Identifying and Evaluating Techniques for Wildlife Habitat Management in Interior Alaska: Moose Range Assessment

Final Research Technical Report
1 July 2005–30 June 2008

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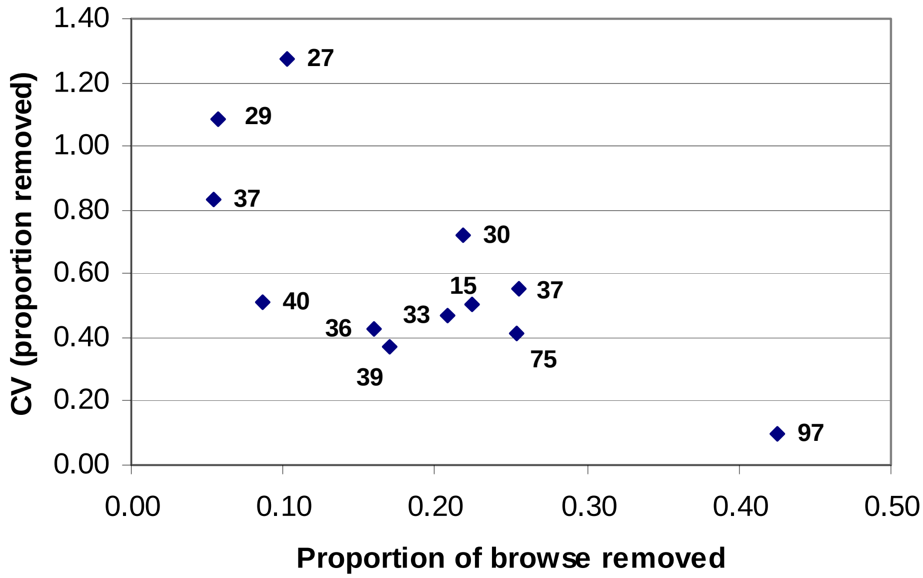
Cover Photos: Front – Moose amid willow browse; Back – Tom Seaton, ADF&G Wildlife Biologist, demonstrating unbrowsed (left) and broomed forms of Bebb willow, the latter showing the effect of moose browsing over multiple years on plant architecture

Errata and addendum for final research report 5.10 (15 December 2009, replacing earlier errata sheet of 3 June 2009):

PARAGI, T.F., C.T. SEATON, AND K.A. KELLIE. 2008. Identifying and evaluating techniques for wildlife habitat management in Interior Alaska: moose range assessment.

1) In Figure 3b the sample size for GMU 20D plots should be 76.

2) Figure 5 was missing a study area with a CV of 1.27:

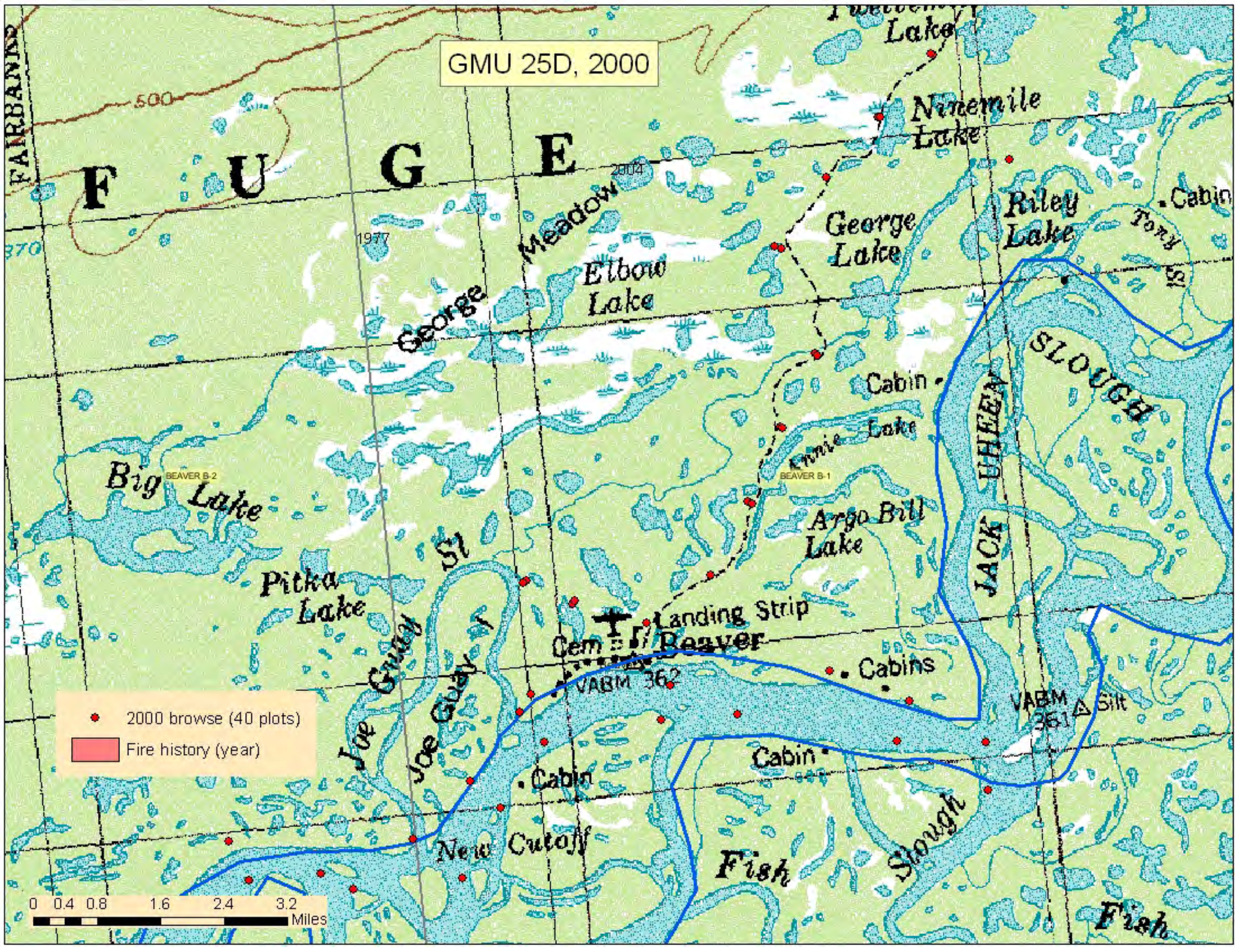


3) Table 1 the sample size of plots for the 2007 foothills stratum in Unit 20D should be 30, making a total of 76 plots for Unit 20D in 2007. (The “hover” box indicating that the helicopter did not land for a ground visit was incorrectly checked for plot 109 in the Access file for the foothills stratum, which affected a manual plot tally but not calculations of browse removal.) Also, the sample size of plants in Unit 25D should be 234.

