# Draft

# Report of Findings

## Five-Year Study of the Ecology of Bluestem-dominated Grasslands of the Rocky Flats Area

**1996-2001**

## Jefferson and Boulder Counties, CO

*Prepared in Response to:*
Direction from Jefferson County Commisioners
*(????legal descrcription of this direction??????)*

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*April 2002*

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ADMIN RECORD

SW-A-006089

## INTRODUCTION

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A study of the grasslands of the Rocky Flats Alluvial Surface and similar regional grasslands was undertaken in late summer 1996, continued annually through 2000, and was terminated in spring 2001. The purpose of this study was to investigate the nature and ecological / conservation importance of these grasslands.

Grasslands of the Rocky Flats Alluvial Surface have attracted interest for some time because of the distinctive dominant plant species that include two species from the prairie and two species from mountain environments. These dominant species include 1) big bluestem and little bluestem, both grasses with their central distribution in the eastern Great Plains and both requiring greater moisture than is typically present in the western Great Plains and 2) mountain muhly, a grass generally from higher elevations along with Porter aster, a species endemic to (found only in) the eastern mountain front of Colorado (and perhaps extreme northern New Mexico and southern Wyoming). Mountain muhly is generally found in the middle to higher elevations of the Central and Southern Rocky Mountains, Great Basin, and Sierra Nevada. It is a prominent component of middle to higher elevation grasslands.

Branson et al. (1965) studied these areas along with grasslands growing on different soils nearby and documented the basic nature and distinction of these grasslands. They pointed out the paradox of coincidental occurrence of mountain and plains species on the grasslands occupying the surface of the Rocky Flats alluvium and speculated on the reasons that these species requiring more moisture than climate would normally provide would occur here. The general nature of this ecosystem has also been acknowledged by the U.S. Soil Conservation Service (now Natural Resources Conservation Service) in the description for Cobbly Foothill range site (December 1975) in which co-dominance of big bluestem, little bluestem, and mountain muhly is acknowledged. Also set forth in the range site description is the dependence of the type on the occurrence of soils in which 1) high rock volume reduces the volume of effective soil and magnifies incident moisture and 2) argillic B horizons (heavy-textured subsoils) accompany high moisture-holding capacities. Similar observations were made previously by Branson et al. (1965).

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The Rocky Flats alluvial surface [illegible] omorphic/quaternary stratigraphic studies for some ti[illegible] Ma[illegible] ch[illegible]s have examined the age of the surface and its relationship to other terraces along the east slope of the Front Range. In one of the most recent studies, Birkeland et al. (1996) placed the age at something older than 1.69 to 1.82 million years, making it one of the oldest, if not the oldest geological surface in Colorado.

In late October 1994, ESCO Associates undertook an examination of a part of the subject grassland area in W2 Sec. 16, R70W, T2S. Purposes of this examination were 1) to begin to assess the extent and distinguishing characteristics of the grassland, 2) to document through limited quantitative sampling the species composition/density in the proposed Phase 2 mining area in W2 Sec. 16, and the upper portions of the Woman Creek drainage, and 3) to set forth the critical features of a reclamation plan for the Sec. 16 grassland were it to be mined and reclaimed. Comparison of the Section 16 Phase 2 proposed mining area and the Woman Creek drainage was undertaken to provide some technical basis for discussion of the degree to which conservation of the Woman Creek drainage would protect plant community characteristics that may be deemed important in the Section 16 Phase 2 mining area, especially warm season grass abundance and overall species composition and richness.

The grassland area in question in the Section 16 Phase 2 proposed mining area is dominated by warm season grasses, especially big and little bluestem, more well known for their dominance of lowland prairie in the eastern Great Plains where average annual precipitation is often two to three times greater than that of the Colorado eastern plains. In addition to these grasses, dominance is shared with mountain muhly and some forbs more typical of lower montane environments, also usually recipient of greater average annual precipitation than the plains. The 1994 studies were reported in detail in ESCO (1994).

Since that time, interest has continued in the degree to which this grassland ecosystem in general, and its representation in the school section (Section 16) in particular, constitutes a valuable resource that should be perpetuated into the future even to the

exclusion of other resources. Other resources that may be represented on the site include gravel deposits, potential [illegible] development area, or other uses.

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In 1996, ESCO Associates undertook the data collection portion of a study of these grasslands as they occur in Section 16 on Rocky Flats, in adjacent areas of the Rocky Flats surface, and elsewhere in northern Jefferson County and adjacent Boulder County. This study was part of a joint effort between Jefferson County Open Space Department, Jefferson County Nature Association, the Jefferson County Soil Conservation District, the Colorado State Land Board, and Western Aggregates, which mines gravel on Rocky Flats in the area where these grasslands occur. Data were collected from a total of 33 sample sites during 1996, 1997, and 1998. In 1999, the opportunity for physical access and sample placement on a large area occupied by this ecosystem that lies west of Highway 93 and north of Highway 72 arose (sections 5, 8, 17, and 18). Seven additional samples were placed in this area. Samples were also added in the east 1/2 of Section 16 where disturbed conditions had previously discouraged sampling. For purposes of accumulating the most complete picture of the status of this ecosystem, information from that eastern portion of Section 16 should also be available. In total, 15 more samples were added in 1999, bringing the total number sampled to 47. (Note that data for and locations of samples 37 and 39 are not shown on data tables; these data are being kept from public view at the request of the private landowner).

## METHODS

Data of three types have been collected during the course of these studies: cover by species, frequency by species and species presence. The use of cover sampling in the late summer when vegetation could be expected to have achieved its full development for the year was the main thrust of the study. The timing of sampling that occurred during the study is presented below.

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| Year | Pres/Abs | Freq- micro | Freq-meter | | | | Cover | Pres/Abs |
|---|---|---|---|---|---|---|---|---|
| 1996 | | | | | | x | x | x |
| 1997 | | x | x | | | | x | x |
| 1998 | x | | | | | | x | x |
| 1999 | x | | | | | x | x | x |
| 2000 | x | | | | | x | x | x |
| 2001 | x | | | | | | | |

* Study began in Late Summer 1996 and ended in Spring 2001
x = Data of this type collected in this time period
Pres/Abs = Species presence within 2 m x 50 m sample area
Freq-micro = Frequency data based on species presence within ten 20cmx50cm plots per sample transect
Freq-meter = Frequencydata based on species presence within ten 1 m x 1m plots per sample transect
Cover = Point intercept cover sampling with 100 projected points
NDC = No data collected

Cover sampling has provided reliable estimates of the abundance of the major species at each of the sites, while frequency data have provided details of the distribution of the less common as well as the dominant species. Frequency sampling, which is much more time-consuming was undertaken at the beginning of studies and again later because additional sample locations had been established and a round of sampling including all samples at the most detailed level was deemed necessary. Species presence sampling was conducted primarily for the purpose of establishing the presence of spring ephemeral species that might not be apparent in August sampling. These spring observations were conducted within 2m x 50m belt transects. This form of observation allowed accumulation of continued information on floral composition without large expenditure of effort.

Sample Locations

Samples have been located subjectively with consideration of incorporating the variability of each site. A few samples thought to be clearly different were included to provide a context for the other sites. Sample locations are shown on Maps 1, 2, 3a and 3b. At each location, the end points of the sample transect were marked with a rebar stake driven flush with the ground (for subsequent use with a metal detector) and a fiberglass post. Jefferson County Open Space personnel surveyed the endpoints of samples identified in 1996 with high resolution Global Positioning System (GPS) equipment to establish permanent record of them. Coordinates of additional samples located in 1999 were established using a consumer-grade Garmin II GPS (i.e. accuracy plus or minus 15 m). Samples included in this study are listed below along with rationale

for their inclusion. The bulk of the points are located approximately on the oblique photograph from the north that is [illegible]. Maps 2, 3a and 3b are included to show the location of [illegible] shown on Map 1.

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| Sample | Location | Rationale |
|---|---|---|
| 1 | Section 16 | Document conditions of contested area |
| 2 | Section 16 | Document conditions of contested area |
| 3 | Section 16 | Document conditions of contested area |
| 4 | Section 16 | Document conditions of contested area |
| 5 | Section 16 | Document conditions of contested area |
| 6 | Section 16 | Document conditions in lower (more deeply incised) Woman Creek - North-facing |
| 7 | Section 16 | Document conditions in lower (more deeply incised) Woman Creek - South-facing |
| 8 | Section 16 | Document conditions in lower (less deeply incised) Woman Creek - North-facing |
| 9 | Section 16 | Document conditions in lower (more deeply incised) Woman Creek - South-facing |
| 10 | Section 16 | Document conditions on upper surface of propsoed conservation area |
| 11 | JeffCo OS, above Coal Cr. | Document conditions on RF Alluvial Surface - far west |
| 12 | Ranson-Edwards JeffCo OS | Document conditions on misc. hogback colluvium |
| 13 | Rocky Flats Buffer Zone | Document conditions on eastern extreme of RF Alluvial Surface |
| 14 | Rocky Flats Buffer Zone | Document conditions on eastern extreme of RF Alluvial Surface |
| 15 | Rocky Flats Buffer Zone | Document conditions on middle of RF Alluvial Surface |
| 16 | Rocky Flats Buffer Zone | Document conditions on middle of RF Alluvial Surface |
| 17 | Rocky Flats Buffer Zone | Document conditions on middle of RF Alluvial Surface |
| 18 | Rocky Flats Buffer Zone | Document conditions on west-middle of RF Alluvial Surface |
| 19 | Rocky Flats Buffer Zone | Document conditions on west-middle of RF Alluvial Surface |
| 20 | Rocky Flats Buffer Zone | Document conditions on eastern extreme of RF Alluvial Surface |
| 21 | Rocky Flats Buffer Zone | Document conditions on Middle RF Alluvial Surface |
| 22 | Rocky Flats Buffer Zone | Document conditions on Middle RF Alluvial Surface |
| 23 | Rocky Flats Buffer Zone | Document conditions on Middle RF Alluvial Surface |
| 24 | Rocky Flats Buffer Zone | Document conditions on eastern extreme of RF Alluvial Surface |
| 25 | Jewel Mtn. Boulder OS | Document conditions on RFAS west of Hwy 93 |
| 26 | Jewel Mtn. Boulder OS | Document conditions on RFAS west of Hwy 93 |
| 27 | Jewel Mtn. Boulder OS | Document conditions on RFAS west of Hwy 93 |
| 28 | Jewel Mtn. Boulder OS | Document conditions on RFAS west of Hwy 93 |
| 29 | Jewel Mtn. Boulder OS | Document conditions on RFAS west of Hwy 93; swale (concave) micro-topo |
| 30 | Jewel Mtn. Boulder OS | Document conditions on RFAS west of Hwy 93; convex pair w/29 |
| 31 | Jewel Mtn. Boulder OS | Document conditions on RFAS west of Hwy 93; swale (concave) micro-topo |
| 32 | Jewel Mtn. Boulder OS | Document conditions on RFAS west of Hwy 93; convex pair w/31 |
| 33 | VanVleet Boulder OS | Document conditions on RFAS west of Hwy 93 |
| 34 | VanVleet Boulder OS | Document conditions on RFAS west of Hwy 93 |
| 35 | VanVleet Boulder OS | Document conditions on RFAS west of Hwy 93; pre-Rocky Flats age |
| 36 | Section 16 | Document conditions on East half of Section 16 |
| 37 | Confidential | Confidential |
| 38 | Section 16 | Document conditions on East half of Section 16 |
| 39 | Confidential | Confidential |
| 40 | Jewel Mtn. Boulder OS | Document conditions on RFAS west of Hwy 93; convex pair w/41 |
| 41 | Jewel Mtn. Boulder OS | Document conditions on RFAS west of Hwy 93; swale (concave) micro-topo |
| 42 | Jewel Mtn. Boulder OS | Document conditions on RFAS west of Hwy 93 |
| 43 | Jewel Mtn. Boulder OS | Document conditions on RFAS west of Hwy 93 |
| 44 | Jewel Mtn. Boulder OS | Document conditions on RFAS west of Hwy 93 |
| 45 | JeffCo OS | Document conditions on RFAS south of Hwy 72 |
| 46 | JeffCo OS | Document conditions on RFAS south of Hwy 72 |
| 47 | JeffCo OS | Document conditions on RFAS south of Hwy 72 |

## Cover

For assessment of cover, the point intercept cover method was chosen because it provides superior objectivity and repeatability; the inherent tendency to encounter only the more abundant species has been compensated through use of a total vascular

species inventory along the sam[illegible]nsect (see b[illegible]). In addition, frequency plot data have been collected in thre[illegible]ing sampling to provide further details of the abundance [illegible]ee below).

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Point intercept cover sampling was developed early in the history of plant ecology (Levy and Madden 1933), and translated into varying forms by subsequent researchers (Goodall 1952, Winkworth and Goodall 1962).

Cover data were tabulated as interceptions of a point with plant species, soil, standing dead plant material (produced in a previous year but still erect), litter (fallen dead plant material), or rock. Plant material produced during the sample year and still standing was tallied by species. The point was optically projected using a Cover-Point Model 5 Optical Point Projector. The sample was taken along a 50 m transect; each sample consisted of 100 projected points.

Species Presence

At each occasion of sampling, all species present within a 2m x 50m belt transect (quadrat) oriented along and centered on the 50 m permanent transect were tallied. This provides information on all species present in addition to the information on what are likely to be the most abundant species that is provided by the point intercept cover sampling. It also offers the opportunity to compare the "packing" or density of species within a consistent and fairly large unit of landscape (100 square meters).

Frequency

Frequency data were collected in addition to cover data in August 1996, 1999, and 2000, as well as May 1997. These data were taken in each of ten 1m x 1m plots located at 5m intervals along each 50m transect. In each plot, all species present were tallied. For each species, the number of plots in which the plant was observed was divided by the number of plots observed (10). Thus, for example, if Species A occurred in seven plots, its frequency for the transect is 7/10, or 70 percent. Frequency data offer the opportunity to view the uniformity of distribution of plant species present. This is important for assessment of details of plant community composition. In August 1996, frequency data were also collected in very small (20cm x 50 cm = 0.1 sq.m., aka "Daubenmire" or "micro"') plots at the request of the oversight committee.

## RESULTS

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Data from the various periods of [illegible] collection are presented in tables on the CD available upon request. Included on the CD is a Read Me table of contents in which the various included spreadsheet files are described and related to the file codes. Results that are referenced in the discussion below are present in Figures 1 through 8.

## DISCUSSION

### Nature of the Section 16 Grasslands – Plants Species Present

The grasslands of the western half of Section 16 have been documented in this study by samples 1 through 10 (see Map1). The contested area in Section 16 is represented by samples 1 through 5. The most abundant species are big bluestem, mountain muhly, and Porter's aster. As noted below, little bluestem was once a co-dominant with these species but has declined substantially over the past few decades. It is treated here as a major species nonetheless.

*Big Bluestem*

The grasslands specifically included in this study were those of relatively dry nature that included big bluestem (*Andropogon gerardii*). This species, more than any other single grassland species, has attracted general interest in our area because it is so prominent in the tall grass prairie of the midwestern U.S. where average yearly precipitation is easily more than double that in our area. Its presence here seems such an anomaly that it immediately elicits questions about how it could be here and what it represents. The presence of big bluestem along with other tall grass species such as switchgrass, yellow Indian grass, prairie dropseed and little bluestem was noted by early botanists of the area (see Shantz (1906), Vestal (1914), and James (1930)) and was instrumental in the recognition of the Tall Grass Natural Areas established in the late 1980's by the Colorado Natural Areas Program in conjunction with what is now known as the City of Boulder Open Space and Mountain Parks Department. The grassland communities included in the Natural Area designation are mostly examples of sites that have supplemental soil moisture related to near-surface ground water. On these sites, in relatively moist and warm years, the stature of the big

bluestem at 5 to 6 feet can be [illegible] approach [illegible] 8 foot range that gives tall grass prairie its name in the [illegible]

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Within the borders of Colorado, big bluestem occurs primarily near the eastern mountain front. There moisture suddenly elevates from as little as 12 to 13 inches average annual precipitation within 10 miles of the mountain front to 16 to 18 inches within the couple miles immediately east of the front. Of course, even 16 to 18 inches falls far short of the 30 to 40 inches associated with the midwestern occurrence of tall grass prairie. Consequently, the occurrence of big bluestem and other tall grass community species is usually tied to some fairly evident supplemental source of moisture. The Tall Grass Natural Area parcels near Boulder are situated on lower terrace sites for the most part that are subirrigated by the water table associated with South Boulder Creek and/or by ground water from upslope that sometimes is itself supplemented by (anthropogenic) irrigation through-flow.

Big bluestem can also occur on sites drier by nature that have no subirrigation. On Rocky Flats in the area addressed by this study, the presence of big bluestem is not obviously related to near-surface ground waters. Over the past 20 years in the Front Range piedmont area, big bluestem has made (re)appearance at a great many locations, especially in the foothills where rocky substrates are abundant. Those past 20 years have been relatively moist and in fact comprise the longest drought-free period in the historic record (*ref*). From this evidence it is clear that the presence of big bluestem by itself gives a suggestion of comparatively high availability of moisture but by no means proves the existence of particularly unusual and/or special environmental conditions.

The enhanced presence of big bluestem in recent times relates, as suggested above, partly to the frequent occurrence of above-average precipitation years. However, it is also connected to the abatement of excessive grazing that characterized much of post-settlement history. Big bluestem is a nutritious and relatively palatable species that attracted heavy livestock use. It cannot withstand close cropping to the degree that smaller stature species such as buffalograss or blue grama can. Hence over the period of the 1870's to 1970's, through heavy grazing and several significant drought periods, its prevalence was suppressed.

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Although some sites in the fo[illegible] perhaps redeveloped) substantial presence of big b[illegible]mes, other sites such as Rocky Flats have had long-term presence of this grass. The earliest known data from the Rocky Flats Bluestem Grassland collected in 1960 by F. A. Branson and others (1965) showed an average of 6.7 percent cover by big bluestem, very close to what it has comprised over the five years of this study.

*Little Bluestem*

Little bluestem (*Schizachyrium scoparium*) is also a member of the tall grass ecosystem of the midwestern U.S. Although it often occurs with tall grasses, it is smaller and is generally regarded as a grass of medium stature (i.e. "mid grass"). In the present study area it is one of the subdominant grasses, but over the past 30 years of drought-free conditions, it has declined from a considerably greater abundance. For example, in the grasslands of the contested portion of Section 16 (samples 1 through 5) little bluestem now comprises less than one percent cover, whereas in 1960, Branson et.al. (1965) found it to comprise 6.1 percent cover on apparently nearby parcels. This may relate to grazing management, but more likely to competitive effects as other plants in the community have responded to favorable moisture and have slowly expanded to the detriment of little bluestem. The onset of the studies reported here probably coincided with the tail end of its decline: 1996 cover in Section 16 averaged about 2 percent and two years earlier a separate study (ESCO 1994) revealed an average of 3.6 percent cover.

*Mountain Muhly*

Mountain muhly (*Muhlenbergia montana*) is warm season grass occurs in the Central and Southern Rocky Mountains, in the California Sierra Nevada and through Mexico to Guatemala at mid to high elevation. It is a very prominent and often dominant or co-dominant component of mountain grasslands throughout Colorado. It is not a species of the central plains grasslands and its presence in the Rocky Flats Bluestem Grasslands in the midst of central plains species, especially the tall grass species, is believed to represent more than a random distributional anomaly.

*Porter Aster*

Porter aster (*Aster porteri* )is an [illegible] cky Mountain front that occurs from southern Wyoming [illegible] exico between 5500 and 9500 feet. It occurs primarily in mountainous habitats east of the Continental Divide. Its presence in grasslands of the piedmont region is not unusual, though it is almost always present as a member of a larger cast of many wildflower (forb) species and typically provides less than one percent cover.

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Comparison of Section 16 Grasslands to Other Similar Grasslands

Toward the end of evaluating the grasslands of Section 16 with other grasslands nearby and others not so nearby that are distinguishable by the presence of big bluestem or other tall grass species as dominants, it is appropriate to examine comparable data from those sites. The complete and voluminous body of cover, frequency, and species presence data from sampling of the sites included in this study are available as a CD Appendix to this report. An example of the cover data is present in Table 1. These cover data are from the late summer sampling of year 2000.

Review of such data from the five years of (cover) sampling (1996 to 2000) began with an assessment of the five samples located in the contested portion of Section 16, i.e. numbers 1 through 5. Here, for example, in 1998, the most abundant (dominant) plant species were (in descending order) mountain muhly (*Muhlenbergia montana*), big bluestem (*Andropogon gerardii*), Porter aster (*Aster porteri*), hairy grama (*Chondrosum hirsutum*), prairie junegrass (*Koeleria macrantha*), and sun sedge (*Carex pennsylvanica* ssp. *heliophila*). This combination of dominant species represents two mountain species (mountain muhly and Porter aster), two eastern prairie species (big bluestem and sun sedge) and two species of very wide distribution (hairy grama and prairie Junegrass). Hairy grama is very widely distributed throughout the western two-thirds of North America, but is generally confined to lower elevations. Prairie Junegrass occurs even more widely throughout North America and also occurs over a very wide elevational range. These six do not comprise a common combination of species. Grasslands of the northern Great Plains often have abundant presence of sun sedge and prairie Junegrass, but completely lack big bluestem and hairy grama, as well as the mountain species. Grasslands of the

mountains commonly possess mountain muhly and porter aster, but lack the other four species entirely. This is where the lack of these species together, much less as dominants, is very striking.

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One of the outcomes of having looked at the study area for five years is that we can verify that this odd combination is not an erratic event that showed up one year and disappeared the next. The above-described composition has persisted in the Section 16 samples (1 through 5) for the entire period of 1996 through 2000.

Beyond the lack of similarity of the Section 16 grasslands to other regional grasslands, the question that underlies this study is basically as follows: Of similar (big bluestem-dominated) grasslands in the general area, how do those of section 16 compare? Are they distinct and, if so, why? If so, what is their significance?

To begin the comparison, we will look at the diagnostic species of the grasslands of Section 16. A list of diagnostic species would naturally include the dominant species that show consistent presence. Thus, we will include as a basis of comparison the presence of big bluestem, mountain muhly, hairy grama, prairie Junegrass, and Porter aster. We will omit sun sedge because it is the least abundant and occurs at the same low level in most of the samples in the study. In addition to these most abundant species, we will examine some that, like four of the dominant representatives, are primarily found in geographically and biologically different environments. Species present that are mountain representatives include Fendler sandwort (*Eremogone fendleri*) and blanketflower (*Gaillardia aristata*). Representatives of the eastern prairies that we will include in the diagnosis are James nailwort (*Paronychia jamesii*), little bluestem (*Schizachyrium scoparium*), and various goldenrods (mostly *Solidago mollis* and *S. simplex*). Little bluestem, as has been mentioned above, has been a dominant in these grasslands in the historic past, but has declined for reasons speculated upon above. Despite its decline in abundance, it is an important species and will be included in the analysis.

Before we examine the full ten, however, a look at the contribution of the most abundant (dominant) three (plus the one-time codominant little bluestem) will

provide a useful first look at the sampled grassland (Figure 1). In this illustration, the relative cover of the four species each year at each site is plotted. As can be seen, red bluestem is almost always prominent in almost all largely because that is what caused the area to be selected for inclusion in the study. A balance of blue (mountain muhly) and green (Porter aster) along with the red (big bluestem) characterizes the Section 16 samples (1 through 5). While several outlying sites (e.g. A1 on Davidson Mesa in Boulder County, CR1 and CR2 at Ken Caryl Ranch, and RD-1 and Rd-2 at Ralston Dike) have very high abundance of big bluestem, they lack measurable cover by the mountain species (mountain muhly and Porter aster).

Note that within Section 16 (Samples1 through 10), numbers 1 through 5 have the aforementioned balance of big bluestem, mountain muhly, and Porter aster, as does 10 (located north of Woman Creek in the planned conservation area). These latter samples are all on the level, un-dissected Rocky Flats Alluvial Surface. However, numbers 6 through 9 are located on the slopes of Woman Creek where the ancient pediment surface has been nibbled away by the erosive action of Woman Creek. The depression associated with the drainage is fairly subtle, but the effects are noticeable, especially on the where the most erosion of the original surface has taken place (samples 6 and 7). Notice that for samples 6 and 7, the mountain muhly and porter aster are nearly absent. At sites 8 and 9 located further west where the erosional depression is shallower (i.e. the alluvium is more intact), the effect is smaller, but still the abundance of mountain muhly and Porter aster is distinctly less. Number 8 has higher cover by big bluestem and Porter aster perhaps because it is the north-facing side of the "valley"; number 7 is on the south- facing side. Sample 11 is on the far west edge of the Rocky Flats Alluvial surface (just inside the boundary of Jefferson County Open Space and just above Coal Creek, Map 3). There, as can be seen, the diagnostic balance of dominant species is present. Sample 12, a short distance to the northwest on Jefferson County Ranson-Edwards property is off the Rocky Flats alluvium and on miscellaneous hogback colluvium. As reflected in Figure 1, the abundance of the four species is substantially depressed.

Samples 13 and 14 are located in the Rocky Flats (RF) Buffer Zone on the far east end of the Rocky Flats Alluvial Surface, though at this distance away from the mountain front, the alluvial veneer is thinned considerable, and the influence

of underlying shale on soils is [illegible] ough big bluestem is present, the diagnostic balan[illegible] and Porter aster is not. Further west in the RF Buffer [illegible] ch of the "Smart Ditch" drainage, the "fingerpint" of the dominants and the pattern of balance among them is regained (Samples 15, 16 and 17). In Samples 18 and 19 located near the western edge of the RF Buffer Zone, the grasslands have been affected by seepage from Rocky Flats Reservoir, and the balance seen in Samples 1 through 5, 10, 11, 15, 16 and 17 is distorted. Note that in Samples 15, 16, 17, 18, and 19 that Porter aster suddenly disappeared part way through the study, probably as a result of spray or drifting spray of herbicide during on-going weed control efforts in the RF Buffer Zone.

Samples 20 and 24 located toward the eastern limit of the Rocky Flats Alluvial Surface between Walnut Creek and Rock Creek in the RF Buffer Zone again show the effect of distance from the mountain front (whether this is a difference in the substrate of land use history) with almost no mountain muhly or Porter aster present. Further west in the RF Buffer Zone, samples 21, 22 and 23 again show the characteristic balance.

Samples west of Highway 93 on what is now City of Boulder Open Space (Jewel Mountain and VanVleet properties, Numbers 25 through 35 and 40 through 43) seem to show, based on relative cover, the diagnostic balance of the major components being discussed here. However, there are evident effects of past land use that have measurably reduced the proportion of total vegetation that these (four main) species comprise. The samples immediately south of Highway 72 on Jefferson County Open Space (45 through 47) again show the pattern and magintude of dominance seen in Section 16 and RF Buffer Zone areas discussed above.

Another approach to comparison of plant communities involves the use of summed frequency values. Whereas the cover approach used above assesses the amount of ground surface covered by the species in question, the summation of frequency reflects the "commonness" and equitability of distribution of the species in question through a 50 meter reach of the plant community. Examination of the summed frequency values for each of the above-discussed ten diagnostic species (Figure 2) reveals 1) that the sites on Rocky Flats alluvium

are distinctly different from th[illegible] CR1, 2, 3, RD1, 2) and 2) sites on Rocky Flats alluvium [illegible] lally thinned (e.g. 6 and 7) or where the alluvium has be[illegible] s never thick anyway (e.g. 13, 14, 20 and 24). Even slight erosional thinning of the alluvial cap correlates with reduced occurrence of these diagnostic species. In samples 8 and 9 in the upper end of Woman Creek, note the absence of Fendler sandwort and blanketflower. At an even greater of level sensitivity, the very slight thinning associated with sample 5 is apparent in the reduction in cumulative frequency compared to samples 1 through 4.

Note that samples 15 through 17 in the Rocky Flats Buffer Zone began the study in 1996 with a fairly strong compositional "signature" and then lost it (in 1997 and 1998) probably as a result of the effects of broadleaf herbicide used for the control of diffuse knapweed and other problem species in the Buffer Zone area. Samples 18 and 19 also suffered reductions in the broadleaf (forb) component, but these had started at a slightly lower level, possibly because of the effects of disruption caused by the presence of leakage from Rocky Flats Reservoir to the west.

