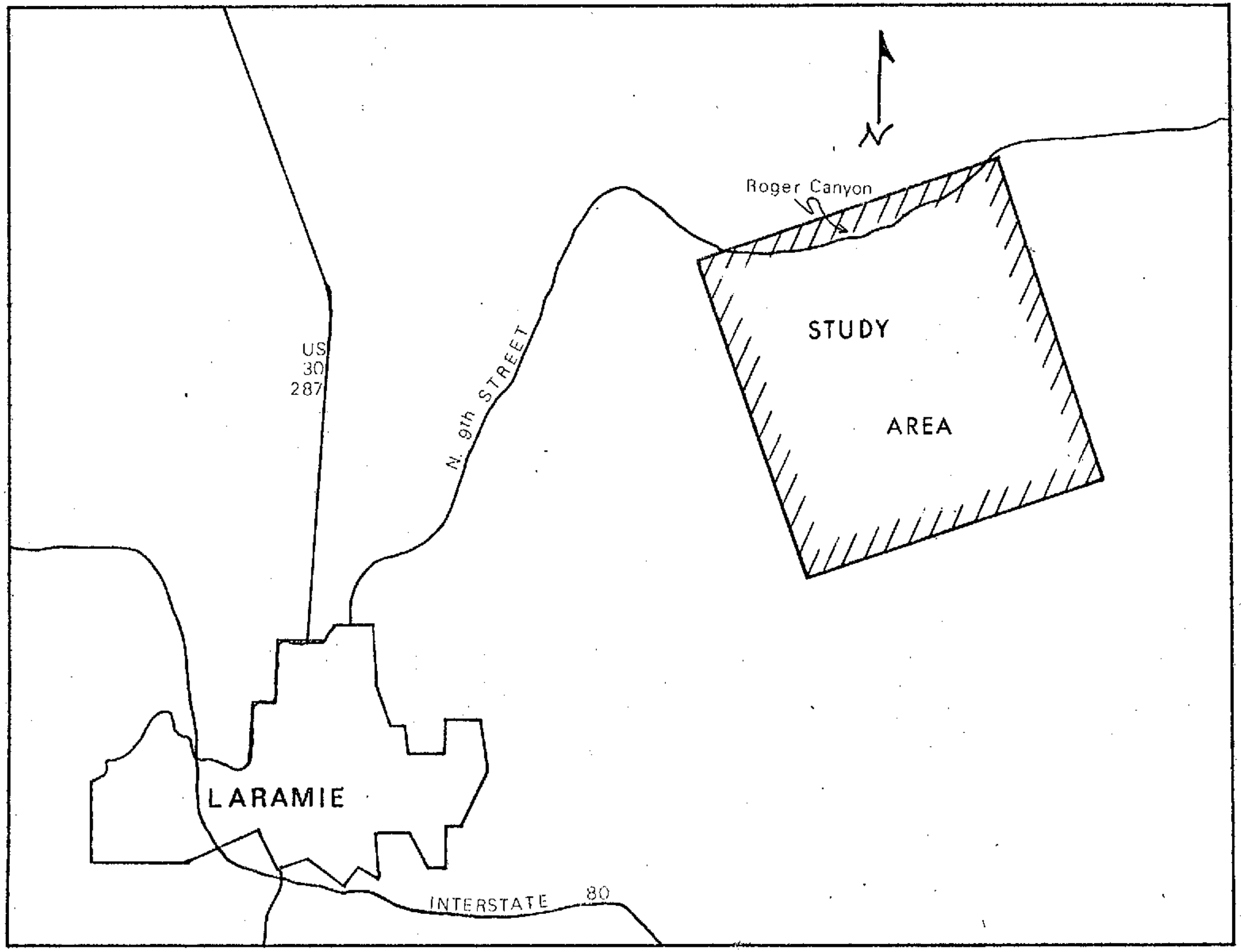



Figure 11. Index map for the Laramie Range study area

Figure 12. An aerial photo (NASA Mission 213, Flight 2, Line 20, Frame 124) of the Laramie Range Study Area used for the large-scale vegetation mapping.

The land rises eastward from about 8,200 feet on the western edge of the study site to over 8,300 feet at the apex of a hogback ridge stretching northwest to southeast and higher on the southeast portion. Dry Gulch and an associated intermittent stream to the east divide the ridge from the main body of the Laramie Mountains on the east. Many intermittent streams, flowing westward, dissect the western slope of the Laramie Mountains forming canyons before converging with the intermittent stream east of Dry Gulch. The prevalent eastward rise of the main body of the mountains top out within the study area at an altitude of about 8,600 feet. Thence the land descends to the northeast, east, and southeast, first markedly and then more gently.

Just east of the latter ridge is the contact of the Casper limestone on the west and Precambrian granite on the east, the limestone outcropping prominently along the vertex of the ridge. The soils to the west of this ridge are calcareous whereas the soils to the east grade into a granitic type.

Figure 13 is a preliminary map of the vegetation zones derived from the low-level photography. Before a field check, all that can be said is that areas of conifers, brush, and grassland demarked on the map should be fairly accurate.

In February, 1973, Mr. Redfern consulted Dr. Dennis H. Knight (Department of Botany, University of Wyoming) and Dr. Alan Beetle (Department of Range Management, University of Wyoming) with regard to the possible identification of the vegetation from the low level imagery.

It must be understood that the vegetation mapping and the following discussion was conducted in the lab and the species composition is only speculative. But a few features of the map can be examined. Though the delineation of brush type is impossible from the low-level imagery alone, the brush growing on the hogback ridge and other calcareous slopes is likely to be mountain mahogany

## INDEX TO FIGURE 13

VEGETATION MAP OF THE LARAMIE RANGE STUDY AREA

The scale is approximately 1:38,500.

| | | |
|---|---|---|
| 1 | Zone I. | Bare areas, limestone outcroppings, sparse grassland, mostly on calcareous soils. |
| 2 | Zone II. | Scattered brush with accompanying grassland of light cover. |
| 3 | Zone III. | Moderate to dense brush. |
| 4 | Zone IV. | Dense brush, sometimes showing mesophitic characteristics on the color infrared photography. |
| 5 | Zone V. | Mesophytic, broad leafed vegetation. |
| 6 | Zone VI. | Wet grasslands. |
| 7 | Zone VII. | Scattered conifers. |
| 8 | Zone VIII* | Dense conifers. |

*Zone VIII is mapped incorrectly, see Figure 20 for the actual distribution.