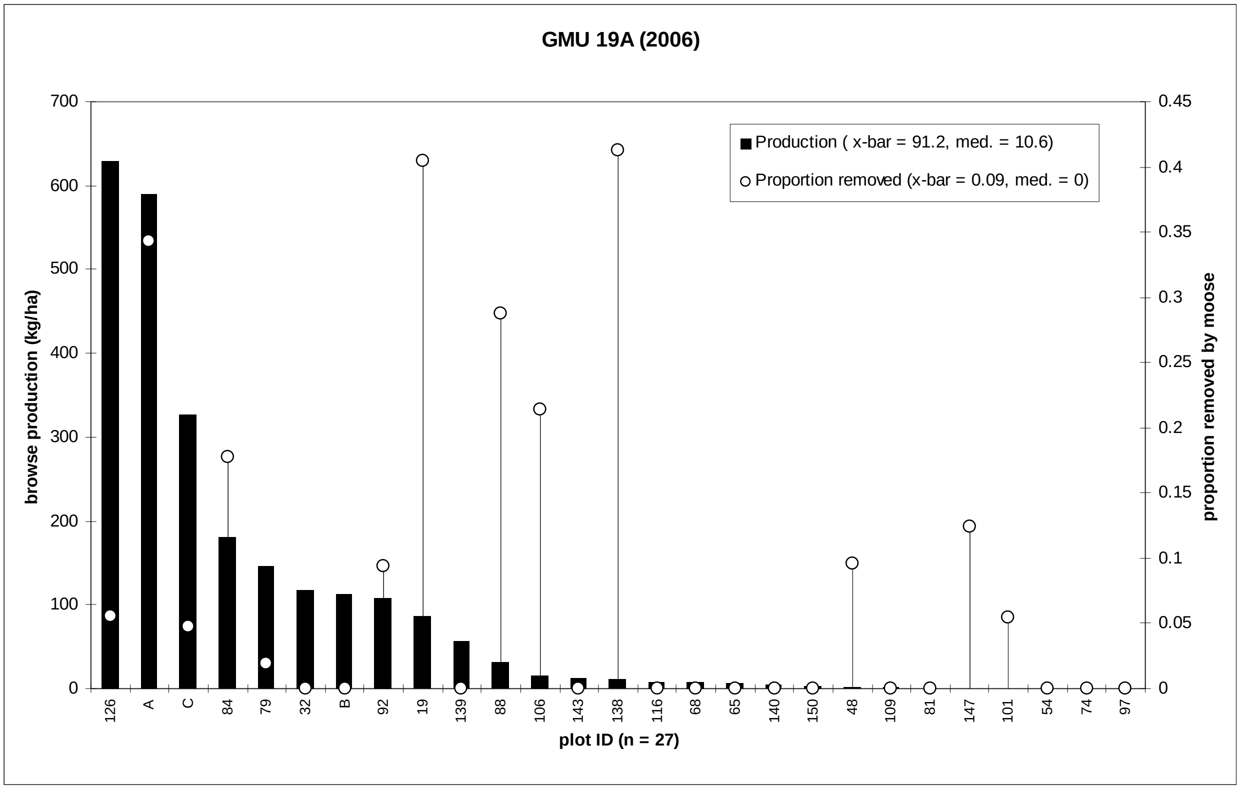
4) Appendix B had several duplicate records where mass-diameter data was substituted from one study area to another; also, values for *Salix glauca* in Unit 20D were changed (revised table follows). Subsequent re-analysis of 20D data with the corrected regression values for the twig mass-diameter relationship resulted in minimal changes in biomass removal estimates because *S. glauca* was a small portion of total forage and found only in the foothills stratum of that study area.

Species	GMU	Intercept	Slope	MSE	*n*	r-squared
Betula neoalaskana	19A	–4.352	3.344	0.134	59	0.928
Betula neoalaskana	19D	–3.273	2.967	0.107	55	0.972
Betula neoalaskana	20A	–3.914	3.338	0.124	259	0.974
Betula neoalaskana	21E	–3.519	2.829	0.097	25	0.763
Betula neoalaskana	25D	–3.721	3.204	0.146	50	0.972
Cornus stolonifera	21E	–5.427	4.023	0.180	61	0.896
Populus balsamifera	19D	–3.335	2.705	0.080	111	0.968
Populus balsamifera	20A	–3.392	2.792	0.100	217	0.947
Populus balsamifera	25D	–5.082	3.660	0.074	10	0.990
P. tremuloides	20A	–3.087	2.694	0.105	259	0.970
P. tremuloides	25D	–4.160	3.139	0.132	100	0.973
Salix alaxensis	19A	–5.645	3.763	0.259	209	0.925
Salix alaxensis	19D	–4.439	3.264	0.192	129	0.953
Salix alaxensis	20A	–4.558	3.304	0.275	751	0.903
Salix alaxensis	21E	–6.154	3.882	0.117	95	0.974
Salix alaxensis	25D	–4.326	3.318	0.161	104	0.963
S. arbusculoides	19A	–3.860	3.076	0.105	58	0.969
S. arbusculoides	20A	–3.575	3.284	0.158	123	0.963
S. arbusculoides	20E	–3.712	3.276	0.223	89	0.947
S. arbusculoides	21E	–3.780	3.294	0.211	37	0.940
S. arbusculoides	25D	–3.604	3.135	0.095	109	0.980
S. bebbiana	20A	–3.880	3.225	0.128	345	0.966
S. bebbiana	25D	–3.286	2.987	0.091	100	0.980
S. glauca	20D	–3.517	2.473	0.201	123	0.909
S. glauca	20E	–5.250	3.585	0.326	127	0.866
S. interior	19D	–3.578	3.014	0.125	96	0.969
S. pulchra	19A	–3.907	2.894	0.389	40	0.824
S. pulchra	19D	–3.203	2.844	0.166	69	0.963
S. pulchra	20A	–3.449	3.010	0.225	637	0.936
S. pulchra	20E	–4.816	3.581	0.277	148	0.926
S. pulchra	21E	–4.428	3.527	0.183	100	0.954
S. Richardsonii	20D	–4.751	3.074	0.242	32	0.903

5) In Appendix A the map for browse plot locations in Unit 25D is as follows (plot access included use of All Terrain Vehicles along a dirt road in addition to boat access described in report):



6) In Appendices E and F, the sample size of plots for Unit 20D foothills stratum should be 30. Also, in Appendix E, insert the following figure between Units 19D (2001) and 25D:



7) In Appendix I, replace Section 3 (error checking in database) with the following:

Missing or incorrect values are obviously best spotted before leaving the plot. A check at the end of the day is the next best remedy to allow the best approximation while details are fresh in memory, and reviewing the plot photo in a digital camera can also help.

The Microsoft Access database has entry forms for tables configured similar to field data sheets. When proofing data entry, key multipliers to check are the count of preferred plants (by species) in each plot and the twig count per sampled plant. Lack of a plant (species) count when a species is reported under twigs will cause an error, as will a blank under number of twigs (the latter reported as "NA" in the output spreadsheet created by the R software; Appendix I). Having a blank in the Twig Data table for diameter at point of browsing (DPB) instead of 0.0 will cause reporting as "NA." Always use the "save" option after corrections are made. Inadvertent blanks on the data sheets for number of twigs can be entered in the database with an average from the other plants of the same species for that plot.

Incorrectly recording or electronic entry of DPB > CAG for a twig can greatly inflate variance at the plant mean level and subsequent extrapolations. (We recognize that browsing beyond current annual growth occurs and note it on data forms, but "CAG" as measured in the field is at the next growth scar, so field measurements should always have CAG > DPB). This type of recording error is often noted during electronic data entry. If not, error checking is accomplished by copying PLANTID, PLOTID, CAG, and DPB from the TWIG table in Access and pasting them into a spreadsheet to allow subtraction of DPB from CAG (IDs allow tracking errors in the database and field forms). Records with CAG > DPB cannot be rectified after the fact and should ideally be deleted, but a reasonable alternative with low sample sizes is to adjust CAG = DPB because a measurement error likely occurred at growth scars not close to perfectly round.