Importance of Topographic Position

Across the extent of Rocky Flats Alluvium at the mouth of Coal Creek Canyon, the bulk of the extent of the erosional surface is strikingly smooth (see Photos 1a and 1b). However, in a wedge-shaped area radiating from the mouth of Coal Creek Canyon to the upper end of Woman Creek and north across the headwaters of Walnut Creek and Rock Creek is a zone that is braided and, while by no means rough, is definitely undulant. Toward understanding what effects slight variations in topographic conformation might have relative to the model of RFBG that is described by samples 1 through 5, 10 and 11, and 21 through 23, all of which are on the smooth uneroded upland pediment surface, three pairs of samples were established on the Jewel Mountain Property in 1999 and 2000. Examination of the cumulative frequency data from Figure 2 reveals that slight effects of topographic position can clearly be seen in the closely paired samples (29 and 30, 31 and 32, and 40 and 41, in which the odd-numbered samples are in slight concavities and the even-numbered samples are on slight convexities). Though Porter aster is frequent in the concavities, as is, to some extent, big

bluestem, very little of the oth[illegible] is seen there. The adjacent convexities by comp[illegible]ng typical signature for Rocky Flats Bluestem Grassl[illegible]

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Importance of Historic Land Use

The samples located on the City of Boulder Open Space and Mountain Parks parcels that lie west of Highway 93 and north of Highway 72 (Jewel Mountain and VanVleet parcels, samples 25 through 28, 30, 32 through 35, 40 through 44) are (except for the samples placed in concavities, samples 29, 31 and 41) possessed of the RFBG signature (Figure 2). Samples among these that are nearer the mouth of Coal Creek Canyon (40, 41 and 44) show evidence of substantial degradation probably from abusive historic grazing (prior to Open Space management) but possibly from the effects of comparatively recent flooding by Coal Creek (i.e. prehistoric, but far younger than the two-million year age of the surface in general). Of samples located on Jefferson County Open Space immediately south of Highway 72, the western-most sample (45) has experienced more extensive disturbance than the two further east (46 and 47) which have the very strong signature of RFBG (Figure 2).

Relation of RFBG to Results of Previous Vegetation Studies of the Area

Studies of the grasslands of the mountain front in this area extend back to the very early 20$^{th}$ century. One of the earliest in this area was a Master's thesis by A.G. Vestal (1913) in which, under the physiographic category of "Higher Mesas" that included the Rocky Flats and Verdos age pediments noted the presence of a Bunch Grass Association (that also included miscellaneous hogback and floodplain occurrences of tallgrasses) in conjunction with "a large number of mountain plants." James (1930) likewise working on a Master's thesis, studied what are now known as "Enchanted Mesa" and "NCAR Mesa" (?Verdos age pediments?) noted the "abundant" presence of big bluestem on the upper surface but made no mention of mountain muhly and listed Porter aster as an "infrequent" species. This documents that then, as now, these areas were quite different from the RFBG composition. Studies of the vegetation of the Rocky Flats Environmental Technology site "buffer zone" have noted the existence of the grassland ecosystem referred to here as RFBG at site TR01 (Kaiser-Hill

1996?). The Colorado Natural Heritage Program (CNHP 1995) identified what it called "Xeric Tallgrass Prairie" within the boundaries of the Rocky Flats Conservation Site, included (?) within the boundaries of the Rocky Flats Environmemtal Technology Site. It would appear that CNHP believed that what is referred to here as RFBG is a mildly interesting variant of Xeric Tallgrass Prairie. The present study demonstrates that the mere presence of big bluestem, while interesting in each case, does not signify ecological equivalence. The variation in ecosystem composition between for example Ken Caryl Ranch (CR1, 2, and 3), Ralston Dike (RD1 and 2), and the RFBG is distinct and stable at least over the five year period.

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Proposed Quality Ratings

In Figure 2, two thresholds are shown that tentatively delineate 1) the minimum cumulative frequency by the diagnostic ten species that accompanies plant communities for which the term RFBG could (based on frequency data) be applicable and 2) the examples of the grassland that are in highest compositional condition. The areas that satisfy the latter criterion possess a well-dispersed presence of the basic compositional species of the type , yet may or may not have those diagnostic species in abundance. Figure 1 depicts the relative cover of three current dominants (big bluestem, mountain muhly, and Porter aster) plus a one-time (and potential future) dominant (little bluestem). From this figure it can be seen that the plant communities represented in samples CC1, 1 through 4, 9, 10 and 11, and 21 through 23 all have had over 50 percent of their total vegetation cover comprised of these species at least two of the five years of observation (1996 through 2000). Note that some sites which, based on cumulative frequency criteria of Figure 2, appear to be at least fairly well-developed RFBG communities have only a very small portion of their vegetation cover comprised of these species. For example, B1 has cumulative frequency high enough to suggest that it is an RFBG site, yet four of the five years there was less than 11 percent of total vegetation cover in the four dominant RFBG species (Figure 1). Similarly site 12 on the JeffCo Ranson-Edwards property has potential in the form of cumulative frequency around 250 (Figure 2), but the proportion on the vegetation cover provided by the four dominants (Figure 1) is quite low.

Figure 3 contains grouped da[illegible]ues for the ten diagnostic species on sites from this stu[illegible] the Superior Associates monitoring (ESCO 1997a, 19[illegible]a), and monitoring sites in the Tall Grass Natural Areas on City of Boulder Open Space (ESCO 1997b, 1998b, 1999b, 2000b, 2001b). What is apparent there is that the great abundance of the ten diagnostic species in RFBG vegetation (Groups 1, 2, 3, and 4) contrasts sharply with the vegetation of nearby sites on the same pediment level (C1/C2) or vegetation of the Tall Grass Natural Areas along South Boulder Creek (Areas 3, 6, and 7). The latter have at least as much and usually substantially greater abundance of big bluestem but almost no development of the other nine species.

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Species Richness and Density

Figures 4 and 5 depict the species density (number of plant species per 100 sq. m.) observed over the life of the study (1996 to 2000) for the RFBG study sites as well as the comparable control sites for studies on the Superior Associates City of Boulder Open Space and the sites of long-term monitoring of Tall Grass Natural Area parcels on the City of Boulder Open Space. Overall, the Section 16 grasslands have relatively low species density compared to some others in the study (e.g. samples 6 and 12), partly because they have very low involvement of introduced species (see below) and low involvement of opportunistic species in general, whether native or introduced. Compared to other areas ( Figure 5), the average values of RFBG species density are moderate.

Stability of RFBG

The degree to which the RFBG grasslands are stable is an attribute of interest to this evaluation.

*Stability of Species Density*

Figure 6 illustrates the relative variability of selected areas as regards the number of plant species present per 100 sq.m. (species density). Areas compared here include locations of RFBG (Groups 1, 2 and 3) as well as transects from the study that are outside the RFBG type. Group 4 includes the

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transects located east of Section [illegible] in the RF Buffer Zone that do not show the characteristic composition of RFBG (see section [illegible] above). Group 5 includes the control transects C1 and C2 and [illegible] Flats pediment a few miles northeast of Section 16 as part of City of Boulder Open Space and Mountain Parks (OSMP) studies there. Group 6 includes the Tall Grass Natural Area, Area 7 transect (data also collected under the auspices of Boulder OSMP). Area 7 transects comprise the portion of the monitored Tall Grass Natural Areas that is most similar to RFBG. The results of this comparison are that areas possessed of what has in this report been referred to as the RFBG vegetation composition (Groups 1, 2, and 3) have had distinctly lower variability in the number of species present during the five years of observation (1996 to 2000) than do the ecologically similar areas represented by Groups 4, 5 and 6 over the same time period. Within the RFBG areas, there is gradation from the Section 16 transects (Group 1) to those in Section 3 (Group 2) to those on the Jewel Mountain and VanVleet Boulder Open Space. The Section 16 transects have shown the least average variability and may by this measure be regarded as the most stable of all the areas examined.

*Relative Susceptibility to Weed Invasion*

Figure 7 shows a compilation of cumulative frequency data for species that may be regarded as "weeds," that is, opportunistic species and/or foreign species. Most of the weeds of this or most any other area of the western U.S. are introduced (i.e. foreign to pre-settlement North America). These then fall into the categories of Introduced Annual & Biennial Forbs (yellow), Introduced Annual Grasses (green), or Introduced Perennial Forbs (blue). Besides these alien species, some native annual and biennial forbs are present and are depicted as well (red).

What can be seen in Figure 8, a summary of Figure 7, is that the level of introduced weed invasion of RFBG (Groups 1, 2, and 3) is much lower than other nearby areas that are similar by virtue of the presence of big bluestem as a dominant. All areas have similar levels of presence of native annual & biennial species, but the presence of introduced annual & biennial forbs and introduced annual grasses (mostly cheatgrass (*Anisantha tectorum)* and Japanese brome (*Bromus japonicus*)) is distinctly lower in Groups 1, 2, and 3. Note, however, the

presence of a fairly consistent [illegible] of the [illegible]ced perennial forb lifeform in Groups 1, 2, and 3. This is [illegible] *Hypericum perforatum*), a weed that is thought to have [illegible] area in 1918 in the southern part of the study area along the railroad. It proliferated on Rocky Flats during the following years and then declined perhaps related to a predatory beetle (*Chrysolina quadrigemina*) released in the 1960's. Why this species succeeded in invading RFBG when so many other aggressive species have been repelled is not known. It may relate to effects of the approx. 20-year cycle of droughts during the first three-quarters of the 20th century and the effects of universal very severe overgrazing during the latter 19th and early 20th centuries.

Despite the St. Johnswort exception, the resistance of RFBG to weed invasion is striking. The question of what attribute(s) of ecosystems relate to the "invasibility" of those ecosystems is prominent in the ecological literature of the past decade, as well it should be. The economic costs, not to mention the dimensions of ecological damage, associated with weed invasions have become rapidly more apparent over the past 20 years. There are relatively few options for action to control weed invasions available that do not bring serious secondary (side) effects. A basic understanding of the ecology of weed invasions and more importantly the ecology of community resistance to weed invasion is sorely needed. Some have related the degree of resistance and higher general ecosystem stability to the presence of greater biodiversity (see Odum 197x). On the other hand field obervations have benn reported that show an inverse relationship between species diversity and invasibility (see Lonsdale 1999). In their proposal of a general theory of invasibility, Davis et al. (2000) predict no necessary relationship between species diversity and susceptibility to invasion. Evidence here is consistent with that prediction in that the RFBG has the lowest species density as well as the lowest invasibility.

Importance of the Rocky Flats Bluestem Grasslands

The western portions of North America are a relatively recently settled area of planet Earth. Although human presence here dates back to a time on the order of 10,000 years, the degree of impact on native vegetation has been, except perhaps for fire frequency, relatively small until the mid-19th century. Since that time, the extent of vegetation change has been very widespread. The

urbanization of many parts in [illegible] the mountain front in Colorado was preceded by a [illegible] ification related first to extremely high intensities of [illegible] vestock in the late 19th century and into the 20th century and later to extensive development of cultivated fields. Few examples of native vegetation that have escaped serious modification by modern man and his biological associates are present.

The Rocky Flats age pediments in northern Jefferson and southern Boulder Counties are thought to have remained geologically undisturbed for nearly two million years (Birkeland et al.1996). They are positioned in the zone where one biome from the central plains of North America meets another biome from the continental backbone, the Rocky Mountains. Over the past two million years, the major glacial periods of the Pleistocene have come and gone, causing the vegetational possibilities of this area to change back and forth. Without a major geological event to "erase the blackboard," the evidences of these fluctuations have had the opportunity to remain in place. Virtually all other sites around Colorado have been subject to the "eraser" in the form of rapid erosion and/or deposition at various times during the preceding two million years. The soils studies of Dr. Peter Birkeland and others have demonstrated the effects of long-term lack of disturbance on soil development on the Rocky Flats surface.

The unusual combination of mountain and plains species as dominants in a recurring consistent assemblage on the least disturbed portions of the Rocky Flats Alluvial Surface, along with evidence of exceptional stability and resistance to weed invasion leads to the conclusion that this ecosystem does possess unique qualities consistent with its very old environment.

One of the frontiers of plant ecology now and probably well into the future is the understanding of physical and biological (and temporal) details of the long-term stability of ecosystems. Unfortunately, our human effects have so pervasively modified ecosystems around the world that examples of truly long-term stable sites are extremely scarce. The RFBG ecosystem, including in particular the Section 16 portions, represents in my opinion, one of those extremely scarce resources, whose availability to scientific research in the future may contribute in a very important way to the eventual knowledge that allows practical advances in ecosystem reconstruction and restoration (see below).

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Prospects for Reconstruction / Restoration of Mined RFBG

One of the considerations leading to decisions that will eventually be made about the future management of lands on which RFBG occurs is the question regarding the prospects of restoring / rehabilitating past or future mined lands that were formerly RFBG. Returning the presence of the dominant species (big bluestem, little bluestem, mountain muhly and Porter aster) appears to be feasible. Reestablishment of some of the other important species such as prairie Junegrass and blanketflower is certainly within the realm of reasonable likelihood. Return of the full array of species is, at present, not technically feasible.

Beyond the list of species that comprise the vascular flora of this ecosystem, the attributes of ecosystem integration and stability discussed above must be addressed here also. Revegetation / restoration efforts on this or most any other mined site should include the reestablishment of ecologically important native species or facilitate the reasonable likelihood of their reappearance. In this case, the prospect of restoring the high level of ecological "inter-relatedness" as it exists in Section 16 grasslands is also an issue. At many mine sites, the pre-existing vegetation, even when predominantly native, is in a damaged condition, sometimes relating to disruptions dating back a century or more. Under such circumstances, the question of replacement of ecological integration is somewhat less prominent. Such replacement is certainly the proper goal of all such restoration efforts, and the results at many sites show promising suggestion that integration and restoration of ecosystem process is indeed being accomplished. However, in this case, the pre-existing vegetation is of unusually high condition, including a high level of ecological integrity, and any decision to disturb it should properly include consideration of the prospects of reestablishing that ecological inter-relatedness. Reconstruction of such integrated species presence (probably mediated through as yet unknown details of the soil micro-flora and -fauna) would require technical knowledge not available at present. The Section 16 grassland and other nearby occurrences of RFBG represent an opportunity to study and come to a better (hopefully someday full) understanding of just what the "inter-relatedness" target is and to hit it in future mine restoration. Ongoing reclamation of the RFBG areas already mined also figures in the growth of

understanding of the ecology [illegible] relict grassl[illegible]nd the technology of reestablishing not only specie[illegible]se species that defines the resilience of the ecosystem.

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Recommendations for Management / Preservation – Section 16 Grasslands

In consideration of the status of this area as a very high quality example of 1) a vegetation type that does not exist elsewhere, 2) a vegetational relict of times as long ago as two million years, and 3) an "intact" and stable ecological community capable of maintaining its biological integrity in the presence of myriad opportunistic invaders, the following recommendations are made:

- Preserve these grasslands for their scientific value

- Continue grazing on the site, but reduce stocking rates and alternate years in which grazing occurs in summer with those in which it occurs in winter/ spring.

- Arrange to allow the land to be prudently used as a resource for scientific research.

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## Executive Summary

Grasslands in and around the Section 16 area of Rocky Flats were examined over a five-year period, late summer 1996 to spring 2001. The objective was to ascertain the similarities or differences between the grasslands in the western half of Section 16, a state section on which mining is proposed, and other regional or local grasslands. If differences were evident, it was intended that the importance of those differences would be determined. Finally an opinion on whether reclamation of mined land would adequately replace lost values was to be rendered.

**Nature and Distinctiveness of the Grasslands**

The grasslands in Section 16 that are in question are dominated by (i.e. the most abundant species are) the grasses mountain muhly, big bluestem, hairy grama, prairie Junegrass, sun sedge, and the forb (wildflower) Porter aster. Mountain muhly and Porter aster are both species of the mountains not found in the general plant communities of the Great Plains. Big bluestem and sunsedge are both species primarily from the central U.S.A. in the Tall Grass Prairie region. This combination of species as dominants is not found elsewhere in North America. In comparison to other grasslands of the area of the East Slope of the Front Range, these from the west half of Section 16 were found to possess a distinctive "signature" matched by others in the immediate Rocky Flats area, but not in areas as far away as Ken Caryl Ranch. This signature and its distinctiveness were stable over the five-year period of this study.

Although this grassland has been categorized as "Xeric Tallgrass Prairie" by a report from the Rocky Flats area by the Colorado Natural Heritage Program, a branch of the Nature Conservancy (CNHP 1995), that categorization is somewhat weak because the tall grass species only comprise a minority portion of the distinctive species combination present. Rather, this ecosystem should be regarded as a unique relict of an extremely long period of surficial stability (as much as 2 million years) during which time it has experienced the ebb and flow of major floral assemblages across its surface in response to the major climatic shifts associated with the glacial periods of the Pleistocene. Tall grass species are but one of the components left from this long history of both vegetational change (in response to climatic environment) and stability (associated with such a uniquely stable geologic surface).

This ecosystem (Rocky Flats Bluestem Grassland) shows evidence of having a quality of integration (of relatively few species) that lends it a stability and resistance to invasion that is highly distinctive on its own.

## Importance of the Grasslands

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The western portions of North America are a relatively recently settled area of planet Earth. Although human presence here dates back to a time on the order of 10,000 years, the degree of impact on native vegetation has been, except perhaps for fire frequency, relatively small until the mid-19th century. Since that time, the extent of vegetation change has been very widespread. The urbanization of many parts including the east slope of the mountain front in Colorado was preceded by a general agricultural modification related first to extremely high intensities of pressure from domestic livestock in the late 19th century and into the 20th century and later to extensive development of cultivated fields. Few examples of native vegetation that have escaped serious modification by modern man and his biological associates are present.

The Rocky Flats age pediments in northern Jefferson and southern Boulder Counties are thought to have remained geologically undisturbed for nearly two million years (Birkeland et al.1996). They are positioned in the zone where one biome from the central plains of North America meets another biome from the continental backbone, the Rocky Mountains. Over the past two million years, the major glacial periods of the Pleistocene have come and gone, causing the vegetational possibilities of this area to change back and forth. Without a major geological event to "erase the blackboard," the evidences of these fluctuations have had the opportunity to remain in place. Virtually all other sites around Colorado have been subject to the "eraser" in the form of rapid erosion and/or deposition at various times during the preceding two million years. The soils studies of Dr. Peter Birkeland and others have demonstrated the effects of long-term lack of disturbance on soil development on the Rocky Flats surface.

The unusual combination of mountain and plains species as dominants in a recurring consistent assemblage on the least disturbed portions of the Rocky Flats Alluvial Surface, along with evidence of exceptional stability and resistance to weed invasion leads to the conclusion that this ecosystem does possess unique qualities consistent with its very old environment.

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**Prospects for Reconstruction / Restoration of Mined Rocky Flats Bluestem Grassland (RFBG)**

One of the considerations leading to decisions that will eventually be made about the future management of lands on which RFBG occurs is the question regarding the prospects of restoring / rehabilitating past or future mined lands that were formerly RFBG. Returning the presence of the dominant species (big bluestem, little bluestem, mountain muhly and Porter aster) appears to be feasible. Reestablishment of some of the other important species such as prairie Junegrass and blanketflower is certainly within the realm of reasonable likelihood. Return of the full array of species is, at present, not technically feasible.

Beyond the list of species that comprise the vascular flora of this ecosystem, the attributes of ecosystem integration and stability discussed in the main report must also be addressed here. Revegetation / restoration efforts on this or most any other mined site should include the reestablishment of ecologically important native species or facilitate the reasonable likelihood of their reappearance. In this case, the prospect of restoring the high level of ecological "inter-relatedness" as it exists in Section 16 grasslands is also an issue. At many mine sites, the pre-existing vegetation, even when predominantly native, is in a damaged condition, sometimes relating to disruptions dating back a century or more. Under such circumstances, the question of replacement of ecological integration is less prominent. Such replacement is certainly the proper goal of all such restoration efforts, and the results at many sites show promising suggestion that integration and restoration of ecosystem process is indeed being accomplished. However, in this case, the pre-existing vegetation is of unusually high condition,

including a high level of ecologic[illegible]on to disturb it should properly include consideration of the pros[illegible]t ecological inter-relatedness. Reconstruction of such integrate[illegible]bly mediated through as yet unknown details of the soil micro-flora and -fauna) would require technical knowledge not available at present.

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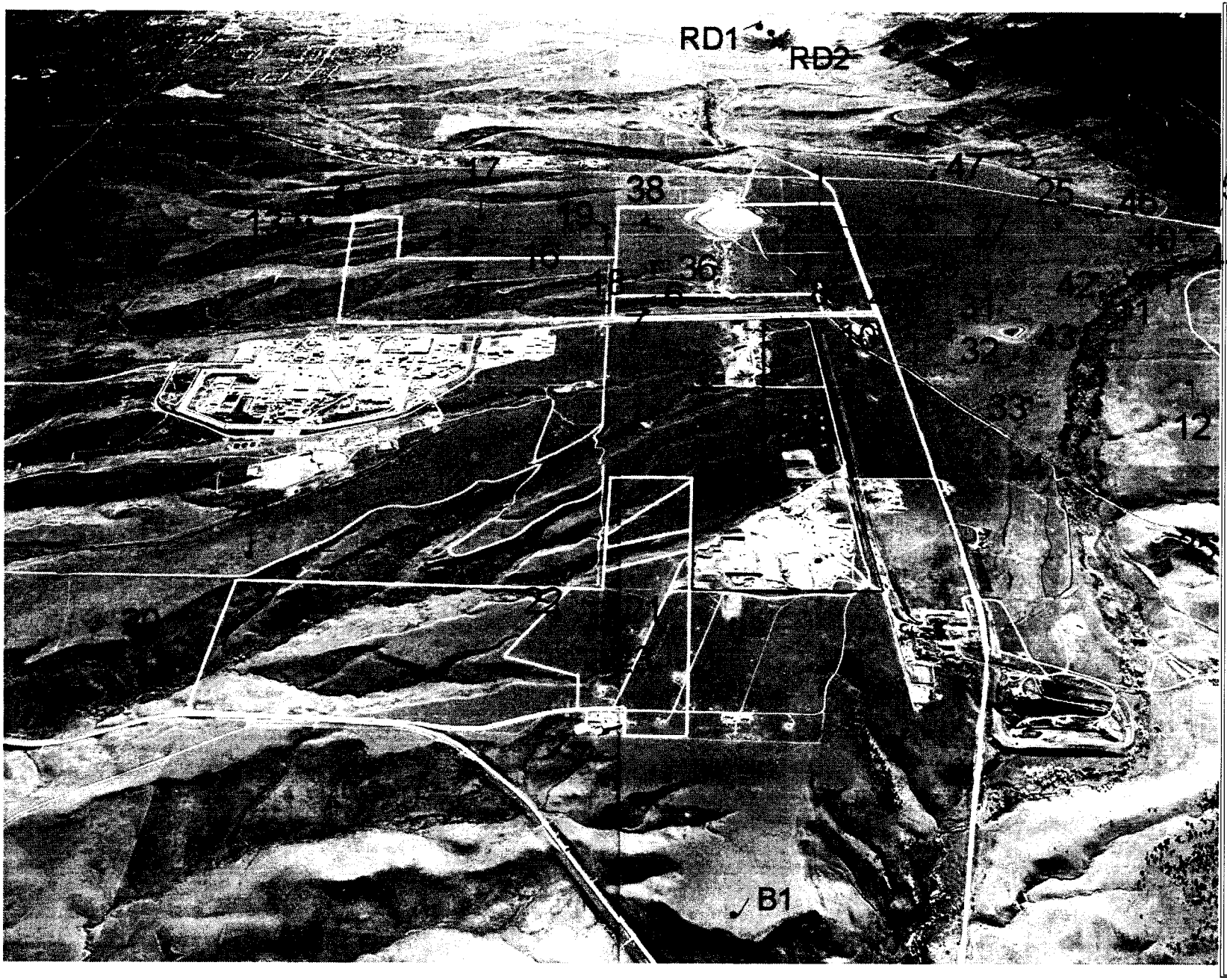



Map 1. Rocky Flats Bluestem Grassland Study.

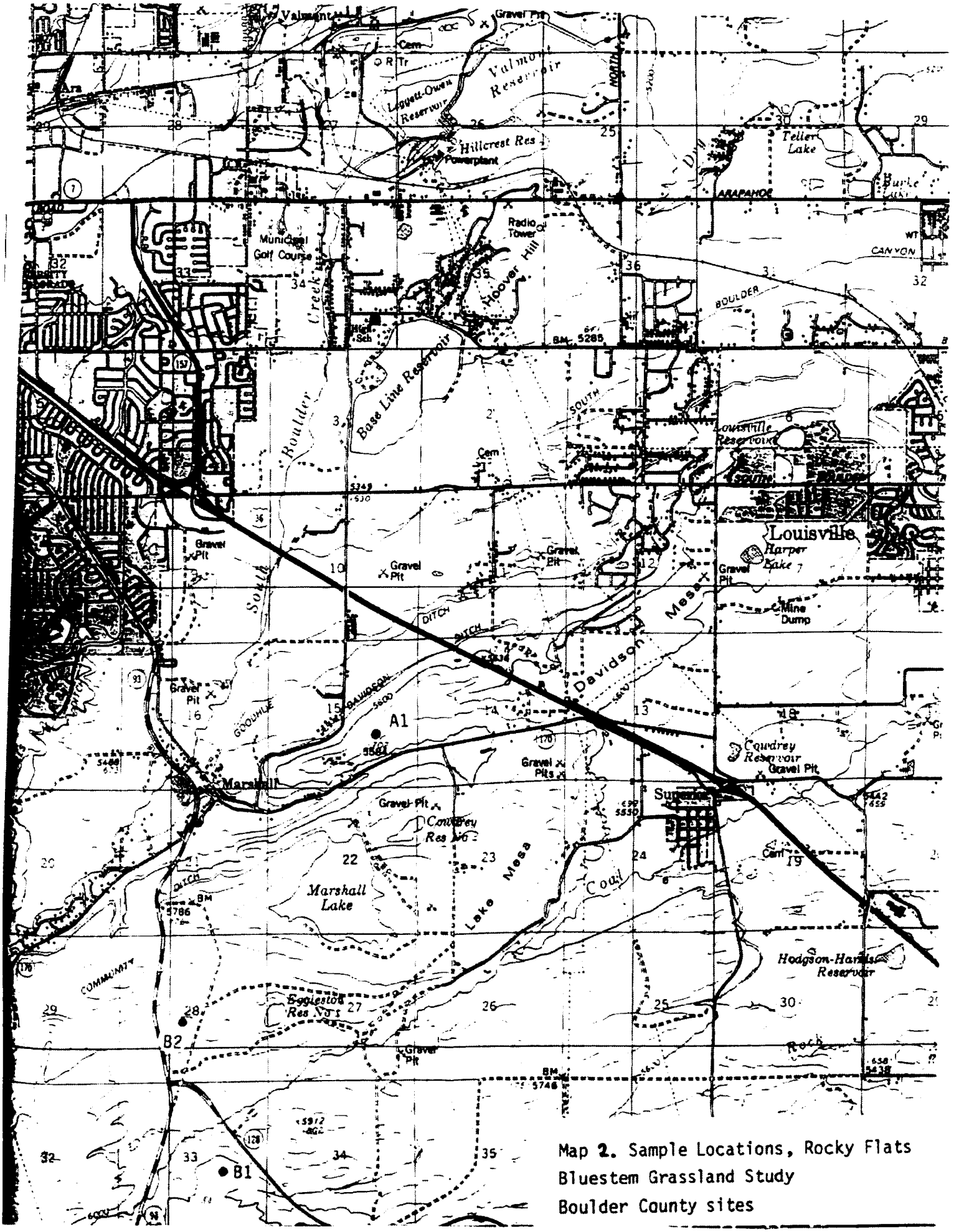
**LEGEND**

Lafarge Mine Permit/Lease Boundaries

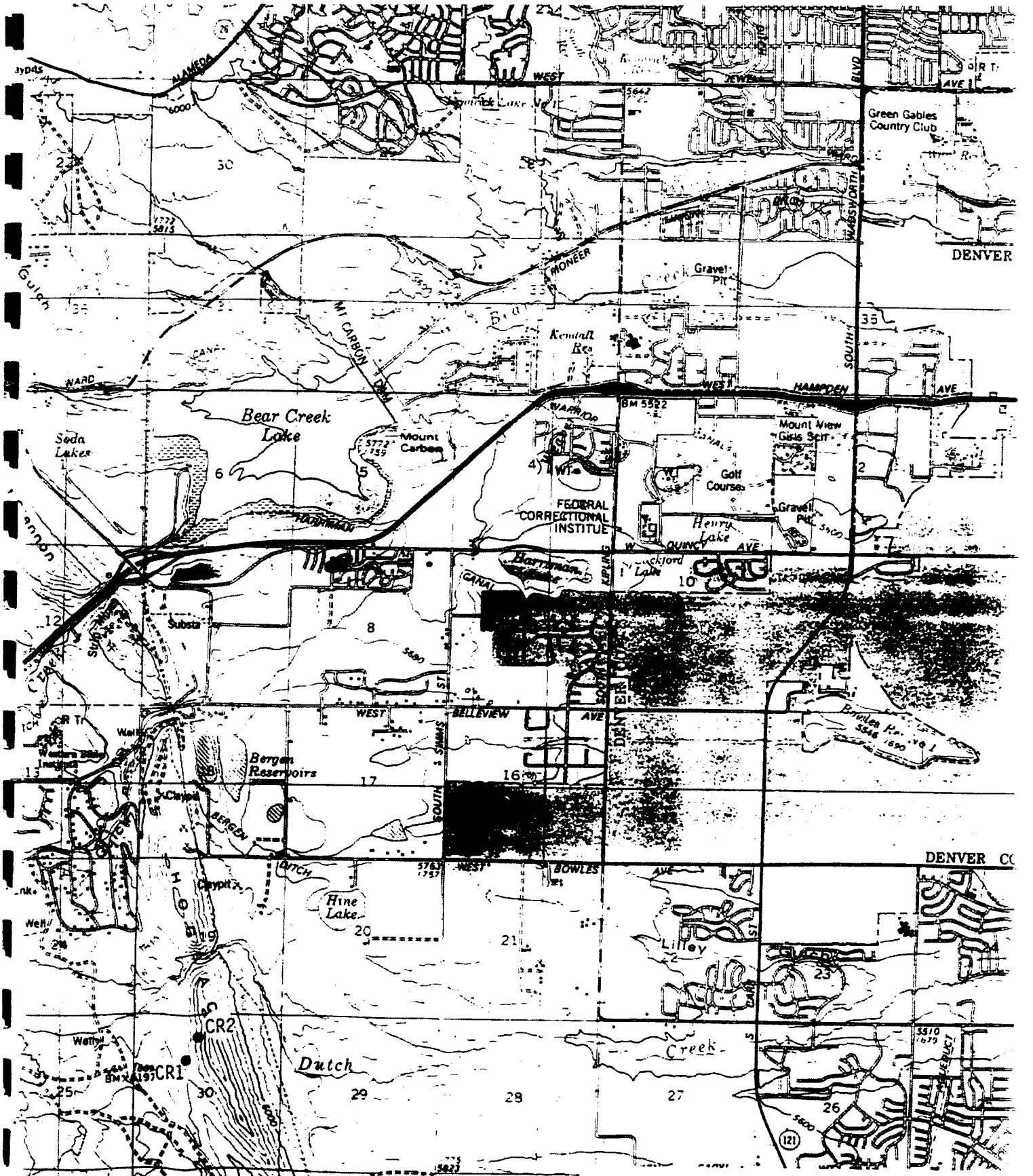
• Study Sample Locations

CR1, CR2, CR3
B2, and A1 are
located outside photo
boundaries

ESCO Associates Inc.




