THESIS

AERIAL PHOTOGRAPHY FOR POST-MINE VEGETATION INVENTORY

Submitted by
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In partial fulfillment of the requirements
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WE HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER OUR SUPERVISION BY ROBERT VICTOR DAMS ENTITLED AERIAL PHOTOGRAPHY FOR POST-MINE VEGETATION INVENTORY BE ACCEPTED AS FULFILLING IN PART REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN RANGE SCIENCE.

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ABSTRACT OF THESIS

AERIAL PHOTOGRAPHY FOR POST-MINE VEGETATION INVENTORY

The objective of this study was to investigate the application of 70 mm aerial photography in the evaluation of revegetated strip mined lands.

Large (1:600) and medium (1:10 000) scale 70 mm color and color infrared (CIR) aerial photography was acquired in July 1980 of reclaimed coal-mined lands in north western Colorado. A concurrent field survey of vegetation cover was also carried out.

Plant species identification keys were developed from the large scale photography with the aid of intensive ground marking, and were tested by six photo interpreters. Crested wheatgrass (*Agropyron cristatum*), intermediate wheatgrass (*A. intermedium*) and smooth bromegrass (*Bromus inermis*), the dominant grass species present, were identified with varying levels of accuracy (70, 69 and 57% respectively) by the photo interpreters. Alfalfa (*Medicago sativa*), yellow sweet clover (*Melilotus officinale*) and thistles (*Cirsium* spp.) were also accurately identified (90, 100 and 75% respectively). Several species of shrub seedlings present could not be readily identified.

A non-parametric statistical evaluation (Friedman index) of individual photo interpreter results indicated that, for the skill levels available for this study, there were no significant differences ($p > 0.05$) based on interpreter experience with the vegetation, study area or photographic interpretation technique.

Estimates of vegetation and other categories of ground cover were made using a point line method on the aerial photographs and compared to corresponding point frame cover estimates made on the ground. Regression analysis indicated that for the dominant species present, only alfalfa cover could be reliably estimated ($r^2 = 0.85$; $p < 0.01$) from the aerial photographs. Cover of the various dominant grass species could not be reliably estimated. Comparisons by ground cover category showed that total forb ($r^2 = 0.85$), total vegetation ($r^2 = 0.71$) and total ground cover ($r^2 = 0.66$) categories were accurately estimated ($p < 0.01$). Grass ($r^2 = 0.58$) and rock cover ($r^2 = 0.52$) estimates were less accurate (although $p < 0.01$) and litter cover ($r^2 = 0.01$) could not be accurately estimated from the large scale CIR photographs.

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I. INTRODUCTION

The objective of this study was to investigate the application of 70 mm color and color infrared aerial photography in the evaluation of revegetated strip mined lands. The primary goal of the research was to establish whether an aerial method could yield comparable results to a conventional ground survey method for the estimation of vegetation cover and other ground cover categories. Numerous preliminary procedures were required in order to attain this goal; most notable of which was the development of a plant species identification key for use with the large scale aerial photography.

Previous research into vegetation analysis from aerial photographs has been mainly concentrated in the areas of forestry (Aldrich et al. 1959; Heller et al. 1964; Sayn-Wittgenstein 1978), range science (Driscoll and Coleman 1974; Lorain 1970; Driscoll et al. 1970), or crop science (Bauer 1975) with only a limited amount of research conducted into the use of aerial photography for evaluation of revegetated or reclaimed lands (Wobber et al. 1975; Cox and Witter 1978), although the principles developed in these other disciplines would also apply. The value of remote sensing for providing timely and accurate surveys for monitoring mined land reclamation and revegetation efforts is yet to be fully realized.

II. LITERATURE REVIEW

A review of recent literature pertaining to this research was divided into two separate sections. The point frame quadrat method was utilized in the field for estimation of ground cover, with a similar point method used in the photo interpretation process; therefore a review of past applications of the point method was considered important. The review of recent literature relating to interpretation and applications of aerial photography for vegetation analysis is presented in a separate section.

A. Point Frame Quadrat Method

The point quadrat method was first used by Cockayne (1926) and was further developed by Levy (1927, 1933) and Levy and Madden (1933). The method has been used, with varying degrees of success, for estimating numerous parameters such as plant height (Heady 1957; Spedding and Large 1957), plant community composition by plant weight (Heady and Van Dyne 1965; Hughes 1962; Sprague and Myers 1945), plant density (Spedding and Large 1957; Warren Wilson 1963), foliage angle (Warren Wilson 1963) and basal cover (Fisser and Van Dyne 1966; Johnston 1957). However, the vast majority of research has been conducted into the use of the point frame quadrat for estimating ground (or foliar) cover, and deriving relative species abundance (composition) therefrom.

Plant cover, or "ground cover" as used in this study will be as defined by Greig-Smith (1957):

> "The proportion of ground occupied by perpendicular projection onto it of the aerial parts of individuals of the species under consideration."

This definition of cover has been used by Brun and Box (1963) in range studies and by Kershaw (1973) in the discussion of quantitative ecology. Greig-Smith's (1957) definition is also similar to that suggested by Daubenmire (1968) for "foliar coverage" but different from his "Leaf Area Index" and "canopy coverage" definitions. According to Daubenmire (1968) "foliar coverage" is:

> "The sum of shadows that would be cast by leaves and stems, taking each species separately, and expressing the result as a percentage of the land surface."

Using this technique, intraspecific leaf overlap is ignored. Stoddart et al. (1975) defined cover in more general terms: "the surface area occupied by each species, stated in percentage of area" and indicated that it could be applied to both tree crowns and plant root crowns or basal cover, in addition to normal foliage considerations.

Both Stoddart et al. (1975) and Kershaw (1973) emphasized the applicability of the point method for estimating plant cover. The validity of the method has been verified by many researchers, in numerous vegetation types throughout the world. Radcliffe and Mountier (1964a, 1964b), Levy (1933), and Levy and Madden (1933) found success in estimating foliar cover of hill pastures and tussock grasslands in

New Zealand. Crocker and Tiver (1948) used the point frame to estimate cover of pastures, Winkworth (1955) examined heathlands, and Winkworth et al. (1962) surveyed arid grasslands in Australia. The point frame method has also been used in the mixed grass prairie in Canada (Johnston 1957), in pastures in England (Spedding and Large 1957), and has been tested in Pakistan and Egypt (Ibrahim 1971). However, the bulk of the practical and statistical research appears to have been done in the United States. The method has found application here in scores of vegetation types, from desert shrub (Brun and Box 1963), to mixed prairie (Hansen 1934), tame pastures (Arny and Schmid 1942; Drew 1944), and reseeded disturbed land (Hofmann et al. 1978).

The theoretical basis for the point method, as described by Brown (1954), is that the point represents a quadrat that has been reduced to a unit area. Or as stated by Radcliffe and Mountier (1964b), "the point is an extreme reduction of a sample area or quadrat". The point, or tip of a metal pin, "actually measures small circular plots with finite area" (Fisser and Van Dyne 1966).

It is therefore recommended (Goodall 1952) that the smallest possible pin diameter be used so that the optimum precision can be achieved in estimating percentage cover. Goodall (1952) used pin diameters of 0, 1.84, and 4.75 mm, and found that the largest pin overestimated cover (from a known or "true" cover value) more than the next smaller size, thereby creating inaccuracy. Johnston (1957) found a similar overestimate of cover using a 2.4 mm pin with a blunt end. As a result of this research, Radcliffe and Mountier (1964a) recommended the use of a needle with a diameter of 0.25 mm rather than a metal "pin". While this improved the precision of measurement, it also led to difficulties in making observations in taller vegetation (they used it on 2.5 - 7.5 cm pasture swards), or on windy days.

The way in which "hits" on vegetation are read has also been the subject of some controversy. Goodall (1952) recorded a hit whenever any part of the pin touched vegetation, while Owensby (1973) recorded the nearest species in a 180° arc in using a step-point method. The more widely accepted method for recording "hits", is to record only what the point of the pin strikes on its way down to the ground (Radcliffe and Mountier 1964a).

There are a number of ways in which plant cover and species composition (in this case, the relative cover of different species) can be recorded from pin point hits. As summarized by Radcliffe and Mountier (1964a), species composition may be determined by recording per pin: (1) the first plant hit, (2) crown hits, (3) the first hit on each species (which they called "cover hits"), or (4) all hits on each species (which they called "total hits"). They state that (1) "is a rapid and easy method for determining dominant species when only one growth form predominates in the association. In a grass-legume association where both erect and prostrate species are present this method clearly leads to bias". The National Research Council (1962) also noted that the point method will overestimate taller plants and underestimate prostrate plant species. This technique has been used by Brun and Box (1963) in sagebrush-grass, and sagebrush-shadscale ranges, with results showing no significant difference for estimating mean cover between the point frame "ground cover" estimate by species, and that estimate made using the line intercept (Canfield 1941) method. In another study, Hofmann et al. (1978) also used the first hit method to demonstrate that cover estimates obtained from point frames were not affected by the orientation of the frame with respect to vegetation rows on drill seeded land.

A tremendous array of point frame designs have been developed since the original by Levy and Madden (1933). Variations of the "pin-point" method have been developed wherein a cross-hair site apparatus is used to identify the point to be sampled. Stanton (1960), Winkworth et al. (1962), and Ibrahim (1971) have used this pinless method with success. In a modification of Winkworth et al.'s sighting tube, Burzlaff (1966) utilized a surveyor's telescope on a tripod and, with rotation of the scope about the tripod axis, randomly located sample points on a "circular" transect. Wind, shadows, and species identification were major problems encountered, however. It is notable that the sighting methods discussed above inherently allow only the "first hit" on any species to be recorded.

Design of the point frame appears to be a function of vegetation type to be sampled (Brown 1954), with the major considerations in determining design specifications being: (1) height of vegetation (Corby 1950), (2) pattern of vegetation (Radcliffe and Mountier 1964a), (3) density of vegetation (Heady and Rader 1958), and (4) foliage size and angle (Winkworth 1955).

The spacing between pins within a frame has also been the subject of much research. Radcliffe and Mountier (1964a) state the most important requirement in the pin spacing is that "hits recorded on separate points should be uninfluenced by the possible contagious distribution of the plants". Goodall (1952) demonstrated that "the probability of hitting a given species will vary less between the frame". When pins have fixed arrangements, as in a frame, Rothery (1974) states that patchiness in the plant cover may impose a correlation structure on scores of pins in the same frame. Crocker and Tiver (1948) also observed that pronounced aggregation of species - for example contagious clumps of thistles - may cause variability in the analysis of the data, however under-dispersion - such as that found in revegetated mined lands - in general does not affect the analysis.

A further design consideration for the point frame has been the angle of orientation of the pins with respect to the foliage and ground. Tinney et al. (1937) originated the idea of an "inclined point frame" in which the pin (or needle) was set at 45°. They assumed that vertically oriented pins would contact the larger leaved plants more frequently than the fine leaved ones. They also concluded that the inclined pin was more clearly visible to observers as it passed through tall, thick vegetation. A further attribute of the method was noted in that a greater number of plants could be encountered when pins were inclined; Tinney et al. assumed that this would inherently increase accuracy. However, Winkworth (1955) reports to the contrary, and demonstrated that the inclined point frame cover estimates were "appreciably different and usually higher" than percentage cover estimated using vertical point quadrats.

From this discussion it becomes obvious that the point method is quite controversial in application, with a wide variety of results obtained in numerous experiments. However, it remains a comparatively rapid, accurate, and objective survey method (Cook and Box 1961) and therefore has found widespread application in range and revegetation inventory work.

B. Aerial Photography

Aerial photography has been an integral part of vegetation surveys for many years. In the past, small- and medium-scale black and white photography have been the most commonly used by foresters and range managers (Tueller et al. 1972). This photography has been used primarily for orientational purposes and broad vegetation type classification (Stoddart et al. 1975). The development of color aerial photography technology greatly improved identification and vegetation type delineation capabilities (Driscoll 1969; Johnson and Atwood 1970). A further improvement in completing aerial surveys of vegetation has been realized with the advent of color infrared (CIR) photography (Yost and Wenderoth 1969). The increased interpretability of color and CIR over black and white has been attributed to the added dimensions of hue, value, and chroma in the color and CIR photography, over the limited discrimination between grey tones associated with black and white photography (Tueller et al. 1972).

Simultaneous analysis of both color and CIR photography is considered by many to yield the highest amount of information for characterizing vegetation and other natural features (Driscoll and Coleman 1974; Lorain 1970). The differences between the two films lies in the differential sensitivity of their dye layers. Color film possesses a three layer emulsion that is sensitive to red, green and blue wavelengths of light. Processing produces a reversal in the layers to form cyan, magenta and yellow colors respectively. The three layers of the emulsion in CIR film are sensitive to green, red and near infrared radiation. Use of a Wratten 12 filter eliminates the blue wavelengths, then the latter three wavelengths activate the yellow, magenta, and cyan dyes respectively. Resultant positive transparencies thus take on a "false color" appearance, with the intensities of the yellow, magenta, and cyan colors representing the relative reflectance of the plants, soil and other features, of green, red, and near infrared radiation respectively. A yellow (Wratten 12) filter is most commonly used with CIR film to screen out blue light, since all layers of the emulsion are sensitive to this wavelength (Meyer and Grumstrup 1978).

Seventy millimeter format photography, using both color and CIR film, has received widespread use in completing both forest and range inventories. The advantages of such small format camera-film combinations over larger conventional camera systems have been identified by Driscoll et al. (1970). Fast shutter speeds and rapid film advance allow for the production of high resolution stereo photography at large scales. These fast cycling capabilities are essential when studying herbaceous species, since a very large scale (≥ 1:600) is recommended for resolution of individual plants. Additional attributes of the 70 mm system include: (1) small size and light weight, (2) rapidly interchangeable lenses, (3) narrow view angle reduces the effects of parallax, (4) small format allows stereoscopic viewing of film in an uncut roll, and (5) easy film processing with consistent results (Driscoll et al. 1970; Tueller et al. 1972).

Since 1969 (Driscoll 1969) a great deal of research has been conducted in the application of large scale 70 mm color and CIR aerial photography for rangeland inventory and analysis. Both shrub and herbaceous plant communities have been studied using large scale photography.

Driscoll and Coleman (1974) developed a species identification key for several shrubs found in southwestern and northwestern Colorado, and found that many of them could be reliably identified on color and CIR photography. Seven out of 11 species were correctly identified by photo interpreters more than 80% of the time on CIR. Color photography notably yielded lower percentage correct identification. They also found that identification of certain shrubs was easier than others primarily due to their larger size. The authors also identified species diversity of the various study sites as being an important factor in the accuracy of species identification.

Lorain (1970) conducted similar research using 70 mm color and CIR, and determined that most shrubs and trees, and several herbaceous species could be positively identified on native range sites in northeastern and southeastern Nevada. He noted that the phenology of various plants was a determining factor in correct species identification, especially for the herbaceous species. In this regard, Lorain identified the optimal time for surveying herbaceous plants as the time at which the grasses had dryed, but before complete deterioration and/or when important forb species were in bloom. Optimal time for studying shrubs was considered to be after the grasses and forbs had dryed in late summer, thereby providing better discrimination between shrubs and herbaceous species.

An estimate of foliar cover by species and a measure of plant density are often of interest in completing a range inventory. Lorain (1970) found that percent cover of recognizable species could be accurately and rapidly extracted from large scale CIR photography using a point method. Similarly, Driscoll et al. (1979) reliably estimated cover of shrubs from aerial photography.

Numerous other range related studies have demonstrated the utility of large scale aerial photography for grazing management (Dudzinski and Arnold 1967; Hayes 1976), range improvement (Waller et al. 1978; Young et al. 1976), and range inventory work (Heintz 1979; Tueller et al. 1972).

In contrast to the many successful forestry and rangeland related studies, use of large scale aerial photography for analysis of mined land revegetation has been rather limited. A great potential exists in utilizing aerial photography for completing timely, cost effective surveys of reclaimed areas. Past experience on native rangeland areas has demonstrated the utility of remote sensing techniques for species identification (Driscoll and Coleman 1974; Lorain 1970; Tueller et al. 1970), plant density determination (Driscoll et al. 1979; Meyer et al. 1972), ground cover estimation (Gerbermann et al. 1976; Tueller et al. 1972), and biomass estimation (Harlan et al. 1979; Pearson et al. 1976; Tucker et al. 1977). All of these measurements are essential to the completion of a vegetation inventory on pre- and post-mine land in order to comply with federal reclamation requirements (Office of Surface Mining 1977).

Reviews of the current and potential applications of remote sensing techniques for mined land inventories have been completed by Wobber et al. (1975) and by Cox and Witter (1978). Wobber et al. (1975) state that remote sensing can "provide a synoptic information base and have special value for rapidly generating a regional inventory, for planning reclamation, for monitoring revegetation success, and for identifying, controlling, and minimizing environmental disruptions resulting from all types of surface mining". These authors also recognized that "while remote sensing technology will not completely replace contemporary data acquisition methods, it can complement and enhance present field methods for acquiring environmental data in mined areas".

Several authors (Green and Buschur 1980; Grumstrup and Meyer 1977; Krumwiede 1980; Wobber et al. 1975) have recognized the utility of large scale color and CIR photography for analysis of revegetated lands. Wobber et al. (1975) have summarized the information content of large scale color and CIR photography as having: "hydrological, geological, and botanical information, particularly in relation to surface-water quality, vegetation, and spoil-bank characteristics. Surface-water turbidity, relative mine-water depth, presence of clay suspensions, iron-oxide deposits in pond bottoms and stream beds, acid seeps and outfalls, and stream sedimentation patterns and spoil types can be identified". All of these characteristics are benefits that might be realized from aerial surveys, in addition to the primary goal of completing a vegetation inventory.

As stated previously, plant species identification, and estimates of plant cover, density, standing crop, and distribution can all be determined from large scale aerial photos. An early indication of plant stress due to spoil toxicity, moisture and/or nutrient deficiency, and acidity or sedimentation effects can also be obtained from CIR imagery (Wobber et al. 1975). These additional attributes are noted here for interest purposes and will not be discussed further since the primary goal of this research was to demonstrate the potential for plant species identification and cover estimation on mined lands.

III. DESCRIPTION OF THE STUDY AREA

A. Location and Overview of the Study Area

The study was conducted in northwest Colorado approximately 20 miles southwest of the town of Steamboat Springs (Figure 1). The legal description of the study area is Townships 4 and 5 North, Ranges 85 and 86, West of the 6th Meridian (40° 20' N latitude - 107° W longitude). Study sites were located on land owned and leased by Colorado Yampa Coal Company[1]. This area was chosen for study because the climate, physiography, vegetation types, and the related reclamation-revegetation problems, were representative of many present and potential coal strip mine areas in western Colorado and Wyoming. In addition, a large number of reclaimed areas provided a variety of introduced plant communities for study.

Rolling hills, sandstone outcrops, and broad open valleys typified the topography of the study area. The elevation ranged from 1980 to 2286 m above sea level.

Mean annual precipitation for the past 40 years was 594 mm for Steamboat Springs and 401 mm for the town of Hayden. The months of

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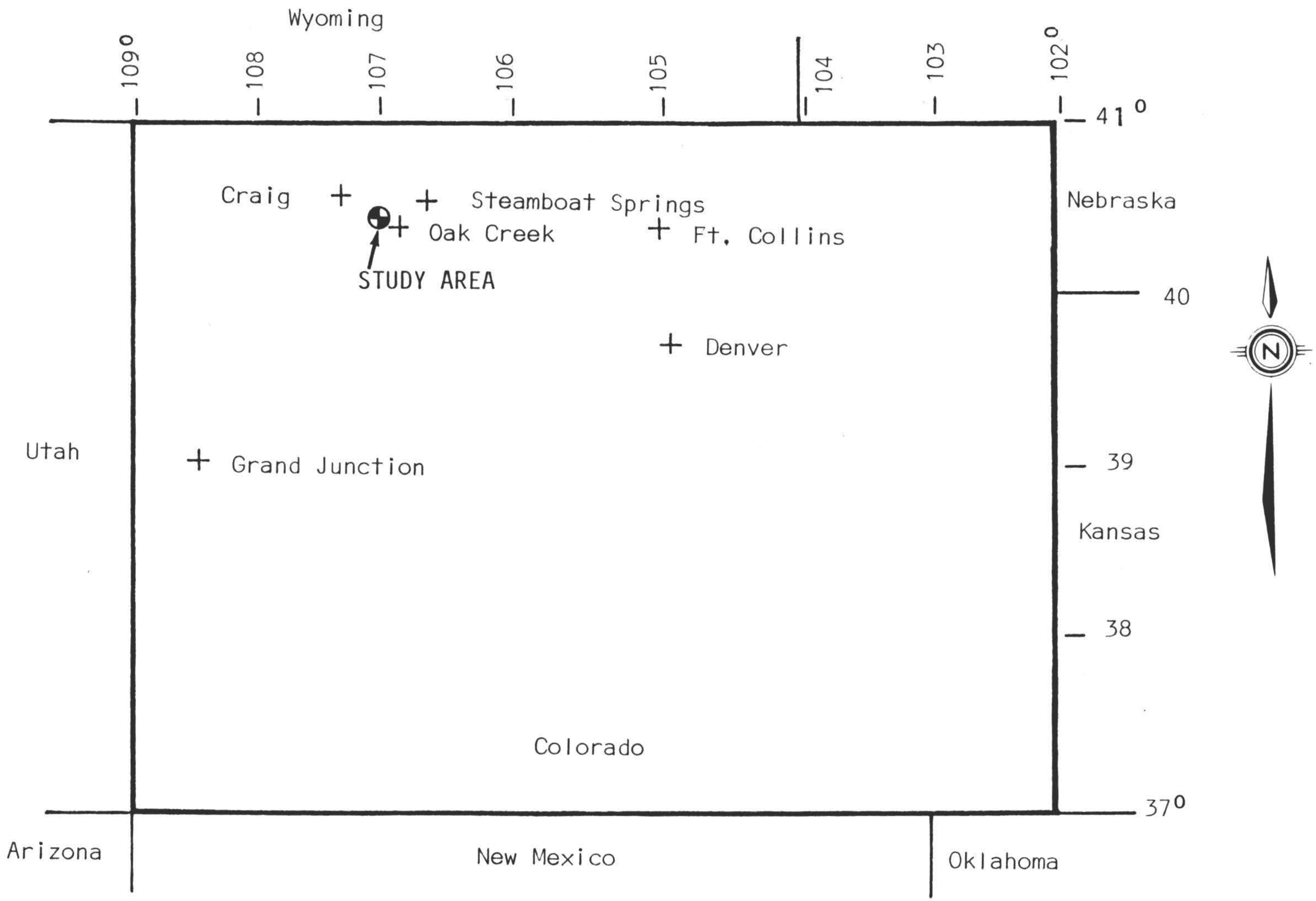
[1] A Subsidiary of Getty Coal Co., Box 772129, Steamboat Springs, CO. 80477.

Figure 1. Map showing location of the study area.



December and January are the wettest months, with an average of 64 mm of precipitation in each month at Steamboat (elevation 2075 m), and 38 mm in December and 33 mm in January at Hayden (1943 m). Peak spring precipitation occurs in April for both of these recording locations, and is evenly distributed through the summer months. Dry west winds frequent the area in both winter and summer. The average growing season (above -2.2 C) for a location near Steamboat Springs is 112 days (Colorado Experiment Station 1977).

Land use of the pre-mine and surrounding area was limited to grazing on native range, or dryland farming of hay and winter wheat crops. Wildlife production was of additional importance in the area, since large populations of mule deer (*Odocoileus hemionus* Rafinesque) and elk (*Cervus canadensis* Erxleben) utilized portions of the mine lease, primarily as winter range. An overwintering population of sage grouse (*Centrocercus urophasianus* Bonaparte) was an additional wildlife concern.

B. Vegetation of the Study Area[1]

The undisturbed portions of the study area possessed native vegetation characterized by big sagebrush (*Artemisia tridentata tridentata* H. & C.) and numerous grasses. Typical grasses included wheatgrasses (*Agropyron* spp. Leyss.), Idaho fescue (*Festuca idahoensis* Elmer), bluegrasses (*Poa* spp. L.), and Letterman's needlegrass (*Stipa lettermani* Vasey). Low sagebrush (*Artemisia tridentata arbuscula* Nutt.)

1 Plant species scientific names after Harrington (1954) and Weber (1976) as identified by K. Demott, Department of Botany, C.S.U., Fort Collins, CO.

- grass communities, with grasses similar to those listed above, were also found throughout the area. Mule's ear (Wyethia amplexicaulis Nutt.), a noxious unpalatable weed, had become a persistent invader of both big and low sagebrush communities. Low lying areas possessed a meadow vegetation dominated by sedges (Carex spp. L.), rushes (Juncus spp. L.), tufted hairgrass (Deschampsia caespitosa (L.) Beauv.), and bluegrass (Poa spp. L.).

Aspen (Populus tremuloides Michx.) forests occupied the mesic upslope positions. These stands commonly possessed a serviceberry (Amelanchier alnifolia Medic.) and chokecherry (Prunus virginiana L.) shrub stratum and had a moderately dense herbaceous understory. Mountain shrub communities dominated by gambell oak (Quercus gambellii Nutt.), serviceberry and snowberry (Symphoricarpos oreophilis Gray) occupied the dryer south aspect slopes.

The revegetated areas studied possessed a variety of native and introduced grasses which included crested wheatgrass (Agropyron cristatum (L.) Gaertn.), intermediate wheatgrass (A. intermedium (Host.) Beauv.), western wheatgrass (A. smithii Rydb.), smooth bromegrass (Bromus inermis Leyss.), orchardgrass (Dactylis glomerata L.), timothy (Phleum pratense L.), and Kentucky bluegrass (Poa pratensis L.). Forb species potentially included in the seed mixes for these sites were cicer milkvetch (Astragalus cicer), crown vetch (Coronilla varia L.), alfalfa (Medicago sativa L.), Rockymountain penstemon (Penstemon strictus Benth.), and small burnet (Sanguisorba minor Scop.). The above perennial grasses and forbs were drill seeded in rows with a 30.5 cm spacing at various dates and in numerous combinations. The dates and mixtures used for each of the twelve revegetated study sites are presented in Table 1.

A large number of shrub seedlings have also been planted by the mining company, at high cost, onto many of the reclaimed areas. Big sagebrush, serviceberry, caragana (Caragana arborescens L.), narrowleaf poplar (Populus angustifolia L.), chokecherry, antelope bitterbrush (Purshia tridentata (Pursh) DC.), willow (Salix sp.), rose (Rosa sp. Lindl.) and snowberry have been established, with varying degrees of success. These shrubs are of particular interest to the mining company, in that the successful and widespread establishment of shrubs on the land would not only help return the land to its pre-mine vegetation and land use condition, but would also help the company to fulfill its plant species and growth form requirement of federal reclamation standards (Office of Surface Mining 1977). One of the study sites (number 11) possessed a temporary, annual crop cover of winter rye (Secale cereale L.) for mulch and stabilization purposes. This site was surveyed primarily for further testing of plant species identification capabilities from the aerial photographs.

In addition to the vegetation manually introduced, a number of forb species have invaded many of the reclaimed sites. The primary invading species were sagewort (Artemisia dracunculus L.), goosefoot (Chenopodium album L.), thistles (Cirsium spp. Hill), summer-cypress (Kochia iranica Bornmuller), heleomeris (Heleomeris multiflora Nutt.), prickly lettuce (Lactuca serriola L.), pepperweed (Lepidium sp. L.), yellow sweet clover (Melilotus officinalis (L.) Lam), knotweed (Polygonum spp. L.), and russian thistle (Salsola kali L.).