For any species listed in the Plant Data and the Twigs Data tables, there must be the corresponding species in the Lab Wetmass and Diameter and the Wet Weight Conversion tables (mass-diameter regression and dry weight correction, respectively). If not, “NA” will be reported for plants (species) lacking the corresponding data in the output spreadsheet. Importing mass-diameter data from another study area can be done as a table export from the source Access file, renaming the table with the source study area. Once the order and spelling of field names is confirmed to exactly match that of the receiving table (add or delete fields if necessary), export a second table within the same (recipient) database that will contain only the species needed after you delete unnecessary records of species you already have. It is helpful to print out the relationships diagram for a recent dataset for cross-checking tables and records in older datasets. Note the source study area (GMU) in the “Zone” field for posterity, which requires creating a column in Excel and pasting into the Zone field. Then append the needed species onto the Lab Wetmass and Diameter table by cutting and pasting (as append option) into the last (blank) record.

When preferred browse species other than the 6 listed on the field form are entered in the corresponding PREF table of entry form of the Access database, any new species should be entered in consistent order in the four blank fields below SABE. For example, if SARI is the first extra species encountered, it should always go in the first blank in all subsequent plots. For the software to correctly use PREF plant counts (number), the Site Data table must be manually edited to rename the field (column) from “SAOT#” to the extra species (e.g., SARI). Failure to do this will result in an “NA” error at the Species Total level of the output spreadsheet.

Attempting to run the data analysis software without having wetmass-diameter values or wet weight conversion values in the corresponding Access database tables will result in the error message “attempting to select less than one element.” Attempting to run the software when one of the three output (.csv) files from a previous run of the same database is open will result in an error message that includes the text “cannot open file” because it is attempting to write to an open file.

FINAL RESEARCH TECHNICAL REPORT

ALASKA DEPARTMENT OF FISH AND GAME
DIVISION OF WILDLIFE CONSERVATION
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Juneau, AK 99811-5526

STATE: Alaska **STUDY:** 5.10

TITLE: Identifying and evaluating techniques for wildlife habitat management in Interior Alaska: moose range assessment

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PERIOD: 1 July 2005–30 June 2008

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GRANTS: W-33-4, W-33-5, W-33-6, and W-33-7

ABSTRACT

A technique developed by Seaton (2002) to estimate production of browse biomass and its proportional removal by moose (*Alces alces*) in Game Management Unit 20A was applied to 9 additional study areas in the boreal forest of Interior Alaska during 2001–2007. The technique includes plot methods to sample the diameter of current annual growth (CAG) and the diameter at point of browsing by moose (DPB) and analytical methods for prediction of browse biomass from twig diameter. We mostly sampled with relatively few (ca. 30) plots across large landscapes and found heterogeneity in browse production, plant species composition, and proportion of biomass removed at the scale of our sample plots. Despite this heterogeneity and differences in scale of sampling, we estimated a consistent proportion of browse removed in 2 years of similar moose density in Unit 19D. The estimated proportion of biomass removed (DPB/CAG) based on sample twigs is robust across levels of sampling effort, whereas removal based on sampled data extrapolated to plot species composition is not. Proportion of browse biomass removed by moose (sampled twigs only) was inversely related to estimates of moose twinning rate in the 8 study areas where we had twinning data. In low-density moose populations where twinning surveys are impractical, the proportion of browse removed provides an alternative means to infer the level of nutritional limitation.

Key words: *Alces alces*, aspen, birch, boreal forest, browse survey, fire, habitat, moose, poplar, willow.

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INTRODUCTION

Wildlife managers in Alaska are often required to estimate harvestable surplus and nutritional status of wild moose (*Alces alces*) populations over large areas (>30,000 km^2) of forested and subalpine wilderness. Biologists must either quantify forage production (kg/ha) in the context of daily food requirements for an absolute estimate of carrying capacity (e.g., Crete 1989, MacCracken et al. 1997) or use indices to assess the relative nutritional status of the moose population. Standardized economical methods for assessing carrying capacity for moose at the landscape scale appropriate for remote areas of Alaska have not been established, so most biologists have opted for documenting indices to nutritional status of the moose population (Boertje et al. 2007). The most established index of nutritional status of a moose population in Interior Alaska is twinning rate (Boer 1992; Gasaway et al. 1992:24; Keech et al. 2000; Boertje et al. 2007). Age at first reproduction, short-yearling masses, and browse removal rates (similar to those presented here) have also been used to estimate nutritional status of moose populations (Boertje et al. 2007). Measuring any particular index has logistical limitations. We sought to further document a browse-based index, which has potential to corroborate alternative nutritional indices.

Research on the population dynamics of moose concurrent with predation and harvest management in Unit 20A began in the 1970s (Gasaway et al. 1992). More recently, research has focused on density-dependent feedbacks as the moose population increased following predator control during 1978–1983 and 1993–1994 and generally mild winters (Boertje et al. 1996). Seaton (2002) reviewed methods of estimating browse removal by moose and used a modified technique to characterize browse production (kg/ha) and its removal by moose in Unit 20A. His technique quantified woody biomass through measuring twig diameter of current annual growth (CAG = production) and the diameter at point of browsing (DPB = removal) in late winter, just prior to the new growing season. Estimating biomass by diameter instead of simply counting browsed twigs is important; not all forage produced is likely to be utilized by moose because nutritional benefit decreases as diameter of CAG increases (Vivas and Saether 1987, Kielland and Osborne 1998). The smallest twigs provide the most nitrogen gain per unit of mass but extend rumen fill time, whereas the largest twigs provide less nitrogen gain per unit mass but shorten rumen fill time (Shipley and Spalinger 1992).

Following Seaton's browse sampling in Unit 20A during 2000, several browse surveys were conducted for management purposes prior to being assumed as a research job under Project 5.10 in fiscal year 2007. This report includes portions of the data from Seaton (2002) for comparison to subsequent surveys. The work was described in Project 5.10's Project Statement as Job/Activity 1J (Estimate browse production and proportional removal [kg/ha] as an index of potential for winter forage to limit growth in moose populations under intensive management).

STUDY AREA

We measured browse production and removal on 10 study sites defined by game management unit across Interior Alaska (Fig. 1). Plant taxonomy followed Collet (2004) for willows and Viereck and Little (2007) for other species. Vegetation was generally mixed boreal forest with canopy dominated by spruce (*Picea* sp.), Alaska paper birch (*Betula neoalaskana*), balsam poplar (*Populus balsamifera),* and quaking aspen (*Populus tremuloides*) grading into shrub communities at higher elevations and in active floodplains of large rivers. Wildland fire and drainage differences influencing flooding dynamics created a mosaic of successional habitats. Aside from portions of Units 20A, 20B, and 20D, the study area habitats were typically unsettled and uncultivated wilderness. Terrain elevation ranged from 30 m in lowland river corridors to 1400 m in subalpine. Peak snow depth by late winter (average 1975–2005, National Weather Service) increased with proximity to the coast, from northeast (<70 cm) to southwest (>90 cm); such gradient thresholds in snow depth and density can influence energetic requirements and habitat selection by moose (Coady 1974).

Unit 20A (Tanana Valley) was comprised of wetlands and uplands between 5 and 105 km south of Fairbanks. The area contained winter range for migratory moose and a winter range for resident moose, both of which shared a common summer range (Keech et al. 2000). The portion of Unit 20B (Tanana Valley) we sampled within 75 km of Fairbanks area was primarily forested uplands with low density housing and small clearings outside the urban footprint. The southwestern portion of Unit 20D (Tanana Valley) varied from canopy forest and agricultural fields near Delta Junction to subalpine terrain 50 km south and contained several upland areas that had burned in the last 20 years. Unit 25D (Yukon Valley) was comprised of floodplain within 25 km east and west of Beaver. Unit 19D (Kuskokwim Valley) was floodplain and uplands within 40 km of McGrath. Unit 19A (Kuskokwim Valley) contained floodplain and uplands between Aniak and Lime Village. Unit 20E (Yukon Valley) was uplands primarily within the Fortymile drainage between 25 and 100 km north and east of Tok. Unit 21E (Yukon Valley) was floodplain and uplands within 30 km of the lower Innoko River.