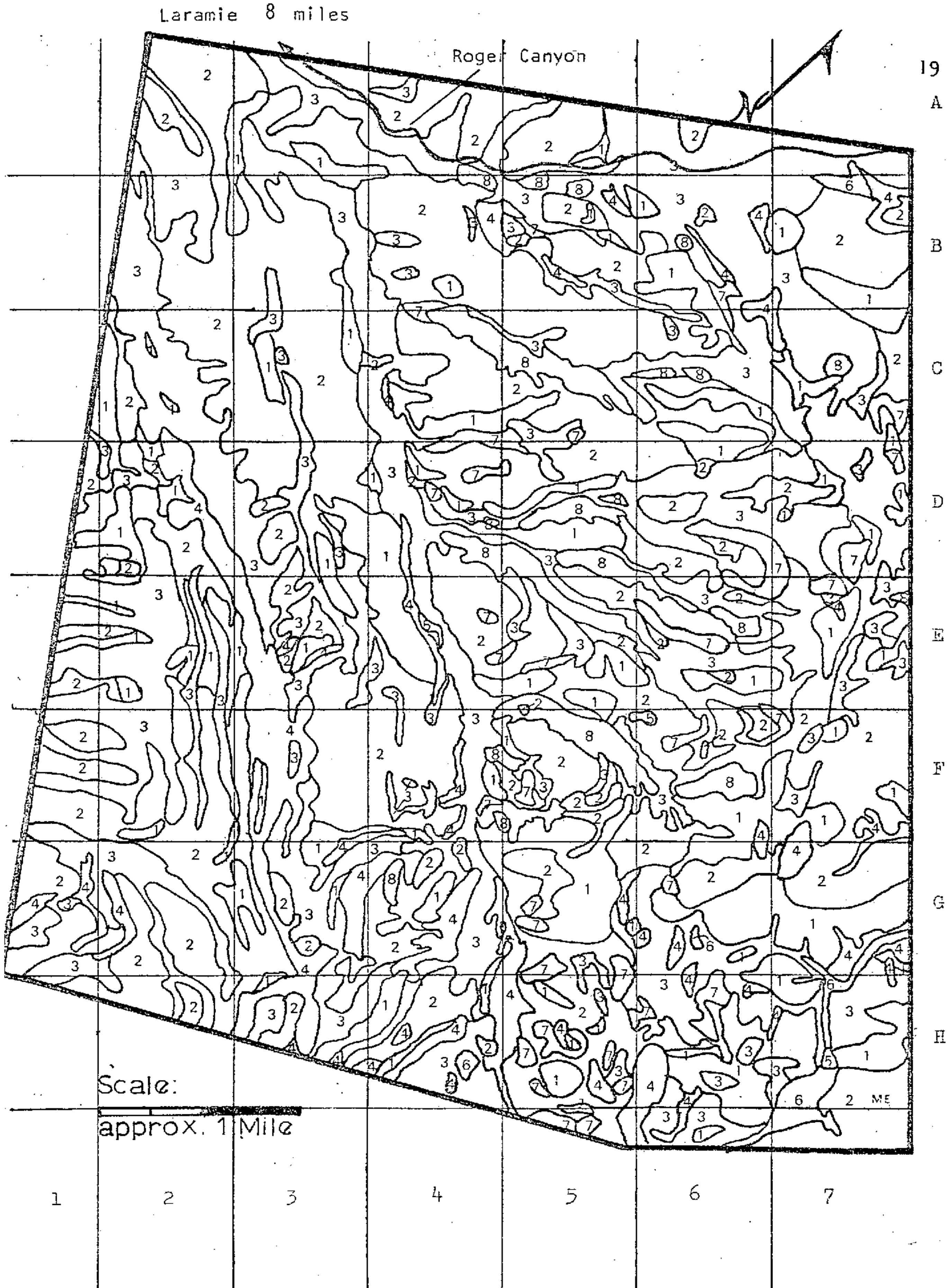



Figure 13: Vegetation Map of Study Area.

(Cercocorpus montanus), whereas brush associated with drainage patterns and growing east of the vertex of the Laramie Range (mostly on granitic soils) could well be sagebrush (Artemisia tridentata). Some willows may also be present in drainage areas. The brush associated with coniferous stands is likely to be sagebrush, with mountain mahogany also present, especially away from drainage areas. Limber pine (Pinus flexilis) probably composes the major portion of the conifer stands, especially those on calcareous substrate, though other species are likely to be present such as ponderosa and lodgepole pine (P. ponderosa and P. contorta), particularly where the substrate is granite. Pockets of aspen (Populus tremuloides) are perhaps interspersed with the conifers, though this appears unlikely from the color infrared photography. The grass cover in most parts of the study site is undoubtedly extremely sparse, judging from the apparent ease with which the substrate is viewed on the low-level photos. The photography used in the large-scale mapping was flown at a time when the vegetation was senescing or becoming dormant, as a result, the photography may not be optimum for vegetation mapping. For example, the fact that the brush showed little infrared reflectance may be either a property of the brush throughout the growing season or the peculiar property of senescing leaves. Also, the more sheltered the habitat, the more lush the vegetation. North-facing slopes are covered by conifers or dense shrubs, whereas south-facing slopes which receive greater heat, desiccation, and little snow accumulation are often bare in appearance and support only sparse grass cover and scattered to isolated shrubs.

## Processing the Imagery

The utility of the ERTS imagery in distinguishing the vegetation of the study area was examined. The object of examining ERTS imagery was two-fold:

to establish the practical spatial limits of vegetation analysis using ERTS imagery and to discover how well various vegetation types could be identified in a diverse landscape.

Isodensity contour maps 1:49,450-scale were constructed for both the red (band 5) Fig. 14, and infrared (band 7) Fig. 15, band ERTS transparencies. Image set No. 1029-17184 was used. Subsequently, the two isodensitracings were combined into a map of radiance types (Figure 16), each type corresponding to two radiance ranges, one in each band. This map simulates automatic analysis, in which a map of radiance types would be produced by computer. Many such automated analyses of multispectral imagery have been done (e.g. Watson and Rowan, 1971; Marshall et al., 1970; and Kolipinski and Higer, 1970), mostly with imagery obtained by aircraft in many radiation bands. A measure of success has been achieved with this general type of analysis, particularly when clustering and data transformation techniques are employed (Smedes, 1971; Kriegler et al., 1970; and Smedes et al., 1971).

Because information relating ERTS imagery gray scales to radiance levels intercepted by the multispectral scanner was not available, the mapped reflectance types have only relative meaning. The Joyce Loeble-Tech/Ops isodensitracer used in this study maps density ranges from a transparency onto a sheet of paper using a color and pattern code, each color pattern contour corresponding to a density range on the transparency. The isodensitracer scale is relative, running from 1 to 65, and was calibrated for both bands 5 and 7 of the ERTS imagery by assigning corresponding gray levels on each transparency to similar density readings on the scale, larger numbers on the scale coinciding with greater density. The scale of the isodensitracer was segmented into six levels of density: 16 and less, 17-21, 22-26, 27-31, 32-35, and 36 and greater. These density levels were

Figure 14. A density contour map (from ERTS-1 image 1029-17184-5) of the Laramie Range study area used for the large-scale vegetation mapping.

Figure 15. A density contour map (from ERTS-1 image 1029-17184-7) of the Laramie Range study area used for the large-scale vegetation mapping.

INDEX TO FIGURE 16

RADIANCE MAP OF THE LARAMIE RANGE STUDY AREA

The scale is 1:38,500.

| | | Radiance Type |
|---|---|---|
| 1 | Zone I. | 22, 23, 24 |
| 2 | Zone II. | 32, 33 |
| 3 | Zone III. | 42, 43 |
| 4 | Zone IV. | 34, 35, 44 |
| 5 | Zone V. | 53 |
| 6 | Zone VI. | 52, 62 |
| 7 | Zone VII. | 45 |
| 8 | Zone VIII. | 54 |
| 9 | Zone IX. | 63 |
| 10 | Zone X. | 55 |
| 11 | Zone XI. | 64 |
| 12 | Zone XII. | 65 |

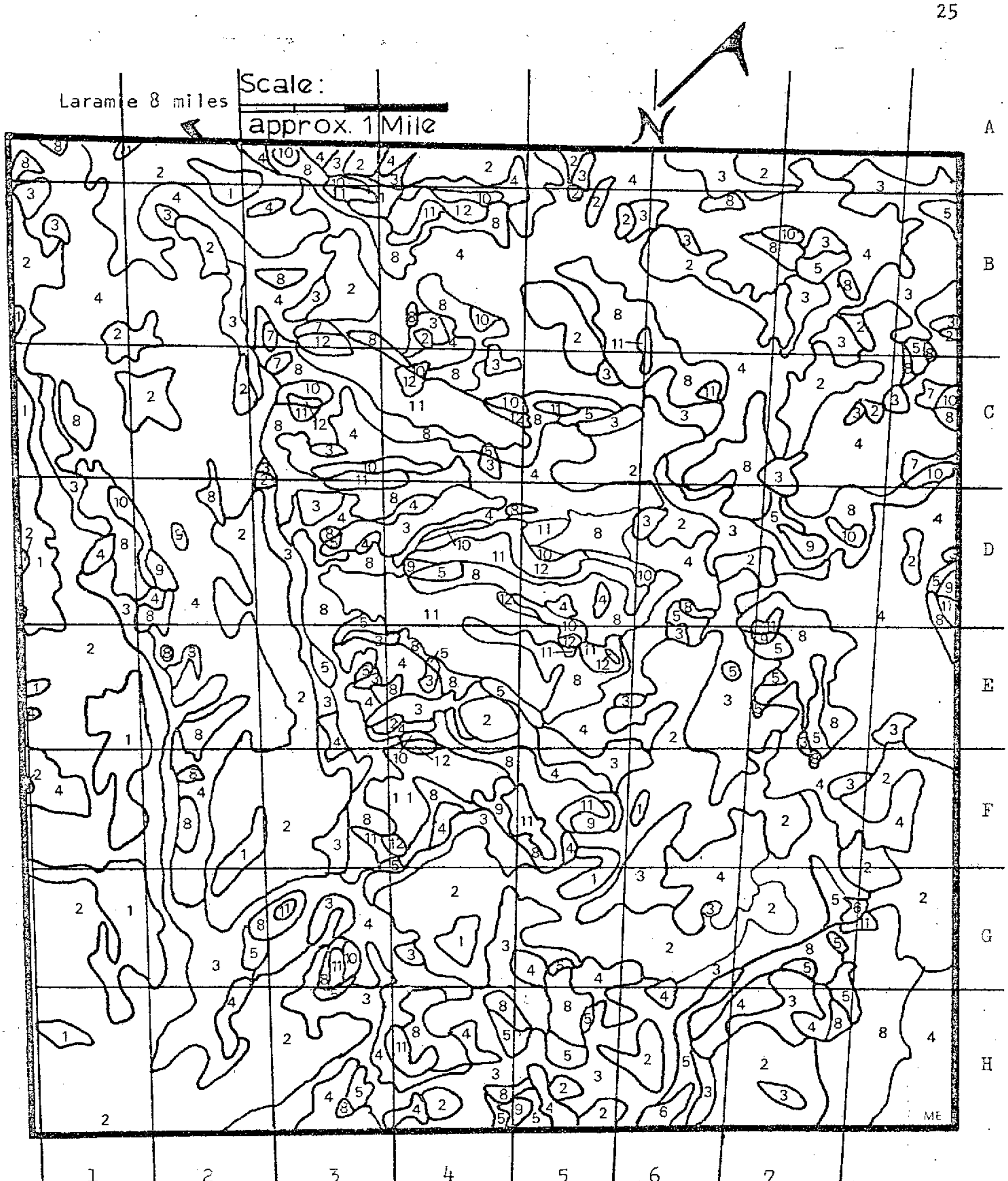



Figure 15: Radiance Map of Study Area. One resolution element (.24 cm) = —

coded from 1 to 6. Thus a radiance type with a code number of 45 means that the red band density was 27-31 whereas the infrared band density fell between 32 and 35. We have a total possibility, then, of 36 radiance types. However, only 22 were actually noted on the map combining the two isodensitracing. Figure 16, derived from the original radiance map, combines these 22 radiance types into 12 categories.