Map 2. Sample Locations, Rocky Flats Bluestem Grassland Study Boulder County sites




Map 3a. Sample Locations, Rocky Flats Bluestem Grassland Study, Southern Jefferson County Sites, Part 1

ROAD CLASSIFICATION

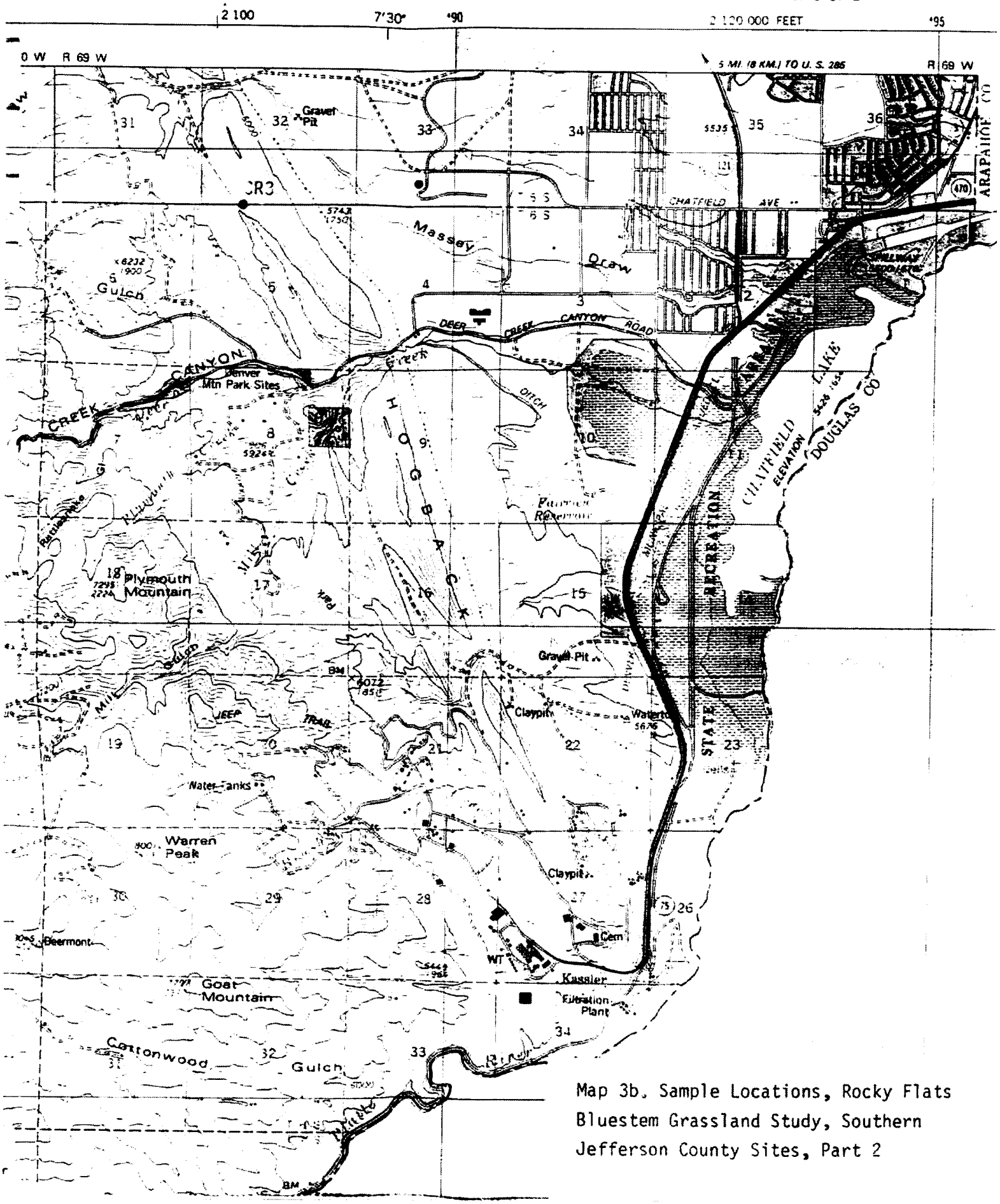
Primary highway, hard surface

Light-duty road improved surfa

# JEFFERSON COUNTY, COLOR

## COUNTY MAP SERIES (TOPOGRAPHI

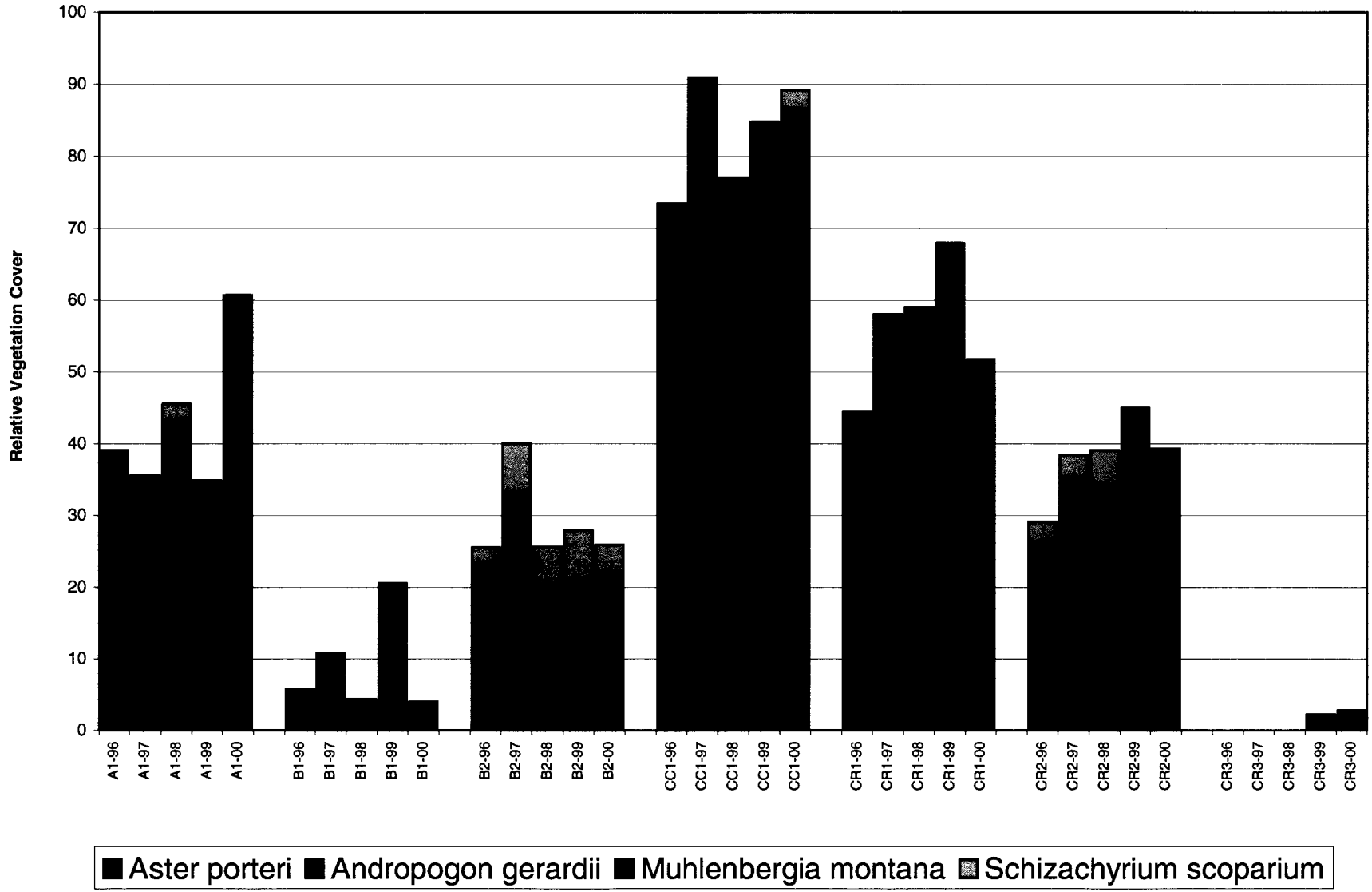
SHEET 2 OF 2




Map 3b. Sample Locations, Rocky Flats Bluestem Grassland Study, Southern Jefferson County Sites, Part 2

Figure 1. Relative Vegetation Cover of Four Select Forbs- All Sites, Rocky Flats Bluestem Grassland Study, Jeff. and Bldr. Co., CO- Fall Cover 1996-2000.





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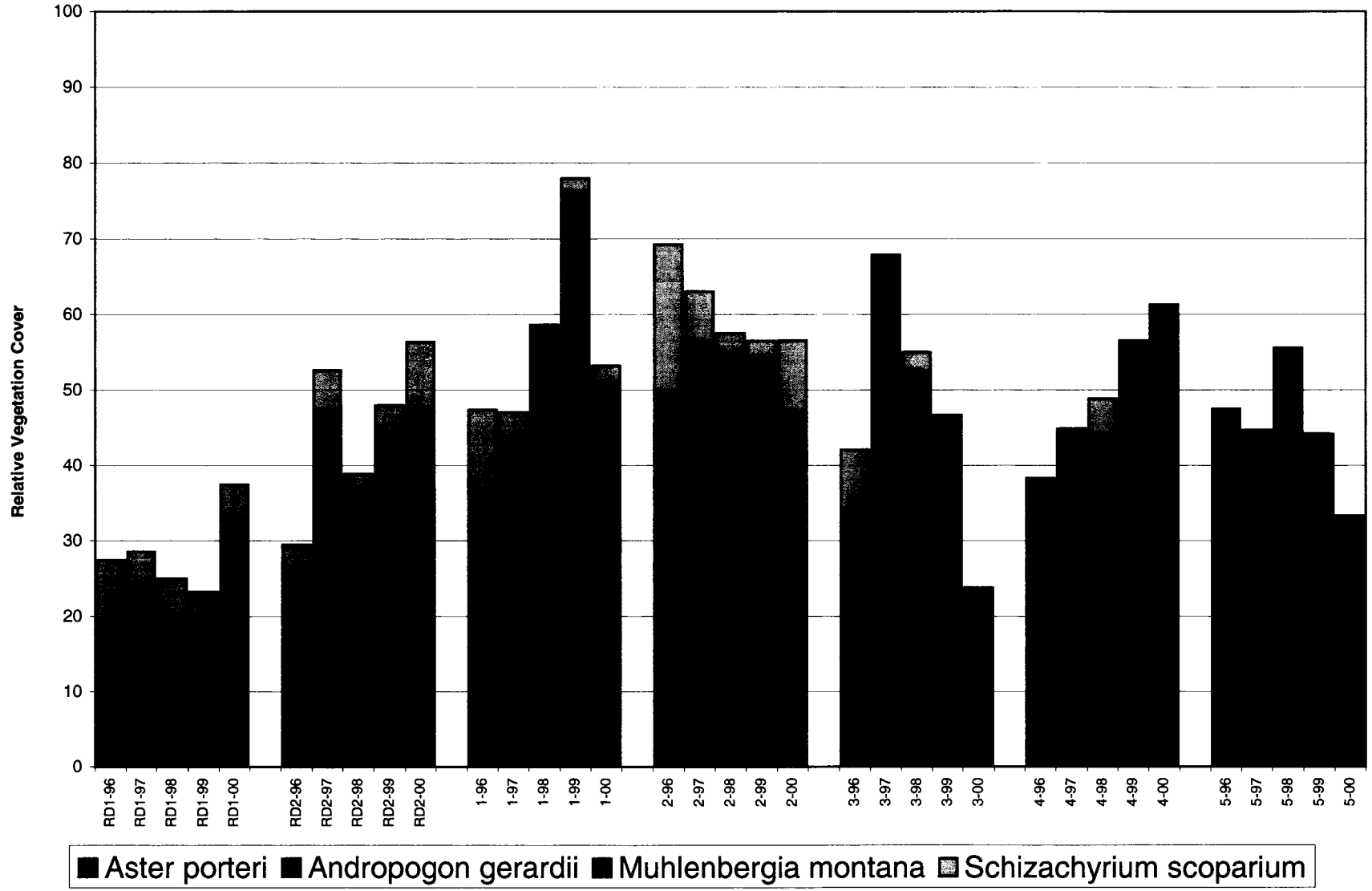

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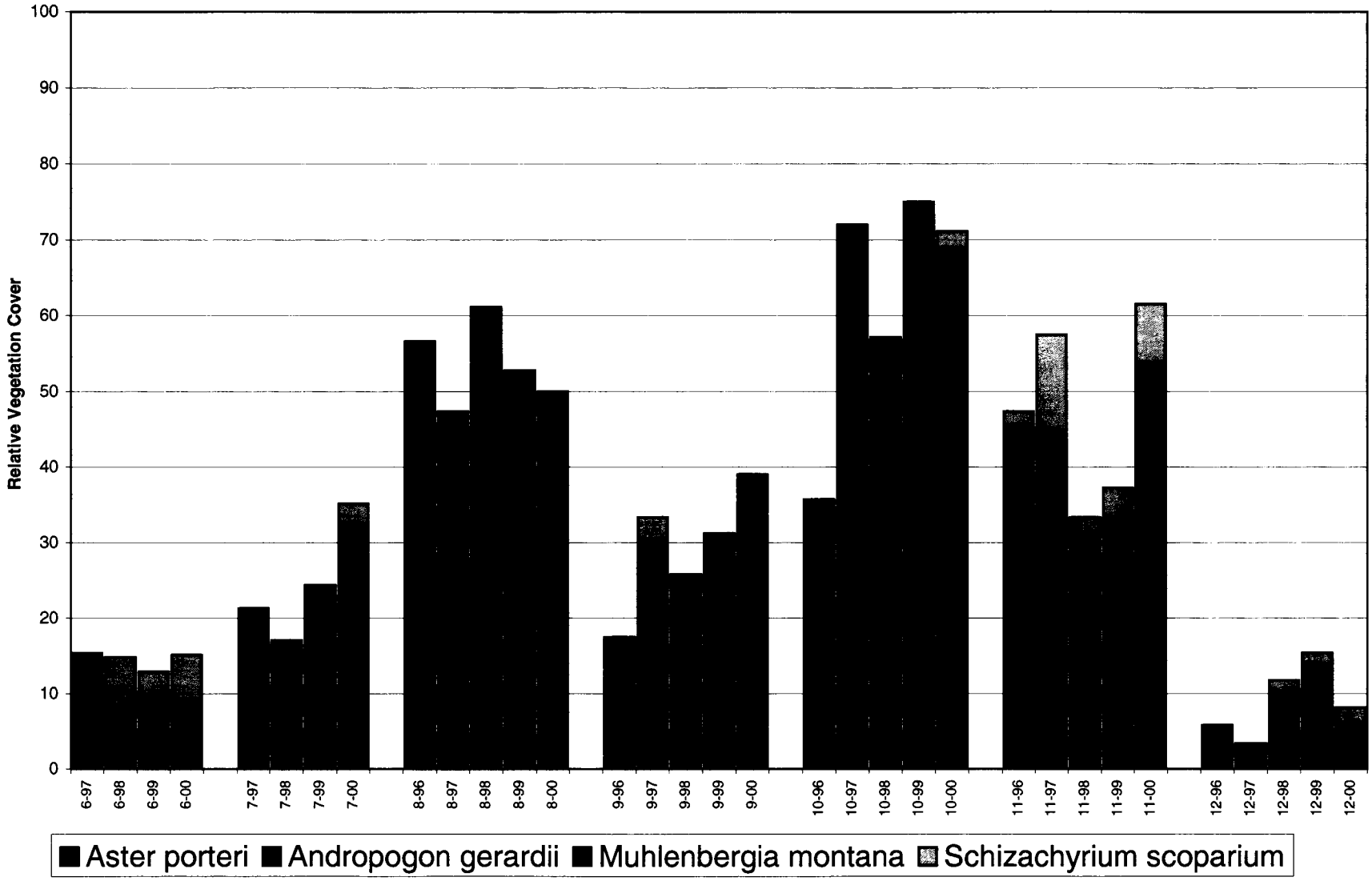

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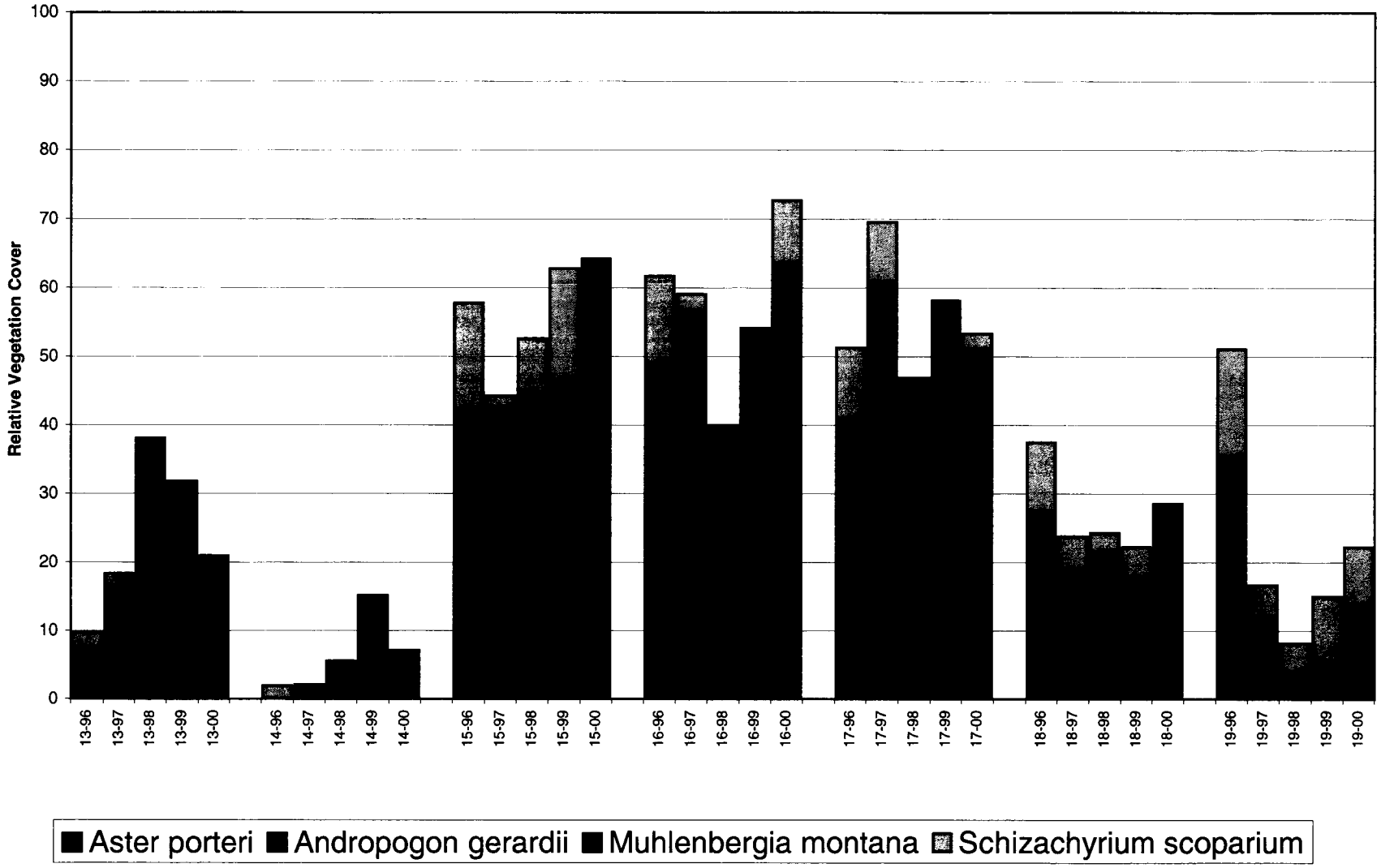


**Figure 1. Relative Vegetation Cover of Four Select Forbs- All Sites, Rocky Flats Bluestem Grassland Study, Jeff. and Bldr. Co., CO- Fall Cover 1996-2000.**

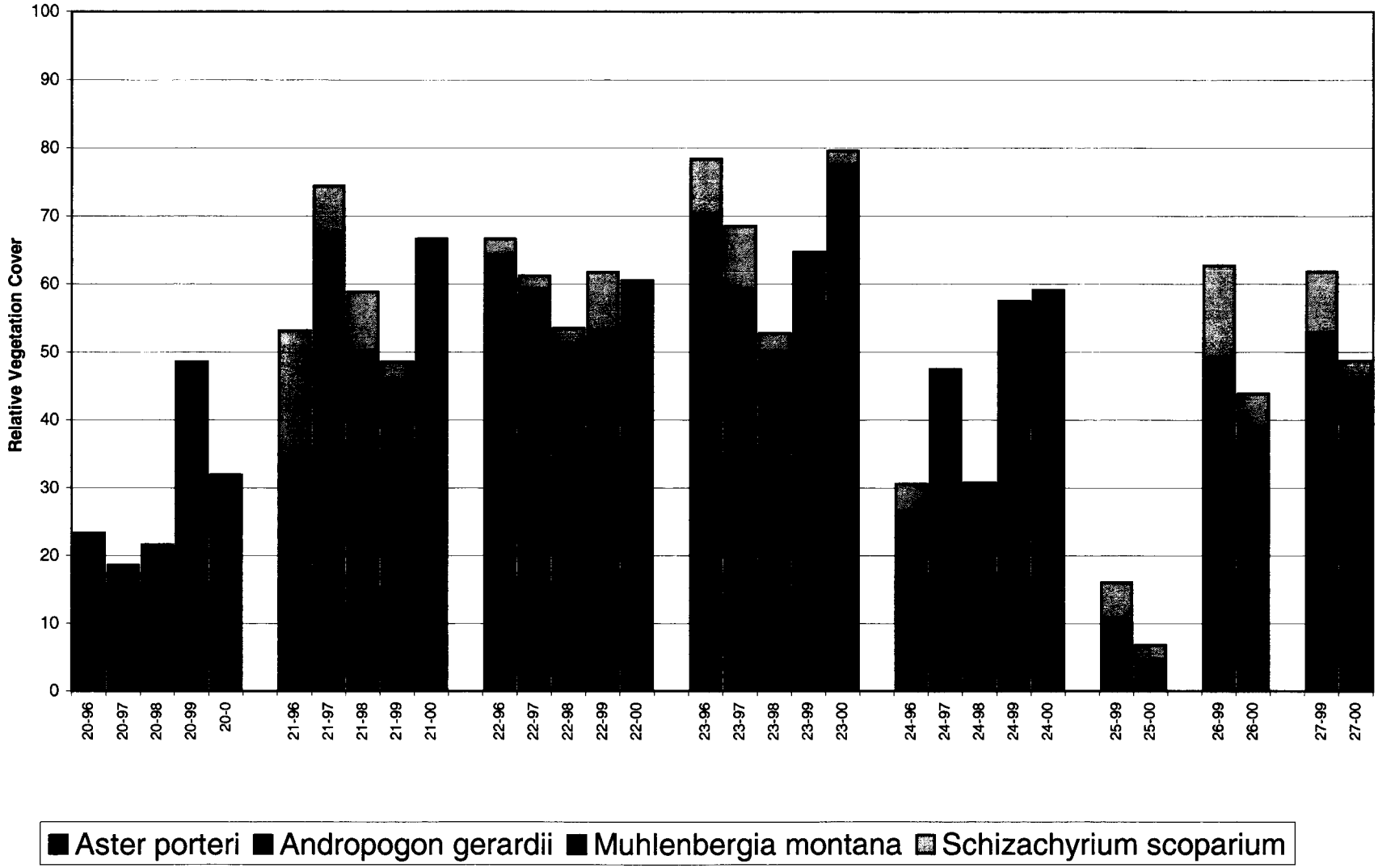


Figure 1. Relative Vegetation Cover of Four Select Forbs- All Sites, Rocky Flats Bluestem Grassland Study, Jeff. and Bldr. Co., CO- Fall Cover 1996-2000.