METHODS AND MATERIALS

SELECTION OF PLOT LOCATIONS

Our design and procedures for selecting plot locations evolved with experience. Selection of locations differed among some of the 10 study areas (Appendix A) because of funding limitations and the availability of moose and habitat data for stratification. In all instances we focused on known winter range and attempted to minimize sampling bias. Definition of browse species is in the section on “Estimating browse removal.”

Seaton (2002) sampled 2340 km^2 of Unit 20A in April 2000 by selecting plots in a stratified random manner based on the vegetative classification, available moose radiolocations, and stratifications of moose survey density. He conducted a reconnaissance of 480 points (405 by helicopter) to eliminate 40% of sites where browse was absent above the snow and subsequently used helicopter and snowmobile to access 97 plots. Analyses in Seaton (2002) excluded 2 plots with extremely high production (n = 95) that we included in our analysis of Unit 20A.

We sampled 50 km^2 of moose winter range in Unit 25D by boat in May 2000 at 2.5-km intervals along the Yukon River east and west of Beaver, including islands and main banks. At each route interval we walked a random distance up to 400 m perpendicular from the shoreline to select plot locations.

A 100-km^2 portion of southwest Unit 20D was sampled in May 2000 and May 2001 along trails accessible by all-terrain vehicles (ATV). Most of this area was burned in 1987 or 1994 (Appendix A). Sampling occurred at systematic intervals (1–4 km) along the ATV trails based on the length of trail and workday. At each interval, sample locations were placed at random distances (up to 200 m) and directions from the trail.

We sampled browse on 10,600 km^2 in eastern Unit 19D in late March 2001, and in late March 2003 we resampled a 1350-km^2 portion of the 2001 survey area described as the Experimental Micro Management Area (EMMA; Appendix A) in a study of predator–prey relationships (Keech 2005). For both surveys we chose sample locations in the office from a vegetative classification of the Stony Military Operations Area that was completed by Ducks Unlimited (DU) for the U.S. Bureau of Land Management in 1999 (Appendix A) and used helicopter and snowmobile access. Ducks Unlimited classified vegetation by using imagery from Landsat Thematic Mapper acquired in June 1986 (eastern portion, most of survey area) and August 1989 (western portion); classification error was 10%. We restricted sample allocation to 3 strata of cover type (Viereck et al. 1992) likely to contain moose browse above snow level in late winter: tall shrub (1% by area); open forest (10–59% canopy cover, 7 DU classes; 78%); and closed forest (60–100% canopy cover, 3 DU classes; 21%). Image pixels (30 m × 30 m) classified as “fire scar” in 1986 was considered tall shrub for our sampling stratification. An area of 2 ha (roughly a block of 5 pixels) was considered the minimum size useful to stratify habitat for actually finding a specific cover type on the ground (D. Fehringer, Ducks Unlimited, personal communication).

Based on variance of estimated parameters from previous browse sampling in Unit 20A, we required ≥30 plots per study area. In Unit 19D we attempted to choose samples uniformly throughout the study areas in 2001 and 2003 by overlaying study areas with a grid defined by rectangular cells used in moose surveys (ca. 15 km^2; Kellie and DeLong 2006) and sampling one plot per cell. We allocated choices equally among the 3 cover types, visually identifying type polygons ≥2 ha in the digital classification. We chose enough sites to allow alternates if browse was absent or the classification was inaccurate. We also chose sampling sites in closed canopy forest within 3 pixels (90 m) of more open habitats (as indicated in the classified image) to facilitate access from helicopter landing areas. Willow patches along the river are relatively rare on the landscape and often undetected by satellite imagery because of their narrow profile. Thus, near the end of sampling in 2001, we subjectively chose 3 additional tall shrub sites in the active floodplain of the Kuskokwim River (<0.5% of study area) to characterize abundant willow forage in a relatively rare portion of the landscape that is heavily used by wintering moose.

The helicopter pilot navigated to the center of chosen polygons by Global Positioning System (GPS) and hovered so we could confirm available browse. If browse was observed, we landed at the nearest available location for snowshoe access. When no CAG of browse species was observed during the hover or the correct stratum was not present within 200 m, we flew to the nearest alternate site in that cover type. We attempted to maintain an even distribution of samples among cover types within time and flying weather constraints for the terrain. In 2003 we sampled 16 plots (108 plants) off the river corridor by helicopter and 23 plots (190 plants) by snowmobile in floodplain stands and willow bars that moose were known to frequent in winter along the Kuskokwim River. In addition, fecal pellets were collected in March 2001 during capture of 25 adult cows (≥1 year old) and 15 short yearling cows for diet analysis to plant genera using microhistological techniques (Wildlife Habitat Laboratory, Washington State University, Pullman, Washington).

In April 2006 we used the rectangular cells from recent moose surveys as strata (high or low density) for browse sampling in 21,000 km^2 of Unit 19A, 14,300 km^2 of Unit 20E, and 17,500 km^2 of Unit 21E. In previous surveys we found only 20–50% of randomly sampled plots contained available CAG within a 15-m radius, so to achieve ≥30 plots per study area we randomly chose 150 cells at a 3:2 ratio of high:low moose density to focus plot sampling where browse production and browse foraging likely occurred. Plot selection within each chosen cell was based on proximity of helicopter landing sites for access on snowshoes. The helicopter pilot flew a northeast heading from the southeast corner of the cell (up to ca. 5.5 km from SE to NW corner). We placed a colored dot on the helicopter windows near each passenger seat to indicate a lateral distance of 100 m on the ground when flying at 30 m above ground level (above the tallest trees typically encountered). At the first safe landing spot encountered within 100 m perpendicular to the heading, the pilot hovered over the landing spot while a GPS location point was marked. The helicopter was then flown a random distance (30–100 m) and bearing (0–359 degrees) to hover over a sample site. In the rare event of no landing site because of solid forest cover in a cell or no vegetation above the snow within 100 m of the landing site (in burns where snags constrained landing spots), we proceeded to the next selected cell. If the general area was vegetated but the random point was not, we continued choosing alternate random points from the landing zone until a vegetated community was chosen. If no browse CAG was visible within a 15-m radius, we noted community type to Level II of Viereck et al. (1992) based on vegetation above snow cover, took a digital photo from the air, collected a GPS fix, and flew to the next cell. If browse CAG was observed, we collected a GPS fix and then visited the site on foot. We recognized that this sampling scheme is biased to edge habitats at the stand scale but consider it a necessary compromise for feasible access at the landscape scale in remote forested environments. In 2006 we also subjectively chose 3 additional tall shrub sites in each survey area to characterize high production sites, typically in active floodplain.

