MASTER

COO-2371-6

A BOTANICAL INVENTORY OF THE ROCKY FLATS AEC SITE

Final Report

for Period April 29, 1976-July 31, 1977

Patrick J. Webber

University of Colorado

Boulder, Colorado 80309

April 1979

Prepared for

DEPARTMENT OF ENERGY

UNDER CONTRACT NO. EY-76-S-02-2371.*000

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

A BOTANICAL INVENTORY OF THE ROCKY FLATS AEC SITE

Final Report

for Period April 29, 1976-July 31, 1977

Patrick J. Webber

University of Colorado

Boulder, Colorado 80309

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Department of Energy, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

April 1979

Prepared for

DEPARTMENT OF ENERGY

UNDER CONTRACT NO. EY-76-S-02-2371.*000

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Energy Research and Development Administration, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product or process disclosed or represents that its use would not infringe privately owned rights.

A BOTANICAL INVENTORY OF THE ROCKY FLATS AEC SITE

FINAL REPORT (COO-2371-6)

TABLE OF CONTENTS

Title page.....	1
Notice.....	2
Table of Contents.....	3
Abstract.....	4
Introduction.....	5
Previous Reports.....	5
Activities during the final phase.....	6
Normal morphology of vascular taxa.....	9
Communications.....	23
Conclusions and Final Commentary.....	24
Acknowledgments.....	24
Literature Cited.....	25
Appendix A (M.A. thesis of S.J.V. Clark).....	27 (+172 pp.)
Appendix B (Letter to Mr. T. Winsor).....	28
Form ERDA-427 (in triplicate).....	31

A BOTANICAL INVENTORY OF THE ROCKY FLATS AEC SITE

FINAL REPORT (COO-2371-6)

ABSTRACT

This report outlines this four-year study, the overall purpose of which was to document the present plant life of the Rocky Flats site and surrounding area. This documentation is intended as a base-line description which may be used by researchers and managers.

The analysis of natural vegetation, including plant species inventory, vegetation composition study and identification of major environmental control factors at the Rocky Flats site provides a data base on which future environmental decisions concerning, for example, future construction and handling of disturbance on this site can be made. The establishment of morphological norms for potential plant indicators of mutagenic hazards serves as a start for development of a vegetation-based system for detection of possible changes in plant life induced by accidental plutonium release around the plant. This study is not directed towards assessing any past or present industrial impacts of plutonium processing.

The principal products from the contract are a list of vascular plants, bryophytes, and lichens, a 1:12,000 color vegetation map, five large scale (1:500) maps of special study and experimental areas, and a description of the morphological norms of two common vascular plant species.

April 16, 1979

Patrick J. Webber.

Patrick J. Webber, Professor
Principal Investigator
University of Colorado
Boulder, Colorado 80309

A BOTANICAL INVENTORY OF THE ROCKY FLATS AEC SITE

FINAL REPORT (COO-2371-6)

Introduction:

This report summarizes the four-year study which was made of the flora and vegetation of the environs of the Rocky Flats plutonium processing plant. This study was not directed towards assessing any past or present environmental impacts of plutonium processing, but rather to provide a data base on which future environmental decisions, for example, concerning future construction and handling of disturbance, can be made.

Previous Reports:

The project began in the summer of 1973 with Dr. William A. Weber as principal investigator. Report numbers COO-2371-1 (Weber, 1974) and COO-2371-2 (Weber et al., 1974) were filed on this phase of the work which consisted of listing the vascular plants, bryophytes and lichens. The latter report provided a detailed annotated list of species, comments on the phenology of flowering, some floristic statistics and a discussion of the past and present status of the flora and vegetation of Rocky Flats. Dr. Patrick J. Webber joined the project in 1974 in order to expand the research to include vegetation mapping and phytosociological analysis to ascertain environmental and other controls on vegetation composition and distribution. This resulted in the submission of two renewal proposals and a further report (COO-2371-3) with Dr. W.A. Weber remaining as the principal investigator (Weber, 1975).

In October, 1975, at Dr. W.A. Weber's request and with the concurrence of Dr. William S. Osburn of DOE, Dr. P.J. Webber became the principal investigator with Dr. W.A. Weber remaining in a consulting capacity. Dr. P.J. Webber then submitted, in 1976, a final renewal proposal with two further reports (COO-2371-4 - Webber (1976) and COO-2371-5 - Webber and Clark (1976)). The latter

report provided details of the mapping program and copies of the six final map products. The maps serve as base-line descriptions of the vegetation as it was in the mid-1970's. A colored map of the entire Rocky Flats area at a scale of 1:12,000 depicted the distribution of 16 vegetation units. Photographs and brief descriptions of each unit were provided. The remaining five maps were presented in black and white at a scale of 1:500. These maps were of special study areas where a number of other investigators had carried out a variety of research, for example, soil erosion studies, small mammal censusing, and micrometeorological monitoring. The maps were contoured at intervals of one meter relative elevation. The maps show the broad pattern of vegetation distribution in relation to drainage patterns, topographic and geologic controls and also land-use patterns such as grazing, damming, ditching, construction of fire-breaks and soil removal. Another approach, that is, ordination analysis or phytosociological modelling, was used to establish more specific controls on vegetation composition and plant distribution. This aspect of the study is reported in Clark (1977; Appendix A). She found that three factors are of overriding importance in controlling plant distribution and vegetation type at Rocky Flats. They are, in order of importance, bare ground, soil moisture, and grazing intensity. This information is of great significance for potential management of the site which tends to be barren, dry and overgrazed. Thus any revegetation or rehabilitation of this rather disturbed site should at least temporarily mitigate its extreme nature by adding top soil or mulching, by irrigating and by removing grazers.

During routine sampling for the ordination analysis several (82) taxa were found which were additional to the Weber et al. (1974) list. Dr. Weber has verified the identifications and they are given in Table I.

Activities during the final phase

The proposal for the final year called for completion of the botanical

Table I. Additions to the Weber *et al.* (1974) floristic lists for Rocky Flats.

Those inside the main Rocky Flats property which
is bounded by a barbed wire fence.*

VASCULAR TAXA (30)

Apocynum cannabinum L.
Arctium minus (Hill) Bernh.
Astragalus agrestis Dougl. ex G. Don
Astragalus sericoleus A. Gray
Routeloua hirsuta Lag.
Chrysothamnus nauseosus (Pall.) Britt. in Britt. et Brown
Draba reptans (Lam.) Fernald
Epilobium leptophyllum Raf.
Equisetum arvense L.
Euphorbia dictyosperma Fisch. et Meyer
Evolvulus nuttallianus R. et S.
Gaura parviflora Dougl. ex Hook.
Geum macrophyllum Willd.
Gratiola neglecta Torr.
Humulus lupulus L.
Hypericum formosum H.G.K.
Lathyrus polymorphus Nutt.
Leersia oryzoides (L.) Swartz
Marrubium vulgare L.
Medicago sativa L.
Monarda pectinata Nutt.
Physalis hederæfolia A. Gray
Poa palustris L.
Polygonum rurivagum Jordan
Pulsatilla patens (L.) Mill. ssp. *multifida* (Pritzel) Zamels
Rumex obtusifolius L.
Salsola iberica Sennen et Pau
Stipa comata Trin. et Rupr.
Stipa neomexicana (Thurb.) Scribn.
Viola papilionacea Pursh

LICHENS (6)

Aspicilia calcarea (L.) Mudd
Cladonia coccifera (L.) Willd.
Collema cf. *tenax* (Sw.) Ach.
Lecanora alphoplaca (Wahlenb. ex Ach.) Ach.
Leptogium cf. *minutissimum* (Florke) Fr.
Microthelia aterrima (Anzi) Zahlbr.

BRYOPHYTES (2)

Leptodictyum riparium (Hedw.) Warnst.
Tortula intermedia (Brid.) Berk.

*This is the area covered by the original Weber *et al.* (1974) report.

Those outside the main Rocky Flats fence
and within the buffer zone.

VASCULAR TAXA (28)

Amaranthus graecizans L.
Apocynum androsaemifolium L.
Aristida fendleriana Steud.
Asclepias engelmanniana Woodson
Asclepias pumila (A. Gray) Vail
Aster arenosus Blake
Aster engelmannii (D.C. Eaton) A. Gray
Aster falcatus Lindl.
Bahia oppositifolia (Nutt.) DC.
Carex filifolia Nutt.
Centaurea diffusa Lam.
Chorisporea tenella DC.
Cryptantha fendleri (A. Gray) Greene
Eriogonum effusum Nutt.
Haplopappus spinulosus (Pursh) DC.
Kochia iranica Bornm.
Lepidium perfoliatum L.
Lesquerella ludoviciana (Nutt.) Wats.
Malva neglecta Wallr.
Penstemon gracilis Nutt.
Plantago major L.
Potentilla rivalis Nutt. et T. et G.
Ranunculus acrifolius A. Gray
Ribes cereum Dougl.
Salsola collina Pall.
Trifolium repens L.
Veronica biloba L.
Vitis riparia Michx.

LICHENS (13)

Acarospora smaragdula (Wahlenb. ex Ach.) Mass.
Buellia punctata (Hoffm.) Mass.
Dermatocarpon miniatum (L.) Mann
Lecanora cf. *dispersa* (Pers.) Somm.
Lecanora melanophthalma (Ram. ex Lam. and DC.) Ram.
Lecidella carpatica (Korb.) Szat.
Lecidella stigmatia (Ach.) Hertel et Leuckert
Physcia callosa Nyl.
Rhizocarpon disporum (Naeg. ex Hepp) Mull.-Arg.
Rhizocarpon riparium Ras.
Rinodina bischoffii (Hepp) Mass.
Staurothele clopima (Wahlenb. ex Ach.) Th.Fr.
Xanthoria elegans (Link) Th.Fr.

BRYOPHYTES (3)

Grimmia calyptrata
Leptobryum pyriforme (Hedw.) Wils.
Orthotrichum alpestre Hornsch. ex B.S.G.

inventory begun in the previous three years with special emphasis on the description of the normal morphological characteristics of selected plant species. The morphological studies and other activities principally those of communication of information are provided below.

Normal morphology of vascular taxa

Introduction. The hypothesis underlying this stage of the project proposes that vegetation growing upon areas subject to irradiation may undergo alterations in growth rate, morphology, and/or genetic constitution. During June and July, 1976, specimens of selected plant species were collected throughout Boulder County, where no source of unnatural radiation is known to exist. Measurement and statistical analysis were carried out during the following months of August and September. Emphasis was placed upon establishing a set of parameters describing a normal specimen of each species studied. Thus, possible influences of radioactivity upon the plants were considered only with respect to determining which features of each species were to be measured. Research may later be conducted on a comparison of specimens growing on both radioactive and non-radioactive sites in an attempt to distinguish possible aberrations caused by onsite plutonium contamination. Ms. Eleanor Werbe carried out the majority of the morphological study and its reporting.

Methods. Eight species were originally chosen for study from the master list of vascular species growing on radioactive areas at Rocky Flats. They are as follows: Alyssum alyssoides, Camelina microcarpa, Collomia linearis, Hypericum perforatum, Paronychia jamesii, Sisymbrium altissimum, Stipa comata, and Veronica peregrina. Selection of these species was based upon such factors as local abundance, seasonality, freedom from excessive size and plasticity, and type of root system. It was anticipated that these particular species would serve to minimize problems of field identification and collection, as well as laboratory measurement. Toward the middle of the summer, it became apparent that there was

not enough time left to both collect and investigate adequate numbers of specimens of each species; concentration was then focused upon Alyssum alyssoides (Figure 1) and Paronychia jamesii (Figure 2).

Overall perspective of Boulder County was provided by the Boulder County Road Map issued by the County Commissioners, which was divided into square-mile sections. In most cases, habitat preference was determined in advance on the basis of elevation, slope, and topography. Locations recorded on University of Colorado Herbarium specimens were also helpful in suggesting potential habitats. Fifty specimens per species were collected. To insure representative sampling, approximately five plants per population were gathered from eighteen different points in and around the city of Boulder, although a total of forty-nine sites were visited during the course of the summer. These sites were located predominantly on the eastern, southern, and western peripheries of the city, where local conditions most resembled those of Rocky Flats. Field work ranged over 24 days from streambeds and weedlots at lower elevations (5200-6000 feet) to grassy mesas, hillsides, and coniferous forests at higher elevations (6000-7200 feet) in an attempt to reach as many different populations of plants as possible.

Collection sites fell within a rectangular-shaped plot of land characterized by varying amounts of disturbance resulting from grazing of domestic animals and the construction of residential areas, highways, and reservoirs. This rectangle was oriented on a north-south axis running nine miles north of the Rocky Flats boundary, and an east-west axis running fourteen miles east of the Front Range (Figure 3). A salient feature in the horizontal layout of this study area was the alignment of sites along the streambeds flowing out of the foothills and along roadsides allowing access to the mountains.

Each specimen was sealed in a plastic bag at the site, then returned to the Plant Ecology Laboratory of the Institute of Arctic and Alpine Research (INSTAAR), where it was numbered, dated, tagged according to Township, Range,

Figure 1

Alyssum alyssoides is an introduced annual plant of varying density found in sunny, disturbed sites throughout Boulder County. It is recognized primarily by its pervasive appearance, terminal yellow flower clusters, many finely stellate-pubescent siliques, and a fibrous, filamentary root system.

Figure 2

Paronychia jamesii is an abundant matte-like perennial plant found in association with pine forests, exposure to strong sunlight, and dry, gravelly soils. It will commonly grow upon either the crest of a ridge or an adjacent south-facing or west-facing hillside. Key taxonomic features include opposite, linear leaves, an extensive taproot system, numerous flowers growing in branched cymes, and papery stipules growing at each node.

Figure 3. The location of sampling sites. Those marked with open circles represent the sites where Alyssum and Paronychia were collected. The closed circles represent the collection sites for the remaining species.

and Section Number, and pressed. Notes regarding topography, elevation, soil condition, degree of disturbance, and number of specimens collected were entered daily in the field notebook.

Both quantitative and qualitative characteristics were sought in order to more thoroughly describe each species studied. Non-parametric (primarily qualitative) factors of classification, phytogeographic distribution, successional status, shoot and root growth-forms, length of life cycle, chromosome ploidy, predators and parasites were either readily apparent in the field or available from the literature. Parametric (primarily quantitative) data were derived from laboratory measurements taking place after specimens had been pressed for a minimum of one week. These specific measurements varied for the two species due to growth-form difference. They included such features as number, length and width of major branches or shoots, curved root length, average size and number of fruits, average number of flowers and buds per shoot, leaf width-length ratio, and root-shoot biomass ratio. These data were expressed in statistical terms of mean, range, and standard deviation.

Parametric data were obtained with the help of Vernier calipers and a Mettler Balance accurate to 0.01 gram. Unless otherwise stated, mean values refer to a straightforward average number for the summed specimens, i.e., root length. In instances of variance occurring within the specimen (number of fruits), it was necessary to first derive a mean value for the individual plant; these 50 values were then summed and averaged to yield a mean mean value for the sample as a whole.

Primary branches were those major stems intersecting at the base of the plant, whereas secondary branches were shorter and stemmed from a primary branch at any point along its length.

The measurements selected per species were chosen for two reasons: (1) a clear, precise description of key plant features, and (2) independence of age

and stature factors. Because it is not known how irradiation might affect plant metabolism and morphology, it is also not known how best to try to monitor the possible changes. It was hoped that the measures discussed in the following section would prove likely to reflect sudden change, should any occur.

Results and discussion. The following information is presented to outline both parametric and non-parametric characteristics of a normal specimen of each plant species studied. Because this project is designed to recommend ways in which possible change in plants exposed to irradiation may be monitored, these results are organized with respect to standard deviation groupings. Those measures yielding low standard deviation values were interpreted as more reliable gauges of normal plant morphology than those whose standard deviations exhibited wide amplitudes about the mean value.

Alyssum alyssoides (Figure 4) is an annual plant of consistent proportions and abundant distribution in the Boulder area. It grows throughout the elevational gradient in highly-disturbed, level areas exposed to strong sunlight. Alyssum alyssoides thrives in open spaces where the soil has a silty-sand texture, especially along the margins of dirt and paved roads, where it benefits from road-side drainage. However, this member of the Crucifer family also flourishes on overgrazed mesatops, along streamside banks, and wherever large-scale construction of housing and roads has occurred. It appears that this species requires an element of disturbance before success can be assured.

As an annual plant, Alyssum alyssoides devotes the greater portion of its energy toward the production of flowers, fruits, and seeds. This fact is reflected in the overall morphology of the plant, as well as in the mean root-shoot biomass ratio of 0.13 (Table II). The small size of this number would indicate that the mean above-ground shoot mass of the species is approximately eight times as much as the mean below-ground root mass. Further support for this statement can be found in the short, filamentary root system of Alyssum alyssoides.

Figure 4

Alyssum alyssoides

1. Number of Primary Branches
2. Number of Secondary Branches
3. Average Number of Siliques per Primary Branch
4. Average Diameter(mm.) of Siliques, 20 random samples per plant
5. Average Curved Length of Primary Branches
6. Curved Length of Root
7. Average Stem Diameter

Table II. The dimensions of Alyssum alyssoides. Fifty measurements were made of each character.

Character	Mean	Standard Deviation	Range
Number primary branches	2.8	2.37	10-1
Number secondary branches	5.6	10.76	44-0
Number siliques	37.3	13.32	78-11
Silique diameter (mm)	2.9	0.21	3.4-2.5
Primary branch length (cm)	17.4	4.91	27.6-9.2
Root length (cm)	6.8	2.04	13.0-3.2
Stem diameter (mm)	1.2	0.31	2.2-0.8
Root-shoot biomass ratio	0.13	0.08	0.30-0.03

Table III. The dimensions of Paronychia jamesii. Fifty measurements were made of each character.

Character	Mean	Standard Deviation	Range
Number shoots	34.5	26.80	166-4
Stem length (cm)	11.4	2.80	19.2-6.5
Stem diameter (mm)	0.8	0.15	1.1-0.5
Number flowers and/or buds	25.2	20.58	101.3-2.3
Leaf width-length ratio	0.07	0.02	0.13-0.04
Root length (cm)	10.9	6.79	37-3.25
Root-shoot biomass ratio	0.5	0.29	1.43-0.08
Third internode length - shoot length ratio	0.14	0.03	0.22-0.09

The range and standard deviation calculated for the mean root-shoot biomass ratio were respectively 0.3-0.03 and 0.08. Other morphological features revealing similar constancy throughout the sample were stem diameter and silique diameter. The mean mean stem diameter for Alyssum alyssoides was calculated to be 1.2 mm, with a standard deviation of 0.31, and a range between 2.2 mm and 0.8 mm. The mean mean silique diameter was determined, using twenty fruits per plant, at 2.9 mm, with a standard deviation of 0.21 and a range of 3.4 mm to 2.5 mm. These three small deviation values indicate that 68% of the individual scores fall within a narrow amplitude about the mean mean value, and that few of these scores fall at the extreme ends of the range. Root-shoot biomass ratio, stem diameter, and silique diameter are excellent indicators of normal plant morphology.

Other morphological features revealed considerable variation in their dimensions. Intermediate standard deviations applied to the measures of number and length of primary branches and root length. In this sample, the mean number of primary branches was 2.8 per specimen; the standard deviation was 2.37. Anywhere from one to ten branches per plant was found. The mean length of primary branches was derived by caliper measurement of the length of string used to follow the curve of the branch. Each primary branch was included in the calculated mean values per individual. These were compiled to give a mean mean primary branch length of 17.4 cm. Standard deviation was 4.91, while the range extended from 27.6 cm to 9.2 cm. The mean root length of Alyssum alyssoides was figured at 6.8 cm. The standard deviation for this measure was 2.04 and the range values were 13.0 cm to 3.2 cm. A point to be stressed with respect to these root length numbers is that despite the potential that root length might have in contributing to clear-cut parameters for the species, extraction of the root system without breakage of the fine roots, and in some cases the major root itself, was difficult in almost every case. It is recommended that these values are considered in moderation as they probably do not accurately

reflect the true nature of the plant. The root-shoot biomass ratio figures should also be viewed with this factor in mind, although fine roots may only amount to a small fraction of the actual total.

The largest standard deviation values and greatest amplitudes about the mean occurred in two last measures of the species, the number of siliques per plant and the number of secondary branches. The mean mean number of siliques per plant was first figured by counting the number of fruits for every primary branch and deriving the individual mean. These were compiled to yield the mean mean number of fruits - 37.3 per plant. The standard deviation was 13.32; a maximum of 78 and a minimum of 11 fruits per plant were found. Slightly lesser extremes were found in the range pertaining to numbers of secondary branches. This mean mean value was determined at 5.6 per plant, with a standard deviation of 10.76 and a range between 44 and 0 per plant.

Paronychia jamesii (Figure 5) is a mat-like perennial plant characterized by numerous thin stems branching from the base of the plant and minuscule yellow flowers growing in compound cymes. It is a member of the Caryophyllaceae family and has diagnostic opposite and linear leaves, papery stipules, and an extensive taproot system. In contrast to Alyssum alyssoides, Paronychia jamesii has more consistent proportions but less abundant distribution in the Boulder vicinity. It is found primarily in piedmont communities of widely-spaced individuals, although this species also occurs with patchy distribution in the upper zones of the grassland community. This plant prefers the porous soil and extreme exposure to both wind and sunlight found on the crest of Lower Montane ridges at elevations between 6,800 and 7,500 feet. It grows commonly in open, dry spaces in association with Pinus ponderosa on either south-facing or west-facing slopes of varying steepness.

Paronychia jamesii is typical of most perennial plants in that its energy is divided more evenly between reproduction and maintenance than in annual plants.

Figure 5

Paronychia jamesii

1. Number of Shoots
2. Average Length of Shoots, 3 samples
3. Average Width of Shoots, 3 samples
4. Average Number of Flowers and/or Buds per Shoot, 10 samples
5. Average Leaf Width-Length Ratio, 3 samples
6. Curved Length of Root
7. Ratio of Third Internode Length to Shoot Length

This perennial's concern for growth, repair, and maintenance throughout all seasons is reflected in its inconspicuous appearance and extensive root system. Its mean mean of 25.2 flowers or buds manufactured per plant (Table III) was derived by taking the average number of flowers or buds of 10 stems per specimen, summing the individual means, and dividing by the total number of specimens; the standard deviation is 20.58 and the range is from 101.3 to 2.3. This significant difference in productivity levels is an essential ingredient to our understanding of functional dissimilarities between plant types. The excess energy Paronychia jamesii does not channel toward the production of flowers and fruits is utilized for the repair and maintenance of tissue vital to plant species which must sustain themselves for several full-length life cycles.

This physiological requirement is manifested in two additional morphological features of Paronychia jamesii, the mean root length and the mean root-shoot biomass ratio. The mean root length of this species was determined at 10.9 cm, with a standard deviation of 6.79 and a range falling between 37.0 cm and 3.25 cm. Collection of these specimens in intact condition proved even more challenging than the collection of Alyssum alyssoides, due to the thickness of the root and length of rootlets. Because of some inevitable fine root breakage, this value should be considered as only a general index of mean root length.

This precaution applies for the same reason to the mean root-shoot biomass ratio. The figure 0.5 indicates that the below-ground root mass constitutes approximately one-half of the above-ground shoot mass. The standard deviation in this instance was derived at 0.29; the range is from 1.43 to 0.08. A comparison of these measures for both species reveals that the root of Paronychia jamesii is proportionately almost four times as "massive" as that of Alyssum alyssoides.

The remainder of measures pertain to above-ground features of the species. The greatest standard deviation for either species (26.8) occurred with respect to the mean number of shoots per specimen of Paronychia jamesii. The maximum number of shoots supported by one specimen was 166, whereas the minimum number supported by a specimen was 4 shoots. These figures contrast sharply with those generated for primary branch number in Alyssum alyssoides and indicate a very wide amplitude about the mean value of 34.5 shoots.

Greater similarity was found in both measures of stem diameter and stem length. Because so little variation in stem diameter did occur in Paronychia jamesii, the mean mean value (0.8 mm) was taken from a sum of individual means derived from three stem measurements per specimen. This relative constancy is also reflected in the standard deviation of 0.15 and a narrow range of 1.1 mm to 0.5 mm. Slightly greater standard deviation (2.8) was found among the mean stem lengths per specimen. These individual mean values were also obtained by measuring three stem lengths per plant; they were later compiled to yield a mean mean value of 11.4 cm. The range of values fell between 19.2 cm and 6.5 cm.

The two remaining measures involve ratios included for their merit in achieving values independent of age and stature. Both of these plant features exhibit the smallest standard deviations found within the entire study. The mean mean leaf width-length ratio was derived at 0.07, indicating that leaf length is greater than ten times the width of the leaf. Standard deviation was obtained at 0.02; the range covered values between 0.13 and 0.04. This specimen mean was taken from three randomly-chosen samples of the feature, as was the following measure of third internode length to shoot length ratio. This last mean mean ratio was figured at 0.14, while the standard deviation was 0.03. The range extended from 0.22 to 0.09.

In conclusion, assessment of Tables II and III reveals that some features of each plant are more consistent in their dimensions than others, and offer a

more reliable gauge of normal morphology against which further research at the Rocky Flats installation may be correlated. Questionable measures are those which yield a high proportional standard deviation. Such features were found to be too unstable, or too plastic for the purpose of this project. They are as follows: number of siliques and number of secondary branches in Alyssum alyssoides, and number of shoots and number of flowers and buds in Paronychia jamesii. However, it would best serve the needs of the project to repeat all sixteen measures of this first half of the study at the Rocky Flats site. Although it is likely that these four unstable measures will be discarded upon completion of the project, rejection at this time would be unsound.

The best measures of plant normalcy are simply those which yielded a low standard deviation value. This stipulation applies to all of the remaining twelve measures, with the exception of root length in Paronychia jamesii. This measure was inadvertently influenced by methods of root extraction, as already noted.

Communications

A manuscript was prepared on the mapping and ordination analyses (Clark et al., in prep.) and submitted to Ecology for publication. In addition to this formal communication, two papers were presented at a symposium on the Rocky Flats buffer zone (Webber et al., 1977; Webber and Werbe, 1977). The symposium was organized by Rockwell International, the operators of the Rocky Flats plant (Hunt, 1977).

The members of the project have received frequent inquiries about the botany of Rocky Flats. Two inquiries are worth noting here. The first from Mr. Terol Winsor of Rockwell International concerned the possible presence of threatened and endangered species on the site. Appendix B contains a letter relating that in our opinion no species on the site fell into this category. The second concerned the selection of suitable sites for the location of

sensitive clones of Tradescantia (Spiderwort) hybrids to be used for the biological monitoring of low level radiation. A local citizens group was proposing to start a monitoring program. The principal investigator put forward the thesis that the extreme physical environment of the site precludes the use of such a monitoring system without a great expenditure of effort and manpower. However, Tradescantia occidentalis occurs frequently on valley sides throughout the area. Apparently no monitoring is being planned.

Conclusions and Final Commentary:

This four-year study has provided a botanical base-line for the previously poorly known Rocky Flats site. The information gained has already been of value to the operators of the Rocky Flats site and consideration of the information must be part if any management consideration of the area. Future monitoring of flora and vegetation should be carried out at regular intervals, the frequency of which will be dependent upon the system being monitored. For example, the 1:500 map areas might be rechecked every two years, the 1:12,000 map area every five years, and the floral listing every ten years. It is recommended that the establishment of morphological norms be continued for more taxa since the long-term effects of radioactive contaminants on the flora is unknown and likely to be undemonstrable with an inadequate data base.

Acknowledgments:

This research was supported by the U.S. Department of Energy (contract no. EY-76-S-02-2371.*000). The personnel of the Rocky Flats, Rockwell International Plant was very helpful during the course of the contract. Ms. Vicki Dow drafted the map, and some of the figures, and prepared the color map copy. Mr. Kenneth Bowman also drafted many of the figures. Tewell Printing and Lithographing Company printed the map. Dr. William A. Weber, University of Colorado Museum, identified bryophytes and lichens and verified the identification of vascular plants. Mr. Rolf H. Kihl, Sedimentology

Laboratory, Institute of Arctic and Alpine Research, analyzed the soil samples. Assistance with computer programs was provided by Dr. Jim A. Clark and Mrs. Margaret Eccles. A special thanks goes to Dr. Vera Komárková, Ms. Susan Vetter Clark, and Ms. Eleanor Werbe, all of whom assisted with the technical, analytic, and writing aspects of the research. Mrs. Laura Koch typed and prepared all the reports.

Literature Cited:

- Clark, S.J.V., 1977. The vegetation of Rocky Flats, Colorado. M.A. thesis, University of Colorado, Boulder, Colorado. 172 pp.
- Clark, S.J.V., P.J. Webber, and V. Komárková, 1979. Map of Mixed Prairie Grassland Vegetation, Rocky Flats, Colorado. Submitted for publication - 58 ms. pp.
- Hunt, D.C. (ed.), 1977. Transactions of Meeting on Rocky Flats Buffer Zone Ecological and Environmental Research Meeting, March 4, 1977. Rockwell International, Rocky Flats Plant, Golden, Colorado. 100 pp.
- Webber, P.J., 1976. A Botanical Inventory of Rocky Flats AEC Site. Progress Report (COO-2371-4), U.S. Energy Research and Development Administration contract no. E(11-1)-2371. 2 pp.
- Webber, P.J. and S.V. Clark, 1976. A botanical inventory of the Rocky Flats AEC site: mapping methods and preliminary maps. Progress report (COO-2371-5), U.S. Energy Research and Development Administration contract no. E(11-1)-2371. 29 pp.
- Webber, P.J., S.V. Clark, and V. Komarkova, 1977. Botanical survey of the environs of the Rocky Flats (ERDA) Plant: mapping and ordination analyses. In Hunt, D.C. (ed.), Transactions of Meeting on Rocky Flats Buffer Zone Ecological and Environmental Research Meeting, March 4, 1977, Rockwell International, Rocky Flats Plant, Golden, Colorado, pp. 29-34.
- Webber, P.J. and E. Werbe, 1977. A method of establishing the morphological norms for potential indicators of mutagenic hazards. In Hunt, D.C. (ed.), Transactions of Meeting on Rocky Flats Buffer Zone Ecological and Environmental Research Meeting, March 4, 1977, Rockwell International, Rocky Flats Plant, Golden, Colorado, pp. 35-38.
- Weber, W.A., 1974. A Botanical Inventory of Rocky Flats AEC Site. Progress Report (COO-2371-1), U.S. Atomic Energy Commission contract no. AT(11-1)-2371. 2 pp.

Weber, W.A., 1975. A Botanical Inventory of Rocky Flats AEC Site. Technical Progress Report (COO-2371-3), U.S. Atomic Energy Commission contract no. AT(11-1)-2371. 2 pp.

Weber, W.A., G. Kunkel, and L. Shultz, 1974. A botanical inventory of the Rocky Flats AEC site. Final {sic} report (COO-2371-2), U.S. Atomic Energy Commission contract no. AT911-1)-2371. University of Colorado, Boulder, Colorado. 40 pp.

Appendix A to Final Report COO-2371-6

Master of Arts thesis of Susan Vetter Clark entitled
The Vegetation of Rocky Flats, Colorado. University
of Colorado, Boulder, Colorado. 172 pp. (1977)

THE VEGETATION OF ROCKY FLATS, COLORADO

by

Susan J. Vetter Clark

B.A., Augustana College, 1974

A thesis submitted to the Faculty of the Graduate
School of the University of Colorado in partial
fulfillment of the requirements for the degree of

Master of Arts

Department of Environmental, Population, and Organismic Biology

1977

This Thesis for the Master of Arts Degree by
Susan J. Vetter Clark
has been approved for the
Department of
Environmental, Population, and Organismic Biology
by

Patrick J. Webber.