In order to correlate the many radiance types with the vegetation of the study area, a map was made from the low-level color infrared photography of the study area which defined eight broad vegetation types, namely dense conifers, sparse conifers, grassland and/or bare areas (including quarries), scattered brush and grassland, dense brush, very dense brush (often with a slight reddish hue in the color infrared), vegetation giving a bright red reflectance in the color infrared (indicating mesic species), and wet bottomland (grassy meadows with some cottonwoods). The lush mesic vegetation types were so ill represented that no large-scale analysis of these types could be considered. Also, very little of the total area was in wet bottomland.

## Field Check Results

A field check of the vegetation zones mapped by Mr. F. R. Redfern, and included in this paper as Figures 2 and 13 was conducted in late June and early July 1973 by Mike Evans. Both the Laramie Basin and Laramie Range study areas were field checked. In both areas a number of each of the mapped zones were checked, and a species account was made. The dominant species in each area were determined and a list was made of all species encountered in each area.

The first portion of the field checking involved the vegetation map of the Laramie Basin, Figure 2. This was accomplished from 25 June to 2 July 1973. Mr. Redfern produced this map from ERTS-1 image No. 1029-17184 bands 5 and 7 (see Figures 3 and 4) and the density contour map in Figure 5. A brief description of each zone is below with the species composition list.

ZONE I: ALKALINE AREAS

| | |
|---|---|
| Sarcobatus vermiculatus | Black Greasewood |
| Atriplex corrugata | Mat Saltbush |
| Opuntia polyacantha | Plains Pricklypear |
| Gutierrezia sarothrae | Broom Snakeweed |
| Agropyron smithii | Western Wheatgrass |
| Erigeron engelmanni | Engelmann Fleabane |

Zone I is a sparsely vegetated area dominated by greasewood. The saltbush and prickleypear are very common, with the wheat grass sparsely scattered. There is much bare ground which is sandy and alkaline. Zone I occurs in low-lying areas, often on the eastward side of the intermittent lakes, i.e. Cooper Lake; which has some well developed dunes.

ZONE II: AREAS OF ALKALINITY AND/OR LIGHT GRASSLAND

| | |
|---|---|
| Agropyron smithii | Western Wheatgrass |
| Koleria cristata | June grass |
| Poa sandbergii | Sandberg Bluegrass |
| Artemisia frigida | Fringed sage |
| Musineon lenuifolium | Musineon |
| Lesquerella condensata | Bladderpod |
| Erigeron engelmanni | Engelmann Fleabane |
| Phlox austromontana | Desert Phlox |
| Atriplex corrugata | Mat Saltbush |
| Astragalus spp. | Milkvetch |

Zone II areas are low grassy areas dominated by Western Wheatgrass, with June Grsss and Sandberg Bluegrass being quite common. The areas are often adjacent to Zone I. There is much bare ground, and the soil is sandy and is probably alkaline.

ZONE III: GRASSLAND OF LIGHT COVER

| | |
|---|---|
| Bouteloua gracilis | Blue Gramma |
| Agropyron smithii | Western Wheatgrass |
| Agropyron cristatum | Crested Wheatgrass |
| Orozopsis Hymenoides | Indian Ricegrass |
| Stipa comata | Needle and thread |

| | |
|---|---|
| Koleria cristata | Junegrass |
| Carex Filifolia | Threadleaf Sedge |
| Artemisia frigida | Fringed Sage |
| Eurotia lanata | Common Winterfat |
| Sphaeralcea coccinea | Scarlet Globemallow |
| Descurania pinnata | Tansy Mustard |
| Gutierrezia sarothrae | Broom Snakeweed |
| Chrysothamnus nauseosus | Rubber Rabbitbrush |
| Delphinium geyeri | Plains Larkspur |

Zone III, the major zone in the Laramie Basin, can be considered as a shortgrass prairie. Blue gramma is the dominate species, with the other grasses, shrubs, and forbs scattered throughout the zone. Stipa comata is very evident in late summer due to its large influorescence, which are light in color and dark in mid-summer. Thus, late summer imagery may show large stands of Stipa. The zone has little bare ground, being covered by the Blue Gramma sod. A September 1973 check of the area shown in Figures 8 and 9 showed that the tonal changes are due to large stands of Stipa comata and Agropyron cristatum, Crested Wheatgrass. At this time of year these two species have died back and appear light in color. Thus the reason for the tonal changes, at this time, appear to be a result of grazing and range re-seeding. These same tonal changes occur in the Saratoga, Wyoming area, shown in Figure 17 (upper left corner) presented later in this report.

ZONE IV: GRASSLANDS AND BRUSHLANDS, MOIST AREAS

(Zone IV is a continuation of Zone III into areas of greater moisture, with the addition of the following:

| | |
|---|---|
| Salix spp. | Willows |
| Populus sargentii | Plains Cottonwood |
| Rosea spp. | Wild Rose |
| Sisyrinchium heterocarpum | Blue-eyed Grass |
| Iris missouriensis | Iris |
| Eleocharis spp. | Spike Rush |
| Carex spp. | Sedges |

Zone IV is a continuation of Zone III into moister areas, with the addition of sedges and rushes. In some places in the Laramie and Little Laramie river-bottoms there are stands of Populus sargenti, Plains Cottonwood; Salix spp., willows, and other moist-habitat shrubs. In these areas the grass cover grows quite thick and lush. The spring flood areas on the rivers are covered almost entirely by willows. Cooper Lake was full of water throughout the summer of 1973, thus the species composition on the lake bed could not be determined. The lake was dry when the 21 August 1972 ERTS imagery was obtained. The area mapped as Zone IV in the Laramie Range area of Fig. 2 corresponds to Zone II of the Laramie Range study area, discussed later in this report (See Figure 13).

ZONE V, VI, AND VII; FLOODPLAINS, IRRIGATED FIELDS AND HAY MEADOWS.

In areas along the rivers and around lakes there are zones of lush vegetation, varying according to the amount of moisture present. In the areas undisturbed by man there are numerous rushes and sedges and, where water persists in the flood plain, Typha latifolia, Cattail, Juncus spp. and Carex spp. occur in swampy and marshy areas. In irrigated hay meadows Bromus intermis, Smooth Bromgrass, Agrostis alba, Red Top, Phalaris arundinacea, Reed Canarygrass, Poa pratensis, Bluegrass, Phleum pratense, Timothy, Dactylis glomirata, Orchardgrass, Festuca elatior, Meadow Fescue and Festuca arundinacea, Reed Fescue have been introduced. In addition there are many other moist habitat species of grasses, forbes and flowering plants. An exact list of the species present was not obtained because of restricted access.

Mr. Redfern indicated differences in the vegetation Zones V, VI and VII. His map work was obtained from ERTS imagery from 21 August 1972, while the field work was conducted in early July, 1973 and no apparent differences could be seen from the ground. It is very possible that the differences he detected were a result of either less water i.e. drier areas in August 1972, than in early July 1973, or portions of the hay crop could have been harvested. Both would result in different shades on the imagery.

Figure 6 shows a portion of the study area on 11 July, 1973 from ERTS image No. 1353-17190-5. At this time of year, most of the irrigated and floodplain areas were wet and hay had not been cut. One can see that the same areas are more homogeneous earlier in the summer than in Figure 3. The darkest areas define stands of Cottonwoods and swampy, marshy areas.