In April 2007 we stratified sampling of rectangular cells by high and low moose density for browse sampling in 4 areas. We used the helicopter heading procedure to sample browse in 15,600 km^2 of Unit 24B (in cooperation with Kanuti National Wildlife Refuge) and 13,200 km^2 of Unit 24C. In southwestern Unit 20D we used the helicopter heading procedure in combination with ground access to additional sites on 4550 km^2. For ground access in Unit 20D we identified chosen cells near a highway or forest road, drove to the nearest point perpendicular to the GPS location of the cell corner by truck or snowmobile, and walked a randomly chosen 15–100 m perpendicular toward the cell corner to establish the plot center (2 sites visited by ground transportation contained no browse). We also used the ground procedure to access chosen cells near a highway or forest road on 3900 km^2 in central Unit 20B surrounding Fairbanks.

ESTIMATING BROWSE REMOVAL

We analyzed the proportional removal of annual browse production over the subsequent winter in each study area to describe the interaction between moose and their winter forage (Seaton 2002). We defined *Salix* spp., *Populus* spp., and *B. neoalaskana* as browse species. These taxa are important to moose throughout their continental range (Peek et al. 1976, Risenhoover 1989, Weixelman et al. 1998). We also included red osier dogwood (*Cornus stolonifera*) in our analysis; this widely distributed but relatively uncommon shrub was usually heavily browsed. We excluded other deciduous woody plants such as *Alnus* spp., *B. nana*, and *B. glandulosa* because these plants are less important food items on moose winter range in Interior Alaska

(Bryant and Kuropat 1980), and we observed comparatively little use of these species. Sampling occurred in late winter or early spring to integrate browse removal over the entire period of winter dormancy in forage. Sampling may occur until dormant twigs swell (thus biasing mass-diameter relationship) just prior to leaf emergence.

We sampled only plants with CAG between 0.5 and 3.0 m above ground level. This interval represents the normal range in which moose forage on *Salix* spp., *Populus* spp., and *B. neoalaskana*. Woody forage below 0.5 m is commonly considered below the minimum foraging height for moose (Wolff and Zasada 1979, Wolff and Cowling 1981, Weixelman et al. 1998) and is often snow covered. We used the upper limit of 3.0 m because preliminary reconnaissance in Interior Alaska showed higher browsing to be uncommon, and 3.0 m is commonly considered the upper limit in forage surveys (Danell and Ericson 1986, Hjeljord et al. 2000). We sampled all plants before leaf emergence in spring. We chose a 15-m radius plot to correspond with Landsat pixel size of the DU cover classifications. Preliminary reconnaissance by Seaton (2002) indicated that this large plot size would reduce the number of plots with no browse in the vegetation types typical of moose winter range in Interior Alaska. The random selection of 3 plants per species in our comparatively large plots reduced potential for pseudoreplication when using plants as the sample unit for inference on browse removal at the scale of study area. Clumped distributions of plants at low plot-level density could reduce independence of sampled plants with respect to browsing but also likely resulted in a low degree of habitat selection by moose because of low browse availability.

At each sample plot we randomly selected 3 plants from each species and 10 twigs on each of the selected plants. For each twig we recorded DPB, if applicable, and diameter at base of current annual growth (DCAG, Lyon 1970). Starting in 2001 we separately noted if browsing occurred beyond CAG. We then counted the number of CAG twigs 0.5–3.0 m above ground level on the 3 plants and noted snow depth. From November through April, we collected unbrowsed reference twigs of variable sizes (1–10 mm diameter) from each forage species sampled for biomass estimation (Seaton 2002). In the lab we measured, oven dried, and weighed these twigs to develop regression relationships between diameter and dry mass (Brown 1976, Oldemeyer 1982, Alaback 1986, Kielland and Osborne 1998). We used the regression coefficients relating diameter to dry mass (Appendix B) and the number of twigs per plant to estimate forage production and removal (Telfer 1969) for plants within the 10 study areas. We used DCAG to predict production and DPB to predict removal (Oldemeyer 1982). In study areas where unbrowsed specimens of a species were relatively rare, we augmented samples or used the regression coefficients from the nearest study area to predict biomass. Proportional removal of browse biomass in a study area was estimated with the following equation.

$$browse\ biomass\ removal = \left(\frac{\sum biomass\ removal\ from\ all\ plants\ sampled}{\sum CAG\ biomass\ produced\ on\ all\ plants\ sampled} \right)$$

Unless noted otherwise, we reported the estimate of proportion of biomass removed based on sampled twigs only (mean twig per sampled plant) with plants as the sample unit.

ANALYSIS OF BIOMASS REMOVAL

Dry biomass of browse was expected to have an exponential relationship to diameter ($z = ax^b$; Oldemeyer 1982), where z was dry mass and x was twig diameter. This relationship was estimated using linear regressions of log-transformed dry mass on log-transformed twig diameter for the forage plants collected in the study areas. After estimating coefficients on the log scale, estimates of dry mass were converted back to the original scale (grams) using the equation

$$\hat{z} = \exp(\hat{a} + \hat{b}\ln(x_0) + \sigma^2 / 2)$$

to correct for approximate bias resulting from skewness (Brown 1976), where $\hat{a}$ was the intercept coefficient and $\hat{b}$ was the slope coefficient on the log scale, σ^2 was the mean square error on the log scale, x_0 was the diameter input, and $\hat{z}$ was the resulting predicted value. We extrapolated variance of $\hat{z}$ to the plant level using the delta method (Bain and Englehardt 1987:178) and constructed 95% confidence intervals on biomass estimates.

We contracted development of software written in R language (R Development Core Team 2008) to read a Microsoft® Access® database with plot counts, twig diameters, diameter–biomass pairs, and dry-weight conversions and then estimate the diameter–biomass relationships and production and removal (g/plot and kg/ha) on the basis of plant, species, plot, and study area. We estimated proportion of browse biomass removed at the plant level (twigs that were actually sampled) rather than extrapolating production and removal to the plot level, which could introduce bias through variation in the proportion of total plants sampled per species in a plot. (Seaton [2002:73] estimated production and removal at the plot level for Unit 20A to allow modeling of forage intake by moose relative to estimated forage production.) The software also estimated mean and 95% confidence limits using bootstrap techniques (Efron and Tibshirani 1993). The bootstrap technique allows calculation of asymmetric confidence limits, which is important as proportion of browse removal approaches zero. At each bootstrap iteration, a sample of size n (total number of plots sampled per study area) was drawn. Mean and standard error of mean for production, removal, and proportion removed were estimated as the sample standard deviation of 1000 bootstrap samples. Confidence intervals were obtained by applying the basic percentile method (Davidson and Hinkley 1997). To examine how the number of plots sampled in a study area affected the estimate of proportional browse removal and its variance, for Units 20A and 20D (sampled number of plots = 97 and 75, respectively) we chose random samples with replacement of 5, 10, 15...to n plots and performed 1000 replicate calculations with each sample to estimate mean and sample standard deviation.

SENSITIVITY OF BROWSE REMOVAL

To evaluate whether the browse removal technique can distinguish spatial variation in moose populations, we used prior knowledge to subdivide Unit 19D. Estimates of moose density do not exist at a scale fine enough to distinguish riparian and off-river sites, but are based on locations of radiomarked moose and winter observations (moose were more concentrated in the riparian floodplain than in nonriparian areas during winter). We tested whether browse removal differed between moose subpopulations with different winter densities in Unit 19D.