Table 1. Revegetation Seed Mixtures and Seeding Dates

Mix No.		Common Name	Seed Rate (lbs/ac.)
1	Grasses	Intermediate Wheatgrass (Amur)	6.0
(Drilled		Smooth Bromegrass (Lincoln)	5.0
Oct. 1976)		Western Wheatgrass (Barton)	3.0
(Sites 4, 7,		Crested Wheatgrass (Nordan)	2.0
8, 9, 12)		Hard Fescue (Durar)	1.0
		Kentucky Bluegrass	1.0
		Winter Wheat (Baca)	10.0
	Forbs	Alfalfa	0.5
			28.5
2	Grasses	Intermediate Wheatgrass (Amur)	12.0
(Broadcast		Smooth Bromegrass (Lincoln)	8.0
Jan. 1976)		Western Wheatgrass (Barton)	6.5
		Crested Wheatgrass (Nordan)	4.0
	Forbs	Alfalfa	0.5
			31.0
3	Grasses	Slender Wheatgrass (Revenue)	2.0
(Drilled		Intermediate Wheatgrass (Oahe)	1.5
Oct. 1977)		Pubescent Wheatgrass (Luna)	1.5
(Sites 1, 2,		Smooth Bromegrass (Lincoln)	2.0
3, 5, 6)		Desert Wheatgrass (Nordan)	0.25
		Streambank Wheatgrass (Sodar)	0.25
		Great Basin Wildrye	0.25
		Orchardgrass	0.125
		Timothy	0.05
		Kentucky Bluegrass	0.02
		Hard Fescue (Durar)	0.125
		Western Wheatgrass	0.25
			8.32
	Forbs	Cicer Milkvetch (Lutana)	0.5
		Emerald Crownvetch	0.5

Table 1. Revegetation Seed Mixtures and Seeding Dates (Cont'd)

Mix No.		Common Name	Seed Rate (lbs/ac.)
3 (Cont'd)		Arrowleaf Balsamroot	0.01
		Small Burnet	0.5
		Sweetanise	0.5
		Alfalfa	0.25
			2.26
	Shrubs	Mountain Big Sagebrush	0.025
		Antelope Bitterbrush	0.50
			0.25
			0.525
		TOTAL	11.105
4 (Drilled June 1978) (Site 11)		Winter Rye (for mulch)	72.0
5 (Drilled June 1975)	Grasses	Intermediate Wheatgrass (Amur)	8.0
		Smooth Bromegrass (Lincoln)	4.0
		Orchardgrass	2.0
		Oats	30.0
	Forbs	Alfalfa	2.0
			46.0
6 (Drilled Oct. 1977) (Site 10)	Grasses	Intermediate Wheatgrass (Amar)	6.0
		Smooth Bromegrass (Lincoln)	4.0
		Western Wheatgrass (Barton)	3.0
		Crested Wheatgrass (Nordan)	2.0
		Oats	25.0
	Forbs	Alfalfa	0.5
			40.5

IV. METHODS AND MATERIALS

The project research was conducted in three separate phases. A field survey utilizing the point frame quadrat method was one phase, acquisition of large and medium scale 70 mm color and CIR aerial photography was a second and concurrent phase, and data analysis and interpretation in the laboratory was the final phase of the research. The methods and materials used in completing the three phases will now be discussed in detail.

A. Field Procedures

The ground survey of the vegetation was conducted on three days (17, 18, 21 July 1980) near the date of the remote sensing overflight (17 July 1980). It was essential that the ground survey be completed as near the date as possible such that changes in phenological state and plant cover would not be experienced, thereby causing differences in ground versus aerial estimates.

Two pre-mine (or undisturbed) and twelve post-mine (or revegetated) sites were chosen for study. The two pre-mine sites, which were considered to be supplementary sites to be examined if time permitted, were located within low sagebrush and big sagebrush reference areas delimited by the mining company. These two sites were chosen as they were considered to be representative of the vegetation on the largest area of land to be affected by strip mining. Post-mine or revegetated sites were chosen from the total 550 ha area that had been reclaimed by the mining company. These twelve areas represented the complete range of expected revegetation success; from very sparse herbaceous cover with few species established, to dense stands with numerous species and growth forms present. An additional consideration in choosing these areas, was in the possible detection and cover estimation of a number of species of transplanted shrub seedlings (Table 2) and seeded forbs (cicer milkvetch, crownvetch, Rockymountain penstemon, and small burnet) of interest.

1. Ground Cover Estimates

Three - 100 m transects were established at each of the study sites. Transect starting points were randomly chosen in the field, with the direction of the transects determined by the shape of the revegetated area and by the slope at each of the sites. The lines were laid out along the contour of the slope, in order to maintain a nearly constant photographic scale along each transect. An additional constraint imposed by the photography, was that in order to enable direct comparison of photo cover estimates to the cover estimate made on the ground, the transects were spaced approximately 5 m on either side of the flightline or central (marked) ground transect. This was necessary because the final photographic product from the 70 mm format camera was to be a 57 mm square positive transparency. At an approximate scale of 1:600, this indicates a photographic coverage of about 30 m or very roughly 15 m on either side of the center of the

Table 2. List of Transplanted Shrub Species

Scientific Name	Common Name
Amelanchier alnifolia	serviceberry
Artemisia tridentata	big sagebrush
Caragana arborescens	caragana
Populus angustifolia	narrowleaf poplar
Prunus virginiana	chokecherry
Purshia tridentata	antelope bitterbrush
Rosa sp.	rose
Salix sp.	willow
Symphoricarpos oreophilis	snowberry

flightline. Thus, to allow for scale variations and airplane drift off of the marked flightline, the ground survey transects were safely established at the 5 m distance on either side.

The three transects were designated as A - central, B - 5 m right of central, and C - 5 m left of central (Figure 2). This allowed for later comparisons with the corresponding photo transect estimate. The trio of transects would allow for improved explanation for a variation of plant cover or composition across a site, should such be encountered. This was also the reasoning behind the extended length of the transects.

A total of twenty point frame quadrats were established at 5 m intervals along the length of each 100 m long transect. The ten pin point frame used (designed by Mr. C. Parkin, Colorada Yampa Coal Co.) was 91.4 cm high by 91.4 cm long. Two pieces of 2.5 cm angle aluminum made up the cross pieces which were V-notched at 7.6 cm intervals. Front and back legs were made of hollow 1.3 cm diameter, 91.4 cm long aluminum tube. The back leg was hinged to the top aluminum crosspiece and attached by a small chain to the lower crosspiece so as to produce a 45° pin angle to the ground (Figure 3). It is notable that this angle could not be maintained at all times due to roughness of the ground. The angle would, however, theoretically help to reduce bias of overestimation of narrow leaf erect species versus broad leaf plants, as well as improve visibility of the point in tall grass (see Chapter II for literature citations). A single 101.6 cm long, 3.2 mm diameter brass pin was used by repetitively lowering it down to the vegetation or ground in each of the ten notches. The pin tip was sharpened so as to provide an "infinitely small" plot. Each set of ten pins comprised a

Figure 2. Flightline ground markers and transect locations.

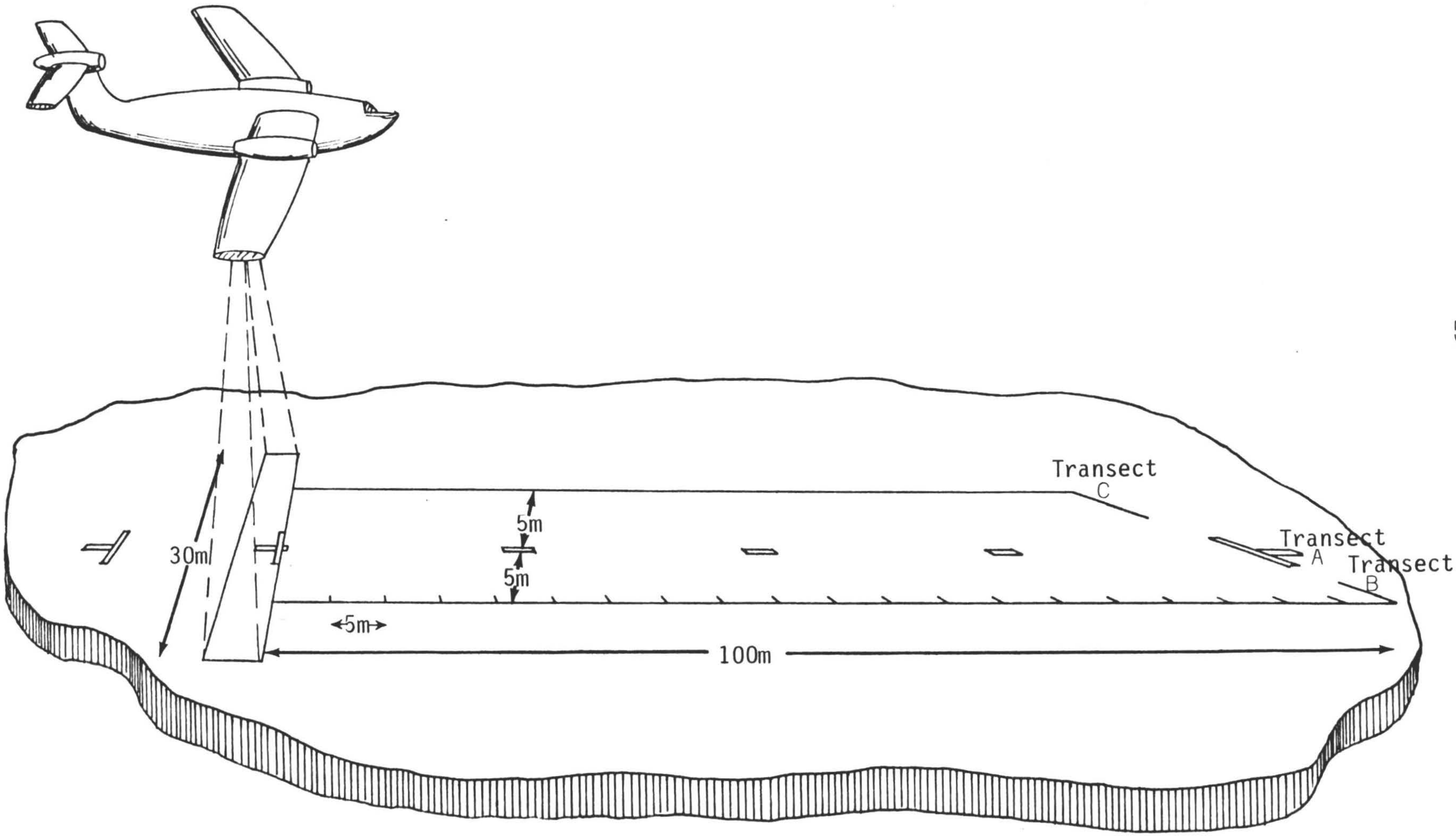


Figure 3. Sampling ground cover with the ten-point frame.

quadrat, with the first hit of each pin on any category (grass, forb, shrub. litter, rock, bare ground) representing 10% of the quadrat (similar to Hofmann et al. 1978). Thus, for each study site, three transects with 20 point frames each, totalled 60 samples of vegetation ground cover for species composition, with a total of 600 points read.

Mean ground cover values by species and by category were calculated for each transect in a trio, at each site. A mean cover value for each species and each category was then determined for a site by averaging the three transect means.

The time required to complete each point frame reading and also to complete each 100 m transect was recorded. These were used later to complete a cost comparison between ground and aerial survey methods.

2. Ground Markers

Ground markers used were similar to those described by Francis (1970). Three meter strips of 46 cm wide white butcher paper (wax coated side up) were the primary markers employed to identify the flightline and transect location to the airplane pilot. A double "T" system (Figure 2) identified the start of each transect and allowed the pilot to align the airplane along the line. The first "T" indicated to the photographer to turn the cameras on, while the second indicated the actual start of the 100 m transect. A 46 x 31 cm white poster card, with the transect number written in black marker, was nailed to the ground on the inside of the second "T". Three additional 3 m long strips of butcher paper were located at approximate 25 m intervals along the 100 m length of the transect. These markers were necessary for initial airplane alignment and also to guide the pilot over the length of the transect (although the markers pass by very rapidly at 45 m/s when only 100 m Above Ground Level!). An additional benefit of all of the 3 m strips is in facilitating later photo scale determinations. A final "T" was located at the 100 m mark to indicate the end of the transect and to identify the point at which the aerial photographer should turn the cameras off (Figure 4). All butcher paper was secured to the ground using the "shoestring tie down" method as suggested by Francis (Francis 1980), which entailed pounding nails at alternate distances along the length of the strip, and zig-zagging a length of cotton string between the nails. Then by stepping the nails into the ground, the strip was secured. By using this method, strips were located and secured on the ground up to three days before the date of overflight. Other factors may disallow this early strip placement - as will be discussed later in the results section of this paper.

Additional ground markers employed included white painted 40 cm surveyor stakes, 23 cm diameter white pie plates and 46 x 31 cm white poster cards. Pie plates were placed at the ends of each surveyor stake, with the points of the stakes located at the edge of the crowns of plant species to be identified (Figure 5). Surveyor stakes were oriented at an angle perpendicular to the estimated sun angle at time of overflight so as to maximize the visibility of the stakes in shadows cast by the vegetation. Plant species were marked in this manner in a random order along the length of the flightline. For each transect, a field map was prepared showing the approximate angle and direction that each stake pointed, and the species that each pointed to. Pie plates were numbered with a black marking pen to aid in later positive identification of each marker and associated plant. This was necessary

Figure 4. Illustration of flightline marker layout and dimensions.

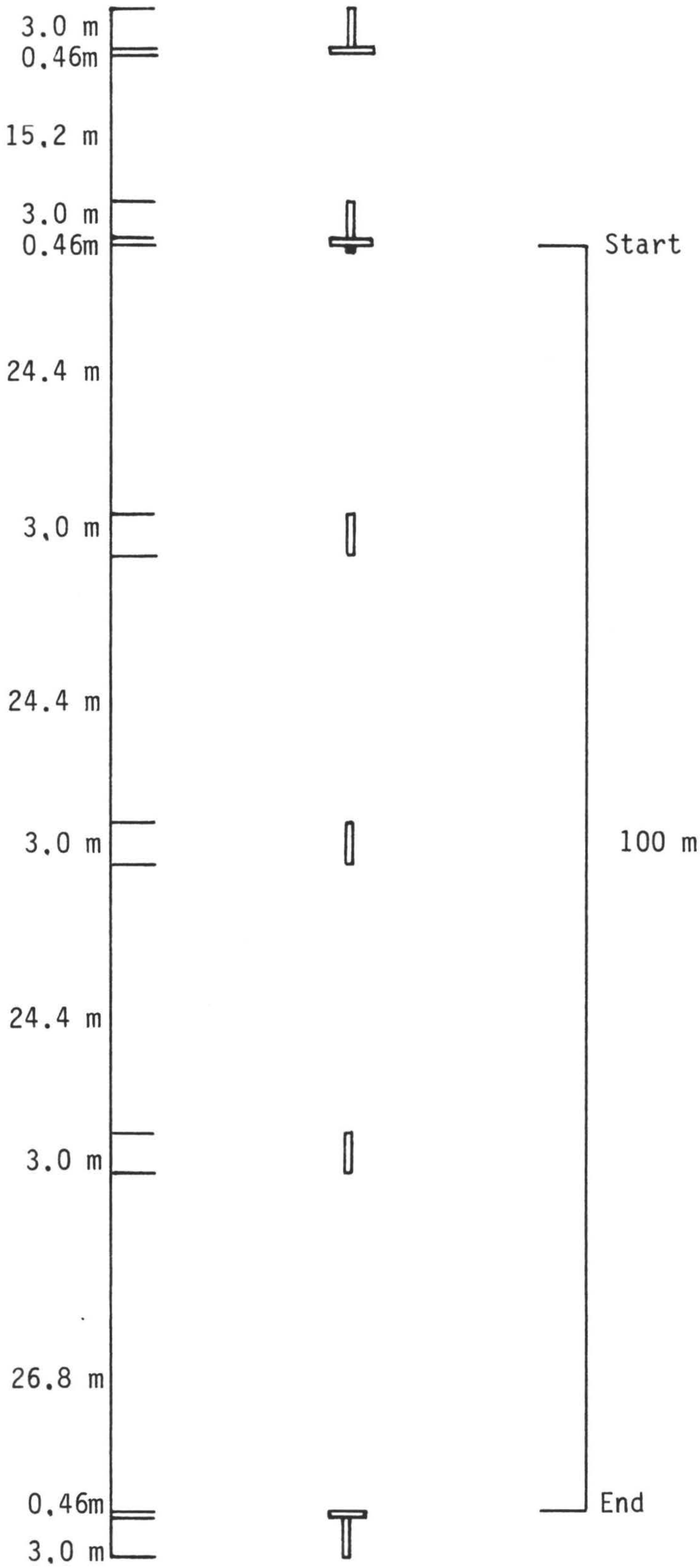


Figure 5. Surveyor stake - pie plate marker used in plant species identification.

for the accurate development of a species identification key from the photography.

B. Acquisition of Aerial Photography

1. Equipment

The aerial photography for this study was taken from a Cessna 185 airplane.[1] The fusilage camera hatch was sufficiently large to allow for the photographer to see just far enough ahead of the plane to be able to switch the cameras on when the plane was over the first ground marker of a flightline.

Two Hulcher 70 mm, Model 103 rapid sequence cameras equipped with 150 mm Schneider - Zenotar F2.8 lenses were used to obtain both color and color infrared (CIR) photography. Available shutter speeds ranged from 1/125th to 1/3000th of a second, and the cameras could be pulsed at 5 to 10 frames per second or in single sequence (Lorain 1970). The cameras were cycled at 5 fms/s at the 1/1500th shutter speed for the large scale photography, and at 5 s/fm at the 1/1000th shutter speed for the medium scale photography obtained. An intervalometer provided synchronous cycling of the two cameras, producing simultaneous frame by frame color and CIR photography. Each camera was attached to an external 12 volt battery by a cord. A problem was encountered during the flight mission when one of the batteries lost power. As a result, about one half of the study sites had to be flown twice in order to obtain both color and CIR coverage. Thus, a direct frame by frame match

1. Aerial photography was flown by Mr. G.E. Lorain, N.R.C. Inc., Reno, Nevada.

up did not exist between both types of photography: however this was not absolutely essential since the flightlines were intensively marked and features of interest could be easily identified. A Spotmatic light meter manufactured by Honeywell, New York, was utilized to measure available light. Correct exposures for aerial photography are often difficult to obtain (Garwin Lorain, personal communication, 1980), and a wide range of exposures actually resulted (see Chapter V). A Wratten 12 filter was used in conjunction with the CIR film, for reasons discussed in Chapter II.

Flight costs are presented in Section D of Chapter V.

2. Film Types

Both color and CIR films were purchased from Eastman Kodak Stores Inc., San Francisco, California. Subsequent processing of the films was by Rapid Color Inc., Glendale, California.

The color film used was 70 mm Kodak Ektachrome Aero, Exposure Index 50, Type 2448, SP494, with Type II perforations. This is a color reversal film with colors in the resultant photographic transparencies resembling those of the original scene (Chapter II B).

The CIR film used was 70 mm Kodak Ektachrome Aero Infrared Exposure Index 100, Type 2443, SP494 with Type II perforations. This film is also a color reversal type, with positive transparencies similarly resulting (Chapter II B).

Purchase and processing prices for both film types are presented in Section D of Chapter V.

3. Date and Scales of Photography

All aerial photography was acquired on one date, 17 July 1980, for the fourteen study sites. This date was chosen as an estimate of peak growth for most of the herbaceous species to be studied (as estimated by a local Range Scientist, Mr. Clem Parkin, Colorado Yampa Coal Company). Peak growth period was chosen since this is the time when the cool season grasses have matured and are beginning to dry, and a number of the common forbs are in bloom; both conditions facilitating more accurate species identification. Budget constraints limited the number of possible overflights to a single time.

Scales of photography obtained were low level 90 m Above Ground Level (AGL) large scale (approximately 1:600), and medium altitude 1830 m AGL medium scale (approximately 1:10 000). The large scale photography was used for species identification and ground cover estimation on reclaimed areas. The medium scale photography was used for evaluating the revegetation success and distribution of plants across the reclaimed areas. It was also useful in recording reclamation progress and in identifying areas of gully erosion and surface slumping. Results of the interpretation of the medium scale photography are provided in Appendix B.

Approximate scales of 70 mm color and CIR photography are provided in Table 3.

C. Photo Interpretation and Office Procedures

Color and CIR positive transparencies were interpreted using a Bausch and Lomb zoom 70 stereoscope mounted on a Richards light table (Figure 6). This set up allowed for easy viewing of the photography

Table 3. Approximate Scales of 70 mm Color and Color Infrared Aerial Photography[1]

Study Site	Color	Color IR
1	1:650 , 1:10 940	1:620 , 1:10 940
2	- 1:11 580	1:480 , 1:11 580
3	1:660 , 1:10 940	- 1:10 940
4	1:600 , 1:10 940	1:610 , 1:10 940
5	1:500 , 1:10 940	1:420 , 1:10 940
6	1:520 , 1:10 940	1:510 , 1:10 940
7	1:480 , 1:10 940	1:240 , 1:10 940
8	1:670 , 1:10 940	1:800 , 1:10 940
9	1:460 , 1:10 940	1:400 , 1:10 940
10	1:380 , 1:10 940	1:420 , 1:10 940
11	1:630 , 1:10 940	1:630 , 1:10 940
12	1:500 , 1:11 580	1:460 , 1:11 580
13	1:820 , 1:12 300	1:790 , 1:12 300
14	1:920 , 1:12 300	1:640 , 1:12 300

1 Differences between scales for color and CIR photography were the result of battery failure; the cameras could not be cycled at the same time and the sites had to be reflown to obtain both large scale color and CIR photography.

Figure 6. Photo interpretation apparatus - a Bausch and Lomb zoom 70 stereoscope mounted on a Richards light table. Note NBS color book in the background.

over a range of from 1 to 40 power magnification. Two light intensities were also available with the Richards light table (3500 λ and 5000 λ). The higher intensity (5000 λ) was utilized for most of the interpretation as it provided better definition of the individual plants on the CIR photography, while the low intensity was used for interpretation of the color photography.

Scales for each flightline (Table 3) were determined using the method described by Aldrich (1979). This method measures absolute parallax, and the distance covered along the flightline between endpoints. Transparent templates are aligned with the fiducial marks of consecutive 70 mm photos to identify the principal points of each photo. Using a 2X stereoscope, the absolute parallax and the effective distance for the photo pair are easily measured. The effective distances are then accumulated for the consecutive photo pairs over the length of the flightline. The photo scale is then computed by:

$b/10,000 = 1/X$ where b is the accumulated photo distance, and X is final scale.

This method is essential to maintaining 70 mm in film strips, since other methods require movement of individual photo frames to locate the principal points. Scale determination was necessary for descriptive purposes, and for the accurate development and placement of the point line overlay to estimate ground cover (this Section, subsection 3).

With scale determination as a preliminary step, photo interpretation for this project consisted of a development phase and a testing phase. A species identification key, and a transect "point line" cover estimation system were developed for the large scale photography. The identification key was then tested by six unbiased photo interpreters, and after completion of the test each interpreter conducted a "photo inventory" of plant cover by species for one of the revegetated study sites. In some cases, time permitting, the photo interpreter may have surveyed two sites using the point line method. The time that each volunteer could contribute was the determining factor in the number of transects that he/she actually surveyed.

The final stage in photo interpretation was the mapping of the study sites using the smaller scale (1:10 000) color and CIR photography. This stage was completed without the involvement of the volunteer photo interpreters.

All of the above photo interpretation processes will now be discussed in greater detail.

1. Plant Species Key Development

Plant species identification keys were developed for both pre- and post-mine areas using the large scale aerial photography. Upon initial testing, CIR photography was found to be superior to the color photography in acheiving correct species identification. This observation was also made by Driscoll and Coleman (1974) in a previous study. The key for the pre-mine low sagebrush (site 13) and big sagebrush (site 14) areas (Table 18, Appendix A) was simple to devise and employ, since its intention was to identify differences between the two sagebrush species, mule's ear, herbaceous plants, litter, and bare ground. In contrast to this, the key developed for the reclaimed areas (Table 19, Appendix A) was quite complex and attempted to identify a number of the more common herbaceous and woody species found on these areas. The difference in the complexity of the keys is a reflection of the priorities for this study, as well as the inherent species complexities of the two different vegetation types.

The species identification keys were developed using plant descriptors similar to those used by Driscoll and Coleman (1974). Some modification and redefinition of terms was necessary in order to adapt their terms (used for mature shrubs) for use in describing grasses, forbs and shrub seedlings found on the reclaimed areas.

Table 4 illustrates the descriptor form utilized in the development and later testing of the keys. Characteristics such as plant height, crown margin and shape, foliage pattern and texture, shadow distinctness, and color were examined. Plant heights were estimated by viewing the length of the adjacent surveyor stake (known to be 40 cm) and then judging the height of the subject plant through a combination of three dimensional subjective judgement (available through stereoscopic viewing) and through evaluation of the length of the plant's shadow. Presence or absence of a shadow and its relative distinctness was next determined, followed by crown margin (outer extent of the plant crown), and plant shape (overall shape of the plant) characterization using the sketches shown to the right of the descriptors in Table 4. Foliage pattern assessment and textural analyses were similarly evaluated using the associated sketches. Designation of a color, or range of colors, to each species completed the development of the keys; colors were chosen from those presented in the National Bureau of Standards ISCC (U.S. Department of Commerce 1977) system, wherein both descriptive and numerical designations are provided for a wide range of colors. This technique was previously employed by Driscoll and Coleman (1974). A corresponding numerical Munsell (1961)

Table 4. Descriptor Form Utilized in Development and Testing of Species Identification Keys.

(Check Appropriate Box)

Color ☐ or CIR ☐

Photo Interpreter:

Transect Number:

Date:

Marker Number:

1. Estimated Plant Height:

   a. <30 cm ☐
   b. >30 cm but <60 cm ☐
   c. >60 cm ☐

2. Shadow Characteristics:

   a. distinct ☐
   b. indistinct ☐

3. Crown Margin:

   a. smooth ☐
   b. wavy ☐
   c. irregular ☐
   d. rough ☐
   e. broken ☐

4. Crown Shape:

   a. indistinct ☐
   b. round ☐
   c. oblong ☐
   d. uneven ☐

5. Foliage Pattern:

   a. continuous ☐
   b. clumpy ☐
   c. irregular ☐

6. Texture:

   a. fine ☐
   b. medium ☐
   c. coarse ☐
   d. stippled ☐
   e. hazy ☐

7. Color Designation:

   a. Matrix ____________
   b. Mottling ____________

PLANT SPECIES:

designation could also be assigned to each species if so desired. More precise definitions of each of the various form descriptors are presented in Table 20, Appendix A.

It should be noted that the keys were developed by studying all ground marked individuals of a given species, over the length of all transects in the relevant pre- or post-mine areas. The description of each species presented in the key therefore necessarily represents the most common, or average appearance of the species, since a detailed description of the range of appearances for a species would create an overly complex and difficult key.

2. Photo Interpreters

Upon completion of and self testing with the keys, six unbiased volunteers were obtained from the Colorado State University Departments of Range and Forest Science to test the accuracy and applicability of each key. Two of the interpreters were familiar with the vegetation of the study area as they had either worked in the area (interpreter A) or had visited and viewed the reclaimed areas (interpreter B). Interpreters C and D had never been to the study area, however they were both knowledgeable about the numerous species found across the area. The first four interpreters had very little or no stereoscopic photo interpretation experience. The last two volunteers, E and F, were experienced photo interpreters, but had no knowledge of the plant species present across the site. Both of these people had previously used color and CIR photography for mapping overstory or tree species, but had no experience in identifying or quantifying low growing herbaceous or woody species from large scale 70 mm photography. Each interpreter was tested separately on as many of the flightlines as possible for the time that they were available. It was hoped that by using a number of both experienced and inexperienced photo interpreters, it might become obvious whether prior experience with a stereoscope and color and CIR film would be beneficial to the successful completion of such an aerial survey project for a given mine site. Similarly, the familiarity with the plant species might also become a criterion in choosing the personnel to complete such a study. The use of photo interpreters with a variety of qualifications was previously used by Driscoll and Coleman (1974).