Figure 17 shows an enlargement of a portion of ERTS image No. 1029-17184-5 (21 August, 1972) near Saratoga, Wyoming. In the 21 August image, one sees an "L" shaped field of irrigated alfalfa. In an 8 September image (ERTS image 1047-17184-5) one sees the same field but all of the hay is cut except for a small central portion in one of the irrigated areas. This image is very cloudy, and the field is hard to see, nevertheless, the uncut area can be seen. Figure 18 shows this same field taken from a color aerial photograph on 8 September and one can readily see the uncut portion.

ZONE VIII; BODIES OF WATER.

Zone VIII, as suggested, includes bodies of water.

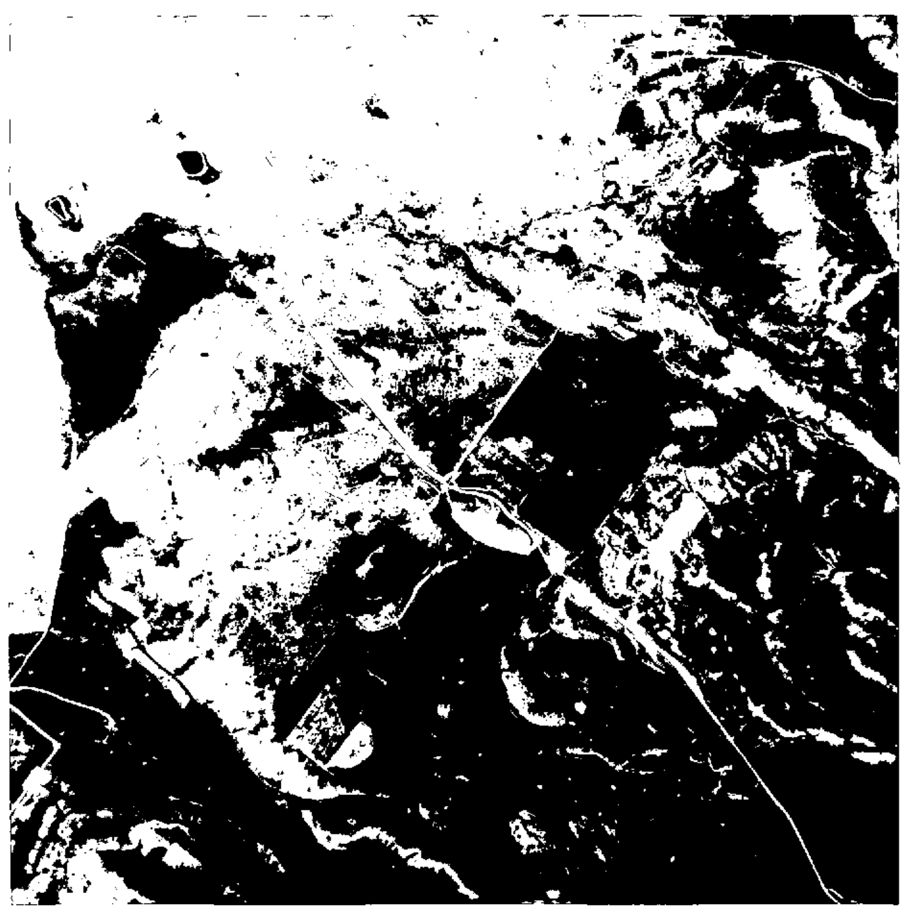
ZONE IX,X; CONIFERS AND VEGETATION GROWING ON THE CASPER LIMESTONE FORMATION.

The conifers growing in Zone IX and Pinus flexus, Limber Pine and Pinus Ponderosa, Ponderosa Pine. Zone IX is actually a combination of Populus tremuloides, Quaking Aspen and Limber Pine. Both Zone IX and X are fully discussed in the following discussion of the vegetation zones in the Laramie Range study area.

The second portion of the field check involved checking the vegetation zones of the Laramie Range study area mapped by Mr. Redfern in large scale (1:38:500) and shown in Figure 13.

Figure 17. A portion of ERTS-1 image 1029-17184-5 showing the "L" shaped alfalfa field on 21 August 1972, three weeks before it was cut. See arrow.

Figure 18. An aerial photo (NASA Mission 213, Flight 2, Line 1, Frame 17) of the same "L" shaped alfalfa field on 8 September 1972, after a portion was cut. ERTS-1 image 1047-17184-5 shows the field, but haze and cloudiness make for a poor illustration.



ZONE I; BARE AREAS, LIMESTONE OUTCROPPINGS.

| | |
|---|---|
| Agropyron smithii | Western Wheatgrass |
| Agropyron trachycaulum | Slender Wheatgrass |
| Koeleria cristata | June Grass |
| Buteloua gracilis | Blue Gramma |
| Stipa comata | Needleandthread |
| Artemisia frigidia | Fringed Sage |
| Paronychia depressa | Nailwort |
| Eriogonum spp. | Buckwheat |
| Erigeron spp. | Fleabane |
| Mertensia lanceolata | Bluebells |
| Musineon lenuifolium | Musineon |
| Astragalus spatulatus | Milkvetch |
| Alium textile | Wild Onion |
| Lesquerella condensata | Bladderpod |
| Sedum lanceolatum | Stonecrop |
| Cerastium arvense | Field Cerastium (Chickweed) |
| Zigadenus venenosus | Meadow Death Camas |
| Achilles lanulosa | Western Yarrow |
| Taraxacum officinale | Common Dandelion |
| Hymenoxys torreyana | Sunflower |
| Frasera speciosa | Showy Elkweed |
| Coryphantha vivipara | Purple Ballcactus |
| Phlox hoodii | Hoods Phlox |

Zone I is a sparse grassy area, usually with outcroppings of limestone. Interdispersed with the grasses are the various low-growing, flowering,herbaceous plants. Since the zone is dry, the grasses persist into the summer and the other plants die back. Also, since the field check took place in the early part of the growing season, this would account for the abundance of the minor flowering plants. The dominate grass is Western Wheatgrass.

ZONE II; SCATTERED BRUSH WITH ACCOMPANYING GRASSLAND OF LIGHT COVER.

| | |
|---|---|
| Artemisia tridentata | Big Sagebrush |
| Cerocarpus montanus | True Mountainmahogany |
| Orozopsis hyminoides | Indian Ricegrass |
| Agropyron smithii | Western Wheatgrass |
| Agropyron trachycaulum | Slender Wheatgrass |
| Poa spp. | Bluegrass |
| Koleria cristata | Junegrass |
| Achillea lanulosa | Western Yarrow |
| Cerastium arvense | Field Cerastium (Chickweed) |
| Chrysothominus spp. | Rabbitbrush |
| Alium textile | Wild Onion |
| Phlox hoodii | Hoods Phlox |
| Carex filifolia | Threadleaf Sedge |

Zone II is dominated by Mountainmahogany and is characteristic of dry hillsides. The grasses are scattered throughout the brush. There is sparse cover, resulting in much exposed, rocky ground. The Big Sagebrush is common in the area, and Indian Ricegrass is the most common grass.

ZONE III; MODERATE TO DENSE BRUSH

| | |
|---|---|
| *Artemisia tridentata* | Big Sagebrush |
| *Agropyron smithii* | Western Wheatgrass |
| *Agropyron trachycaulum* | Slender Wheatgrass |
| *Agropyron* spp. | Wheatgrass |
| *Stipa comata* | Needleandthread |
| *Aristida* spp. | Threeawn |
| *Lupinus humicola* | Lupine |
| *Hydrophyllum fendleri* | Fendler Waterleaf |
| *Mahonia ripens* | Oregon Grape |
| *Claytonia lanceolata* | Lanceleaf Springbeauty |
| *Senicio intergerrimus* | Lambstongue Groundsel (Ragwort) |
| *Cirsium* spp. | Thistle |
| *Ranunculus glaberrimus* | Sagebrush Buttercup |

Zone III is dominated by Big Sagebrush, and is usually associated with moist areas where snow has accumulated, or along the upper portions of stream beds. Zone III seems to be the expansion of Zone IV into somewhat drier areas.

ZONE IV; DENSE BRUSH

| | |
|---|---|
| *Artemisia tridentata* | Big Sagebrush |
| *Agropyron smithii* | Western Wheatgrass |
| *Poa* spp. | Bluegrass |
| *Koleria cristata* | Junegrass |
| *Aristida* spp. | Threeawn |
| *Stipa comata* | Needleandthread |
| *Elymus cinereus* | Giant Ryegrass |
| *Carex* spp. | Sedge |
| *Rosa acicularis* | Prickley Rose |
| *Smilacina stellata* | Starry Falsesolomonseal |
| *Senicio intergerrimus* | Lambstongue Groundsel (Ragwort) |
| *Viola vallicola* | Yellow Violet |
| *Viola nephrophylla* | Purple Violet |
| *Lupinus humicola* | Lupine |
| *Delphinium nelsonii* | Nelson Larkspur |
| *Eriogonum ovalifolium* | Cushion Wildbuckwheat |
| *Mahonia ripens* | Oregon Grape |
| *Musineon tenuifolium* | Musineon |
| *Zigadenus venenosus* | Meadow Death Camas |
| *Erigerion* spp. | Fleabane |
| *Geranium richardsoni* | Richardson Geranium |
| *Amelanchier alnifolia* | Saskatoon Serviceberry |
| *Hydrophyllum fendleri* | Fendler Waterleaf |
| *Hesperochloa kingii* | King Spikefescue |

Zone IV is dominated by Big Sagebrush, where it grows very thick, up to four feet tall. Under the sage a thick layer of grasses and forbs grow. This is a moist area, at least in the early summer, and is typical of the leeward side of ridges where snow accumulates and in intermittent stream beds.