TWINNING RATES

Boertje et al. (2007) described estimation of moose twinning rates from aerial surveys shortly after peak of calving in late May, in most instances from a sample of unmarked individuals. Moose density and sample size for twinning rate for 6 of our study areas (Units 19D, 20A, 20D, 20E, 21E, and 25D) were reported in Table 1 of Boertje et al. (2007); we added 2 more years of twinning data (2006 and 2007) for Units 20D (n = 102 unmarked cows) and 20E (n = 69). In Unit 19A the twinning rate was estimated from aerial surveys in 2002 and 2005 (n = 63); spring moose density was estimated at 0.11 moose/km^2 in 2005 and 0.15 in 2006 (Seavoy 2006). In central Unit 20B, twinning rate was estimated in 2006, 2007, and 2008 (n = 120), and autumn density was estimated at 1.4 moose/km^2 in 2005 (Young 2006). We have only 1 year of twinning data from Unit 24B and no twinning data from Unit 24C, thus did not analyze them further.

Standard errors and 95% confidence intervals for twinning rate were estimated for each study area using bootstrap techniques (Efron and Tibshirani 1993). Within each study area, twinning rate for each of n years (where n = number of years of twinning rate data for that study area) was modeled as a binomial using total number of parturient cows observed and observed numbers of twins. At each iteration, a sample of size n was drawn from these n modeled twinning rates, and the mean of this bootstrap sample was calculated. The standard error of mean twinning rate was estimated as the sample standard deviation of 10,000 bootstrap samples. Confidence intervals were obtained by applying the basic percentile method (Davidson and Hinkley 1997).

Seaton (2002:19) classified forage plants based on their history of browsing by moose and the resulting physical characteristics, termed “architecture.” Three categories of plant architecture were defined from evidence of browsing prior to the current year for each plant: “broomed” (>50% of CAG twigs between 0.5 and 3.0 m arose as lateral stems produced as a result of browsing); “browsed” (browsing in past years, but <50% CAG twigs between 0.5 and 3.0 m arose from lateral stems that were produced from browsing); and “unbrowsed” (no evidence of browsing prior to the current year). Seaton also classified plants as having no dead CAG stems, <50% dead, and >50% dead.

For consistency, information in tables, figures, and appendices are reported by study area–year in decreasing order of the proportion of CAG browse removed, which generally corresponded to decreasing order in moose density (Boertje et al. 2007:Table 1). We tested for difference between proportions of browse biomass removed (2-tailed) and between frequency of plants with browse removed or with no browse removed (1-tailed) with a z-test (Zar 1984:396).

RESULTS

We achieved the desired sample size of 30 plots in most study areas with a few exceptions because of time constraints (Unit 20D in 2000–2001) or flying weather (Table 1). When we used vegetation cover as sampling strata in Unit 19D, disagreement between type classification and actual cover type in the field, along with lack of browse at some sites, required frequent visits to alternative plots (Table 1). In surveys during 2006 and 2007 (no vegetation strata in sampling design), lack of browse above the snow at the first safe landing spot for a helicopter still required substantial flying effort to visit 30 plots for sampling and resulted in lower tendency to sample closed forest (Table 1). Browse biomass is dominant in tall shrub type compared with open forest or closed forest (Appendix C).

Salix spp. composed the majority (60–92%) of the plants sampled for biomass in the 10 study areas (Fig. 2 and was confirmed as the dominant item in winter diet of moose in Unit 19D [Table 2]). *Salix* dominated browse production and biomass removed by moose in all study areas except Unit 20B (Appendix D), which was dominated by *Betula neoalaskana* in the predominantly upland sites we visited along the road system. In Units 20A and 20D, *S. bebbiana* dominated production and removal biomass on the boreal forest and wetlands of the flats (Appendix D), whereas *S. alaxensis* dominated in the subalpine Alaska Range foothills to the south (Appendix A). We have rarely observed moose browsing of shrub birch (*B. glandulosa*) in the Interior, in contrast to observations in Unit 13 (W. B. Collins, ADF&G, personal communication).

The effect of landscape topography (flats and foothills, riparian and upland) on potential for disturbance events (e.g., fire or flooding) is evident in sample distribution and estimates of browse production. For example, prevalence of recent burns in Unit 24B increased the proportion of tall shrub and reduced the proportion of closed forest types sampled compared with a similar sampling technique applied to adjacent Unit 24C (Table 1), which had less area affected by fires (Appendix A). We sampled a greater proportion of floodplain in Unit 19D in 2003 compared with a larger area dominated by uplands in 2001 (Appendix A) and found 3-fold higher CAG biomass (per-plot basis) in 2003 than in 2001 (Table 3).

When sampled twigs were extrapolated to species composition at the plot level, estimates of production and removal of browse varied widely across plots within a study area (Appendix E). By comparison, estimates of production and removal from sampled twigs only for the flats and foothills strata in Units 20A and 20D (2007) were relatively more uniform across plots (Appendix F). Estimates of proportional browse removal calculated across a range of resampling levels in Units 20A and 20D (2007) suggested that sampled twigs alone are more robust as a forage removal index compared with sample data extrapolated to species composition at the plot level (Fig. 3). The effect of including 2 plots of extremely high production in Unit 20A (IDs 353 and 481, Appendix E) became evident at larger sample sizes for the extrapolated estimates but not estimates from sampled twigs alone (Fig. 3a).

The bootstrap estimate of CAG biomass removed by browsing (sampled twigs only) was stable at ≥15 plots and not different from the deterministic estimate in Units 20A and 20D, whereas the variance around the mean declined with increasing sample size (Fig. 4). Little relative gain in precision for each additional 5 plots occurred after the confidence limits in Unit 20A decreased to 13% of the mean at $n = 30$ (Fig. 4a). A similar rate of change in precision occurred at $n = 30$ in Unit 20D, although the confidence limit was substantially larger at 46% of the mean, and the bootstrap confidence interval was 3-fold larger than the deterministic calculation at the actual sample size (Fig. 4b). Coefficient of variation in the proportion of browse removed generally increased as the proportion removed decreased, but the relationship did not appear to be strongly influenced by the number of plots sampled among the 10 study areas (Fig. 5). In the 8 study areas with estimates of twinning rate, browse biomass removed by moose varied from 9% to 43% of CAG and was inversely correlated to moose twinning rate, which ranged from 7% to 64% (Fig. 6). For this comparison we used browse data from the Unit 19D EMMA in 2003 (better twinning data in EMMA than the larger study area in eastern Unit 19D we sampled in 2001) and browse data from southwest Unit 20D in 2007 (5 times the number of browse plots sampled compared with smaller area we sampled in 2001; Table 1).

Scale of sampling did not appear to influence the estimate of proportion of browse removed when moose density did not change between years, but removal was influenced by landscape position in a given year. Density of moose in the EMMA of eastern Unit 19D did not change between 2001 and 2003 (0.38 and 0.42/km^2, respectively; M. A. Keech, ADF&G, unpublished data, Fairbanks). Estimated proportion of browse removed by moose was not different ($z = 0.35$, $P > 0.5$) between 2001 and 2003 (Table 4) despite substantial differences between years in scale of sampling (Appendix A), cover types sampled (Table 1), browse species sampled (Appendix D), or production of browse sampled in the 2 surveys (Table 3). In eastern Unit 19D the diameter of CAG and DPB was similar for most plant species between 2001 and 2003 (Appendix G). In 2003 the proportion of CAG browse removal on riparian willow bars in Unit 19D was 0.205 (bootstrap 95% confidence interval: 0.169–0.273; $n = 190$ plants on 23 plots) compared with off-river removal of 0.122 (0.095-0.181; $n = 106$ plants on 16 plots; $z = 1.80$, $0.10 < P < 0.05$).