Percent correct identification by each interpreter for all species marked on a transect was first recorded. Total percent correct identification by each interpreter, for each species, over all transects was also recorded. Overall percent correct identification by each interpreter was used to test if a difference in accuracy existed between the individuals. When recording the accuracy obtained by each interpreter, species names for all wrong answers were recorded to determine whether the error was a consistent one of commission (when two species appeared the same).

Upon completion of the species identification test for as large a number of sites as possible, one of the sites viewed by that person was chosen for conducting the cover estimate by species. Before initiating the cover estimate, the identities of the plants that were just previously tested were revealed to the interpreter, and a review of the characteristics and appearance of each of the dominant species on the transect was completed.

3. Point Line Method

The point method utilized on the photography to estimate percent ground cover and species composition was an attempt to closely approximate the point frame method used on the ground. A linear arrangement of 10 minute dots was made using a 4 x 0 Rapidograph pen. The dots were spaced 2.5 mm apart on clear acetate overlay material. The linear grid or "point line" was then photographically reduced by ten times to produce a line of points that were spaced .25 mm apart and only visible under 10X magnification. Unfortunately, this spacing did not exactly provide the same point spacing on the photo as was used on the ground (7.6 cm), however it was the photographer's opinion that the dots might completely disappear with any further reduction (Mr. Dick Myer, Personal Communication, U.S. Forest Service, Fort Collins, CO. 1980). The point line method was developed with the assistance of Mr. Dick Myer and Mr. Dick Francis, U.S. Forest Service, Fort Collins, CO.

The photographic ground cover estimate was obtained by moving the point line down the length of the 100 m flight line, in 5 m (ground distance) intervals. The 5 m ground interval was closely approximated on the photography by using a scale that was premarked to correspond with the photographic scale for the given flightline (Table 5). In this way, twenty point lines, each with ten points, were read along the center of the flightline; twenty were read at a 5 m distance right of center; and twenty were read at a 5 m distance left of center. Thus, the ground survey method was reproduced as accurately as possible on the photos, with three transect estimates for ground cover and species composition obtained for each site.

Table 5. Point Line Spacings Necessary to Achieve a 5 m Ground Distance on the Various Scales of Aerial Photography Obtained at each Study Site.

Study Site Number	Photographic Scale of CIR	5 m Point Line Spacing on Overlay (cm)
1	1:620	0.84
2	1:480	1.14
3	-	0.84
4	1:610	0.84
5	1:420	1.14
6	1:510	0.84
7	1:240	2.08
8	1:800	0.63
9	1:400	1.14
10	1:420	1.14
11	1:630	0.84
12	1:460	1.14
13	1:790	0.63
14	1:640	0.84

V. RESULTS AND DISCUSSION

A. Field Results

1. Point Frame Data

The first-hit point method has been shown (Chapter II, Section A) to be a reliable method for estimating ground cover of dominant species in a sward of relatively constant height. Revegetated areas examined in this study generally consisted of swards that possessed mainly tall, erect grasses such as the wheatgrasses, smooth bromegrass, orchardgrass and timothy, with alfalfa sometimes occurring as a dominant or codominant. Thus the swards were generally not well stratified according to height, and an underestimation of cover of more prostrate species should not be a problem. Such species as Kentucky bluegrass, hard fescue, cicer milkvetch or pepper-grass might pose a problem in their estimation with the first-hit point method. However, such low growing species, as well as the introduced shrub seedlings (Table 2), were very minor components of the swards studied, and for this reason, the first-hit method should suffice for characterizing the ground cover of the taller even-height stands. Although no comparisons between sampling methods were made in this study, the point method allowed for a rapid and objective estimate of dominant species cover. For this reason, numerous researchers (Cook and Box 1963; Johnston 1970; Lorain 1970) have preferred its use over alternative quadrat or line estimation methods. The objectivity of the point method is also a very important factor in achieving consistent consecutive annual cover estimates of revegetated areas; this being important in establishing trends in increasing cover towards a financial bond release date. It should be noted that a multiple-hit method should be employed in preference to the first hit method when the vegetation community growth form structure becomes more diversified to insure that prostrate species are not underestimated.

The point frame used in completing the ground survey was designed with a number of factors in mind. The 45° pin angle theoretically allowed for equal sampling effectiveness of plants with leaves oriented either vertically or horizontally. In addition, the angle provided easier viewing of the pin hits than with a vertically oriented pin. The cast aluminum frame was very light and easily moved along the transects in the field. The three-legged design with connecting chain provided frame stability on most ground surfaces with the exception of rocky or steeply inclined surfaces such as the banks of contour furrows. The 45° angle was difficult to maintain on these surfaces, however, and the development of an adjustable angle frame - perhaps through the use of a plumbob for vertical orientation - is recommended to better maintain the angle.

Objective readings were easily obtained by guiding the brass pin over the V-notches to the ground. A heavier, stiffer, steel pin may improve objectivity further by reducing the vibration generally associated with the lowering of the brass pin. A needle welded to the tip of the pin should serve to reduce the size of the point "plot" and thereby reduce the chance of overestimating cover.

2. Ground Markers

Ground markers utilized in the location and identification of flightlines and individual species proved to be adequate for the completion of this study. The pilot (who had rather limited experience) was able to locate the flightlines and align the airplane with relative ease. Exceptions to this were sites 7 and 8 which were located near a rock cliff that caused dangerous updrafts and disallowed proper navigation along the flightlines. Site 7 was nearest the cliff edge, and a very large scale (1:240) resulted due to the plane dropping down after passing the cliff. Site 8 was eventually flown sideways for safety reasons, at a scale of 1:800. This resulted in unuseable photography for this site.

The photographer found the ground markers to be easily visible and encountered very few or no difficulties in camera synchronization with transect start or end points.

The wax coated butcher paper, used as the primary flightline markers, was inexpensive to purchase (Table 17, Section D) easily prepared into the correct lengths and numbers, and quickly and simply installed in the field. The 3 m lengths, which were precut and bound with rubber bands, were rapidly installed using the "shoestring tiedown" method (Francis 1980). These markers were light in comparison to alternative markers such as plywood boards. The nine strips required to mark each sample transect could be easily carried to sites distant from vehicular access.

Longevity of the wax coated strips was considered to be a potential problem prior to the remote sensing overflight. At least three days spectral signature did it become difficult to identify which plant the stake pointed to on the aerial photograph. Further to this, the placement of the pie plate at the "tail of the arrow" insured that the tip would not be confused with the tail of the surveyor stake.

Two centimeter wide black numbers drawn on the pie plates for identification purposes were only occasionally visible on the largest scales of photography, as a result of the numbers being too small, too close together and perhaps as a result of image motion (Francis 1980). However these numbers were found to be unnecessary to the proper identification of the marked species because an accurate ground map showing marker direction and species at each was prepared for each transect. Several possible alternatives for ameliorating this problem have also been suggested in the Future Research Chapter (VII).

A similar problem was encountered in positively identifying the transect numbers on the poster cards located at the second "T" at the start of each transect. Only about one half of these numbers could be resolved, so the pattern of surveyor stakes was again utilized to establish the identity of each transect on the aerial photography. Several alternative improvements have again been suggested in Chapter VII.

B. Photo Interpretation Results

Interpretation of the 70 mm color and CIR aerial photography was carried out in three general phases (Chapter IV, Section C). The following provides the results obtained for the pre- and post-mine vegetation identification keys, photo interpreter tests, and aerial cover estimates using the point line method. A comparison of ground versus aerial estimates for ground cover and related species composition was the final result.

1. Pre-Mine Plant Species Identification Key

The pre-mine photography species and ground cover dichotomous key (Appendix A) was devised to test for the discrimination between two shrub species (actually subspecies; low and big sagebrush), all herbaceous species as a group (a variety of grasses and forbs), a prominent noxious weed (mule's ear), litter (dryed detached plant material), and bare soil. The small size and intermixed nature of the herbaceous species at these sites prevented further separation to the species level.

The difference between the two sagebrush subspecies was identified on the ground primarily by their height differential and that the low sagebrush leaves tended to terminate on the branches in a rosette form. Samples of representative individuals of each were collected in the field according to their height and were positively identified as being the two different subspecies[1]. Therefore, in this particular shrubland, where few shorter big sagebrush seedlings were established, an adequate subspecies separation could be made based primarily on shrub height. The three dimensional projection of height under stereoscopic vision, and the shadow lengths in relation to 40 cm long ground markers were the criteria used by the interpreters in identifying the sagebrush heights on the color and CIR aerial photography.

---

[1] Kirby Demott, Department of Botany, Colorado State University, Fort Collins, Colorado.

An additional difference became apparent in the examination of the average color of the shrubs. While both shrub subspecies appeared the same color on the color photography, the big sagebrush appeared more light gray (grayish yellow green-NBS number 122), and the low sagebrush appeared darker (dark grayish yellow - 91) and often olive (light olive brown - 94) on the CIR. These colors varied somewhat, however, with some low sagebrush individuals taking on the big sagebrush color on CIR.

Green herbaceous material apparently could be separated (although not statistically tested with ground markers) from dead or dry plant material (litter) primarily based on its color on the CIR photography; strong reddish orange (35) to brownish orange (54) for the former versus grayish greenish yellow (105) for the latter. The three dimensional projection of the live plant material also provided textural information that allowed separation between these categories in some cases. No quantification of green versus brown herbage was attempted in these pre-mine shrublands however, primarily due to their intermixed nature. This quantification is reserved for future research.

The identification of the large (30 to 60 cm long) leaved mule's ear that was invading a large proportion of the big and low sagebrush shrublands was easily made using the pre-mine key. Although no numerical tests were performed on the reliability of its identification, it could be easily discriminated from the indigenous flora of the area on both color and CIR photography.

In contrast, the identification of bare soil was difficult; confusion resulted from its similarity in both color and texture to the plant litter found on the sites.

All of the afforementioned observations were qualitative in nature since the emphasis for this study was placed on evaluating the effectiveness of the aerial survey method on post-mine lands.

2. Post-Mine Plant Species Identification Key

In contrast to the pre-mine dichotomous key, the post-mine key was more complex because it involved the identification of a large number of herbaceous and woody species.

A total of twenty different species possessing a wide variety of growth forms and spectral signatures were tested with varying results obtained. Because of the number of species involved and the resultant complexity of the key, an examination of each species will not be made here; rather the highlights of the key will be discussed. The reader is referred to the key itself for more specific comparisons (Appendix A).

Plants were initially separated according to their apparent heights, based on shadow length (in relation to ground markers present) and their three dimensional projected height. Only three species found in the reclaimed areas ever equalled or exceeded an estimated 60 cm height. Thus the occurrence of a relatively tall plant indicated either yellow sweet clover, thistle or alfalfa. These three could then be easily separated on the basis of: (1) flower color and crown paucity (yellow sweet clover), (2) crown margin and shadow shape (thistles), or (3) crown shape, texture, and color (alfalfa).

The remaining plants in the key were generally all shorter than the 60 cm division and were often more difficult to identify. Provisions for the occurrence of shorter (less than 60 cm) thistle, sweet clover and alfalfa plants were also made in the key. Several of the shorter species that possessed very characteristic flowers, growth forms or spectral signatures were relatively easily and accurately identified (see the next subsection). In particular, species such as heleomeris (large, white, round flowers on CIR; yellow on color), Russian thistle (low, spreading, relatively large plant - orange on CIR), knotweed (prostrate, mat-like, orange) or Kentucky bluegrass (prostrate, fine textured, yellow green) were easily separated.

The remaining species could be identified as either grasses, forbs or woody species based primarily on color and crown shape. Grasses were generally either yellow, pale orange or green, while forbs and shrubs were most commonly red, orange, or pink in color. An exception to this color coding was that big sagebrush seedlings were generally a moderate olive green color (NBS no. 125), with some light reddish brown (42) mottling in their canopies. Thus, the very small individuals of this species, that had crown diameters of less than about 10 cm and were shorter than about 15 cm, were not readily separated from grasses. Neither did the smaller big sagebrush cast the diagnostic round shadows of the larger seedlings of the species.

Separation of the various grasses was done based upon their spectral signatures. However, large clumps of tall intermediate wheatgrass could also be identified based on its growth form and associated crown shape. This species commonly appeared pale yellow (89) to pale greenish yellow (104), while other grasses were more orange (smooth bromegrass - 52), pink (timothy - 27), or green (crested wheatgrass - 118). This produced a correct identification in many cases, however errors of comission among the grasses remained high due to overlap in the characteristic colors.

Separation among and between forb and woody species proved to be difficult except for the species already discussed. While certain plants, such as Rocky Mountain penstemon and snowberry, could be occasionally identified, the majority of the remaining species that were tested did not yield promising results for their correct identification.

The numerical analysis of the photo interpreter results for species identification are provided in the following subsection.

3. Photo Interpreters

While a very large number of individuals of numerous different plant species were actually marked in the field the following numerical analysis relates only to the most commonly encountered species. This is because unequal sample sizes between the various species tested became an unanticipated problem in completing the numerical analysis. Many of the less common species and species that were preconceived as having unique and readily identifiable spectral, height, canopy or shadow characteristics were less intensively marked during the ground marking phase of the study. Although these field determinations were well founded, and identification of these species was in general easily and accurately carried out by the photo interpreters, the low and unequal sample sizes prevented detailed numerical analysis. Such species as yellow sweet clover, alfalfa and thistles were sufficiently large and had some unique characteristic (yellow sweet clover - color, height, irregular foliage pattern; alfalfa - color, height, clumpy foliage pattern; thistles - height, distinct shadow) that they were readily identified. Table 6 presents the number of plants tested (n), the number correctly identified (c), and the resultant percentage (c/n x 100) for yellow sweet clover, alfalfa and several other common plants. While the individual sample sizes by photo interpreter are too small to draw detailed conclusions, the species identification accuracy is well reflected in the percentages presented under the "All Photo Interpreters" row.

The results in Table 6 for crested wheatgrass, intermediate wheatgrass, smooth bromegrass (these were the three most commonly encountered species in the post-mine areas) and big sagebrush (seedlings) were used later in this section for numerical analysis.

Table 7 presents a list of the other species marked and tested during the study. The results are presented for all photo interpreters combined only, again because of the small and unequal sample sizes for different observers. The reader should thus draw his own conclusions from this table based upon the sample sizes given. It does appear, however, that Kentucky blue grass could be more accurately identified than the other two grass species listed (orchard grass and timothy) primarily due to its contrasting low growth form and medium yellow green (120) color. Similarly, knotweed and Russian thistle were relatively easily distinguished primarily due to their canopy characteristics and colors (knotweed - low spreading plant, gray reddish orange color (39); Russian thistle - spreading plant, continuous foliage, strong reddish brown color (40)), although further testing with higher sample sizes would ascertain this.

Correct shrub seedling identification did not appear promising, especially where numerous different species were intermixed. This difficulty is accurately represented in these shrub values, even though

Table 6. Photo Interpreter Results for the More Common Plant Species in the Post-Mine Areas.

Photo Interpreter	Item	PLANT SPECIES: Agropyron cristatum	Agropyron intermedium	Bromus inermis	Melilotus officinalis	Medicago sativa	Artemisia tridentata	All Species
A	n	4	15	10	1	5	2	37
	c	2	9	6	1	5	0	23
	%	50	60	60	100	100	0	62
B	n	12	27	17	2	5	7	70
	c	9	20	12	2	5	4	52
	%	75	74	71	100	100	57.1	74
C	n	11	30	17	2	1	12	73
	c	9	18	11	2	0	5	45
	%	82	60	65	100	0	41.7	62
D	n	8	31	14	1	5	5	64
	c	6	21	6	1	5	1	40
	%	75	68	43	100	100	20.0	63
E	n	12	39	15	1	5	9	81
	c	8	30	8	1	5	7	59
	%	67	77	53	100	100	77.8	73
F	n	3	11	13	1	1	8	37
	c	1	7	6	1	0	3	18
	%	33	64	46	100	0	37.5	49
All Photo Interpreters	N	50	153	86	8	22	43	362
	C	35	105	49	8	20	20	237
	%	70	69	57	100	90	46	65

n = number of markers examined by a given interpreter
c = number of marked individuals of a species correctly identified by a given interpreter.
N = number of markers examined by all interpreters
C = Number of marked individuals of a given species correctly indentified by all interpreters.

Table 7. Photo Interpreter Results for the Less Common Plant Species in the Post-Mine Areas.

Growth Form	Plant Species	All Photo Interpreters		
		N	C	%
Grasses				
	Dactylis glomerata	12	3	25
	Phleum pratense	18	3	17
	Poa pratensis	15	12	80
Forbs	Astragalus cicer	18	7	39
	Cirsium spp.	8	6	75
	Kochia iranica	12	8	67
	Lactuca serriola	8	5	62
	Penstemon strictus	6	3	50
	Polygonum sp.	4	4	100
	Salsola kali	4	4	100
	Sanguisorba minor	8	0	0
Shrubs	Caragana arborescens	14	6	43
	Populus angustifolia	16	6	38
	Prunus virginiana	20	10	50
	Syphoricarpos oreophilis	12	6	50

test sample sizes were relatively small, and unequal between photo interpreters. Surveying the shrubs after they had experienced further growth (>15 cm height) should provide improved identification.

No attempt was made to identify significant differences between the identification levels of the various species. For the available data, this should only be done subjectively, with the total number of individuals marked used as the major criterion in establishing the level of confidence that should be placed in the accuracy level (percentage) presented. Thus, one might place considerable confidence in the percent correct identification for crested wheatgrass, intermediate wheatgrass, smooth bromegrass and big sagebrush; while values provided for alfalfa, timothy, cicer milkvetch and chokecherry could be considered marginally acceptable; and one might be somewhat skeptical about the percentage values provided for all other species, based on their small test sample sizes.

An evaluation of the interpretation capabilities of the various interpreters and interpreter types was carried out next. In order to do this, only the plant species that were viewed by all six interpreters could be used. Unequal sample sizes were again a problem; this resulting from the differing amounts of time that each interpreter could volunteer, and thus the total number of markers that each could be tested on. The binomial (correct-incorect; 1-0) nature of the data and its relationship to the number of markers (n) and number correctly identified (c) in Table 6, prevented the use of a two-way analysis of variance with unequal sample sizes as suggested in Steel and Torrie (1960) or in Snedecor and Cochran (1967). For this and other reasons, a non-parametric test was used to identify differences between interpreters. The Friedman Index (Gibbons 1976) was employed as it does not require the assumption that the data to be analyzed are normally distributed. Another reason was that the data were discrete (0-1) and not continuous as required in the parametric test. The Friedman Index also provides a robust test for detecting differences where a small sample size is concerned.

Table 8 presents the results of the non-parametric analysis and the details of the calculation. The interpreters were ranked according to their abilities to correctly identify the four most commonly marked plant species with the percentages presented in Table 6 assumed representative. Rank midpoints were assigned where interpreters had similar abilities. The Rj's represent the rank sums or overall capabilities of the interpreters, with the lowest total indicating the most accurate interpreter across the four species evaluated and the highest score representing the least accurate interpreter. The ensuing calculations (Table 8) indicated that based on the four species evaluated, there was no significant difference in the abilities of the interpreters to accurately identify the plants marked. The interpreter results were then categorized into types according to their previous experience:

Type 1 = Familiar with the vegetation and the study area; no previous photo interpretation experience.

Type 2 = Familiar with the vegetation but not the study area; no previous photo interpretation experience.

Type 3 = Not familiar with the vegetation or the study area, previous black and white and small scale color infrared aerial photo interpretation experience.

Table 8. Evaluation of Photo Interpreter Capabilities Using the Friedman Index (Gibbons 1976).

Plant[1] Species	Photo Interpreter A	B	C	D	E	F
Agcr	5	2.5	1	2.5	4	6
Agin	5.5	2	5.5	3	1	4
Brin	3	1	2	6	4	5
Artr	6	2	3	5	1	4
Rj	19.5	7.5	11.5	16.5	10	19

Rj = Rank sum

C = 6 (number of columns) $R = \frac{M\ (C+1)}{2}$

M = 4 (number of rows) $R = \frac{4(6+1)}{2} = 14$

$$S = \sum_{j=1}^{C} (Rj-R)^2$$

$$S = (19.5-14)^2 + (7.5-14)^2 + (11.5-14)^2 + (16.5-14)^2(+0-14)^2 + (19-14)^2 = 126.0$$

$$T = \frac{12S}{M^2C(C^2-1)} \quad \frac{12(126.0}{(4^2)6(36^-1)} = 0.45$$

$$F = \frac{(M-1)T}{1-T} \quad \frac{(4-1)0.45}{1-0.45} = 2.45 \text{ with 4 and 14 df.}$$

Using χ^2 table - Not significant. (at $\alpha = 0.05$)

Conclusion: There is no significant difference between the accuracies obtained by the different photo interpreters.

[1] Plant species abbreviation names provided in Appendix C.

Results of the Friedman Index by interpreter type are presented in Table 9. Since the rank sums (Rj's) were all equal, it became obvious that there was no difference in identification accuracies between the three types of interpreters, indicating that based on the data:

1. Familiarity with vegetation species and study area does not necessarily lead to increased interpretation accuracy over familiarity with the vegetation alone; and
2. Experience with black and white and small scale color infrared aerial photography will not necessarily increase the interpretation accuracy (on large scale color infrared) over that achieved by totally inexperienced photo interpreters.

Thus, the qualifications of the available volunteer interpreters were apparently not sufficiently refined to create significant differences between interpreter types. The testing of more highly trained photo interpreters may have produced a separation between interpreter types. A larger number of test species may have also helped to separate better between interpreters.

The separation of vegetation according to life form (Table 10) was more accurate than separation by species. All interpreters had high success in separating life forms, and it was observed that grasses could be reliably separated (93%) from forbs or shrubs, while there were more errors of commission between forbs and shrubs. These observations were important in evaluating the success of the cover estimation results discussed in the following section.

Table 9. Evaluation of Photo Interpreter Types Using the Friedman Index (Gibbons 1976).

Plant Species	PHOTO INTERPRETER TYPE*		
	1	2	3
Agcr	2	1	3
Agin	2	3	1
Brin	1	2	3
Artr	3	2	1
Rj	8	8	8

All rank sums (Rj's) are equal, therefore there is no difference between interpreter types based on these data.

* Type 1 = Familiar with the vegetation and the study area; no previous photo interpretation experience.

$$\frac{\%\ \text{correct interpreter A} + \%\ \text{correct interpreter B}}{2}$$

Type 2 = Familiar with the vegetation but not the study area; no previous photo interpretation experience.

$$\frac{\%\ C + \%\ D}{2}$$

Type 3 = Not familiar with the vegetation or the study area; previous black and white and small scale color infrared aerial photo interpretation experience.

$$\frac{\%\ E + \%\ F}{2}$$

Table 10. Ground Marker Sample Sizes and Mean Percentage Correct Identification by Life Form[1]

Photo Interpreter	Item	Life Form			
		Grasses	Forbs	Shrubs	All Herbage
A	N	34	10	11	55
	C	31	10	4	45
	%	91	100	36	82
B	N	61	11	16	88
	C	59	10	13	82
	%	97	91	81	93
C	N	63	28	33	124
	C	59	19	23	101
	%	94	68	70	81
D	N	63	11	6	80
	C	60	10	2	72
	%	95	91	33	90
E	N	71	13	21	105
	C	71	7	18	96
	%	100	54	86	91
F	N	42	25	18	85
	C	32	19	8	59
	%	76	76	44	69
All Photo Interpreters	N	334	98	105	537
	C	312	75	68	455
	%	93	76	65	85

1. These values represent the ability of the observers to separate the herbage by life form only, without consideration given to confusion between species in a given category. All markers tested were included here.

4. Point Line Data

As discussed in the research methodology (Chapter IV, Section C.3), the point line method was developed in order to emulate the point frame method used in the ground survey. A number of design factors had to be considered: (1) size of each of the points, (2) distance between each of the ten points in a line, (3) length of each line, and (4) distance between point line locations along a transect. The latter two specifications were determined by the designer, and the former two were dictated by the photographic reducing technique. The importance of each of these items with regard to vegetation sampling was discussed previously (Chapter II. A).

Since the size of the effective sample point used in the aerial survey was larger than that used on the ground, and since point sample locations in either case do not correspond, the use of the individual point samples were ruled out for making the comparisons between the aerial and ground data. It was first thought that the relatively large size of the points in the point line would produce a consistent overestimate of the various cover categories, however this was not found to be the case (see next section). Neither did the difference between the 45° average angle of point descent on the ground versus the theoretical 90° "descent" on the air photo cause any apparent consistent over or underestimation of all ground cover categories. The literature states that point size (Goodall 1952), angle of descent (Tinney et al. 1937), and spacing between points in a frame (Radcliffe and Mountier 1964a) will cause changes in estimation of percent cover. A study testing the statistical comparability of different point sizes and spacings used on aerial photographs would be an interesting item for future research.

methods. The objectivity of the point method is also a very important factor in achieving consistent consecutive annual cover estimates of revegetated areas; this being important in establishing trends in increasing cover towards a financial bond release date. It should be noted that a multiple-hit method should be employed in preference to the first hit method when the vegetation community growth form structure becomes more diversified to insure that prostrate species are not underestimated.

The point frame used in completing the ground survey was designed with a number of factors in mind. The 45° pin angle theoretically allowed for equal sampling effectiveness of plants with leaves oriented either vertically or horizontally. In addition, the angle provided easier viewing of the pin hits than with a vertically oriented pin. The cast aluminum frame was very light and easily moved along the transects in the field. The three-legged design with connecting chain provided frame stability on most ground surfaces with the exception of rocky or steeply inclined surfaces such as the banks of contour furrows. The 45° angle was difficult to maintain on these surfaces, however, and the development of an adjustable angle frame - perhaps through the use of a plumbob for vertical orientation - is recommended to better maintain the angle.

Objective readings were easily obtained by guiding the brass pin over the V-notches to the ground. A heavier, stiffer, steel pin may improve objectivity further by reducing the vibration generally associated with the lowering of the brass pin. A needle welded to the tip of the pin should serve to reduce the size of the point "plot" and thereby reduce the chance of overestimating cover.

and by setting the transects up in trio. Thus the cover estimate by site should have been the most representative estimate obtained.

The airphoto point line data were summarized in a similar fashion to the ground point frame data. Results of transect mean cover values and site mean cover values are provided in the following section (C).

The point line method was relatively easy to learn, even by the inexperienced photo interpreters, and its expediency compared favorably with the ground survey method employed. Details of a time comparison are provided in Section D of this chapter.

C. Comparison of Field and Aerial Estimates

A correlation and linear regression statistical analysis, using the least squares method of estimation (Weisberg 1980) was used to compare between aerial and ground survey cover data. Aerial estimates were considered the independent variable and the ground estimates the dependent variable. The variables were considered in this fashion (aerial=X; ground=Y) because the purpose of the analysis would eventually be to predict actual (ground) cover values from the aerial perspective. A total of nine sites (1, 2, 4-7, 9, 10, 12) were analyzed; sites 3 and 8 were missed during the aerial survey, and site 11 had an anomalous vegetation cover type (Chapter V, Section A.2).