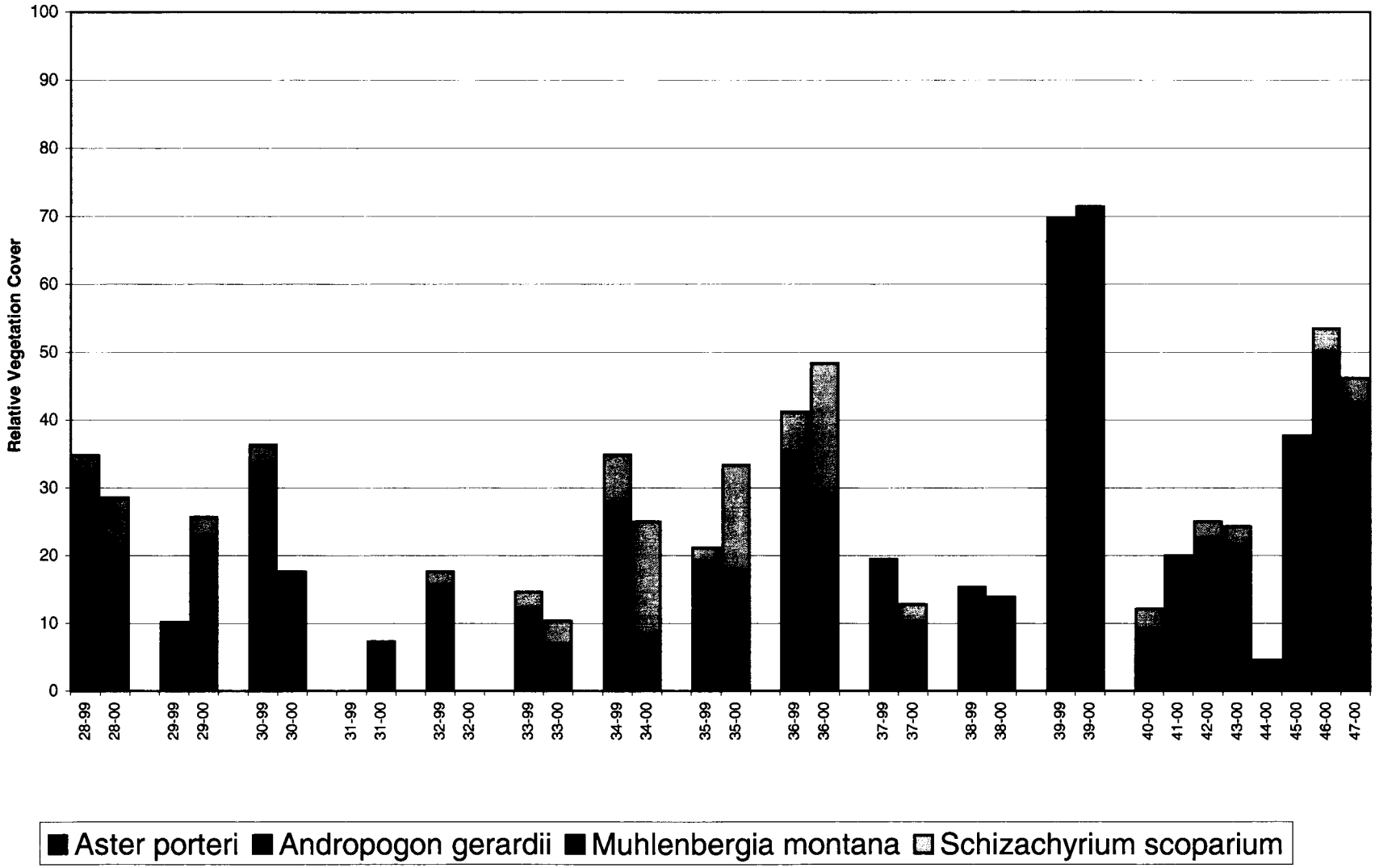
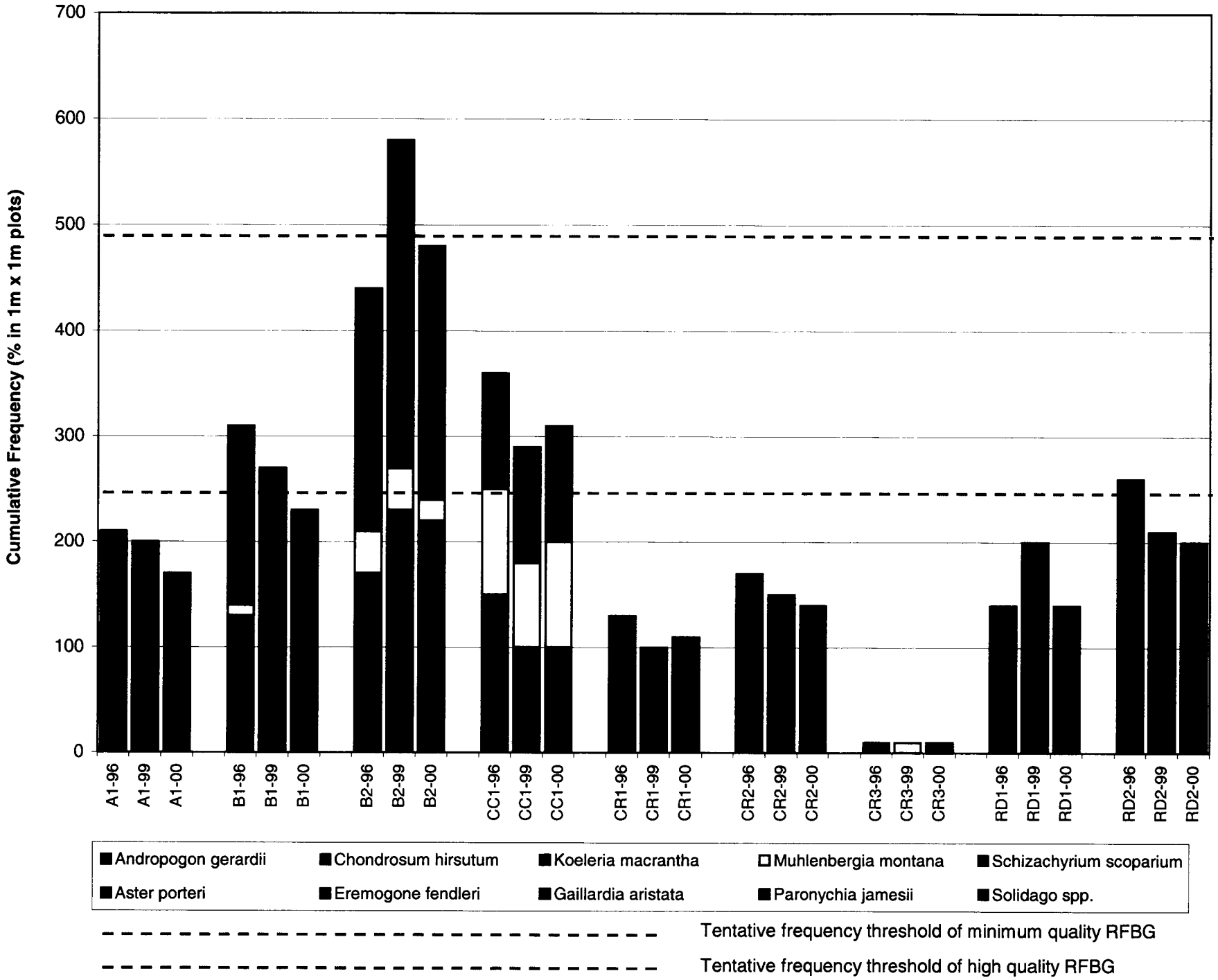
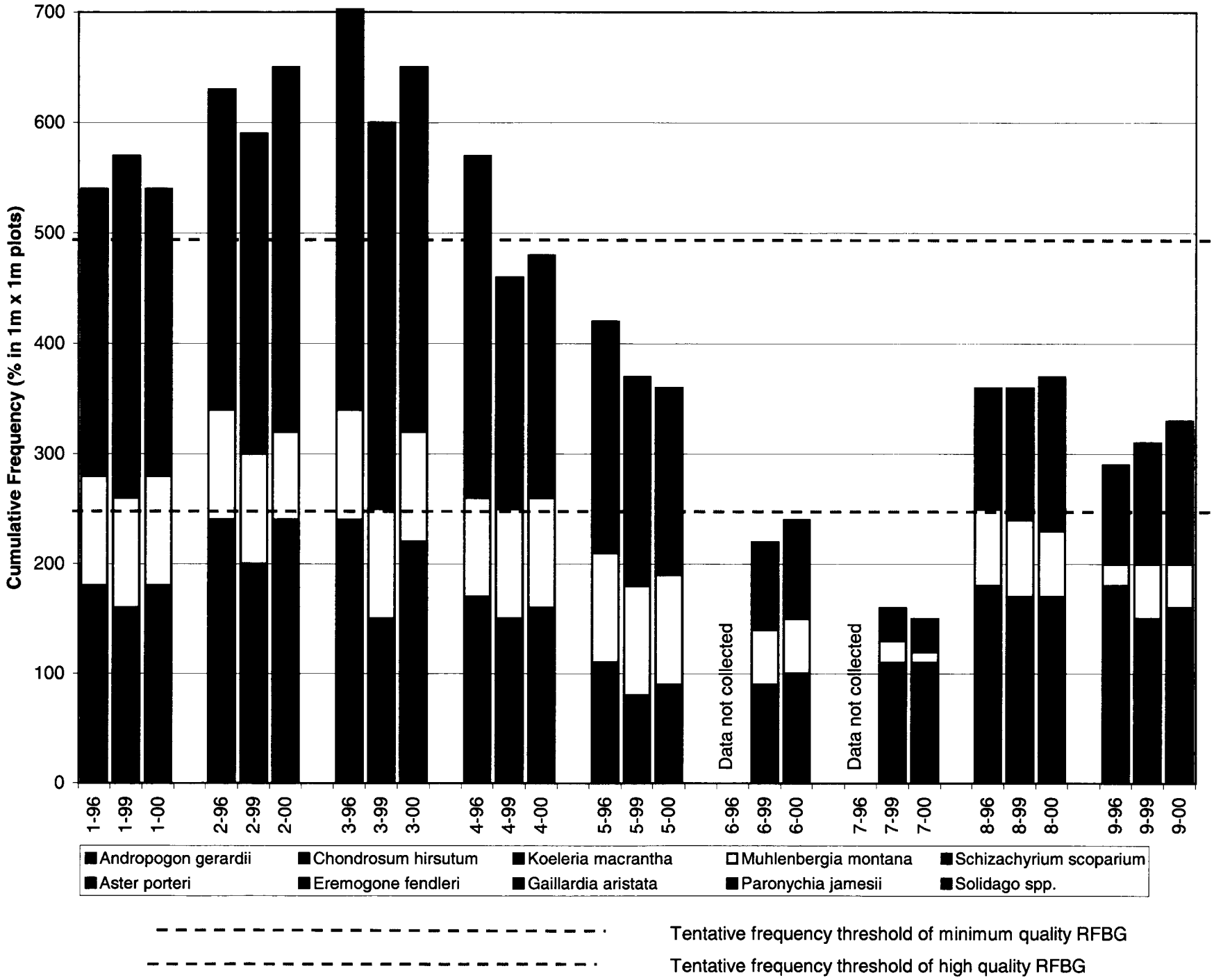
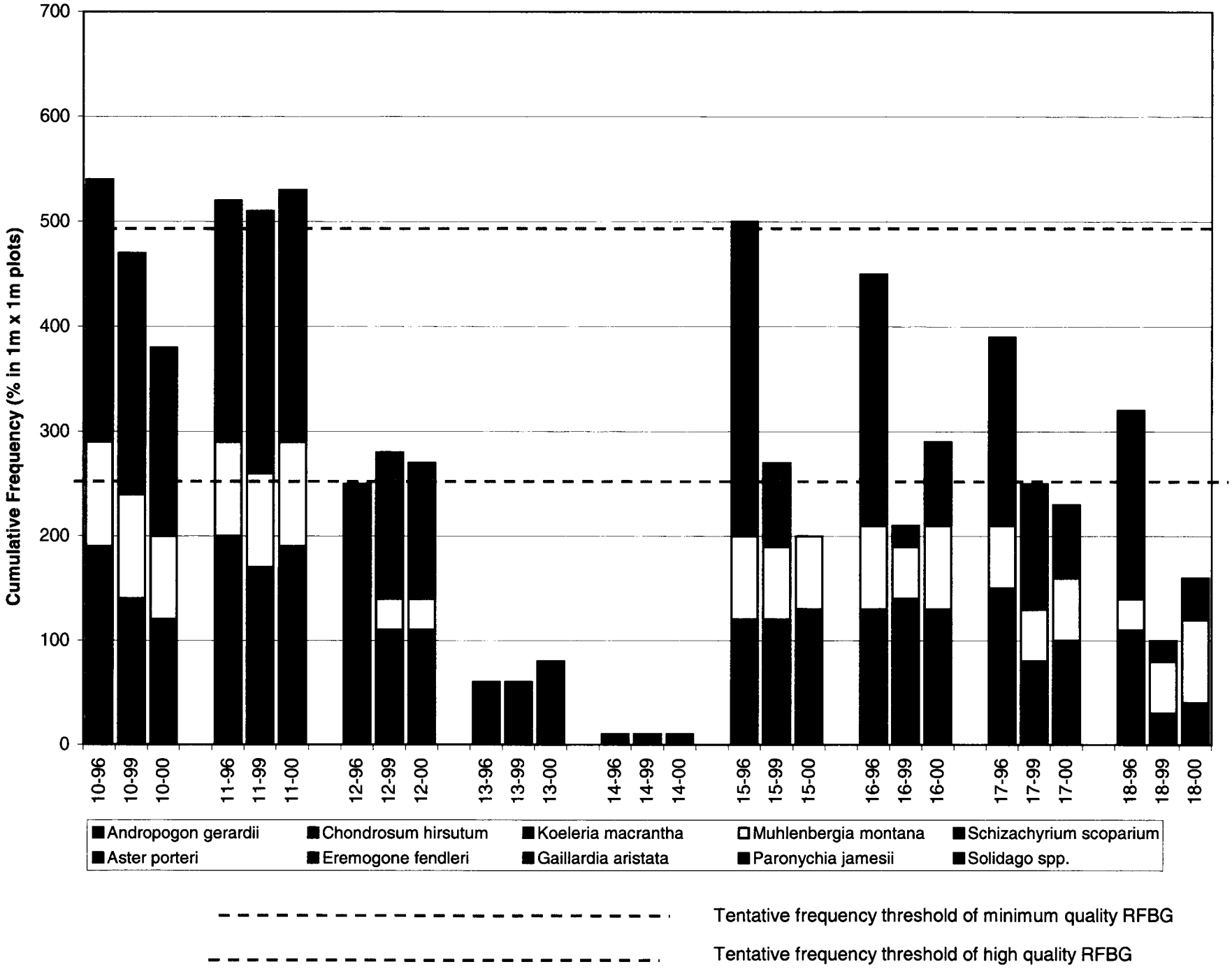
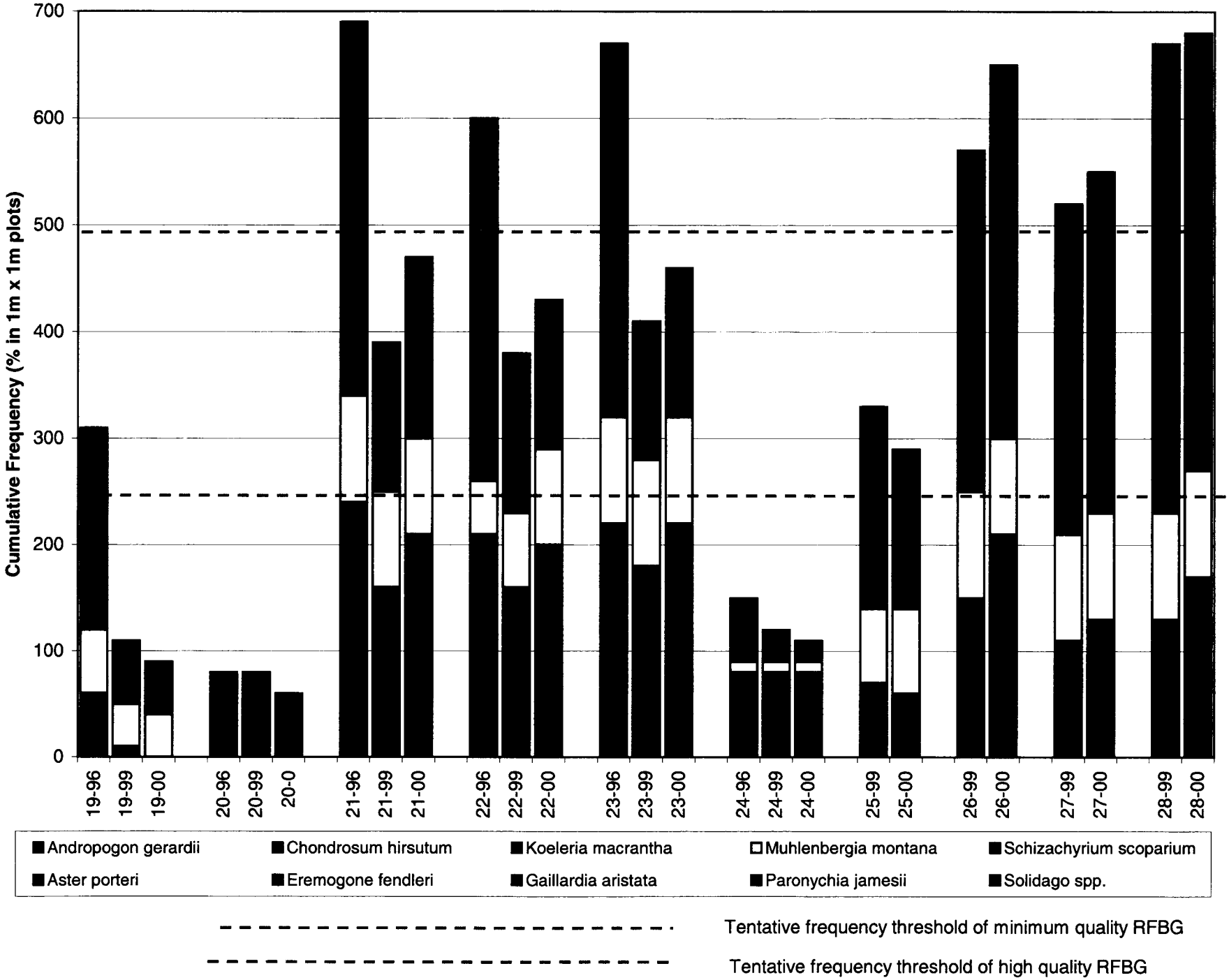


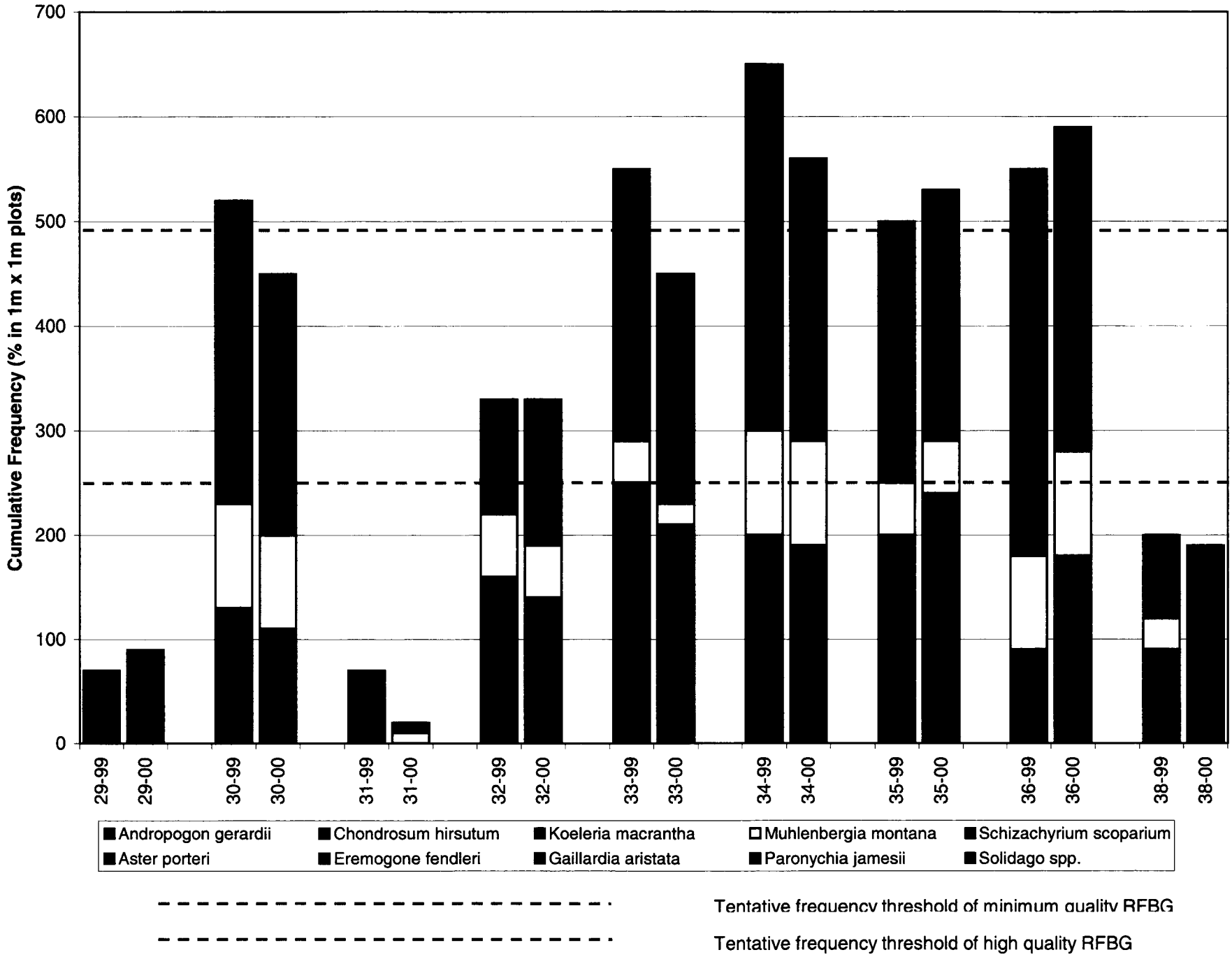
**Figure 2. Cumulative Frequency Data for Selected Species, RFBG Transects, Superior Associates Control Transects, and Tallgrass Monitoring (Areas 3, 6, and 7), Jeff. and Bldr. Cos., CO - 1996-2000**

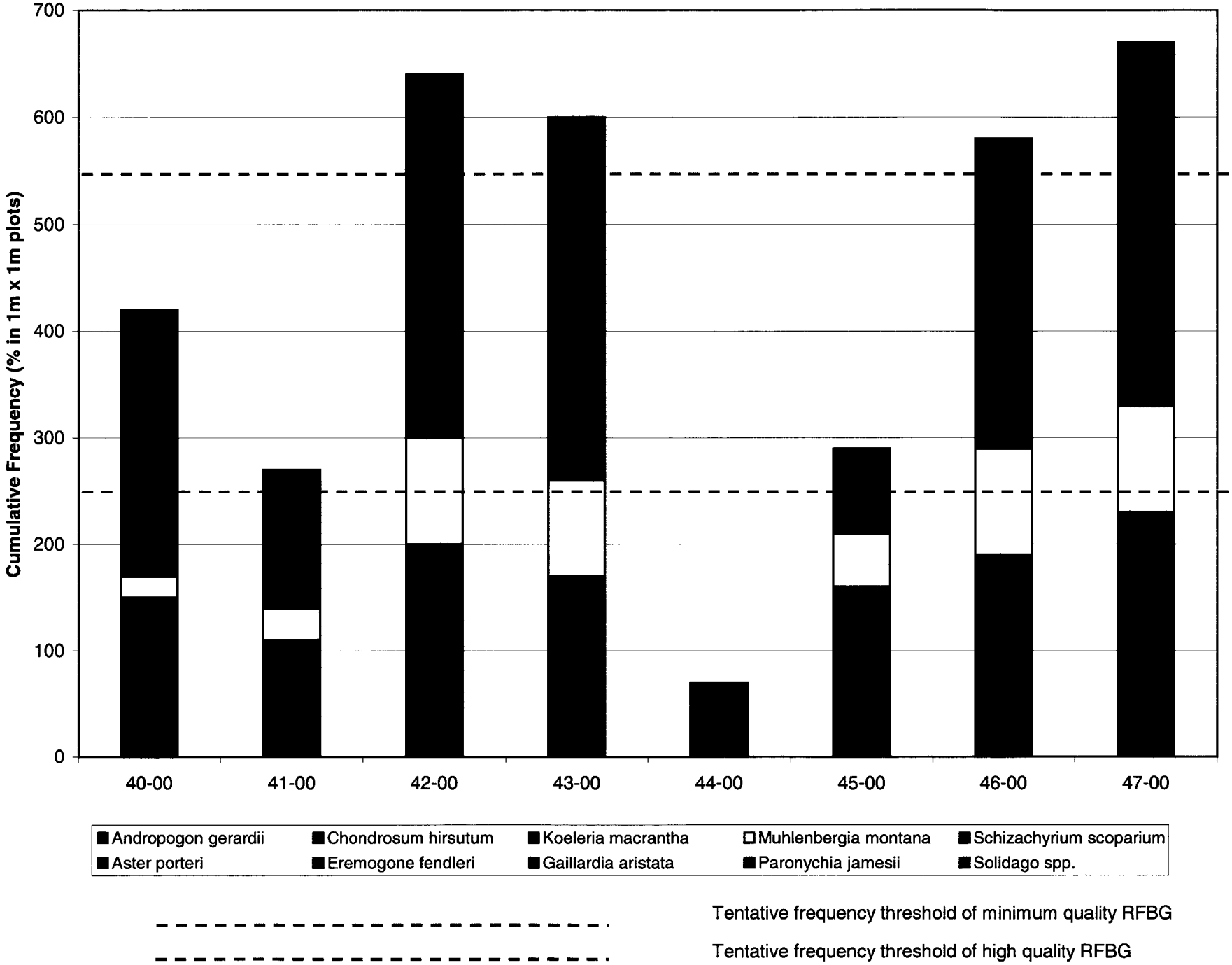


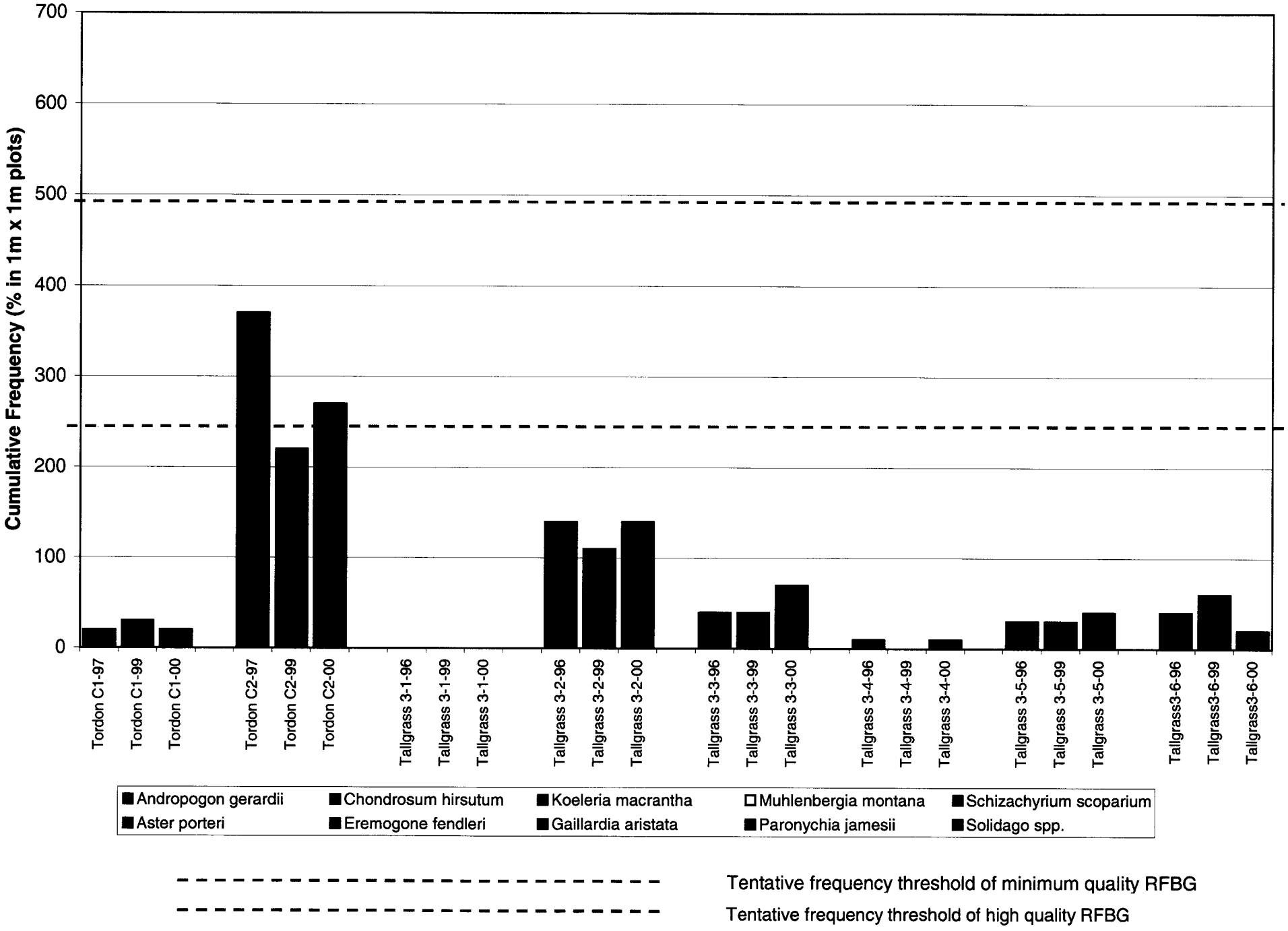

Cumulative Frequency (% in 1m x 1m plots)
700
600
500
400
300
200
100
0
1-96
1-99
1-00
2-96
2-99
2-00
3-96
3-99
3-00
4-96
4-99
4-00
5-96
5-99
5-00
6-96
6-99
6-00
7-96
7-99
7-00
8-96
8-99
8-00
9-96
9-99
9-00
Data not collected
Data not collected
Andropogon gerardii
Chondrosum hirsutum
Koeleria macrantha
Muhlenbergia montana
Schizachyrium scoparium
Aster porteri
Eremogone fendleri
Gaillardia aristata
Paronychia jamesii
Solidago spp.
Tentative frequency threshold of minimum quality RFBG
Tentative frequency threshold of high quality RFBG