Patrick J. Webber

Michael C. Grant

Michael C. Grant

Date *July 29, 1977*

Clark, Susan J. Vetter (M.A., Biology)

The Vegetation of Rocky Flats, Colorado

Thesis directed by Associate Professor Patrick J. Webber

A detailed documentation of the vegetation of Rocky Flats, Colorado, is provided by way of a color vegetation map at the scale of 1:12,000. Sixteen vegetation types are identified on the map. Photographs and descriptions of 32 representative vegetation stands (two per vegetation type) are included. Soil samples collected at each stand and measurements of other environmental variables provide a description of the environmental conditions which are associated with each vegetation type. Characteristics of the vegetation in the 32 stands are used to compose vegetation type summaries and also to provide a data base for various vegetation analysis techniques, including classification and ordination.

Classification indicates that various related environmental variables form three distinct clusters which can be termed moisture, soil grainsize, and disturbance (including grazing and soil disturbance caused by humans and small mammals). Classification of the 32 vegetation stands on the basis of values of the seventeen measured environmental variables produces four general groups of related vegetation types at the fifty percent similarity level as follows: valley-side--valley-bottom, agricultural field--barrens, pasture, and prairie vegetation. Classification of the 32 stands on the basis of importance measures of 227 species produces five general groups at the 25 percent similarity level as

follows: valley-side, valley-bottom, agricultural field, barrens, and pasture--prairie--savannah vegetation.

A successful method of reducing the size of the original data matrix without losing information, in order that ordination techniques can be used, is to combine the 227 plant species at Rocky Flats into ten life-forms. A Bray and Curtis indirect stand ordination, based on importance measures (species index) of ten life-forms, effectively summarizes the vegetation data within three dimensions. A high negative correlation ($r_s = -.853$) between interstand distances in three dimensions of this ordination and interstand percentage similarity of the vegetation based on life-forms indicates that the ordination is extremely accurate in representing the life-form data. A high negative correlation ($r_s = -.545$) between interstand distances in three dimensions of this ordination and interstand percentage similarity based on 227 species indicates that the life-form ordination accurately represents the original data matrix also.

Most important environmental correlations with the axes of the life-form ordination are as follows: the x axis and percentage non-vegetated area, the y axis and moisture regime, and the z axis and grazing regime. These three variables are significantly related to, and, in the case of moisture regime and grazing regime, influence the distribution of the vegetation at Rocky Flats.

When species are plotted within two dimensions of the life-form ordination, trends in their distributions and importance values are meaningful in terms of the environmental variables

which are associated with the ordination axes. This result is also observed when importance measures of the ten life-forms are plotted within three dimensions of the life-form ordination.

Relationships among the prairie, pasture, and meadow vegetation types are examined through a combined analysis of the vegetation map and the ordination. Theories as to how these types replace each other in response to environmental changes, primarily those caused by grazing, are given. Recommendations for future study of the vegetation of Rocky Flats are made. Finally, predictions of the results on the various vegetation types of a minimal program of vegetation management at Rocky Flats, including irrigation and some reseeding, are given.

This abstract is approved as to form and content.

Signed

Disabber.

Faculty member in charge of thesis

ACKNOWLEDGMENTS

This study was funded by an Energy Research and Development Administration grant--contract number E(11-1-2371)--to Dr. William A. Weber of the University of Colorado Museum and Dr. Patrick J. Webber of the Institute of Arctic and Alpine Research, Boulder. I am very grateful for this support. Dr. Patrick J. Webber directed my research and I owe greatest thanks to him for his patience and guidance. Dr. William A. Weber and Dr. Věra Komárková collected and identified many of the Rocky Flats plant species during 1973 and 1974, and I am grateful for the access to these collections provided by the University of Colorado Herbarium. Field work, including mapping and quadrating, was jointly accomplished by Věra Komárková and myself, Věra's contribution in terms of knowledge and experience to this portion of the project was invaluable. Cartography and drafting were patiently accomplished by Vicki Dow, for which I am thankful. Drafting was also done by Ken Bowman. Assistance with computer programming was provided by Jim Clark and Margaret Eccles. I thank Diane Ebert May for her general helpfulness in my initiation to the Plant Ecology Laboratory at INSTAAR. I thank my husband, Jim Clark, for the many statistical discussions which he patiently endured and for his support of my research.

TABLE OF CONTENTS

CHAPTER	PAGE
I. INTRODUCTION	1
II. DESCRIPTION OF THE STUDY AREA	5
Location	5
Geology	5
Topography	10
Climate	12
Soils	14
Vegetation	20
III. THE METHODS OF VEGETATION MAPPING	23
Introduction and concepts	23
Methods	24
Unit selection	27
Unit sampling	45
Soil sampling and analysis	52
Cartography	54
IV. THE METHODS OF VEGETATION ANALYSIS	60
Introduction	60
Data transformations	61
Original data	61
Species elimination	61
Life-forms	63
Life-forms with degrees of absence	66

CHAPTER	PAGE
Summary	71
Ordination	74
Concepts	74
Methods	76
Classification	80
Concepts	80
Methods	81
Environmental correlation	86
V. RESULTS AND DISCUSSION	89
Vegetation type summaries	89
Comparison of ordinations based on four data matrices	101
Comparison of four ordination techniques	104
Classification of stands, based on life-forms and species	109
Environmental correlations and classifications	120
Species and life-forms plotted on the ordination	129
VI. CONCLUSIONS, RECOMMENDATIONS, AND PREDICTIONS	145
LIST OF REFERENCES	156
APPENDIX A. RESULTS OF SOIL ANALYSES OF 32 VEGETATION STANDS	160
APPENDIX B. SPECIES INDEX VALUES FOR TEN LIFE-FORMS, AND TEN LIFE-FORMS WITH DEGREES OF ABSENCE, IN 32 STANDS	160
APPENDIX C. SPECIES INDEX VALUES FOR 227 SPECIES IN 32 STANDS	161
APPENDIX D. VEGETATION TYPE SUMMARIES	165

LIST OF TABLES

TABLE	PAGE
II-1. Selected weather conditions at Rocky Flats during 1974.	15
III-1. Derivation of map colors from relative moisture and disturbance	56
IV-1. Percentage of zero values contained in the data matrices used for the vegetation analysis.	72
V-1. The percentage of variance extracted from the data by each axis of three ordinations (based on ten life-forms and 32 stands) and the total percentage variance extracted	105
V-2. Interstand distances in one, two, and three dimensions of the seven Rocky Flats indirect stand ordinations correlated with the four similarity and correlation matrices.	108
V-3. Important correlations among measured environmental variables and ordination axes	121

LIST OF FIGURES

FIGURE	PAGE
II-1. Location of the study area	6
II-2. Geology of the study area	8
II-3. Geologic section through the study area	9
II-4. Topography along four transects through the study area	11
II-5. Wind rose for Rocky Flats during 1974	16
II-6. Soils of the study area	18
III-1. DRY, <i>BUCHLOË DACTYLOIDES</i> — <i>MEDICAGO SATIVA</i> , PASTURE . . .	29
III-2. DRY, <i>BUCHLOË DACTYLOIDES</i> — <i>ARNICA FULGENS</i> , PASTURE	30
III-3. DRY, <i>KOELERIA MACRANTHA</i> — <i>AGROPYRON TRACHYCAULUM</i> PRAIRIE	31
III-4. DRY, <i>CARDUUS NUTANS</i> — <i>BROMUS TECTORUM</i> , BARRENS	32
III-5. DRY, <i>STIPA COMATA</i> — <i>KOELERIA MACRANTHA</i> , PRAIRIE	33
III-6. DRY, <i>HETEROTHECA VILLOSA</i> — <i>BUCHLOË DACTYLOIDES</i> , PASTURE .	34
III-7. MOIST, <i>SYMPHORICARPOS OCCIDENTALIS</i> — <i>POA COMPRESSA</i> , LOW SCRUB	35
III-8. MOIST, <i>AGROPYRON TRACHYCAULUM</i> — <i>POA COMPRESSA</i> , MEADOW . .	36
III-9. WET, <i>SALIX EXIGUA</i> — <i>BARBAREA ORTHOCERAS</i> , STREAMBANK . . .	37
III-10. WET, <i>CAREX NEBRASKENSIS</i> — <i>JUNCUS ARCTICUS</i> , MARSH	38
III-11. DRY, <i>POLYGONUM AVICULARE</i> — <i>AMBROSIA PSILOSTACHYA</i> , BARRENS.	39
III-12. DRY, <i>HYPERICUM PERFORATUM</i> — <i>PARONYCHIA JAMESII</i> , PASTURE .	40
III-13. DRY, <i>HYPERICUM PERFORATUM</i> — <i>AMBROSIA PSILOSTACHYA</i> , BARRENS	41
III-14. DRY, <i>PINUS PONDEROSA</i> — <i>BROMUS TECTORUM</i> , SAVANNAH	42

FIGURE	PAGE
III-15. DRY, <i>SECALE CEREALE</i> — <i>BROMUS TECTORUM</i> , FIELD.	43
III-16. MOIST, <i>CRATAEGUS ERYTHROPODA</i> — <i>GALIUM APARINE</i> , SCRUB. . .	44
III-17. The locations of the 32 vegetation stands within the map area	48
IV-1. Amount of stress (loss of information) resulting from reduction of species number.	64
IV-2. Representative species from the ten life-form categories at Rocky Flats	68
IV-3. Relative abundance of the ten life-forms in the 32 sampling stands at Rocky Flats, based on an im- portance measure ("species" index)	69
IV-4. Comparison of two classification methods	87
V-1. Relative number of species in each vegetation stand and overlap of the two stands in a vegetation type	91
V-2. Relationships among the various vegetation types	96
V-3. Results of using the four data sets as the basis for Bray and Curtis ordination	103
V-4. Classification of the 32 vegetation stands based on their percentage similarity in terms of ten life-forms	111
V-5. Classifications of the 32 vegetation stands based on percentage similarity in terms of species or life- form composition	114
V-6. The noda produced by the stand classification based on life-forms plotted on the Bray and Curtis life-form ordination	118

FIGURE

PAGE

- V-7. The noda produced by all of the classifications,
 plotted within two dimensions of the Bray and
 Curtis life-form ordination 119
- V-8. Isolines representing values of the environmental
 variables which showed the highest correlations
 with the x axis, plotted on the Bray and Curtis
 life-form ordination 124
- V-9. Isolines representing values of the environmental
 variables which showed the highest correlations
 with the y and z axes, plotted on the Bray and
 Curtis life-form ordination 125
- V-10. Classifications of environmental variables and of stands,
 based on environmental variables. 127
- V-11. Isolines encircling stands that contain similar importance
 measures (species index) of *Stipa comata*, plotted in
 two dimensions of the Bray and Curtis life-form
 ordination. 130
- V-12. Isolines encircling stands that contain similar importance
 measures (species index) of *Agropyron trachycaulum*,
 plotted in two dimensions of the Bray and Curtis
 life-form ordination 131
- V-13. Isolines encircling stands that contain similar importance
 measures (species index) of *Poa compressa*, plotted in
 two dimensions of the Bray and Curtis life-form
 ordination. 132

FIGURES

PAGE

- V-14. Isolines encircling stands that contain similar importance measures (species index) of *Medicago sativa*, plotted in two dimensions of the Bray and Curtis life-form ordination 133
- V-15. The amounts of the life-form WOODY, LESS THAN 5 METERS IN HEIGHT in the 32 vegetation stands are plotted on three planes of the ordination. 135
- V-16. The amounts of the life-form HERBACEOUS, BROAD-LEAVED PERENNIALS in the 32 vegetation stands are plotted on three planes of the ordination. 136
- V-17. The amounts of the life-form HERBACEOUS, BROAD-LEAVED BIENNIALS in the 32 vegetation stands are plotted on three planes of the ordination. 137
- V-18. The amounts of the life-form HERBACEOUS, BROAD-LEAVED ANNUALS in the 32 vegetation stands are plotted on three planes of the ordination. 138
- V-19. The amounts of the life-form SUCCULENTS in the 32 vegetation stands are plotted on three planes of the ordination. 139
- V-20. The amounts of the life-form HERBACEOUS, NARROW-LEAVED PERENNIALS in the 32 vegetation stands are plotted on three planes of the ordination. 140
- V-21. The amounts of the life-form HERBACEOUS, NARROW-LEAVED ANNUALS in the 32 vegetation stands are plotted on three planes of the ordination. 141

FIGURES

PAGE

- V-22. The amounts of the life-form BRYOPHYTES in the 32 vegetation stands are plotted on three planes of the ordination. 142
- V-23. The amounts of the life-form LICHENS in the 32 vegetation stands are plotted on three planes of the ordination. 143
- V-24. The amounts of the life-form WOODY, GREATER THAN 5 METERS IN HEIGHT in the 32 vegetation stands are plotted on three planes of the ordination 144

PLATE 1. VEGETATION, ROCKY FLATS COLORADO pocket

CHAPTER I

INTRODUCTION

The area of Rocky Flats which is the subject of this vegetation study serves as a buffer zone around a plutonium processing plant. Much of the area is barren and disturbed from the combined effects of an exposed windy location, poor soil, excavating for fire-breaks, and animal activities such as small mammal burrowing and cattle and horse grazing. Parts of the area have soil which is contaminated by radioactive waste and soil erosion and subsequent redistribution of pollutants presents a problem. If the vegetation cover of the soil at Rocky Flats can be increased, the soil can be stabilized and this hazard can be lessened. The primary purpose of this study, therefore, is to describe and analyze the vegetation of Rocky Flats as it currently exists in order to facilitate the planning of vegetation management practices with a view towards increasing the vegetation cover.

This purpose can be accomplished through the achievement of two distinct, yet complementary, goals. The first is to produce a vegetation map of the area. The second is to analyze the vegetation in order to determine relationships among vegetation types and also to identify the environmental factors which are significantly related to, and perhaps have an influence on, the vegetation distribution within the area. These two goals are distinct in that different techniques and even attitudes toward the nature of the vegetation must be employed in attaining each. The first goal necessitates the

use of subjective, qualitative techniques and the attitude that the vegetation may be divided into discrete homogeneous types. The second goal is best achieved by the use of objective, quantitative techniques and the attitude that the vegetation distribution of the area is continuous along certain environmental gradients and that, although various vegetation types may need to be identified, the types are not discrete and are more or less related to each other. The two goals of this study are complementary to each other in that, together, they provide for a balanced and comprehensive means of describing the vegetation of this diverse area, an achievement which could not be attained through only one of these goals.

The Rocky Flats area of Colorado is a particularly interesting and complicated one at the scale (1:8,000) on which the vegetation mapping and analysis was conducted. The area is very diverse vegetatively for many reasons, including the following ones which were alluded to by Vestal (1914). Rocky Flats is located only a few miles to the east of an area where the plains abruptly meet the mountains. The fact that it is situated in a climatic and topographic transition zone results in such factors as an annually fluctuating climate and locally variable soil conditions and topography. In addition: "Opportunity for invasion by mountain plants is very good" and "Environmental conditions are on the whole severe; the vegetation is in large part open" (Vestal 1914, pp. 381 & 382). The result is that the vegetation is mixed and plant competition is not particularly evident. Instead, the nature of the vegetation is primarily a response to physical

environmental conditions. Thus, comparison of vegetation types in the Rocky Flats area to types commonly found in the Great Plains or mountain regions is difficult, since, for instance, plant species which are typically dominants of different associations elsewhere may be found growing together at Rocky Flats. A further complication at Rocky Flats is described by Vestal (1914, p. 382): "Present tendencies toward stabilization of mesa vegetation are more or less obscured by artificial factors, chief of which is grazing." In certain areas of Rocky Flats, excavating produces similar, but more drastic, results. The end result of all of these factors at Rocky Flats is a vegetation spectrum which contains elements of mixed prairie in the mesic areas, short-grass prairie in the dry areas and where the soil is compacted, ponderosa pine savannah on rocky ridges, and foothill ravine vegetation in the v-shaped valleys.

Knowledge of how the various diverse vegetation types of Rocky Flats are related to each other and to the environment will indicate changes that can be expected in the nature and distribution of the vegetation as a result of changes in the physical and chemical environment. Conversely, if the vegetation can be correlated with the physical and chemical environment, a vegetation map can be used to monitor changes in the environment as a whole--perhaps with less effort and more comprehensively than would be done by monitoring single environmental variables.

This study was part of a Botanical Inventory of the Rocky Flats region which was carried out by the Museum and the Institute of

Arctic and Alpine Research of the University of Colorado. Funding for the study was supplied by a contract from the Energy Research and Development Administration. Drs. William A. Weber and Patrick J. Webber were the principal directors of this study. A preliminary report (Weber, Kunkel and Schultz, 1974) from the study provided a list of the species found within the Rocky Flats Plant boundary in summer, 1973. This dissertation reports the vegetation mapping and vegetation analysis phase of the Botanical Inventory.

CHAPTER II

THE DESCRIPTION OF THE STUDY AREA

Location

The Rocky Flats area is located eight miles south of Boulder, Colorado, and ten miles northwest of Denver. The foothills of the Rocky Mountains lie two miles to the west. Most of the study area is included in Jefferson County with the exception of the northernmost portion which lies in Boulder County. The area comprises fifteen square miles (38.8 square kilometers) and is bordered on all sides by paved roads: Highway 128 on the north, Indiana Street on the east, Highway 72 on the south, and Highway 93 on the west. The Rocky Flats Plant, owned by the Energy Research and Development Administration and operated by Rockwell, International, is located within the study area and covered approximately one-fourth of the study area in 1974. The remainder of the area is privately owned, most of it is used as pasture for range animals and as agricultural fields. Figure II-1 shows the location of the study area with respect to Denver and Boulder, Colorado.

Geology

Two types of bedrock immediately underlie the surficial deposits in the study area. Laramie Formation is younger and underlies most of the area, Pierre Shale is found along a narrow margin on the western edge. The boundary between the two types forms a north-south line paralleling but approximately one-half mile east of Highway 93.

Figure II-1. Location of the study area.

Laramie Formation is described as: "Light-to-medium-gray quartzose sandstone and claystone", with "several lenticular sub-bituminous coal beds in the lower 200 feet"; Pierre Shale is described as: "Predominantly medium-gray clayey shale and some calcareous concretions, interbedded with some siltstone and silty sandstone" (Van Horn 1972, Map 1-761-A). Hurr (1976) describes two additional bedrock formations. The Fox Hills Sandstone underlies the Laramie Formation and is 40 to 90 feet (12 to 27 m) thick. It " consists of sandy shale grading stratigraphically upward into a massive sandstone" (Hurr 1976, p. 4). The Arapahoe Formation overlies (unconformably) the Laramie Formation and its maximum thickness is approximately 270 feet (82 m). "The Arapahoe Formation is a continental deposit of lenticular sands interbedded with clay" (Hurr 1976, p. 4). This formation is " either exposed at land surface or covered unconformably by unconsolidated surficial deposits" over most of the eastern half of the study area (Hurr 1976, p. 4). The Laramie Formation can also be divided into two units--a lower sandstone one which " consists of 150 to 320 feet (46 to 98 m) of interbedded sandstone and claystone" and an upper shale one which consists of 450 to 630 feet (137 to 192 m) of claystone (Hurr 1976, p. 4). Figure II-2 and II-3, the bedrock and surficial geology of the study area, are adapted from Hurr (1976, plate 1) and Malde (1955).

The surficial deposits which cover nearly the entire western half and the valley-sides and -bottoms of the eastern half of the study area " consist of terrace alluvium, colluvium, and valley-fill alluvium" (Hurr 1976, p. 4). Hurr (1976) further states that

Figure II-2. Geology of the study area. The map is adapted from Hurr (1976, plate 1) and Malde (1955).

Figure 11-3. Geologic section through the study area. The diagram is taken from Hurr (1976, plate 1).

they are usually not more than 50 feet (15 m) thick and are composed of all soil fractions from clay to cobbles and often contain boulders. These deposits are derived mainly from the Precambrian quartzite of the mountains which lie a few miles to the west of the study area, although some material is provided by the sedimentary bedrock and also by the surficial deposits which are the oldest. The most important and widespread surficial deposit is the Rocky Flats Alluvium--"Contact springs commonly issue from the base of the Rocky Flats Alluvium"--making it important hydrologically as well (Hurr 1976, p. 5). "The Rocky Flats Alluvium is a broad planar deposit which, in this area, is an alluvial fan deposited downslope from the mouth of Coal Creek Canyon" (Hurr 1976, p. 5).

Topography

The elevation of the area ranges from 6250 feet (1905 m) at the plains of the southwestern sections to 5600 feet (1707 m) at the valleys of the southeastern sections. Figure II-4 shows the topography along four transects through the study area. The topographic base is taken from the United States Geological Survey maps of Colorado--Golden Quadrangle and Louisville Quadrangle on a scale of 1:24,000 with 10-foot contour intervals. Small ephemeral streams and drainage channels dissect much of the central and eastern sections and the whole area slopes gently towards the east. The hydrology of the area, including drainage basins of three streams, is described by Hurr (1976).

Figure II-4. Topography along four transects through the study area. The topographic base is taken from U. S. Geological Survey maps of Colorado--Golden and Louisville Quadrangles.

Climate

The climate of the Rocky Flats area is similar to that of the Great Plains in general although it is tempered by the proximity of the Front Range of the Rocky Mountains. Characteristically, winters are cold and dry and precipitation occurs mainly during the warmer seasons (Livingston 1952). Wind gusts, caused by the nearness of the mountains, are generally higher in the Rocky Flats area than in other areas of the Great Plains. Based on climatological data gathered in 1974 (the year in which the field work for this study was done) at the Rocky Flats Plant and stored in their Environmental Master File, the following conclusions and comparisons can be made. The month in which mean temperatures are the lowest is January and the month in which mean temperatures are the highest is July (based on a 22-year monthly average). 1974 followed this pattern, differing only in that mean temperatures were three to five degrees Fahrenheit higher during the months of February through July than the 22-year average. The growing season began slightly earlier than usual as a result and many of the early-blooming annual plants were not represented in the vegetation sampling which was done during July and August. The mean daily temperature during 1974 was 51 degrees Fahrenheit, slightly above the 22-year average of fifty degrees Fahrenheit. Average relative humidity generally peaks during the months of March through May with another smaller peak occurring during November. In 1974, average relative humidity was highest during the months from August to November with the peak occurring during October. The average relative humidity of

this peak was over ten percent higher than the 22-year average for the month of November. A smaller peak occurred during the months of March and April in 1974. The relative humidity of this peak was two percent higher than the 22-year average for the months of March and April. The relative humidity was lower than the 22-year average during the months of January, February, and May, 1974. Amount of precipitation was higher during the months of January through April and lower during the months of May through December, 1974, than the 22-year average. This may have resulted in somewhat lusher, as well as earlier, vegetation in the spring of 1974. The summer of 1974 was very dry and the total precipitation for the year was over two inches less than the 22-year average of annual precipitation. Wind velocity at Rocky Flats is generally the highest during the months of November through March and is lowest during August. Peak gusts of wind were higher than the 22-year average during June through September of 1974. A summary of some weather conditions during the months when the field work for this study was done--June through August, 1974--indicates that peak gusts of wind were higher, monthly precipitation was lower, and mean monthly temperatures were slightly higher than the 22-year averages. The combination of these three conditions may have resulted in earlier-than-usual senescence of plant parts, resulting, in turn, in a greater cover of plant litter over the ground. This may have somewhat alleviated the greater amount of wind erosion which would be expected during this period. Selected weather conditions at the Rocky Flats Plant site during 1974 are given in

Table II-1. Figure II-5 is a wind rose for 1974. The predominant wind direction in 1974 was from the northwest as opposed to the 22-year average which is from the west. Table II-1 and Figure II-5 are adapted from the Rocky Flats Environmental Master File.

Soils

The vegetation and soils of an area are necessarily related to each other. Properties of the soils which are particularly important to vegetation distribution include soil particle size, soil pore size, amounts of nutrient elements which are available for plant use, amount and availability of soil moisture, and soil stability. Together with the local climate and often the topography, these variables primarily " determine the differences in plant communities" (Branson et al. 1965, p. 311).

The vegetation gradually changes the character of the soil on which it grows, primarily by the addition of organic matter to the surface horizons through partial decomposition of above- and below-ground plant parts. "Where landscapes are predominantly grassland of sufficient age, the soils usually have dark-colored, neutral to mildly alkaline surface horizons that have more than 1 percent organic matter" (Moreland and Moreland 1975, p. 76).

The soils of the Rocky Flats area belong to the Larimer, Fort Collins, Cass, and Terry series with the surface layers of each being a type of loam. In addition, a significant percentage of the area (forty percent) is classified as "Rough broken land", suitable only for pasture because of steepness or large amounts of

TABLE II-1

SELECTED WEATHER CONDITIONS AT ROCKY FLATS DURING 1974

COMPARISONS WITH A 22-YEAR RECORD ARE INCLUDED

	1974 Record	1974 Average	22-Year Average	22-Year Record
Temperature (based on hourly observations)				
Mean Daily Temperature	74°F (23°C)	51°F (11°C)	50°F (10°C)	75°F (24°C) 7-64, 7-65
Maximum Daily Temperature	95°F (35°C)	79°F (26°C)	77°F (25°C)	102°F (39°C) 7-12-71
Minimum Daily Temperature	-8°F (-22°C)	24°F (-4°C)	22°F (-6°C)	-26°F (-32°C) 1-12-63
Relative Humidity				
Average Relative Humidity		49%	46%	60%
Precipitation				
		1974		
Total Annual Precipitation		13.73" (34.87 cm)	15.75" (40.01 cm)	24.67" (62.66 cm) 1969
Greatest Amount of Precipitation in a Single Month		2.87" (7.29 cm)	2.88" (7.32 cm)	9.70" (24.64 cm) 5-69
Greatest Amount of Precipitation in a Single Day		April 1.68" (4.27 cm) 6-8-74	1.04" (2.64 cm)	3.40" (8.64 cm) 5-6-69
Wind Conditions				
Mean Wind Velocity		8.3 mph (13.4 kmph)	8.2 mph (13.2 kmph)	9.0 mph (14.5 kmph) 1953
Greatest Monthly Mean Wind Velocity		11.3 mph (18.2 kmph)	10.0 mph (16.1 kmph)	15.0 mph (24.1 kmph) 1-53
Peak Gust Velocity		79.0 mph (127.1 kmph) NW, 12-18-74	77.0 mph (123.9 kmph)	106.0 mph (170.6 kmph) W, 3-1-56, 1-18-59
Predominant Wind Direction		Northwest		West (31%) 1953

Figure II-5. Wind rose for Rocky Flats during 1974.

surface boulders (Harper 1932, p. 30). The following soil descriptions are taken from Harper (1932) as is the soil map of the study area shown in Figure II-6.

Larimer gravelly loam covers approximately 43 percent of the study area and is found over much of the western half of Rocky Flats. It contains a portion of large stone which makes it unsuitable for cultivation. The surface horizon is eight inches deep and consists of a brown moderate- or highly-calcareous gravelly loam or gravelly sandy loam. Below this is a layer of calcareous clay. A dense lime carbonate horizon occurs below fifteen or twenty inches. The lime content increases up to a depth of four to six feet below the surface, at which point it begins to decrease and the amount of gravel increases. Larimer gravelly clay loam is similar to Larimer gravelly loam except that the upper layers have a clay loam texture and are noncalcareous. This soil has a heavy texture and is useful mainly for pasture although crops can be grown in areas which are free of large stones. At Rocky Flats, Larimer gravelly clay loam covers approximately five percent of the area and a shallow phase, underlain by sandstone at about two to five feet below the surface, covers eight percent. The Larimer gravelly clay loams are found on the eastern half of Rocky Flats and farther from the source of the Larimer soil materials, which is old weathered material to the west.

Fort Collins stony clay loam, light textured phase, covers about two percent of the study area and is found along valley-sides in the eastern part of Rocky Flats. It was developed from alluvial

Figure II-6. Soils of the study area. The soil map is adapted from Harper (1932).

materials carried down out of the mountains and deposited on the creek beds. The surface layer of this soil consists of eight inches of brown noncalcareous stony clay loam with a component of fine sand which somewhat lightens the texture. From eight to sixteen inches below the surface, the soil is a noncalcareous clay mixed with gravel and stones, making it unfit for cultivation. A stony loam containing some lime carbonate forms a grayish brown horizon from sixteen inches to five feet below the soil surface. Below five feet, loose sand, gravel, and stones are moderately calcareous.

Cass loam and Cass clay loam each cover less than one percent of the study area and are found on three valley-bottoms at Rocky Flats. These soils developed over alluvium which was mainly granitic in content. The surface layer of these soils consists of ten inches of deep-brown friable noncalcareous loam or clay loam with a significant mica content. A horizon which is varied in texture and may be up to four feet deep is sometimes found below the surface layer. A gravelly sandy loam layer starts at from ten inches to five feet below the soil surface and is six or more feet deep. If this gravelly layer lies near the surface the soil is hard to cultivate, otherwise, well-drained soil of this type is particularly useful for cultivation.

Terry fine sandy loam covers less than one percent of the study area and is found on the sides of one valley at Rocky Flats. This soil develops primarily from sandstone. The top ten inches of soil are a brown loam or fine sandy loam that is noncalcareous and friable. The clay content increases in the next layer which

extends from ten inches to two feet below the soil surface. Below this layer, or at other depths up to six feet, bedrock, composed of sandstone, occurs.

Vegetation

The dominant vegetation of the western portion of Rocky Flats is disturbed " mixed prairie "--a type of grassland which is generally equally dominated by both mid and short grasses (Weaver and Clements 1938, p. 523). The mid grasses are the most conspicuous element in this type because of their height, and the appearance of an undisturbed mixed prairie is of a more or less dense swale of grasses two to four feet in height with an understory of short grasses and a mixture of subdominant forbs. Over much of the area, where overgrazing favors the growth of short grasses, or the soil is more compact or drier, a short-grass version occurs. In the enclosed Plant site, where barbed-wire fences surrounding the four-square-mile area have prevented grazing by stock for the last twenty years, vegetation similar to the mixed prairie type, but much less floristically diverse, now occurs. The areas of the eastern portion of Rocky Flats which are outside of this barbed-wire boundary fence are overgrazed, drier, and the soil is compacted, and short grasses have formed an almost continuous sod over them as a result. The importance of grazing as an influence on the nature of the vegetation is indicated by the sharp demarcations between these two types of grassland wherever fences result in differential

grazing on either side. Where overgrazing is very severe or where bulldozing or excavating occurs periodically, grasses no longer dominate the vegetation and annual weedy species are abundant. These areas may be called "pastures" if there is any resemblance to grassland, or "barrens" if they are very disturbed and no longer resemble grassland at all.

A successful invasion of montane forest vegetation into the grassland of Rocky Flats probably occurred during the Pleistocene when climatic conditions were favorable for the advance of the forest onto the plains (Weber, Kunkel and Shultz 1974). This would have required " a period of above-normal rainfall long enough to enable the young trees to reach a considerable size and great enough to supply them with underground water" (Gleason and Cronquist 1964, p. 202). This process can be reversed as follows:

With a long or permanent reduction of the rainfall to a point below the limit of tolerance of the pines, the herbaceous plants will die out completely (or almost so), the trees will succumb one by one (thereby reducing the shade and further hampering the forest herbs), and the whole floristic group of the plains will gradually move up into the mountains (Gleason and Cronquist 1964, p. 202).

The ponderosa pine savannah which occupies a north-south ridge one-half mile east of Highway 93 at Rocky Flats, as well as the flora of some of the ravines at the site, are probably remnants of the eastward advance and subsequent retreat of the forest-plains margin.

Dense swales of marsh vegetation, composed mainly of sedges, are found in the relatively wet valley-bottoms at Rocky Flats.