Comparisons were initially made between ground and aerial estimates of the dominant species; defined as those species having the highest average ground cover values across all sites (Table 11). Paired t-tests (Ryan et al. 1976) indicated that the aerial cover estimates for the three dominant grasses were significantly higher ($p<0.05$) than the

Table 11. Ground and Aerial Estimates of Ground Cover by Species on 9 Study Sites Analyzed.

PLANT[1] SPECIES	STUDY SITE NUMBER 1		2		4		5		6		7		9		10		12	
	Ground	Aerial	Ground	Aerial	Ground	Aerial	Ground	Aerial	Ground	Aerial	Ground	Aerial	Ground	Aerial	Ground	Aerial	Ground	Aerial
Grasses:																		
Agcr	0.7	2.5	8.0	2.8	2.3	7.8	0.7	3.3	0.2	20.2	0.2	3.8	0.4	4.4	3.4	8.2	9.0	9.7
Agin	5.6	18.5	10.2	18.2	5.2	6.5	0.3	10.8	4.5	15.6	13.4	3.4	5.3	3.3	10.0	13.8	12.8	21.5
Brin	3.8	4.0	10.8	7.6	5.8	9.9	4.5	1.5	2.6	1.0	6.4	0.0	1.0	0.0	5.3	2.8	6.7	18.2
Dagl	6.7	1.3	0.7	1.0			4.5	0.0							0.4	1.0		
Phpr	5.3	1.7	1.3	1.0			2.1	0.0							0.2	2.9		
Popr			1.7	0.0	0.2	0.0											2.3	4.4
Misc. Grass							0.3	0.0									1.7	0.0
Total Grass	22.2	28.0	32.7	30.7	13.5	24.2	12.5	15.7	7.3	36.8	20.0	7.2	6.7	7.7	19.3	28.7	32.5	53.8
Forbs:																		
Ascl	0.7	0.2	2.3	0.3											0.5	0.0		
CHENO	1.7	0.0					1.0	0.0										
CIRSI	0.7	0.0					0.7	1.8	0.2	0.0								
Hemu	0.0	0.5	0.3	0.8														
Meof							2.6	0.2	2.2	2.2								
Mesa	0.0	2.0	0.2	1.5	8.7	6.5			0.0	2.6	31.0	62.3	50.8	53.7	4.0	6.7		
POLYG	6.8	0.5	1.4	0.3			1.5	1.0							0.2	0.0		
Misc. Forb	0.1	6.5	0.8	4.5	0.0	0.3	1.2	0.3	0.3		0.3	0.0			1.0	0.0		
Total Forbs[2]	13.0	9.7	5.2	7.5	8.7	6.8	7.0	3.3	2.7	4.8	31.3	62.3	50.8	53.7	5.7	6.7	0.0	0.0
Total Shrubs	1.4	-	0.8	-	0.0	-	1.0	-	1.1	-	0.9	-	7.2	-	1.0	-	0.2	-
Total Vegetation	36.6	37.7	38.7	38.2	22.2	31.0	20.5	19.0	11.1	41.6	52.2	69.5	58.7	61.4	26.0	35.4	32.7	53.8
Litter	19.7	19.0	37.5	28.2	21.5	9.2	10.7	12.2	52.5	6.3	30.8	12.8	28.0	8.0	41.7	24.8	25.0	7.7
Rock	6.0	6.0	2.5	2.8	5.5	5.7	10.0	2.7	2.7	2.3	0.7	1.2	1.8	0.3	0.3	1.0	3.5	5.2
Total Cover	62.3	62.7	78.7	69.2	49.2	45.9	41.2	33.9	66.3	50.2	83.7	83.5	88.5	69.7	68.0	61.2	61.2	66.7
Bare Soil	37.7	37.3	21.3	30.8	50.8	54.1	58.8	66.1	33.7	49.8	16.3	16.5	11.5	30.3	32.0	38.8	38.8	33.3

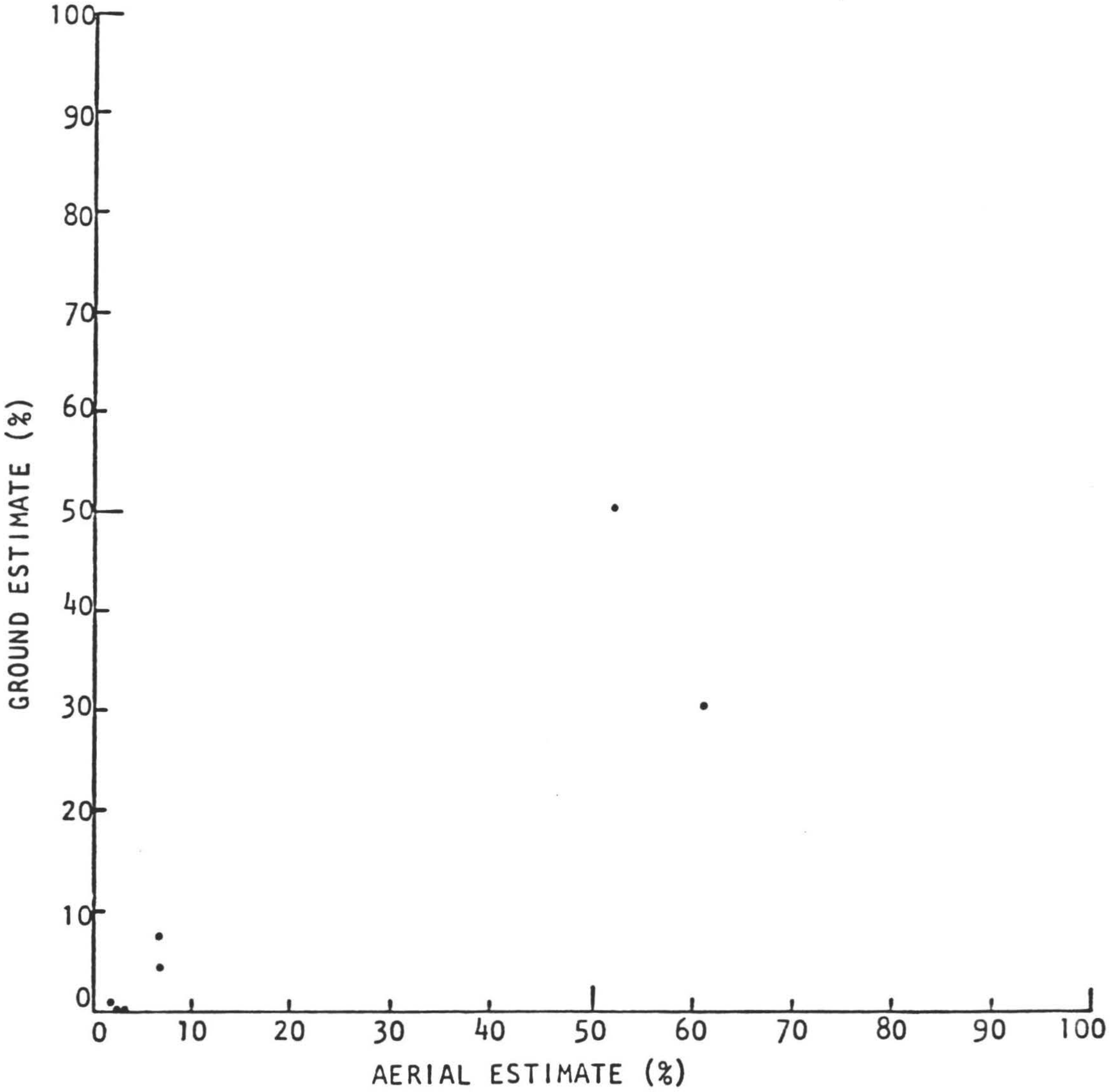
1 Plant species abbreviation names provided in Appendix c.

2 Total forbs-aerial estimates includes shrubs, since forbs and shrubs were generally indistinguishable on the aerial photography.

corresponding estimates made on the ground. However, alfalfa cover estimates by site were not significantly different ($p>0.05$) between aerial and ground perspectives. Similarly, total grass, forbs plus shrubs, and rock cover estimates were not significantly different. The aerial estimates of total vegetation cover at each site were significantly higher ($p<0.05$) than those estimates made on the ground. The aerial underestimate ($p<0.05$) for litter cover accounted for the lack of difference ($p>0.05$) in estimation of total ground cover.

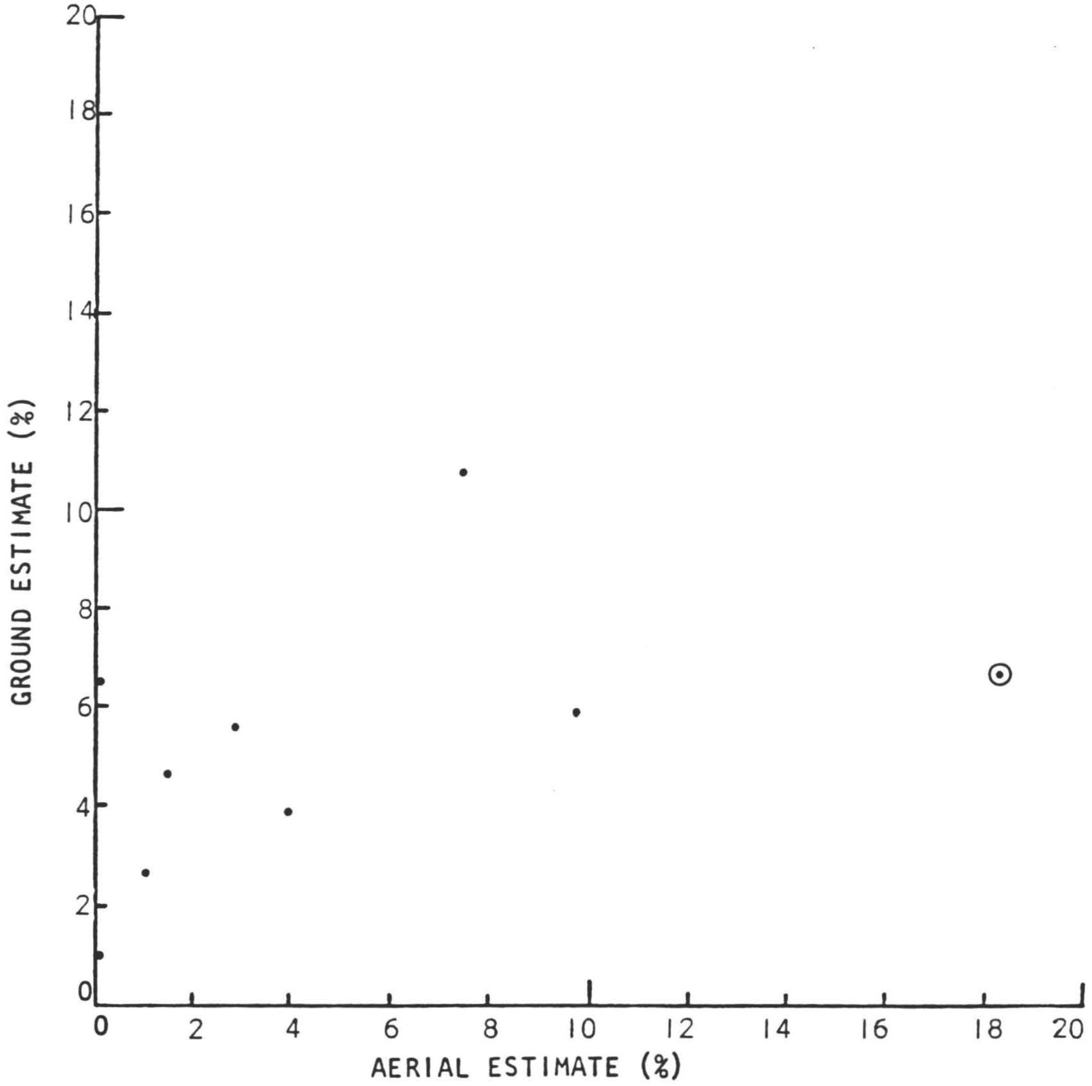
Figures 7 through 10 provide graphical representations of the comparisons made between aerial and ground estimates of alfalfa, smooth bromegrass, intermediate wheatgrass, and crested wheatgrass ground cover. A summary of the correlation and regression values obtained for each of these dominant species is presented in Table 12. The regression analysis showed that while the ground cover of alfalfa could be reliably estimated from aerial photographs ($p<.001$), that of the dominant grass species could not. These capabilities are probably intimately related to the ability with which observers could identify the individual plant species, although cover hits and species identification accuracies were not determined from the same sample cases. While the identification of alfalfa by all observers was relatively accurate (90%), the average correct identifications for the dominant grasses were substantially lower, although different test sample sizes were used, as discussed earlier. Correct identifications by all observers combined for smooth bromegrass, intermediate wheatgrass, and crested wheatgrass were 57%, 69% and 70% respectively. It is surprising that of the three grasses, the aerial estimation of smooth bromegrass cover was the most accurate (though remaining non-significant at the 0.05 level), yet the

Figure 7. Alfalfa Cover by Site.



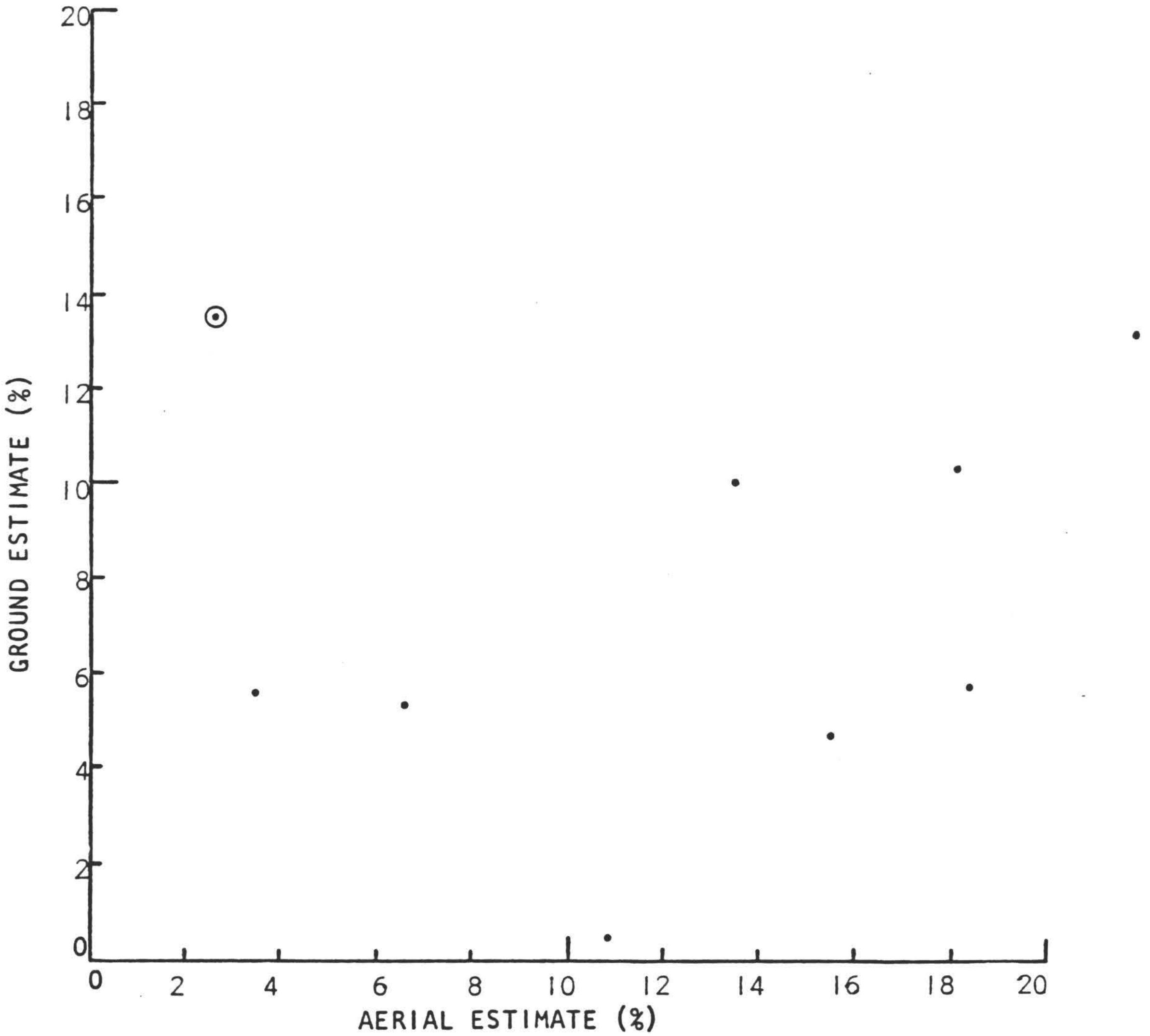
(N = 7; r = .92; α (2) p < 0.001)

Figure 8. Smooth bromegrass Cover by Site.



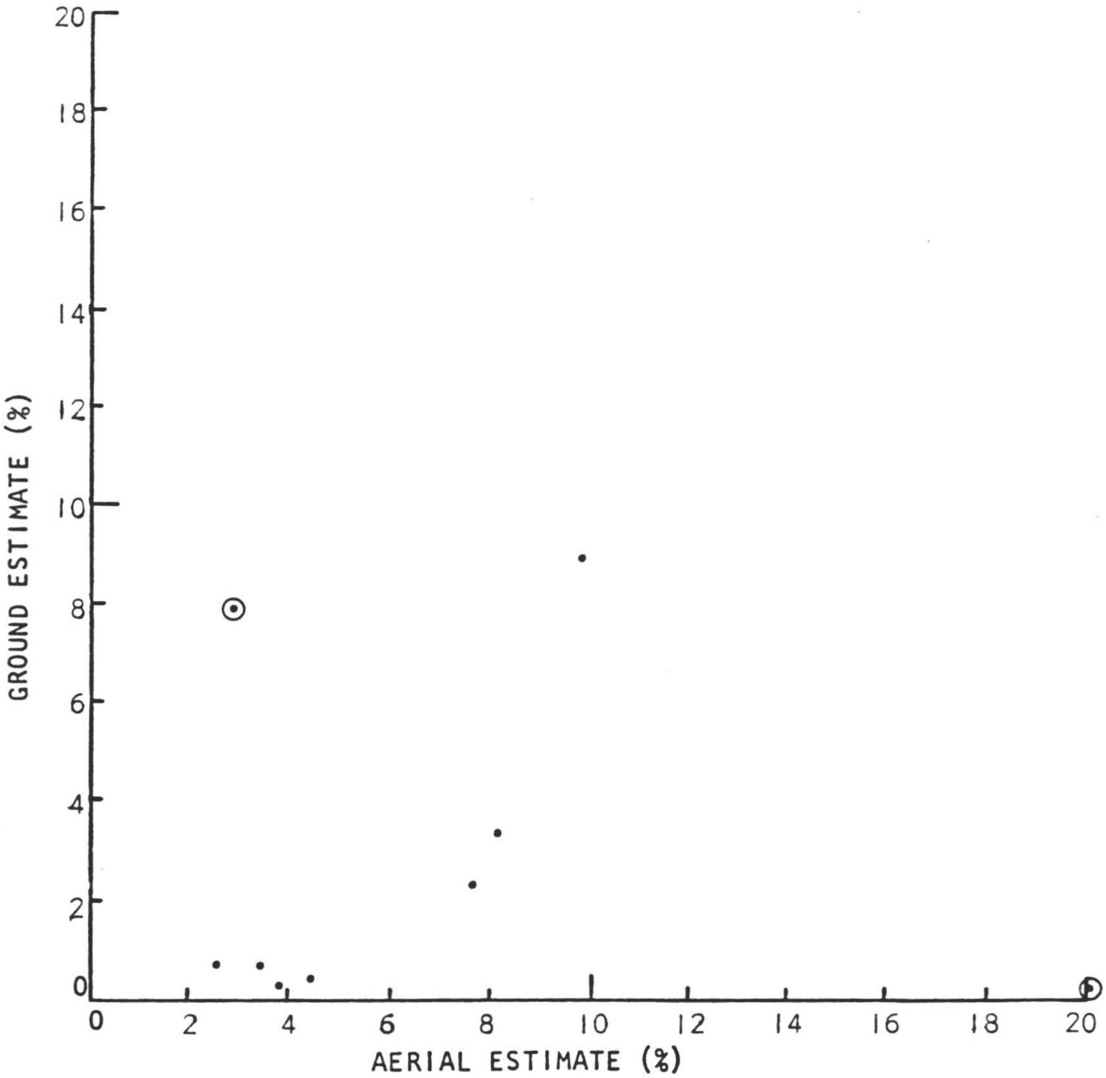
(N = 9; r = .49; α (2) p < 0.20)

Figure 9. Intermediate Wheatgrass Cover by Site.



(N = 9; r = .16; Not significant)

Figure 10. Crested Wheatgrass Cover by Site.



(N = 9; r = -.05; Not significant)

Table 12. Correlation and Regression Values of Aerial Estimates (X) and Ground Estimates (Y) for Four Common Plant Species.

PLANT SPECIES (N=9)	CORRELATION COEFFICIENT (r)	REGRESSION EQUATION
Alfalfa	0.92**	Y = 0.28 + 0.68X
Smooth Bromegrass	0.49	Y = 4.06 + 0.23X
Intermediate Wheatgrass	0.16	Y = 6.19 + 0.10X
Crested Wheatgrass	-0.05	Y = 2.97 - 0.03X

Critical values correlation coefficients:

* significant at $p<0.05$

** significant at $p<0.01$

reliability of its identification was the lowest. The latter point remains an anomally, that may be the result of pure chance. Aerial estimates of shrub cover were not made due to: (1) scarcity of shrubs along the transects as reflected in the ground estimates; and (2) a high degree of error of commission with forbs (Section B subsection 3). A more detailed discussion of the reliability of identification of the various species of vegetation has been provided previously in this chapter (Section B, subsection 3).

Influential outliers were obvious in the data for all three dominant grass species. These outliers have been circled on Figures 8, 9 and 10. Removal of these data points improved the correlation coefficient (r) values in all cases (smooth bromegrass = 0.59; intermediate wheatgrass = 0.56; crested wheatgrass = 0.84), however, these omissions can not be justified in terms of experimental procedural error, since the three outliers were caused by different photo interpreters at different study sites (sites 12, 7 and 2 respectively).

Inspection of Figure 10, with removal of the outliers, would indicate an exponential relationship between the ground and aerial estimates of crested wheatgrass cover. However, upon testing these data with multiple regression (quadratic), the fit did not improve greatly, and the relationship could not be explained; a larger sample size would be required to ascertain this.

Since the above analyses did not provide favorable results for estimating cover for individual species, (because of small sample sizes and possible non-linear relationships), species cover values were grouped into their corresponding herbage categories (grasses, forbs, shrubs) and the regression analyses between aerial and ground estimates were performed again. The analyses were carried out under the assumption that the higher precision with which grasses and forbs were separated from each other and from shrubs on the aerial photographs would be reflected in a more accurate aerial estimation of cover by category. This was generally found to be the case.

The regression analyses were first performed by evaluating ground versus aerial estimates on a transect basis. The cover by herbage category, as well as the cover of litter and rock categories, by transect, have been summarized in Table 13. Figures 11 through 16 provide graphical comparisons between aerial and ground estimates of grass, forb (and shrub), total vegetation, litter, rock, and total cover by transect. Correlation and regression values resulting from the comparison of aerial and ground estimates for each cover category, are provided in Table 14.

Paired t-tests indicated that the aerial estimates by transect of grass cover and total vegetation cover were significantly higher ($p<0.05$) than the corresponding estimates made on the ground. There were no significant differences ($p<0.05$) between aerial and ground estimates of forb (plus shrubs) or rock cover. The underestimate ($p<0.05$) of litter cover by transect from the aerial photographs produced a significant ($p<0.05$) underestimate of total ground cover by transect.

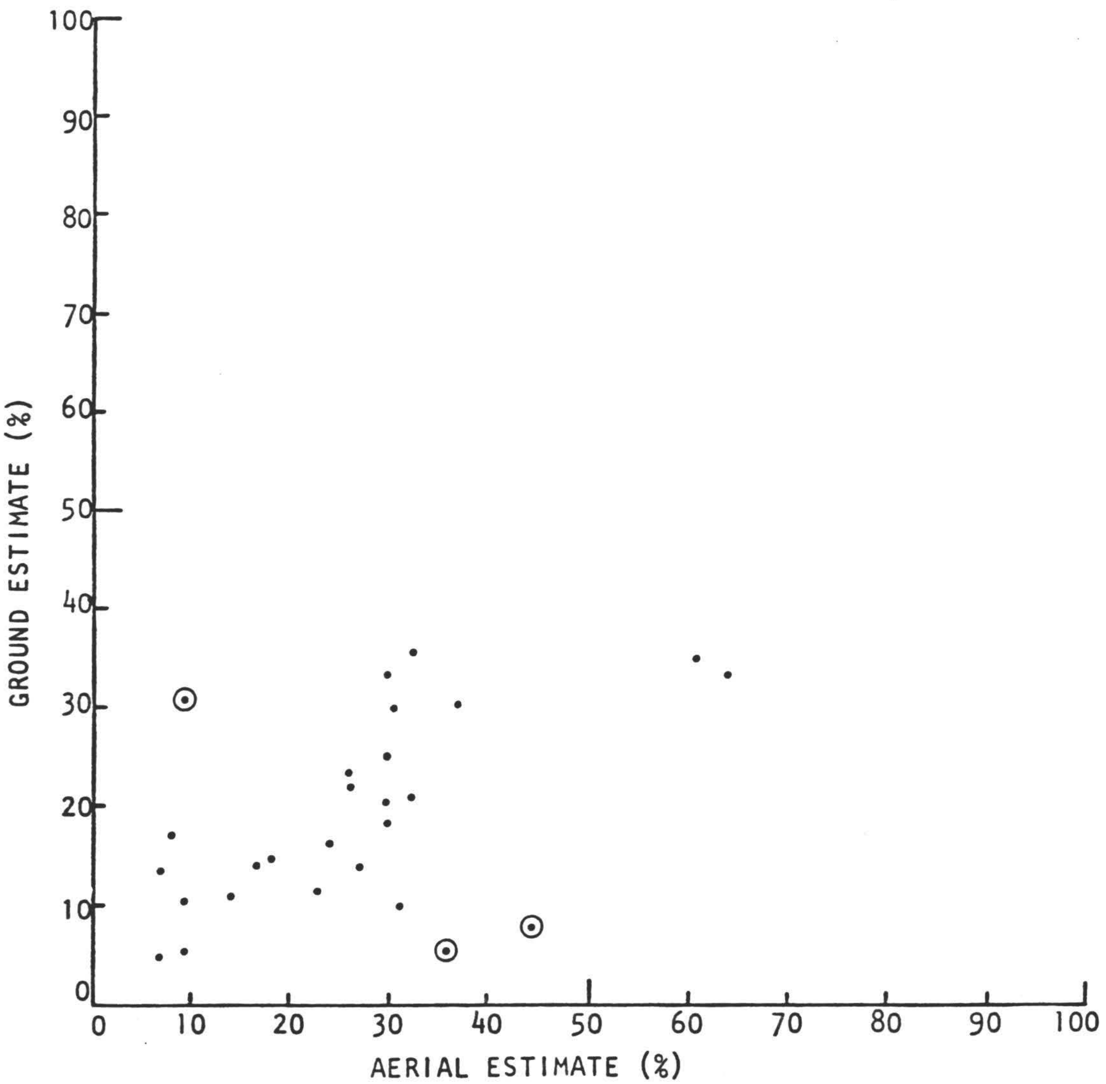
Regression analyses showed that grass, forb, total vegetation, and total ground cover could be estimated with good accuracy ($p<0.01$) from the large scale CIR aerial photographs. Litter or rock cover estimates were not significantly correlated, although the p-value for the correlation coefficient (r) calculated for the rock cover estimates

Table 13. Percent Ground Cover by Transect for each Ground Cover Category.