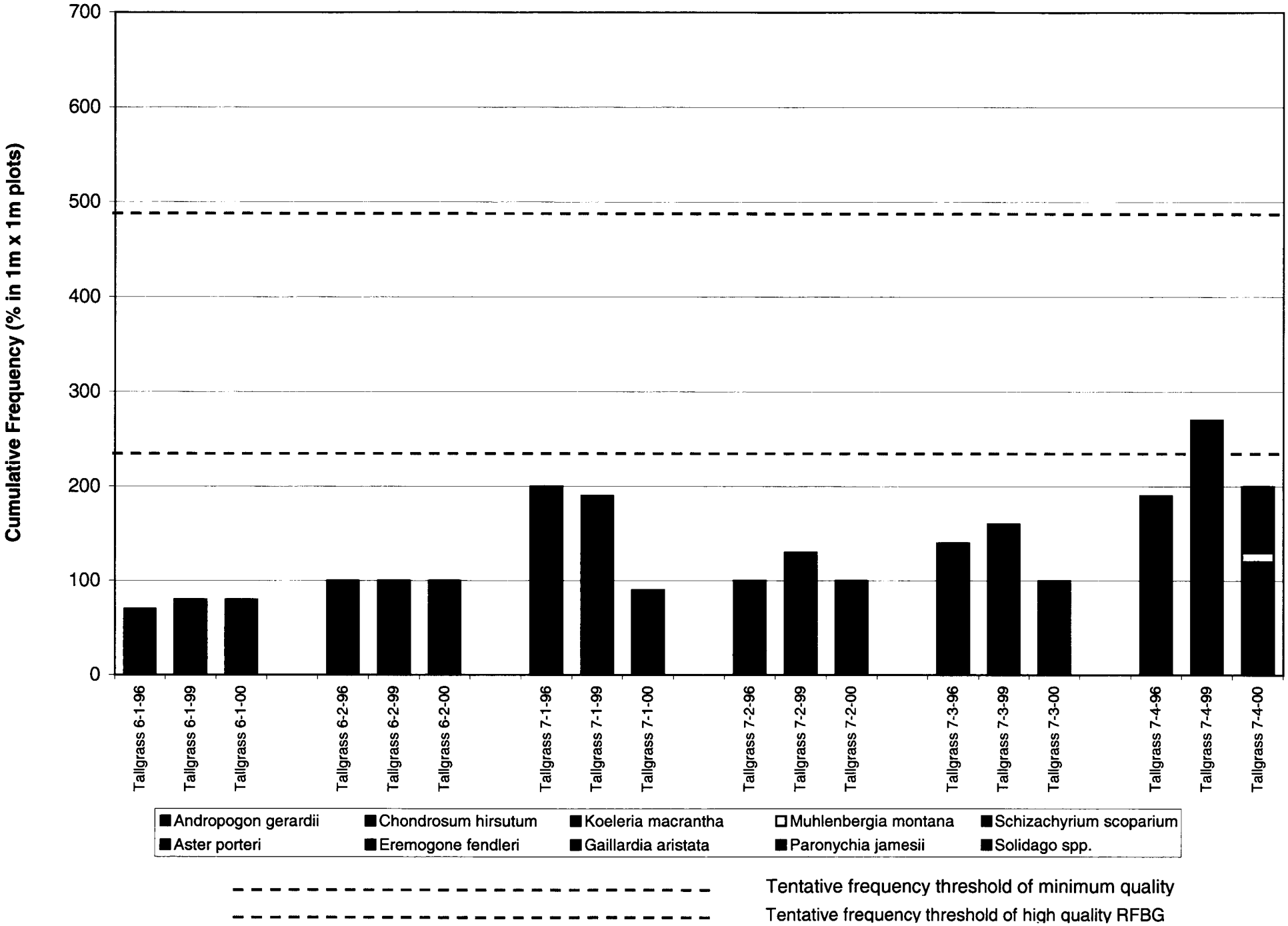

Cumulative Frequency (% in 1m x 1m plots)
700
600
500
400
300
200
100
0
10-96
10-99
10-00
11-96
11-99
11-00
12-96
12-99
12-00
13-96
13-99
13-00
14-96
14-99
14-00
15-96
15-99
15-00
16-96
16-99
16-00
17-96
17-99
17-00
18-96
18-99
18-00
Andropogon gerardii
Chondrosum hirsutum
Koeleria macrantha
Muhlenbergia montana
Schizachyrium scoparium
Aster porteri
Eremogone fendleri
Gaillardia aristata
Paronychia jamesii
Solidago spp.
Tentative frequency threshold of minimum quality RFBG
Tentative frequency threshold of high quality RFBG


Cumulative Frequency (% in 1m x 1m plots)
700
600
500
400
300
200
100
0
19-96
19-99
19-00
20-96
20-99
20-0
21-96
21-99
21-00
22-96
22-99
22-00
23-96
23-99
23-00
24-96
24-99
24-00
25-99
25-00
26-99
26-00
27-99
27-00
28-99
28-00
Andropogon gerardii
Chondrosum hirsutum
Koeleria macrantha
Muhlenbergia montana
Schizachyrium scoparium
Aster porteri
Eremogone fendleri
Gaillardia aristata
Paronychia jamesii
Solidago spp.
Tentative frequency threshold of minimum quality RFBG
Tentative frequency threshold of high quality RFBG


Cumulative Frequency (% in 1m x 1m plots)
700
600
500
400
300
200
100
0
29-99
29-00
30-99
30-00
31-99
31-00
32-99
32-00
33-99
33-00
34-99
34-00
35-99
35-00
36-99
36-00
38-99
38-00
Andropogon gerardii
Chondrosum hirsutum
Koeleria macrantha
Muhlenbergia montana
Schizachyrium scoparium
Aster porteri
Eremogone fendleri
Gaillardia aristata
Paronychia jamesii
Solidago spp.
Tentative frequency threshold of minimum quality RFBG
Tentative frequency threshold of high quality RFBG


Cumulative Frequency (% in 1m x 1m plots)
700
600
500
400
300
200
100
0
40-00
41-00
42-00
43-00
44-00
45-00
46-00
47-00
Andropogon gerardii
Chondrosum hirsutum
Koeleria macrantha
Muhlenbergia montana
Schizachyrium scoparium
Aster porteri
Eremogone fendleri
Gaillardia aristata
Paronychia jamesii
Solidago spp.
Tentative frequency threshold of minimum quality RFBG
Tentative frequency threshold of high quality RFBG


Cumulative Frequency (% in 1m x 1m plots)
700
600
500
400
300
200
100
0
Tordon C1-97
Tordon C1-99
Tordon C1-00
Tordon C2-97
Tordon C2-99
Tordon C2-00
Tallgrass 3-1-96
Tallgrass 3-1-99
Tallgrass 3-1-00
Tallgrass 3-2-96
Tallgrass 3-2-99
Tallgrass 3-2-00
Tallgrass 3-3-96
Tallgrass 3-3-99
Tallgrass 3-3-00
Tallgrass 3-4-96
Tallgrass 3-4-99
Tallgrass 3-4-00
Tallgrass 3-5-96
Tallgrass 3-5-99
Tallgrass 3-5-00
Tallgrass3-6-96
Tallgrass3-6-99
Tallgrass3-6-00
Andropogon gerardii
Chondrosum hirsutum
Koeleria macrantha
Muhlenbergia montana
Schizachyrium scoparium
Aster porteri
Eremogone fendleri
Gaillardia aristata
Paronychia jamesii
Solidago spp.
Tentative frequency threshold of minimum quality RFBG
Tentative frequency threshold of high quality RFBG


Cumulative Frequency (% in 1m x 1m plots)
700
600
500
400
300
200
100
0
Tallgrass 6-1-96
Tallgrass 6-1-99
Tallgrass 6-1-00
Tallgrass 6-2-96
Tallgrass 6-2-99
Tallgrass 6-2-00
Tallgrass 7-1-96
Tallgrass 7-1-99
Tallgrass 7-1-00
Tallgrass 7-2-96
Tallgrass 7-2-99
Tallgrass 7-2-00
Tallgrass 7-3-96
Tallgrass 7-3-99
Tallgrass 7-3-00
Tallgrass 7-4-96
Tallgrass 7-4-99
Tallgrass 7-4-00
Andropogon gerardii
Chondrosum hirsutum
Koeleria macrantha
Muhlenbergia montana
Schizachyrium scoparium
Aster porteri
Eremogone fendleri
Gaillardia aristata
Paronychia jamesii
Solidago spp.
Tentative frequency threshold of minimum quality
Tentative frequency threshold of high quality RFBG

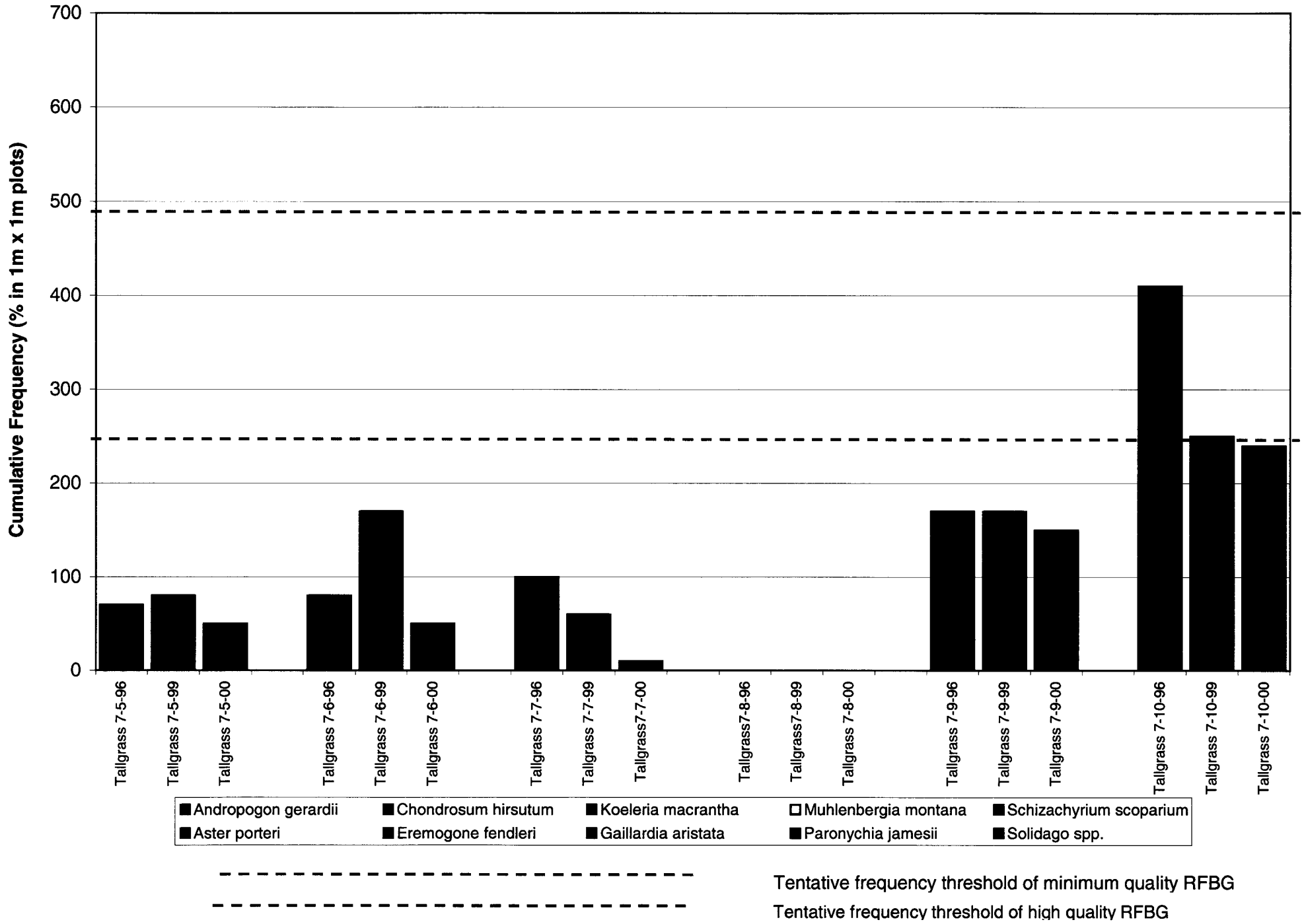
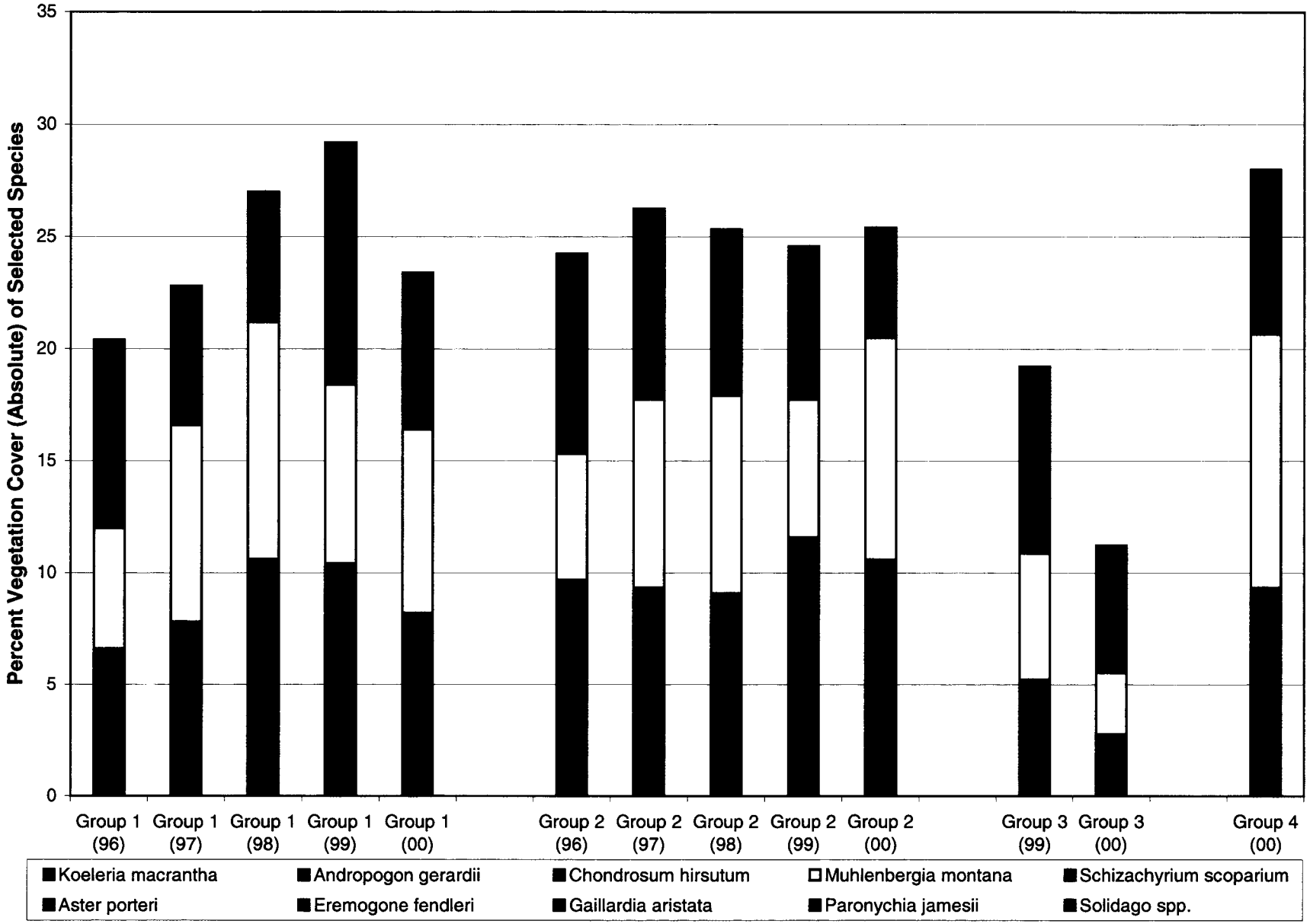
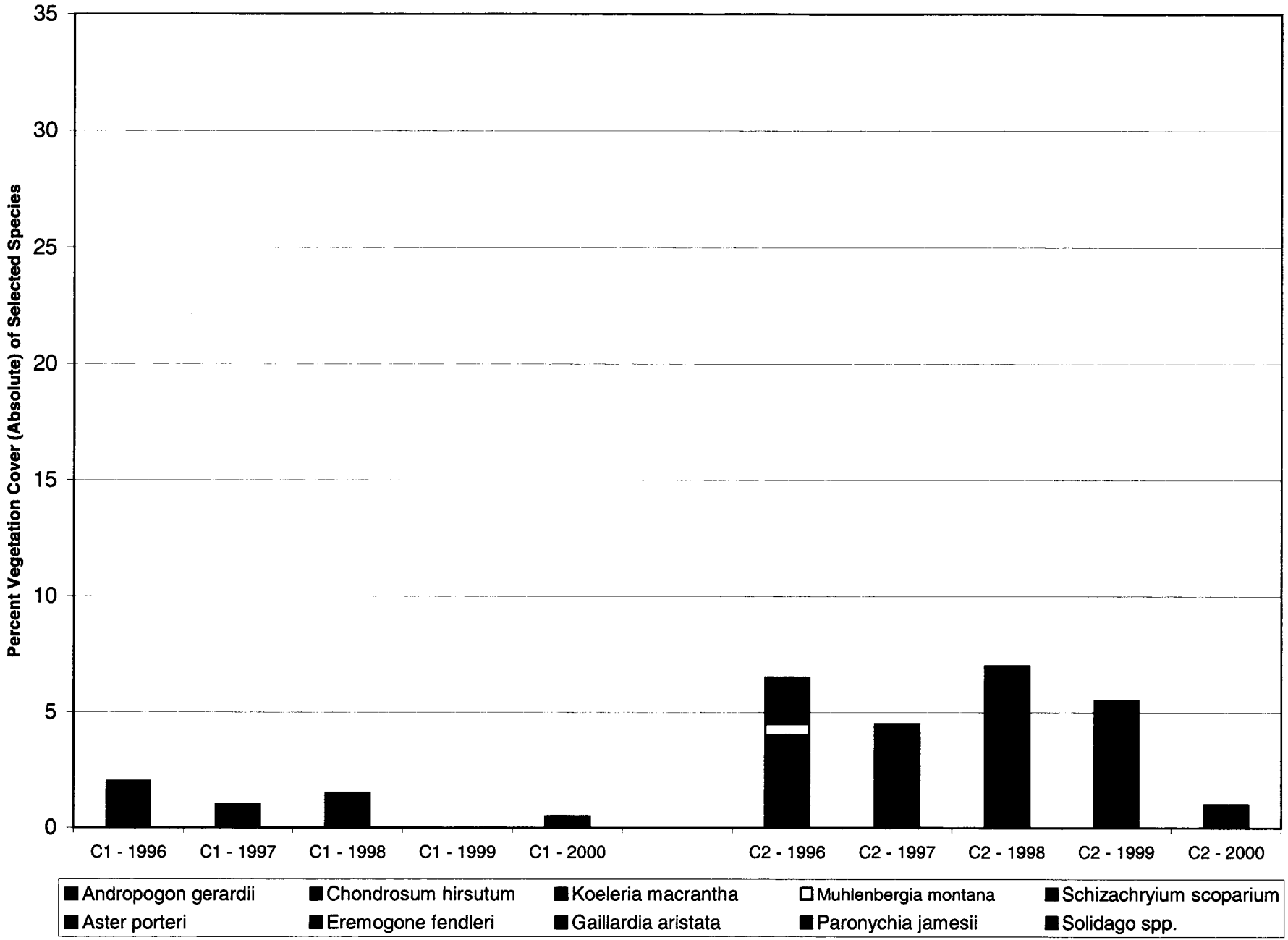

Cumulative Frequency (% in 1m x 1m plots)
700
600
500
400
300
200
100
0
Tallgrass 7-5-96
Tallgrass 7-5-99
Tallgrass 7-5-00
Tallgrass 7-6-96
Tallgrass 7-6-99
Tallgrass 7-6-00
Tallgrass 7-7-96
Tallgrass 7-7-99
Tallgrass7-7-00
Tallgrass7-8-96
Tallgrass7-8-99
Tallgrass 7-8-00
Tallgrass 7-9-96
Tallgrass 7-9-99
Tallgrass 7-9-00
Tallgrass 7-10-96
Tallgrass 7-10-99
Tallgrass 7-10-00
Andropogon gerardii
Chondrosum hirsutum
Koeleria macrantha
Muhlenbergia montana
Schizachyrium scoparium
Aster porteri
Eremogone fendleri
Gaillardia aristata
Paronychia jamesii
Solidago spp.
Tentative frequency threshold of minimum quality RFBG
Tentative frequency threshold of high quality RFBG

**Figure 3. Absolute Cover of Selected Species, RFBG transect Groups, Superior Associates Control Transects, Tallgrass Monitoring (Areas 3, 6, and 7) Jeff. and Bldr. Cos., CO - 1996-2000**




Group 1=Transects 1-5
Group 2=Transects B2, CC1, 1-5, 10, 11, 21, 22, 23

Group 3=Transects 25-28, 30, 32-35 (1999)
Transects 25-28, 30, 32-35, 40-43 (2000)
Group 4=Transects 45-47 (2000 only)


Percent Vegetation Cover (Absolute) of Selected Species
35
30
25
20
15
10
5
0
C1 - 1996
C1 - 1997
C1 - 1998
C1 - 1999
C1 - 2000
C2 - 1996
C2 - 1997
C2 - 1998
C2 - 1999
C2 - 2000
Andropogon gerardii
Chondrosum hirsutum
Koeleria macrantha
Muhlenbergia montana
Schizachryium scoparium
Aster porteri
Eremogone fendleri
Gaillardia aristata
Paronychia jamesii
Solidago spp.

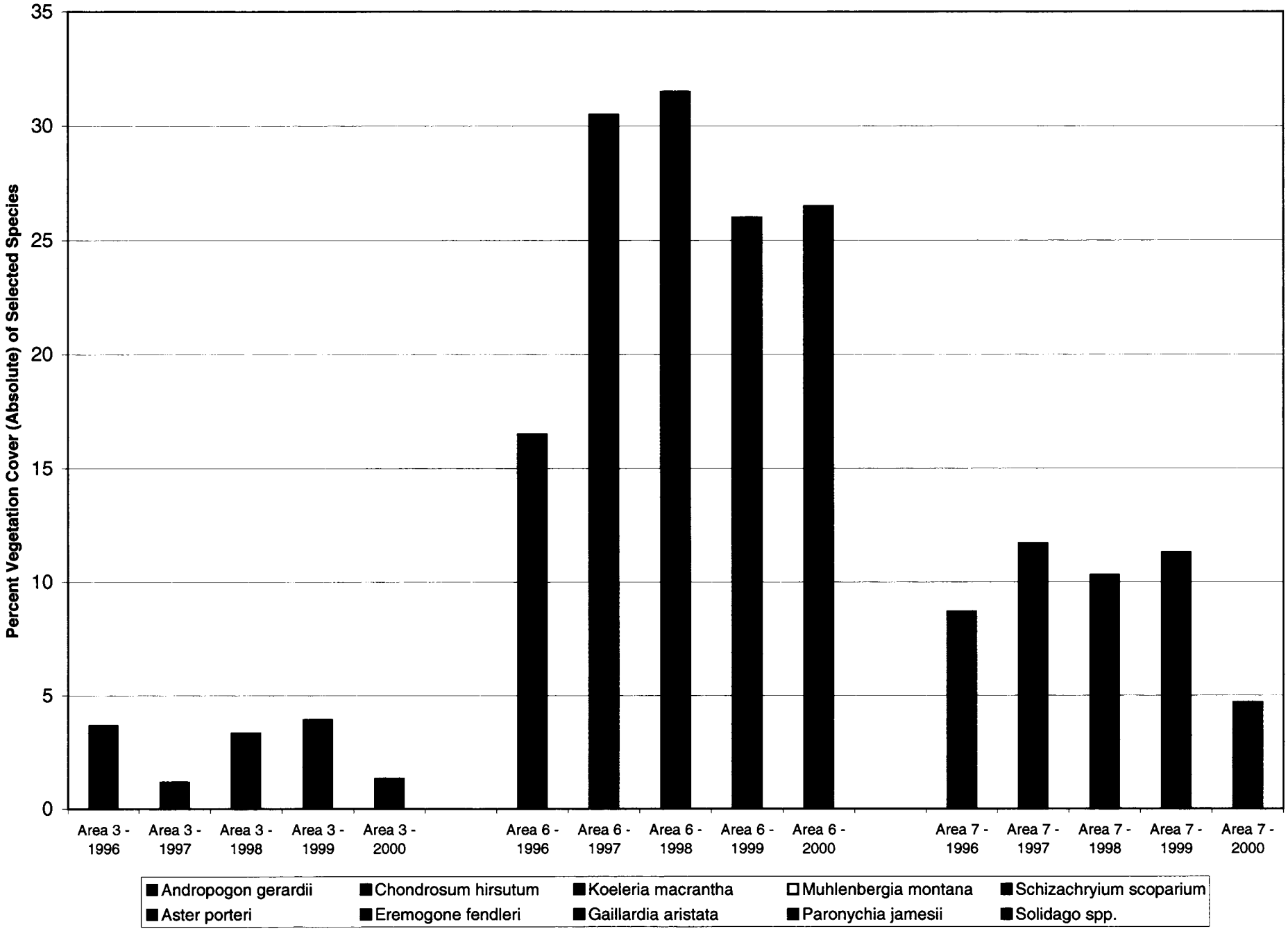

Percent Vegetation Cover (Absolute) of Selected Species
35
30
25
20
15
10
5
0
Area 3 - 1996
Area 3 - 1997
Area 3 - 1998
Area 3 - 1999
Area 3 - 2000
Area 6 - 1996
Area 6 - 1997
Area 6 - 1998
Area 6 - 1999
Area 6 - 2000
Area 7 - 1996
Area 7 - 1997
Area 7 - 1998
Area 7 - 1999
Area 7 - 2000
Andropogon gerardii
Chondrosum hirsutum
Koeleria macrantha
Muhlenbergia montana
Schizachryium scoparium
Aster porteri
Eremogone fendleri
Gaillardia aristata
Paronychia jamesii
Solidago spp.