Tall, dense streambank communities occur along many of the ephemeral streams and ditches which dissect the area. In the southeastern corner of the study area, agricultural fields have almost replaced the natural vegetation entirely.

The various types of disturbance of the vegetation at Rocky Flats have increased the number of vegetation types which cover the area and have sharpened the boundaries between those types. At the same time, the number of species in each of the types has been reduced, compared to the great diversity of species which is a characteristic of the natural vegetation of the area.

CHAPTER III

THE METHODS OF VEGETATION MAPPING

Introduction and Concepts

A vegetation map is a qualitative description of the spatial distribution of plant associations or communities. A useful definition of plant communities is that they are " . . . subdivisions of a vegetation cover. Wherever the cover shows more or less obvious spatial changes, one may distinguish a different community" (Mueller-Dombois and Ellenberg 1974, p. 4). A list of possible manifestations of these changes would include the following:

" . . . spatial changes in species composition, changes in spacing and height of plants, changes in growth form or life form of plants, or seasonal plant responses of other vegetation properties . . . " (Mueller-Dombois and Ellenberg 1974, p. 4).

Vegetation mapping is a form of classification which is of value to other ecologists in that the map, combined with map unit descriptions, may be used without a comprehensive knowledge of the vegetation. Like all classification, vegetation mapping seeks to compartmentalize the vegetation into discrete units. Each of the units is an abstract representation of one or more homogeneous plant communities. A plant community is " . . . a combination of plants that are dependent on their environment and influence one another and modify their own environment" (Mueller-Dombois and Ellenberg 1974, p. 27). Unlike objective quantitative

classification, a vegetation map may be subjectively based on one or a variety of vegetation characteristics which are incorporated to different degrees at the discretion of the mapper. Although difficult, it is necessary to verbalize what combination of characteristics is used in constructing a particular map.

Methods

A widely-used method of vegetation mapping in the United States is that of Küchler (1967). Briefly, this method entails the following steps: (1) compiling a floristic inventory of the map area; (2) determining the approximate number and size of the prospective map units; (3) outlining the areas of different shades on black-and-white aerial photographs of the area, in the laboratory; (4) field verifying each outlined area to determine its vegetation composition, environmental characteristics, and homogeneity; (5) classifying the areas into the desired number of map units on the basis of any number of characteristics noted in the previous step--objective quantitative classification may be incorporated at this step and will serve to define what the basis for the map actually is, and make repetition and comparisons possible; and, finally, (6) constructing the final version of the map at the desired scale. It should be noted that once the field verifications and summaries are made, a different map based on a different classification may be compiled easily in the laboratory, based on the field observations, when this method is used.

The original intent was that Kùchler's method, as outlined above, would be followed as much as possible in mapping the vegetation of Rocky Flats. Two important deviations from this method were made in order to adapt it to the Rocky Flats situation. The first involved drawing unit boundaries on the photographs while the mapper was in the field rather than in the laboratory as stated in step 3, above. The second involved omitting a portion of step 4, above. While almost all areas outlined on the aerial photos were field verified (since this was necessary for drawing boundaries), the various ecological characteristics of each individual area were not recorded. This would have been much too time-consuming for the purposes of this study. Instead, each area was given a number corresponding to a mapping unit with which its floristic composition was most readily identified. It was stated in step 5 that objective quantitative classification could be carried out before field mapping is done and advantages for doing this were pointed out. When time is a limiting factor, as it was at Rocky Flats, this is usually not feasible. Kùchler (1967, p. 98) has made the following statements on this subject:

An author desiring to study the vegetation of any given area will obtain particularly satisfactory results if he prepares a detailed vegetation map as a first step and bases his map on aerial photographs. He will then base his investigations on the map and on the observations he made in preparing it. To prepare a vegetation map after the study has been completed is to deprive oneself of the most enlightening study method yet devised.

The following section on unit selection gives the steps of the procedure which was actually used as they correlate with the steps of Küchler's method listed above. A section on unit sampling techniques is included next since sampling is an integral part of vegetation mapping and must be compatible with vegetation mapping methods. Vegetation mapping is not complete without gathering a data bank on the map units for the purpose of performing quantitative analytical techniques. These analyses are able both to demonstrate the success of the mapping and to elucidate inter-relationships among the map units and the environmental factors. Vegetation analysis, in turn, is not complete without the correlation of environmental factors and a section explaining soil sampling techniques is included. The final section is on cartography. The concern for cartography is becoming more prevalent in vegetation mapping. More ecologists are realizing that much of the time-consuming gathering of information can be wasted unless as much of the information as possible is presented in the form of a logically organized, useable map. Information which cannot be presented within the framework of a map can be included in a text which accompanies the map, but it should be kept in mind that not all of the map users will want to read it. Thus, a reasonable goal is to make the map and the legend as comprehensive as possible.

Unit Selection

A species inventory of vascular plants, bryophytes, and lichens of the Rocky Flats Plant site proper (Weber et al., 1974) was expanded by plant collections from the remaining peripheral areas made by Věra Komárková in summer, 1974. A preliminary survey of the vegetation resulted in a decision that approximately twelve mapping units would adequately represent the vegetation. It was estimated that the final map would be a fifty percent reduction of the original map and a minimal field mapping area of 65 feet (19.8 m) square was chosen; this size of area would be represented as one millimeter square on the final color version of the map--a size which Kùchler (1967) considers to be the smallest distinguishable area on a color map. Black-and-white aerial photographs of the Rocky Flats area taken in 1972 by NASA were enlarged to a ratio scale of 1:7920. Examination of the photography led to the decision that many more types of plant communities could be identified in the field than could be distinguished on the photographs. This potential problem was pointed out by Mueller-Dombois and Ellenberg (1974, pp. 425 & 426):

Vegetation units defined by their total floristic composition cannot always be clearly recognized on air photos because the structure visible on air photos is primarily conditioned by the dominant species and their developmental status.

Since it was desired to map on a large scale and on the basis of total floristic composition, a modification of Kùchler's method was utilized in mapping most of the Rocky Flats area.

The modification involved establishing and verifying community boundaries on the aerial photographs directly in the field, based on a subjective classification of changes in floristic species composition. Where ground access to private property within the mapping area was not granted, unit boundaries were merely drawn on the photos based on shades of gray. Not all of these restricted areas could be visited and field verification had to be made from a distance. Units were combined and additional ones were incorporated during the mapping process. Sixteen final mapping units were selected for visual vegetational homogeneity and the map was reorganized on this basis. They are illustrated and briefly described in Figures III-1 through III-16. It should be noted that both disturbed and nondisturbed plant communities are represented as mapping units. Some ecologists consider disturbed vegetation to be successional stages of nondisturbed vegetation and that it should be classified with the related nondisturbed or natural unit (Mueller-Dombois and Ellenberg 1974). This weighting of nondisturbed vegetation would be impractical at Rocky Flats for several reasons: (1) there is very little nondisturbed or natural vegetation left at Rocky Flats with which to compare and classify the many types of disturbed communities; (2) the purpose of the map is to show existing vegetation; Mueller-Dombois and Ellenberg (1974, p. 417) state that if the existing vegetation rather than the potential natural vegetation is mapped, the map will " . . . form a documentation 'frozen' in time" and " . . . may thus serve to evaluate successional

Figure III-1

DRY, *BUCHLOE*^{II} *DACTYLOIDES*--*MEDICAGO SATIVA*, PASTURE.
 This vegetation unit occurs in patches on dry, heavily-
 grazed pediment. It covers approximately 2.5 percentage
 of the total area. *Buchloë dactyloides* forms a compact
 sod and is only a few centimeters high. *Medicago sativa*
 and *Gutierrezia sarothrae* form an open stand and are
 about 0.5 meters in height.

Figure III-2

DRY, *BUCHLOE DACTYLOIDES*--*ARNICA FULGENS*, PASTURE.
 This vegetation type covers much of the dry, heavily-
 grazed pediment in the eastern portion of the area.
 It comprises approximately 16.4 percentage of the
 total area. *Buchloë dactyloides* forms an almost
 continuous sod. *Arnica fulgens* and *Bromus tectorum*
 are scattered throughout the area.

Figure III-3

DRY, *KOELERIA MACRANTHA*, *AGROPYRON TRACHYCAULUM*, PRAIRIE. This vegetation unit is found on pediment within the barbed wire fence boundary of the site where grazing does not occur. It covers approximately 7.8 percentage of the total map area. Grasses are dominant and range in size from 0.25 meters to nearly one meter. Common grasses include *Koeleria macrantha*, *Agropyron trachycaulum*, *Muhlenbergia montana*, and *Schizachyrium scoparium*--an indicator of mid-grass prairie. Herbs are represented by *Artemisia ludoviciana* and *Heterotheca villosa* (left, A), and *Antennaria parviflora* (left and bottom, B). Succulents include *Sedum lanceolatum* (right, B) and *Opuntia compressa* (top, B).

Figure III-4

DRY, *CARDUUS NUTANS*--*BROMUS TECTORUM*, BARRENS.

This vegetation type occurs in patches on disturbed soil throughout the area. It covers approximately 3.2 percentage of the total area. Two distinct facies are represented. *Carduus nutans* may reach over one meter in height and forms open stands on dry soil with a dense understory of *Bromus tectorum* (A). *Cirsium arvense* is smaller in stature and forms more dense stands on moist valley-sides and in meadows (B).

Figure III-5

DRY, *STIPA COMATA*--*KOELERIA MACRANTHA*, PRAIRIE.
This vegetation type approximates native prairie and covers areas of relatively undisturbed pediment. It comprises approximately 7.1 percentage of the total area. The dominant and most conspicuous species is *Stipa comata*, a native prairie grass which may grow to one meter in height. Other indigenous grasses include *Koeleria macrantha*, *Andropogon gerardii*, and *Sitanion longifolium*.

Figure III-6

DRY, *HETEROTHECA VILLOSA*--*BUCHLOË DACTYLOIDES*, PASTURE. This vegetation type is found on rocky ridges and pediment. It covers approximately 8.4 percentage of the total area. *Heterotheca villosa* is a conspicuous yellow-flowered composite which grows to a height of about 0.25 meters and forms an open, spreading cover. Dominant grasses in this type include *Buchloë dactyloides*, *Bouteloua curtipendula* and *Bromus tectorum*.

Figure III-7

MOIST, *SYMPHORICARPOS OCCIDENTALIS*--*POA COMPRESSA*, LOW SCRUB. This vegetation type is scattered in discrete stands along many of the valley-sides. It covers approximately 0.7 percentage of the total area. *Symphoricarpos occidentalis* and *Symphoricarpos oreophilus* form a dense scrub about 0.5 meters high. Many grasses including *Poa compressa*, *Agropyron trachycaulum*, and *Bromus tectorum* grow at the margins of the stands but there is virtually no understory within the stands.

Figure III-8

MOIST, *AGROPYRON TRACHYCAULUM*--*POA COMPRESSA*, MEADOW. This vegetation type is found on many of the valley-sides and bottoms. It covers approximately 22.9 percentage of the total area. *Agropyron trachycaulum* grows to nearly a meter in height in the drier areas along with *Bromus tectorum*, *Poa pratensis*, and *Tragopogon dubius*. *Poa compressa* is a shorter grass which often dominates the wetter slopes and valley-bottoms.

Figure III-9

WET, *SALIX EXIGUA*--*BARBAREA ORTHOCERAS*, STREAMBANK. This vegetation occurs along the larger streams and covers approximately 0.7 percentage of the total area. *Salix exigua* often grows to a height of two meters and, with other shrubs, provides cover for the deer which inhabit the area. *Cirsium arvense* often forms a dense understory. Other species which sometimes are present include *Barbarea orthoceras*, *Epilobium adenocaulon*, and *Fallopia convolvulus*.

Figure III-10

WET, *CAREX NEBRASKENSIS*--*JUNCUS ARCTICUS*, MARSH.

This vegetation type occurs in stream flood-plains and along wet valley-bottoms. It covers approximately 3.5 percentage of the total area. The proportion of *Carex nebraskensis* is greater along streams where it forms dense swales 0.5 meters in height. *Juncus arcticus* dominates in slightly drier areas and forms taller, more open swales with a thick ground cover of litter through which small mammals tunnel. Another facies of this type is composed of *Typha latifolia* which forms small dense stands in very wet areas such as pond-margins (B).

Figure III-11

DRY, *POLYGONUM AVICULARE*--*AMBROSIA PSILOSTACHYA*, BARRENS. This vegetation unit is typically found on heavily bulldozed areas including fire breaks and old road beds. It comprises approximately 1.5 percentage of the total area. The plants are mainly decumbent annuals with the exception of *Ambrosia psilostachya* which often grows to 0.5 meters (B). The vegetation cover is very sparse and is a poor barrier to wind erosion.

Figure III-12

DRY, *HYPERICUM PERFORATUM*--*PARONYCHIA JAMESII*, PASTURE.
 This vegetation type covers much of the pediment that
 has been disturbed by over-grazing. It comprises
 approximately 11.5 percentage of the total area.
 Dominant and conspicuous herbs include *Hypericum*
perforatum, *Paronychia jamesii*, *Eriogonum alatum* and
Liatris punctata. The grasses are represented by
Koeleria macrantha and *Buchloë dactyloides*.

Figure III-13

DRY, *HYPERICUM PERFORATUM*--*AMBROSIA PSILOSTACHYA*, BARRENS. This vegetation unit is found on heavily grazed pastures and mechanically disturbed roadsides. It covers approximately 3.3 percentage of the total area. The dominant herbs, including *Ambrosia psilostachya* (left, A), are weedy perennials. The grasses are mainly represented by a weedy annual, *Bromus tectorum* (B), and an indigenous perennial, *Bouteloua hirsuta*. The vegetation often averages 0.25 meters in height.

Figure III-14

DRY, *PINUS PONDEROSA*--*BROMUS TECTORUM*, SAVANNAH. This vegetation type forms a stand of scattered trees on a dry, rocky, north-south ridge in the northwest corner of the area. It covers approximately 0.04 percentage of the total map area. *Pinus ponderosa* often grows to a height of 10 meters. Typical understory species are *Bromus tectorum* and *Rhus trilobata*. Many species of rock lichens are present, such as *Lecanora muralis* and *Acarospora fuscata*. *Pinus ponderosa* needles form a partial layer of litter over the soil surface; this may protect the soil from the wind erosion which is frequent in such an overgrazed area.

Figure III-15

DRY, *SECALE CEREALE*--*BROMUS TECTORUM*, FIELD.

This vegetation unit contains both planted and fallow fields and covers approximately 9.7 percentage of the total area. A typical field of *Secale cereale* has an understory of weedy annuals such as *Bromus tectorum* and *Lactuca serriola* (B). Harvesting results in a layer of litter over the soil surface which may protect it from wind erosion during the winter.

Figure III-16

MOIST, *CRATAEGUS ERYTHROPODA*--*GALIUM APARINE*, SCRUB. This vegetation type forms discrete stands on north-facing valley-sides and in gulches. It covers approximately 0.9 percentage of the total area. The dominant shrub species, *Crataegus erythropoda* often grows to two meters in height. Understory species include *Galium aparine*, *Bromus tectorum*, *Arctium minus* and *Hydrophyllum fendleri*. A shorter facies of this vegetation unit which is included in this type is often dominated by another shrub, *Rhus trilobata*.

changes . . . " and it is anticipated that the Rocky Flats map will prove to be useful in this respect; (3) most of the plant community boundaries on which the Rocky Flats map is based resulted from preferential disturbance of the natural vegetation. An obvious example of this is where fence lines have prevented grazing from occurring on one side but not the other, resulting in a straight-line demarcation between two plant communities. Furthermore, some very sharp boundaries occur at Rocky Flats in areas where managed vegetation--called "Replacement Communities" (Mueller-Dombois and Ellenberg 1974, p. 413)--has replaced the natural vegetation. These are the agricultural fields which cover a major portion of the southeastern section of the map area.

Whittaker came to the following conclusion in Poole (1974, p. 372):

Because of the tapered form of the population gradient, the composition of communities changes continuously along environmental gradients if the gradients are uninterrupted and communities undisturbed. Disruptions will tend to produce distinct community types or groups, in the same way that a cornfield is distinct from a neighboring pasture.

Thus some of the problems inherent in drawing arbitrary boundaries around natural vegetation communities, and making vague subjective classifications have been alleviated at Rocky Flats. It is easier to map a disturbed area and to distinguish amounts of disturbance than to map a natural area.

Unit Sampling

A vegetation type or map unit is an abstract classification unit with many concrete members in the field. No one plant community will be found which will identify exactly with the

vegetation type as a whole. Although one or more representative stands must be chosen for sampling purposes, it is important to recognize that each stand is a real individual member of the abstract unit. As used in this thesis, the words vegetation type and map unit will refer to an abstract classification unit and the words plant community and stand will refer to a concrete member of an abstract unit (Mueller-Dombois and Ellenberg 1974).

There were several decisions to be made concerning sampling format. These include the following: (1) What number of sampling stands and how much repetition was necessary such that the plant community closely approximates the vegetation type? (2) How many quadrats should be sampled per stand, i.e., what should be the sample size? (3) What should be the size and shape of the quadrats? (4) What quantifiable feature of the vegetation should be measured? (5) At what level should measurements be taken? Since phytosociology was to be the most important part of the study, samples had to be chosen such that they would best represent the vegetation types (Whittaker 1973). Once the vegetation has been divided into segments through mapping or other means of classifying, stands or plots are sampled to determine the validity of that classification. Thus the question of whether to locate sample stands randomly or systematically does not arise in classification studies. "These plots are established in the vegetation segment in locations wherever the segment appears to be most typically represented" (Mueller-Dombois and Ellenberg 1974, p. 38).

Although it was desirable to limit the number of sampling stands, some repetition was considered necessary to account for variability across the mapping area and to sample for patterns which occur across the area, for classification purposes (Mueller-Dombois and Ellenberg 1974). Since several of the vegetation types contained two ecological facies, two sampling stands were considered to be the minimum number which would adequately represent each vegetation type within the map area, therefore, a total of 32 stands were chosen. Many of the stands were located on land that was privately owned at the time. Therefore, all the stands were treated as temporary stands to be used for immediate sampling purposes rather than permanent stands which could be sampled every year. The stand locations within the mapping area were plotted and are shown in Figure III-17.

Techniques to determine the minimal sample area which will adequately represent the vegetation are commonly used when it is desirable to sample for plant communities that recur throughout the area (Mueller-Dombois and Ellenberg 1974). Unfortunately, these techniques are time-consuming and for this reason it was decided to sample ten quadrats per stand at Rocky Flats. It was desirable to use the same size quadrat in sampling all of the vegetation types for ease in statistical analysis and a quadrat size and shape of 1 x 1 meter was chosen. This size and shape of quadrat is commonly used to sample the herbaceous layer of vegetation (Mueller-Dombois and Ellenberg 1974). Although four distinct layers of vegetation are represented at Rocky Flats

Figure III-17. The locations of the 32 vegetation stands within the map area.

the herbaceous layer is common to all of the vegetation types and is dominant in most of them. Twelve of the sixteen vegetation types are composed mainly of an herbaceous layer of vegetation--some of these contain an insignificant layer of bryophytes or lichens. Three of the remaining four types contain an herbaceous layer but also have a significant component of woody vegetation that is less than five meters in height. One vegetation type contains not only herbaceous vegetation and woody vegetation less than five meters in height but also a significant lichen layer and a canopy of woody vegetation that is greater than five meters in height.

Three quantities of vegetation which can be measured are considered to be most important for sampling plant communities: density (abundance), frequency, and cover (Mueller-Dombois and Ellenberg 1974). It was decided that a cover measurement of the vascular plants, lichens, and bryophytes at Rocky Flats would be essential to the vegetation analysis for two reasons. First, measuring the cover of plant species gives a better approximation of plant biomass than does counting the individuals. Plant biomass may demonstrate the ability of the vegetation to build up organic material. Plant biomass is also important in that it affects many of the abiotic properties of the stand and should correlate more readily with these variables than would the number of individual plants. Second, cover is a quantity by which all four layers of the Rocky Flats vegetation, from the bryophyte and lichen layer to the tree layer, can be measured and compared. An

added advantage is that environmental factors such as amount of rocks and bare soil can be quantified by this same measurement, cover, and can be compared with vegetation cover. There are several methods of measuring cover. A form of the quadrat-charting method was used at Rocky Flats. This method usually involves replicating the vegetation, on paper or film, exactly as it appears in the quadrat, a method which is chiefly useful for continuing evaluation of permanent quadrats and is very time-consuming (Mueller-Dombois and Ellenberg 1974). At Rocky Flats, the crown cover of the plant species was estimated as a percentage of the total area of the quadrat. Since the cover was estimated rather than measured, this method allowed for the greatest amount of sampling for cover in the available time. The use of square quadrats as opposed to rectangular or circular ones contributed to the ease of estimating cover.

Measurements can be taken at four levels: nominal, ordinal, interval, and ratio. Certain statistical procedures are appropriate at each level. Parametric statistical tests are appropriate only at the interval and ratio level of measurements. Cover is often measured at the interval level. At Rocky Flats, cover was measured at the ratio level in order that all statistical procedures, including geometric mean and coefficient of variation, could be applied to the data (Siegel 1956).

Percentage cover (PC) of the vegetation was measured according to the procedure outlined above. Species that occupied less than one percent of the quadrat area were given the minimum value

of one percent. Frequency (P) of each species was determined by noting the number of quadrats per stand in which the species occurred. Other species importance measures, relative cover (RC), relative frequency (RF), and species index (SI), were computed from the percentage cover and frequency data according to the formulas given in May (1973, pp. 26 & 27) as follows:

$$\text{"RC of a species"} = \frac{\text{PC of that species} \times 100}{\text{Total PC of all species}},$$

$$\text{"RF of a species"} = \frac{\text{P of that species} \times 100}{\text{Total number of occurrences of all species}},$$

$$\text{"Species Index (SI)} = \frac{\text{RC} + \text{RF}}{2}.$$

All species whose field identification was questionable were collected and identified by Dr. Věra Komárková and verified by Dr. William A. Weber, Curator of the University of Colorado Herbarium.

Percentage cover estimates at the ratio level were also made in each quadrat of the following variables: bare soil, rocks and stones, surface water, soil lichens, rock lichens, and bryophytes. In addition, three types of ground or vegetation disturbance were estimated for each stand as a whole. Visual estimates of disturbance caused by small mammals, grazing, and human activity were made for the following reasons. Burrowing by small mammals is important in that it reduces the cohesion of soil particles.

This causes the soil to be more susceptible to eroding agents, in particular wind, which is a major force in soil movement at Rocky Flats. Overgrazing by domesticated animals is effective in causing erosion in that it reduces the vegetative cover of the soil. Vegetation is perhaps the single most important element in increasing soil stability. Continual removal of vegetation further results in the loss of topsoil which is necessary for plant growth, thus increasing the problem. Man-induced disturbance, including bull-dozing, plowing, and widespread removal of vegetation with chemicals is potentially the most significant of the three types of disturbance at Rocky Flats. Although direct disturbance by man is usually not as common in this area as is overgrazing, its effect on the vegetation is of a more drastic and permanent nature. The amounts of these types of disturbance are difficult to estimate accurately and an ordinal scale containing five categories was resorted to. The first category corresponded to the least disturbance of the type throughout the mapping area and the fifth corresponded to the greatest disturbance. Relative moisture of the vegetation stands was also visually estimated according to an ordinal scale of one to five. The driest stand of vegetation at Rocky Flats was given a moisture regime rating of one and the wettest stand was given a rating of five.

Soil Sampling and Analysis

A soil sample was collected from the top five centimeters of soil in each of the 32 vegetation stands at Rocky Flats and air-dried for approximately fourteen days. The 32 soil samples

were analyzed by Mr. R. H. Kihl according to standard unpublished methods of the Sedimentology Laboratory of the Institute of Arctic and Alpine Research, University of Colorado, Boulder. Sub-samples of the 32 soil samples were separated into a > 2 mm fraction and a < 2 mm fraction. The < 2 mm fractions of all 32 sub-samples were split into several portions for further analysis. One set of < 2 mm sub-samples was pretreated with H_2O_2 for removal of organic matter; in addition, three of these which contained carbonates were pretreated with 0.5 N. HCL for carbonate removal, before further textural analysis. These fractions were then further separated into sand, silt, and clay fractions according to three scales: Wentworth; USDA; and a modified USDA scale in which very fine sand (0.10 - 0.05 mm) is included in the silt fraction rather than the sand fraction. All textural fractions were expressed as percentages by weight. Other sets of < 2 mm fraction sub-samples were used to make the following determinations: percentage soil moisture (including field capacity, wilting point, and available water), percentage hygroscopic moisture loss, percentage carbonates, percentage water absorption, percentage organic matter, and pH. The percentage soil moisture measures of field capacity and wilting point were determined by placing a sub-sample on a pressure membrane and subjecting it to 1/3 bar of pressure (5 P.S.I.) and 15 bars of pressure (220 P.S.I.), respectively. Amount of available water for plant use of a sub-sample was determined by subtracting the measured wilting point

(amount of soil moisture at which a plant begins to wilt) from the measured field capacity. Percentage hygroscopic moisture loss is equal to the loss of weight of air-dried sample after oven-drying for fifteen hours at 105°C temperature. Percentage organic matter is equal to the loss of weight on ignition of the oven-dried sample after two hours at 550°C. Water absorption is the " amount of water a <2 mm oven dry sample can absorb when held in a perforated can standing in water, expressed as a percentage of the dry weight . . . " (May 1973, p. 25).

Determination of pH is " based on a soil/water ratio of 1:2.5 by volume and is measured with a combination electrode" (May 1973, p. 25). Carbonate content is determined using a Chittick gasometric technique. A table containing the results of this soil analysis is contained in Appendix A.

Cartography

There were basically four considerations in the drafting of the final version of the vegetation map: scale, colors, legend, and base. The size and therefore the scale of the final map was determined largely by standard press and paper sizes. This was anticipated and the area was originally mapped at 1:7920; this is fairly close to being twice the scale of the final version which is 1:12,000, as Küchler (1967) suggests.

Several authors (Küchler 1967; Mueller-Dombois and Ellenberg 1974; Unesco 1973) suggest that vegetation map colors be

chosen such that additional information about the map units (e.g., environmental conditions or density and height of the vegetation) is presented through the use of a consistent meaningful color scheme. Two factors, moisture and disturbance, were considered to be important in choosing the colors for the Rocky Flats map. The moisture factor was based partially on soil water absorption and partially on a visual estimate of moisture regime and colors were assigned as follows: orange = least moisture (dry), yellow = intermediate moisture (dry-moist), blue = most moisture (moist-wet). The disturbance factor was based primarily on percentage cover of bare soil and colors were assigned as follows: red = least disturbance, yellow = intermediate disturbance, gray = most disturbance. Table III-1 shows how the two factors were combined to derive possible map colors.

Since each factor was divided into three nominal groups, several map units could be closely related in both factors and could be represented by the same color. Where this occurred variation was achieved by using tints or shades of the color or by placing a pattern over the color. When more variation was required, an analogous color that would not otherwise be used was chosen. For example, five vegetation units had a low moisture rating (orange) and a high disturbance rating (gray) and could be represented by the color brown. A medium value of brown was chosen for one of the vegetation units, a pattern was placed over the same color to represent another vegetation unit which was closely related to the first in terms of floristic composition but was

TABLE III-1

DERIVATION OF MAP COLORS FROM RELATIVE MOISTURE AND DISTURBANCE

		MOISTURE
		Orange (dry)	Yellow (moist)	Blue (wet)
DISTURBANCE	Red (low)	Red-Orange	Orange	Purple
	Yellow (medium)	Yellow-Orange	Yellow	Green
	Grey (high)	Brown	Tan	Blue-Grey

more disturbed, and a shade of the color was used to represent a third vegetation unit. This exhausted the range of browns which could be distinguished easily on the map. An analagous color to orange, red, was chosen to represent the low moisture rating of the remaining two stands and combined with gray (high disturbance rating) to yield pink--a color which was not being used to represent any other vegetation units. The two vegetation units were closely related in terms of floristic content so the same color was used for both; a tint represented the more disturbed unit and a shade represented the less disturbed unit. In another case, only one vegetation unit had both a high moisture rating (blue) and a high disturbance rating (gray) and it is the only vegetation unit that is represented on the map by the color blue-gray. One other consideration was made in choosing map colors; in general, map units which covered large areas were represented by light colors and those that covered small areas were represented by dark colors. This was done in order that the many small isolated areas would be clearly visible on the map.

Since the mapping was done on the basis of floristic composition the map units could be described best by a floristic term. For consistency and definition, two species which were dominant in terms of cover and frequency in the two representative stands of each vegetation type were chosen to represent that type in the map legend. In the case of a vegetation type that is characterized by a large number of species, the two dominant species might represent

a small fraction of the total number of species. In the case of a vegetation type with a very small number of species, the two dominant species might represent a high percentage of the species in some areas. Also, (particularly for those vegetation types with two ecological facies, each of which is dominated by one plant species) the two species which are dominant in the vegetation type as a whole and therefore appear together in the map legend may never occur together within a small area in the field.

To make this map more legible to non-botanists and to show relationships between units, a descriptive, physiognomic term was added for each vegetation type. Thus, two vegetation types labeled "pasture" are more similar physiognomically than one type labeled "pasture" and one type labeled "prairie". One additional term: "dry", "moist", or "wet", is used in the map legend to describe the relative moisture content of the vegetation types--the term was derived directly from the visual estimate of moisture, called moisture regime, since the soil analyses were not completed at this time. Vegetation types were also classified as barren or well-vegetated on the map. This classification was based on the relative amount of bare soil in the sampling stands.

The topographic base of the vegetation map was taken from United States Geological Survey maps of Colorado--Golden Quadrangle and Louisville Quadrangle--on a scale of 1:24,000, with 10-foot contour intervals. Only the 50-foot contour intervals were used for the final vegetation map in order to keep it as uncluttered as possible. The vegetation types were then transferred from the

aerial photographs on which they were mapped to this topographic base by the cartographer, and corrected for any scale-distortion caused by the use of the aerial photographs.

CHAPTER IV

THE METHODS OF VEGETATION ANALYSIS

Introduction

As previously stated, vegetation analysis must be complementary to and is, in fact, an integral part of vegetation mapping. Methods used in the analysis of the data therefore depend to an extent upon the proposed uses of the vegetation map. Other factors which are equally important and should be considered include the nature of the data, the types of statistical procedures which are appropriate and whether the analysis will only attempt to describe the current status of the vegetation or will include a prediction of long term changes in the vegetation based on changes in the environment. On the basis of these considerations, three main goals became the purpose of the vegetation analysis: (1) to determine whether life-form data would provide a satisfactory alternative to species data as input to ordination and classification programs, (2) to determine which of many available types of ordination and classification programs were the most efficient and successful aids in interpreting the vegetation distribution, and (3) to determine which environmental factors are important controls of the vegetation distribution at Rocky Flats.

Data Transformations

Original Data

The original data set was composed of a species index value for each plant species in each stand, therefore it was of a floristic (as opposed to physiognomic) nature. Although the data were collected in one geographical site, they are a composite of sampling many vegetation types which are very diverse in terms of plant species composition--the usual input to ordination and classification programs. That is, each vegetation type contained only a small percentage of the total number of plant species in the mapped area. This resulted in a data bank with an abundance of zero values which " can cause distortion of gradients running through ordination models" (Webber and Keammerer, eds. 1973, p. 128).