Zone V; MESOPHYTIC, BROAD LEAFED VEGETATION.

| | |
|---|---|
| Populus tremuloides | Quaking Aspen |
| Prunus virginiana | Chokecherry |
| Amelanchier alnifolia | Saskatoon Serviceberry |
| Cereocarpus montanus | True Mountainmahogany |
| Juniperus communis | Common Juniper |
| Pinus flexilis | Limber Pine |
| Pinus ponderosa | Ponderosa Pine |
| Picea pungens | Blue Spruce |
| Mahonia ripens | Oregon Grape |
| Artemisia tridentata | Big Sagebrush |
| Viola adunca | Hookedspur Violet |
| Viola vallicola | Yellow Violet |
| Viola nephrophylla | Purple Violet |
| Poa spp. | Bluegrass |
| Koleria cristata | Junegrass |
| Andropogon spp. | Bluestem |
| Agropyron spp. | Wheatgrass |
| Elymus cinereus | Giant Ryegrass |
| Delphinum nelsonii | Nelson Larkspur |
| Aquilegia laramiensis | Columbine |
| Cerastium arvense | Field Cerastium (Chickweed) |
| Smilacina stellata | Starry Falsesolomonseal |
| Taraxacum officinale | Common Dandelion |
| Fragaria vesca americana | American Strawberry |
| Rosa woodsii | Woods Rose |
| Achillea lanulosa | Western Yarrow |
| Anemone patens | Spreading Pasqueflower |
| Halimolobos virgata | |
| Hydrophyllum fendeleri | Fendler Waterleaf |
| Scenicio intergerrimus | Lambstongue Groundsel (Ragwort) |
| Saxifraga rhomboidea | Diamondleaf Saxifrage |
| Lithophragma glabra | Woodlandstar |

Zone V is a moist area predominated by Quaking Aspen. Beneath the Aspen there are the shrubs, Serviceberry, Mountainmahogany, Chokecherry, Juniper and some Limber Pine. In addition, there is a lush growth of grasses and forbes. The field check revealed Zone V to be a major zone in this study area. Its vegetative biomass far exceeds all other zones.

ZONE VI; WET GRASSLANDS

| | |
|---|---|
| Agropyron smithii | Western Wheatgrass |
| Poa pratensis | Kentucky Bluegrass |
| Poa compressa | Canada Bluegrass |
| Elymus cinereus | Giant Ryegrass |
| Carex spp. | Sedge |
| Carex spp. | Sedge |
| Juncus balticus | Baltic Rush |
| Juncus nodsus | Jointed Rush |
| Equisetum spp. | Horsetail |
| Salix bebbiana | Bebb Willow |

| | |
|---|---|
| Iris missouriensis | Rockymountain Iris |
| Sambucus spp. | Boxelder |
| Achillea lanulosa | Western Yarrow |
| Smilacina stellata | Starry Falsesolomonseal |
| Clematis Hirsutissima | Virgin's Bower |
| Cerastium arvense | Field Cerastium (Chickweed) |
| Geranium richardsoni | Richardson Geranium |
| Heracelum lanatum | Common Cowparsnip |
| Hydrophyllum spp. | Waterleaf |
| Mertensia lanceolata | Lanceleaf Bluebells |
| Viola nephrophylla | Purple Violet |

Zone VI is moist grassy areas along streams and wet spots. The Willows grow right along the water's edge, and grow quite thick in spots. The grasses, Sedges and Rushes are dominate in the moist areas. The forbs and annuals are scattered throughout the zone.

ZONE VII; SCATTERED CONIFERS

| | |
|---|---|
| Pinus flexilis | Limber Pine |
| Pinus Ponderosa | Ponderosa Pine |
| Juniperus communis | Common Juniper |
| Populus tremuloides | Quaking Aspen |
| Zone II vegetation | |
| Zone V vegetation | |

In this study area, Limber Pine is the dominate conifer with some Common Juniper and Ponderosa Pine present. In the moist spots, small stands of Quaking Aspen and Zone V vegetation occur. Where the Limber Pine grows dense, the underlying soil is practically bare. The soil, is covered with pine needles and other litter. Where the conifers are scattered, the underlying vegetation is the same as that of Zone II.

ZONE VIII

Upon field checking Zone VIII, the areas mapped in Figure 13 by Mr. Redfern as dense conifers proved to be inaccurate. The dense stands of conifers are actually dense stands of Populus tremuloides, Quaking Aspen, characteristic of Zone V. These linear, finger-like areas do have Pinus flexilis, Limber Pine, growing around the edges and scattered among the Aspen, especially on the upper portion of the slopes. The areas are all on the north-facing slopes, apparently due to greater soil moisture content from snow melt and springs.

Close visual inspection of the aerial photography reveals the differences between Quaking Aspen and conifer vegetative growth (See Figure 12). An isodensitracing was made of the area containing these dense growths of Aspen to determine whether or not one can use ERTS imagery to detect these different vegetative growths. Figure 19 shows the isodensitracing of a small portion (5.1X2.76 mm) of ERTS image No. 1029-17184-5 (21 August,1972) magnified 50X to a scale of 1:20,000.

A revised vegetation map from a portion of Figure 13 is shown in Figure 20. Figure 20 is set up in such a way to allow direct comparison of Zones V, VII and VIII as mapped from the aerial photo (Fig. 12) and the density contour map (Fig. 19). Thus, as Figure 20 compares Figures 12 and 19, one can see that the isodensitracer is capable of defining small vegetation zones from ERTS imagery. Figure 20, therefore, eliminates most of Zone VIII, as described by Mr. Redfern, and the extent of Zone V is shown.

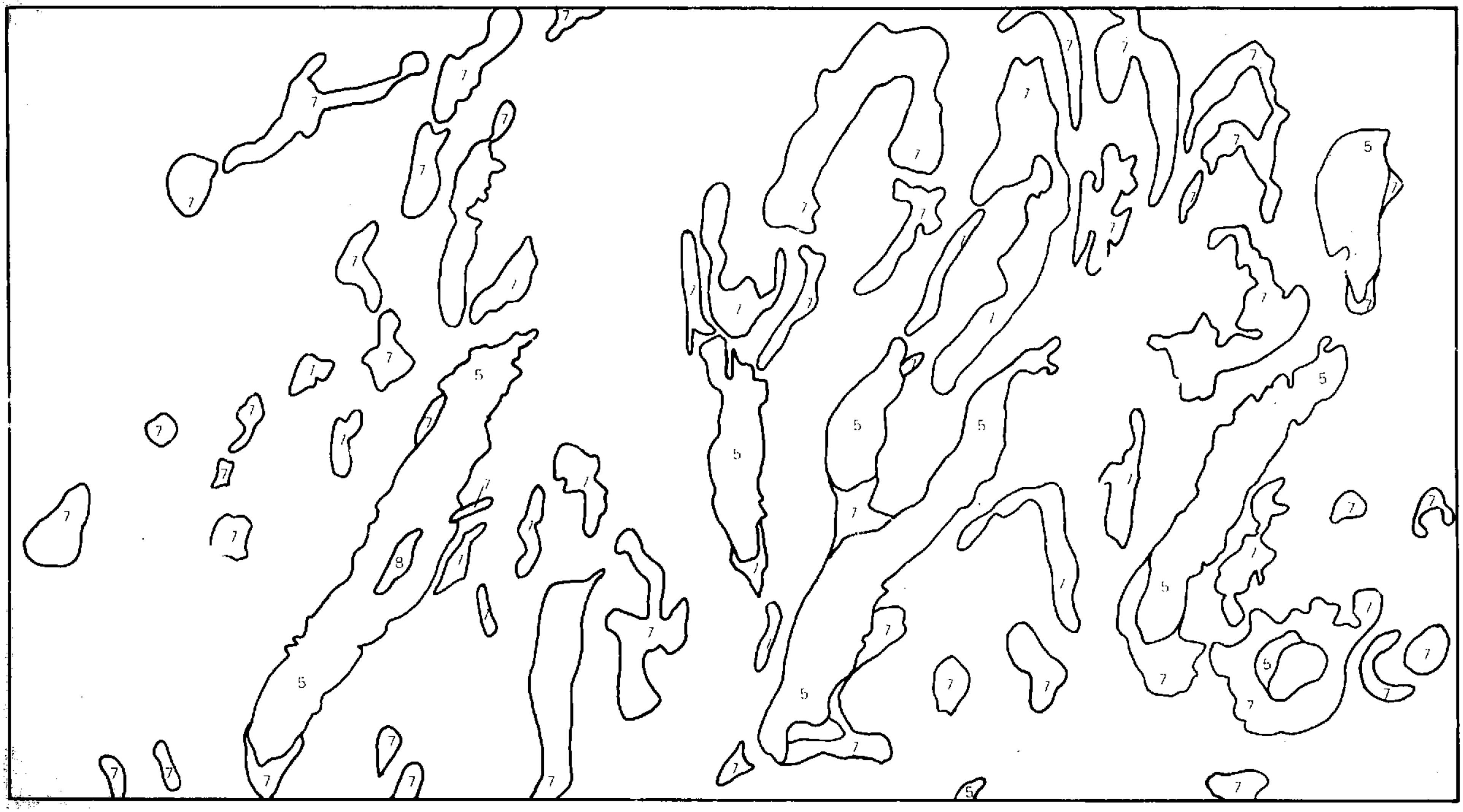
This concludes the field check results of Mr. Redfern's initial mapping. It should be understood that this work was accomplished early in the growing season, and that many of the minor forbes and annual species were listed to show diversity of the species composition within each zone. This was done because, not only do the dominants characterize a vegetation zone but often a single, minor species may also. The ERTS imagery and aerial photographs Mr. Redfern used for this particular study were taken 21 August, and 8 September, 1972 respectively, or near the end of the growing season. Thus, many of the species encountered in the field check were not present or growing when the imagery was collected. Also most species growing and having much chlorophyll in the plant in June will be dying out in August and September. These plants will, therefore, appear much lighter on ERTS imagery band 5 in August and September than in June. The main species which show this are Stipa comata, Needleandthread, Agropyron cristatum, Crested Wheatgrass, Poa sandbergii, Sandberg Bluegrass, Koleria cristata, Junegrass and most forbes and annuals. For illustrative purposes only, refer back to Figure 3 and compare to Figure 6. Figure 6 is much darker due to greater vegetative biomass present thus more chlorphyll and growth.