Transect Number		Grasses		Forbs		Total Vegetation		Litter		Rock		Total Ground Cover		Bare Soil	
		Ground	Aerial	Ground	Aerial	Ground	Aerial	Ground	Aerial	Ground	Aerial	Ground	Aerial	Ground	Aerial
1	A	24.0	29.0	10.5	8.5	34.5	37.5	30.5	20.5	2.5	5.0	67.5	63.0	32.5	37.0
	B	19.5	29.0	7.5	5.5	27.0	34.5	18.5	20.0	9.5	6.5	55.0	61.0	45.0	39.0
	C	23.0	26.0	21.0	15.0	44.0	41.0	39.5	16.5	6.0	6.5	89.5	64.0	10.5	36.0
2	A	33.5	29.5	6.5	7.0	40.5	36.5	31.0	33.5	2.5	0.5	74.0	70.5	26.0	29.5
	B	35.5	32.0	5.5	6.5	42.5	38.5	29.5	27.5	2.0	4.5	74.0	70.5	26.0	29.5
	C	29.0	30.5	3.5	9.0	33.0	39.5	52.0	23.5	3.0	3.5	88.0	66.5	12.0	33.5
4	A	11.0	22.0	7.5	6.0	18.5	28.0	19.0	14.0	5.0	8.0	42.5	50.0	57.5	50.0
	B	13.5	27.0	7.5	6.0	21.0	33.0	31.0	6.0	3.5	4.0	55.5	43.0	44.5	57.0
	C	16.0	23.5	11.0	8.5	27.0	32.0	14.5	7.5	8.0	5.0	49.5	44.5	50.5	55.5
5	A	10.5	13.5	4.0	5.2	14.5	18.7	6.5	10.5	14.5	0.5*	35.5	29.7	64.5	70.3
	B	14.0	17.5	12.0	2.6	26.0	20.1	12.0	12.5	6.0	4.5	44.0	37.1	56.0	62.9
	C	13.0	16.0	5.0	2.1	18.0	18.1	13.5	13.5	9.5	3.0*	41.0	34.6	59.0	65.4
6	A	7.5	44.5*	7.0	8.5	14.5	53.0*	48.5	11.0	3.0	2.0	66.0	66.0	34.0	34.0
	B	9.5	30.5	0.5	3.5	10.0	34.0*	59.5	6.0	2.0	3.0	71.0	43.0	29.0	57.0
	C	5.0	35.5*	0.5	2.5	5.5	38.0*	49.5	2.0	3.0	2.0	58.0	42.0	42.0	58.0
7	A	17.0	6.5	28.0	55.0	45.0	61.5	37.0	17.5	0.0	0.0	82.0	79.0	18.0	21.0
	B	30.0	8.5*	27.5	56.5	57.5	65.0	30.0	18.0	0.5	0.5	87.5	83.5	12.5	16.5
	C	13.0	6.5	38.5	75.5	61.5	82.0	25.5	3.0	1.5	3.0	87.0	88.0	13.0	12.0
9	A	5.0	8.5	46.5	58.5	51.5	67.0	29.5	9.0	3.0	0.0	84.0	76.0	16.0	24.0
	B	4.5	6.0	63.5	52.5*	68.0	58.5*	27.5	2.5	1.0	0.5	96.5	61.5*	3.5	38.5
	C	10.5	8.5	42.5	50.0	53.0	58.5	27.0	12.5	1.5	0.5	81.5	71.5	18.5	28.5
10	A	20.5	31.5	4.5	5.5	25.0	37.0	50.0	25.5	0.0	0.0	75.0	62.5	25.0	37.5
	B	22.0	25.5	5.5	8.0	27.5	33.5	25.5	29.0	1.0	0.5	53.0	63.0	47.0	37.0
	C	18.0	29.0	7.0	6.5	25.0	35.5	49.5	20.0	0.0	2.5	74.5	58.0	25.5	42.0
12	A	30.0	36.5	0.0	0.0	30.5	36.5	27.5	1.5	3.5	6.5	61.5	44.5	38.5	55.5
	B	34.5	61.0	0.0	0.0	34.5	61.0	29.5	10.0	2.0	1.5	66.0	72.5	34.0	27.5
	C	33.0	64.0	0.0	0.0	33.0	64.0	18.0	11.5	5.0	7.5	56.0	83.0*	44.0	17.0

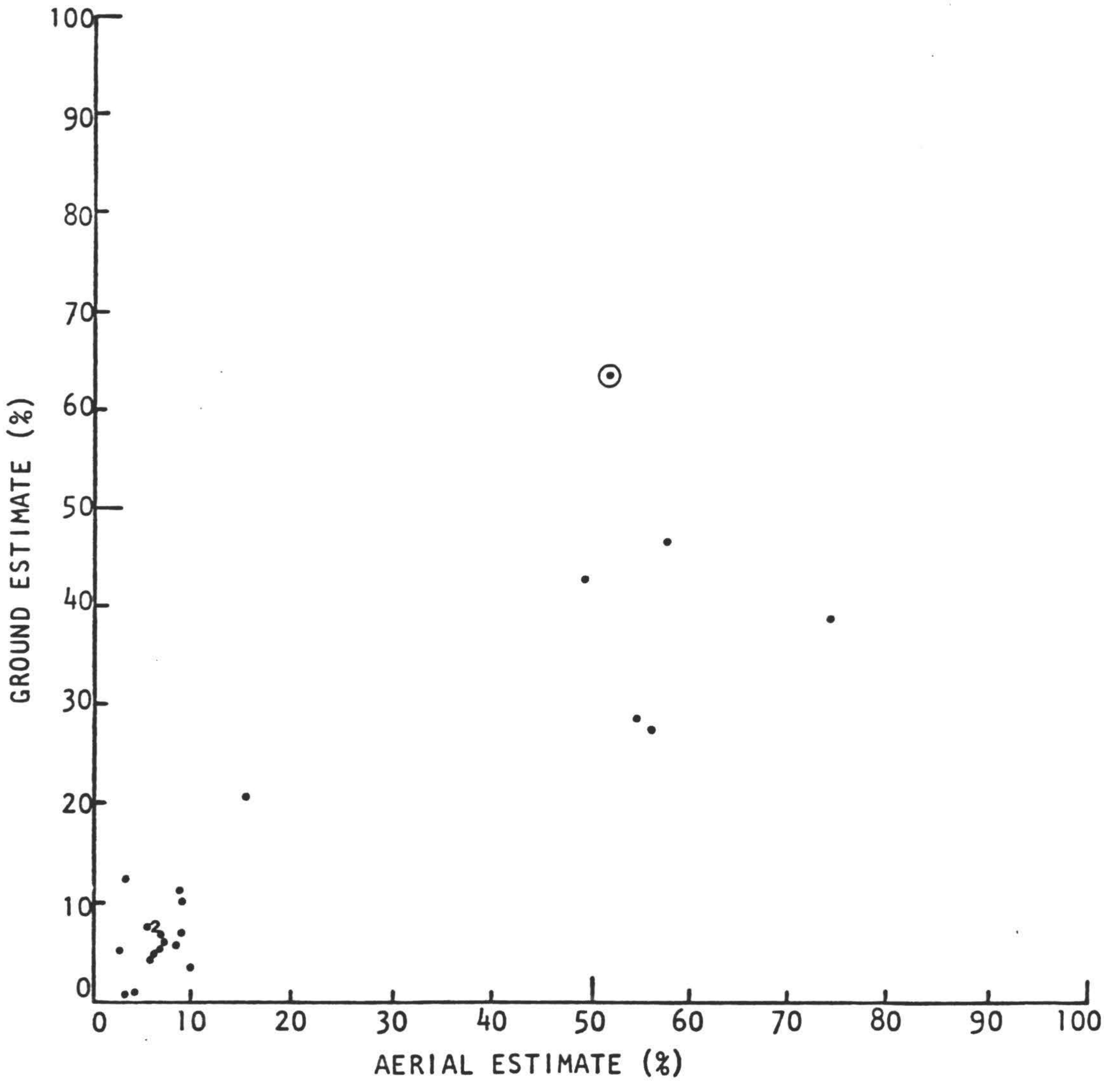
* Outlier data point that has larger influence and/or a large standardized residual (Ryan et al. 1976).

Figure 11. Grass Cover by Transect.



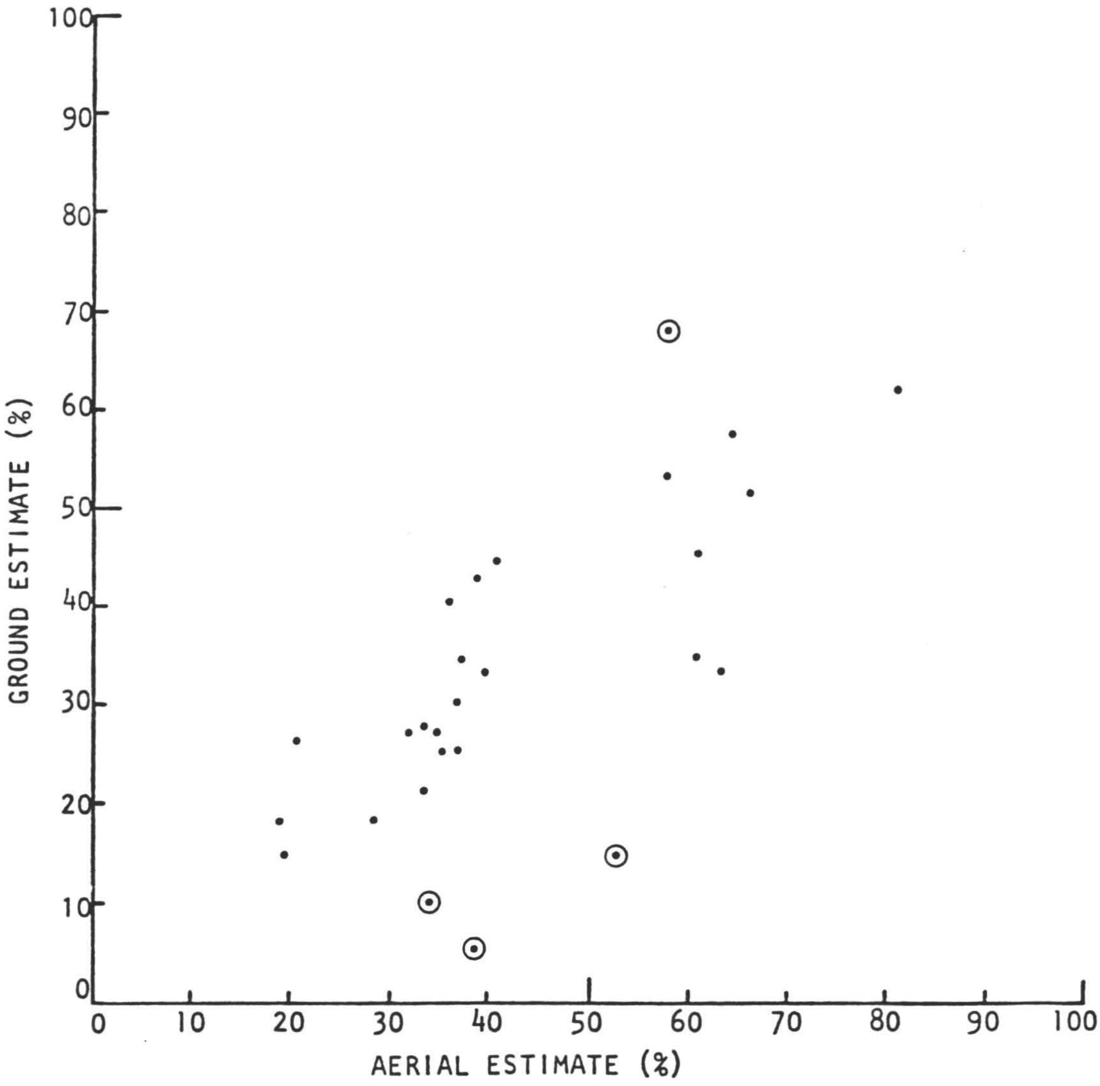
(N = 27; r = .50; α (2) p <0.01)

Figure 12. Forb Cover by Transect.



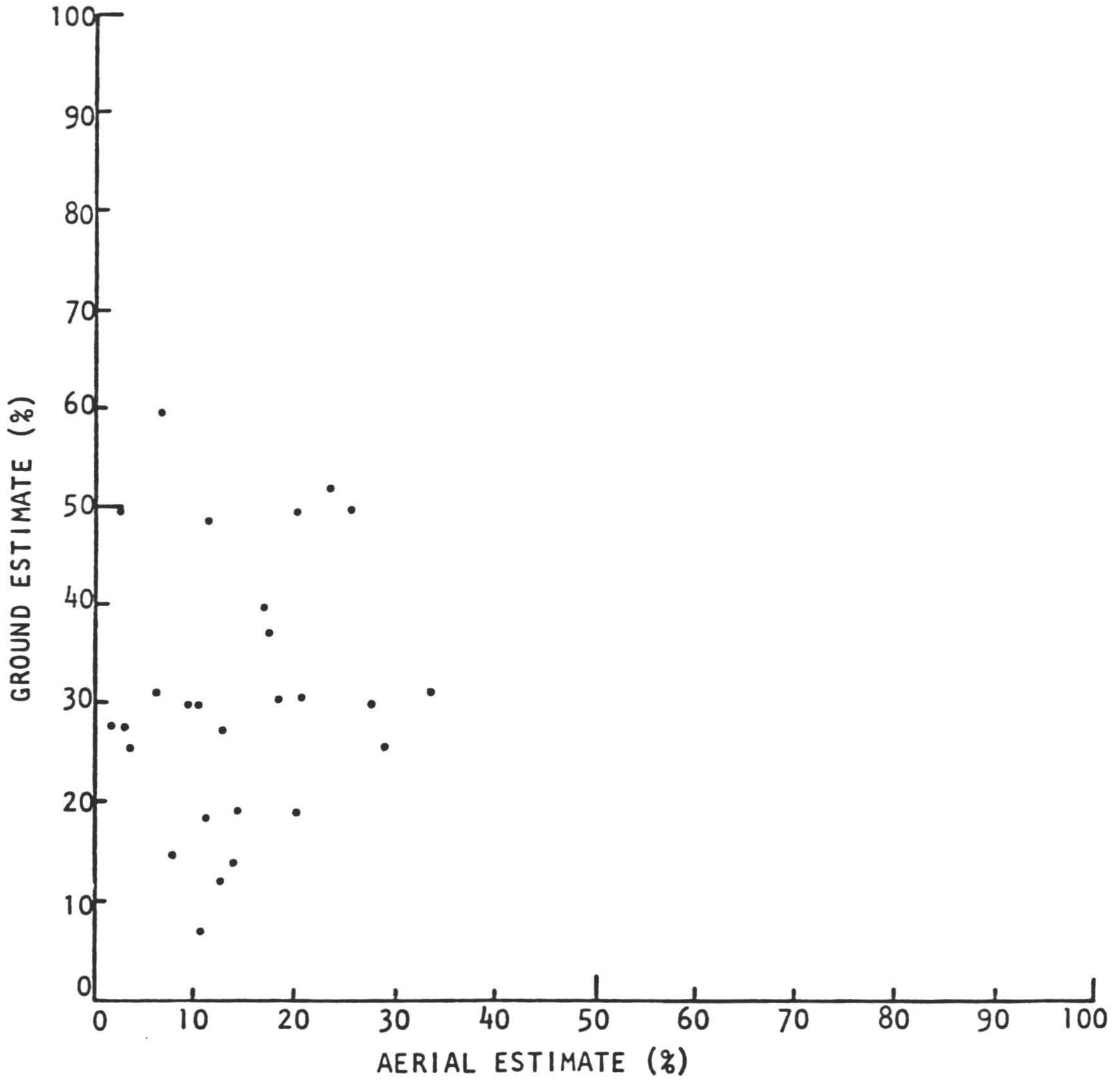
(N = 24; r = .89; α (2) p <0.001)

Figure 13. Total Vegetation Cover by Transect.



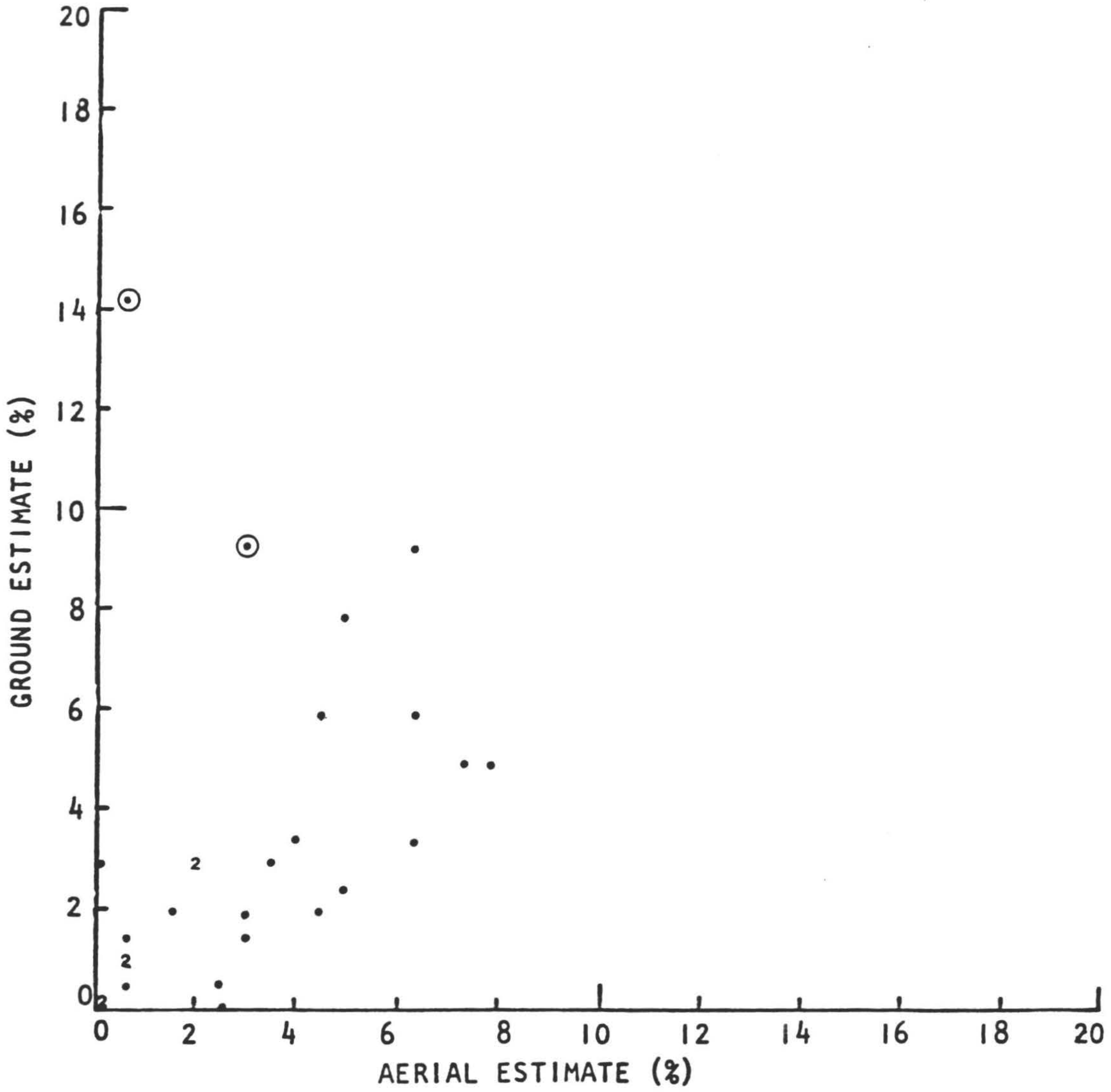
(N = 27; r = .71; α (2) p <0.001)

Figure 14. Litter Cover by Transect.



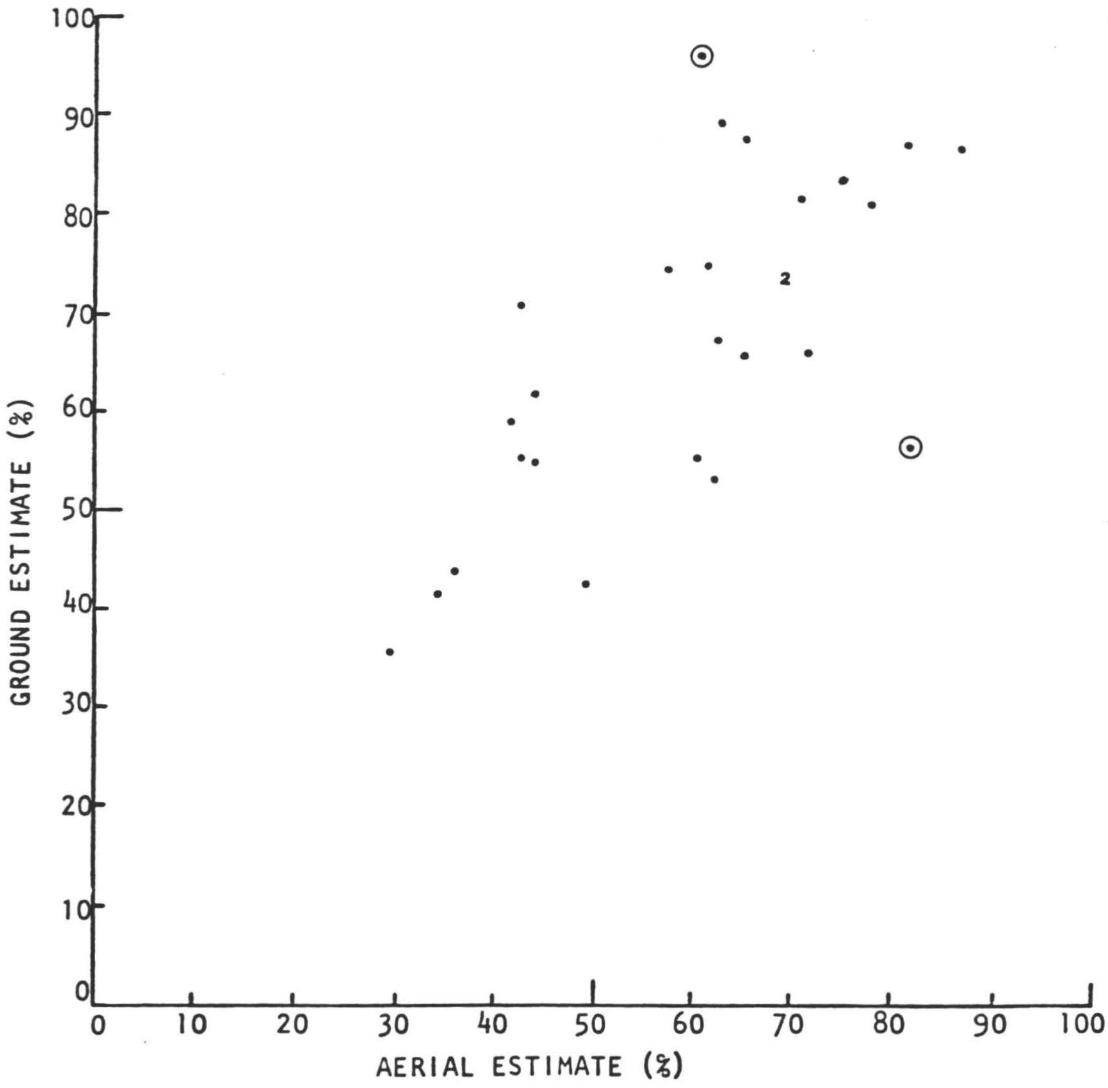
(N = 27; r = .10; Not Significant)

Figure 15. Rock Cover by Transect.



(N = 27; r = .36; α (2) p <0.10)

Figure 16. Total Cover by Transect.



(N = 27; r = .70; α (2) p <0.001)

Table 14. Correlation and Regression Values of Aerial Estimates (X) and Ground Estimates (Y) by Transect for Each Ground Cover Category.

Herbage Category (N = 27)	Correlation Coefficient (r)	Regression Equation
Grasses	.50**	Y = 10.0 + .33X
Forbs (N = 24) (includes shrubs)	.89**	Y = 2.69 + .65X
Total Vegetation[1]	.71**	Y = 2.92 + .70X
Litter	.10	Y = 28.50 + .16X
Rock	.36	Y = 2.21 + .48X
Total Ground Cover[2]	.70**	Y = 23.10 + .73X

Critical values of correlation coefficients:
* significant at $p < 0.05$
** significant at $p < 0.01$

1. Total vegetation = Grass + Forb Cover

2. Total Ground Cover = Grass + Forb + Litter + Rock Cover

approached the 0.05 level of significance. The r-values for the various cover categories accurately reflect the relative ease with which these categories could be identified on the aerial photographs. For example, forbs (shrubs were also included in this group) were the most easily and accurately separated, followed by grasses, rock, then litter. The forb (plus shrub) cover graph (Figure 12) accurately reflects two general types of sites studied; one having very low forb/shrub cover and the other type possessing very high forb (alfalfa) cover. The resultant data clustering may have influenced the strength of the forb estimation relationship. The very low r-value resulting from the litter cover estimation is an accurate representation of the difficulty encountered in separating this category from bare soil and other cover categories on the aerial photography.

Elimination of the outliers encircled on Figures 11, 12, 13, 15 and 16 improved the overall fit of the data (r-values) to their respective linear regression equations. The outlier values are also identified in Table 13. Interpreter error was the apparent reason for these anomalous results, since they generally varied across sites; however, site six results were particularly erroneous and were caused by one interpreter's cover overestimates from the aerial photographs. The interpreter's lack of previous photo experience, coupled with a limited amount of available time to contribute, may have caused these poor relative results.

Removal of the influential outliers improved the r-values in the following ways:

1. Grass Cover: $r = 0.76$;
2. Forb Cover: $r = 0.92$;
3. Total Vegetation Cover: $r = 0.84$;

4. Rock Cover: $r = 0.72$; and

5. Total Ground Cover: $r = 0.81$.

The higher sample size (N = 27 by transect) gives greater confidence in these results (cover category, by transect) than those from the previous analysis for individual species by site (N = 9). By squaring the above r-values we obtain the percent of variation in the ground estimate that is accounted for by the aerial estimate. The respective r^2 values are:

1. Grass Cover: $r^2 = 0.58$;

2. Forb Cover: $r^2 = 0.85$;

3. Total Vegetation Cover = $r^2 = 0.71$;

4. Rock Cover: $r^2 = 0.52$; and

5. Total Ground Cover: $r^2 = 0.66$.

Although all of the r-values are significant at $p<0.01$, a subjective evaluation is required to determine whether one is willing to accept the "risk" associated r^2-values.

Two factors should be considered when evaluating the significance of the resultant p- and r-values. These are that: (1) sample size has a direct effect on the p-value (Weisberg 1980) and therefore the significance of the correlation between aerial and ground estimates; and (2) the herbage and ground cover categories were added together to produce the total vegetation and total ground cover categories, thus the r-values of these two larger categories are influenced by the correlation found in their composite subcategories. In other words, the estimation of total vegetation cover is related directly to the estimation of grass and forb cover, and the estimation of the total ground cover is directly related to the estimation of the total vegetation, litter, and rock categories.

The final step in completing the comparison between aerial and ground cover estimates involved the averaging of the three transect values at each site to provide a single value by cover category for each site. This provided representative mean values for each of the nine study sites, and a determination of whether the significance of the calculated r-values in the transect comparisons, were primarily a function of the large sample size or whether they were in fact significant.