Species Elimination

There are several methods of transforming a data set containing many zero values. One method is to simply eliminate from the set any species or stands which are considered unimportant, based on some characteristic. Muckattu (1974, p. 2343) makes the following statement: "If such a reduction is warranted, it is advisable to reduce species number and keep all sampling units so that the sampling error will be kept at a minimum." A reason for including all of the stands, which is just as valid as Muckattu's, follows. Two of the map units, the dry savannah with *Pinus ponderosa* and *Bromus tectorum* (represented by stands 21 and 22) and the dry barrens with *Polygonum aviculare* and *Ambrosia psilostachya*

(represented by stands 3 and 4), had little in common with the rest of the vegetation in terms of plant species composition and could conceivably have been dropped from the data set.

However, they represent, on the one hand, the way much of the area may have looked years ago, and, on the other hand, the way the area may look in the future wherever human disturbance is at a maximum. The history of the vegetation is often given a much smaller role in vegetation analysis than it actually assumes in nature and to avoid this pitfall all of the Rocky Flats mapped vegetation units must be included in the vegetation analysis.

Since there were two sampling stands for each mapped vegetation unit, half of the stands could have been eliminated thus retaining all map units, each represented by only one remaining stand.

However, two stands per map unit is the minimum number of stands which will account for the heterogeneity which is present across the site. Thus, eliminating species was much more feasible than reducing the number of sampling stands as a means of reducing the number of zero values in the data set.

Whether stands or species are eliminated from the data set, the result is a loss of information. Several methods which have been used to eliminate species while retaining as much information in the data set as possible are listed in Muckattu (1974, p. 2343):

. . . . Williams and Dale (1963) have used the sum of square correlations as a criterion. Gower (1967) suggested the use of multiple correlation coefficient. Orloci and Mukkattu (1973), and Orloci (1973) used a covariance criterion, whose strategy is used in the present paper. In this procedure the species are ranked according to specific sum of squares for which they individually account. Stress analysis, which follows ranking, determines how closely the covariance structure of the quadrats in the reduced sample approximates the structure in the original sample. If they differ, a stress value other than zero indicates the loss of information resulting from the reduction.

Figure IV-1 is adapted from Mukkattu (1974, p. 2343) and shows that he reduced an original data set of 77 species in ninety quadrats to about half the number, forty species, with a stress value of only five percent. Reducing the number of species to less than one-half of the original resulted in a significantly increasing loss of information. The 227 species found in 32 stands at Rocky Flats were reduced to about one-half the number, 114, by simply eliminating any species which did not have a species index value greater than one in at least one stand.

Life-forms

It is also possible to combine species according to physiognomic structure and life cycle, thus reducing all of the species in the data set to a few life-forms which are likely to be common to most of the vegetation units. The theory is that the life-forms of the vegetation are influenced by environmental factors to the extent that there is a significant relationship between the two, as is the case with species composition. If the right life-form categories are chosen description of the

Figure IV-1. Amount of stress (loss of information) resulting from reduction of species number. The graph is adapted from Mulkattu (1974, p. 2343).

vegetation in terms of life-forms rather than species is desirable for two reasons. Life-form data is both easier to collect and to analyze than species data. Scientists, without an extensive knowledge of the vegetation of the area, could recognize and record the life-forms of the vegetation but would have considerable trouble in differentiating among the vast number of species at Rocky Flats. Furthermore, the diversity of the vegetation is such that two stands may have only a few species in common and would be considered fairly unrelated in terms of species composition. When the same two stands are analyzed in terms of life-form composition the dominant species in each stand may fall into the same life-form category and the stands may be very similar in respect to abiotic factors as well. In this case the different species (but the same life-form) in the two stands would have a similar influence on the nature of the vegetation in each and the two stands could be considered as representing ecological facies.

The life-form concept is not a new one. Knight (1965) states that this concept is commonly used in describing and interpreting vegetation. In the past, however, the physiognomic approach (including the use of life-forms) to the description of vegetation has mainly been applied to the comparison of large vegetation areas around the earth. The present trend in describing local vegetation is toward a floristic approach. While floristic descriptions are very informative, the potential for using the physiognomic approach to describe local vegetation has not been realized (Knight and Loucks 1969).

In combining plant species into life-forms information is not lost from the data set but is somewhat obscured or hidden. The 227 plant species at Rocky Flats were placed in the following twelve life-form categories: WOODY--greater than 5 meters in height (1 species); WOODY--less than 5 meters in height (11 species); HERBACEOUS, BROAD-LEAVED, PERENNIAL (57 species); HERBACEOUS, BROAD-LEAVED, BIENNIAL (11 species); HERBACEOUS, BROAD-LEAVED, ANNUAL (22 species); HERBACEOUS, NARROW-LEAVED, PERENNIAL (61 species); HERBACEOUS, NARROW-LEAVED, ANNUAL (14 species); SUCCULENT (5 species); BRYOPHYTE (9 species); LICHEN (34 species); PTERIDOPHYTE (1 species); and PARASITE (1 species). The last two categories, PTERIDOPHYTE and PARASITE, were dropped from the vegetation analysis since they each only contained one species which appeared in one stand and had a small species index in that stand. This resulted in a data matrix of ten life-forms x 32 stands. Representative species from each of the ten life-form categories used in the vegetation analysis are illustrated in Figure IV-2. Figure IV-3 shows the relative abundance of the ten life-forms in the 32 sampling stands at Rocky Flats and indicates that HERBACEOUS NARROW-LEAVED and BROAD-LEAVED PERENNIALS dominate the vegetation.

Life-forms With Degree of Absence

Many different values can be used to indicate to what degree species are present in a stand. It is equally important to determine to what degree species are absent from a stand, but this information is hidden in the many zero values which appear in

Figure IV-2. Representative species from
the ten life-form categories
at Rocky Flats.

Figure IV-3. Relative abundance of the ten life-forms in the 32 vegetation stands at Rocky Flats, based on an importance measure ("species" index).

most vegetation data. Swan (1970) gives a procedure for deriving this information and his method was used on the Rocky Flats data. Briefly, a matrix of species associations is used to determine to what degree the species absent from a stand are associated with the species that are present in the stand. A species that had a presence value of zero in the original matrix may be given a " degree of absence . . . " value which represents the probability of its being present based on which other species are present in the stand or its zero value may be left unchanged (Swan 1970, p. 148). If a certain species, "A", never occurs in a stand containing one or more of species "B", "C", or "D", its association index with each of those species is zero and its probability of being in a stand containing species B, C, and D is zero. In this case, its original zero value for that stand is unchanged. If species A always occurs with species B, C, and D with the exception of one stand which contains B, C, and D, but not A, A's zero value in that stand is replaced with a very small presence value based on its association indices with B, C, and D. Because of the complexity of computing the degrees of absence values and the need for a matrix of species associations, this method was used on a trial basis and was performed on the life-form composition data rather than on the species composition data. This method actually "adds" information to the data bank although it would be more appropriate to say that it uncovers information that cannot be measured directly.

Summary

Four final data matrices for use in the vegetation analysis were produced by these transformations of the data set. They include the original matrix containing species index values of 227 species in 32 stands, a matrix containing species index values of 114 species in 32 stands, a matrix containing "species" (life-form) index values of ten life-forms in 32 stands, and a matrix containing "species" index with degrees of absence values of ten life-forms in 32 stands. Table IV-1 gives the percentage of zero values contained in each of these data matrices.

Reducing the number of species to 114 probably resulted in a very small loss of information from the data set but it also had very little effect on the percentage of zero values in the data matrix. It seems that there would have to be a trade-off between number of zero values and the amount of information retained in the data set if the method of eliminating species is used.

In order to reduce the number of zero values by any significant amount a large number of the species would have to be eliminated. This is not feasible since it greatly increases the possibility of eliminating one or more species which may be indicative of major environmental conditions in the stand of vegetation. Often species with small "importance" values such as species index are good ecological indicators just as dominant species may be.

Combining the species into life-forms resulted in a substantial decrease in the amount of zero values and this method appears to be a particularly valid and useful one. The life-forms

TABLE IV-1
PERCENTAGE OF ZERO VALUES CONTAINED IN THE DATA MATRICES
USED FOR THE VEGETATION ANALYSIS

227 species, 32 stands	88.41
114 species, 32 stands	82.68
10 lifeforms, 32 stands	41.25
10 lifeforms with degrees of absence, 32 stands	0

with degrees of absence matrix contained no zero values, but this method seemed to have several problems associated with it. Most notably, several of the zero values of a particular life-form were replaced by the same numerical value--this is no improvement over a zero value for use in differentiating among the stands based on the amount of that life-form present in them. An absent life-form will be given the same degree of absence value in any stands which contain the same complement of other life-forms. This is because only the presence or absence of the other life-forms is taken in to account--not their species index, which may vary widely--when the degree of absence values are calculated. This would not be as likely to happen if species data were used because of the larger number of species and the smaller probability of two stands having the same complement of species.

A modified Bray and Curtis ordination was performed on all four data matrices to determine which was the best input to ordination programs and for comparison. In addition, a principal components analysis or ordination (a type of factor analysis) using a standard Pearson product-moment correlation matrix, a principal components ordination using a Spearman's rank correlation matrix, and a Swan, Dix and Wehrhahn ordination were all performed on the life-form data matrix without degrees of absence. The matrix of species index values for 227 species in 32 stands is given in Appendix C (the species are classified by life-form). The matrix of species index values for 114 species in 32 stands is not given since it is contained in the matrix of 227 species.

"Species" index values for ten lifeforms (with and without degrees of absence) in 32 stands are given in Appendix B. Nomenclature of the species is after Weber (1972), Weber (1973), and has been updated according to Weber and Johnston (1976).

Ordination

Concepts

Ordination and factor analysis are simply means of summarizing the information in a data matrix. The elements of the matrix " define the spatial relationships between ecological entities" (Orloci 1966, p. 193). In the case of indirect ordinations the elements of the matrix are the importance measures of the species or the life-forms found in the stands of vegetation and the ecological entities are the stands themselves. The entities " are visualized as points in space with their attribute scores as co-ordinates" (Orloci 1966, p. 193).

"Summarization is achieved by projection of the points into a space which has less dimensions than the original" (Orloci 1966, p. 193). The result is a " simplified geometric model" which can then be analyzed for ecological gradients and clustering of the stands (Orloci 1966, p. 193). Since a stand will have a score or value (which is used as a co-ordinate to locate the stand in space) for each species or life-form, the original space will have as many dimensions as there are species or life-forms, whichever is the basis for the ordination. It is reasonable to assume that an ordination which attempts to summarize ten dimensions

(using a data matrix with ten life-forms and 32 stands) into three dimensions has a better chance of succeeding than an ordination which attempts to summarize 227 dimensions (using a data matrix with 227 species in 32 stands) into three dimensions. Therefore, it is desirable to limit the number of attributes on the basis of which the stand is located--this is a distinct advantage of using life-form data rather than species data. The reason for projecting the stands into a three (or less) dimensional space is simply that this space is much easier to comprehend and visualize than one with more than three dimensions. An ordination can be efficient, then, if the data can be summarized accurately within the spatial framework of three or fewer dimensions. The accuracy of the ordination depends first of all on how closely the three-dimensional ordination model represents the multi-dimensional original space. Since the relationship of the stands to each other is of primary concern in ordination modeling, a simple measure of accuracy would be to compare interstand distances in three (and fewer) dimensions to interstand distances in all dimensions of the original space. The interstand distance in all dimensions of the original space are hard to arrive at directly but they have a correlation of -1 with the Bray and Curtis measure, "percentage similarity", and the factor analysis measure, "correlation coefficient", of all stand pairs based on their vegetation composition. Therefore, a high negative correlation between interstand distances in three (or fewer)

dimensions and percentage similarity measures or correlation coefficients would indicate an accurate summarization (Webber 1971; Austin and Orloci 1966). Other indications of a useful ordination are a non-random " distribution of species within the spatial framework . . . " of the ordination, and " . . . some clear correlations between stand coordinates and stand environments . . . " (Webber 1971, p. 120). These last two criteria are mainly indicative of how interpretable the ordination is for vegetation analysis.

Methods

Three types of ordination and factor analysis were chosen for use in analyzing the Rocky Flats vegetation. They include:

- (1) a Beals modification of Bray and Curtis ordination,
- (2) a principal components analysis, (3) a Swan, Dix, and Wehrhahn ordination.

A complete discussion and some comparison of these methods can be found in the literature (Beals 1960; Bray and Curtis 1957; Austin and Orloci 1966; Swan, Dix, and Wehrhahn 1969; Grieg-Smith 1964). A brief summary of the uses and limitations of each method which are applicable to this study follows.

Bray and Curtis ordination is generally used to orient stands of vegetation relative to each other in three or fewer dimensions based on the percentage similarity of their species

composition. Environmental variables are then correlated with the axes of the ordination (which are defined by the most dissimilar stands) to determine which simple or complex measured variables have the greatest influence on the vegetation distribution. This is known as indirect ordination because the axes may or may not represent environmental gradients. An ordination is termed direct when the stands are initially ordered along the environmental gradients themselves (the gradients then become the axes) according to the environmental characteristics (as opposed to species) which the stands possess (Hill, 1973).

Criticisms of Bray and Curtis ordination include the following:

(1) axes are not orthogonal to each other, (2) distance between the stands is not Euclidean since stand positions are based on a matrix of percentage values, and (3) axes are often defined by extreme stands which have a small percentage similarity to the remaining stands, which are generally clustered indiscriminantly somewhere in the spatial framework of the ordination (Webber and Keammerer, eds. 1973). Very little helpful information is derived as a result of the latter condition since a good spread of the stands in the space is necessary for accurate identification of influential environmental factors. The main advantage of the Bray and Curtis ordination is the simplicity of the calculations involved, which enables the handling of large data matrices. Another advantage is that presence-absence data can be input, as well as quantitative importance measures.

The diversity of the vegetation stands at Rocky Flats made it desirable to experiment with a type of factor analysis as well and to compare the results to those of the Bray and Curtis ordination. Therefore, principal components analysis based on a standard Pearson product-moment correlation coefficient matrix was used. In this method, a matrix of interspecies correlations is generated. The matrix is used to derive eigenvectors which are located orthogonally to each other in multi-dimensional space. The number of eigenvectors corresponds to the number of species or life-forms in the data matrix.

The stands are located according to their values on the eigenvectors. The first eigenvector is oriented such that it extracts or explains the most variance. "Variance is a measure of the variability, or lack of homogeneity, in a variable" (Nie, et al. 1975, p. 279). The second eigenvector extracts the most possible variance of the remaining variance in the data with the condition that it must be located orthogonally to the first, and so on.

The main advantage of principal components analysis is that the axes do not have to be defined by stands. This means that it has the possibility of being a much more efficient method of summarizing information than Bray and Curtis ordination. The main limitations of principal components analysis is that it is based on a standard Pearson product-moment correlation coefficient matrix, which, in turn, is based on the assumption that the data are normally distributed and are at the interval or ratio level of measurement (Nie, et al. 1975). Vegetation data are usually

highly skewed rather than normally distributed and it can be assumed that the Rocky Flats data are skewed also. Since the data were collected at the ratio level the second consideration was not a problem. A modified principal components analysis was used as well. In this method, a Spearman's rank correlation coefficient matrix, which does not assume normal distribution (Nie, et. al. 1975), was substituted for the standard correlation matrix. Whereas principal components analysis based on Pearson product-moment correlations exaggerates the effect of very distant stands, this modification using Spearman's rank correlations does not.

A third ordination technique proposed by Swan, Dix and Wehrhahn (1969) was used on the Rocky Flats life-form data also. This method resembles Bray and Curtis ordination in that the axes are defined by stands. It differs in that the reference stands for the axes are not necessarily the most dissimilar ones in terms of species composition. The basic assumption is that a few axes must be defined that will locate the stands in space such that the interstand distances closely approximate the corresponding distances (percentage dissimilarity of the stands) in the original matrix (Swan, Dix and Wehrhahn 1969). Swan, Dix, and Wehrhahn (1969) make this comparison of their method to Bray and Curtis ordination and principal components analysis:

. . . . from all possible stand-defined axes, those which best represent the information in a matrix are selected by a relatively simple yet mathematically sound principle. In theory, this principle is certainly superior to the distant stand criterion of the Wisconsin method. However, it involves some increase in complexity and computational expense and our ordination has yet to be compared with other techniques to determine whether the refinement is a significant one. Because it is based on axes derived from similar geometric constructions, we believe the method is simpler to understand than the analogous but more sophisticated principal components "factor" analysis. Where there are many species in the data our procedure also requires much less computation.

Several criteria for evaluating the different techniques were mentioned, including efficiency and accuracy. The efficiency of principal components analysis and Swan, Dix, and Wehrhahn ordination are reflected by the amount of variance which each axis extracts from the data and the total variance extracted by three axes. There is no comparable index of efficiency for the Bray and Curtis ordination. The three ordination methods can be compared and evaluated qualitatively by plotting species within the ordinations and noting their distributions and by correlating environmental variables with the axes. In addition, one quantitative measure, accuracy, can be determined for all three ordinations and provides a means for comparing them objectively.

Classification

Concepts

Classification is a term which includes both qualitative, subjective methods such as those used to construct the Rocky Flats vegetation map and quantitative, objective methods such as the

clustering ones used in the vegetation analysis. Although the clustering methods are objective in themselves, the stands which are being clustered are derived from the subjectively classified vegetation map units. Classification assumes that the vegetation can be divided into more or less discrete units. This is in contrast to ordination which assumes that the vegetation is distributed continuously along environmental gradients. Different vegetation areas may approach one or the other of these extremes but the present trend is to use both ordination and classification methods to analyze an area of vegetation. Pomyatovskaya (1961) discusses and compares the classification and ordination approaches to vegetation study.

Methods

A cluster analysis method may be either monothetic or polythetic. In monothetic clustering, " attributes are considered singly" while in polythetic clustering, " a number of different attributes are taken into account simultaneously" (Goodall 1973, p. 590). Cluster analyses may also be either agglomerative or divisive. In divisive cluster analysis, all of the stands are initially grouped into one large cluster. This cluster is then split, and the resulting clusters split, etc., until the desired number of separate clusters is reached. Stands can be added to the initial group after the splitting is done and be " keyed out" just as a plant species would be to determine where they would be placed in the final clusters (Hill et al. 1975, p. 602). This is not true of agglomerative clustering.

In contrast to divisive clustering, all stands begin as individual units. Two stands are linked, forming the first cluster.

Remaining stands may be added to this cluster, linked with each other, or not linked at all. Linkage continues until the desired number of clusters are obtained. The decision of when to stop either divisive or agglomerative clustering may be based on some objective criteria and Goodall (1973) lists several possible ones or it may be subjectively based. Goodall (1973) thoroughly discusses various numerical classification techniques. Hill, et. al. (1975), makes an important distinction between divisive and agglomerative clustering. He states that in divisive clustering, the association of a stand with a cluster is not dependent on which other stands are already part of that cluster. In agglomerative clustering, whether a stand will be linked with a cluster is wholly dependent on which stands already make up that cluster. The final outcome of agglomerative clustering is therefore dependent on the correctness of each step and especially so on the initial linkings of stands. The addition of one stand at the initial step of agglomerative clustering may drastically change the stand composition of the final clusters. Hill, et. al. (1975, p. 598) gives the following criteria for a useful vegetation classification method:

(1) The method should be able to classify even visually heterogeneous data so as to provide a convenient framework with which to summarize the range of variation in the vegetation. As far as possible, the resulting groups should have a straightforward ecological interpretation.

(2) The method should be open-ended. That is to say, new stands should be capable of being assigned to their correct place in the resulting classification without necessitating further laborious calculations.

(3) The method should be computationally efficient. To be of practical utility it should be applicable to full-scale surveys.

(4) The method should not be capable of making serious errors of misclassification.

Hill et. al. (1975, p. 598), states that agglomerative methods satisfy neither criteria #2 nor #3, and that "The divisive method of association-analysis . . . " satisfies the first three criteria but not the fourth. He presents a modified method of association-analysis which satisfies all four criteria. Unfortunately, Hill's classification method was discovered at too late a stage in the Rocky Flats vegetation analysis and, although the method has much potential, it was not incorporated in this study. In the absence of a good divisive classification at the time the study was undertaken, two agglomerative methods were used to cluster the 32 vegetation stands.

The four matrices of percentage dissimilarity values among the 32 stands based on composition of 227 species, 114 species, ten life-forms and ten life-forms with degrees of absence, which were the bases of Bray and Curtis ordinations, were also used as bases for four clustering analyses. The average linkage method of Sokal and Sneath (1963) was used to construct four polythetic,

agglomerative, hierarchical dendrograms of the 32 stands. This method was summarized by Clark (1973) as follows: The scale of the dendrogram is comprised of the percentage dissimilarity values at which the stands are linked together. The matrix of percentage dissimilarity (PD) values is searched for the smallest value between any two stands. Those stands, stand "a" and stand "b", are linked at the $PD_{a,b}$ level of the dendrogram scale. To determine the percentage dissimilarity of the newly-formed cluster of stands a and b to each of the other stands, for example to stand x, the following formula is used:

$$PD_{ab,x} = (PD(a,x) + PD(b,x)) / 2$$

If $PD_{ab,x}$ is smaller than any of the PD values in the original matrix, then stand x will be linked to the cluster of stands a and b at the $PD_{ab,x}$ level on the dendrogram scale. The clusters are built up in this way until finally all of the stands are in one cluster. A level of clustering is then chosen which will give the desirable number and composition of clusters.

An alternative agglomerative clustering technique was suggested by Clark (1974, p. 101) and is summarized as follows:

A dendrogram may be constructed by searching the distance matrix for the smallest distance. These two stands then form a cluster in n-space. After finding the center of mass of these two stands a new distance matrix is tabulated replacing the two mudflows by the position of their center of mass. So the distance is the average distance to the entire cluster studied in n-space and n dimensions are used for the basis of the clustering. The scale (=C) is computed as the $\log_{10}$ of the ratio of the sum of the between group variances and the sum of the within group variances.

The distance matrix which Clark refers to is derived from the positions of the stands in n -space, which is determined by their scores on n orthogonal axes. The n orthogonal axes are the components produced by principal components analysis, n being the number of components (also dimensions) selected for input to the clustering analysis. This clustering technique necessarily has the same limitations as principal components analysis. The most important limitations are that it cannot be used with data that contains a large number of species or that was collected at or below the ordinal level of measurement. In view of these limitations, this clustering technique was used on the Rocky Flats life-form data matrix. The distance matrices for this clustering technique were derived from two 3-dimensional principal components analyses, one with a standard Pearson product-moment correlation matrix and one with a Spearman's rank correlation matrix. Three dimensions (components) were used with the assumption that the resulting cluster analyses would best complement the three-dimensional ordinations and principal components analyses that had already been done.

Clark (1973) used hypothetical data which consisted of 25 stands and eighteen species to compare his clustering technique, using an interstand distance matrix based on two components (dimensions), to the average linkage clustering method using a Bray and Curtis percentage dissimilarity matrix. This comparison may be misleading since the Bray and Curtis percentage dissimilarity

matrix can be interpreted as being a non-Euclidean interstand distance matrix based on all possible dimensions, in this case, eighteen, whereas the other distance matrix is based on only two dimensions. Ideally, all possible components should be used in Clark's technique in order to make the best use of this method. Figure IV-4 illustrates differences between the two agglomerative clustering techniques which were used on the Rocky Flats vegetation data. Although only two dimensions are used in Figure IV-4, a basic weakness of the average linkage method is apparent. This is that the method is insensitive to the positions of the stands relative to each other and is sensitive only to the interstand distances, which are represented by percentage dissimilarities. Clark's method, on the other hand, is based on stand coordinates on the various components or axes, hence the relative positions of the stands to each other is the main criteria on which stands are clustered. Theoretically, Clark's method (using all components) is an improvement over the average linkage method of Sokal and Sneath (1963), but is limited in its usage.

Environmental Correlation

The correlation of simple and/or complex environmental variables with the ordination axes is important in determining which of the measured variables are significantly related to and perhaps have an influence on the distribution of the vegetation at

Figure IV-4. Comparison of two classification methods. Stands *a* and *b* form a cluster. Stand *c* is equidistant from stands *a* and *b* in all four examples shown. The distance from stand *c* to the cluster *ab* is always 1 when calculated by the average linkage method, but varies when calculated by Clark's method. The dotted lines indicate the calculated distances. Clark's method is more sensitive to the position of stand *c* in relation to cluster *ab*.

Rocky Flats. Once the importance of the various environmental variables is known, changes in the vegetation patterns can be more successfully implemented or predicted.

Spearman's rank correlation coefficients were generated among the measured environmental variables and also among single environmental variables and the axes of the seven ordinations. The use of Spearman's rank correlations as opposed to Pearson product-moment correlations was necessitated by the fact that some of the environmental variables were measured at the ordinal level.

In addition, the two clustering techniques which were described in the previous section were used to generate dendrograms of the environmental variables in order to identify complex groups of two or more environmental variables. Stand dendrograms, based on the values of the environmental variables, were also generated using these two clustering methods in order to identify groups of stands that might have similar environments. All components of a principal components analysis using Spearman's rank correlations were used as input to Clark's clustering method in order that this method could be compared, on equal terms, to the average linkage method.

CHAPTER V

RESULTS AND DISCUSSION

Vegetation Type Summaries

The product of the vegetation mapping was a 1:12,000 color map of the Rocky Flats area (Plate 1, pocket). Sixteen vegetation types are represented on the map. Thirty-two vegetation stands (two per vegetation type) were chosen for vegetation analysis of the map units. Characteristics of the 32 representative vegetation stands were also used to compose vegetation type summaries of the sixteen map units. The summaries are contained in Appendix D. The concept of a vegetation type summary (including several of the terms used in the summaries) was taken from Curtis (1959). The index of homogeneity of a vegetation type was not defined as in Curtis (1959); rather, it was defined as the "Percentage similarity" (Webber 1971, p. 114), based on a quantitative measure (species index) of the species or life-form composition, of the two stands which represent that type. Field distance between vegetation stands was included in the summaries since it may influence the index of homogeneity of a vegetation type. Percentage similarity values of each of the two stands in one vegetation type to each of the two stands in another vegetation type were averaged to determine which types were most closely related in terms of species or life-form composition. The total

number of species found in each stand and the number of species in each of several life-form categories are also included in the summaries. The values of three environmental variables--percentage non-vegetated area, moisture regime, and grazing regime--are given for each vegetation type also. These three variables were shown to have a significant influence on the distribution of the vegetation. Major dominant species and life-forms for each stand of a vegetation type were determined on the basis of species index values, those species or life-forms having the largest values were considered dominant, and are included in the summaries. " Modal species" of a vegetation type were determined, using species index, according to the following definition (Curtis 1959, p. 81): "These are the plants which have their maximum presence value in the given community." They may be either dominant or rare in that vegetation type. These vegetation type summaries are designed to aid interpretation of the vegetation map by other researchers at Rocky Flats since the ultimate determination of the usefulness and accuracy of the map will be made by those who use it in the field.

The homogeneity of each vegetation type is also shown in Figure V-1. Each circle represents a vegetation stand. The area contained within a circle represents the number of species found in that stand. The area of overlap of the two circles represents the number of species which the two stands of a vegetation type have in common.

Figure V-1. Relative number of species in each vegetation stand and overlap of the two stands in a vegetation type.

The three vegetation types which most closely approximate native prairie at Rocky Flats are the DRY, *Stipa comata* - *Koeleria macrantha*, PRAIRIE, the DRY, *Koeleria macrantha* - *Agropyron trachycaulum*, PRAIRIE; and the DRY, *Hypericum perforatum* - *Paronychia jamesii*, PASTURE. Figure V-1 shows that these three types have both the largest number of species and the greatest homogeneity between stands. Of these three the two stands of the DRY, *Hypericum perforatum* - *Paronychia jamesii*, PASTURE, have the greatest proportion of species in common and these two stands were also located very close to each other in the field--the distance between them was only 0.09 miles (0.15 km). The field distance between the two stands of the DRY, *Stipa comata* - *Koeleria macrantha*, PRAIRIE is greater--0.77 miles (1.23 km)--and the proportion of species in common is significantly less. The field distance between the two stands of the DRY, *Koeleria macrantha* - *Agropyron trachycaulum*, PRAIRIE is slightly greater yet, 0.86 miles (1.38 km), and the proportion of species in common is even less. Number of species in common between two stands of a vegetation type may be related to the field distance between them rather than to the actual homogeneity of the type, therefore the relative size of the circles in Figure V-1 is more informative than overlap of the circles. The number of species in the stands of each of these three types is very similar and ranges from 38 to 50. The two vegetation types

labeled "PRAIRIE" occur either within the barbed-wire boundary fence at Rocky Flats, where cattle grazing has not occurred for approximately 20 years, or on properties outside the fence where overgrazing is not a problem. Where grazing is more intense, the third of these three vegetation types replaces the two "PRAIRIE" types.

Three other vegetation types, the DRY, *Buchloë dactyloides* - *Medicago sativa*, PASTURE; and the DRY, *Buchloë dactyloides* - *Arnica fulgens*, PASTURE; and the DRY, *Heterotheca villosa* - *Buchloë dactyloides*, PASTURE; form a homogeneous "PASTURE" group which is somewhat related to the group of "PRAIRIE" vegetation types in that the "PASTURE" types also contain some native prairie species, especially short grasses, and occur on the plains of the Rocky Flats area. The "PASTURE" vegetation types occur only outside the barbed-wire boundary fence and on areas which tend to be overgrazed. The percentage of non-vegetated area in these types is small in spite of the overgrazing. This is probably because of *Buchloë dactyloides*, a very short native prairie grass which forms an almost continuous sod wherever it dominates the vegetation. The DRY, *Buchloë dactyloides* - *Arnica fulgens*, PASTURE is the least disturbed of the three types and its percentage non-vegetated areas varies from 8.2 to 10.2. The DRY, *Buchloë dactyloides* - *Medicago sativa*, PASTURE contains more weedy species and has a larger percentage of non-vegetated area--the range is from 22.5 to 26.9. The DRY, *Heterotheca villosa* - *Buchloë dactyloides*, PASTURE is found on ridge-tops or flat areas

and although it is not as heavily grazed as the other two "PASTURE" types, the percentage of non-vegetated area is greater and ranges from 33.4 to 38.0. This may be due to wind erosion of the areas where *Buchloë dactyloides* does not dominate the vegetation. Figure V-1 shows that the size of the circles, hence the relative number of species, in the PASTURE group of vegetation types is slightly smaller than in the PRAIRIE group. This may be indicative of the greater amount of disturbance, such as over-grazing, in the PASTURE types.

A third group of very distinct but related vegetation types includes the DRY, *Carduus nutans* - *Bromus tectorum*, BARRENS and the MOIST, *Symphoricarpos occidentalis* - *Poa compressa*, LOW SCRUB which both occur on valley-sides; and the MOIST, *Agropyron trachycaulum* - *Poa compressa*, MEADOW which is found on the bottoms of shallow valleys and which extends up the sides. The BARRENS type has a percentage non-vegetated area which ranges from 8.1 to 9.3. The LOW SCRUB type has essentially the same percentage of non-vegetated area with a range of 6.6 to 11.9. The MEADOW type has the smallest percentage of non-vegetated area with a range of 4.1 to 4.3. This may be a result of the fact that the MEADOW type occurs primarily on lower valley-sides where vegetation litter is less likely to be removed by wind. It may also be a result of the dominance of tall perennial grasses which tend to form thick swales. The dominant species of each of these three vegetation types belong to different life-form categories and therefore cause the structure of the vegetation in each to appear quite distinct. They have many other species in common, however,

and they almost always occur together in the valleys at Rocky Flats.