**Figure 4. Species Density by Lifeform by Transect and Year of Sample - All Transects, Fall Sample Dates, Rocky Flats Bluestem Grassland Study, Jeff. and Bldr. Co., - CO, Fall Cover 1996-2000**

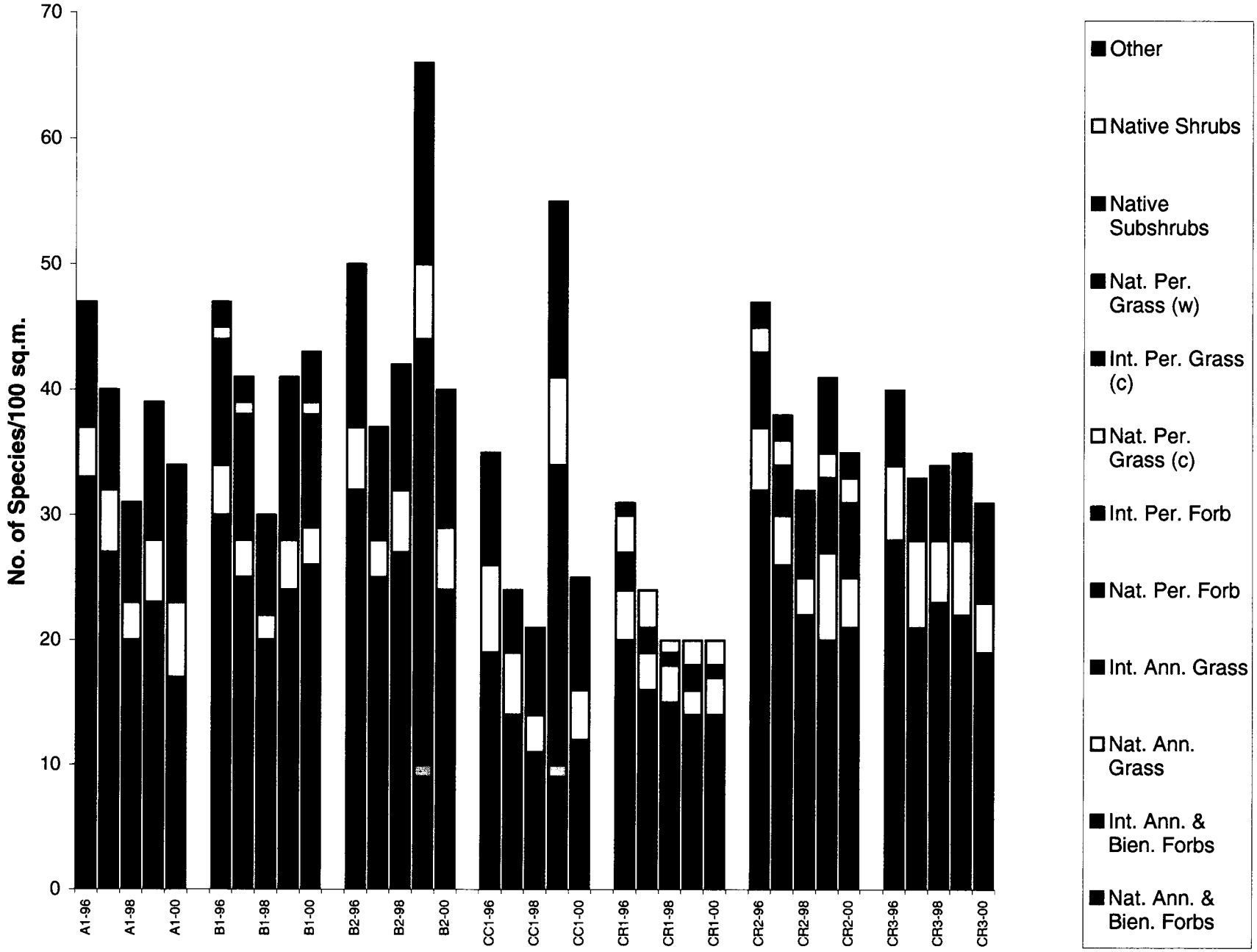


**Figure 4. Species Density by Lifeform by Transect and Year of Sample - All Transects, Fall Sample Dates, Rocky Flats Bluestem Grassland Study, Jeff. and Bldr. Co., - CO, Fall Cover 1996-2000**

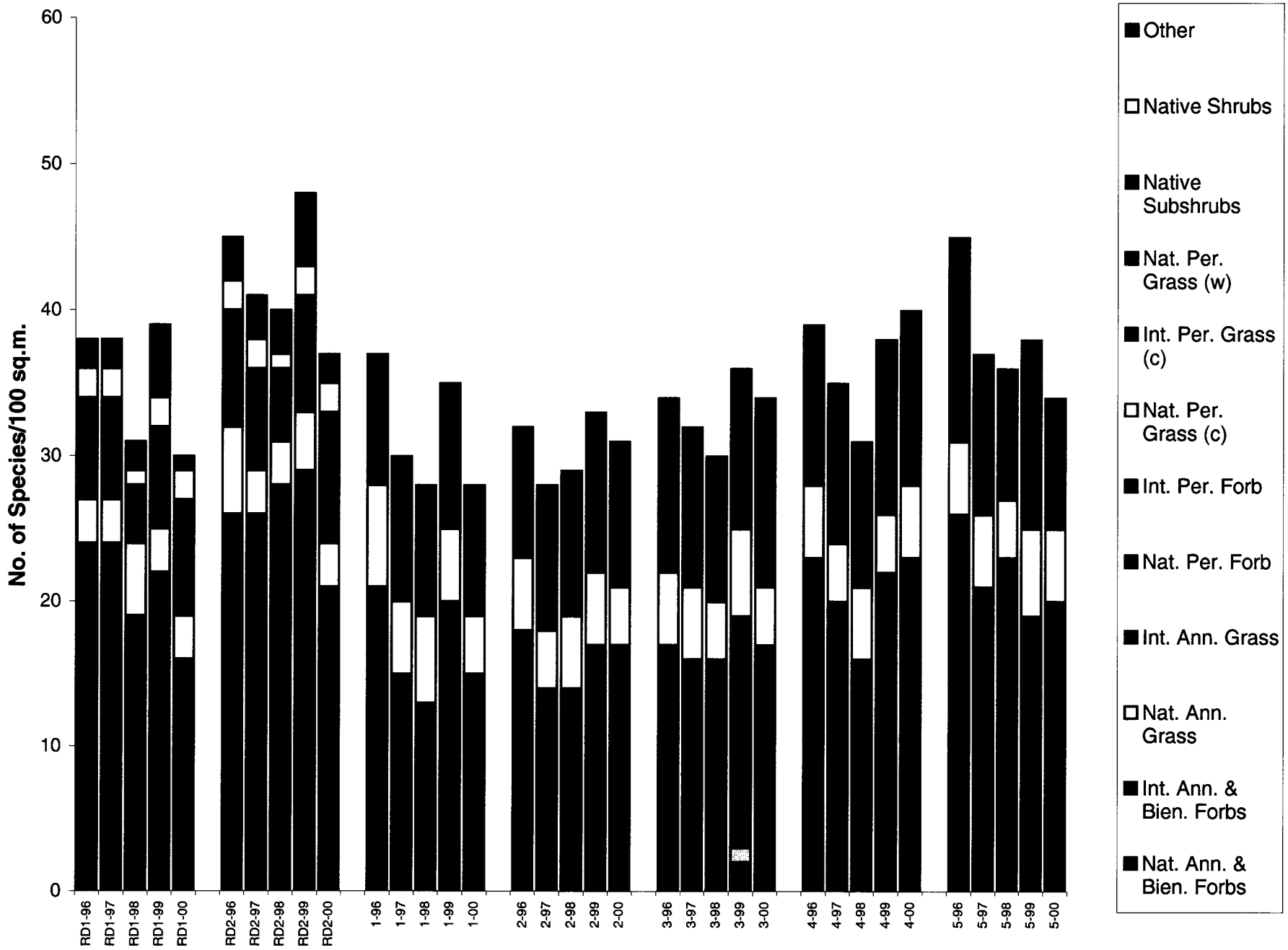


**Figure 4. Species Density by Lifeform by Transect and Year of Sample - All Transects, Fall Sample Dates, Rocky Flats Bluestem Grassland Study, Jeff. and Bldr. Co., - CO, Fall Cover 1996-2000**

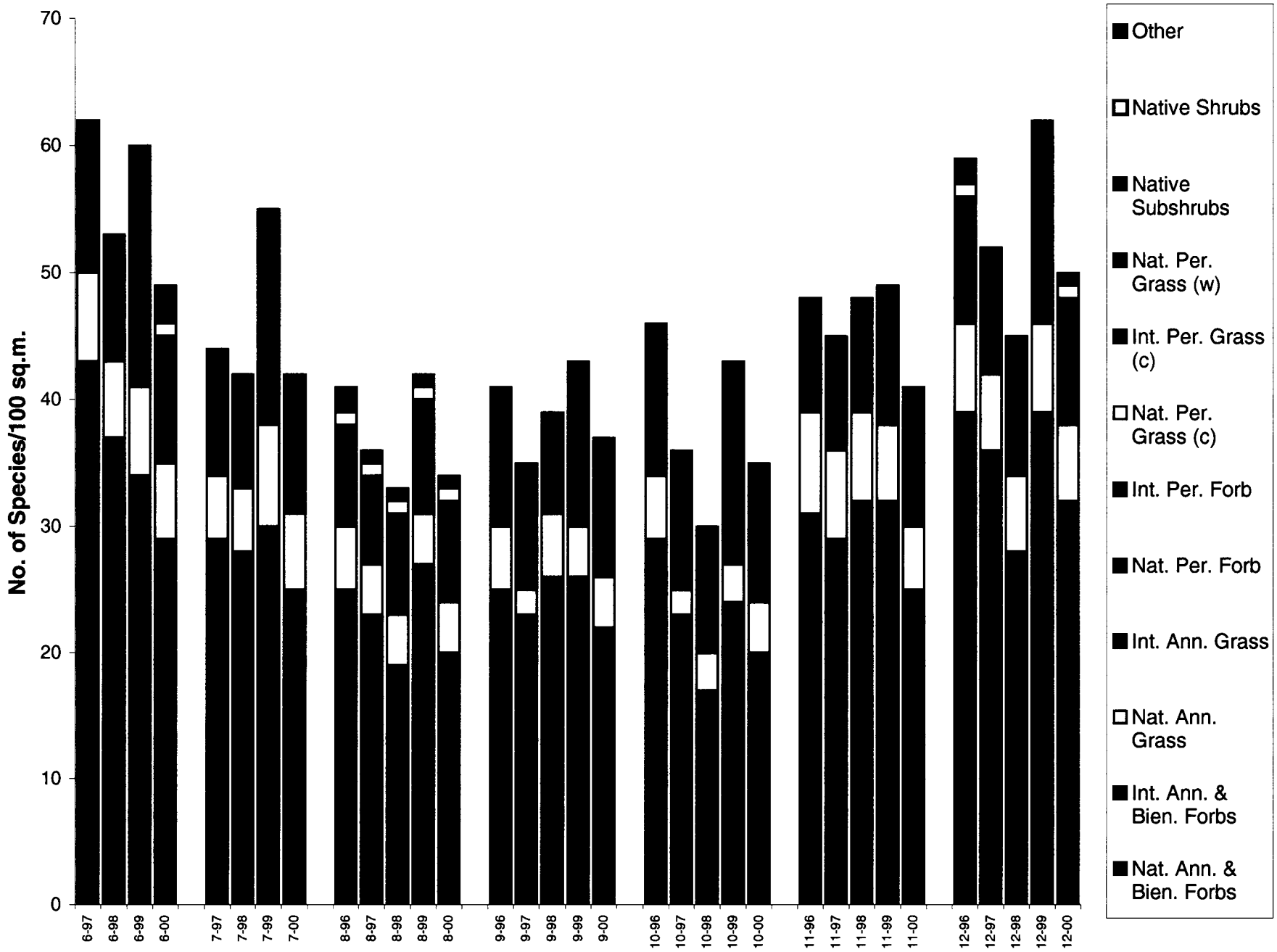


**Figure 4. Species Density by Lifeform by Transect and Year of Sample - All Transects, Fall Sample Dates, Rocky Flats Bluestem Grassland Study, Jeff. and Bldr. Co., - CO, Fall Cover 1996-2000**

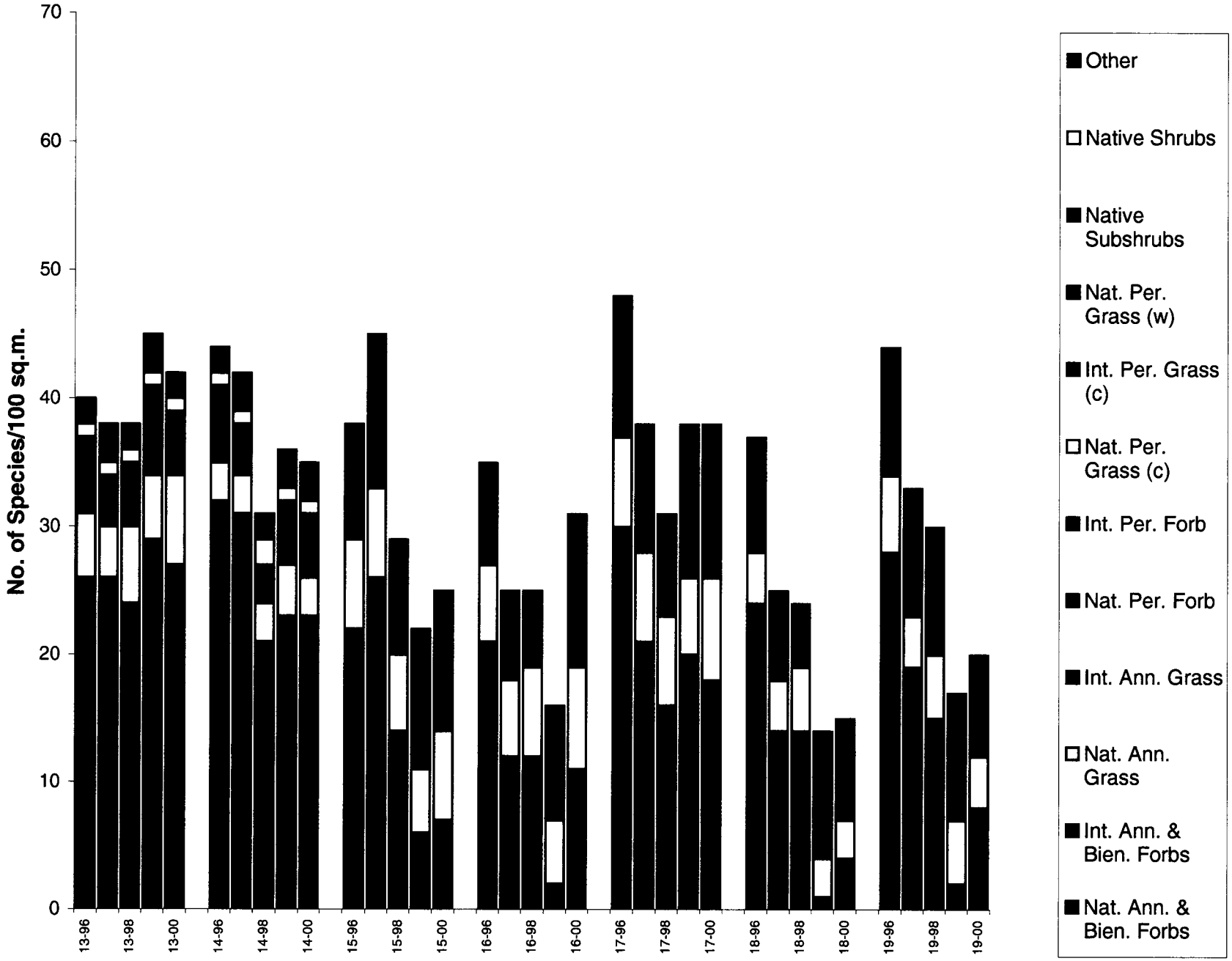


**Figure 4. Species Density by Lifeform by Transect and Year of Sample - All Transects, Fall Sample Dates, Rocky Flats Bluestem Grassland Study, Jeff. and Bldr. Co., - CO, Fall Cover 1996-2000**

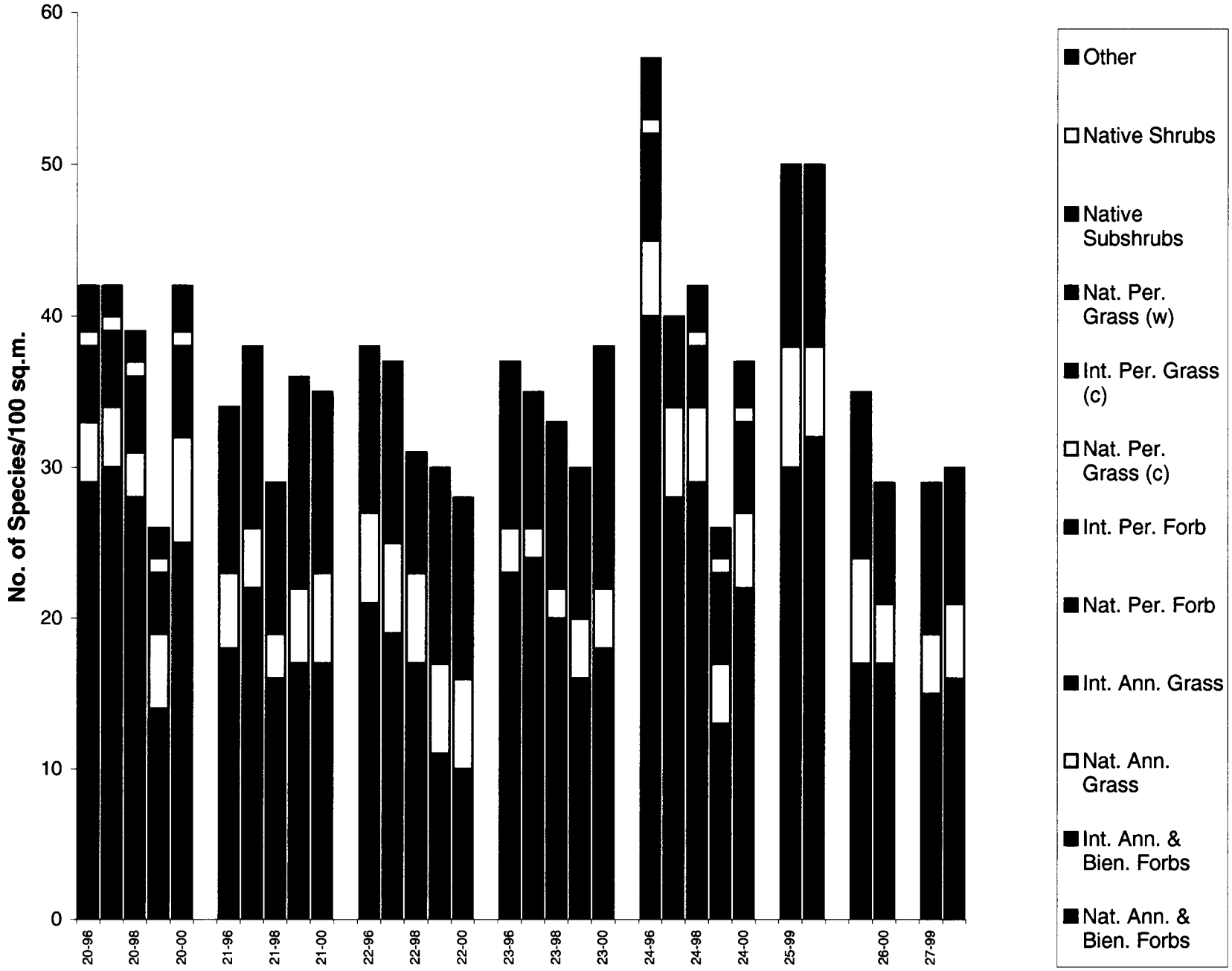


**Figure 4. Species Density by Lifeform by Transect and Year of Sample - All Transects, Fall Sample Dates, Rocky Flats Bluestem Grassland Study, Jeff. and Bldr. Co., - CO, Fall Cover 1996-2000**

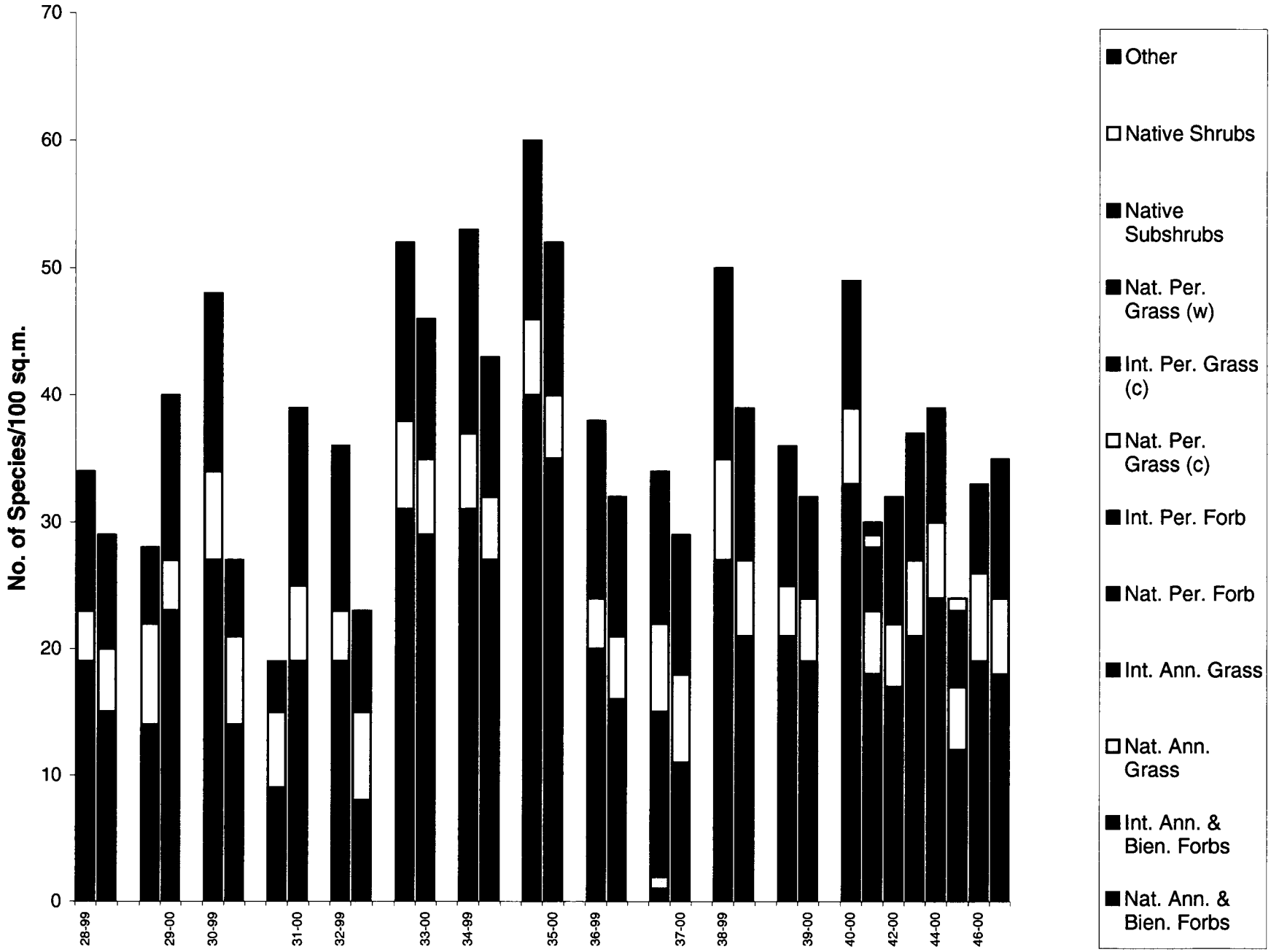
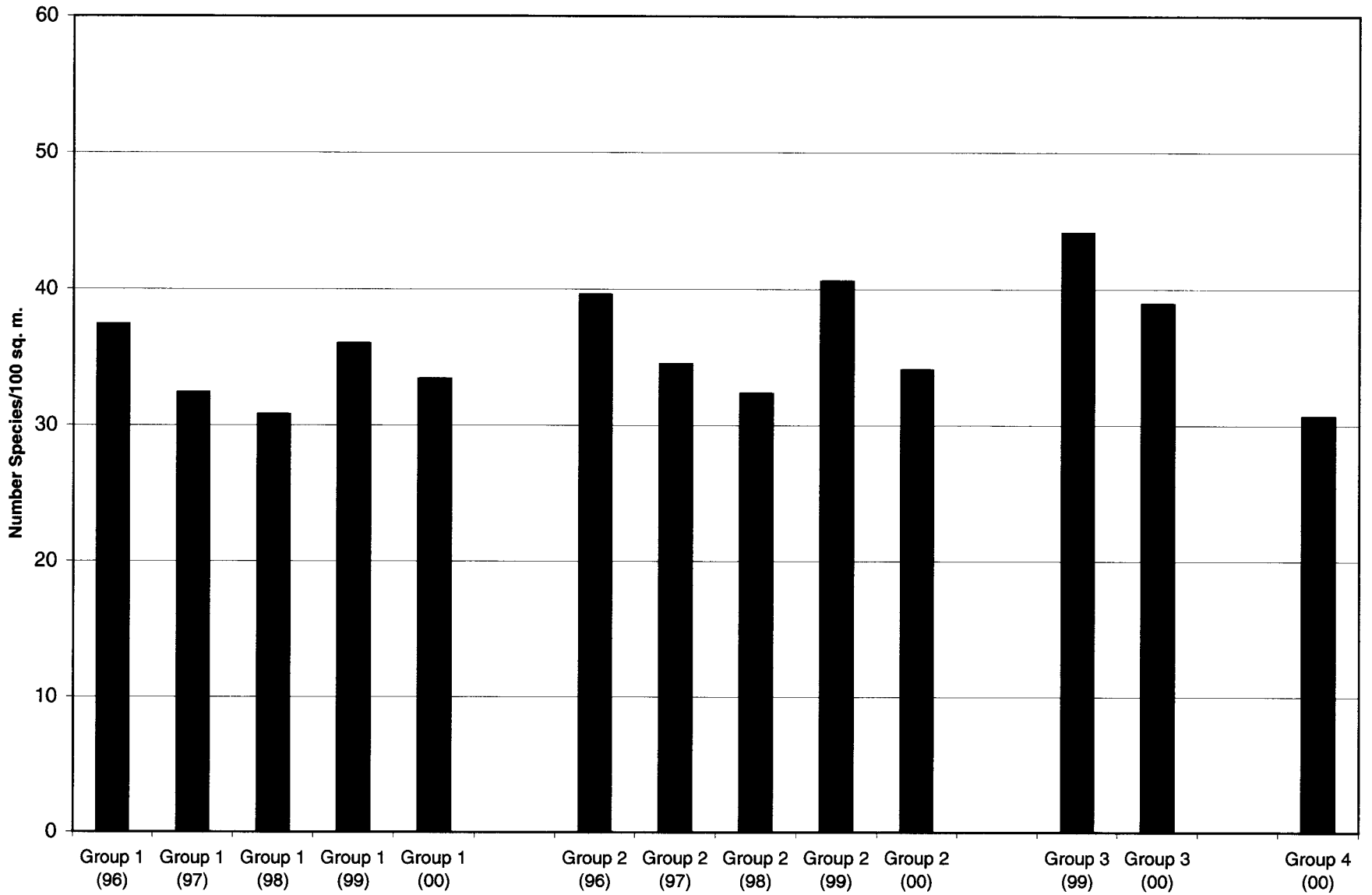
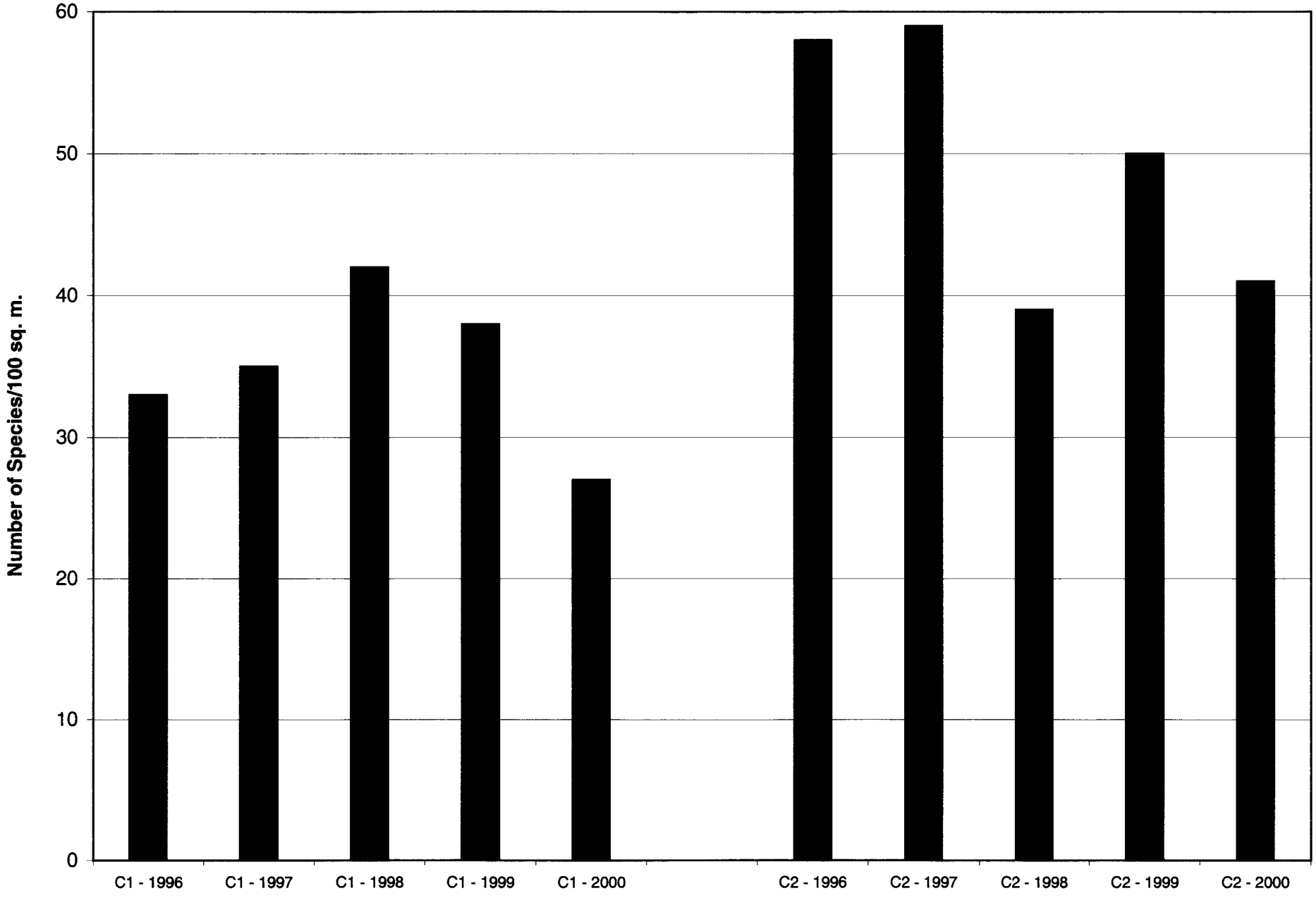