Mean cover values by category for both aerial and ground estimates by site produced several changes in the significance of the r-values for the various ground cover categories (Table 15, Figures 17-22). While r-values for forb and total ground cover categories remained highly significant ($p<0.01$), the significance of r for the total vegetation class was reduced ($p<0.05$) and that of the grass class became non-significant at the 0.05 level (Table 16). It should be noted that the grass, rock <u>and</u> litter categories were all marginally non-significant at the 0.05 level, and this should be evaluated with the small sample size (N=9) in mind. With a slightly larger sample size, it is likely that we would conclude that <u>all</u> categories (including litter) might be reliably estimated from large scale CIR aerial photography.

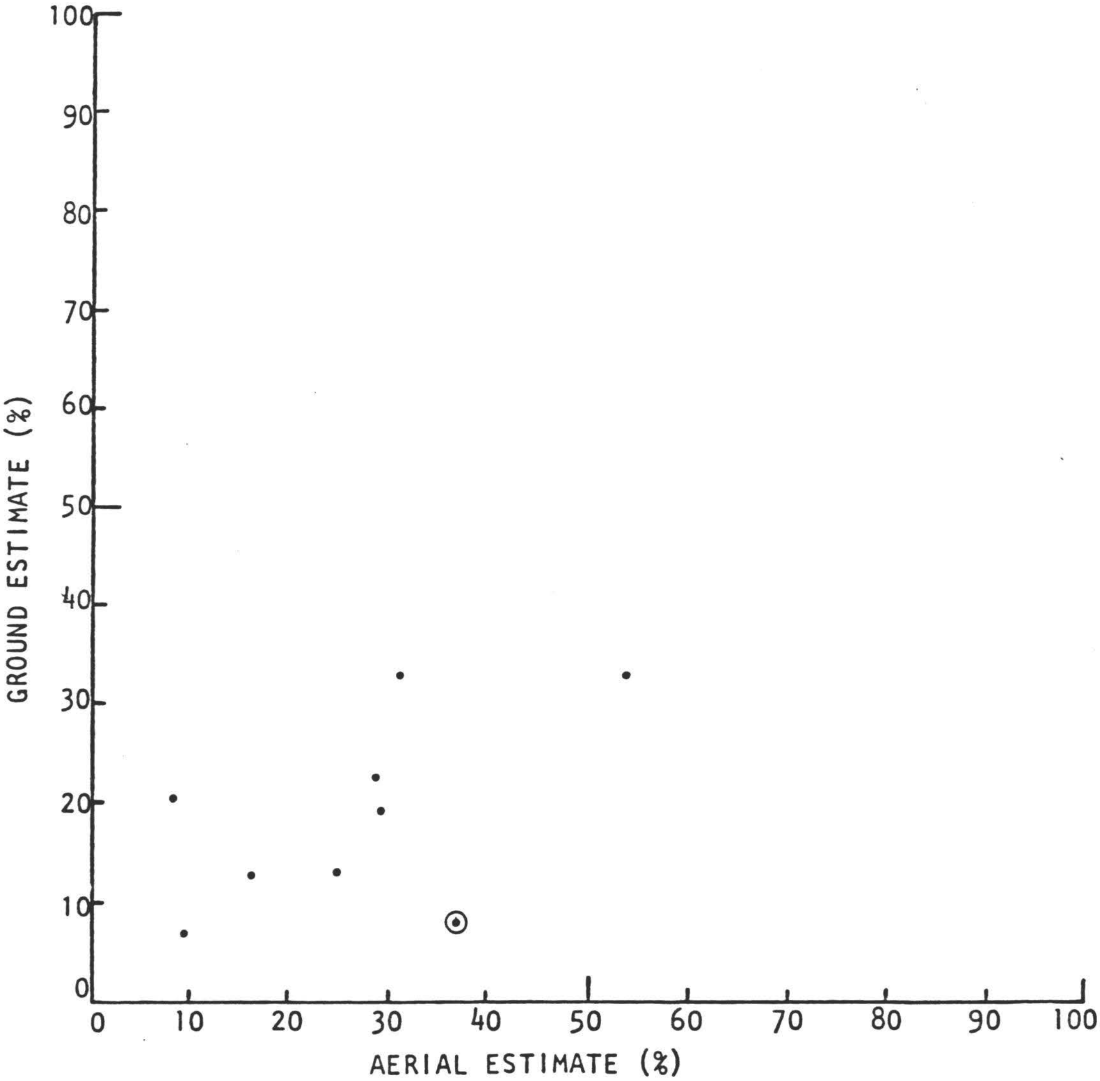
Paired t-tests (Ryan et al. 1976) were also performed on the site data with similar results obtained to the transect analysis. Total vegetation cover was generally overestimated ($p<0.05$), and litter and total ground cover were underestimated ($p<0.05$) from the aerial photography. In contrast to the transect analysis, grass cover

Table 15. Percent Ground Cover by Site for Each Ground Cover Category.

Site Number	Grasses		Forbs		Total Vegetation		Litter		Rock		Total Ground Cover		Bare Soil	
	Ground	Aerial	Ground	Aerial	Ground	Aerial	Ground	Aerial	Ground	Aerial	Ground	Aerial		
1	22.0	28.0	13.0	9.7	36.6	37.7	19.7	19.0	6.0	6.0	62.3	62.7	37.7	37.3
2	32.7	30.7	5.2	7.5	38.7	38.2	37.5	28.2	2.5	2.8	78.7	69.2	21.3	30.8
4	13.5	24.2	8.7	6.8	22.2	31.0	21.5	9.2	5.5	5.7	49.2	45.9	50.8	54.1
5	12.5	15.7	7.0	3.3	19.5	19.0	10.7	12.2	10.0	2.7*	40.2	33.8	59.8	66.2
6	7.3	36.8*	2.7	4.8	11.1	41.6*	52.5	6.3*	2.7	2.3	66.3	50.2	33.7	49.8
7	20.0	7.2	31.3	62.3	52.2	69.5	30.8	12.8	0.7	1.2	83.4	83.5	16.6	16.5
9	6.7	7.7	50.8	53.7	58.7	61.4	28.0	8.0	1.8	0.3	88.5	69.7	11.5	30.3
10	19.3	28.7	5.7	6.7	26.0	35.4	41.7	24.8	0.3	1.0	68.0	61.2	32.0	38.8
12	32.5	53.8	0.0	0.0	32.7	53.8	25.0	7.7	3.5	5.2	61.2	66.7	38.8	33.3

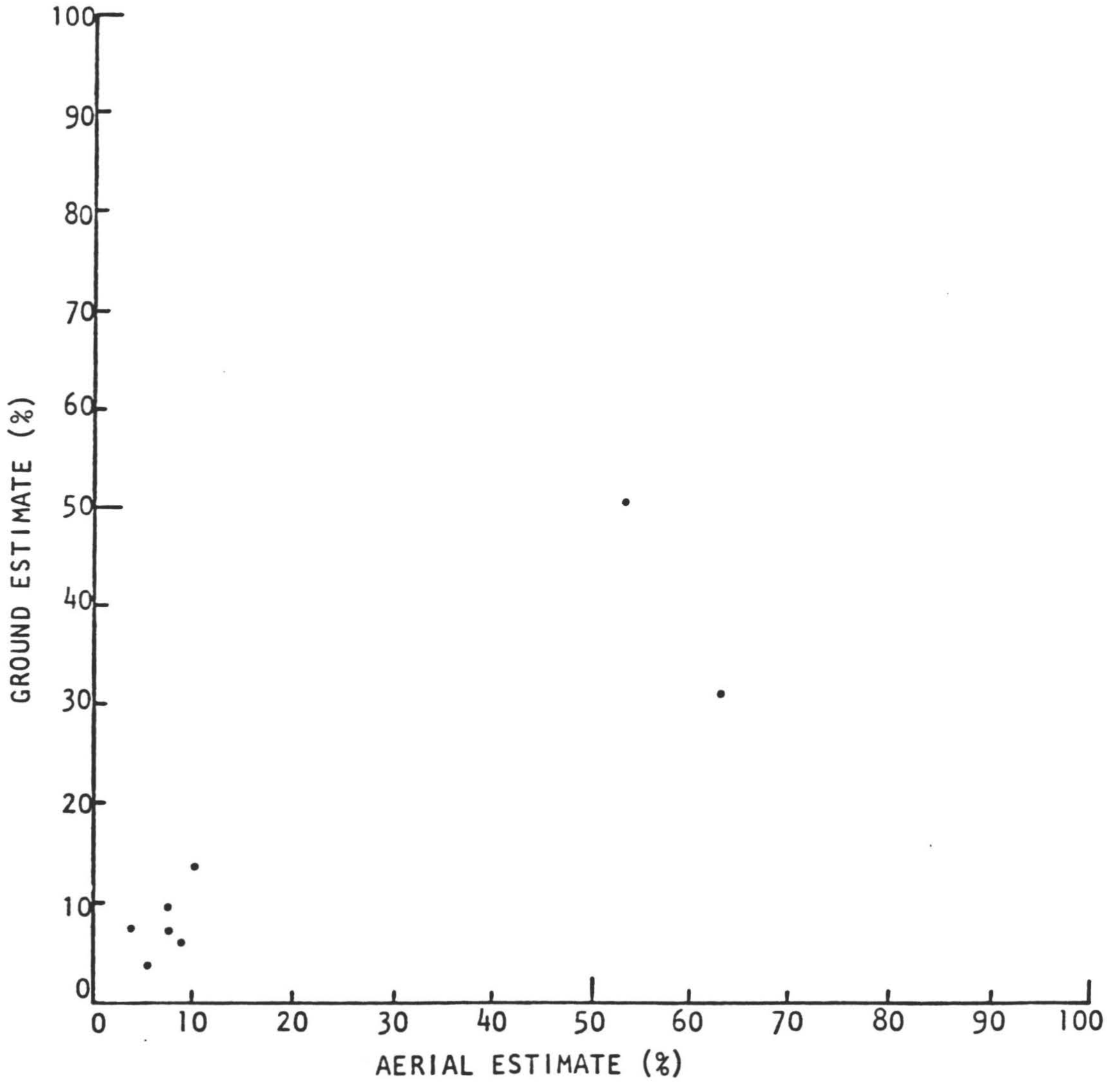
* Outlier data point that has large influence and/or a large standardized residual (Ryan et al. 1976).

Figure 17. Grass Cover by Site.



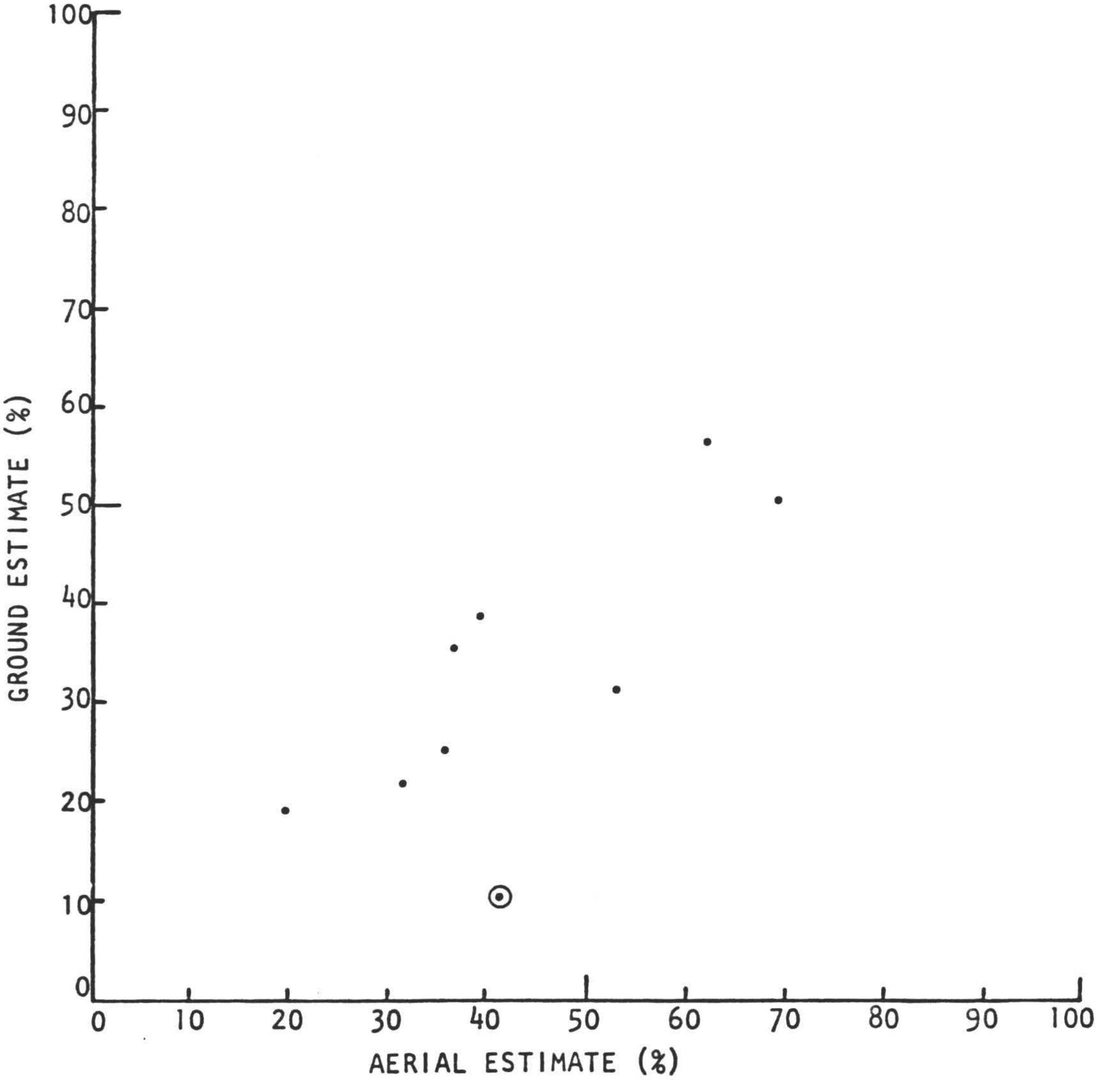
(N = 9; r = .54; α (2) p <0.10)

Figure 18. Forb Cover by Site.



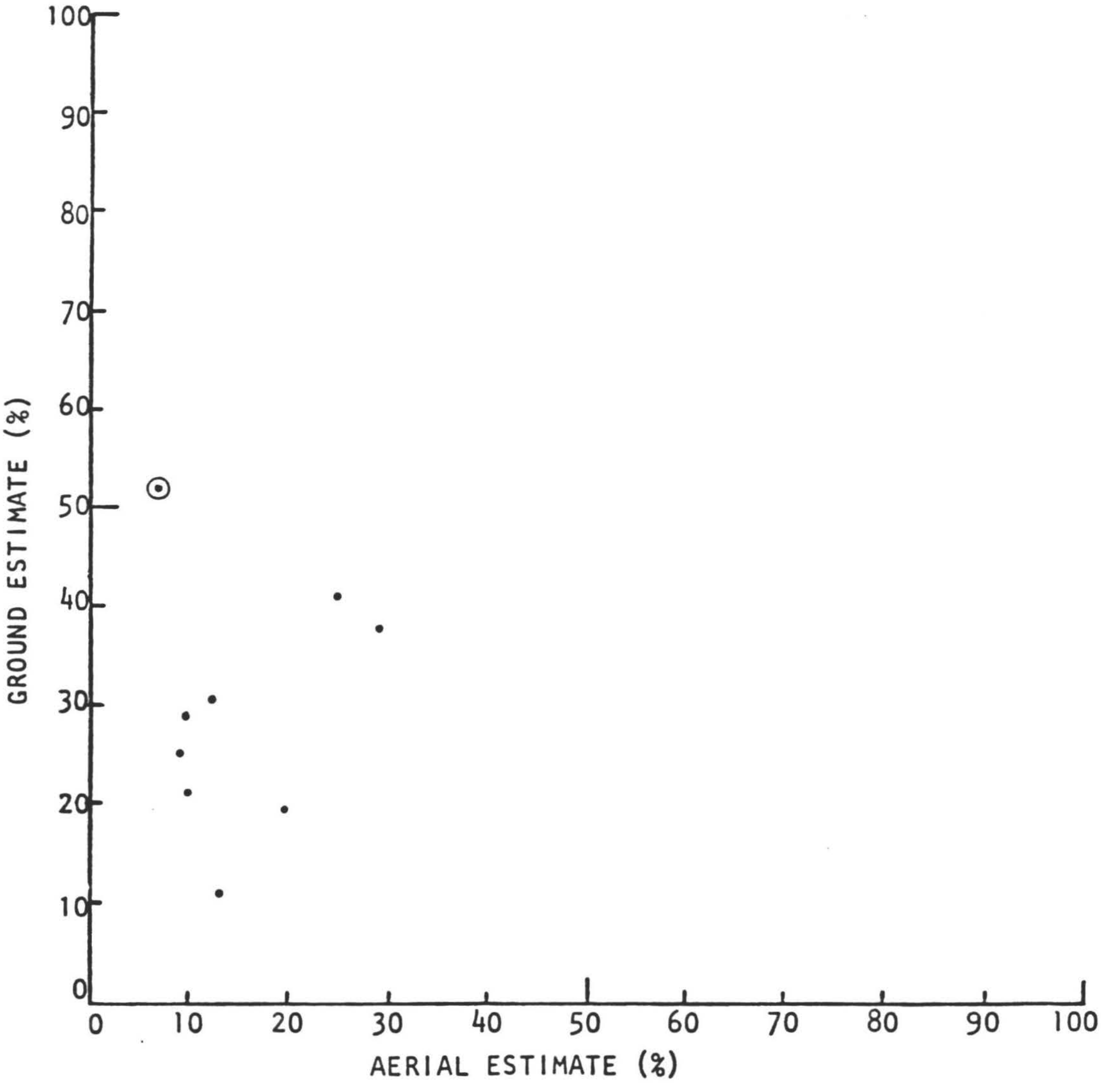
(N = 8; r = .91; α (2) p <0.001)

Figure 19. Total Vegetation Cover by Site.



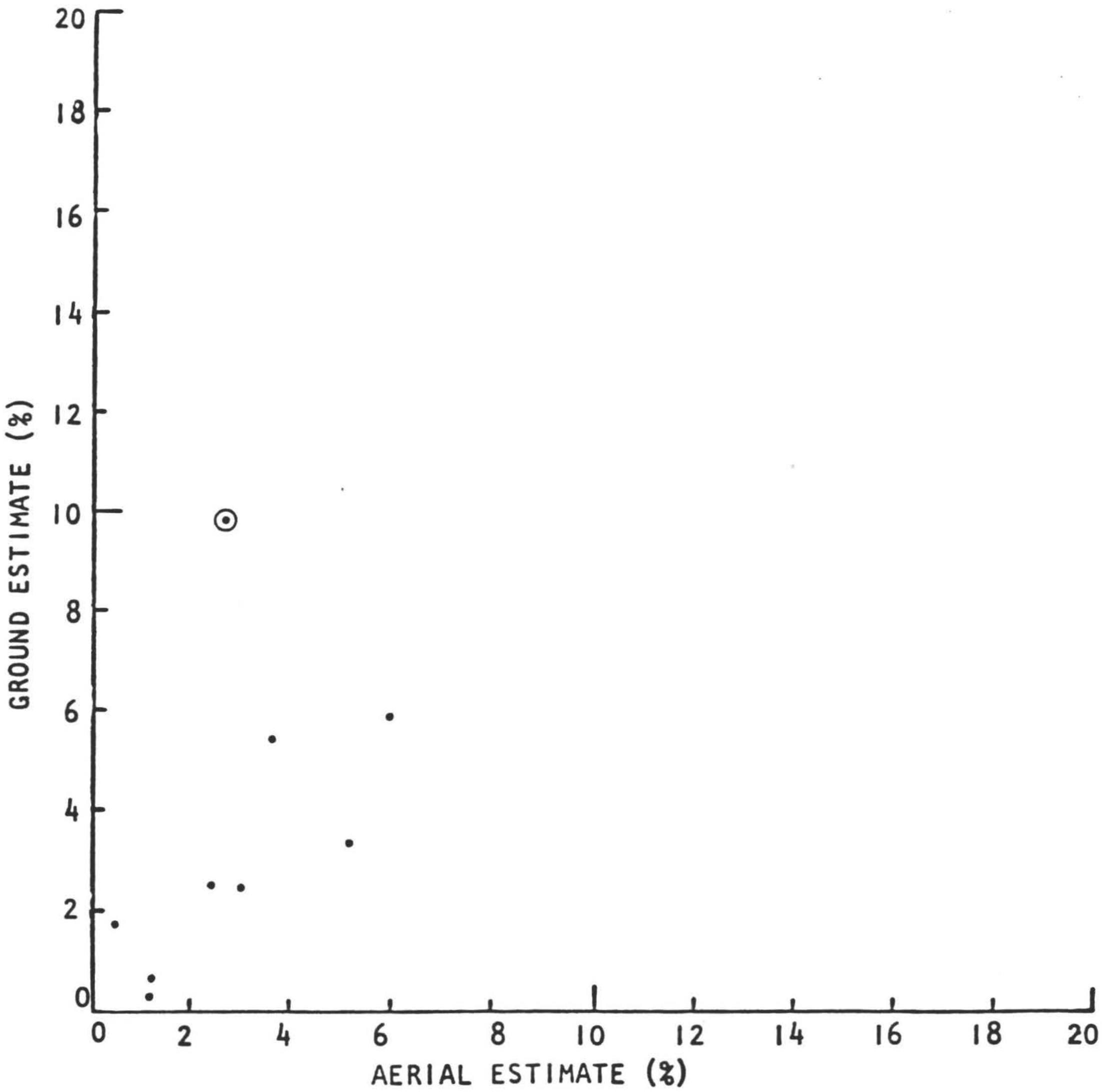
(N = 9; r = .75; α (2) p <0.02)

Figure 20. Litter Cover by Site.



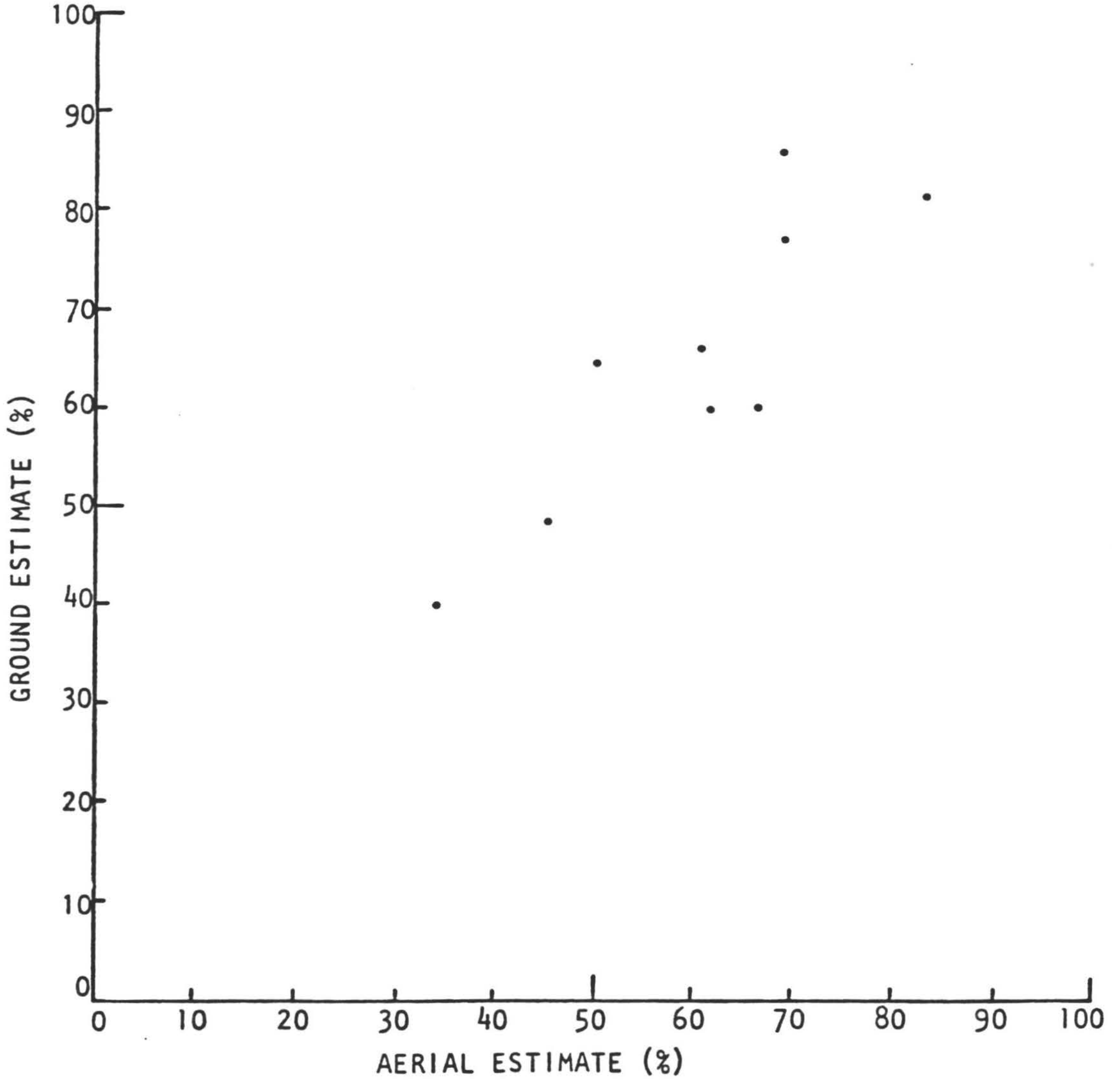
(N = 9; r = .16; Not Significant)

Figure 21. Rock Cover by Site.



(N = 9; r = .53; α (2) p <0.20)

Figure 22. Total Cover by Site.



(N = 9; r = .87; α (2) p <0.002)

Table 16. Correlation and Regression Values of Aerial Estimates (X) and Ground Estimates (Y) by Site for Each Ground Cover Category.

Herbage Category (N = 27)	Correlation Coefficient (r)	Regression Equation
Grasses	.53	Y = 9.45 + .35X
Forbs	.91**	Y = 2.68 + .65X
Total Vegetation[1]	.75*	Y = 1.28 + .72X
Litter	.50	Y = 26.10 + .25X
Rock	.53	Y = 1.36 + .76X
Total Ground Cover[2]	.87**	Y = 11.30 + .90X

Critical values of correlation coefficients:
* significant at $p < 0.05$
** significant at $p < 0.01$

1. Total vegetation = Grass + Forb Cover

2. Total Ground Cover = Grass + Forb + Litter + Rock Cover

estimates were similar ($p>0.05$) to the corresponding ground estimates on a site basis. Forb and rock cover estimates were not significantly different between aerial or ground perspectives.

Influential outlier data points also occurred with the analysis by site. The inconsistency in air photo estimation of cover by interpreter D, produced a set of inaccurate data for the transects at study site six (Table 15). This type of erroneous data, which drastically influenced the strength of the aerial-ground relationships, might have been avoided by using the same observer for all point line estimates. In this way, a consistency in data points could have been obtained with the benefit of additional experience in using the point line method for estimating cover.

Removal of these outliers improved the relationships as follows:

1. Grass Cover: $r = 0.76$ ($r^2 = 0.58$);
2. Total vegetation cover: $r = 0.87$ ($r^2 = 0.76$);
3. Litter cover: $r = 0.60$ ($r^2 = 0.36$); and
4. Rock cover: $r = 0.91$ ($r^2 = 0.83$).

The r-values for forb cover and total ground cover categories remained the same as those in Table 16, since influential outliers were not present. The effectiveness of cover estimation from the aerial perspective can thus be subjectively evaluated from these r-values, based on the risk one is willing to take, or the level of accuracy required for a given study.