Two vegetation types which often occur together in the valley-bottoms of Rocky Flats are the WET, *Carex nebraskensis* - *Juncus arcticus*, MARSH and the WET, *Salix exigua* - *Barbarea orthoceras*, STREAMBANK. The first of these two types has two facies, each dominated by one of the species listed above. Both facies form continuous dense swales and the percentage non-vegetated area ranges from 1.3 to 7.1. The second vegetation type is typically found along streambanks, is much less dense, and has a percentage non-vegetated area range from 29.9 to 72.3. The two types are very different in structure and life-form and are only slightly related to each other in terms of species composition. The species which they do have in common are mainly insignificant ones. Figure V-1 shows that these two types have approximately the same number of species and that they have a smaller number of species than the PASTURE and PRAIRIE types.

The remaining five vegetation types do not fit well into any of the above groups but are slightly related to one or more of them in terms of species composition. Figure V-2 shows the relationships within and between the homogeneous groups and also relates the other vegetation types to those groups. The length of the lines connecting the vegetation types indicates their similarity in terms of species composition and is scaled to represent their percentage dissimilarity (100 minus the percentage similarity) based on species index. Thus, a short line between

Figure V-2. Relationships among the various vegetation types. The length of the solid and dotted lines connecting the vegetation types indicates their similarity in terms of species composition and is scaled to represent their percentage dissimilarity. The percentage dissimilarity between stands connected with a broken line is indicated by a number.

two types indicates that they are very similar while a long line indicates that they are very dissimilar. The three related groups of vegetation types are encircled by solid lines and their average percentage dissimilarities to one another are represented by scaled lines. Where percentage dissimilarity values between individual types in separate groups were smaller than those between types within the same group, the former types are connected by curved broken lines and the percentage dissimilarity values are indicated. Vegetation types which do not fit into the PASTURE, PRAIRIE, or VALLEY-SIDE groups are connected only to the type which is most closely related in terms of species composition. The dotted lines which connect these types are scaled to represent percentage dissimilarity.

The vegetation types labelled DRY, *Koeleria macrantha* - *Agropyron trachycaulum*, PRAIRIE; DRY *Stipa comata* - *Koeleria macrantha*, PRAIRIE; and DRY, *Hypericum perforatum* - *Paronychia jamesii*, PASTURE on the vegetation map were found to be particularly homogeneous and also to contain the largest number of species of all of the vegetation types. The two prairie types are dominated by native grasses. The pasture type in this group is dominated by a weedy species, *Hypericum perforatum*, but also contains some of the same native perennial forbs such as *Liatris punctata* and many of the native grasses which are found in the prairie types. This pasture type is probably an overgrazed representative of the prairie vegetation types and, in particular, of the DRY, *Koeleria macrantha* - *Agropyron trachycaulum*, PRAIRIE.

The two prairie vegetation types can be placed in "THE PRAIRIE-GRASS ASSOCIATION" according to Vestal's classification (1914, p. 390), because of the dominance of such species as *Koeleria macrantha*, *Stipa comata*, and *Agropyron trachycaulum*. However, in areas where there is a large percentage of bare, gravelly soil, and the vegetation is less dense, these types more closely approximate "THE BUNCH-GRASS ASSOCIATION" and such species as *Schizachyrium scoparium*, *Muhlenbergia montana*, *Bouteloua curtipendula*, and *Liatris punctata* become more prevalent (Vestal 1914, p. 388). This latter association is more dependent on moisture and therefore " . . . is limited to moist slopes, the higher mesa-tops, and small depressions" such as those found around boulders at the ground surface (Vestal 1914, p. 389). One of the prairie types, the DRY, *Stipa comata* - *Koeleria macrantha*, PRAIRIE, is perhaps best placed in "THE STIPA-ARISTIDA ASSOCIATION" and particularly, in "The *Stipa comata* consocieties [which] occurs in the region on gravelly slopes and on wind-swept tops and crests of mesas" (Vestal 1914, p. 394). Thus, three of Vestal's associations intergrade in the prairie at Rocky Flats, on the scale at which the mapping was done.

The remaining three pasture types, the DRY, *Buchloë dactyloides* - *Arnica fulgens*, PASTURE; the DRY, *Buchloë dactyloides* - *Medicago sativa*, PASTURE; and the DRY, *Heterotheca villosa* - *Buchloë dactyloides*, PASTURE, each contained a smaller number of species and were slightly less homogeneous than the prairie types mentioned above. All three pasture types can be placed in

"THE SHORT-GRASS ASSOCIATION" (Vestal 1914, p. 386). This association is typically found on the plains around Boulder and is often composed of nearly pure stands of short grasses (Vestal 1914, p. 386). This is true of the two Rocky Flats vegetation types which are dominated by *Buchloë dactyloides*. When this association occurs on " the coarse soil of the mesa-terrace . . . " (as does the type: DRY, *Heterotheca villosa* - *Buchloë dactyloides*, PASTURE at Rocky Flats) the short-grasses are mixed with legumes and composites (Vestal 1914, p. 386). One of the two representative stands of the DRY, *Buchloë dactyloides* - *Medicago sativa*, PASTURE is located at the very western edge of the study area and contains large amounts of *Gutierrezia sarothrae* and *Artemisia frigida*. This stand could be considered as intermediate in character between THE SHORT-GRASS ASSOCIATION and "THE GUTIERREZIA-ARTEMISIA ASSOCIATION" as described by Vestal (1914, p. 398). The other representative stand of this vegetation type is located approximately three miles to the east of the intermediate stand. In this stand *Gutierrezia sarothrae* is present in only a small amount and *Artemisia frigida* is not present at all.

The MOIST, *Agropyron trachycaulum* - *Poa compressa*, MEADOW type was the least homogeneous of all of the Rocky Flats vegetation types. One of the two representative stands of this type can be placed in "THE WHEAT-GRASS ASSOCIATION", the other stand is intermediate between this association and "THE SHORT-GRASS ASSOCIATION" of Vestal's classification (1914, pp. 385-387). The former

association is typically found on clayey soil at " the deposition area at the base of side-slopes of mesas, with fine soil washed down from above" (Vestal 1914, p. 387). According to Vestal (1914, p. 388), the short-grass association often invades the wheat-grass association where grazing occurs which " appears to favor succession of wheat-grass by grama-grass". This explains the heterogeneity of the meadow vegetation type at Rocky Flats, which covers the sides of all of the more shallow valleys of the area and often comes in contact with the short-grass dominated pastures in the eastern half of Rocky Flats. The stand (#12, Figure III-17) which can be placed in the wheat-grass association is located within the Rocky Flats plant boundary where grazing by domesticated stock has not occurred for at least twenty years. The nearest short-grass pasture is located approximately one mile away from this stand. The stand (# 11, Figure III-17) which is intermediate in nature is located outside of this boundary fence, on grazing land, and very close to short-grass pasture vegetation in the eastern part of the Rocky Flats area.

The seven, grass-dominated, vegetation types which have been discussed thus far together cover 76 percent of the total vegetated area at Rocky Flats. Agricultural fields cover another ten percent of the area. Eight percent of the area is covered by the three vegetation types labeled DRY, *Polygonum aviculare* - *Ambrosia psilostachya*, BARRENS; DRY, *Hypericum perforatum* - *Ambrosia psilostachya*, BARRENS; and DRY, *Carduus nutans* - *Bromus tectorum*, BARRENS. These types (especially the former two) can be placed in "THE PLAINS RUDEAL ASSOCIATION" of Vestal's classification,

which contains mainly annual plants which are the first invaders of disturbed soil (Vestal 1914, p. 397). Ruderal species in these vegetation types at Rocky Flats include the annuals: *Chenopodium botrys*, *Dyssodia papposa*, *Alyssum alyssoides*, and *Bromus tectorum*, as well as others.

The five vegetation types, including the DRY, *Pinus ponderosa* - *Bromus tectorum*, SAVANNAH; the MOIST, *Crataegus erythropoda* - *Galium aparine*, SCRUB; the MOIST, *Symphoricarpos occidentalis* - *Poa compressa*, LOW SCRUB; the WET, *Salix exigua* - *Barbarea orthoceras*, STREAMBANK; and the WET, *Carex nebraskensis* - *Juncus arcticus*, MARSH cover the remaining six percent of the Rocky Flats area. Many of the plants in these vegetation types, particularly the shrub and tree species, are common in the foothills to the west of the area, and presumably have invaded the plains and become established in the more mesic areas.

Comparison of Ordination Based on Four Data Matrices

Several different criteria may be used in judging the usefulness of an ordination and they have been discussed in Chapter IV. However, the best single indication of the usefulness of an ordination as a tool for vegetation analysis is the amount of information which can be derived from it. While this may be subjectively judged by the researcher, in general, a large amount of information can be extracted from an ordination which exhibits the following three properties. First, the stand positions should be well spread out within the three-dimensional ordination. If this is not the

case, accurate identification of environmental factors which may influence the distribution of the vegetation is impossible.

Second, there must be high correlations between the ordination axes and some important environmental variables. Third, distinct patterns in the distribution of species or life-forms within the ordination framework must emerge. The first of these three properties is especially important in that it is a prerequisite for both of the others.

The results of using the four data sets described in Chapter IV as the basis for a Bray and Curtis indirect three-dimensional ordination of the 32 Rocky Flats vegetation stands are shown in Figure V-3. Only the two ordinations based on life-forms exhibit a well-spaced arrangement of stand positions. Since this is a requirement for a useful ordination, the data sets with 227 and 114 species cannot be considered suitable bases for ordination techniques. Although stand positions were well-spaced in the ordination based on ten life-forms with degrees of absence, correlations with the ordination axes were limited to environmental variables which had values other than zero in only a few stands. One of these environmental variables correlated highly with both the x and y axes of this ordination. Since the axes are supposedly orthogonal to each other, this situation indicates that these correlations are the result of insufficient variation in the data and that these environmental variables probably do not have a great influence on the distribution of the vegetation at the scale of this study. The stand positions were well-spaced within the ordination based on ten life-forms, and several environmental

Bray and Curtis Ordination, 227 species, 32 stands

Bray and Curtis Ordination, 114 species, 32 stands

Bray and Curtis Ordination, 10 life-forms, 32 stands

Bray and Curtis Ordination, 10 life-forms with degrees of absence, 32 stands

Figure V-3. Results of using the four data sets as the basis for Bray and Curtis three-dimensional ordination.

variables were highly correlated with the ordination axes as well. For these reasons, and, also, since there were distinct patterns in the vegetation distribution within the ordination, it can be concluded that the data set containing species index values for ten life-forms in 32 stands is the best of the four data sets as a basis for ordination techniques.

Comparison of Four Ordination Techniques

Four ordination techniques, as described in Chapter IV, were used with the life-form data set. All four techniques produced three-dimensional indirect ordinations with well-spread stand positions. There were high correlations among environmental variables and most of the axes of these ordinations, although the most meaningful correlations were between environmental variables and the three axes of the Bray and Curtis life-form ordination.

Three of the ordinations--the Principal components ordination, the Spearman's rank ordination and the Swan, Dix and Wehrhahn ordination--can be compared with each on the basis of the amount of variance (variability) extracted from the data by their axes (Table V-1). Table V-1 indicates that the first two axes of the Swan, Dix, and Wehrhahn ordination extract nearly as much variance as the first three axes of the Principal components ordination. The Spearman's rank ordination extracts only slightly more total variance than the Principal components ordination. The Swan, Dix and Wehrhahn ordination extracts large amounts of variance with the

TABLE V-1

THE PERCENTAGE OF VARIANCE EXTRACTED FROM THE DATA BY EACH AXIS OF THREE
ORDINATIONS (BASED ON TEN LIFE-FORMS AND 32 STANDS) AND THE TOTAL
PERCENTAGE VARIANCE EXTRACTED

Ordination Method	axis: 1st	2nd	3rd	Total
Principal components ordination	21.00	19.00	18.00	58.00
Spearman's rank ordination	24.60	20.61	15.55	60.76
Swan, Dix, and Wehrhahn ordination	33.54	24.09	15.25	72.89

first and second axes, while the third axis is not nearly as successful in doing this, indicating that two axes may be sufficient for representing the data when using this technique.

A large amount of variance extracted from the data by an ordination has been used as an indication of an effective ordination, the amount of variance being defined as " the sum of squares of stand positions on an axis expressed as a percentage of the total matrix sum of squares" (Swan 1970, p. 95). The calculations for amount of variance extracted are included in many ordination computer programs, indicating the widespread usage of this term in evaluating ordinations. A related concept is that of correlating interstand distances in one, two, and three dimensions of an ordination to the original input matrices of percentage similarities or correlation coefficients. The percentage similarity or correlation coefficient between two stands is, in essence, their interstand distance in all dimensions of the ordination. Thus, percentage variance extracted and interstand distance correlation are both comparisons of stand positions on one or a few axes with stand positions in the original space. Of the two methods, interstand distance correlation is simpler to calculate and more straightforward to understand than is amount of variance extracted. In my opinion, it is the best quantitative method for testing the accuracy of one-, two-, and three-dimensional (or more) ordinations. It is also useful in determining quantitatively which ordination techniques produce the most similar end-products.

Table V-2 gives Spearman's rank correlations among interstand distances (in one, two, and three dimensions of the seven Rocky Flats ordinations) and the original input matrices (percentage similarity based on 227 species and on ten life-forms, and Pearson product-moment and Spearman's rank correlation coefficients). Interstand distances in ten dimensions (because of ten life-forms) of the Principal components ordination and the Spearman's rank ordination were actually used rather than the correlation coefficients, since the two measures are equal except in that one correlates positively and the other negatively with interstand distances in fewer dimensions. Spearman's rank correlations were used in constructing Table V-2 because it would not be appropriate to use standard Pearson product-moment correlations with percentage measures (percentage similarity).

Table V-2 shows that all three-dimensional ordinations were extremely accurate. The three-dimensional Principal components ordination was the most accurate with a correlation of $-.877$, the three-dimensional Bray and Curtis life-form ordination was second with a correlation of $-.853$, and the two-dimensional Bray and Curtis life-form ordination was third with a correlation of $-.847$. The two Bray and Curtis ordinations based on 227 species and 114 species were also quite accurate with correlations of $-.792$ and $-.766$ respectively. The five life-form ordinations may be compared with each other most readily on the basis of how well their interstand distances correlated with the matrix of percentage similarity between stands based on 227 species, since

TABLE V-2.

INTERSTAND DISTANCES IN ONE, TWO, AND THREE DIMENSIONS OF THE SEVEN ROCKY FLATS INDIRECT STAND ORDINATIONS ARE CORRELATED WITH THE FOUR SIMILARITY AND CORRELATION MATRICES

(The number of dimensions is indicated in the table by numbers enclosed in parentheses. High negative correlations between interstand distances in an ordination and the similarity or correlation matrix on which that ordination is based indicate accuracy of the ordination; these correlations--for the three-dimensional ordinations--are indicated in the table with an *. All correlations in the table are based on 496 cases and all are significant to within the 0.05 percent level.)

	Interstand distances Bray and Curtis ordination 227 species	Interstand distances Bray and Curtis ordination 114 species	Interstand distances Bray and Curtis ordination 10 life-forms	Interstand distances Bray and Curtis ordination 10 life-forms with degree of absence	Interstand distances Principal components ordination 10 life-forms	Interstand distances Spearman's rank ordination 10 life-forms	Interstand distances Swan, Dix, and Wehrhahn ordination 10 life-forms
Percentage similarity between stands based on 227 species	-.334 (1) -.740 (2) -.792 (3) *	-.216 (1) -.746 (2) -.766 (3) *	-.284 (1) -.610 (2) -.545 (3)	-.418 (1) -.490 (2) -.566 (3)	-.510 (1) -.407 (2) -.468 (3)	-.352 (1) -.360 (2) -.415 (3)	-.510 (1) -.465 (2) -.465 (3)
Percentage similarity between stands based on 10 life-forms	-.573 (1) -.309 (2) -.544 (3)	-.272 (1) -.312 (2) -.461 (3)	-.192 (1) -.847 (2) -.853 (3) *	-.532 (1) -.689 (2) -.716 (3) *	-.305 (1) -.720 (2) -.807 (3)	-.533 (1) -.569 (2) -.683 (3)	-.306 (1) -.819 (2) -.770 (3) *
Pearson's product-moment correlations between stands based on 10 life-forms	-.351 (1) -.257 (2) -.482 (3)	-.409 (1) -.280 (2) -.412 (3)	-.319 (1) -.726 (2) -.707 (3)	-.512 (1) -.694 (2) -.789 (3)	-.221 (1) -.816 (2) -.877 (3) *	-.422 (1) -.624 (2) -.731 (3)	-.221 (1) -.550 (2) -.474 (3)
Spearman's rank correlations between stands based on 10 life-forms	-.373 (1) -.233 (2) -.455 (3)	-.413 (1) -.237 (2) -.374 (3)	-.308 (1) -.741 (2) -.712 (3)	-.479 (1) -.676 (2) -.758 (3)	-.172 (1) -.814 (2) -.859 (3)	-.383 (1) -.696 (2) -.750 (3) *	-.173 (1) -.652 (2) -.573 (3)

the goal of the life-form ordinations was to summarize the original matrix. The three-dimensional life-form ordinations which correlated most highly with that matrix were the Bray and Curtis life-form with degrees of absence ordination (-.566) and the Bray and Curtis life-form ordination (-.545). It is interesting to note that the two-dimensional Bray and Curtis life-form ordination had the highest correlation (-.610) with the matrix of percentage similarity between stands based on 227 species of all the life-form ordinations in one, two, and three dimensions. The Bray and Curtis life-form ordination appears to be quite adequate in summarizing the original matrix in both two and three dimensions. This purely quantitative method of evaluating the various life-form ordinations substantiates the conclusion that the Bray and Curtis technique, when used with life-form data, produced the best results of the four ordination techniques used in the vegetation analysis of Rocky Flats.

Classification of Stands, Based on Life-forms and Species

The limitations on ordination techniques caused by large data banks and a high percentage of zero values in the data do not apply as significantly to classification methods. Thus, life-form data may not be as desirable a substitute for species data as input to classification programs as it is to ordination programs. As might be expected, when classification is based on life-forms the result is clusters of stands containing the same life-forms but

perhaps widely different in terms of species composition. This technique may be useful in illuminating similarities between stands, perhaps in terms of environmental factors necessary for the growth of a particular life-form, that might not otherwise be recognized unless comprehensive environmental measurements were taken. On the other hand, life-form classifications are not very useful in determining which stands might be grouped together in order to reduce the number of vegetation types, or in determining which stands might be successional stages of other stands. Figure V-4 is a classification of the 32 Rocky Flats vegetation stands based on their percentage similarity in terms of ten life-forms. The average linkage method was used and seven clusters, or noda, were produced at about 73 percent similarity. Nodum I is a large heterogeneous group containing nearly all of the upland prairie and pasture stands. This group also includes the agricultural fields, valley-side vegetation and valley-bottom vegetation as well as one stand of barrens. The stands in this group are alike in that grasses form a significant component of each of them. Density of the vegetation varies widely within this group, the barrens and agricultural fields are sparsely vegetated while the valley-side stands are very dense. Nodum II contains two upland pasture stands and one barrens. The two pasture stands belong to the same vegetation type and they are similar to the barrens stand mainly in that the vegetation is fairly sparse in all three. Nodum III and Nodum V each contain one stand of upland barrens which belong to the same vegetation type. They are not classified in the same cluster based on life-form composition,

Figure V-4. Classification of the 32 vegetation stands based on their percentage similarity in terms of ten life-forms. Seven clusters are identified at the 73% level of similarity.

but this is most likely due to the extreme sparseness of the vegetation in them, and hence, the lower probability of finding exactly the same species, or even life-form, in any two stands of this vegetation type. Nodum IV contains two upland barrens stands which belong to one vegetation type. These stands are characterized by a dense layer of tall thistles with an understory of weedy grasses. Nodum VI includes two stands of ponderosa pine savannah. This vegetation type is the only one which contains the tree life-form. Nodum VII contains the two stands of valley-side vegetation which is dominated by a very dense layer of low shrubs. Nodum VIII includes four stands of tall shrub vegetation. These stands are very similar in vegetation density as well as in life-form. However, they represent two vegetation types which occur in quite different habitats--one is found on mesic to dry valley sides while the other is found along streambanks.

The type of input to the classification technique seemed to be more important in determining results than was the use of either the average linkage method or Clark's method of clustering. Both methods produced similar results when used on various forms of the life-form data, as shown in Figure V-5, and these clusters are generally similar to those in the life-form classification shown in Figure V-4. The corresponding clusters produced in each of the five life-form classifications usually differ from each other in composition by only one or two stands at the clustering level

113

Figure V-5. Classifications of the 32 vegetation stands based on percentage similarity in terms of species or life-form composition as indicated. Those classifications which used the average linkage method are marked with an *, while those classifications which used Clark's method are marked with a +.

marked by a dashed line in Figures V-4 and V-5. When a lower clustering level (containing three or four clusters) is examined the composition of the clusters is seen to vary widely among the five classifications. This result is typical of agglomerative clustering and illustrates its basic weakness, as discussed in Chapter IV.

Two classifications based on species (227 and 114 species) and using the average linkage method are also shown in Figure V-5. The stand composition of the eight clusters produced at the 33 percent similarity level in each classification is identical. However, the two clusters produced at the fifteen percent similarity level in the 227 species classification are quite different from the two clusters produced at the same level in the 114 species classification. The two clusters in the former classification are much more meaningful in that valley-side and -bottom vegetation composes one cluster while the other cluster includes pasture, prairie, barrens, and pine savannah vegetation. In the 114 species classification, valley-bottom vegetation is included in the pasture--prairie cluster while the pine savannah which is found on ridgetops at Rocky Flats is included in the valley-side vegetation cluster. While this is probably due to the aforementioned weaknesses of agglomerative clustering, it is also possible that reducing the species number to one-half of the original number is responsible for the less meaningful classification based on 114 species.

Of all seven classifications, the one based on 227 species is the most useful for evaluating relationships between the 32 stands. Eight noda can be recognized at the 33 percent similarity level in this classification (Figure V-5). Nodum A contains two valley-bottom, marsh vegetation stands. Nodum B contains two shrub-dominated streambank vegetation stands. Nodum C contains four prairie and eight pasture stands, representing the two prairie and four pasture vegetation types at Rocky Flats. Nodum D contains the two most highly-disturbed stands of barrens vegetation at Rocky Flats. Nodum E contains valley-side vegetation including two stands of thistle barrens, two meadow stands, two low scrub stands and one additional barrens stand. Nodum F contains the two stands of ponderosa pine savannah. Nodum G contains two valley-side stands which are dominated by tall shrubs. Nodum H contains two stands of agricultural fields and one barrens stand. The two noda (E and G) containing valley-side vegetation join into one group at about thirty percent similarity. The two noda (A and B) containing valley-bottom (marsh and streambank) vegetation join at about 31 percent similarity. The ponderosa pine savannah nodum (F) joins the prairie--pasture nodum at about 28 percent and the other upland, but highly-disturbed, nodum (D) joins this new cluster at about 22 percent similarity. The agricultural field nodum (H) joins the valley-side group at about 25 percent similarity. The new valley-side group and the valley-bottom group form one cluster

at about eighteen percent similarity. This results in two major clusters, one upland and one lowland cluster, which join together at about fourteen percent similarity. The life-form classification which most closely resembles this 227 species classification is one which also uses the average linkage method and is based on ten life-forms with degrees of absence (Figure V-5). Some stands are slightly misplaced within the noda but basically there is a prairie--pasture group (Z); a pine savannah group (F); two barrens groups (K and J); a thistle-dominated barrens group (R); a somewhat-heterogeneous valley-side, valley-bottom, and fields group (X); and a shrub-dominated group (Y); at about ninety percent similarity.

Plotting the noda produced by the various classifications within the ordination framework is useful in determining which axes of the ordination (therefore, which environmental variables) are most closely related to major differences in the vegetation. Figure V-6 shows the noda produced by the life-form classification (Figure V-4) plotted on three dimensions of the Bray and Curtis life-form ordination. While each nodum is limited to a fairly small portion of the x and y axes, Noda I, II, V, VII, and VIII are spread over a fairly large portion of the z axis. Thus, the z axis is not nearly as useful in separating out the life-form clusters as are the x and y axes. Although the noda overlap somewhat on this two-dimensional representation of the ordination, it appears that they are distinct in three-dimensional space.

Figure V-7 shows all the noda (produced at the percentage similarity levels which are marked by dashed lines in Figure V-5)

Figure V-6. The clusters identified on the stand classification based on life-forms (see Figure V-4) plotted on three planes of the Bray and Curtis ordination based on life-forms.

Figure V-7. The clusters identified in all of the classifications illustrated in Figure V-5 are plotted on two planes of the Bray and Curtis ordination based on life-forms. The clusters identified on the classifications based on 227 and 114 species are plotted on the same frame in this figure since they are identical at the chosen similarity level in Figure V-5. Curved arrows identify a stand which occurs in a different cluster in each classification. Straight arrows identify a stand which occurs in the same cluster in all of the classifications.

plotted within two dimensions, the x and y axes, of the Bray and Curtis life-form ordination. The nodes are identified by the same letters used in Figure V-5. The stand position (dot) marked by a curved arrow in Figure V-7 can be seen to belong to a different cluster in each of the five classifications illustrated, while the stand position marked by a straight arrow remains in the same cluster through all the classifications. The former situation is typical of agglomerative clustering methods while the latter, more desirable, situation is usually associated with divisive clustering methods.

Environmental Correlations and Classifications

Important correlations among measured environmental variables and ordination axes are listed in Table V-3. All correlations listed are significant to within the one percent level, while underlining indicates significance to within the 0.1 percent level. Negative correlations are marked with a minus sign, all others are positive. The correlations are listed in the table in order of significance, the highest correlations being listed first. Neither of the Bray and Curtis ordinations based on species had particularly meaningful environmental correlations. The x axis of both appeared to be related to grain size, the y axis to presence of soil lichens, and the z axis to grain size. The x and z axes of these ordinations were also highly correlated with each other. This situation confuses interpretation of an ordination. The x axis of the Bray and Curtis life-form ordination

TABLE V-3
 IMPORTANT CORRELATIONS AMONG MEASURED ENVIRONMENTAL VARIABLES
 AND ORDINATION AXES

Variables and axes	Significant correlations
Percentage of pebbles and granules (PEBB)	ROCK, -WABS, -FCAP, -BC114Z, BC227Z, -SILT, -ORGM, -HYGR, -BC114X, -BC227X, SAND, LICH.
Percentage of sand (SAND)	-SILT, -CLAY, -FCAP, -HYGR, -WABS, ROCK, -ORGM, -PEBB, -AWAT.
Percentage of silt (SILT)	-SAND, FCAP, WABS, HYGR, ORGM, CLAY, -ROCK, -PEBB, AWAT, -SPRLF3, SDWLF3.
Percentage of clay (CLAY)	-SAND, SILT, HYGR, FCAP.
Percentage of hygroscopic moisture loss (HYGR)	FCAP, SILT, WABS, -SAND, CLAY, ORGM, -PEBB.
Percentage of water absorption (WABS)	ORGM, FCAP, SILT, HYGR, -PEBB, -SAND, -ROCK, -HUMA, MOIS, -BC227Z.
Percentage of organic matter (ORGM)	WABS, FCAP, SILT, -HUMA, HYGR, -PEBB, -SAND, -ROCK.
Field capacity (FCAP)	WABS, SILT, ORGM, HYGR, -SAND, -PEBB, CLAY, ROCK, AWAT.
Available water (AWAT)	SILT, FCAP, -PCALF1, -SAND.
Moisture regime (MOIS)	-ROCK, WABS, BCLFMY.
pH (pH)	PCOLF3.
Grazing (GRAZ)	
Soil disturbance caused by small mammals (MAMM)	-ROCK, -SOIL.
Soil disturbance caused by humans (HUMA)	-BCLFAX, -ORGM, -SPRLF2, -WABS, -BCLFMX, BC227Z, PCOLF3.
Percentage of bare soil (SOIL)	ROCK, SPRLF3, -PCOLF2, -BCLFMX, -SDWLF3, -MAMM.
Percentage of rocks (ROCK)	SPRLF3, PEBB, SOIL, -PCOLF2, -SILT, -BC114Z, SAND, -WABS, -MOIS, -SDWLF3, -FCAP, -BCLFMX, -MAMM, -ORGM, -BC114X, -BC227X.
Percentage of soil lichens (LICH)	-BC114Y, -BC227Y, BCLFAY, -SPRLF1, -PCOLF1, -BC114X, -BC227X, BCLFAX, PEBB.
Bray and Curtis ordination, 227 species, X axis (BC227X)	BC114X, BC114Z, -BC227Z, PCALF1, SPRLF1, -PEBB, -LICH, -BCLFAY, -ROCK.
Bray and Curtis ordination, 227 species, Y axis (BC227Y)	BC114Y, -LICH, -BCLFAY, SPRLF1, -BCLFMX.
Bray and Curtis ordination, 227 species, Z axis (BC227Z)	-BC114Z, -BC114X, -BC227X, PEBB, HUMA, -WABS.
Bray and Curtis ordination, 114 species, X axis (BC114X)	BC227X, BC114Z, -BC227Z, PCOLF1, -PEBB, SPRLF1, -LICH, -BCLFAY, -ROCK.
Bray and Curtis ordination, 114 species, Y axis (BC114Y)	BC227Y, -LICH, -BCLFAY, SPRLF1, PCOLF1, -BCLFMX.
Bray and Curtis ordination, 114 species, Z axis (BC114Z)	-BC227Z, BC114X, BC227X, -ROCK, -PEBB, -SPRLF3, PCOLF1.
Bray and Curtis ordination, 10 life-forms, X axis (BCLFMX)	SDWLF3, PCOLF2, -SOIL, -BC114Y, -BC227Y, -PCOLF3, -HUMA, -ROCK.
Bray and Curtis ordination, 10 life-forms, Y axis (BCLFMY)	-BCLFAZ, PCOLF1, MOIS, SPRLF1.
Bray and Curtis ordination, 10 life-forms, Z axis (BCLFMZ)	-SDWLF2.
Bray and Curtis ordination with degrees of absence, 10 life-forms, X axis (BCLFAX)	SPRLF2, -HUMA, LICH, -PCOLF3, -PCOLF1, -SPRLF1.
Bray and Curtis ordination with degrees of absence, 10 life-forms, Y axis (BCLFAY)	-PCOLF1, -SPRLF1, LICH, -SDWLFY, -BC114Y, -BC227Y, -BC114X, -BC227X.
Bray and Curtis ordination with degrees of absence, 10 life-forms, Z axis (BCLFAZ)	-BCLFMY, -PCOLF3.
Swan, Dix, and Wehrhahn ordination, 10 life-forms, X axis (SDWLF3)	-SPRLF3, PCOLF2, BCLFMX, SDWLF2, -ROCK, -PCOLF3, -SOIL, SILT.
Swan, Dix, and Wehrhahn ordination, 10 life-forms, Y axis (SDWLFY)	-BCLFAY, SPRLF2, PCOLF1, SPRLF1.
Swan, Dix, and Wehrhahn ordination, 10 life-forms, Z axis (SDWLFZ)	-BCLFMZ, SDWLF3, PCOLF2.
Principal components ordination, 10 life-forms, first component (PCOLF1)	SPRLF1, -BCLFAY, -LICH, SDWLFY, BC114Y, BC227X, BC114X, BCLFMY, -BCLFAX, -AWAT, BC114Z.
Principal components ordination, 10 life-forms, second component (PCOLF2)	SDWLF3, -ROCK, BCLFMX, -SOIL, SDWLFZ.
Principal components ordination, 10 life-forms, third component (PCOLF3)	-BCLFAZ, -BCLFMX, -SDWLF3, pH, -BCLFAX, -SPRLF2, HUMA, SPRLF3.
Spearman's rank ordination, 10 life-forms, first component (SPRLF1)	PCOLF1, -BCLFAY, -LICH, BC114Y, SDWLFY, BC227Y, BC227X, BC114X, BCLFMY, -BCLFAX.
Spearman's rank ordination, 10 life-forms, second component (SPRLF2)	SDWLFY, BCLFAX, -HUMA, -PCOLF3.
Spearman's rank ordination, 10 life-forms, third component (SPRLF3)	-SDWLF3, ROCK, SOIL, -BC114Z, -SILT, PCOLF3.

was significantly related to percentages of bare soil, rock, and human disturbance; the y axis appears to represent a moisture regime; and, although the correlation is only significant to within the five percent level, the z axis is related to a grazing regime. The axes of the Bray and Curtis life-form with degrees of absence ordination did not correlate very well with the measured environmental variables. This was disappointing since this ordination appeared to be very successful in all other respects. The x axis of this ordination is related to human disturbance and presence of soil lichens, the y axis to presence of soil lichens, and the z axis was related to percentage moisture loss on ignition and moisture regime--but these correlations with the z axis are only significant to within the five percent level. Amount of human disturbance and presence of soil lichens are variables which had values other than zero in only a few of the Rocky Flats vegetation stands, therefore, these variables cannot be considered to be particularly useful in analyzing the distribution of the vegetation. The x axis was the only one of the Swan, Dix, and Wehrhahn ordination to be significantly (to within the one percent level) related to the measured environmental variables. This axis was correlated with percentage rock and bare soil, and also soil grain-size (silt). The first axis of the Principal components ordination was significantly correlated with presence of soil lichens and also with available water, the second axis with percentages of rock and bare soil, and the third with pH and human disturbance.