Except with the exceptions mentioned, the vegetation zones mapped by Mr. Redfern do exist and are distinguishable on ERTS imagery often with the aid of the isodensitracer.

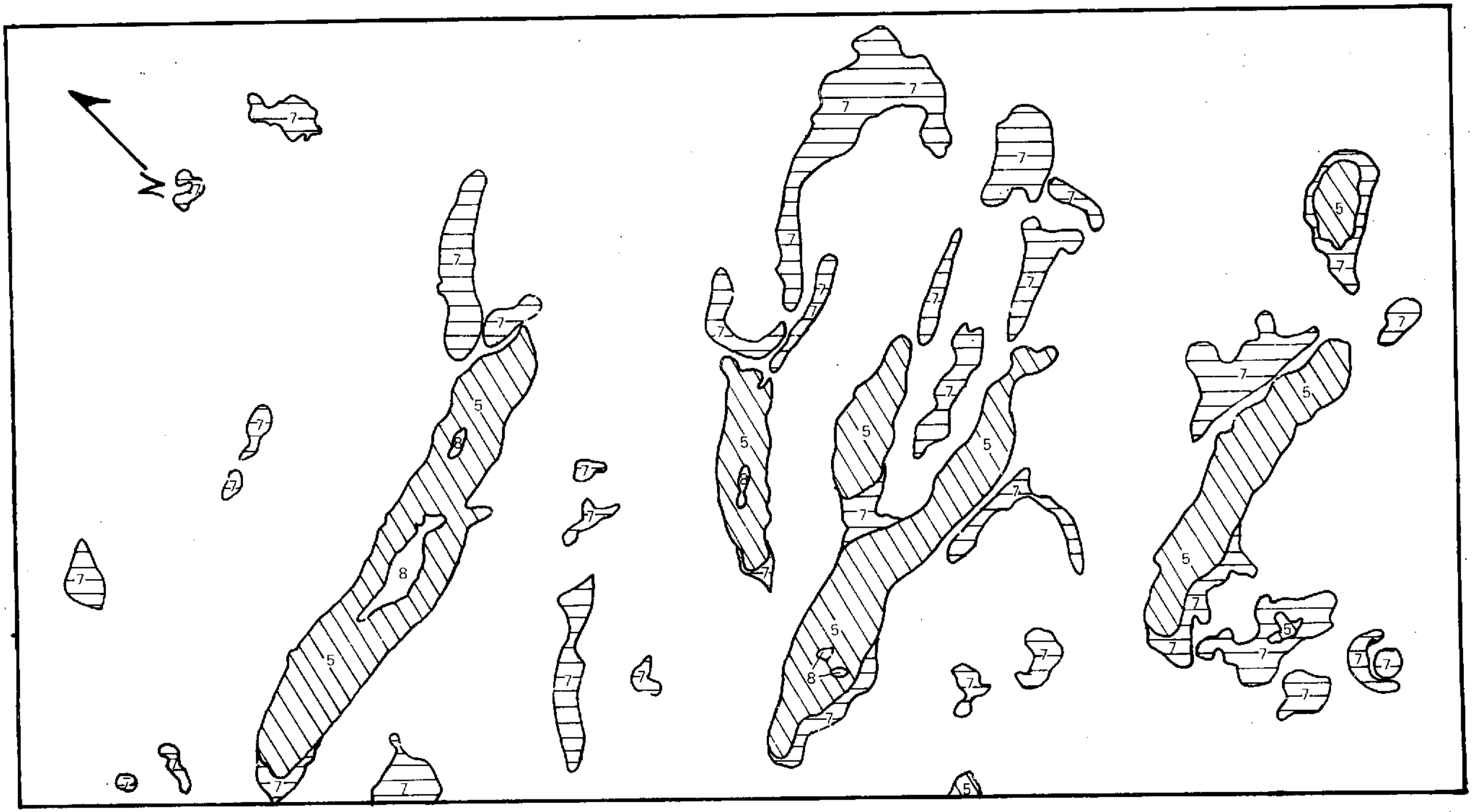
## Factors Perturbing the Radiance of the Vegetation

Before proceeding to evaluate the ERTS imagery in the study area, it is necessary to discuss the problems 1) of resolution imposed by the effects of the finite instantaneous fields of view (IFOV) of both the isodensitracer and the ERTS multispectral scanner (MSS), 2) of the differences in radiation and the absolute values of radiation received by the MSS, and 3) of scattering of light into the aperture (IFOV) of the MSS by the atmospheric aerosol. The slit width (or the IFOV) of the isodensitracer was set at .035 mm which translates to .82 mm on the map of Figure 16, and is insignificant when compared to the IFOV of the MSS as related to the same map (.24 cm, as shown). The very best resolution that can theoretically be achieved with the ERTS imagery

Figure 19. A 50X density contour map (from ERTS-1 image 1029-17184-5) of the Laramie Range study area, which was used to make the revised vegetation map in Figure 20.



igure 20. An overlay showing vegetation Zones V, VII and VIII mapped from the aerial photo (See Figure 12).



Scale:

approx. 1 Mile

Figure 20. A vegetation map of the Laramie Range Study Area showing Zones V, VII and VIII, taken from the density contour map shown in Figure 19.

is the aperture of the IFOV at the earth's surface (about 80 meters). An assumption that could be induced from Figure 16 is that the resolution of the imagery often exceeds theory. This is erroneous for two reasons. First, the isodensitracer will map the densities it detects on the transparency, which are not constituted of discrete IFOV signals, but rather are a continuum of the combined contributions of patterns often smaller than the IFOV of the MSS. Thus a small dark spot on the ERTS image may simply be a more dense area of a widespread pattern of minute dark elements or the manifestation of a larger dark area masked because it is surrounded by much lighter areas. Secondly, the super imposition of the two radiance maps occasions the overlapping of a radiance value from one map into that of the other, creating minute and often misleading detail. For this reason much of this detail was left out of the radiance map (Fig. 16).

Both the finite size of the IFOV and the scattering of light (diffusely and from objects surrounding the IFOV) into the aperature of the MSS contribute to the received electromagnetic radiation. The scattered light modifies the desired signal. The scattered radiation produces edge effects around objects greater in size than the IFOV; dilution of the radiation from objects on the order of, or smaller than, the IFOV; and, in the case of diffuse scattering, a degree of obscurity of the entire image. Edge effects consist of gradual radiance changes from one object to another despite the existence of sharp boundaries. Such perturbations can lead to erroneous interpretations when small, highly contrasting objects are examined. Larger or lower contrast objects should rarely be affected to any significant degree by edge effects.