D. Time and Cost Analysis

This section deals with the analysis and comparison of costs incurred during both the field and aerial surveys of ground cover. The following table represents an attempt to provide an estimate of what each type of survey would cost, so that an approximate cost-benefit analysis could be completed.

The approximate total costs are very similar for both the ground and aerial surveys. While the ground cover information available from the aerial method is somewhat lower, this survey method becomes more attractive with an increase in the number of sample sites required for a survey, and also when an accurate spatial perspective (map) and a permanent visual record of conditions is desirable.

Table 17. Time and Cost Comparison between Aerial and Field Survey Methods.

Field Survey		Aerial Survey	
1. Gas for 4 field vehicles	$30.00	1. Cessna 185 for 5 hrs. @ $90.00/hr.	$ 450.00
2. N/A		2. Photographer Charges which included: $329.00 for photographer's return flight from Reno, Nevada to Denver, Colorado. - 1 30 m roll Kodak 2448 color film @ $175.00 purchase price - 1 30 m roll Kodak 2443 CIR film @ $175.00 purchase price - developing for color film was $125.00 and that for CIR film $125.00. - photographer's services were thus = $360.00	1,289.00
3. N/A		3. Ground Markers which included: - 3 28 m rolls of 46 cm wide butcher paper @ $20.00/roll - 550 40 cm long surveyor stakes	140.00

Table 17. Concluded.

Field Survey		Aerial Survey	
		- 100 lath strips	
		- and all other materials for ground marking (pie plates, nails, string, paint, etc.)	
4. N/A		4. Ground Marker Layout: 2-8 hrs/day @ $7.00/hr. for 2 people (approximately 1 hr./transect actual layout time)	224.00
5. Point Frame Equipment N/C		5. Point Line Equipment (assumed equal) N/C	
6. 12 people for 3 8 hr. days @ $7.00/hr.	$2,016.00	6. 6 people for a total of 60 hrs. @ $7.00/hr	420.00
(approximately 1 min./ point frame)		(approximately 30 sec./point line)	
(approximately 20 min./ 100 m Transect		(approximately 35 min./100 m Transect)	
Total Cost Field Survey	$2,046.00	Total Cost Aerial Survey	$2,423.30

VI. SUMMARY AND CONCLUSIONS

A. Summary

This study was designed to evaluate the utility of large scale, 70 mm color and color infrared aerial photography for plant species identification and ground cover estimation on revegetated coal-mined lands.

The study area was flown on one date only, July 17, 1980, due to budget limitations. A plant species identification key and point method for estimating ground cover were developed for the 1:600 scale photography. Six volunteer photo interpreters were used to provide a range of values on the feasibility of using air photos to identify plant species at twelve revegetated study sites. After key testing, each photo interpreter conducted an estimate of ground cover by species and herbage category using a "point line" grid overlay on the color infrared photography. These estimates were then compared statistically to point frame cover estimates that were made on the ground at the time of overflight.

Results indicated that all photo interpreters could readily (>80% correct with varying sample sizes) identify Kentucky bluegrass, yellow sweet clover, alfalfa, knotweed, and Russian thistle due to their unique crown shapes, textures, shadows and/or spectral signatures. In addition, other common herbaceous species including intermediate wheatgrass, crested wheatgrass, thistle and summer cypress could often (<65% correct) be identified. All life forms (grasses, forbs, shrubs) could be separated from each other, although a higher error of comission was evident between forbs and shrub seedlings. A statistical comparison (Friedman Index) between the six photo interpreters tested indicated that familiarity with the vegetation and/or study area, or previous experience with small scale black and white and CIR photography did not significantly ($p>0.05$) improve their abilities to correctly identify the dominant plant species present.

Statistical comparisons were made between ground and aerial estimates of dominant plant species cover and of various more general ground cover categories. Paired t-tests were used to identify significant trends in over or underestimation of cover from the aerial perspective. Linear regression-correlation was used to assess the accuracy of the aerial esimates.

The paired t-tests by species indicated that the aerial estimates of the three dominant grasses (smooth bromegrass, intermediate wheatgrass and crested wheatgrass) were significantly higher ($p<0.05$) than their corresponding ground estimates, while the alfalfa estimates were not significantly different ($p>0.05$). The regression analysis showed that the cover by species for three dominant grasses could not be estimated from the aerial photos using the line point technique. In contrast to this, good results ($r^2 = 0.85$) were obtained for alfalfa cover estimation from the large scale CIR aerial photographs.

Aerial estimation of the various herbage (grasses, forbs plus shrubs, total vegetation) and other ground cover categories (rock, litter, total ground cover) yielded good results both on transect and site bases. Paired t-tests showed that grass cover and total vegetation cover were generally overestimated ($p<0.05$), while litter and total ground cover were underestimated ($p<0.05$). Forb (plus shrub) and rock cover air photo estimates were not significnatly ($p>0.05$) different from the corresponding ground estimates. Regression analyses indicated that forb cover was generally the most reliably estimated cover category, followed by total vegetation and total ground cover. Removal of influential outlier data points improved the relationships for grass and rock cover estimation. Litter cover could not be reliably estimated from the large scale CIR aerial photographs.

A time and cost analysis indicated that the aerial and ground surveys costs were similar for the present study, although less ground cover information was available from the aerial photography.

B. Conclusions

The point frame method was effectively and rapidly employed on the field to obtain estimates of vegetation and other categories of ground cover.

Ground markers established at the time of the field survey were light, inexpensive and easily installed to aid in the acquisition of the aerial photography for this study.

The 70 mm large scale color and color infrared (CIR) aerial photography was acquired at "peak" vegetation growth; this allowed for the successful identification of nine important herbaceous species, and the characterization of numerous additional species found on the reclaimed areas. CIR was considered superior to normal color photography for species identification. Small transplanted (<15 cm height) shrub seedlings could not be separated according to species and were often mistaken for forbs.

An evaluation of individual and grouped photo interpreter results indicated that knowledge of the vegetation and the specific study area did not improve the ability of the interpreters to correctly identify the ground marked plant species. Similarly, previous (though limited) photo interpretation experience did not improve the success in plant species identification from the CIR photography. This would also indicate that an adequate photo interpretation key was prepared, and emphasis should be placed on the key when completing such species identification tasks.

As with the point frame method, the point line photo interpretation technique was rapidly learned and objectively employed by the photo interpreters to obtain accurate estimates of alfalfa, forbs plus shrubs, total vegetation and total ground cover categories; marginally accurate estimates of grass and rock cover were also obtained. Improved success is likely with repeated use and further refinement of the technique. Further refinement might include a further reduction of the point size, spacing or locational technique in relation to the corresponding ground point.

While the total costs for ground and aerial surveys were similar, the ground cover information available from the aerial photography was lower; primarily due to lower species differentiation and litter cover estimation capabilities. However, the use of the aerial survey would become attractive where a larger number of sample sites or a larger study area are to be studied, when an accurate spatial representation of ground cover is required and where a permanent record of conditions is beneficial. A permanent visual record is invaluable for monitoring revegetation success. Also, the rapid access of data is important to avoid effects of phenological confounding. More efficient year-round utilization of manpower could also be realized by using aerial photo interpretation in the winter to complement informaiton gathered on the ground during the previous growing season. Finally, government regulatory requirements should be closely examined to determine whether the growth form information available from the aerial photography (cover by form) is sufficient, provided that life forms present represent acceptable species.

VII. FUTURE RESEARCH

As a result of this study, a number of questions have arisen that must be reserved for future research. A study that examines all possible uses of aerial photography for mined land reclamation and revegetation analyses would be the ideal. However, it is likely that such a study would be made impossible due to time, budget and technical limitations. Therefore, numerous studies dealing with individual pieces of the land reclamation puzzle will be required to realize all applications of aerial photography. Studies designed to evaluate various film types, scales and dates for surveying pre- and post-mine vegetation types are required.

This study has demonstrated aerial photo applications for pre- and post-mine vegetation analyses. Further research is required to determine the optimum flight date to maximize on phenological differences between species for species identification purposes. Phenologies of the dominant species should be the major consideration in deciding upon the date of overflight, particularly where herbaceous species are to be studied. Further refinement and testing of the point line method for estimating cover is suggested, with various dot sizes and spacings tested. It is recommended that post-mine shrub identification aerial surveys not be carried out prior to the time when the shrubs reach an average height of 30 to 60 cm such that they can be differentiated from forbs. A fall survey would also provide for maximum phenological differentiation between shrubs and forbs.

Ground markers utilized for this project were generally of excellent utility, however an evaluation of new methods to accurately identify transects and/or individual markers is required. Larger black numbers (>5cm wide) and/or different colored markers (with a knowledge of what color they will appear as on CIR film) are recommended.

Further applications for remote sensing will be found in estimating other plant variables (such as phytomass), detecting and quantifying erosion, and monitoring many other aspects of mined land reclamation. It should be realized that while remote sensing is a valuable tool for natural resource work, it does have its limitations.

A number of general observations about experimental procedures would be of benefit to other researchers. Of prime importance is the aspect of experimental planning. It is vital to identify the goal or overall objective of the research, and then work back from this through the statistical methods proposed to ensure that the results will answer the stated hypotheses. In this manner, the researcher will identify the best statistical method to employ, with particular emphasis placed on the kind (count, ordinal, interval) and distribution (normal, binomial, poisson) of the raw data collected. Sample size is a very important factor to consider and may be determined statistically, but more often is limited by available budget or time. Large sample sizes are often, but not always, preferrable for parametric analyses. Non-parametric statistics should not be discounted, as they provide many similar (to parametric) analytical results, and are less dependent on the kind, distribution and sample size of the data. Finally, a literature review and a preliminary field sampling program are essential initial steps toward developing a sound research design and ultimately the successful project completion.

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IX. APPENDICES

APPENDIX A

Plant Species Identification

Keys and Descriptors

Table 18. Pre-Mine Plant Species and Ground Cover Identification Key

1. Plant greater than 60 cm in height.

   Shadow distinct; wavy margin; round to uneven shape; clumpy pattern; medium to coarse texture; grayish yellow green (122).
   ....*Artemisia tridentata tridentata*.

1. Plant less than 60 cm in height.

   2. Plant greater than 30 cm high

      3. Shadow distinct or indistinct; smooth to wavy margin; round shape; continuous pattern; fine to medium texture; dark grayish yellow (91) to light olive brown (94).
      ....*Artemisia tridentata arbuscula*.

      3. Large leaves visible, shadow indistinct; irregular margin; uneven shape; continuous pattern; mottled; grayish reddish orange (39) mottled with light yellow green (119).
      ....*Wyethia amplexicaulis*.

   2. Plant very low (less than 30 cm).

      3. Color orangish: indistinct shadow; broken margin; indistinct shape; continuous pattern; fine to medium texture; strong reddish orange (35) to brownish orange (54).
      ....Herbaceous cover (grasses, forbs).

      3. Color not orangish, but greenish or yellowish.

         4. Color grayish greenish yellow (105); no height or shadow; broken margin; continuous pattern; fine texture.
         ....Litter.

         4. Color pale yellow green (121); no height; fine texture.
         ....Bare soil.

Table 19. Post-Mine Plant Species Identification Key

1. Plants tall (greater than 60 cm in height).

    2. Crown sparse; shadow indistinct; broken crown margin; crown shape indistinct; irregular foliage pattern; medium to coarse texture; dark yellowish pink (30) to deep reddish orange (36) with yellowish white mottling (92) on color infrared; brilliant yellow (83) on color.
    ....*Melilotus officinalis*.

    2. Crown dense, shadow distinct.

        3. Very distinct spire shaped shadow; very rough crown margin; round crown shape; continuous foliage pattern; medium texture; deep reddish orange (36) on color IR; dark yellowish green (137) on color.
        ....*Cirsium* spp.

        3. Shadow not spire shaped but is round or irregular; wavy crown margin; continuous foliage pattern; fine to medium texture; strong red (12) to dark red (16) or dark reddish orange (38); and commonly mottled with pale orange yellow (73).
        ....*Medicago sativa*.

1. Plants not as tall (less than 60 cm in height).

    2. Plants medium height (less than 60 cm but greater than 30 cm high).

        3. Very obvious, round elevated yellowish white (92) flowers; indistinct shadow; irregular or broken crown margin; indistinct crown shape; irregular foliage pattern; fine texture; vivid red (11) with yellowish white (92) flowers on color IR.
        ....*Heleomeris multiflora*.

        3. Elevated flowers not present.

            4. Spire shaped, distinct shadow; very rough crown margin; round crown shape; continuous foliage pattern; medium texture; deep reddish orange (36) on color IR.
            ....*Cirsium* spp.

            4. Shadow not spire shaped, distinct or indistinct shadow.

                5. Color light orange or yellow (52, 70, 71, 89, 104).

                    6. Color pale yellow (89), pale greenish yellow (104), or rarely moderate orange yellow (71);

Table 19 Continued.

shadow distinct or sometimes indistinct; wavy to irregular crown margin; round to uneven crown shape; clumpy to continuous foliage pattern; coarse texture (erect seedheads are commonly visible).
....................<u>Agropyron</u> <u>intermedium</u>.

6. Color light orange (52) with light orange yellow (70) or dark greenish yellow (103), long seedheads visible; shadow may be distinct or indistinct; irregular to wavy crown margin; uneven crown shape; clumpy foliage pattern; coarse texture.
....................<u>Bromus</u> <u>inermis</u>.

5. Color not light orange or yellow.

6. Shadow distinct; wavy crown margin; uneven crown shape; clumpy foliage pattern; medium texture; strong red (12) to dark red (16) or dark reddish orange (38), commonly mottled (73).
....................<u>Medicago</u> <u>Sativa</u>.

6. Shadow indistinct (or very small); plant spreading; irregular or rough margin; uneven crown shape; continuous foliage pattern; fine texture; strong reddish brown (4) or strong brown (55) on color IR.
....................<u>Salsola</u> <u>kali</u>.

2. Plants very short (less than 30 cm high).

3. Plant prostrate, very low growing, no obvious crown height; shadow always indistinct.

4. Moderate yellow green (120) on color IR; irregular or rough crown margin: uneven crown shape; continuous foliage pattern; fine texture.
..........................<u>Poa</u> <u>pratensis</u>.

4. Color not medium yellow green.

5. Deep reddish orange (36); irregular crown margin; indistinct crown shape; continuous foliage pattern; fine texture; flat topped plant crown.
.......................<u>Penstemon</u> <u>strictus</u>.

5. Grayish reddish orange (39) or moderate orange (53); mat-like, spreading, very low-growing plant; rough crown margin; round to uneven crown shape; continuous foliage pattern; fine to hazy texture.
.......................<u>Polygonum</u> sp.

3. Crown height is discernible, shadows may be present or absent.

Table 19 Continued.

4. Shadow distinct.

  5. Color light orange or yellow (52, 70, 71, 89, 104).

    6. Color pale yellow (89), pale greenish yellow (104), or rarely moderate orange yellow (71); shadow distinct or indistinct; wavy to irregular crown margin; round to uneven crown shape; clumpy to continuous foliage pattern; coarse texture; erect seedheads commonly visible.
    ....Agropyron intermedium.

    6. Color light orange (52) with light orange yellow (70) or dark greenish yellow (103) long drooping seedheads visible; shadow may be distinct or indistinct; irregular to wavy crown margin; uneven crown shape; clumpy foliage pattern; coarse texture.
    ....Bromus inermis.

  5. Color not light orange or yellow.

    6. Shadow linear, lumpy; crown clumpy.

      7. Rough crown margin; indistinct crown shape; clumpy foliage pattern; coarse texture; light reddish brown (42) or grayish reddish orange (39).
      ....Populus angustifolia.

      7. Wavy crown margin; indistinct crown shape; clumpy foliage pattern; medium texture; moderate reddish orange (37) or dark reddish orange (38).
      ....Prunus virginiana.

    6. Shadow not linear and lumpy.

      7. Shadow round, small plants.

        8. Color light reddish brown (42) and medium olive green (125) mottled; smooth to wavy crown margin; round to uneven crown shape; clumpy foliage pattern; fine texture.
        ....Artemisia tridentata.

        8. Color deep redish orange (36) mottled with moderate yellowish pink (29); smooth crown margin; round crown shape; medium or fine texture.
        ....Symphoricarpos oreophilis.

Table 19 Concluded.

7. Shadow not round (may be just barely distinguishable), medium or small plants; rough or irregular crown margin; hazy texture; moderate reddish orange (37). ....*Sanguisorba minor*.

4. Shadow indistinct.

5. Seed stalks visible; plant light orange yellow (70); wavy to irregular crown margin; indistinct crown shape; irregular folliage pattern; medium texture. ....*Dactylis glomerata*.

5. Seed stalks not visible, plant not yellow or orange.

6. Plant dark greenish yellow (103) to deep yellow green (118); wavy or irregular crown margin; indistinct crown shape; fine or hazy texture. ....*Agropyron cristatum*.

6. Plant not greenish.

7. Crown shape oblong, or if not, then distinct, (round topped); clumpy pattern; medium texture; deep yellowish pink (27) or dark yellowish pink (30). ....*Phleum pratense*.

7. Crown shape indistinct; crown margin smooth.

8. Texture hazy; continuous foliage pattern; strong yellowish pink (26) or light yellowish pink (28). ....*Caragana arborescens*.

8. Texture medium; continuous foliage pattern; dark reddish orange (38) with moderate yellowish pink (29) mottling. ....*Astragalus cicer*.

Table 20. Species Identification Keys Descriptor Form Definitions

1. Estimated Plant Height:

   a. less than 30 cm - low, prostrate plant, no obvious height.
   b. greater than 1 foot but less than 60 cm - plant of average height on reclaimed area.
   c. greater than 60 cm - tall plant, often with a long distinct shadow.

Plant heights were estimated by completing a three dimensional judgement as seen through stereoscopic viewing, and also through examination of the plants' shadow.

2. Shadow Characteristics:

   a. distinct - shadow cast by plant is present and relatively clear and obvious.
   b. indistinct - shadow is absent or, if present, very weak and hazy.

Shadow shape and length also provides clues for species identification.

3. Crown Margin: (outermost edge of the plant):

   a. smooth - outermost margin of the plant's crown has few of no irregularities or indentations.
   b. wavy - crown margin has regular, smooth indentations.
   c. irregular - coarse, jagged indentations.
   d. rough - numerous small, jagged indentations giving an uneven appearance to the plant's edge.
   e. broken - the margin of the plant is not contiguous, it has no apparent pattern.

4. Crown Shape: (the overall appearance of the plant):

   a. indistinct - no apparent plant shape, resulting from fine foliage and flowers and a very sparse canopy.
   b. round - overall plant shape is circular, showing no irregularities in its form.
   c. oblong - gross appearance of the plant is elongated along an axis to produce an oblong form.
   d. uneven - the plant has a spreading irregular shape with several random growth extensions.

5. Foliage Pattern: (gross foliage appearance within the crown):

   a. continuous - a solid cover of foliage with very few or no gaps.
   b. clumpy - the foliage exhibits an obvious contagious distribution within the crown, producing several distinct groups.
   c. irregular - the foliage is neither continuous or clumpy within the crown, but rather randomly aggregated or sparse.

Table 20 Concluded.

6. Texture: (appearance of the individual foliar components within the crown; not a function of aggregation)

    a. Fine - very tiny dot like appearance, resulting from small leaves or flowers on the plant.
    b. Medium - larger, more distinct foliar components (than fine).
    c. Coarse - very large leaves or flowers that appear obviously as such.
    d. Stippled - a combination of dots (flowers, seedheads) and lines (leaves, branches) obvious within the crown.
    e. Hazy - no apparent texture.

7. Color Designation: (number drawn from ISSC - National Bureau of Standards Color Book).

    a. NBS number - number of color or colors which appeared dominant in the crown.
    b. Mottling - number of color or colors which appeared to a lesser degree within the crown.

APPENDIX B

Reclamation Maps of Study Sites
From 1:10 000 Scale Color and Color
Infrared Aerial Photography
(Approximate Map Scales = 1:6,250)

Table 21. Legend For Reclamation Maps of Study Sites.

A	aspen vegetation
B	building
BS	big sagebrush vegetation
CC	cover crop (annual grass)
EP	experimental plots
GS	graded minespoils
LS	low sagebrush vegetation
MS	mountain shrub vegetation
R	road
RV	revegetated area (perennial grasses, forbs, shrubs) a - dense alfalfa cover d - dense vegetative cover (not only alfalfa) s - sparse vegetative cover
T	transplanted trees and shrubs
TS	topsoil stockpile
US	ungraded minespoils
W	water
WM	wet meadow
	feature type boundary
	study site location and number
	rill erosion

Figure 21. Reclamation Map of Study Sites 1 and 2.

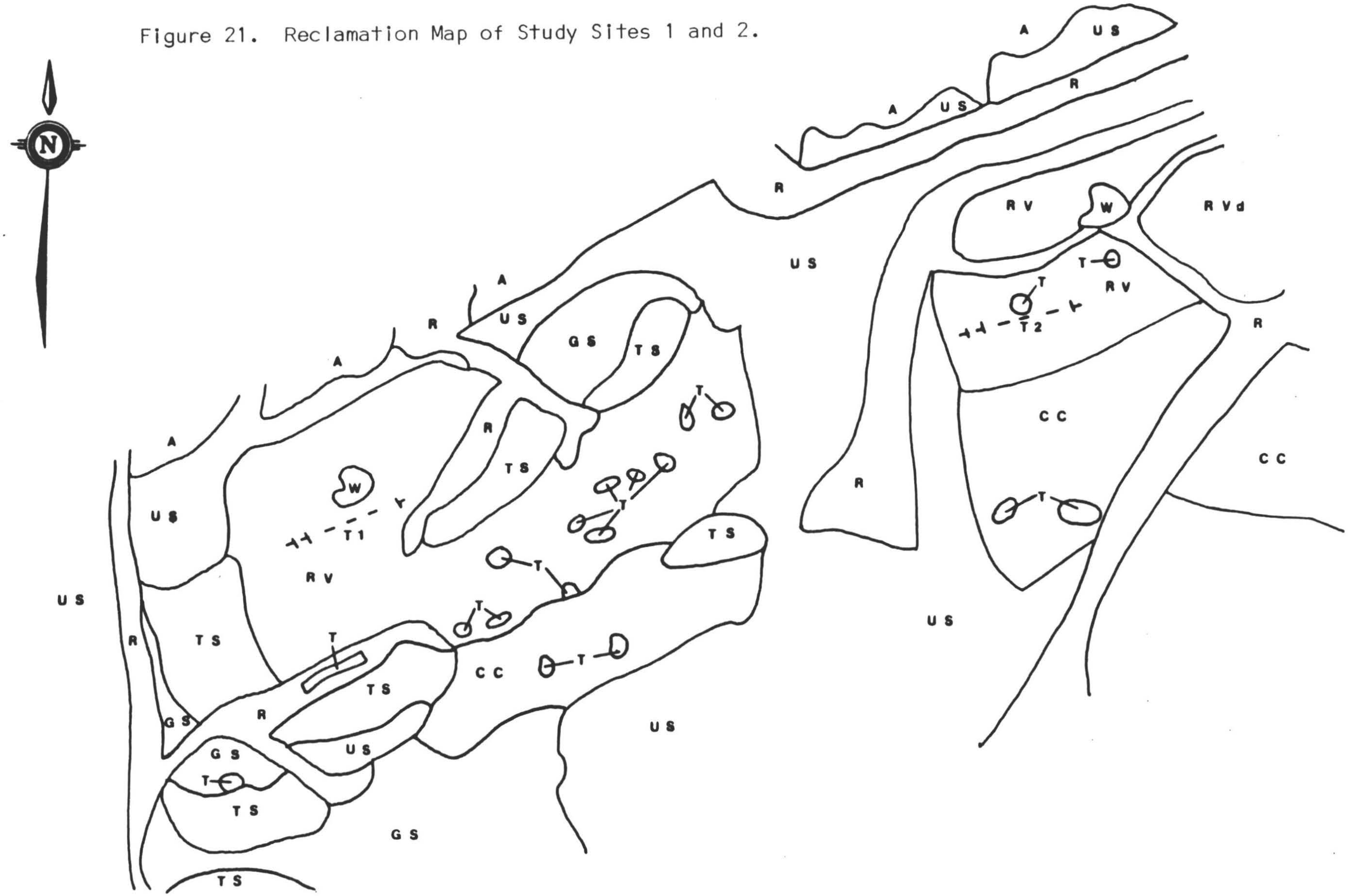


Figure 22. Reclamation Map of Study Sites 2 and 3.

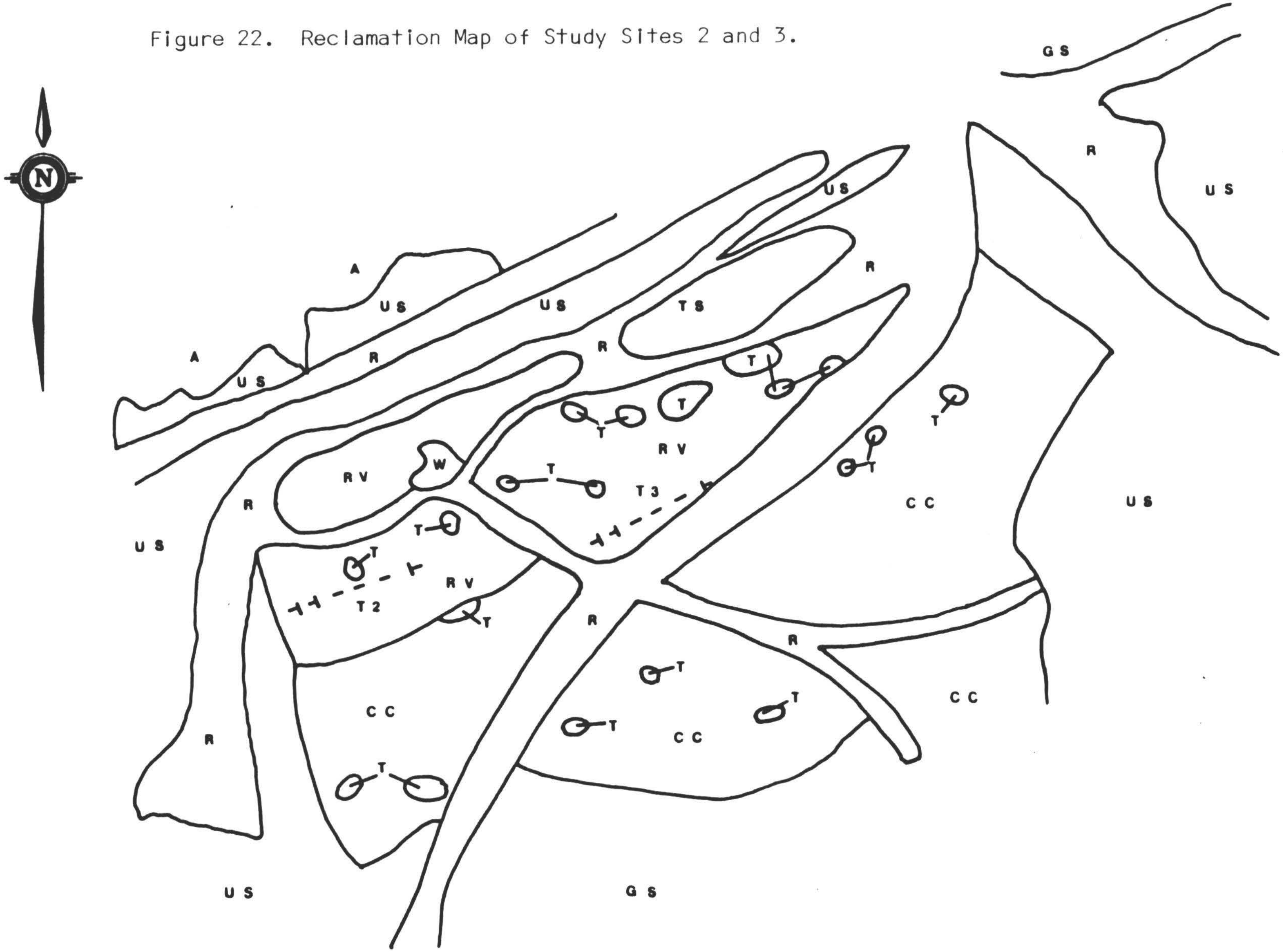


Figure 23. Reclamation Map of Study Site 4.