The first axis of the Spearman's rank ordination was significantly related to presence of soil lichens, the second to human disturbance and the third to percentages of rock, bare soil, and silt. Several of the environmental variables which correlated with the axes of the Bray and Curtis life-form ordination; especially percentages of bare soil and rocks, and moisture regime; were known to be related to the distribution of the vegetation at Rocky Flats before the vegetation analysis was completed and two of these variables, percentage of bare soil and moisture regime, were used as the basis for choosing the colors for the vegetation types on the Rocky Flats vegetation map. Since two environmental variables, percentage bare soil and percentage rocks, both correlated especially highly with the x axis of the Bray and Curtis life-form ordination, it seemed that this axis might best represent some sort of complex variable. When the percentage bare soil and rocks values for each stand were added together and the new variable which resulted, called "percentage of non-vegetated area", was correlated with the x axis, the correlation was higher than those of the two original variables to the x axis. Non-vegetated area can be defined as the area at ground surface which is not occupied either by vegetation or by current year's vegetation litter. Figure V-8 shows isolines representing values of some environmental variables plotted within the framework of the three-dimensional Bray and Curtis life-form ordination. These environmental variables are those which showed the highest correlations with the x axis of this ordination. Figure V-9 shows isolines of the environmental

Figure V-8. Isolines representing values of the environmental variables which showed the highest correlations with the x axis are plotted on three planes of the Bray and Curtis ordination based on life-forms.

Moisture Regime (five-part scale, 1-5)

Soil Lichens (presence+, absence-)

Grazing Regime (five-part scale, 0-4)

Percentage Moisture Loss on Ignition (hygroscopic, 0-5cm)

Figure V-9. Isolines representing values of the environmental variables which showed the highest correlations with the y and z axes are plotted on three planes of the Bray and Curtis ordination based on life-forms.

variables which correlated most highly with the y axis (moisture regime and presence of soil lichens) and the z axis (grazing regime and percentage moisture loss on ignition) plotted within the three-dimensional Bray and Curtis life-form ordination. Based on these two figures, the final conclusions are that the x axis of the Bray and Curtis life-form ordination best represents the variable "percentage of non-vegetated area", the y axis best represents "moisture regime" and the z axis best represents "grazing regime".

Two classifications of the 32 vegetation stands on the basis of environmental variables are shown in Figure V-10. The two methods, average linkage and Clark's method, produced classifications which were very similar. Corresponding clusters in each of the methods are indicated by diagonal shading in Figure V-10. It is hard to draw conclusions from Figure V-10 as to which vegetation types have similar environments since the two stands of a vegetation type are often not even clustered together. Some general conclusions can be made, as follows, but it must be kept in mind that they are based only on the environmental data that were gathered. Environmental variables which are also important may not be included in the data, either because their importance was overlooked or because time limits did not permit taking the necessary measurements. Four general groups of stands can be recognized at the fifty percent similarity level in Figure V-10. The agricultural fields (stands 1 and 2) and the most highly-disturbed barrens stands (3, 4, 7, and 8)

Figure V-10. Classifications of environmental variables and of stands, based on environmental variables. The corresponding clusters which contain the same stands in the two stand dendrogram are cross-hatched. The three main clusters formed in the environmental variable dendrograms are also indicated.

form one group of environmentally similar stands. Another group is composed of valley-side and valley-bottom vegetation, including two stands of thistle-dominated barrens (9 and 10), one meadow stand (11), two marsh stands (15 and 16), one streambank stand (14), one scrub stand (20) and one low scrub stand (24). A third group contains mainly prairie vegetation (stands 5, 6, 25, and 26) but also includes one meadow stand (12) and one streambank stand (13). The fourth group contains all of the pasture stands (17, 18, 27, 28, 29, 30, 31, and 32), the two pine savannah stands (21 and 22), one scrub stand (19) and one low scrub stand (23). The major groups of vegetation types in terms of environment can be considered to roughly correspond to pasture, prairie, valley-sides, and barrens. This stand classification is different from the classifications which are based on the vegetation in that it differentiates between pasture and prairie groups of stands.

Figure V-10 also shows two classifications of the seventeen environmental variables for which measurements were taken at Rocky Flats. The two methods used in these classifications produced completely different clusters, unlike the case in which these two methods were used in classifying stands. There is very little evidence of the formation of complex environmental variables from single environmental variables in either of these two classifications, although a complex moisture variable, soil particle size variable, and soil disturbance (including grazing) variable are somewhat indicated.

Species and Life-forms Plotted on the Ordination

Isolines of species or life-form importance measures (species index) in the vegetation stands, when plotted within the Bray and Curtis life-form ordination, indicated that the distribution of the vegetation is related to the environmental variables which are associated with the axes of the ordination. Many of the Rocky Flats species are not found in more than a few stands, making it hard to determine how the distribution of these species is related to the ordination axes. The species index values in the 32 vegetation stands of some species which occur in several stands are plotted in two dimensions of the Bray and Curtis life-form ordination (Figure V-11, V-12, V-13, and V-14). *Stipa comata* is a native mixed-prairie perennial grass whose distribution was limited to dry and dry-mesic stands. Largest values of this species occurred in the dry stands (Figure V-11). *Agropyron trachycaulum*, another native mixed-prairie perennial grass has a wider distribution which includes the wet stands (Figure V-12). Distribution of this species is also related to the variable "percentage of non-vegetated area" and its largest values occur in stands where the vegetation as a whole is densest. *Poa compressa* is another perennial grass which has a very wide distribution along the moisture gradient at Rocky Flats (Figure V-13). Largest values of this species occur in mesic stands which are also densely vegetated. *Medicago sativa*,

Figure V-11. Isolines encircling stands that contain similar importance measures (species index) of Stipa comata are plotted on one plane of the Bray and Curtis ordination based on life-forms.

Figure V-12. Isolines encircling stands that contain similar importance measures (species index) of Agropyron trachycaulum are plotted on one plane of the Bray and Curtis ordination based on life-forms.

Figure V-13. Isolines encircling stands that contain similar importance measures (species index) of *Poa compressa* are plotted on one plane of the Bray and Curtis ordination based on life-forms.

Figure V-14. Isolines encircling stands that contain similar importance measures (species index) of Medicago sativa are plotted on one plane of the Bray and Curtis ordination based on life-forms.

a broad-leaved perennial weedy herb occurs in dry and dry-mesic stands at Rocky Flats (Figure V-14). The largest values of this species occur in dry stands which have a higher percentage of non-vegetated area than those stands in which *Agropyron trachycaulum* and *Poa compressa* are most prevalent.

The amounts of the ten Rocky Flats vegetation life-forms in the 32 stands are represented by circles within the framework of the three-dimensional Bray and Curtis life-form ordination in Figures V-15 through V-24. Figure captions relate the distribution of the life-forms to the environmental variables which are represented by the ordination axes. Accurate relationships between life-form distribution and all three axes indicate that the three-dimensional Bray and Curtis ordination based on ten life-forms in 32 stands is particularly useful in explaining the vegetation distribution at Rocky Flats.

Figure V-15

The amounts of the life-form WOODY, LESS THAN 5 METERS IN HEIGHT in the 32 vegetation stands are plotted on three planes of the ordination. The ordination axes are labeled with the three most important of the measured environmental variables at Rocky Flats. The size of the circles represents the amount (based on an importance measure, species index) of the life-form present in the stand which is located at the center of each circle. This life-form category contains 11 species, including both shrubs and lianas. This life-form is found in only 9 of the 32 stands. It occurs in very small amounts in a few dry stands but occurs in large amounts in mesic to wet stands. It is not affected by grazing but does not occur in the stands which have a high percentage of non-vegetated area.

Figure V-16

The amounts of the life-form HERBACEOUS, BROAD-LEAVED PERENNIALS in the 32 vegetation stands are plotted on three planes of the ordination. The ordination axes are labeled with the three most important of the measured environmental variables at Rocky Flats. The size of the circles represents the amount (based on an importance measure, species index) of the life-form present in the stand which is located at the center of each circle. This life-form category contains 57 species, including both native plants and weeds. Herbaceous, broad-leaved perennials occur in nearly every stand. The amount of this life-form the stands increases with increased grazing intensity. Largest quantities occur in the relatively dry stands. Percentage of non-vegetated area does not seem to influence the distribution of this life-form, and it is found in both barren and well-vegetated stands. Moisture also does not seem to limit this life-form although it occurs in largest amounts in dry to mesic stands.

Figure V-17

The amounts of the life-form HERBACEOUS, BROAD-LEAVED BIENNIALS in the 32 vegetation stands are plotted on three planes of the ordination. The ordination axes are labeled with the three most important of the measured environmental variables at Rocky Flats. The size of the circles represents the amount (based on an importance measure, species index) of the life-form present in the stand which is located at the center of each circle. This life-form category contains 11 species, including both native plants and weeds. This life-form occurs in small amounts in nearly all stands except those which have a high percentage of non-vegetated area. It occurs in largest amounts in mesic and wet stands which have a low percentage of non-vegetated area. Grazing intensity does not seem to affect the distribution of this life-form.

Figure V-18

The amounts of the life-form HERBACEOUS, BROAD-LEAVED ANNUALS in the 32 vegetation stands are plotted on three planes of the ordination. The ordination axes are labeled with the three most important of the measured environmental variables at Rocky Flats. The size of the circles represents the amount (based on an importance measure, species index) of the life-form present in the stand which is located at the center of each circle. This life-form category contains 22 species, which are primarily weedy plants. Herbaceous, broad-leaved annuals are found in small amounts in nearly every stand but occur in large amounts in the two fairly dry stands which have a high percentage of non-vegetated area. The distribution of this life-form does not seem to be particularly influenced by grazing or moisture regimes.

Figure V-19

The amounts of the life-form SUCCULENTS in the 32 vegetation stands are plotted on three planes of the ordination. The ordination axes are labeled with the three most important of the measured environmental variables at Rocky Flats. The size of the circles represents the amount (based on an importance measure, species index) of the life-form present in the stand which is located at the center of each circle. This life-form category contains four species of cacti and one species of sedum. Succulents are found in 11 of the 32 stands. They are not found in stands which have a large percentage of non-vegetated area. They also decrease somewhat in amount with increased grazing intensity. They are found only in dry to mesic stands.

Figure V-20

The amounts of the life-form HERBACEOUS, NARROW-LEAVED PERENNIALS in the 32 vegetation stands are plotted on three planes of the ordination. The ordination axes are labeled with the three most important of the measured environmental variables at Rocky Flats. The size of the circles represents the amount (based on an importance measure, species index) of the life-form present in the stand which is located at the center of each circle. This life-form category contains 61 species, including primarily native grasses and narrow-leaved forbs. A few weedy species are also contained in this category, which includes more species than any other life-form at Rocky Flats. This life-form is found in large amounts in nearly every stand, particularly in the dry ones, but is not found in those stands which have a high percentage of non-vegetated area. The amount of this life-form decreases with increased grazing intensity.

Figure V-21

The amounts of the life-form HERBACEOUS, NARROW-LEAVED ANNUALS in the 32 vegetation stands are plotted on three planes of the ordination. The ordination axes are labeled with the three most important of the measured environmental variables at Rocky Flats. The size of the circles represents the amount (based on an importance measure, species index) of the life-form present in the stand which is located at the center of each circle. This life-form category contains 14 species, including primarily weedy annual grasses and narrow-leaved forbs. Herbaceous, narrow-leaved annuals occur in nearly every stand except those with a very high percentage of non-vegetated area. The amount of this life-form in the stands increases with increased grazing intensity. The greatest amounts are found in dry to mesic stands.

Figure V-22

The amounts of the life-form BRYOPHYTES in the 32 vegetation stands are plotted on three planes of the ordination. The ordination axes are labeled with the three most important of the measured environmental variables at Rocky Flats. The size of the circles represents the amount (based on an importance measure, species index) of the life-form present in the stand which is located at the center of each circle. This life-form category contains 9 species including both mosses and liverworts. Bryophytes are found in 11 of the 32 stands. They do not occur in stands which have a high percentage of non-vegetated area. They also decrease in amount with increased grazing intensity. They are found along the entire moisture gradient but occur in largest amounts in the mesic to wet stands.

Figure V-23

The amounts of the life-form LICHENS in the 32 vegetation stands are plotted on three planes of the ordination. The ordination axes are labeled with the three most important of the measured environmental variables at Rocky Flats. The size of the circles represents the amount (based on an importance measure, species index) of the life-form present in the stand which is located at the center of each circle. This life-form category contains 34 species, including both saxicolous and terricolous lichens. This life-form occurs in 13 of the 32 stands. The amount of lichens in the stands increases with increased grazing intensity. Lichens are not found in the stands which have a high percentage of non-vegetated area. The greatest amounts of lichens are found in the driest stands. Lichens are not present in the mesic to wet stands.

Figure V-24

The amounts of the life-form WOODY, GREATER THAN 5 METERS IN HEIGHT in the 32 vegetation stands are plotted on three planes of the ordination. The ordination axes are labeled with the three most important of the measured environmental variables at Rocky Flats. The size of the circles represents the amount (based on an importance measure, species index) of the life-form present in the stand which is located at the center of each circle. This life-form category contains 1 species, ponderosa pine, which was the only tree found in the vegetation sampling stands, although other tree species are present at Rocky Flats. This life-form occurred in only two stands but was present in large amounts in each of them. The two stands are both located on very dry, heavily grazed ridgetops.

CHAPTER VI

CONCLUSIONS, RECOMMENDATIONS, AND PREDICTIONS

The vegetation mapping phase of this study was successful in producing a 1:12,000 color vegetation map of the Rocky Flats area. This map will serve as a description of the vegetation at this point in time and also as a documentation against which future changes in the vegetation can be compared. The vegetation analysis not only complements the map by providing insight as to how the vegetation types on the map are related to each other and to the environment, it also provides the necessary baseline figures for determining the rate and magnitude of future changes in the vegetation.

Sixteen vegetation types are identified on the map. As was mentioned in the introduction, it is difficult to compare the mixed growth of these vegetation types to recognized vegetation types found elsewhere in the Great Plains. The Rocky Flats area is located in a transition zone between mountains and plains and this affects the local topography, surficial geology, and climate, allowing a much wider spectrum of vegetation types to exist than would otherwise be expected in this size area. An attempt was made, however, to compare the seven pasture, prairie, and meadow vegetation types at Rocky Flats to the associations which Vestal (1914) identified in this general vicinity sixty years ago. As Vestal predicted, the vegetation does not appear to be any more stable now than it was in 1914; if anything, it is more of a

mixture at present. This is undoubtedly caused by the two factors which Vestal (1914) mentioned: its location in a transition zone; and disturbance by unnatural factors, primarily grazing.

The six prairie and pasture vegetation types, the three barrens types, and the field, streambank, marsh and low scrub types were found to be fairly homogeneous, in terms of number of species, across the study area. These types are probably adequately represented by the two stands which were chosen for the purpose of gathering the vegetation and environmental data used in the vegetation analysis. The meadow, scrub (and, to a lesser degree, the savannah) vegetation types were found to be more heterogeneous, in terms of number of species, and probably not adequately represented by the two sampling stands which were chosen.

As a result of performing the vegetation analysis, the following statements can be made. Life-form data produced ordinations that were more efficient and successful than those based on species data. A Bray and Curtis ordination proved to be the best method of analyzing the life-form data. A high negative correlation ($r_s = -.853$) between interstand distances in three dimensions of this ordination and interstand percentage similarity of the vegetation based on life-forms indicated that the ordination was extremely accurate in representing the life-form data. A high negative correlation ($r_s = -.545$) between interstand distances in three dimensions of this ordination and interstand

percentage similarity of the vegetation based on 227 species indicated that the life-form ordination accurately represented the original data matrix also. This ordination method was efficient in that the data was effectively summarized within three dimensions. Several environmental variables correlated highly with the three axes of the Bray and Curtis life-form ordination. Most important correlations were as follows: the x axis and percentage non-vegetated area, the y axis and moisture regime, and the z axis and grazing regime. These three variables are significantly related to, and, in the case of moisture regime and grazing regime, influence the distribution of the vegetation at Rocky Flats. Percentage non-vegetated area is a variable which is derived by adding together the values of two other, measured, variables: percentage bare soil and percentage rocks. The variables percentage bare soil and moisture regime were thought to be important factors at Rocky Flats when the vegetation mapping was concluded, therefore, colors for the vegetation map units were chosen on the basis of the values of these two variables in the representative vegetation stands.

When species were plotted within two dimensions of the Bray and Curtis life-form ordination, trends in their distributions and importance values were meaningful in terms of the environmental variables which were associated with the ordination axes. This result was also observed when importance measures of the ten life-forms were plotted within three dimensions of the Bray and Curtis

life-form ordination. Grazing regime and moisture regime, respectively, seemed to have the greatest influence on the distribution of the life-forms, while percentage non-vegetated area was not quite as important. Moisture regime also seemed to have a greater influence than percentage non-vegetated area on the distribution of the four species which were plotted on the ordination.

Percentage similarity based on 227 species proved to be the best data base for stand classification using the average linkage method of Sokal and Sneath (1963). This method combined the sixteen vegetation types into eight general groups at the 33 percent similarity level as follows: marsh, streambank, prairie--pasture, barrens, valley-side, savannah, tall scrub, and agricultural field vegetation. At a slightly lower level of similarity (25 percent) the following groups were formed: valley-side, agricultural field, valley-bottom, barrens, prairie--pasture--savannah vegetation. At the fifteen percent similarity level all of the stands were classified into one of two groups which generally correspond to upland and lowland vegetation. A stand classification based on percentage similarity in terms of ten life-forms with degrees of absence produced seven groups of vegetation types at the ninety percent similarity level as follows: valley-side--valley-bottom--fields, barrens, barrens, thistle-barrens, shrub-dominated, savannah, and pasture--prairie vegetation. When the stands were classified on the basis of seventeen environmental variables, four general groups of vegetation types were

formed at the fifty percent similarity level as follows: valley-side--valley-bottom, agricultural field--barrens, pasture, and prairie vegetation. These classifications indicate that the vegetation types (map units) are more diverse in terms of species composition than in terms of stand environments. However, the vegetation types are slightly more diverse in terms of stand environments than in terms of life-form composition.

Because of the diverse nature of the vegetation at Rocky Flats the ordination methods benefited from the use of life-form rather than species data. However, the best basis for the classifications (including the vegetation mapping) was species rather than life-form data.

When seventeen measured environmental variables were clustered using the average linkage method, two groups which formed at the 65 percent similarity level were: moisture-related variables and percentages of organic matter and pebbles and granules; percentages of sand, silt, clay, and available water. Additional variables which were somewhat related to the first group include percentage of rocks, soil disturbance caused by humans, grazing regime, percentage of soil lichens, and pH. Variables which were related to the second main group include soil disturbance caused by small mammals and percentage of bare soil. When another clustering method, also agglomerative, was used on the environmental data, completely different clusters were formed. The main cluster formed

by this method contained the two soil disturbance variables as well as the grazing regime variable.

The vegetation analysis, vegetation type summaries, and the map indicate the following relationships among the vegetation types. As grazing increases, the DRY, *Hypericum perforatum* - *Paronychia jamesii*, PASTURE replaces both the DRY, *Koeleria macrantha* - *Agropyron trachycaulum*, PRAIRIE and the DRY, *Stipa comata* - *Koeleria macrantha*, PRAIRIE. Where grazing is particularly severe or there has been, in the past, human-caused disturbance such as bull-dozing, the DRY, *Hypericum perforatum* - *Ambrosia psilostachya*, BARRENS is found in place of the DRY, *Hypericum perforatum* - *Paronychia jamesii*, PASTURE. The DRY, *Polygonum aviculare* - *Ambrosia psilostachya*, BARRENS is the vegetation type which is found on recently or continually disturbed areas. All of the vegetation types which have been mentioned thus far are found almost exclusively on a substrate of Rocky Flats Alluvium in the western half of the study area. A different succession occurs in the eastern, valley-dissected half of the study area where there is a larger portion of the clay fraction in the soil. The DRY, *Buchloë dactyloides* - *Arnica fulgens*, PASTURE, and, in the southeastern quadrat, the DRY, *Secale cereale* - *Bromus tectorum*, FIELD cover most of this area, which is underlain by Arapahoe Formation. In isolated areas, probably where the soil is looser or where grazing is more severe, broad-leaved herbs are able to invade the DRY, *Buchloë dactyloides* - *Arnica fulgens*, PASTURE and the vegetation type labeled: DRY,

Buchloë dactyloides - *Medicago sativa*, PASTURE replaces it.

Where the soil is gravelly and there is an even smaller portion of clay the vegetation changes from being dominated by short-grasses to being dominated by broad-leaved herbs. In these areas the DRY, *Heterotheca villosa* - *Buchloë dactyloides*, PASTURE replaces the other two *Buchloë dactyloides*-dominated pasture types.

Unlike the latter two types, the DRY, *Heterotheca villosa* - *Buchloë dactyloides*, PASTURE seems to be able to successfully invade the western half of the map area, where it is found in greatest abundance, mingling and intergrading with the DRY, *Hypericum perforatum* - *Paronychia jamesii*, PASTURE. These two types seem to have a similar tolerance of grazing. Typically, there is a smaller percentage of non-vegetated area in the DRY, *Heterotheca villosa* - *Buchloë dactyloides*, PASTURE because of the sod-forming tendency of the latter species, which is lacking in the DRY, *Hypericum perforatum* - *Paronychia jamesii*, PASTURE. Soil data from stands which represent these two types indicate that there is a larger portion of clay in the soil on which the former type is found, but not as large a portion as in the soil on which the other two *Buchloë dactyloides* pasture types are found.

The MOIST, *Agropyron trachycaulum* - *Poa compressa*, MEADOW is found throughout the middle portion of the study area where the valley-sides are slightly steeper and more mesic than in the eastern part and where grazing is not severe. Like the two

Buchloë dactyloides-dominated pasture types, this type is found on soil which is underlain by Arapahoe Formation, and where it contacts these two pasture types it tends to intergrade with them. Thus, nature of the substrate, moisture availability, and grazing seem to be particularly important in determining the distribution of the vegetation at Rocky Flats.

The sharp, straight-line boundaries on the map, in certain areas, occur along fence lines where differential amounts of grazing on either side of the fence favor different vegetation types. The types which show this pattern are prairie, pasture, and meadow units, which is to be expected since grazing particularly affects grasses and these types all contain a very high portion of grasses. This again indicates that physical conditions in the environment, such as grazing, are more influential on the vegetation distribution than is competition between the types.

While the nature of the substrate and the amount of clay and rocks in the soil are not easily modified artificially, grazing intensity and moisture availability are. When grazing is discontinued, the vegetation has much potential for recovery, as has been exhibited over the past twenty years by the four square-mile area in the center of the vegetation map, which is within the barbed wire fence surrounding the Rocky Flats Plant. Increasing the moisture content of the soil through irrigation, and reseeding the barren areas with native grass seed would undoubtedly hasten the process. It is reasonable to expect that the following vegetation types--the DRY, *Koeleria macrantha* - *Agropyron trachycaulum*, PRAIRIE;

the DRY, *Buchloë dactyloides* - *Arnica fulgens*, PASTURE; and the MOIST, *Agropyron trachycaulum* - *Poa compressa*, MEADOW--would then cover 95 percent of the vegetated area at Rocky Flats, instead of 47 percent as at present. The average vegetation density of these types is such that 86 percent of the ground surface would be occupied by vegetation, leaving fourteen percent of bare soil and rocks. The density of the vegetation could probably be further increased by increasing the moisture availability, since moisture seems to be a limiting factor to lushness of plant growth at Rocky Flats. The remaining five percent of the vegetated area at Rocky Flats would probably continue to be occupied by the same vegetation types as are present in the valley-bottoms, and scattered along the valley-sides and the ridges at present: the marsh, streambank, scrub, low-scrub, and savannah communities. The vegetation density in the marsh and low-scrub communities is very high and vegetation occupies an average of 94 percent of the area at ground surface in these types. Trees and tall shrubs dominate the streambank, scrub, and savannah communities and the understory is poorly developed, hence, the vegetation density at ground surface in these types is low. This is probably due to competition for water rather than for light since the canopy in these stands is fairly open. Again, an increase in moisture availability should result in increased vegetation density in these stands.

Recommendations for further study of the vegetation of Rocky Flats are as follows. Several permanent, fenced enclosures should be set up in representative areas of each of the sixteen vegetation types. Moisture and grazing amounts should be varied in different enclosures in each vegetation type and changes in the vegetation, particularly in terms of cover, should be monitored, perhaps on a life-form basis. Sections of the plots should be clipped for productivity determinations at regular intervals. In addition, the enclosures in the vegetation types labeled "BARRENS" on the map should be reseeded with native, dryland species and the success of these species should be noted.

The goals set forth in the introduction to this dissertation are achieved by the following results. A detailed documentation of the vegetation of Rocky Flats by way of a vegetation map and map unit descriptions is provided. This study illustrates relationships among the various vegetation types on the map through vegetation analysis techniques. Three important environmental variables and their relationships to the distribution of plant species and life-forms at Rocky Flats are noted. Speculations on past changes in the vegetation distribution as a result of changes in these environmental variables are included, and some predictions and recommendations for the future are made. This study is also of particular value, not only to other researchers of the Rocky Flats area but to plant ecologists in general for the following reason. It illustrates that life-form data from a

area such as Rocky Flats can successfully be used (and may be the best basis for) ordination techniques wherever a large number of species are present--this has previously only been demonstrated for large, diverse areas.

LIST OF REFERENCES

- Austin, M. P. and L. Orloci. 1966. Geometric models in ecology. II. An evaluation of some ordination methods. J. Ecol., 54: 217-227.
- Beals, E. W. 1960. Forest bird communities in the Apostle Islands of Wisconsin. The Wilson Bull., 72: 156-181.
- Branson, F. A., R. F. Miller and I. S. McQueen. 1965. Plant communities and soil moisture relationships near Denver, Colorado. Ecology, 46: 311-319.
- Bray, J. R. and J. T. Curtis. 1957. An ordination of the upland forest communities of southern Wisconsin. Ecol. Monogr., 27: 325-349.
- Clark, J. A. 1973. An analysis of clustering methods. Unpublished paper, Geography Department, University of Colorado, Boulder. 33 pp.
- Clark, J. A. 1974. Mudflows in the San Juan Mountains, Colorado: controls and work. Unpublished M.A. thesis, University of Colorado, Boulder. 102 pp.
- Curtis, J. T. 1959. The Vegetation of Wisconsin: an Ordination of Plant Communities. University of Wisconsin Press, Madison. 657 pp.
- Gleason, H. A. and A. Cronquist. 1964. The Natural Geography of Plants. Columbia University Press, New York. 420 pp.
- Goodall, D. W. 1973. Numerical classification. In: Tüxen, R. (ed.), Handbook of Vegetation Science. Part 5, Whittaker, R. H. (ed.), Ordination and Classification of Communities. Dr. W. Junk N. V., Den Haag. pp. 575-615.
- Harper, W. G., L. Acott and E. Frahm. 1932. Soil Survey of the Brighton Area, Colorado. U.S. Dept. Agriculture, Bureau of Chemistry and Soils. Soil survey series 1932, No. 1. 35 pp., 1 map.
- Hill, M. O. 1973. Reciprocal averaging: an eigenvector method of ordination. J. Ecol., 61: 237-249.

- Hill, M. O., R. G. H. Bunce and M. W. Shaw. 1975. Indicator speices analysis, a divisive polythetic method of classification, and its application to a survey of native pinewoods in Scotland. J. Ecol., 63: 597-614.
- Hurr, R. T. 1976. Hydrology of a nuclear-processing plant site, Rocky Flats, Jefferson County, Colorado. U.S. Geol. Survey, Open-file report 76-238. 68 pp., 2 maps.
- Knight, D. H. 1965. A gradient analysis of Wisconsin prairie vegetation on the basis of plant structure and function. Ecology, 46: 744-747.
- Knight, D. H. and O. L. Loucks. 1969. A quantitative analysis of Wisconsin forest vegetation on the basis of plant function and gross morphology. Ecology, 50: 219-234.
- Küchler, A. W. 1967. Vegetation Mapping. Ronald Press, New York. 472 pp.
- Livingston, R. B. 1952. Relict true prairie communities in Colorado. Ecology, 33: 72-86.
- Malde, H. E. 1955. Surficial geology of the Louisville Quadrangle, Colorado. U.S. Geol. Surv. Bull. 996-E, pp. 217-257.
- May, D. E. 1973. Models for predicting composition and production of alpine tundra vegetation from Niwot Ridge, Colorado. Unpublished M.A. thesis, University of Colorado, Boulder. 99 pp.
- Moreland, D. C. and R. E. Moreland. 1975. Soil Survey of the Boulder County Area, Colorado. U.S. Dept. Agriculture, Soil Conserv. Serv., Cartographic Div. 86 pp., 17 maps.
- Mueller-Dombois, D. and H. Ellenberg. 1974. Aims and Methods of Vegetation Ecology. John Wiley and Sons, Inc., New York. 547 pp.
- Mukkattu, M. M. 1974. Classification of natural communities based on covariance and related functions. Can. J. Bot., 52: 2341-2349.
- Nie, N. H., C. H. Hull, J. G. Jenkins, K. Steinbrenner and D. H. Bent. 1975. Statistical Package for the Social Sciences. Second edition. McGraw-Hill, Inc., New York. 675 pp.
- Orloci, L. 1966. Geometric models in ecology. I. The theory and application of some ordination methods. J. Ecol., 54: 193-215.