The scattering problem can be formulated for ERTS empirically as follows:

$$R = I\exp(-t) + D + S$$

R is the radiation received by the MSS sensor in some band. I is the radiation reflected directly into the aperature by the target; t is the total optical density of the atmosphere. (Hence the first term on the right represents the target radiance attenuated by the atmosphere.) D is the diffuse radiation sensed, and S equals that radiation scattered into the aperature from objects surrounding the target. If the radiation scattered from objects around the target into the aperture of the MSS and received by the sensor is assumed to be an exponential function of the distance r measured along the surface of the earth from the center of the target, then the radiance per unit area of earth surface from an increment rdrdθ sensed by the MSS should vary as $\exp(-r/r_o)$, where $r_o$ has the unit of distance and serves as in index of scattering from areas surrounding the target into the aperature. If the IFOV is imagined to subtend part of a relatively large area of homogeneous reflectance, then the ratio of S to I exp(-t) would be

$$(2r_o\ (r_i + r_o)/\ r_i^2)\ \exp\ (-r_i/r_o + t)$$

where $r_i$ is the radius of the IFOV. Knowing t, I and D, it should be possible to calculate $r_o$ from this expression. Since none of these three parameters was known, another expression was derived from the assumptions given above and was used to approximate $r_o$ from the ERTS imagery. The probable value of $r_o$ for the imagery was found to fall between 25 and 50 meters. This range is quite extreme, as can be seen from the expression given above, which takes on the values .03 and .41, respectively, for the two terminal values of the range. In the former case there is little scattering and in the latter case significant scattering. Therefore, it is necessary to evaluate $r_o$ rather accurately. Using the subjective value of 40 meters for $r_o$, it is seen from the expression above that the ratio S/I exp(-t) is about .20, given that t is small. With an IFOV of 80 meters and $r_o$ equal to 40 meters, an object would have to have a radius of 200 meters in order to insure that 90% of the scattered radiation would come from that object, the exact radius depending upon the contrast surface-character and the surrounding areas. Since most of the "objects" in the study area were 160 meters or less in diameter, some degradation of the signal by scattered light from surrounding areas should be expected. Diffuse scattering can be estimated by dark level subtraction techniques, but it is generally not a significant factor in Wyoming atmosphere and no attempt was made to determine it. The simple and crude model of scattering briefly given here at least indicates the possibility of empirical evaluation of this factor. Turner el al(1971) have developed and are continuing to improve and refine a theoretical model of scattering which should be useful for aircraft - as well as satellite-based sensors.

The effect of slopes on solar influx at the time of the ERTS imaging was calculated for typical slope aspects in the study area. There are numerous north-, south-, and west-facing slopes of varying degrees of incline, the steeper ones often 30° or more. The sun elevation was 51° with an azimuth angle of 134°. Figure 12 shows that the steeper slopes either face Dry Gulch or are located within the canyons incising the western slope of the Laramie Range. For north, west, and south slopes of 33°, the percentage of full sunlight intercepted at the time of imaging was approximately 40%, 40%, and 90%, respectively. The northeast-facing slope of the hogback ridge west of Dry Gulch received about 66% of full sunlight. Most other slopes (mostly 2° to 5°), including the gentler ones of Dry Gulch canyon, received approximately 75% of full sunlight except for south-facing ones which were almost fully illuminated.

The influence of slope on vegetation radiance and that of vegetation on slope radiance are each masked by the other. Slope effects appear most pronounced on the infrared band imagery, most vegetation effects are interelated with slope and the vegetation is highly reflective in the infrared band. For example, the north-facing slopes of the canyons (figure 16) generally coincide with image areas of lessened infrared reflectance. The same effect is also noted on the northeast-facing slope of the hogback ridge, illustrating that slope aspect can significantly influence interpretation of vegetation, particularly automated interpretation.

Interpretation of the Vegetation

The impressive resolution obtained from the ERTS MSS is apparent from the constructed maps. For example, in the lower and upper right of sections 5F and 4F, respectively, of Figure 13, a sharp boundary is seen between a bare south-facing slope and north-facing slope occupied by conifers. In figure 16 a scene-radiance gradient in the corresponding area passing sequentially, from light to dark, through codes 33, 34, 44, 54, 55 and 65. The gradient is about the order of one resolution element (80 meters) and the radiance of the lightest spot on the radiance map must approach the actual radiance of the light area, being comparable to those of similar areas located on the low-level imagery. Thus the transition on the radiance map, the edge effect, takes place over about one resolution element, indicating that little scattering is occurring into the IFOV of the MSS from surrounding areas and that edge effects are largely due to the discrete spatial extent of the IFOV itself. Examination of the radiance characteristics in the vicinity of the conifers reveals that a boundary of radiance type 54 generally surrounds the characteristic conifer radiances of 64 and 65 and that this edge is also on the order of one resolution element. At first, it was thought that radiance type 54 represents dense brush, but this is often not the case in areas of conifers. Dense brush on north-facing slopes can even give the same radiance as conifers, as is seen in section 6D of the radiance map.

At first it was planned to compare the vegetative covering with reflectance type on a quantitative basis. However, considerable distortion in the low-level imagery made this facet of the investigation impossible. This distortion is also responsible for the obliquity in the grid of the radiance map. Area estimates were made for the various plant communities even though the distortion causes these estimates to be as much as 50% uncertain. The six largest communities of dense conifers, all on calcareous substrate, cover areas in square miles of .05 (two stands), .06, .11 (two stands), and .13 (sections 6F, 5D, 5D-4E, 4D-5E, and 5F, respectively). All of these but one of the smallest are characterized nearly completely by radiance type 64, the steeper portions of the north-facing slopes indicating 55 or 65. One of the smallest stands (section 6F) displays a radiance of predominantly 63. Since this radiance is about the width of a resolution element and adjacent to an exposed area of very light calcareous soil (22), an edge effect is probably being observed. Another area of 63 radiance is noted in the stand of section 5F, one of the larger stands (.11 square miles). A light spot is adjacent to the stand in the same vicinity, but the color infrared photo indicates the lighter infrared radiance is due in part to vigorous young trees in that area. A number of small dense stands of conifers are also identified with radiance types 64 and 65 (see sections 5F and 4F, for example), but others (e.g. section 6F) are not identified at all. The smaller stands of conifers often appear to be "identified" because of surrounding dense brush. Though there were no large conifer stands on granitic soils to compare with those on calcareous soils, the radiance characteristics of dense conifers should not be greatly affected by soil. Scattered conifers, if accompanied by dense brush, also give radiance values near 64. Others, such as the dumbbell-shaped stand in section 4D, are obscured, occupying areas of light soil.

The identification of brush on the ERTS imagery is strongly controlled by slope aspect and proximity to conifers. From Figures 4 and 5 it is evident that shrub stands on the west slope of the hogback ridge, which was receiving 75% of full sunlight, have a lighter radiance (34 to 44) than corresponding stands on the east slope, which were receiving about 66% of sunlight (radiances ranged from 43 to 55). On the western slope of the Laramie Mountains, the dense brush areas are predominantly masked by their proximity to conifers. There are areas of brush identified primarily by radiance type 54, however. See for example, sections 6D, 6E, 5B, and 2C-3F. Brush in some areas of north-facing slopes, such as section 6D, displays radiances of 55, 64, and 65, the same as dense conifers. Once again the difficulty of remote sensing of natural vegetation due to topography and complex associations is demonstrated.

On the more positive side, areas of grassland with scattered brush seem fairly well correlated to radiance types 34, 43, and 44, though the lighter areas covered with such vegetation give a radiance of 33, which is generally correlated with barren sites. This may only be an artifact contingent upon the choice of the density ranges on the isodensitracer (see sections 4F and 3F). In some areas, as in section 3G, the radiance 43 correlates to dense brush with a greater infrared reflectance than most other brush, as is evidenced on the color infrared aerial photography. "Bare" areas, those of sparse grassland and few shrubs through which the soil (calcareous in every case) shows clearly, seem well identified by radiance types 22-33. Notice especially the clearly indicated limestone outcroppings from section 5B to 7E to 5G. Only two examples of broad-leafed deciduous trees occur in the study area (4E and 7H), both, unfortunately, too small to draw any conclusions about. Both exhibit high infrared radiances (53 and 52) as would be expected. A large stand of aspen is just outside the limits of the isodensitracings, which only graze its edge. The scene-radiance representing this stand, which is in the granite area, is probably 63 or 62- dark in the red and very light in the infrared. A smaller stand of aspen, but still a respectable size, was also partially intercepted by the isodensitracings on the north-east. Occurring on a north-facing slope, its radiance is 64--similar to that of conifers. The small stretch of wet grasslands included in the area can be studied in sections 7G to 6I. Its radiance varies from 54 and 53 to 63, confirming the relatively high near infrared reflectance one would expect from a mesic grassland.