Density of moose in southwestern Unit 20D was estimated at 0.9/km^2 (2.3/mi^2) in 2001 and had increased to 2.2/km^2 (5.6/mi^2) in 2006 (DuBois 2008), with growth rate estimated at 15%/yr in 2006 (S. D. DuBois, unpublished data). Estimated proportion of browse removed by moose was not different ($z = 0.35$, $P > 0.5$) between 2000–2001 (low sampling effort) and 2007 (Table 4) despite substantial differences in scale of sampling (Appendix A), browse species sampled (Appendix D), or production of browse sampled in the 2 surveys (Table 3). In 2007 we did not detect browse removal differences between the flats and foothills in Unit 20D using either bootstrap ($z = 1.72$, $0.10 < P < 0.05$) or deterministic estimates ($z = 1.86$, $0.10 < P < 0.05$) despite a lack of overlap in 95% confidence intervals with the less conservative deterministic method of estimating variance (Table 4, Appendix H). In southwest Unit 20D the diameter of CAG and DPB tended to be greater in the flats samples in 2007 than those in 2000–2001 (all from the flats; Appendix G), but there was no difference in proportion of biomass removed for these areas between the 2 sample periods ($z = 0.04$, $P > 0.5$; Table 4). Browsing at diameter larger than CAG occurred in all study sites (no data from Unit 20A), ranging from 1% of browsed twigs measured in Unit 25D to 21% in Unit 20D (Table 4).

Relative to plant architecture, we observed that frequency of current year browsing on plants (or lack thereof) in a study area often corresponded to historical moose browsing on plants in the same area. The proportion of plants with a broomed architecture appeared positively correlated to the proportion of plants having at least some current browse removed by moose (Fig. 7a), and the proportion of plants with no browsing history appeared positively correlated to no browsing removal in the current year (Fig. 7b). In areas where we surveyed at 2 spatial scales and different years, we found that a larger proportion of plants in early seral habitats resulted in a higher frequency of current browsing evidence, regardless of moose density. We found higher current browsing ($z = 2.1$, $0.025 < P < 0.01$) and lower current evidence of no browsing ($z = 9.4$, $P < 0.001$) in Unit 19D samples with a higher proportion of floodplain habitat in 2003 compared with broader landscape samples in 2001 (Figs. 7a and 7b); moose density was similar between these years. In Unit 20D where we compared samples in 2000–2001 dominated by recent burn to samples in 2007 that included closed forest (Figs. 7a and 7b), we found evidence that current browsing was higher in 2001 ($z = 7.5$, $P < 0.001$) and evidence of no current browsing was lower in 2007 ($z = 4.9$, $P < 0.001$) despite the fact that moose density doubled from 2001 to 2007. The extent of structural mortality caused by moose browsing did not follow a pattern similar to architecture in Units 19D and 20D, but across all study sites the frequency of plants with <50%

dead biomass generally increased as proportion of biomass removal decreased (left to right in Fig. 8).

DISCUSSION

Sampling a large diverse landscape in remote areas to draw objective inferences on range condition and utilization by moose is the primary challenge faced in browse surveys (details of designing and conducting a browse survey are outlined in Appendix I). We sampled browse CAG production and removal by moose with relatively few plots across large landscapes and found heterogeneity in browse production, plant species composition, and proportion of biomass removed at the scale of our sample plots. Despite this heterogeneity and differences in scale of sampling, using sampled twigs only we estimated in Unit 19D a consistent proportion of browse removed in 2 years of similar moose density. However, we were not able to distinguish browse removal between sample strata representing a difference in winter moose distribution when we subdivided the data set in 2003. The biomass technique permits estimation of browse production (kg/ha) and removal (kg/ha) at multiple levels (plant, species, plot, cover type) by bite diameter, bite mass, size of CAG twigs, and other parameters useful in modeling moose foraging ecology (Seaton 2002). Thus, it permits extrapolating production and removal by type class for landscape estimates in a Geographic Information System, with appropriate assumptions. Analysis methods were automated with programming code to rapidly permit a variety of outputs (Appendix J).

Spatial diversity of vegetation at a given time and the dynamics of vegetation and moose density over time may not be readily evident with a simple index of browse removal. Proportion of browse removed by moose in southwest Unit 20D in 2007 was lower (z = 5.65, $0.02<P<0.05$) than removal in Unit 20A during 2000 (Table 4) despite Unit 20A having only about half the moose density ($1.1/km^2$) at the time of browse surveys (Seaton 2002). Recent large fires in Unit 20D (Appendix A) combined with forest succession on lands cleared for agriculture or other purposes doubled production of browse we sampled on the flats from 2000–2001 to 2007 (Table 3). This increased production is noteworthy given that the earlier survey was confined primarily to recent burns, whereas the 2007 flats survey included recent burns, agricultural land, and mature forest with closed canopy (Table 1), a type class with lower production than tall shrub (Appendix C). Larger bite diameters in the latter survey may partly reflect a change in availability of larger stems (closer to optimal diameter for energy intake; Kielland and Osborne 1998) and partly higher utilization by a more dense moose population. Despite high density of moose in 2007 and the highest rate of browsing beyond CAG (Table 4), a relatively high proportion of stems we sampled in Unit 20D were not browsed (Table 4, Fig. 7b). The proportion of browse removed as a measure of range utilization should be further evaluated to understand its sensitivity as a management tool in study areas where demonstrated changes in moose density or browse availability (e.g., following large wildland fires or extensive flooding events) have occurred.

Browse production varies by community type (Appendix C), so stratified sampling of browse production and its removal by moose could be based on community type (e.g., Seaton 2002). Lord (2008) studied a recent burn in Unit 20D and found higher browse production and higher proportion of browse removed by moose on sites with high fire severity (extent of organic layer consumption) compared with sites having low or moderate fire severity. However, other environmental factors may influence browse availability and use. Deep snow can restrict moose movement when it reaches 70 cm and make movement very difficult at 90 cm (Telfer 1970, Coady 1974). Areas of consistently deep snow may exclude moose from parts of a landscape, and sampling these areas would contribute little to understanding of browse utilization or inference on range condition relative to moose density. Climate data that define which portions of a range frequently experience deep snow may be useful to focus sampling in areas where moose are known or expected to concentrate (e.g., Poole and Mowat 2005). Conversely, information on moose habitat selection relative to snow depth could also aid the design of browse surveys.

Remote sensing products are desirable for stratifying habitat features of large landscapes, but their usefulness depends on resolution. For example, we noted that moose foraged heavily in narrow (1–5 m wide) incised drainages in the Unit 20A foothills that often contained high browse production, but these features were often poorly defined or not distinguished by Landsat pixels and thus rarely chosen in random selection (e.g., 2 plots of extreme production from Unit 20A [Appendix E]). We encountered similar Geographic Information System bias against selecting narrow bands of young willows in the Kuskokwim River floodplain because disturbance had been confined to a narrow channel in recent years. Object-oriented classification of polygons from pixels with similar reflectance values imagery may allow adequate definition of these narrow features in higher resolution (Baatz et al. 2001), but such efforts are expensive and require specialized equipment and skills (T. Paragi, ADF&G, unpublished data, Fairbanks). Presently this level of habitat resolution is suitable only to relatively small areas for research projects, not as a management tool that could be consistently applied across Interior Alaska.

A priori selection of sampling sites by a stratified random method often created the logistical problem of needing to select alternative sites based on incorrect stratum typing, and many sites did not contain browse (a fact useful in estimating landscape-level production but not removal). Selection of alternative plots without a separate reconnaissance is desirable when expensive means of access are used. Distance to landing site is also important because snowshoe access in deep snow can be time-consuming. In 2006 we began using the helicopter heading method to efficiently sample large remote landscapes based on moose density strata (i.e., evidence of winter range use). Moose surveys in areas of Interior Alaska where snow is most frequently deep (e.g., Units 19 and 21) typically are done in mid to late winter for logistic reasons (flying weather, complete snow cover, day length), thus potentially represent the greatest concentration of moose on available range. Moose surveys in other areas of the Interior are done in early winter to permit estimates of sex composition but may not represent the greatest concentration of moose observed in deep snow years.