- Ponyatovskaya, V. M. 1961. On two trends in phytosociology. Translated by J. Major. Vegetatio, 10: 373-385.
- Siegal, S. 1956. Nonparametric Statistics for the Behavioral Sciences. McGraw-Hill Book Company, New York. 312 pp.
- Sokal, R. R. and P. H. A. Sneath. 1963. Principles of Numerical Taxonomy. W. H. Freeman and Co., San Francisco. 359 pp.
- Swan, J. M. A. 1970. An examination of some ordination problems by use of simulated vegetational data. Ecology, 51: 89-102.
- Swan, J. M. A., R. L. Dix and C. F. Wehrhahn. 1969. An ordination technique based on the best possible standard axes and its application to vegetational analysis. Ecology, 50: 206-212.
- Unesco. 1973. International Classification and Mapping of Vegetation. UNIPUB, Inc., New York. 93 pp.
- Van Horn, R. 1972. Surficial and bedrock geologic map of the Golden Quadrangle, Jefferson County, Colorado. U.S. Geol. Surv. Misc. Geol. Inv. Map 1-761-A.
- Vestal, A. G. 1914. Prairie vegetation of a mountain-front area in Colorado. Bot. Gaz., 58: 377-399.
- Weaver, J. E. and F. E. Clements. 1938. Plant Ecology. Second edition. McGraw-Hill Book Company, Inc., New York. 601 pp.
- Webber, P. J. 1971. Gradient analysis of the vegetation around the Lewis Valley, North-Central Baffin Island, Northwest Territories, Canada. Unpublished Ph.D. thesis, Queen's University, Kingston, Ontario. 366 pp.
- Webber, P. J. and W. R. Keammerer (eds.). 1973. The Vegetation Continuum: a Collection of Readings. Unpublished manuscripts, University of Colorado, Boulder. 232 pp.
- Weber, W. A. 1972. Rocky Mountain Flora. Colorado University Press, Boulder. 438 pp.
- Weber, W. A. 1973. Guide to the mosses of Colorado. Keys and ecological notes based on field and herbarium studies. Univ. Colorado, Inst. Arct. Alp. Res. Occas. Pap. 6, 48 pp.
- Weber, W. A. and B. C. Johnston. 1976. Natural History Inventory of Colorado. I. Vascular Plants, Lichens, and Bryophytes. University of Colorado Museum, Boulder. 206 pp.

Weber, W. A., G. Kunkel and L. Shultz. 1974. A Botanical Inventory of the Rocky Flats AEC Site. Final report, AEC contract no. AT(11-1)-2371. University of Colorado, Boulder. 40 pp.

Whittaker, R. H. 1967. Gradient analysis of vegetation. In: Poole, R. W., 1974. An Introduction to Quantitative Ecology. McGraw-Hill, Inc., New York. 532 pp.

Whittaker, R. H. 1973. Direct gradient analysis: techniques. In: Tüxen, R. (ed.), Handbook of Vegetation Science. Part 5, Whittaker, R. H. (ed.), Ordination and Classification of Communities. Dr. W. Junk N. V., Den Haag. pp. 9-31.

APPENDIX A

RESULTS OF SOIL ANALYSES OF 32 VEGETATION STANDS

STAND NUMBER	pH			Nitrogen			Phosphorus			Potassium			Field Capacity	Wilting Point	Available Water	Percent Nitrogen	Percent Phosphorus	Percent Potassium	Percent Organic Matter	pH
	1	2	3	4	5	6	7	8	9	10	11	12								
1	14.2	4.0	16.7	25.8	37.9	49.0	27.1	31.7	29.3	37.0	31.7	21.7	11.9	7.8	2.9	-	-	36.9	4.7	6.7
2	2.8	4.0	32.5	25.3	42.2	36.5	27.6	37.9	25.2	36.9	37.9	25.6	16.8	9.8	3.1	-	-	36.5	4.4	6.4
3	42.1	9.8	57.5	13.6	78.7	58.1	16.2	26.7	53.0	58.3	75.7	19.5	11.4	8.1	2.5	1.6	-	43.2	3.6	7.8
4	39.3	8.2	55.5	15.3	30.2	56.5	15.1	28.4	50.9	20.7	28.4	19.2	11.4	7.8	2.7	-	-	49.0	3.8	6.1
5	43.1	3.1	54.1	22.4	25.5	56.2	23.4	20.4	47.3	37.3	29.4	21.4	13.0	8.4	2.1	-	-	57.8	8.1	5.9
6	35.6	1.8	48.8	74.7	78.5	50.5	28.8	21.7	51.4	35.9	22.7	21.5	12.9	10.6	2.2	-	-	59.6	8.1	5.8
7	7.9	10.0	89.8	9.3	20.9	71.0	9.0	20.0	65.1	15.9	20.0	15.8	8.3	7.5	2.1	4.1	-	42.2	2.6	8.0
8	59.6	5.4	58.2	19.3	22.5	59.8	20.5	19.7	50.0	30.3	19.7	17.8	9.7	6.1	1.7	-	-	42.3	5.7	5.7
9	17.7	3.9	61.1	19.5	18.4	64.2	19.0	18.8	52.8	30.4	18.8	11.0	12.2	3.8	1.7	-	-	57.4	6.7	6.4
10	7.5	2.1	48.6	21.6	27.6	50.8	24.5	24.7	39.8	35.5	24.7	22.5	16.4	6.1	2.3	-	-	61.3	8.5	5.9
11	7.5	5.9	56.3	22.8	20.9	58.5	21.2	18.3	49.8	31.9	18.3	20.9	16.5	6.1	2.4	-	-	64.0	9.2	6.5
12	26.0	5.2	57.8	18.6	22.8	59.6	20.2	20.5	59.3	30.5	20.2	17.3	11.4	5.9	1.8	-	-	56.2	6.1	6.3
13	41.4	13.0	79.4	7.0	13.6	74.9	8.5	11.6	78.0	10.4	11.6	10.4	7.3	3.1	1.3	-	-	42.4	5.7	6.5
14	8.7	2.1	49.3	23.8	26.9	51.4	25.6	21.8	40.4	35.8	21.8	30.8	7.9	6.9	3.4	-	-	75.1	13.1	6.3
15	1.5	0.5	45.1	27.0	27.7	47.0	28.0	24.2	19.6	36.2	24.2	59.9	44.7	15.2	5.3	-	-	135.8	26.5	6.0
16	0.6	0.2	34.1	27.1	38.8	35.8	31.2	33.0	26.3	40.7	33.0	31.5	22.6	8.9	3.1	-	-	70.5	11.2	6.5
17	27.2	10.2	52.3	24.0	23.7	56.6	24.9	20.5	46.4	33.1	20.5	22.6	12.5	10.1	1.9	-	-	56.9	8.1	6.3
18	25.1	9.2	59.3	20.3	20.4	61.0	21.4	17.6	51.6	30.6	17.6	20.6	10.5	9.5	1.7	-	-	51.2	7.5	6.3
19	2.8	0.9	52.7	23.9	23.4	56.2	24.0	19.8	42.2	38.0	19.8	30.9	19.3	11.3	2.9	-	-	75.2	12.7	6.6
20	0.4	0.4	51.8	24.1	24.1	51.7	25.7	21.1	41.2	35.7	21.1	48.4	43.1	5.3	5.2	-	-	103.4	25.8	6.8
21	5.2	3.5	61.6	18.9	19.5	63.9	19.1	17.0	51.8	29.2	17.0	20.8	11.2	9.8	1.9	-	-	60.3	9.5	5.1
22	26.1	4.2	51.9	20.9	27.2	51.8	22.0	24.2	42.9	32.9	24.2	18.4	10.1	8.1	1.5	-	-	54.6	6.5	5.6
23	0.3	0.3	37.4	29.3	28.3	37.0	38.3	24.7	22.6	52.7	24.7	30.1	16.8	13.7	2.7	-	-	66.4	10.0	6.9
24	0.1	0.1	43.0	24.6	31.4	44.9	27.3	21.8	34.7	37.5	21.8	21.4	17.7	17.7	6.7	-	-	60.7	8.2	6.0
25	12.1	3.2	52.4	22.6	25.0	55.5	23.4	21.4	44.5	34.1	21.4	21.9	12.8	9.1	1.9	-	-	60.6	6.6	5.8
26	27.7	4.9	46.9	24.3	28.6	46.5	26.1	25.2	40.4	34.4	25.2	23.8	14.8	9.0	2.2	-	-	68.8	9.2	5.9
27	14.0	4.0	38.2	33.2	34.6	33.9	38.7	24.4	22.7	47.9	24.4	30.2	18.1	10.5	2.8	-	-	76.8	11.6	6.2
28	25.1	4.5	46.7	21.2	32.1	47.9	25.1	27.0	41.4	31.6	27.0	21.6	11.9	9.7	2.0	-	-	53.7	7.8	6.2
29	18.9	3.3	33.7	31.7	32.4	39.3	32.7	28.0	27.4	42.4	28.0	32.0	20.9	11.1	3.2	9.8	-	68.4	12.2	7.8
30	0.1	0.1	22.7	38.2	38.1	25.1	42.0	32.9	15.0	53.1	32.9	32.9	22.4	10.4	3.0	-	-	79.6	12.0	6.2
31	31.2	3.7	42.5	72.0	28.9	51.8	22.5	25.6	42.5	31.4	25.6	22.0	15.7	9.3	2.2	-	-	61.2	6.9	6.8
32	27.1	6.9	46.5	21.3	30.2	48.2	22.6	27.2	38.7	31.6	27.2	25.0	12.9	7.1	2.5	-	-	70.9	9.7	6.4

APPENDIX B

SPECIES INDEX VALUES FOR TEN LIFE-FORMS, AND TEN LIFE-FORMS WITH DEGREES OF ABSENCE, IN 32 STANDS

LIFEFORM	STAND:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
LIFEFORM																																	
Woody (greater than 5 m. in height)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	861	944	-	-	-	-	-	-	-	-	-	-
Woody (less than 5 m. in height)	-	-	-	-	-	-	-	-	-	-	-	-	-	609	831	-	12	-	-	932	696	112	69	762	901	-	-	-	-	-	-	-	-
Herbaceous, broad-leaved, perennial	225	171	-	804	366	356	702	814	-	33	426	31	407	291	417	532	566	520	207	219	88	203	81	61	286	286	568	396	322	316	973	1062	
Herbaceous, broad-leaved, biennial	-	79	-	-	163	111	76	59	839	823	68	261	389	371	236	-	143	104	134	259	88	-	-	31	94	43	235	24	55	125	25	-	
Herbaceous, broad-leaved, annual	268	295	2000	1198	144	47	275	352	-	-	236	133	64	172	26	358	49	62	118	453	44	62	135	-	159	21	204	166	27	124	149	89	
Succulent	-	-	-	-	95	131	-	-	-	-	67	-	-	-	-	-	22	43	-	-	-	-	-	-	-	110	220	114	-	27	-	59	30
Herbaceous, narrow-leaved, perennial	1109	1124	-	-	866	775	670	238	465	516	841	1216	189	245	989	1157	722	416	231	21	68	212	705	511	839	1071	614	1016	1369	1214	140	470	
Herbaceous, narrow-leaved, annual	397	330	-	-	48	226	277	537	656	828	362	415	-	89	-	121	251	220	186	353	330	189	317	493	236	141	264	228	230	268	290	287	
Bryophyte	-	-	-	-	144	158	-	-	-	-	-	-	-	139	-	332	-	21	48	-	-	21	-	-	123	65	-	-	-	50	75	-	
Lichen	-	-	-	-	175	206	-	-	-	-	-	-	-	-	-	-	248	215	165	-	506	300	-	-	153	153	-	171	168	-	50	62	
LIFEFORM WITH DEGREES OF ABSENCE																																	
Woody (greater than 5 m. in height)	7	6	7	7	7	7	6	6	6	6	5	6	6	9	9	7	10	7	7	10	9	8630	9440	10	9	7	7	5	8	7	7	7	7
Woody (less than 5 m. in height)	29	28	28	29	24	24	28	28	28	28	24	28	8490	8310	28	320	23	24	9320	6960	1120	690	7620	9010	24	24	24	27	23	26	24	22	
Herbaceous, broad-leaved, perennial	2150	1710	97	8040	3660	3660	7020	8140	94	330	4260	310	4070	2910	4170	5320	5660	5200	2070	2190	880	2030	810	610	2860	2860	5680	3960	3220	3160	9730	10620	
Herbaceous, broad-leaved, biennial	80	790	76	78	1630	1110	760	590	8390	8230	680	2610	3890	3710	2360	78	1430	1040	1340	2590	880	77	78	310	940	430	2350	240	550	1250	250	81	
Herbaceous, broad-leaved, annual	2690	2950	20000	11980	1440	470	2750	3520	89	90	2360	1330	640	1720	260	3580	490	620	1180	4530	440	630	1350	90	1590	210	2040	1660	270	1240	1490	890	
Succulent	38	38	38	38	950	1310	18	38	39	38	670	38	35	37	41	30	220	430	39	32	31	34	30	31	1100	2200	1140	43	270	41	590	305	
Herbaceous, narrow-leaved, perennial	11090	11240	93	93	8660	7750	6700	2380	4650	5160	8410	12160	1890	2450	9890	11570	7220	8160	2310	210	680	2120	7050	5110	8390	10710	6140	10160	13690	12140	1400	4700	
Herbaceous, narrow-leaved, annual	3970	3300	86	86	480	2260	2770	5370	6560	8280	3620	4150	89	890	89	1210	2510	2200	1860	3530	3300	1890	3170	4950	2360	1410	2640	2280	2300	2680	2900	2870	
Bryophyte	36	37	38	38	1440	1580	17	37	16	17	40	17	1590	36	3320	35	43	210	480	36	41	210	35	36	1230	650	50	51	51	505	250	55	
Lichen	44	44	45	44	1750	2060	44	44	44	44	51	44	47	42	50	42	2480	2150	1650	42	4060	3000	42	42	1530	1530	51	1710	1680	59	500	620	

APPENDIX D

VEGETATION TYPE SUMMARIES

VEGETATION TYPE SUMMARY— DRY, *Buchloë dactyloides*—*Medicago sativa*, PASTURE

Percentage of total vegetated area: 2.50

Number of stands studied: 2

Index of homogeneity based on species composition: 38

Index of homogeneity based on lifeform composition: 71

Approximate field distance between stands: 2.54 mi (4.06 km)

Related vegetation types based on species composition (average percentage similarity):

DRY, *Buchloë dactyloides*—*Arnica fulgens*, PASTURE (42.50)DRY, *Heterotheca villosa*—*Buchloë dactyloides*, PASTURE (34.75)

Related vegetation types based on lifeform composition (average percentage similarity):

DRY, *Hypericum perforatum*—*Paronychia jamesii*, PASTURE (80.75)DRY, *Buchloë dactyloides*—*Arnica fulgens*, PASTURE (77.75)

	STAND 27	STAND 28
Percentage non-vegetated area:	22.5	26.9
Moisture regime:	2	3
Grazing regime:	4	4
Number of species:		
Trees	0	0
Shrubs	0	1
Broad-leaved herbs	15	17
Narrow-leaved herbs	18	22
Succulents	1	0
Bryophytes	0	0
Lichens	0	8
Total	34	48
Major dominant species (species index):	<i>Medicago sativa</i> (38.53) <i>Buchloë dactyloides</i> (31.76) <i>Bromus tectorum</i> (17.08) <i>Agropyron trachycaulum</i> (13.09) <i>Artemisia campestris</i> (10.76)	<i>Buchloë dactyloides</i> (43.28) <i>Gutierrezia sarothrae</i> (28.76) <i>Artemisia frigida</i> (9.76) <i>Medicago sativa</i> (8.43) <i>Koeleria macrantha</i> (7.96)
Major dominant lifeforms ("species" index):	Herbaceous, narrow-leaved, perennial (614) Herbaceous, broad-leaved, perennial (568) Herbaceous, narrow-leaved, annual (264)	Herbaceous, narrow-leaved, perennial (1016) Herbaceous, broad-leaved, perennial (396) Herbaceous, narrow-leaved, annual (228)
Modal species (species index):	<i>Artemisia campestris</i> (10.76) <i>Acaepias pumila</i> (2.56) <i>Cryptantha fendleri</i> (4.47) <i>Opuntia compressa</i> (4.89) <i>Oxytropis lambertii</i> (3.90) <i>Vicia americana</i> (2.62) <i>Linum lewisii</i> (3.74) <i>Medicago sativa</i> (38.53) <i>Oxybaphus linearis</i> (2.76) <i>Plantago patagonica</i> (6.70)	<i>Artemisia frigida</i> (9.76) <i>Chenopodium leptophyllum</i> (.55) <i>Erigeron divergens</i> (5.55) <i>Aspicilia calcarea</i> (2.21) <i>Euphorbia robusta</i> (2.76) <i>Gutierrezia sarothrae</i> (28.76)

VEGETATION TYPE SUMMARY— DRY, *Buchloë dactyloides*—*Arnica fulgens*, PASTURE

Percentage of total vegetated area: 16.40

Number of stands studied: 2

Index of homogeneity based on species composition: 54

Index of homogeneity based on lifeform composition: 87

Approximate field distance between stands: 2.45 mi (3.91 km)

Related vegetation types based on species composition (average percentage similarity):

DRY, *Buchloë dactyloides*—*Medicago sativa*, PASTURE (42.50)DRY, *Heterotheca villosa*—*Buchloë dactyloides*, PASTURE (27.00)

Related vegetation types based on lifeform composition (average percentage similarity):

DRY, *Socle cereale*—*Bromus tectorum*, FIELD (83.50)DRY, *Stipa comata*—*Koeleria macrantha*, PRAIRIE (82.50)

	STAND 29	STAND 30
Percentage non-vegetated area:	10.2	8.2
Moisture regime:	2	3
Grazing regime:	4	3
Number of species:		
Trees	0	0
Shrubs	1	1
Broad-leaved herbs	11	11
Narrow-leaved herbs	18	11
Succulents	1	0
Bryophytes	0	2
Lichens	6	0
Total	37	25
Major dominant species (species index):	<i>Buchloë dactyloides</i> (89.59) <i>Eriogonum alatum</i> (6.63) <i>Artemisia frigida</i> (6.27) <i>Heterotheca villosa</i> (5.45) <i>Medicago sativa</i> (5.35)	<i>Buchloë dactyloides</i> (90.01) <i>Arnica fulgens</i> (16.63) <i>Poa compressa</i> (14.12) <i>Koeleria macrantha</i> (11.51) <i>Vulpia octoflora</i> (9.55)
Major dominant lifeforms ("species" index):	Herbaceous, narrow-leaved, perennial (1169) Herbaceous, broad-leaved, perennial (322) Herbaceous, narrow-leaved, annual (230)	Herbaceous, narrow-leaved, perennial (1114) Herbaceous, broad-leaved, perennial (318) Herbaceous, narrow-leaved, annual (268)
Modal species (species index):	<i>Aster cynosuroides</i> (2.49) <i>Aster engelmannii</i> (.83) <i>Bouteloua gracilis</i> (9.91) <i>Lesquerella ludoviciana</i> (4.15) <i>Machiceranthra pinnatifida</i> (2.49) <i>Sphaeralcea coccinea</i> (4.15) <i>Collinsia tenax</i> (2.49) <i>Staurothela alpina</i> (.83) <i>Rinodina bischoffii</i> (.83) <i>Peltigera canina</i> (.83)	<i>Andropogon occidentalis</i> (4.24) <i>Arnica fulgens</i> (16.63) <i>Aster falcatus</i> (1.06) <i>Buchloë dactyloides</i> (90.01) <i>Grindelia squarrosa</i> (5.48) <i>Ratibida columnifera</i> (2.12) <i>Silene antirrhina</i> (2.12) <i>Vulpia octoflora</i> (9.55) <i>Tortula intermedia</i> (2.12)

APPENDIX D (continued)

VEGETATION TYPE SUMMARIES

VEGETATION TYPE SUMMARY— DRY, *Koeleria macrantha*—*Agropyron trachycaulum*, PRAIRIE

Percentage of total vegetated area: 7.82

Number of stands studied: 2

Index of homogeneity based on species composition: 65

Index of homogeneity based on lifeform composition: 87

Approximate field distance between stands: 0.86 mi (1.38 km)

Related vegetation types based on species composition (average percentage similarity):

DRY, *Hypericum perforatum*—*Paronychia jamesii*, PASTURE (49.50)DRY, *Slipa comata*—*Koeleria macrantha*, PRAIRIE (39.50)

Related vegetation types based on lifeform composition (average percentage similarity):

DRY, *Slipa comata*—*Koeleria macrantha*, PRAIRIE (85.00)DRY, *Hypericum perforatum*—*Paronychia jamesii*, PASTURE (82.50)

Percentage non-vegetated area:

Moisture regime:

Grazing regime:

Number of species:

Trees

Shrubs

Broad-leaved herbs

Narrow-leaved herbs

Succulents

Bryophytes

Lichens

Total

Major dominant species (species index):

Koeleria macrantha (24.17)*Arenaria fendleri* (20.99)*Agropyron trachycaulum* (16.45)*Schizachyrium scoparium* (14.81)*Liatris punctata* (11.36)

Major dominant lifeforms ("species" index):

Herbaceous, narrow-leaved,

perennial (866)

Herbaceous, broad-leaved,

perennial (366)

Lichen (175)

Modal species (species index):

Arenaria fendleri (20.99)*Castilleja sessiliflora* (2.04)*Koeleria macrantha* (24.17)*Juncus dudleyi* (.51)*Polygonum douglasii* (1.02)*Veronica peregrina* (.51)*Schizachyrium scoparium* (14.81)*Pohlia nutans* (3.56)*Senecio plattensis* (5.55)*Solidago mollis* (2.13)

STAND 6

23.6

3

0

0

1

10

13

3

3

10

41

Muhlenbergia montana (20.13)*Koeleria macrantha* (19.75)*Agropyron trachycaulum* (19.27)*Salsola iberica* (12.44)*Heterotheca villosa* (12.25)

Herbaceous, narrow-leaved,

perennial (775)

Herbaceous, broad-leaved,

perennial (346)

Herbaceous, narrow-leaved,

annual (226)

Antennaria parvifolia (1.58)*Muhlenbergia montana* (20.13)*Orobancha fasciculata* (.55)*Sedum lanceolatum* (2.95)*Cladonia coccifera* (1.10)*Cladonia pyridata* (8.08)*Diploschistes scarposus* (.55)*Leptogium minutissimum* (.55)*Tortula ruralis* (4.41)VEGETATION TYPE SUMMARY— DRY, *Carduus nutans*—*Bromus tectorum*, BARRENS

Percentage of total vegetated area: 3.19

Number of stands studied: 2

Index of homogeneity based on species composition: 93

Index of homogeneity based on lifeform composition: 96

Approximate field distance between stands: 0.36 mi (0.62 km)

Related vegetation types based on species composition (average percentage similarity):

MOIST, *Agropyron trachycaulum*—*Poa compressa*, MEADOW (45.00)MOIST, *Symphoricarpos occidentalis*—*Poa compressa*, LOW SCRUB (39.75)

Related vegetation types based on lifeform composition (average percentage similarity):

MOIST, *Agropyron trachycaulum*—*Poa compressa*, MEADOW (51.50)MOIST, *Symphoricarpos occidentalis*—*Poa compressa*, LOW SCRUB (46.25)

Percentage non-vegetated area:

Moisture regime:

Grazing regime:

Number of species:

Trees

Shrubs

Broad-leaved herbs

Narrow-leaved herbs

Succulents

Bryophytes

Lichens

Total

Major dominant species (species index):

Carduus nutans (75.55)*Bromus tectorum* (61.26)*Poa compressa* (33.50)*Agropyron trachycaulum* (29.69)

Major dominant lifeforms ("species" index):

Herbaceous, broad-leaved,

biennial (839)

Herbaceous, narrow-leaved,

annual (696)

Herbaceous, narrow-leaved,

perennial (465)

Modal species (species index):

Carduus nutans (75.55)*Bromus tectorum* (61.26)

STAND 9

8.1

3

1

0

0

1

3

0

0

7

Carduus nutans (73.29)*Bromus tectorum* (53.81)*Agropyron trachycaulum* (34.18)*Poa compressa* (29.10)*Trachypogon dubius* (4.80)

Herbaceous, broad-leaved,

biennial (823)

Herbaceous, narrow-leaved,

annual (628)

Herbaceous, narrow-leaved,

perennial (516)

APPENDIX D (continued)

VEGETATION TYPE SUMMARIES

VEGETATION TYPE SUMMARY— DRY, *Stipa comata*—*Koeleria macrantha*, PRAIRIE

Percentage of total vegetated area:	7.07	
Number of stands studied:	2	
Index of homogeneity based on species composition:	59	
Index of homogeneity based on lifeform composition:	83	
Approximate field distance between stands:	0.77 mi (1.23 km)	
Related vegetation types based on species composition (average percentage similarity):		
DRY, <i>Koeleria macrantha</i> — <i>Agropyron trachycaulum</i> , PRAIRIE	(39.50)	
DRY, <i>Hypericum perforatum</i> — <i>Paronychia jamesii</i> , PASTURE	(38.25)	
Related vegetation types based on lifeform composition (average percentage similarity):		
DRY, <i>Koeleria macrantha</i> — <i>Agropyron trachycaulum</i> , PRAIRIE	(85.00)	
DRY, <i>Buchloë dactyloides</i> — <i>Arnica fulgens</i> , PASTURE	(52.50)	
	STAND 25	STAND 26
Percentage non-vegetated area:	33.0	19.2
Moisture regime:	3	3
Grazing regime:	0	0
Number of species:	0	0
Trees	0	0
Shrubs	1	1
Broad-leaved herbs	17	12
Narrow-leaved herbs	20	18
Succulents	2	2
Bryophytes	3	2
Lichens	3	3
Total	46	38
Major dominant species (species index):	<i>Stipa comata</i> (30.53) <i>Koeleria macrantha</i> (17.66) <i>Sitanion longifolium</i> (12.08) <i>Heterotheca villosa</i> (11.54) <i>Andropogon gerardii</i> (10.74)	<i>Stipa comata</i> (77.36) <i>Koeleria macrantha</i> (8.65) <i>Carex heliophila</i> (8.20) <i>Echinocereus viridiflorus</i> (7.59) <i>Lomatium orientale</i> (7.59)
Major dominant lifeforms ("species" index):	Herbaceous, narrow-leaved, perennial (839) Herbaceous, broad-leaved, perennial (286) Herbaceous, narrow-leaved, annual (236)	Herbaceous, narrow-leaved, perennial (1071) Herbaceous, broad-leaved, perennial (286) Succulent (220)
Modal species (species index):	<i>Andropogon gerardii</i> (10.74) <i>Erysimum asperum</i> (3.37) <i>Sitanion longifolium</i> (12.08)	<i>Allium textile</i> (.71) <i>Comandra umbellata</i> (.71) <i>Stipa comata</i> (77.36) <i>Echinocereus viridiflorus</i> (7.59) <i>Lomatium orientale</i> (7.59) <i>Bryum argenteum</i> (1.42)

VEGETATION TYPE SUMMARY— DRY, *Heterotheca villosa*—*Buchloë dactyloides*, PASTURE

Percentage of total vegetated area:	8.35	
Number of stands studied:	2	
Index of homogeneity based on species composition:	68	
Index of homogeneity based on lifeform composition:	93	
Approximate field distance between stands:	1.34 mi (2.16 km)	
Related vegetation types based on species composition (average percentage similarity):		
DRY, <i>Hypericum perforatum</i> — <i>Paronychia jamesii</i> , PASTURE	(36.50)	
DRY, <i>Buchloë dactyloides</i> — <i>Medicago sativa</i> , PASTURE	(34.75)	
Related vegetation types based on lifeform composition (average percentage similarity):		
DRY, <i>Hypericum perforatum</i> — <i>Ambrosia psilostachya</i> , BARRENS	(76.00)	
DRY, <i>Hypericum perforatum</i> — <i>Paronychia jamesii</i> , PASTURE	(69.50)	
	STAND 31	STAND 32
Percentage non-vegetated area:	38.0	33.4
Moisture regime:	3	3
Grazing regime:	3	3
Number of species:	0	0
Trees	0	0
Shrubs	1	1
Broad-leaved herbs	14	9
Narrow-leaved herbs	24	18
Succulents	1	2
Bryophytes	1	0
Lichens	2	5
Total	43	35
Major dominant species (species index):	<i>Heterotheca villosa</i> (69.31) <i>Buchloë dactyloides</i> (9.13) <i>Bromus tectorum</i> (8.40) <i>Artemisia frigida</i> (7.35) <i>Eriogonum alatum</i> (7.26)	<i>Heterotheca villosa</i> (79.15) <i>Buchloë dactyloides</i> (15.00) <i>Bouteloua curtipendula</i> (10.62) <i>Koeleria macrantha</i> (8.25) <i>Sitanion longifolium</i> (8.20)
Major dominant lifeforms ("species" index):	Herbaceous, broad-leaved, perennial (973) Herbaceous, narrow-leaved, perennial (440) Herbaceous, narrow-leaved, annual (290)	Herbaceous, broad-leaved, perennial (1062) Herbaceous, narrow-leaved, perennial (470) Herbaceous, narrow-leaved, annual (287)
Modal species (species index):	<i>Aristida condita</i> (5.24) <i>Eriogonum flagellare</i> (3.87) <i>Eriogonum alatum</i> (7.26) <i>Mertensia lanceolata</i> (1.69) <i>Lappula radwskii</i> (1.13)	<i>Aristida condita</i> (2.94) <i>Artemisia dracunculoides</i> (2.38) <i>Astragalus flexuosus</i> (2.38) <i>Eriogonum canis</i> (1.58) <i>Louisastrum montanum</i> (5.55) <i>Heterotheca villosa</i> (79.15) <i>Opuntia polyacantha</i> (.79) <i>Pentstemon virginicus</i> (1.58)

APPENDIX D (continued)

VEGETATION TYPE SUMMARIES

VEGETATION TYPE SUMMARY—MOIST, *Symphoricarpos occidentalis*—*Poa compressa*, LOW SCRUB

Percentage of total vegetated area:	0.68	
Number of stands studied:	2	
Index of homogeneity based on species composition:	69	
Index of homogeneity based on lifeform composition:	83	
Approximate field distance between stands:	1.57 mi (2.51 km)	
Related vegetation types based on species composition (average percentage similarity):		
	DRY, <i>Carduus nutans</i> — <i>Bromus tectorum</i> , BARRENS (39.75)	
	MOIST, <i>Agropyron trachycaulum</i> — <i>Poa compressa</i> , MEADOW (39.75)	
Related vegetation types based on lifeform composition (average percentage similarity):		
	MOIST, <i>Crotogeomys erythropoda</i> — <i>Galium aparine</i> , SCRUB (64.50)	
	WET, <i>Salix exigua</i> — <i>Barbarea orthoceras</i> , STREAMBANK (59.75)	
	STAND 23	STAND 24
Percentage non-vegetated area:	11.9	6.6
Moisture regime:	4	3
Grazing regime:	3	1
Number of species:	0	0
Trees	1	2
Shrubs	7	2
Broad-leaved herbs	5	5
Narrow-leaved herbs	0	0
Succulents	0	0
Bryophytes	0	0
Lichens	0	0
Total	13	9
Major dominant species (species index):		
	<i>Symphoricarpos occidentalis</i> (69.49)	<i>Symphoricarpos occidentalis</i> (74.79)
	<i>Poa compressa</i> (58.25)	<i>Eromus tectorum</i> (36.42)
	<i>Bromus tectorum</i> (24.97)	<i>Poa compressa</i> (27.22)
	<i>Agropyron trachycaulum</i> (23.07)	<i>Juncus arcticus</i> (26.83)
	<i>Helianthus annuus</i> (4.04)	<i>Rosa arkansana</i> (14.31)
Major dominant lifeforms ("species" index):		
	Woody, less than 5 m in height (762)	Woody, less than 5 m in height (901)
	Herbaceous, narrow-leaved, perennial (705)	Herbaceous, narrow-leaved, perennial (511)
	Herbaceous, narrow-leaved, annual (317)	Herbaceous, narrow-leaved, annual (495)
Modal species (species index):		
	<i>Poa compressa</i> (58.25)	<i>Calochortus gunnisonii</i> (1.79)
		<i>Rosa arkansana</i> (14.31)
		<i>Symphoricarpos occidentalis</i> (74.79)