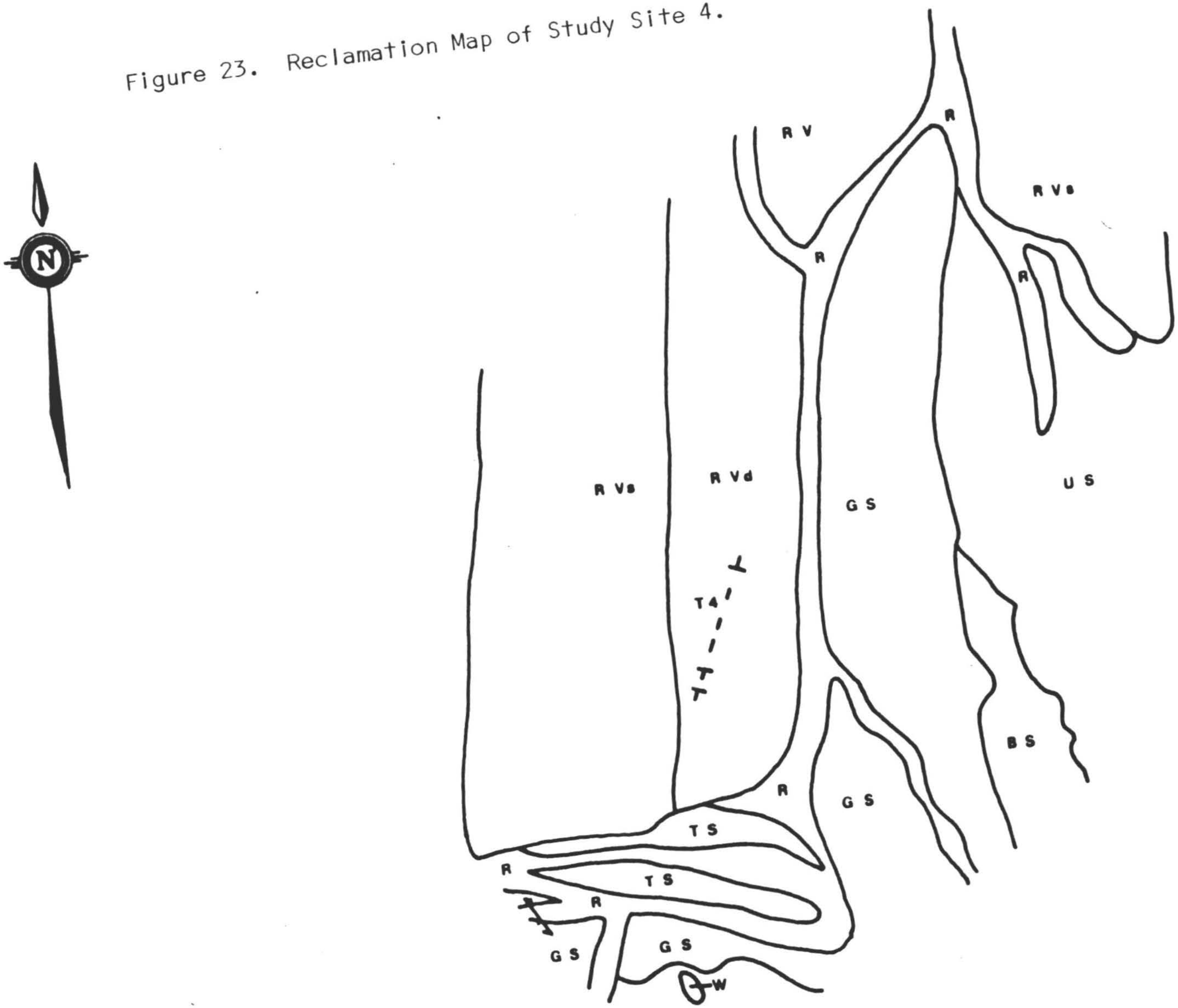


Figure 24. Reclamation Map of Study Site 5.

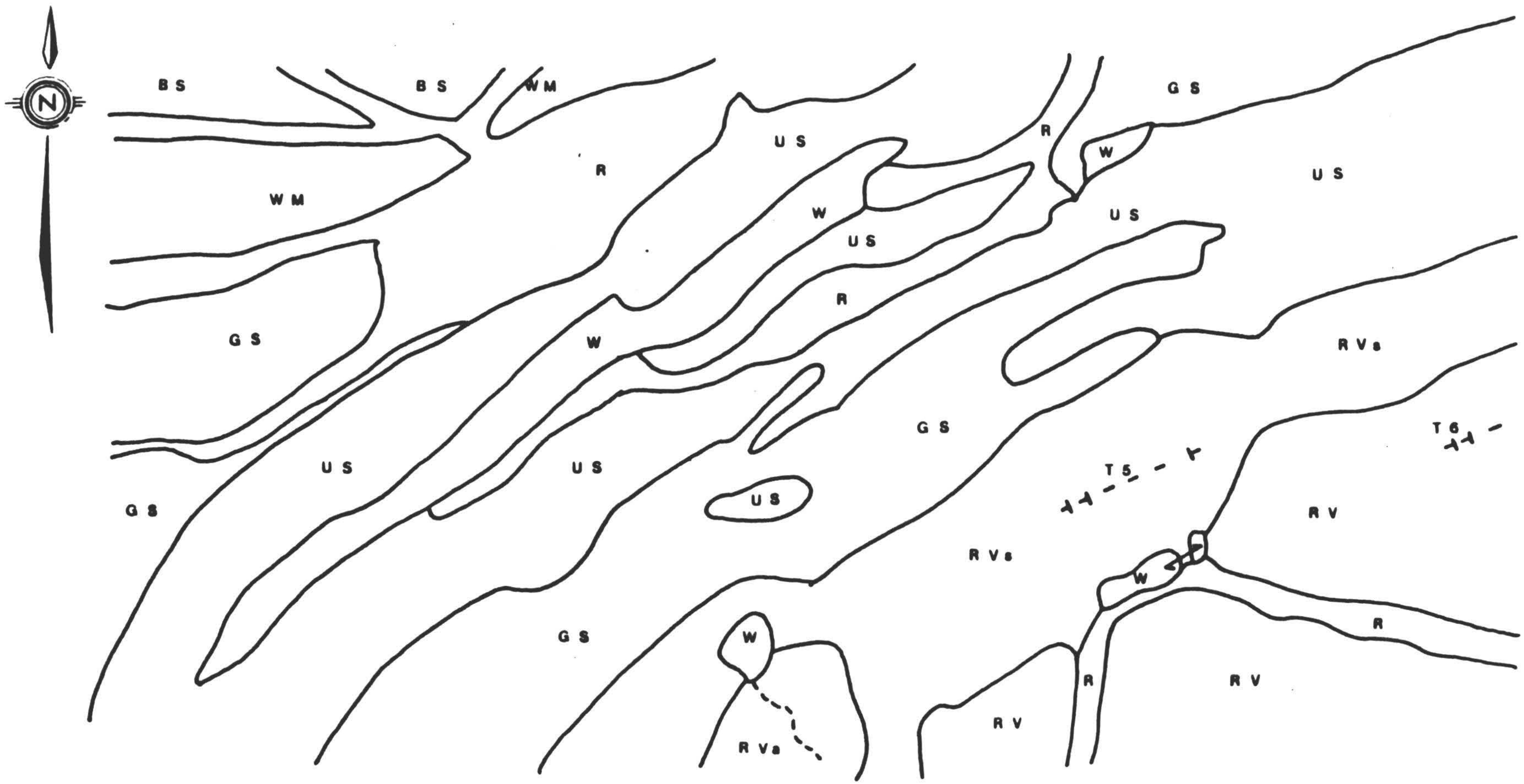


Figure 25. Reclamation Map of Study Site 6.

Figure 26. Reclamation Map of Study Site 7.

Figure 27. Reclamation Map of Study Site 8.

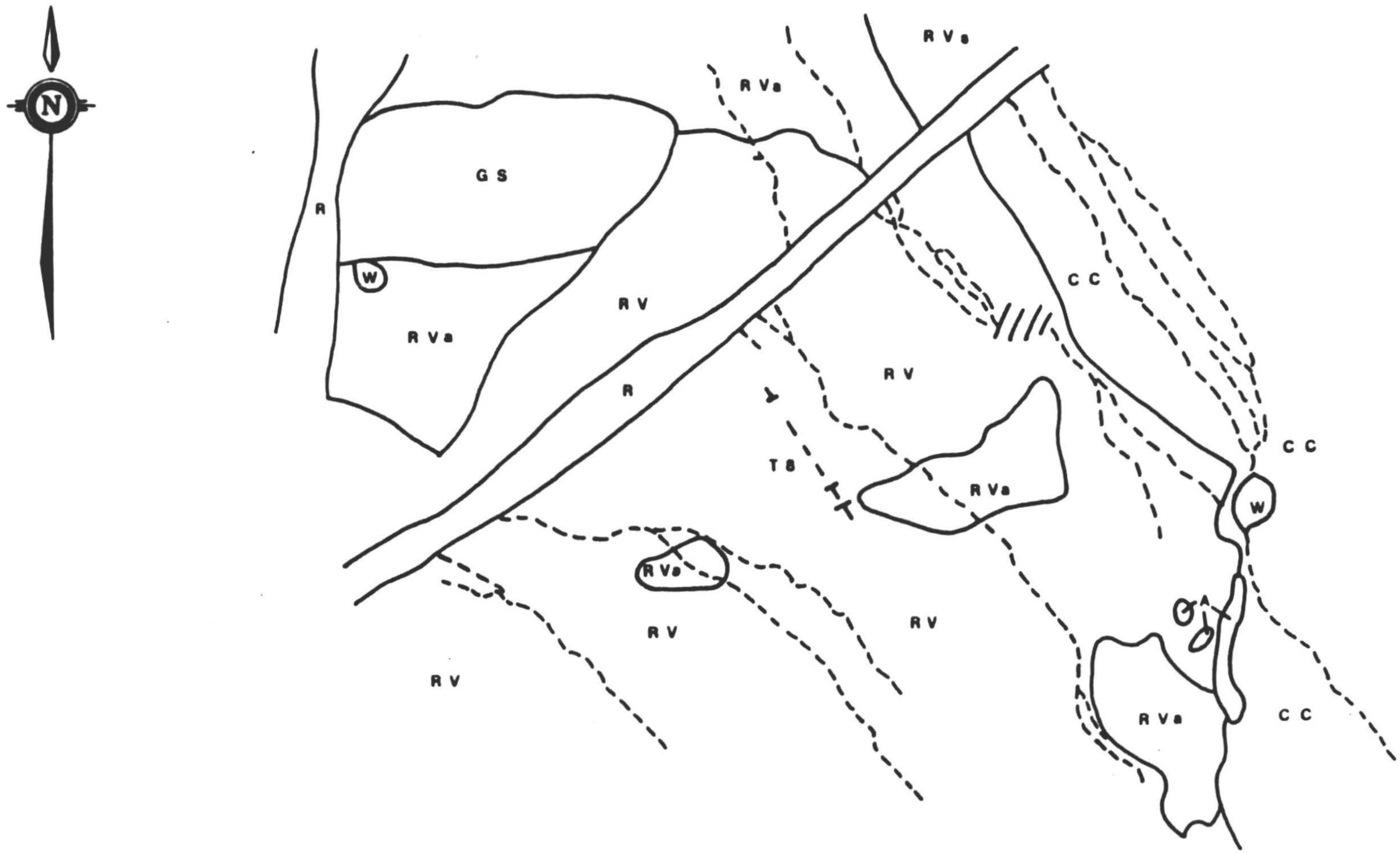


Figure 28. Reclamation Map of Study Site 9.

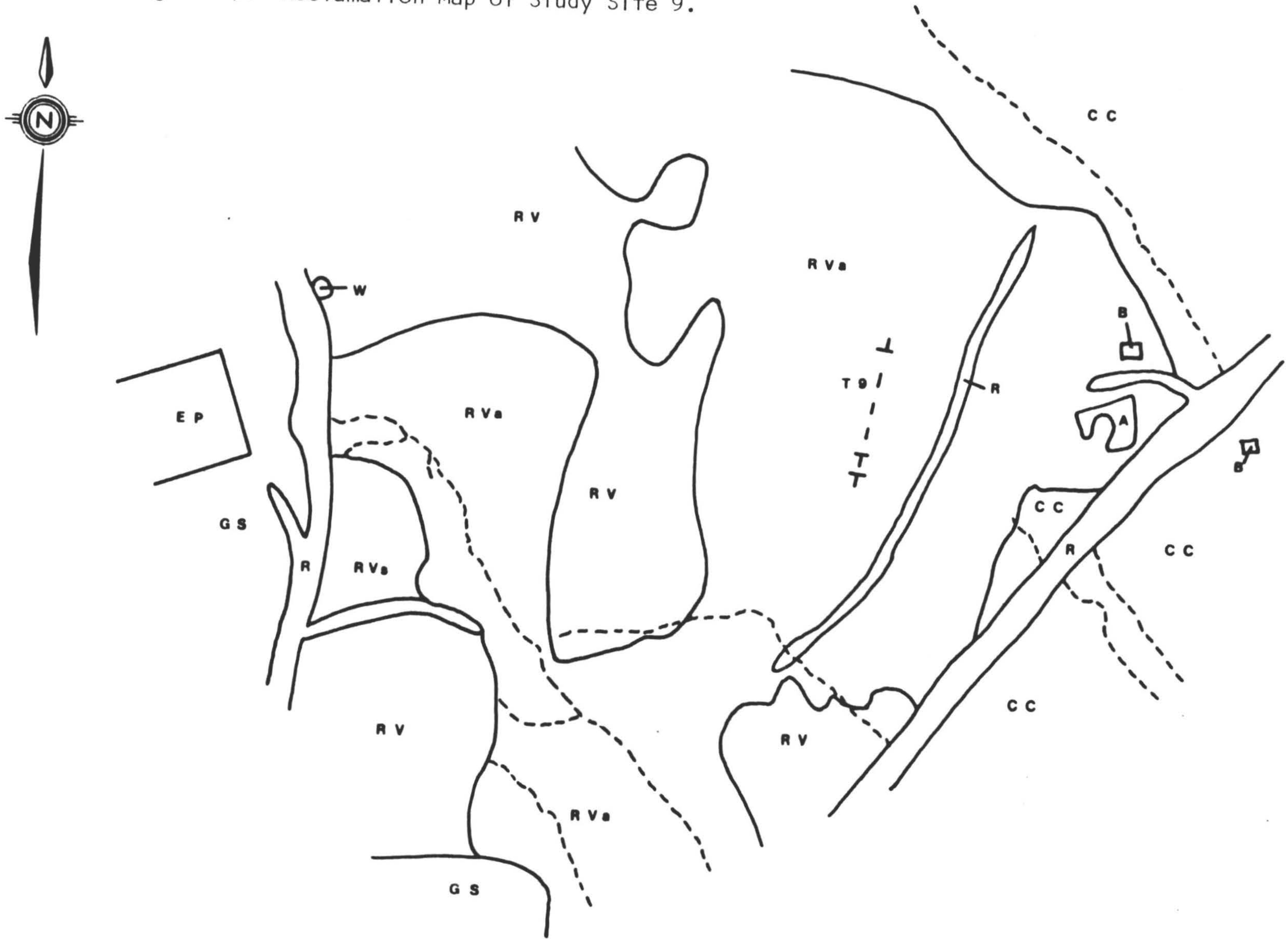


Figure 29. Reclamation Map of Study Sites 10 and 11.

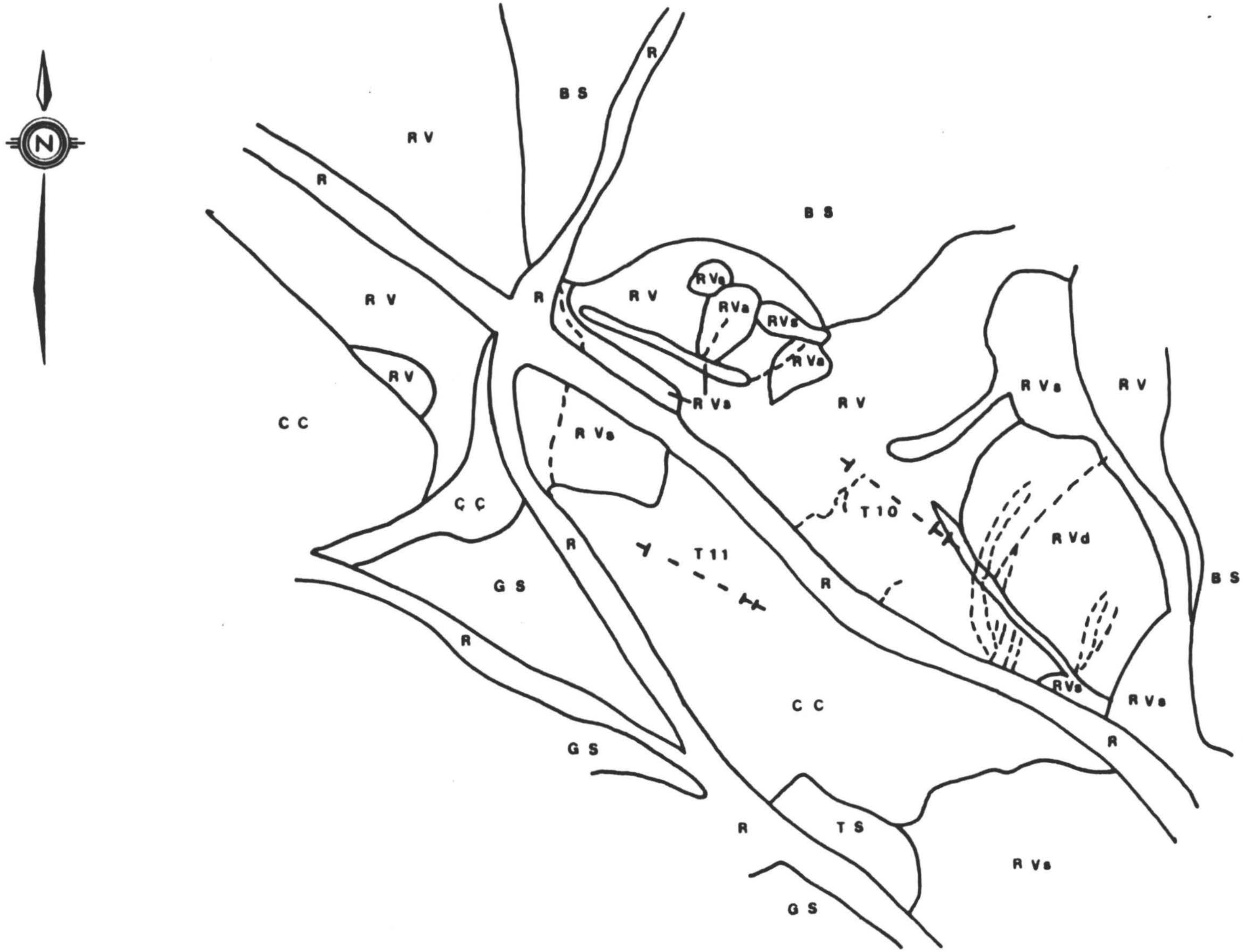
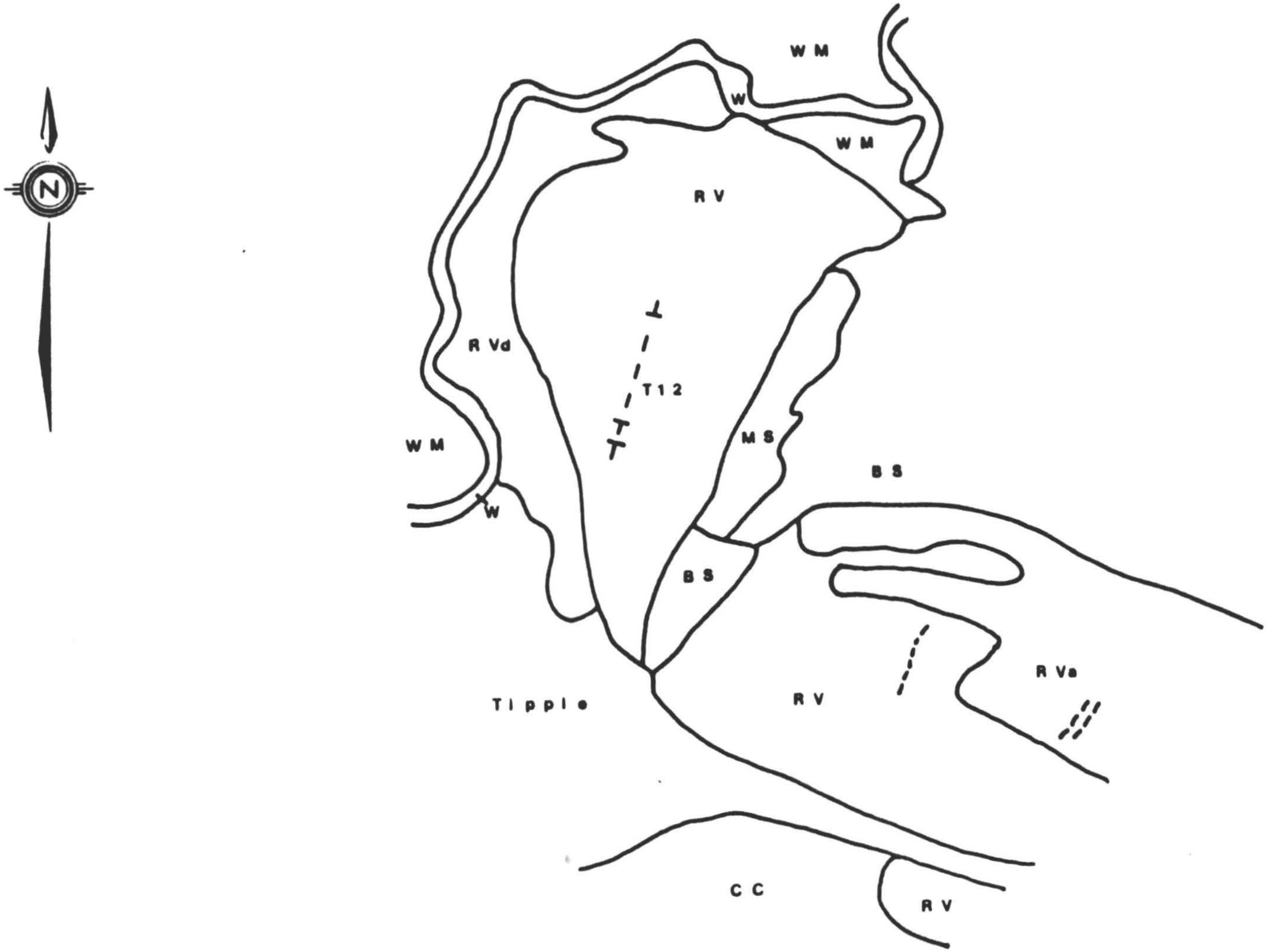


Figure 30. Reclamation Map of Study Site 12.



APPENDIX C

Partial Vegetation Species List for the Study Area

Table 22. Partial Vegetation Species List for the Study Area.

GRASSES

Species Abbreviation	Scientific Name	Common Name
Agcr	Agropyron cristatum (L.) Gaertn.	crested wheatgrass
Agde	Agropyron desertorum (Fisch.) Schult.	desert wheatgrass
Agine	Agropyron inerme (Scribn. & Smith) Rydb.	beardless wheatgrass
Agin	Agropyron intermedium (Host) Beauv.	intermediate wheatgrass
Agri	Agropyron riparium Scribn. & Smith	streamback wheatgrass
Agsm	Agropyron smithii Rydb.	western wheatgrass
Agtra	Agropyron trachycaulum (Link) Malte.	slender wheatgrass
Agtr	Agropyron tricophorum (Link) Richt.	pubescent wheatgrass
Avsa	Avena sativa L.	cultivated oat
Brin	Bromus inermis Leyss.	smooth bromegrass
Brja	Bromus japonicus Thumb.	japanese chess
Brma	Bromus marginatus Nees	
CAREX	Carex spp. L.	sedges
Dagl	Dactylis glomerata L.	orchardgrass
Deca	Deschampsia caespitosa (L.) Beauv.	tufted hair grass
Feid	Festuca idahoensis Elmer	Idaho fescue
Kocr	Koeleria cristata (L.) Pers.	June grass
Phpr	Phleum pratense L.	timothy
Popr	Poa pratensis L.	Kentucky bluegrass
Pose	Poa secunda Presl	Sandberg bluegrass
Sece	Secale cereale L.	rye
Stle	Stipa lettermani Vasey	letterman needlegrass
Trae	Triticum aestivum L.	common wheat

Table 22. Partial Vegetation Species List of the Study Area. (cont'd)

FORBS

Species Abbreviation	Scientific Name	Common Name
Ardr	Artemisia dracunculus L.	sagewort
ASTRA	Astragalus spp. L.	milkvetch
Asci	Astragalus cicer L.	cicer milkvetch
Basa	Balsamorhiza sagittata (Pursh) Nutt.	balsam-root
CHENO	Chenopodium spp. L.	goosefoot
Chal	Chenopodium album L.	common pigweed
Ciar	Cirsium arvense (L.) Scop.	Canada thistle
Civu	Cirsium vulgare (Savi) Airy-Shaw	bull thistle
Coli	Collomia linearis Nutt.	collomia
Cova	Coronilla varia L.	crown vetch
Eppa	Epilobium paniculatum Nutt.	annual willow-herb
Grsq	Grindelia squarrosa (Pursh) Dunal.	gumweed
Hemu	Heliomeris multiflora Nutt.	heliomeris
Koir	Kochia iranica Bornmueller	summer-cypress
Lase	Lactuca serriola L.	prickly lettuce
LEPID	Lepidium sp. L.	peppergrass
Magl	Madia glomerata Hook.	tarweed
Mesa	Medicago sativa L.	alfalfa
M.eof	Melilotus officinalis (L.) Lam	yellow sweet-clover
Pest	Penstemon strictus Benth.	Rocky mountain penstemon
POLYG	Polygonum sp. L.	knotweed
Saka	Salsola kali L.	Russian thistle
Sami	Sanguisorba minor Scop.	small burnet
Wyam	Wyethia amplexicaulis Nutt.	mule's ear

Table 22. Partial Vegetation Species List of the Study Area. (concluded)

SHRUBS AND TREES

Species Abbreviation	Scientific Name	Common Name
Amal	Amelanchier alnifolia Medic.	serviceberry
Arca	Artemisia cana Pursh	silver sage
Artra	Artemisia tridentata arbuscula Nutt.	low sagebrush
Artrt	Artemisia tridentata tridentata H & C.	big sagebrush
Caar	Caragana arborescens L.	caragana
Chna	Chrysothamnus nauseosus (Pallas) Britt.	rubber rabbitbrush
Poan	Populus angustifolia L.	narrowleaf poplar
Potr	Populus tremuloides Michx.	trembling aspen
Prvi	Prunus virginiana L.	chokecherry
Putr	Purshia tridentata (Pursh) DC.	antelope bitterbrush
Quga	Quercus gambellii Nutt.	gambell oak
ROSA	Rosa sp. L.	rose
SALIX	Salix spp. L.	willow
Syor	Symphoricarpos oreophilis Gray	snowberry