**Figure 5. Species Density, RFBG Transect Groups, Superior Associates Control Transects, Tallgrass Monitoring Transects (Areas 3, 6, and 7), Jeff. and Bldr. Cos., CO - 1996-2000**




Group 1=Transects 1-5
Group 2=Transects B2, CC1, 1-5, 10, 11, 21, 22, 23

Group 3=Transects 25-28, 30, 32-35 (1999)
Transects 25-28, 30, 32-35, 40-43 (2000)
Group 4=Transects 45-47 (2000 only)


Number of Species/100 sq. m.
60
50
40
30
20
10
0
C1 - 1996
C1 - 1997
C1 - 1998
C1 - 1999
C1 - 2000
C2 - 1996
C2 - 1997
C2 - 1998
C2 - 1999
C2 - 2000

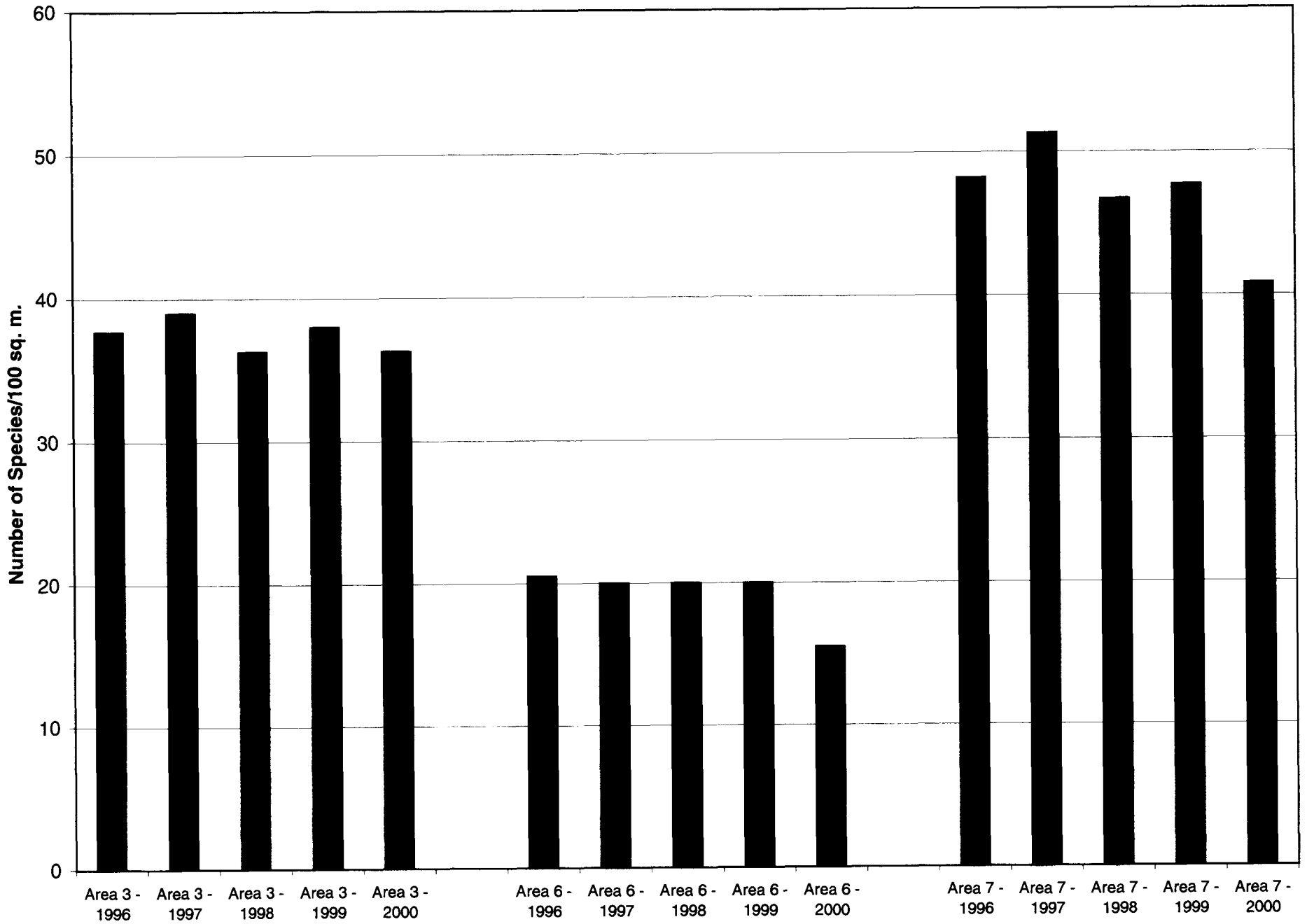
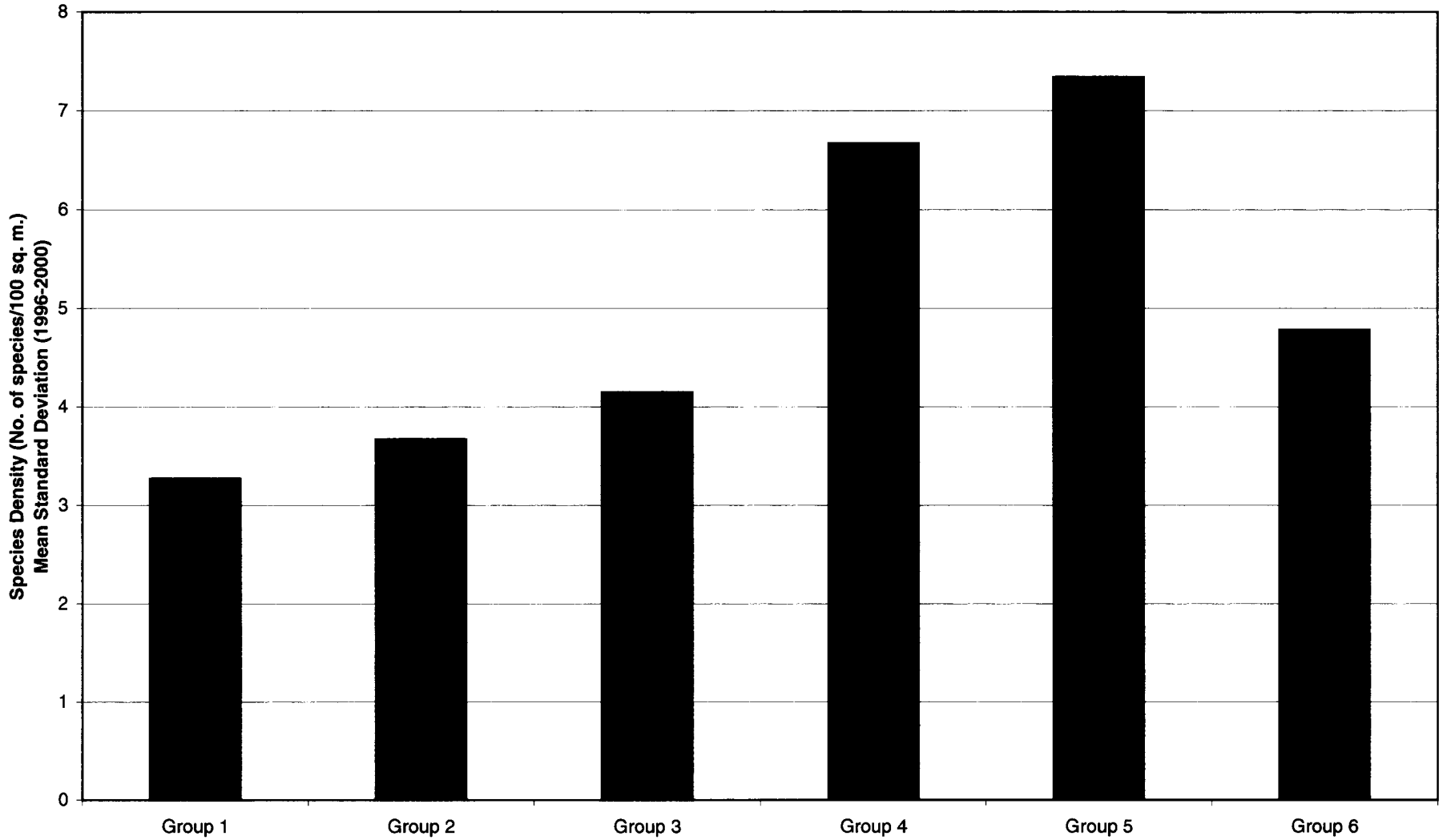

Number of Species/100 sq. m.
60
50
40
30
20
10
0
Area 3 - 1996
Area 3 - 1997
Area 3 - 1998
Area 3 - 1999
Area 3 - 2000
Area 6 - 1996
Area 6 - 1997
Area 6 - 1998
Area 6 - 1999
Area 6 - 2000
Area 7 - 1996
Area 7 - 1997
Area 7 - 1998
Area 7 - 1999
Area 7 - 2000

**Figure 6. Mean Standard Deviation (n-1) for Species Density, RFBG Transect Groups, Superior Associates Control Transects, Tallgrass Monitoring Area 7, Jeff. and Bldr. Cos., CO - 1996-2000**




Group 1 - RFBG Transects 1-5
Group 2 - RFBG Transects 21-23
Group 3 - RFBG Transects 25-28, 30, 32-35
Group 4 - RFBG Transects 13,14,20,24
Group 5 - Superior Associates Transects C1/C2
Group 6 - Tallgrass Natural Area 7 Transects 1-10

Figure 7. Cumulative "Weed" Frequency Data for RFBG Transects, Superior Associates Control Transects, Tallgrass Monitoring (Areas 3, 6, and 7), Jeff. and Bldr. Cos., CO - 1996-2000



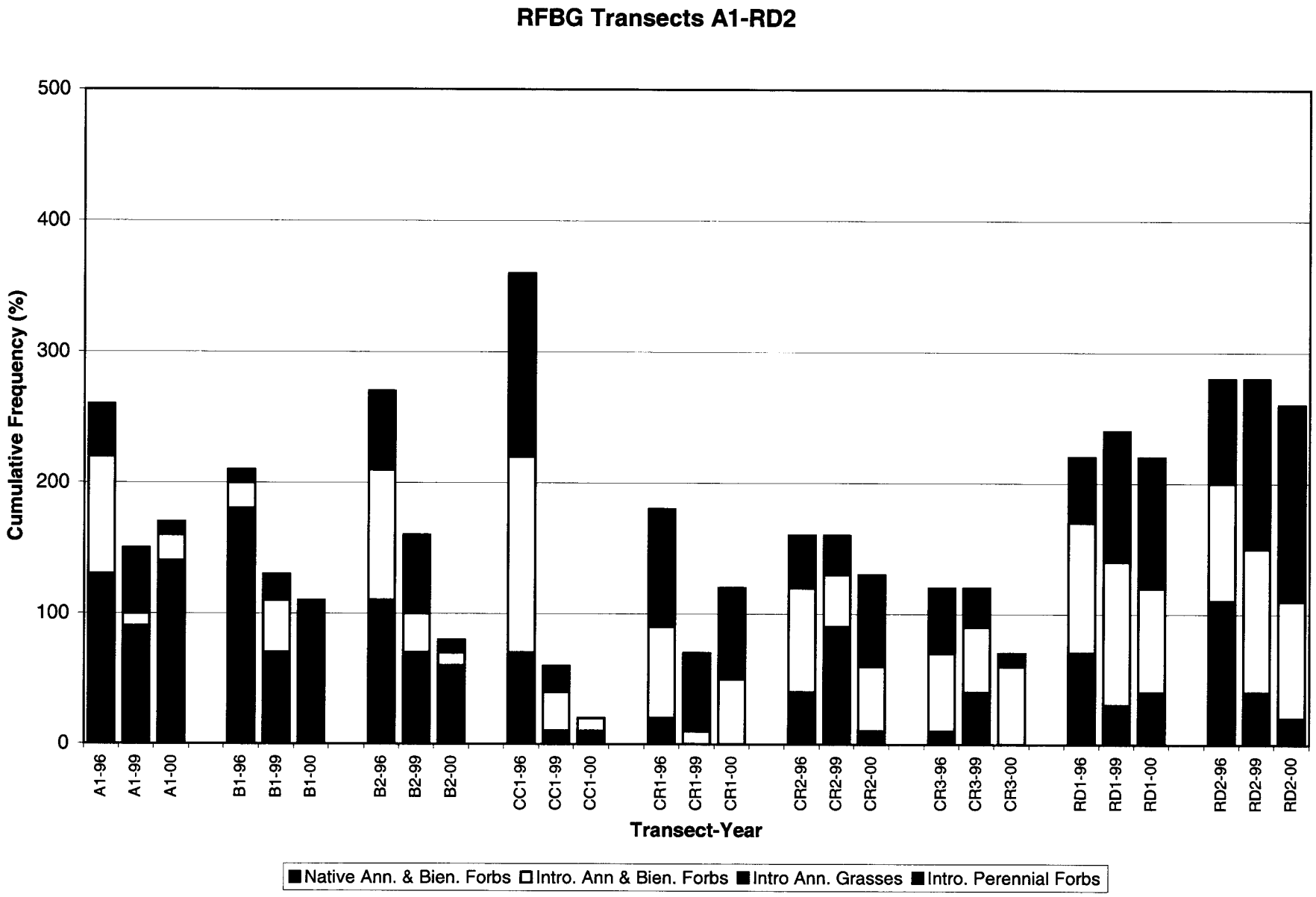


Figure 7. Cumulative "Weed" Frequency Data for RFBG Transects, Superior Associates Control Transects, and Tallgrass Monitoring (Areas 3, 6, and 7), Jeff. and Bldr. Cos., CO - 1996-2000



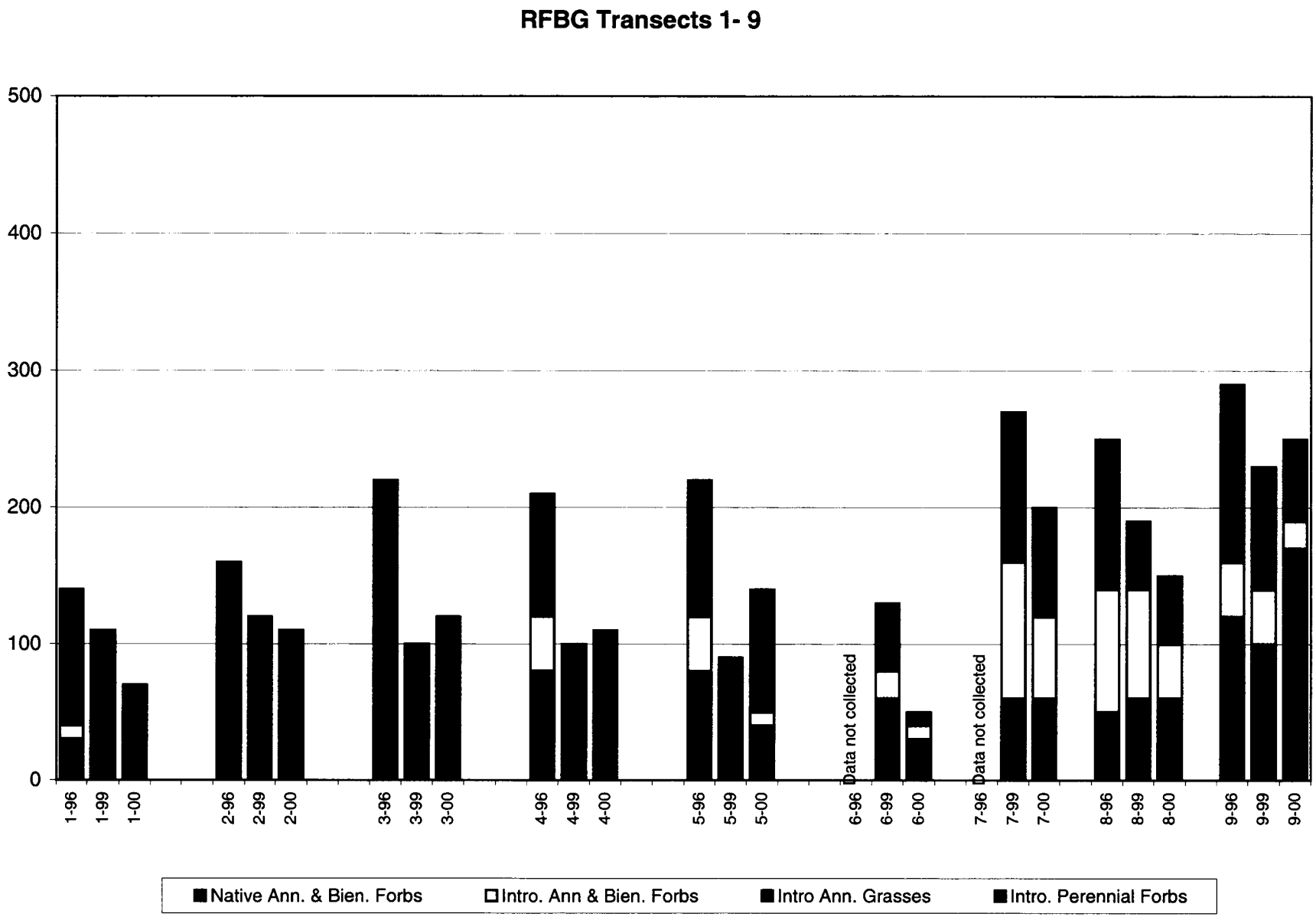


Figure 7. Cumulative "Weed" Frequency Data for RFBG Transects, Superior Associates Control Transects, and Tallgrass Monitoring, (Areas 3, 6, and 7), Jeff. and Bldr. Cos., CO - 1996-2000



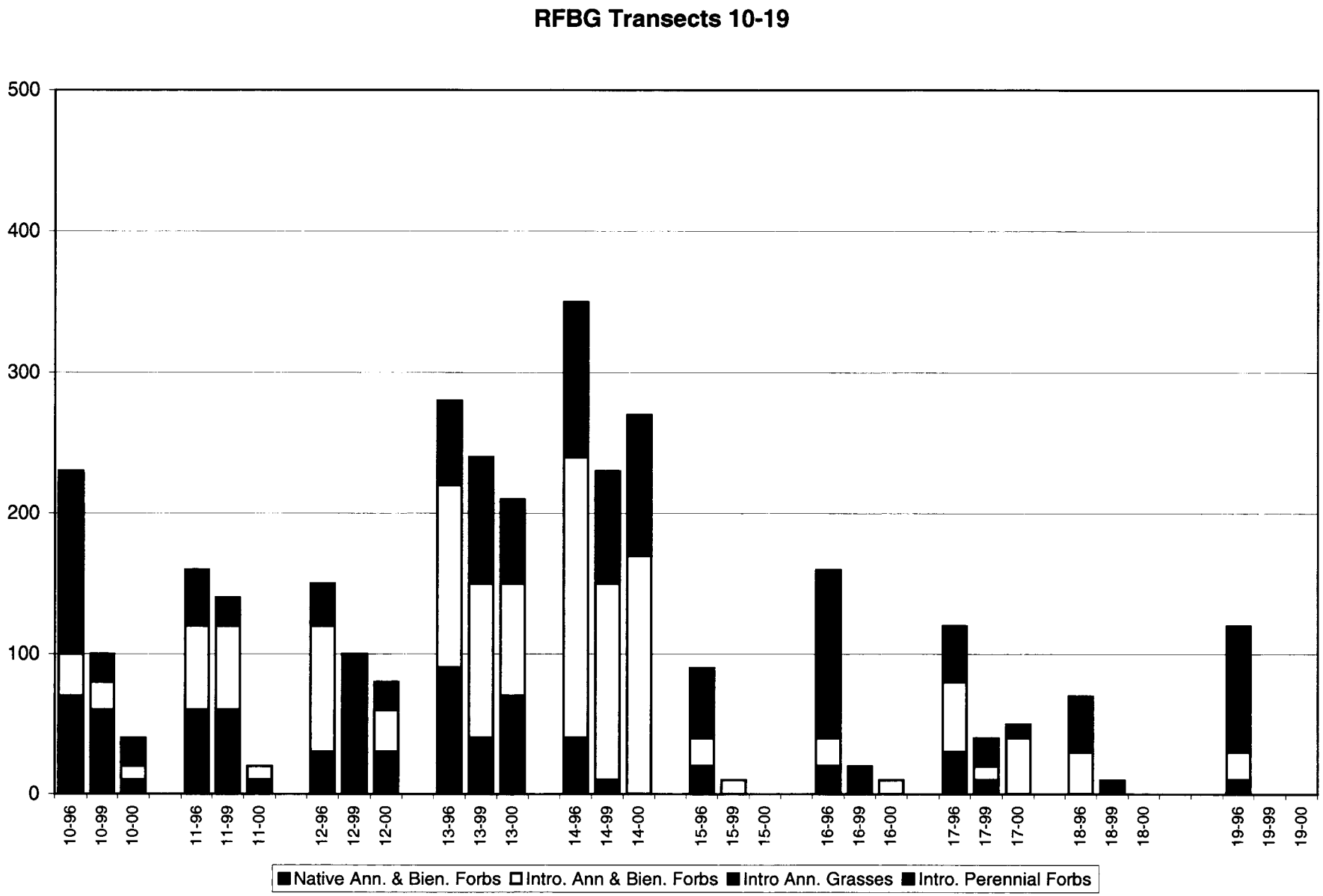


Figure 7. Cumulative "Weed" Frequency Data for RFBG Transects, Superior Associates Control Transects, Tallgrass Monitoring (Areas 3, 6, and 7), Jeff. and Bldr. Cos., CO - 1996-2000



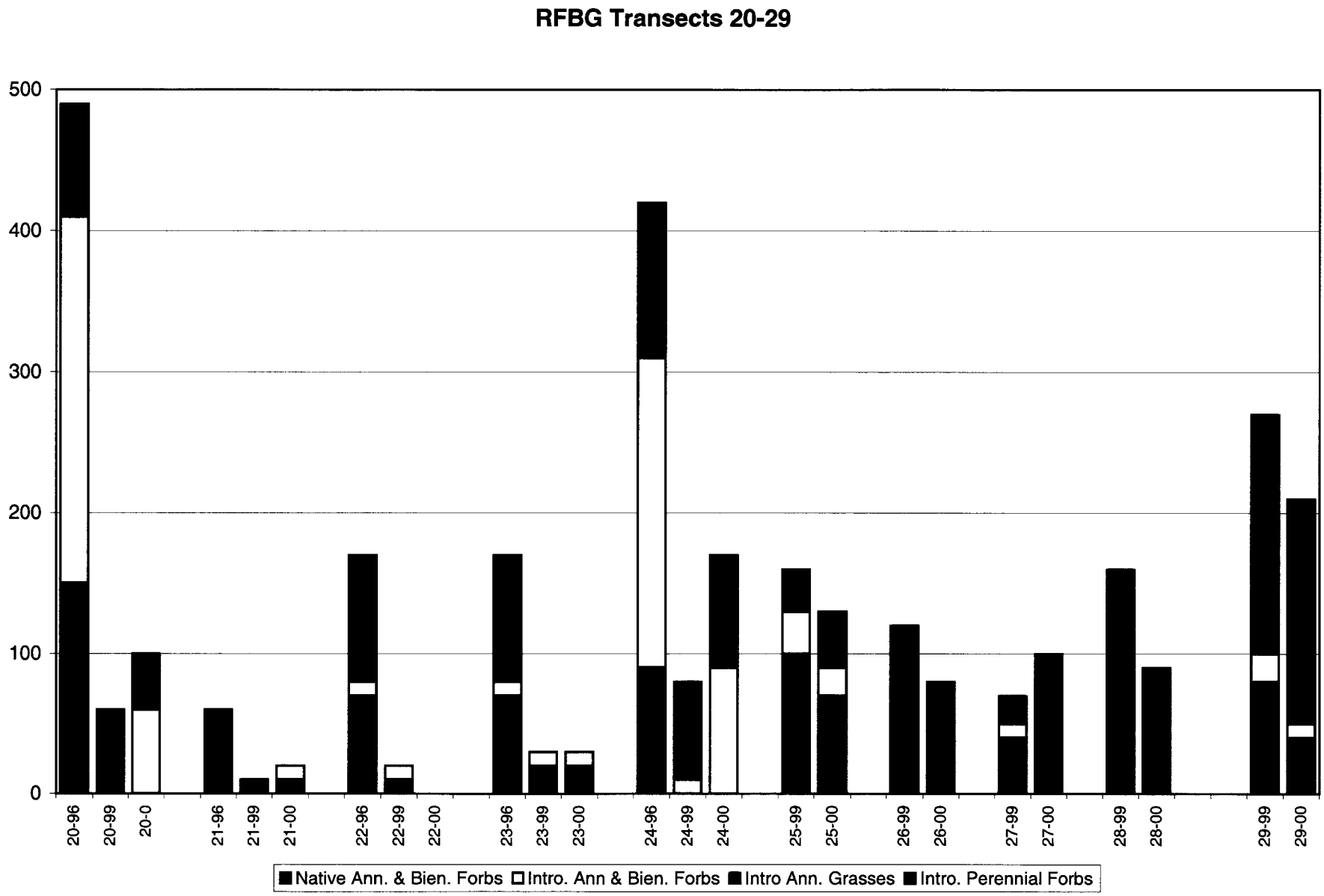


Figure 7. Cumulative "Weed" Frequency Data for RFBG Transects, Superior Associates Control Transects, Tallgrass Monitoring (Areas 3, 6, and 7), Jeff. and Bldr. Cos., CO - 1996-2000



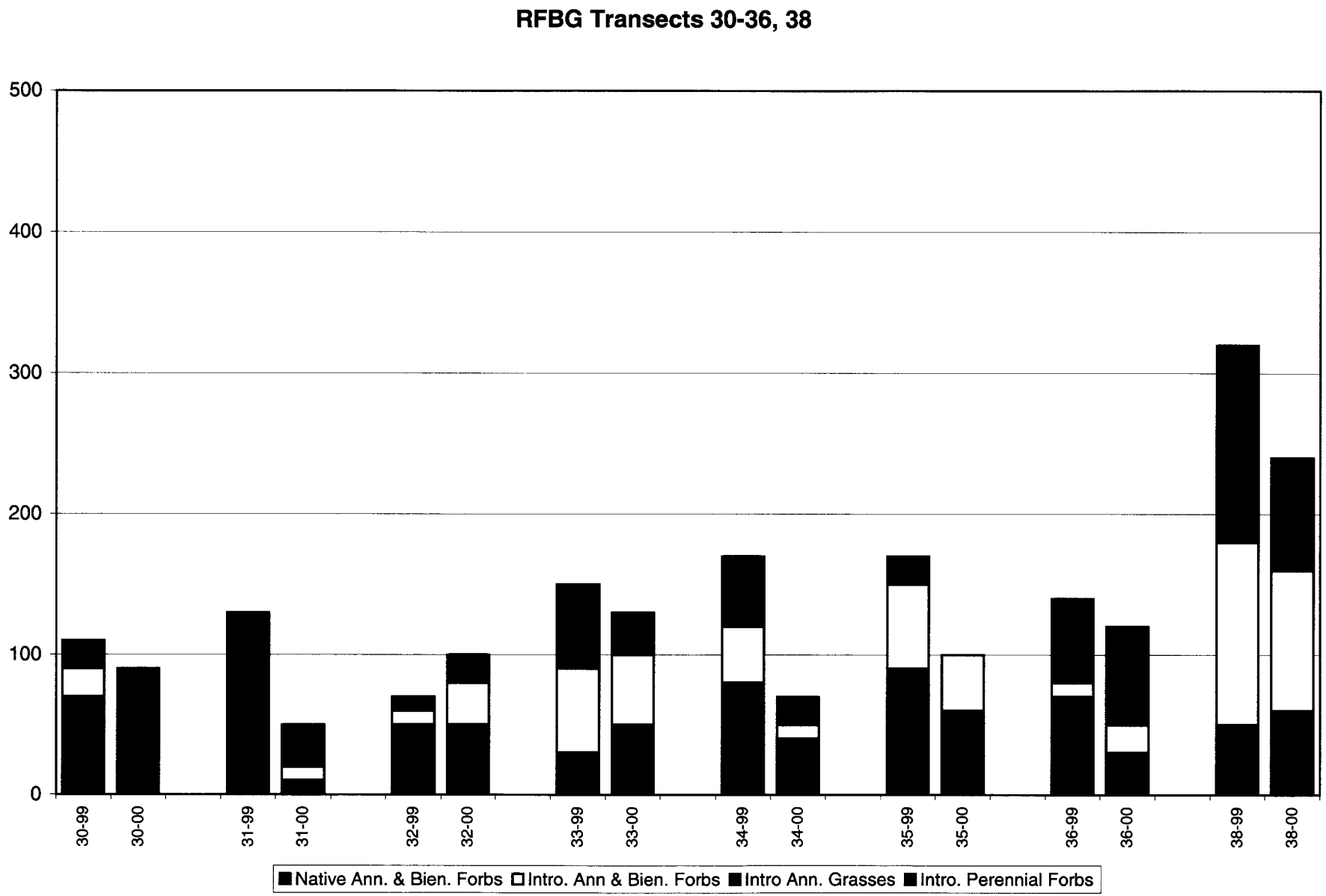


Figure 7. Cumulative "Weed" Frequency Data for RFBG Transects, Superior Associate Control Transects, Tallgrass Monitoring (Areas 3, 6, and 7), Jeff. and Bldr. Cos., CO - 1996-2000