VEGETATION TYPE SUMMARY—MOIST, *Agropyron trachycaulum*—*Poa compressa*, MEADOW

Percentage of total vegetated area:	22.80	
Number of stands studied:	2	
Index of homogeneity based on species composition:	54	
Index of homogeneity based on lifeform composition:	72	
Approximate field distance between stands:	2.54 mi (4.06 km)	
Related vegetation types based on species composition (average percentage similarity):		
	DRY, <i>Carduus nutans</i> — <i>Bromus tectorum</i> , BARRENS (45.00)	
	MOIST, <i>Symphoricarpos occidentalis</i> — <i>Poa compressa</i> , LOW SCRUB (39.75)	
Related vegetation types based on lifeform composition (average percentage similarity):		
	DRY, <i>Secale cereale</i> — <i>Eromus tectorum</i> , FIELD (83.50)	
	DRY, <i>Buchloe dactyloides</i> — <i>Arnica fulgens</i> , PASTURE (78.75)	
	STAND 11	STAND 12
Percentage non-vegetated area:	4.1	4.3
Moisture regime:	4	4
Grazing regime:	2	0
Number of species:	0	0
Trees	0	0
Shrubs	17	4
Broad-leaved herbs	13	8
Narrow-leaved herbs	1	0
Succulents	0	0
Bryophytes	0	0
Lichens	0	0
Total	31	12
Major dominant species (species index):		
	<i>Poa compressa</i> (37.84)	<i>Agropyron trachycaulum</i> (72.62)
	<i>Agropyron trachycaulum</i> (34.16)	<i>Poa compressa</i> (46.70)
	<i>Eromus tectorum</i> (20.93)	<i>Bromus tectorum</i> (25.62)
	<i>Aster</i> (13.39)	<i>Cirsium undulatum</i> (10.58)
	<i>Ambrosia psilostachya</i> (12.70)	<i>Tragopogon dubius</i> (8.53)
Major dominant lifeforms ("species" index):		
	Herbaceous, narrow-leaved, perennial (841)	Herbaceous, narrow-leaved, perennial (1218)
	Herbaceous, broad-leaved, perennial (426)	Herbaceous, narrow-leaved, annual (415)
	Herbaceous, narrow-leaved, annual (362)	Herbaceous, broad-leaved, biennial (201)
Modal species (species index):		
	<i>Achillea lanulosa</i> (3.66)	<i>Agropyron trachycaulum</i> (72.62)
	<i>Artemisia ludoviciana</i> (6.90)	<i>Camelina microparpa</i> (5.12)
	<i>Aster</i> (13.39)	<i>Cirsium undulatum</i> (10.58)
	<i>Collomia linearis</i> (3.82)	<i>Tragopogon dubius</i> (8.53)
	<i>Draba reptans</i> (4.51)	<i>Stipa viridula</i> (7.43)
	<i>Eleocharis elliptica</i> (2.50)	
	<i>Hedeoma pteridifolium</i> (1.75)	

APPENDIX D (continued)

VEGETATION TYPE SUMMARIES

VEGETATION TYPE SUMMARY— WET, *Salix exigua*—*Barbarea orthoceras*, STREAMBANK

Percentage of total vegetated area: 0.69		
Number of stands studied: 2		
Index of homogeneity based on species composition: 63		
Index of homogeneity based on lifeform composition: 86		
Approximate field distance between stands: 0.40 mi (0.64 km)		
Related vegetation types based on species composition (average percentage similarity):		
WET, <i>Carex nebraskensis</i> — <i>Juncus arcticus</i> , MARSH (18.00)		
MOIST, <i>Crataegus erythropoda</i> — <i>Galium aparine</i> , SCRUB (9.25)		
Related vegetation types based on lifeform composition (average percentage similarity):		
MOIST, <i>Crataegus erythropoda</i> — <i>Galium aparine</i> , SCRUB (72.50)		
MOIST, <i>Symphoricarpos occidentalis</i> — <i>Poa compressa</i> , LOW SCRUB (59.75)		
	STAND 13	STAND 14
Percentage non-vegetated area:	72.3	29.9
Moisture regime:	5	4
Grazing regime:	0	0
Number of species:	0	0
Trees	2	1
Shrubs	15	16
Broad-leaved herbs	2	7
Narrow-leaved herbs	0	0
Succulents	1	0
Bryophytes	0	0
Lichens	20	24
Total		
Major dominant species (species index):	<i>Salix exigua</i> (70.16) <i>Barbarea orthoceras</i> (29.41) <i>Epilobium adenocaulon</i> (17.99) <i>Mentha arvensis</i> (14.67) <i>Cirsium arvense</i> (14.35)	<i>Salix exigua</i> (73.16) <i>Barbarea orthoceras</i> (25.09) <i>Fallopia convolvulus</i> (9.76) <i>Galium aparine</i> (9.23) <i>Fevuta cataria</i> (8.64)
Major dominant lifeforms ("species" index):	Woody, less than 5 m in height (809) Herbaceous, broad-leaved, perennial (407) Herbaceous, broad-leaved, biennial (389)	Woody, less than 5 m in height (831) Herbaceous, broad-leaved, biennial (371) Herbaceous, broad-leaved, perennial (291)
Modal species (species index):	<i>Barbarea orthoceras</i> (29.41) <i>Epilobium adenocaulon</i> (17.99) <i>Galium boreale</i> (1.24) <i>Pericaria lapathifolia</i> (2.67) <i>Poa palustris</i> (10.31) <i>Rumex obtusifolius</i> (1.30) <i>Veronica anagallis-aquatica</i> (1.50) <i>Serophularia lanceolata</i> (1.30)	<i>Epilobium paniculatum</i> (3.64) <i>Guara parviflora</i> (2.01) <i>Leersia oryzoides</i> (1.11) <i>Hepeta cataria</i> (8.64) <i>Oenothera strigosa</i> (4.94) <i>Oxalis dillenii</i> (2.21) <i>Ranunculus macounii</i> (2.28) <i>Salix exigua</i> (73.16) <i>Verbascum thapsus</i> (4.29)

VEGETATION TYPE SUMMARY— WET, *Carex nebraskensis*—*Juncus arcticus*, MARSH

Percentage of total vegetated area: 3.53		
Number of stands studied: 2		
Index of homogeneity based on species composition: 48		
Index of homogeneity based on lifeform composition: 67		
Approximate field distance between stands: 0.77 mi (1.23 km)		
Related vegetation types based on species composition (average percentage similarity):		
WET, <i>Salix exigua</i> — <i>Barbarea orthoceras</i> , STREAMBANK (18.00)		
MOIST, <i>Symphoricarpos occidentalis</i> — <i>Poa compressa</i> , LOW SCRUB (11.00)		
Related vegetation types based on lifeform composition (average percentage similarity):		
DRY, <i>Euchloë dactyloides</i> — <i>Arnica fulgens</i> , PASTURE (77.50)		
DRY, <i>Secale cereale</i> — <i>Bromus tectorum</i> , FIELD (74.25)		
	STAND 15	STAND 16
Percentage non-vegetated area:	1.3	7.1
Moisture regime:	5	5
Grazing regime:	0	0
Number of species:	0	0
Trees	0	1
Shrubs	11	8
Broad-leaved herbs	8	7
Narrow-leaved herbs	0	0
Succulents	2	0
Bryophytes	0	0
Lichens	21	16
Total		
Major dominant species (species index):	<i>Carex nebraskensis</i> (73.29) <i>Viola papilionacea</i> (15.75) <i>Mentha arvensis</i> (15.61) <i>Juncus arcticus</i> (12.08) <i>Leptodictyum riparium</i> (11.74)	<i>Carex nebraskensis</i> (73.18) <i>Juncus arcticus</i> (30.32) <i>Cirsium arvense</i> (18.18) <i>Galium aparine</i> (16.47) <i>Lactuca serriola</i> (12.81)
Major dominant lifeforms ("species" index):	Herbaceous, narrow-leaved, perennial (989) Herbaceous, broad-leaved, perennial (417) Bryophyte (332)	Herbaceous, narrow-leaved, perennial (1157) Herbaceous, broad-leaved, annual (358) Herbaceous, broad-leaved, perennial (332)
Modal species (species index):	<i>Arabis glabra</i> (2.02) <i>Carex nebraskensis</i> (73.29) <i>Carex lamymosa</i> (2.57) <i>Carex interior</i> (3.88) <i>Eleocharis racemosa</i> (9.17) <i>Epilobium leptophyllum</i> (5.86) <i>Geum racemophyllum</i> (10.22) <i>Mentha arvensis</i> (15.61) <i>Verbena hastata</i> (1.04) <i>Viola papilionacea</i> (15.75) <i>Lentibrium pyriforme</i> (10.35) <i>Leptodictyum riparium</i> (11.74) <i>Hypericum formosum</i> (2.93)	<i>Cirsium arvense</i> (18.18) <i>Carex praeacutellata</i> (11.35) <i>Juncus arcticus</i> (30.32) <i>Thlaspi arvense</i> (7.87) <i>Spartina pectinata</i> (9.04)

APPENDIX D (continued)

VEGETATION TYPE SUMMARIES

VEGETATION TYPE SUMMARY— DRY, *Polygonum aviculare*—*Ambrosia psilostachya*, BARRENS

Percentage of total vegetated area: 1.62		
Number of stands studied: 2		
Index of homogeneity based on species composition: 39		
Index of homogeneity based on lifeform composition: 60		
Approximate field distance between stands: 1.28 mi (2.04 km)		
Related vegetation types based on species composition (average percentage similarity):		
DRY, <i>Hypericum perforatum</i> — <i>Ambrosia psilostachya</i> , BARRENS (8.75)		
MOIST, <i>Agropyron trachycaulum</i> — <i>Poa compressa</i> , MEADOW (1.50)		
Related vegetation types based on lifeform composition (average percentage similarity):		
DRY, <i>Hypericum perforatum</i> — <i>Ambrosia psilostachya</i> , BARRENS (34.75)		
DRY, <i>Heterotheca villosa</i> — <i>Buchloe dactyloides</i> , PASTURE (26.00)		
	STAND 3	STAND 4
Percentage non-vegetated area:	99.9	99.9
Moisture regime:	1	1
Grazing regime:	0	0
Number of species:		
Trees	0	0
Shrubs	0	0
Broad-leaved herbs	4	2
Narrow-leaved herbs	0	1
Succulents	0	0
Bryophytes	0	0
Lichens	0	0
Total	4	3
Major dominant species (species index):	<i>Polygonum aviculare</i> (126.19) <i>Chamaesyce glyptosperma</i> (29.52) <i>Chenopodium botrys</i> (29.52) <i>Amaranthus graecianus</i> (14.76)	<i>Polygonum aviculare</i> (78.03) <i>Ambrosia psilostachya</i> (69.70) <i>Dysodia papposa</i> (52.27)
Major dominant lifeforms ("species" index):	Herbaceous, broad-leaved, annual (2000)	Herbaceous, broad-leaved, annual (1196) Herbaceous, broad-leaved, perennial (804)
Modal species (species index):	<i>Chamaesyce glyptosperma</i> (29.52) <i>Chenopodium botrys</i> (29.52) <i>Amaranthus graecianus</i> (14.76) <i>Polygonum aviculare</i> (126.19)	<i>Dysodia papposa</i> (52.27) <i>Ambrosia psilostachya</i> (69.70)

VEGETATION TYPE SUMMARY— DRY, *Hypericum perforatum*—*Paronychia jamesii*, PASTURE

Percentage of total vegetated area: 11.51		
Number of stands studied: 2		
Index of homogeneity based on species composition: 74		
Index of homogeneity based on lifeform composition: 93		
Approximate field distance between stands: 0.07 mi (0.15 km)		
Related vegetation types based on species composition (average percentage similarity):		
DRY, <i>Koeleria macrantha</i> — <i>Agropyron trachycaulum</i> , PRAIRIE (49.50)		
DRY, <i>Stipa comata</i> — <i>Koeleria macrantha</i> , PRAIRIE (38.25)		
Related vegetation types based on lifeform composition (average percentage similarity):		
DRY, <i>Koeleria macrantha</i> — <i>Agropyron trachycaulum</i> , PRAIRIE (82.50)		
DRY, <i>Buchloe dactyloides</i> — <i>Medicago sativa</i> , PASTURE (80.75)		
	STAND 17	STAND 18
Percentage non-vegetated area:	55.3	49.6
Moisture regime:	1	1
Grazing regime:	3	4
Number of species:		
Trees	0	0
Shrubs	0	1
Broad-leaved herbs	19	15
Narrow-leaved herbs	23	24
Succulents	1	3
Bryophytes	0	1
Lichens	7	4
Total	50	48
Major dominant species (species index):	<i>Hypericum perforatum</i> (16.44) <i>Liatris punctata</i> (12.59) <i>Paronychia jamesii</i> (12.09) <i>Koeleria macrantha</i> (11.95) <i>Arenaria fendleri</i> (9.39)	<i>Buchloe dactyloides</i> (15.41) <i>Paronychia jamesii</i> (12.82) <i>Koeleria macrantha</i> (12.26) <i>Hypericum perforatum</i> (11.69) <i>Liatris punctata</i> (11.33)
Major dominant lifeforms ("species" index):	Herbaceous, narrow-leaved, perennial (722) Herbaceous, broad-leaved, perennial (566) Herbaceous, narrow-leaved, annual (251)	Herbaceous, narrow-leaved, perennial (816) Herbaceous, broad-leaved, perennial (520) Herbaceous, narrow-leaved, annual (220)
Modal species (species index):	<i>Arenaria fendleri</i> (9.39) <i>Dermatocarpon lachneum</i> (4.54) <i>Aspicilia alaphlaca</i> (1.51) <i>Townsendia hookeri</i> (3.78) <i>Penstemon virens</i> (5.44) <i>Melandrium drummondii</i> (2.02) <i>Liatris punctata</i> (12.59) <i>Ipomopsis spicata</i> (1.50) <i>Gaillardia aristata</i> (2.52) <i>Gaura coccinea</i> (1.51) <i>Panicum nanthe affinis</i> (1.77)	<i>Talinum parviflorum</i> (4.58) <i>Paronychia jamesii</i> (12.82) <i>Lithospermum inosum</i> (1.57) <i>Coryphantha missouriensis</i> (1.57) <i>Eriogonum umbellatum</i> (4.58) <i>Bouteloua curtipendula</i> (10.99) <i>Carex heliophila</i> (9.18)

APPENDIX D (continued)

VEGETATION TYPE SUMMARIES

VEGETATION TYPE SUMMARY-- DRY, *Hypericum perforatum* - *Ambrosia psilostachya*, BARRENS

Percentage of total vegetated area: 3.25

Number of stands studied: 2

Index of homogeneity based on species composition: 28

Index of homogeneity based on lifeform composition: 78

Approximate field distance between stands: 0.85 mi (1.35 km)

Related vegetation types based on species composition (average percentage similarity):

MOIST, *Agropyron trachycaulum* - *Poa compressa*, MEADOW (21.25)DRY, *Hypericum perforatum* - *Paronychia jamesii*, PASTURE (21.25)

Related vegetation types based on lifeform composition (average percentage similarity):

DRY, *Heterotheca villosa* - *Buchloe dactyloides*, PASTURE (76.00)DRY, *Buchloe dactyloides* - *Medicago sativa*, PASTURE (70.00)

	STAND 7	STAND 8
Percentage non-vegetated area:	81.2	93.1
Moisture regime:	1	2
Grazing regime:	1	0
Number of species:		
Trees	0	0
Shrubs	1	0
Broad-leaved herbs	17	17
Narrow-leaved herbs	11	12
Succulents	0	0
Bryophytes	0	0
Lichens	0	0
Total	29	29
Major dominant species (species index):	<i>Bouteloua hirsuta</i> (27.07) <i>Melilotus alba</i> (26.02) <i>Medicago sativa</i> (22.37) <i>Ambrosia psilostachya</i> (16.94) <i>Hypericum perforatum</i> (15.37)	<i>Hypericum perforatum</i> (40.52) <i>Bromus tectorum</i> (31.75) <i>Ambrosia psilostachya</i> (28.45) <i>Salvia ibarica</i> (14.13) <i>Polycnemum arvense</i> (12.76)
Major dominant lifeforms ("species" index):	Herbaceous, broad-leaved, perennial (702) Herbaceous, narrow-leaved, perennial (670) Herbaceous, narrow-leaved, annual (277)	Herbaceous, broad-leaved, perennial (814) Herbaceous, narrow-leaved, annual (537) Herbaceous, broad-leaved, annual (352)
Model species (species index):	<i>Alyssum alyssoides</i> (9.26) <i>Centaurea diffusa</i> (1.85) <i>Dalea purpurea</i> (11.60) <i>Melilotus alba</i> (26.02) <i>Medicago lupulina</i> (4.81) <i>Solidago missouriensis</i> (.93) <i>Bouteloua hirsuta</i> (27.07)	<i>Alyssum minus</i> (1.24) <i>Chenopodium album</i> (12.45) <i>Lesquerella montana</i> (7.76) <i>Hypericum perforatum</i> (40.52) <i>Verbena bracteata</i> (4.98) <i>Siumbrum altissimum</i> (1.24) <i>Salvia ibarica</i> (14.13) <i>Salvia reflexa</i> (1.24)

VEGETATION TYPE SUMMARY-- DRY, *Pinus ponderosa* - *Bromus tectorum*, SAVANNAH

Percentage of total vegetated area: 0.04

Number of stands studied: 2

Index of homogeneity based on species composition: 74

Index of homogeneity based on lifeform composition: 81

Approximate field distance between stands: 0.12 mi (0.26 km)

Related vegetation types based on species composition (average percentage similarity):

MOIST, *Crataegus erythraea* - *Galium aparine*, SCRUB (13.40)MOIST, *Agropyron trachycaulum* - *Poa compressa*, MEADOW (12.75)

Related vegetation types based on lifeform composition (average percentage similarity):

DRY, *Hypericum perforatum* - *Paronychia jamesii*, PASTURE (41.25)MOIST, *Crataegus erythraea* - *Galium aparine*, SCRUB (35.75)

	STAND 21	STAND 22
Percentage non-vegetated area:	88.0	95.5
Moisture regime:	1	2
Grazing regime:	1	3
Number of species:		
Trees	1	1
Shrubs	2	3
Broad-leaved herbs	5	10
Narrow-leaved herbs	4	7
Succulents	0	0
Bryophytes	0	1
Lichens	10	16
Total	22	38
Major dominant species (species index):	<i>Pinus ponderosa</i> (76.35) <i>Bromus tectorum</i> (31.22) <i>Lecanora muralis</i> (21.34) <i>Acanthopora fuscata</i> (13.63) <i>Xanthoparmelia undata</i> (10.48)	<i>Pinus ponderosa</i> (82.81) <i>Lecanora muralis</i> (13.44) <i>Bromus tectorum</i> (10.76) <i>Poa compressa</i> (10.06) <i>Xanthoparmelia undata</i> (9.82)
Major dominant lifeforms ("species" index):	Woody, greater than 5 m in height (863) Lichen (406) Herbaceous, narrow-leaved, annual (330)	Woody, greater than 5 m in height (944) Lichen (300) Herbaceous, narrow-leaved, perennial (212)
Model species (species index):	<i>Campanula rotundifolia</i> (1.35) <i>Rhus trilobata</i> (4.94) <i>Ribes cereum</i> (2.40) <i>Salvia collina</i> (1.20) <i>Acanthopora fuscata</i> (13.63) <i>Acanthopora amarugula</i> (5.47) <i>Aspicilia castoicincta</i> (6.67) <i>Caloplaca annularia</i> (4.27) <i>Candelariella rosulana</i> (8.84) <i>Lecanora muralis</i> (21.34) <i>Xanthoparmelia</i> (10.48) <i>Rhizocarpon riparium</i> (1.20)	<i>Allium cernuum</i> (.92) <i>Chenopodium</i> (.92) <i>Cerastium arvense</i> (2.84) <i>Carex</i> (3.99) <i>Geranium acaesptuosum</i> (3.23) <i>Pinus ponderosa</i> (82.81) <i>Drymonia flexa</i> (1.08) <i>Pilaatilla potius</i> (1.00) <i>Veronica biloba</i> (.92) <i>Coarctodol eulpyretus</i> (.92) <i>Rhizocarpon diporum</i> (.92) <i>Phyacta caesia</i> (.92) <i>Microthalia aterrima</i> (2.76) <i>Leiodalla stigmata</i> (1.84) <i>Buellia punctata</i> (.92) <i>Dimalaena orolina</i> (3.68) <i>Lecanora chrysoleuca</i> (.92) <i>Lecanora melanophthalma</i> (1.84) <i>Leiodalla carpathica</i> (.92)

APPENDIX D (continued)

VEGETATION TYPE SUMMARIES

VEGETATION TYPE SUMMARY—DRY, *Secale cereale*—*Bromus tectorum*, FIELD

Percentage of total vegetated area: 9.68
 Number of stands studied: 2
 Index of homogeneity based on species composition: 81
 Index of homogeneity based on lifeform composition: 94
 Approximate field distance between stands: 0.25 mi (0.42 km)
 Related vegetation types based on species composition (average percentage similarity):
 MOIST, *Agropyron trachycalum*—*Poa compressa*, MEADOW (16.25)
 MOIST, *Symphoricarpos occidentalis*—*Poa compressa*, LOW SCRUB (15.75)
 Related vegetation types based on lifeform composition (average percentage similarity):
 MOIST, *Agropyron trachycalum*—*Poa compressa*, MEADOW (83.50)
 DRY, *Buchloe dactyloides*—*Arnica fulgens*, PASTURE (83.50)

	STAND 1	STAND 2
Percentage non-vegetated area:	65.9	51.3
Moisture regime:	3	3
Grazing regime:	0	0
Number of species:		
Trees	0	0
Shrubs	0	0
Broad-leaved herbs	8	9
Narrow-leaved herbs	2	2
Succulents	0	0
Bryophytes	0	0
Lichens	0	0
Total	10	11
Major dominant species (species index):	<i>Secale cereale</i> (100.96) <i>Bromus tectorum</i> (30.74) <i>Convolvulus arvensis</i> (17.11) <i>Lactuca serriola</i> (13.76) <i>Fallopia convolvulus</i> (13.16)	<i>Secale cereale</i> (106.47) <i>Bromus tectorum</i> (27.28) <i>Chorispora tenella</i> (18.14) <i>Lactuca serriola</i> (13.60) <i>Convolvulus arvensis</i> (9.73)
Major dominant lifeforms ("species" index):	Herbaceous, narrow-leaved, perennial (1109) Herbaceous, narrow-leaved, annual (397) Herbaceous, broad-leaved, annual (269)	Herbaceous, narrow-leaved, perennial (1124) Herbaceous, narrow-leaved, annual (330) Herbaceous, broad-leaved, annual (295)
Modal species (species index):	<i>Convolvulus arvensis</i> (17.11) <i>Lactuca serriola</i> (13.76) <i>Helianthus annuus</i> (4.54) <i>Fallopia convolvulus</i> (13.16)	<i>Chorispora tenella</i> (18.14) <i>Arabis</i> undet. (4.53) <i>Kochia trachica</i> (2.27) <i>Secale cereale</i> (106.47)

VEGETATION TYPE SUMMARY—MOIST, *Crataegus erythropoda*—*Galium aparine*, SCRUB

Percentage of total vegetated area: 0.87
 Number of stands studied: 2
 Index of homogeneity based on species composition: 44
 Index of homogeneity based on lifeform composition: 67
 Approximate field distance between stands: 1.12 mi (1.80 km)
 Related vegetation types based on species composition (average percentage similarity):
 MOIST, *Symphoricarpos occidentalis*—*Poa compressa*, LOW SCRUB (20.25)
 DRY, *Carduus nutans*—*Bromus tectorum*, BARRENS (15.50)
 Related vegetation types based on lifeform composition (average percentage similarity):
 WET, *Salix exigua*—*Barbarea orthoceras*, STREAMBANK (72.50)
 MOIST, *Symphoricarpos occidentalis*—*Poa compressa*, LOW SCRUB (64.50)

	STAND 19	STAND 20
Percentage non-vegetated area:	73.1	30.7
Moisture regime:	4	4
Grazing regime:	3	3
Number of species:		
Trees	0	0
Shrubs	7	1
Broad-leaved herbs	12	6
Narrow-leaved herbs	3	3
Succulents	0	0
Bryophytes	1	0
Lichens	11	0
Total	34	11
Major dominant species (species index):	<i>Crataegus erythropoda</i> (64.09) <i>Symphoricarpos occidentalis</i> (17.01) <i>Poa compressa</i> (14.77) <i>Clematis ligusticifolia</i> (11.04) <i>Viola canadensis</i> (10.07)	<i>Crataegus erythropoda</i> (65.49) <i>Galium aparine</i> (39.53) <i>Bromus tectorum</i> (31.22) <i>Arctium minus</i> (22.01) <i>Hydrophyllum fendleri</i> (12.34)
Major dominant lifeforms ("species" index):	Woody, less than 5 m in height (932) Herbaceous, narrow-leaved, perennial (231) Herbaceous, broad-leaved, perennial (207)	Woody, less than 5 m in height (696) Herbaceous, broad-leaved, annual (453) Herbaceous, narrow-leaved, annual (353)
Modal species (species index):	<i>Clematis ligusticifolia</i> (11.04) <i>Bromus brizaeformis</i> (.77) <i>Prunus virginiana</i> (3.70) <i>Ribes aureum</i> (4.97) <i>Taraxacum officinale</i> (7.25) <i>Viola canadensis</i> (10.07) <i>Vitis riparia</i> (1.64) <i>Calopogon</i> undet. (.77) <i>Dermatocarpus minutum</i> (.77) <i>Lecanora dispersa</i> (1.54) <i>Orthotrichum alpestre</i> (2.31) <i>Xanthoria elegans</i> (.77)	<i>Arctium minus</i> (22.01) <i>Crataegus erythropoda</i> (65.49) <i>Descurainia sophia</i> (1.72) <i>Equisetum laevigatum</i> (8.56) <i>Galium aparine</i> (39.53) <i>Hydrophyllum fendleri</i> (12.34)

Appendix B to Final Report COO-2371-6

Letter to Mr. T. Winsor of the Rocky Flats Plant
concerning threatened and endangered species at
Rocky Flats.

BOULDER, COLORADO 80309

(303) 492-6387

May 1, 1978

Terrol Winsor
Rocky Flats Plant
P.O. Box 464
Golden, Colorado 80401

Dear Mr. Winsor:

Pursuant to your meeting this morning with two of us (W.A.W. and P.J.W.) concerning a suggested study of threatened and endangered plant species on the Rocky Flats Site, we would like to furnish you with the following information constituting the history and thoroughness of our various surveys and analyses of the vegetation of the area as supported through ERDA Grants No. AT(11-1)-2371 and E(11-1)-2371. This research was carried out from 1973 to 1977. The following reports are available to document this work:

Clark, S.J.V., 1977. The vegetation of Rocky Flats, Colorado.
M.A. thesis, University of Colorado, Boulder, Colorado. 172 pp.

Webber, P.J. and Clark, S.V., 1976. A botanical inventory of the Rocky Flats AEC site: mapping methods and preliminary maps. Progress report, U.S. Energy Research and Development Administration contract no. E(11-1)-2371. 29 pp.

Webber, P.J., Clark, S.V., and Komárková, V., 1977. Botanical survey of the environs of the Rocky Flats (ERDA) Plant: mapping and ordination analyses. In Hunt, D.C. (ed.), Transactions of Meeting on Rocky Flats Buffer Zone Ecological and Environmental Research Meeting, March 4, 1977, Rockwell International, Rocky Flats Plant, Golden, Colorado, 29-34.

Webber, P.J. and Werbe, E., 1977. A method of establishing the morphological norms for potential indicators of mutagenic hazards. In Hunt, D.C. (ed.), Transactions of Meeting On Rocky Flats Buffer Zone Ecological and Environmental Research Meeting, March 4, 1977, Rockwell International, Rocky Flats Plant, Golden, Colorado, 35-38.

Weber, W.A., Kunkel, G., and Shultz, L., 1974. A botanical inventory of the Rocky Flats AEC site. Final report, U.S. Atomic Energy Commission contract no. AT(11-1)-2371. University of Colorado, Boulder, Colorado. 40 pp.

A few introductory statements concerning the status of Threatened and Endangered Species in Colorado are in order. First of all, the Federal Government has not placed any Colorado plants on an official protected list through rule-making. Second, the protection of endangered and threatened plants involves only interstate commerce. Colorado has no law concerning protection of such plants, except for the state flower, Aquilegia coerulea, the Colorado Blue Columbine, which of course does not occur on the Rocky Flats site.

Barry Johnston and I, as part of the Committee on Threatened and Endangered Plant species, of the Colorado Native Plants Society, have compiled a Working List of Threatened and Endangered Plant Species of Colorado, some of which are only marginally threatened but were included for the most comprehensive coverage. We can state unequivocally, from long experience in the Colorado flora, that none of these species occur on the site, nor would they be expected to occur because of their known geographical patterns in Colorado.

Our surveys and analyses of the Rocky Flats vegetation were at first comprehensive and detailed for the Rocky Flats Plant Site. A representative herbarium was developed at the University of Colorado Museum, with a duplicate set distributed to Rocky Flats. Later, an intensive survey was made of the outer perimeter for the same purpose and for the ultimate production of a vegetation map. Any species not detected in the first survey were recorded in the second, and preserved for documentation. There were no essential changes in the known composition of the flora following the perimeter study.

It is our considered opinion that the flora and vegetation of the Rocky Flats area are fully explored and that there are in fact no threatened or endangered species in the area nor would any future survey be likely to uncover any.

Yours sincerely,

Vera Komárková
Research Associate
Instaar

Patrick J. Webber
Associate Professor
Instaar

William A. Weber
Professor
Museum

VEGETATION ROCKY FLATS, COLORADO

N 39° 55' 1
W 105° 14' 15"

0 2000 4000 feet

WELL VEGETATED, LESS DISTURBED UNITS

- DRY, *Buchloë dactyloides*—*Medicago sativa*, PASTURE
- DRY, *Buchloë dactyloides*—*Arnica fulgens*, PASTURE
- DRY, *Koeleria macrantha*—*Agropyron trachycolum*, PRAIRIE
- DRY, *Carduus nutans*—*Bromus tectorum*, BARRENS
- DRY, *Stipa comata*—*Koeleria macrantha*, PRAIRIE
- DRY, *Heterotheca villosa*—*Buchloë dactyloides*, PASTURE
- MOIST, *Symphoricarpos occidentalis*—*Poa compressa*, LOW SCRUB
- MOIST, *Agropyron trachycolum*—*Poa compressa*, MEADOW
- WET, *Salix exigua*—*Barbarea orthoceras*, STREAMBANK
- WET, *Carex nebraskensis*—*Juncus arcticus*, MARSH

BARREN, DISTURBED, AND CULTIVATED UNITS

- DRY, *Polygonum aviculare*—*Ambrosia psilostachya*, BARRENS
- DRY, *Hypericum perforatum*—*Paronychia jamesii*, PASTURE
- DRY, *Hypericum perforatum*—*Ambrosia psilostachya*, BARRENS
- DRY, *Pinus ponderosa*—*Bromus tectorum*, SAVANNAH
- DRY, *Secale cereale*—*Bromus tectorum*, FIELD
- MOIST, *Crataegus erythropoda*—*Galium aparine*, SCRUB
- CANAL, PONDS AND RESERVOIRS
- PAVEMENT AND BUILDINGS

- PAVED ROAD
- UNPAVED ROAD
- RAILROAD
- CREEK OR DITCH WITH WATER
- CREEK OR DITCH WITHOUT WATER
- ELEVATION IN FEET

N 39° 51' 1
W 105° 10'