The effect of substrate on scene-radiance is very pronounced. Grasslands in the granitic areas generally display radiances as dark as 44, whereas grasslands on the calcareous soil usually have a radiance of about 33. Unfortunately, the granitic soil barely intrudes the study area, though the eastern edges of the isodensitracings themselves do show generally dark radiances, and these undoubtedly are due largely to the granitic substrate. The only possible example of granitic soil in Figures 13 and 16 is the radiance type 44 in sections 7F and 7G. Grassland is probably the main vegetation type in these sections.

## Conclusions

The ERTS imagery is seen to provide resolution approaching theoretical limits through the clear and dry Wyoming atmosphere. Consequently, comparatively small stands of vegetation can be identified under optimum conditions: they must be somewhat wider than one resolution element. A minimum sized stand should be on the order of .16 km by .16 km, a size equal to four resolution elements, to obtain a value approaching the actual radiance (less atmospheric attenuation). The larger the stand, the less the worry with edge effects and scattering into the instantaneous field of view, and extensive communities of the major vegetation types (conifer, brush, grassland, etc.) should be delimitable from ERTS data. Atmospheric scattering, however, does not appear to be an important problem in the Laramie Basin during optimum imaging weather.

Vegetation identification by ERTS imagery is often limited by factors such as sun angle, topography, complexity of the vegetated landscape, and substrate. A scene-radiance which would be correlated to brush on light soils with a tolerable degree of accuracy could not be so correlated on darker soils, where grassland might give the same radiance. Vegetation on slopes sheltered from full sunlight will reflect levels of radiation dissimilar to corresponding vegetation on slopes bathed in full sunlight. Changes in sun angle can alter reflectance as well as radiance due to the effects of shadows and light incidence angle. In view of such dissimilarities, the concept of "signature" in ecological remote sensing is not useful in a strict sense. Thus automatic mapping and monitoring of "natural" vegetation (that is, nonagricultural) is obviously far more difficult than that of crops, which has had its own share of problems (e.g. Nagy et al., 1971 and Hoffer and Goodrick, 1971).

There are several possible solutions to the problems of satellite-based remote sensing of natural vegetation. Clustering techniques (Smedes et al., 1971), which group like radiances for interpretation, can be useful but not sufficient in themselves for identification as indicated by the present study. With computer analysis of several radiation bands, it is possible to effect various mathematical transforms of the radiance data (Smedes, 1971 and Kriegler et al., 1970). Such transformations promise to be particularly useful in mollifying effects of atmosphere and topography. However, if it is deemed useful to map and monitor vegetation from orbit, it appears clear that much low-level and ground-truth data will be needed for vegetation maps of any accuracy. Apparently it will be easier and more accurate to map vegetation by predominantly manual methods rather than automatically if maps amenable to botanists are to be produced. In addition to proximate data, models which comprehend factors such as topography, sun angle, and substrate are required to automatically monitor vegetation. Of course, the volume of augmentative data is a function of the accuracy desired. If appears possible to map broad vegetation types such as conifers, broad-leafed trees and shrubs, brushland, grassland, desert, etc., with present ERTS imagery alone. Increasing resolution will eventually require more sophisticated imaging coupled with sophisticated techniques of analysis, including modeling.

Even a cursory examination of Figures 13 and 16 indicates a rough inverse correlation between radiance types and the amount of vegetative biomass present. Miller and Pearson (1972), working in the shortgrass prairie of the Pawnee National Grassland, have found good correlation between the ratio of infrared to red reflectance and green biomass. With a proper model, the estimation of biomass over large areas appears possible.

Certain wavelengths seem to be indicators of potential productivity in vegetation. For example, Odum (1971, p. 62) suggests that the "yellow-green" index of Margalef, whcih is inversely correlated with the ratio of productivity to respiration, might be used as a remote sensing tool. Myers (1970, p. 264) suggests that reflectance at about .54 um is a function of the chlorophyll concentration and that increased reflectance of this wavelength possibly indicates nutrient deficiencies. In addition such things as the ratio of reflectance in a near infrared band to reflectance in a band on the red might indicate the potential rate of photosynthesis. Also, remote sensing techniques can measure absorption of photosynthetic wavelengths by vegetation, especially when problems of atmospheric scattering are solved. If suitable remote sensing indices of ecological factors can be found, they can be augmented by meteorological and other data and possibly used to estimate productivity and respiration.

A difficult but important ecological parameter to measure is evapotranspiration. Measurement of this parameter can be apprehended by energy budget studies. If such studies can be done for given elements of terrain from space platforms, this parameter, an important factor in water cycling as well as an indicator of net primary productivity (after Rosenzweig, 1968), might be estimated and applied to vegetation analysis.

# BIBLIOGRAPHY

Anuta, P.E., S.J. Kristof, D.W. Levandowski, T.L. Phillips, and R.B. MacDonald. 1971. Crop, soil, and geological mapping from digitized multispectral satellite photography. Proc. Seventh International Symp. on Remote Sensing of the Environment, The Univ. of Michigan, Ann Arbor, p. 2043.

Gates, D.M. 1970. Physical and physiological properties of plants. In Remote Sensing with Special Reference to Agriculture and Forestry, National Academy of Sciences, Washington, D.C.

__________, H.J. Keegan, J.C. Schleter, and V.R. Weidner. 1965. Spectral properties of plants. Appl. Optics 4:11-20.

Hanna, L.A. 1934. The major plant communities of the headwater area of the Little Laramie River, Wyoming. Univ. of Wyoming Publications in Science. Botany 1(10):243-266.

Hoffer, R.M. and F.E. Goodrick. 1971. Variables in automatic classification over extended remote sensing test sites. Proc. Seventh International Symp. on Remote Sensing of the Environment, The Univ. of Michigan, Ann Arbor, p. 1967.

__________, and C.J. Johannsen. 1969. Ecological potentials in spectral signature analysis. In Remote Sensing in Ecology, P.L. Johnson (ed.), Univ. of Georgia Press, Athens.

Kolipinski, M.C. and A.L. Higer. 1970. Inventory of hydrobiological features using automatically processed multispectal data. Proc. Sixth International Symp. on Remote Sensing of the Environment, The Univ. of Michigan, Ann Arbor, p. 79.

Kriegler, F.J., W.A. Malila, R.F. Nalepka, and W. Richardson. 1970. Preprocessing transformations and their effects on multispectral recognition. Proc. Sixth International Symp. on Remote Sensing of the Environment, The Univ. of Michigan, Ann Arbor, p. 97.

Marshall, R.E., N. Thompson, F. Thompson, and F. Kriegler. 1970. Use of multispectal technique for conducting rapid, wide-area wheat surveys. Proc. Sixth International Symp. on Remote Sensing of the Environment, The Univ. of Michigan, Ann Arbor, p. 3.

Meyers, V.I. 1970. Soil, water, and plant relations. In Remote Sensing with Special Reference to Agriculture and Forestry, National Academy of Sciences, Washington D.C.

Odum, E.P. 1971. Fundamentals of Ecology. W. B. Saunders Co., p.62.

Pearson, R.L. and L.D. Miller. 1972. Remote spectral measurements as a method for determining plant cover. U.S. IBP Grassland Biome Tech. Report No. 167, Colorado State Univ., Fort Collins, Colorado. 48pp.

Rosenzweig, M.L. 1968. Net primary production of terrestrial communities; prediction from climatological data. Amer. Nat., 102:67-74.

Smedes, H.W. 1971. Preprocessing of multispectral data and simulation of ERTS data channels to make computer terrain maps of a Yellowstone National Park test site. Proc. Seventh International Symp. on Remote Sensing of the Environment, The Univ. of Michigan, Ann Arbor, p. 2073.

__________, H.J. Linnerud, S.J. Hawks, and L.B. Woolover. 1971. Digital computer mapping of terrain by clustering techniques using color film as a three-band sensor. Proc. Seventh International Symp. on Remote Sensing of the Environment, The Univ. of Michigan, Ann Arbor, p.2057.

Turner, R.E., W.A. Malila, R.F. Nalepka. Importance of atmospheric scattering in remote sensing, or everything you've always wanted to know about atmospheric scattering but were afraid to ask. Proc. Seventh International Symp. on Remote Sensing of the Environment, The Univ. of Michigan, Ann Arbor, p. 1651.

Watson, R. and L.C. Rowan. 1971. Automated geologic mapping using rock reflectances. Proc. Seventh International Symp. on Remote Sensing of the Environment, The Univ. of Michigan, Ann Arbor, p. 2043.