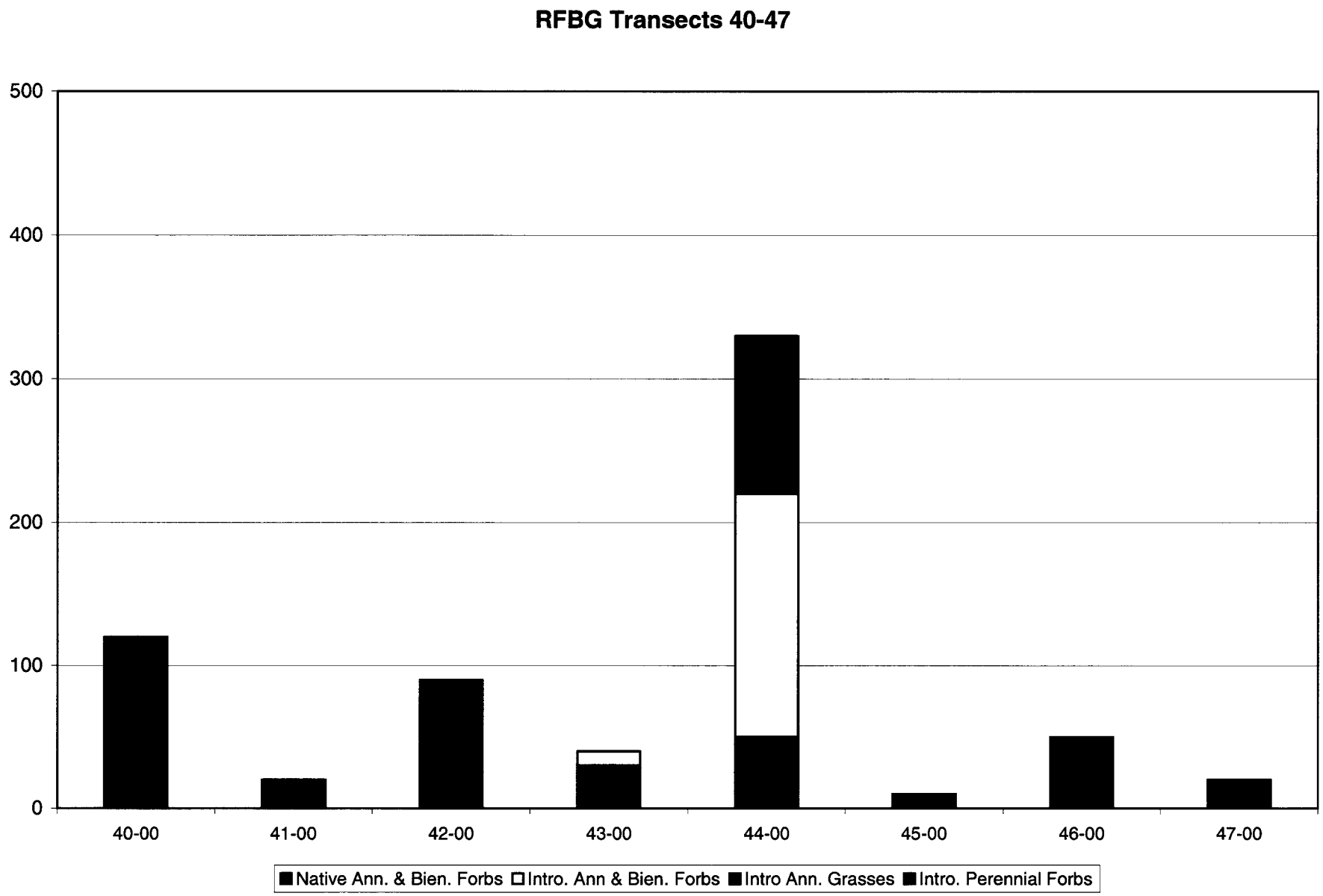


Figure 7. Cumulative "Weed" Frequency Data for RFBG Transects, Superior Associates Control Transects, and Tallgrass Monitoring (Areas 3, 6, and 7), Jeff. and Bldr. Cos., CO - 1996-2000



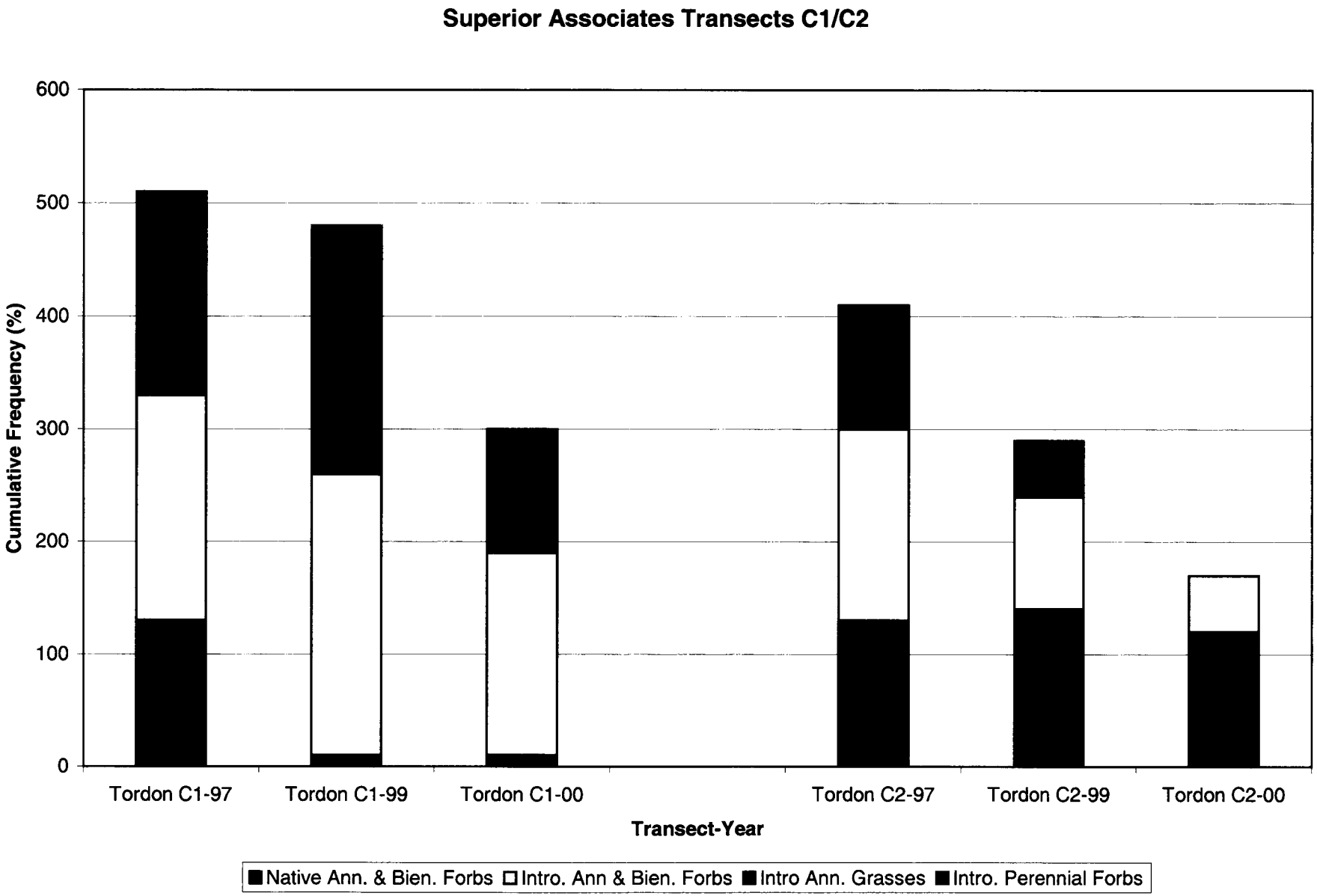


Figure 7. Cumulative "Weed" Frequency for RFBG Transects, Superior Associate Control Transects, Tallgrass Monitoring (Areas 3, 6, and 7), Jeff. and Bldr. Cos., CO - 1996-2000



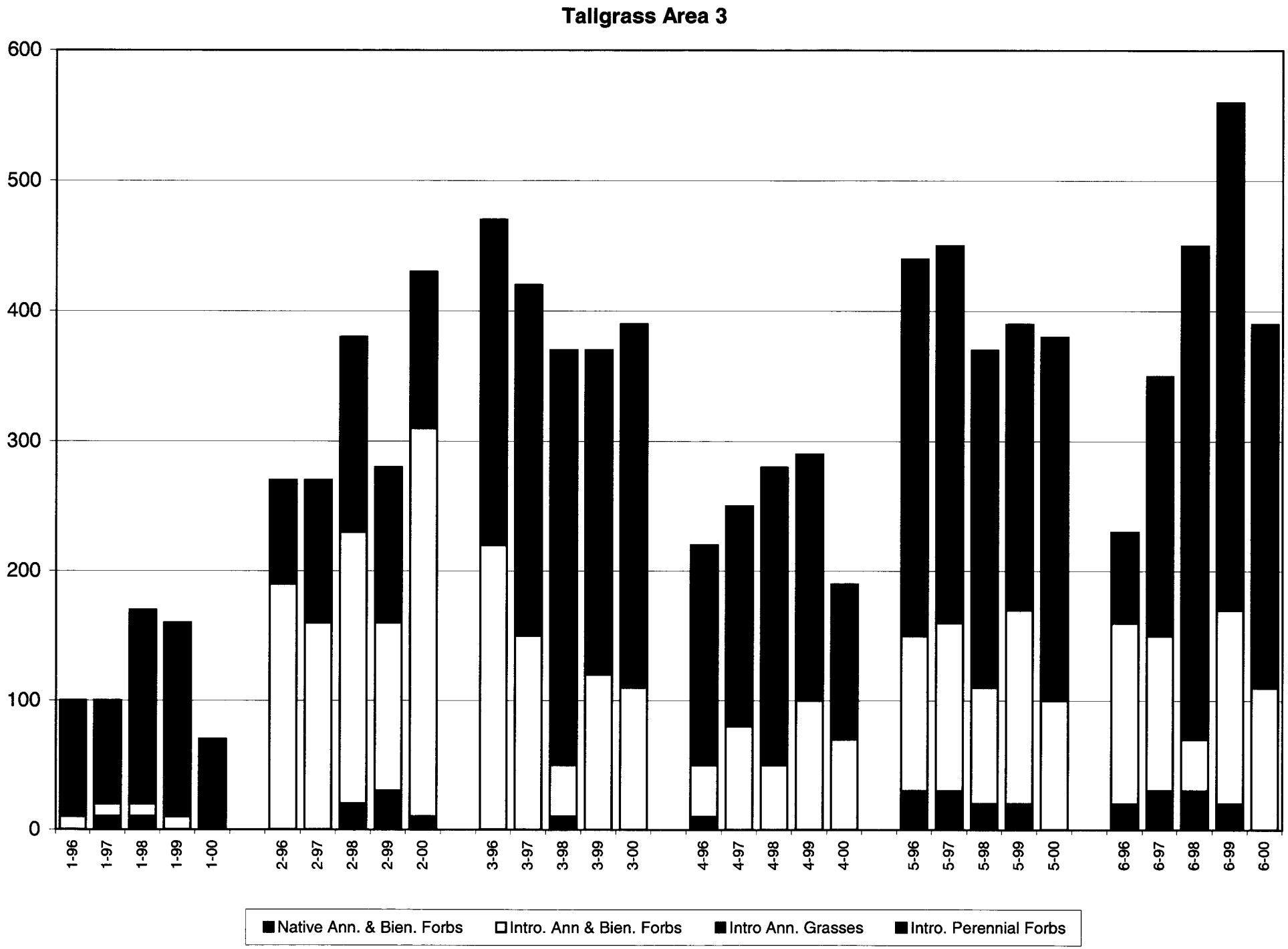


Figure 7. Cumulative "Weed" Frequency Data for RFBG Transects, Superior Associates Control Transects, Tallgrass Monitoring (Areas 3, 6, and 7), Jeff. and Bldr. Cos., CO - 1996-2000



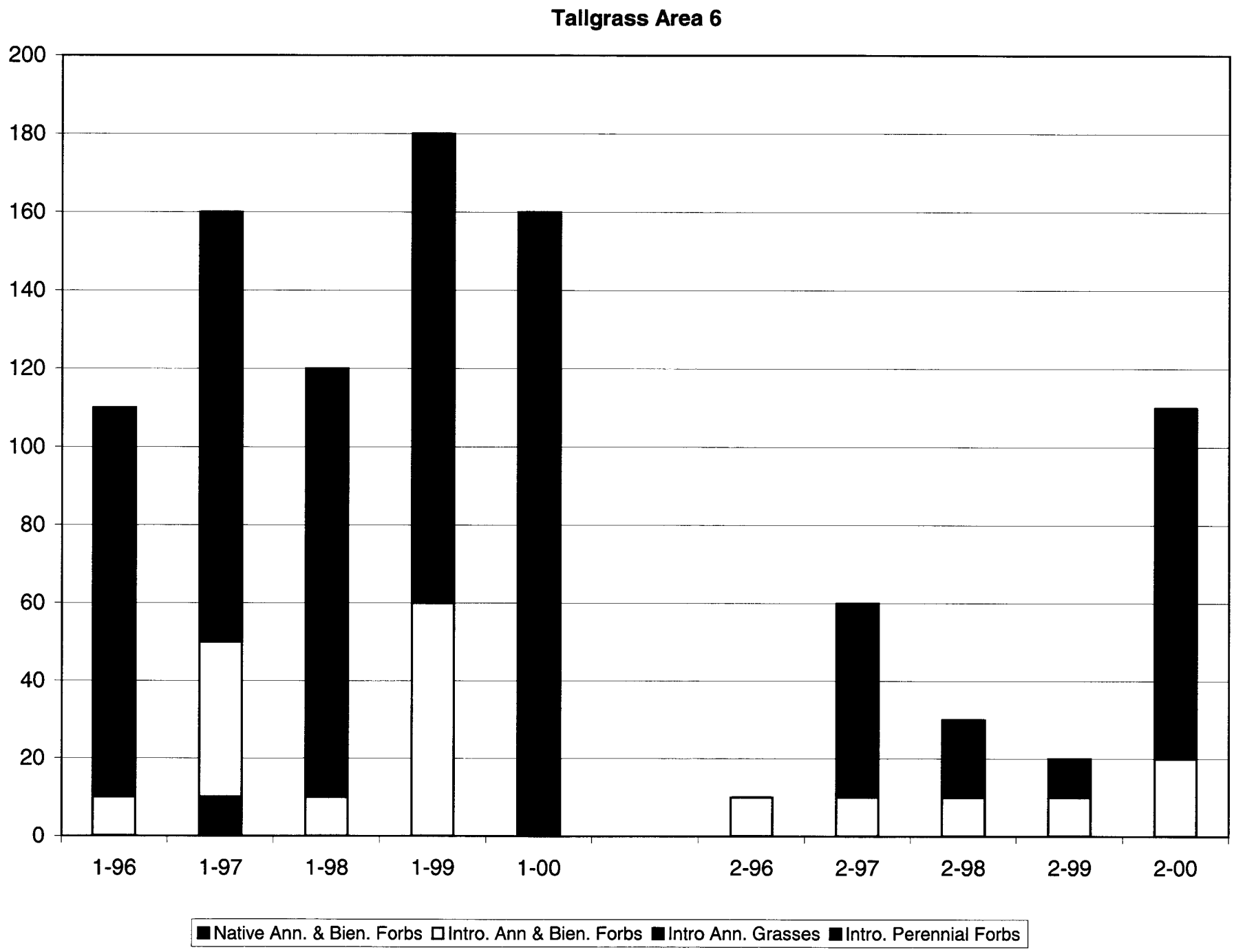


Figure 7. Cumulative "Weed" Frequency Data for RFBG Transects, Superior Associates Control Transects, Tallgrass Monitoring (Areas 3, 6, 7), Jeff. and Bldr. Cos., CO - 1996-2000



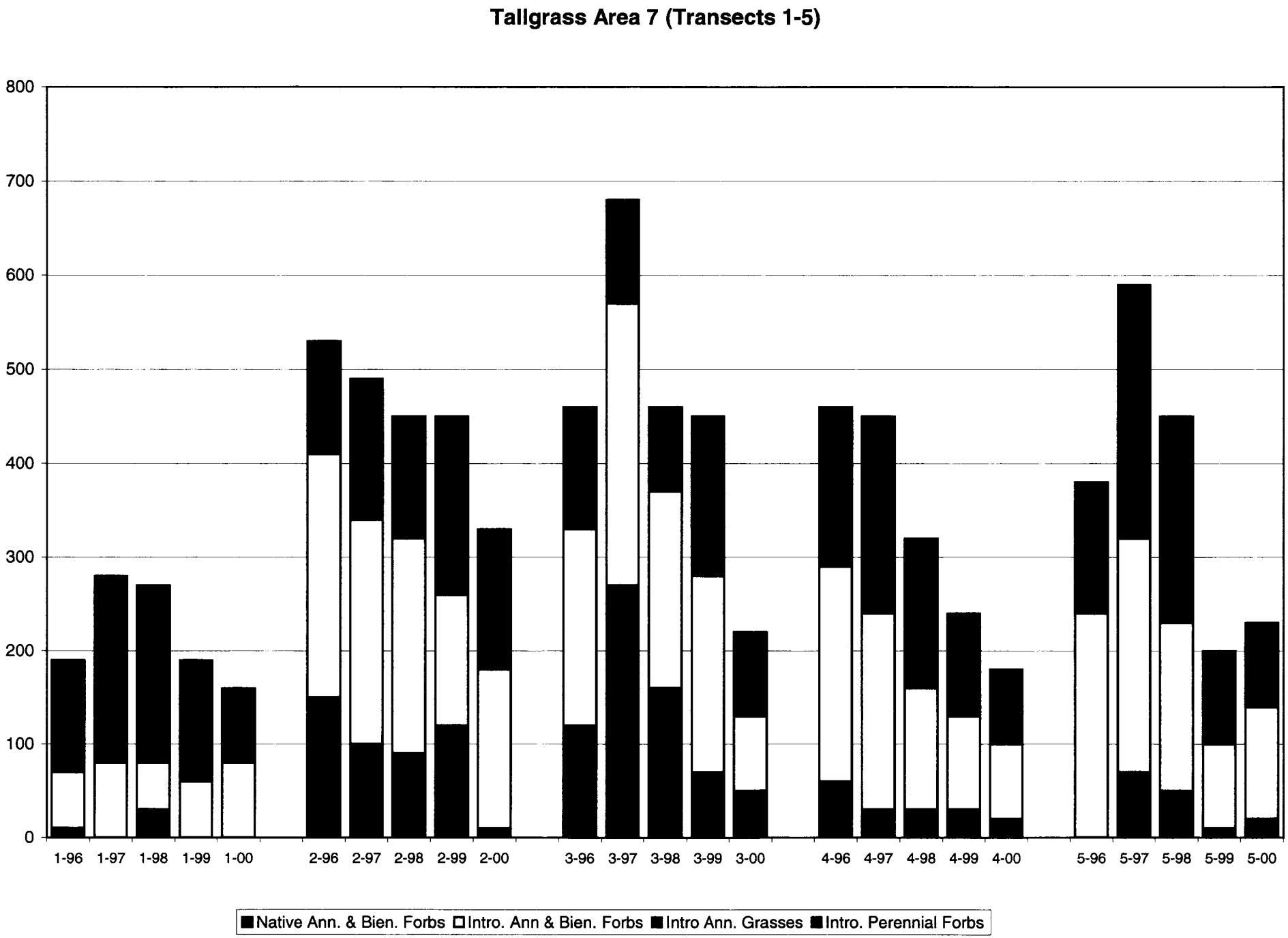


Figure 7. Cumulative "Weed" Frequency for RFBG Transects, Superior Associates Control Transects, Tallgrass Monitoring (Areas 3, 6, and 7), Jeff. and Bldr. Cos., CO - 1996-2000



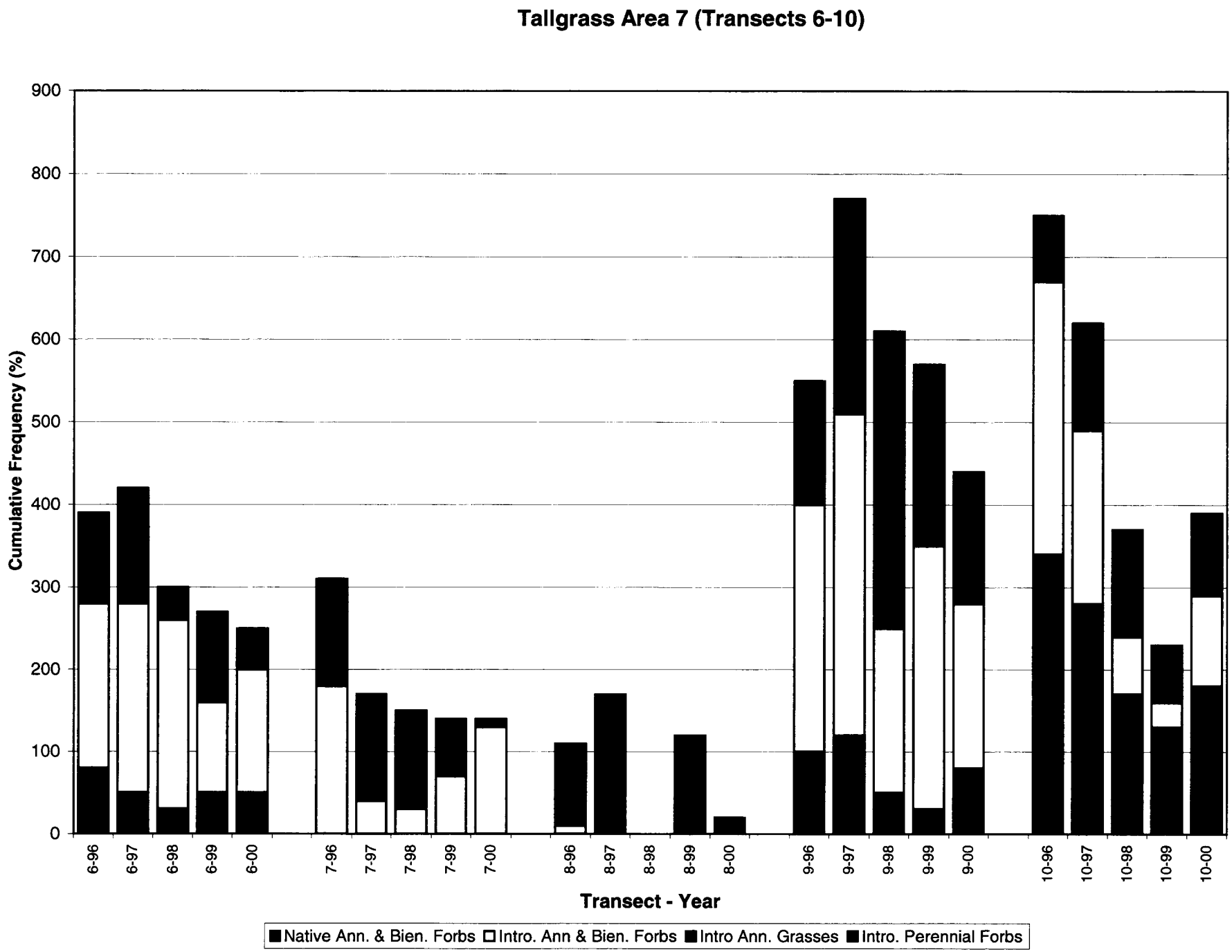


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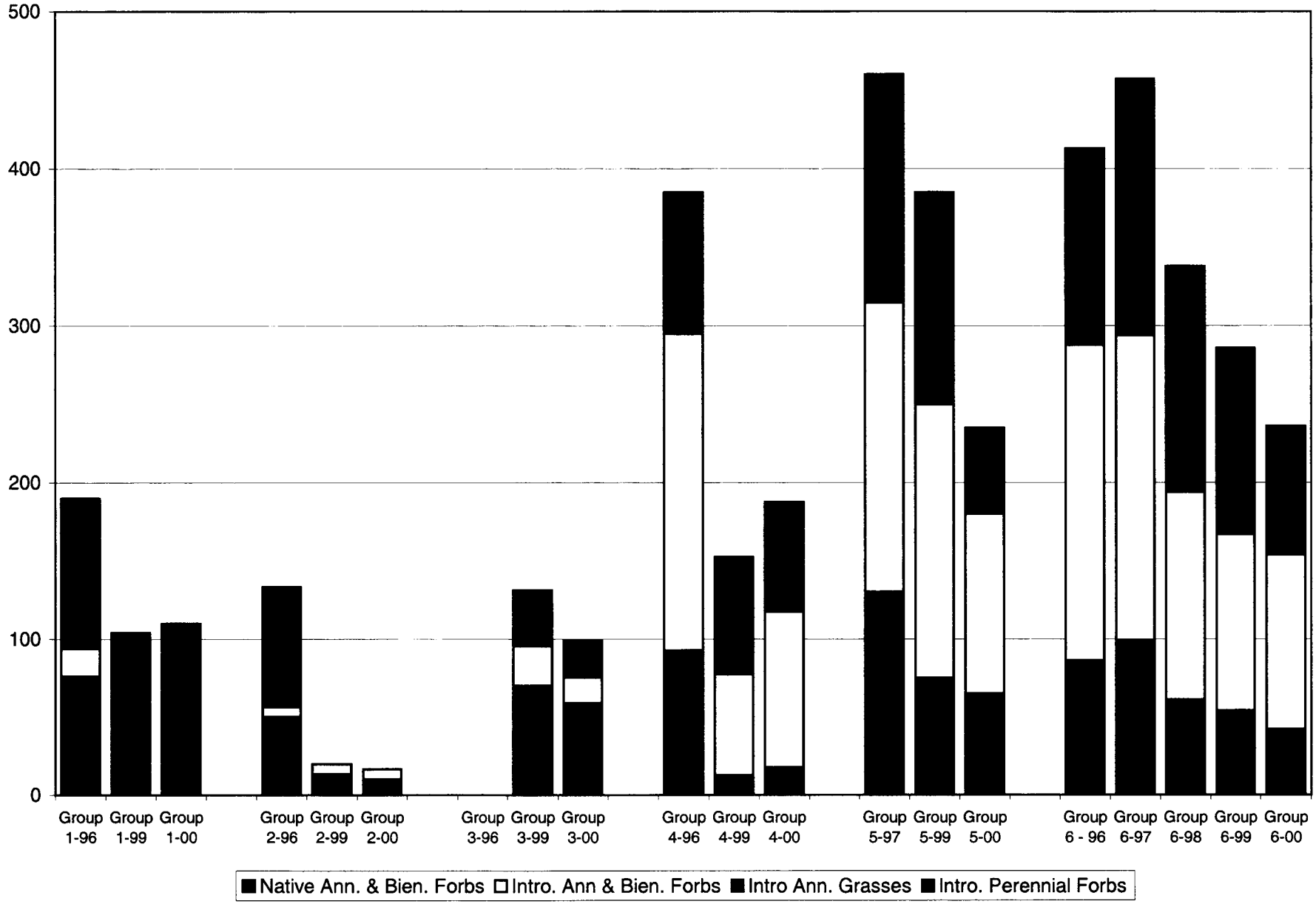
**Figure 8. Average Cumulative "Weed" Frequency Data for RFBG Transect Groups, Superior Associates Control Transects, and Tallgrass Monitoring Area 7, Jeff. and Bldr. Cos., CO - 1996-2000**






Group 1 - Transects 1-5
Group 2 - Transects 21-23
Group 3 - Transects 25-28, 30, 32-35
Group 4 - Transects 13,14,20,24
Group 5 - Superior Associates Transects C1/C2
Group 6 - Tallgrass Natural Area 7 Transects 1-10