One goal of our applied research was to derive cost-effective techniques to assess browse use at a large scale germane to moose population management. Estimating browse removal is labor intensive and must occur just before the start of new plant growth in spring, when travel conditions on snow begin to deteriorate. Cost of access by snowmobile, riverboat, or ATV was about $30/plot based on $40 transportation costs per person per day with a 4-person crew completing 5 sample plots per day. A piston helicopter with 4 seats (charter cost $550/hr excluding fuel) allowed a pair of biologists to sample 3 plots per hour of flight by rapid access to terrain often difficult for ground travel. Flying a helicopter heading to locate landing spots in randomly chosen cells (2006–2007) was about $375/plot to acquire a sample size of 30 plots in a remote area (24–64% of chosen landing sites didn't have browse CAG within 100 m and were skipped; Table 1). We believe the helicopter heading procedure represents a practical means to objectively sample browse in large remote areas. For comparison between indices, operational cost of a browse survey by helicopter in a remote area (ca. $12,000 excluding biologist salary) typically exceeds the cost of 2 years of twinning surveys unless several flights are needed to ascertain date of peak calving.

When interpreting results to a lay audience, it should be clarified that this technique is an *index to moose forage removal* from a minute sample of a large complex landscape, not a robust estimate of total production or total removal at the landscape scale or even within vegetation strata. Twinning rate in moose encompasses many factors (summer forage, winter forage, energetic constraints of snow, age structure of cows, etc.), and fortunately the strength of the inverse correlation of twinning rate with the simple index of browse biomass removal is strong enough to allow inference in instances where twinning rates cannot be obtained from aerial survey (e.g., areas with low moose density or thick vegetation). A common misperception is that the comparatively high browse removal in Unit 20A (42%) means that more than half of the browse remained, which could imply that the population had adequate food to support a further increase in moose density. However, because the moose population in Unit 20A had a concurrent twinning rate of only 7%, such data must be viewed with extreme caution. The population might still increase (albeit at declining nutritional condition with higher density), but the prolonged heavy browsing that creates a high incidence of broomed shrubs and dead twigs interspersed among live twigs on older shrubs will limit the intake rate and increase energy expenditure as moose search for forage. A substantial proportion of forage may not be available to moose under conditions of heavy prolonged browsing, or the smaller diameter twigs in older shrubs may be too small for efficient intake.

CONCLUSIONS AND RECOMMENDATIONS

Browse surveys are one of several tools available to gauge nutritional condition of moose populations in the boreal forest of Alaska (Boertje et al. 2007). Browse surveys characterize one component (winter energy source) of moose survival and reproduction. We recognize the difficulty in consistent interpretation of winter forage indices alone where direct data on autumn body condition (energy gain during prior summer) or winter severity (degree of energy loss to thermoregulation or mobility) are lacking. Annual variation in weather may influence forage production and especially winter access to forage by moose, confounding interpretation of browse data alone as a gauge of condition or a means to estimate carrying capacity. Twinning rate soon after parturition integrates the many functions of habitat (summer and winter forage, mitigation of winter severity, concealment from predators) in a given time frame to gauge productivity potential of a population before post-partum mortality of moose calves occurs. Evidence of annual variation in twinning rate (likely due to sampling error and annual variation in environmental conditions) suggests that multi-year estimates are prudent in harvest management systems (Boertje et al. 2007). Where twinning rate is difficult to rigorously estimate in low-density populations (inadequate sample size) and invasive measures of animal condition are not feasible, the relationship we demonstrated (Fig. 6) suggests that proportion of browse biomass removed is a reasonable proxy to moose population condition. Observations during browse surveys additionally permit inference on vegetative succession useful in understanding the frequency and spatial extent of disturbances (flooding, fire). For example, in the western Interior we have observed feltleaf willow stands that are classified as tall shrub from satellite imagery but exist as 30- to 40-year-old canopy forest of 10 m height formed after flood events that have not reoccurred since.

Evaluating the nutritional capability of range to support wild ungulates has application for assessing development impacts and cost–benefit analysis of habitat enhancement projects (Schwartz and Renecker 1997). The individual-animal approach involves predicting daily dry intake (kg) based on DPB for a given range and comparing it to energy requirements of an average moose to assess ability of a range to support moose (Seaton 2002:26). This approach has a stronger theoretical basis than our index, which merely characterizes the relative proportion of browse biomass removed. Characterizing the quality of browse (e.g., digestible energy as a function of twig diameter by plant species) could further refine predictions of energy intake from biomass alone for comparison to requirements of moose. However, predicting energy balance involves numerous assumptions about a "model" animal, and further laboratory analyses would add expense to our already labor-intensive technique. We believe the idealized scenario of predicting potential moose density from range assessment to set harvest management objectives based on a model of food-based carrying capacity is not practical for free-ranging moose populations under present logistic constraints in Alaska. To our knowledge no such predictions have been field validated at the population or landscape scale. The present use of nutritional indices provides adequate guidance for harvest management decisions within budget constraints (Boertje et al. 2007). Twinning rate and proportion of browse removed have been discussed as tools for planning moose harvest under intensive management in Unit 20D (DuBois 2008). Currently the intensive management population and harvest objectives (5 AAC 92.108) are an expectation of what an area can produce under management of predation and habitat, with yield being a defined proportion of sustainable harvest from the pre-hunt population. As moose density increases, the use of environmental feedbacks (decline in twinning rate or increase in proportion of browse removed by moose) to implement methods of increasing yield (e.g., beginning or increasing level of antlerless harvest) would be an empirical approach by the Alaska Board of Game and its local advisory committees to define the upper range of sustainable population and harvest objectives in high density populations. Population management based on nutritional indices also overcomes the difficulty of modeling energy balances of individual moose by assessing complex range parameters over large, remote areas and modeling energy balance with numerous assumptions.

Future evaluation of the browse technique should include estimating the proportion removed over successive time periods in populations that are relatively stable in abundance to understand whether the index is robust to temporal variation induced by environmental variables, such as snow depth. Defining winter habitat selection by moose during low–moderate and deep snow years may improve browse sample allocation over simply using GSPE cells from moose surveys. We collected snow depth at all plots as a means to gauge browse availability to moose, whether by physical concealment of twigs or by energetic constraints to access for different age classes. A model of winter habitat selection is being developed for the McGrath area based on telemetry and survey data during winters of low and deep snow (Federal Aid Project 5.20, Habitat evaluation techniques for moose management in Interior Alaska). If models predicting regional snow depth and habitat selection by moose prove robust, we can conduct a retrospective spatial analysis of browse data to test whether our characterization of range condition by browse removal or plant architecture is sensitive to position of sample plots on the landscape for years of low snow compared with deep snow. In addition to our index to biomass removal, characterizing the distributions of CAG diameter and DPB with respect to architecture of plants (growth form in response to browsing by moose) may be instructive for interpreting architecture data alone if twig size is consistently different among growth forms in an area. Improved spatial inference and greater understanding of plant architecture indices could enhance use of browse data as a management tool if indices from smaller scale sampling in accessible areas of winter range (e.g., river floodplains) are correlated to population indices, such as twinning rate.

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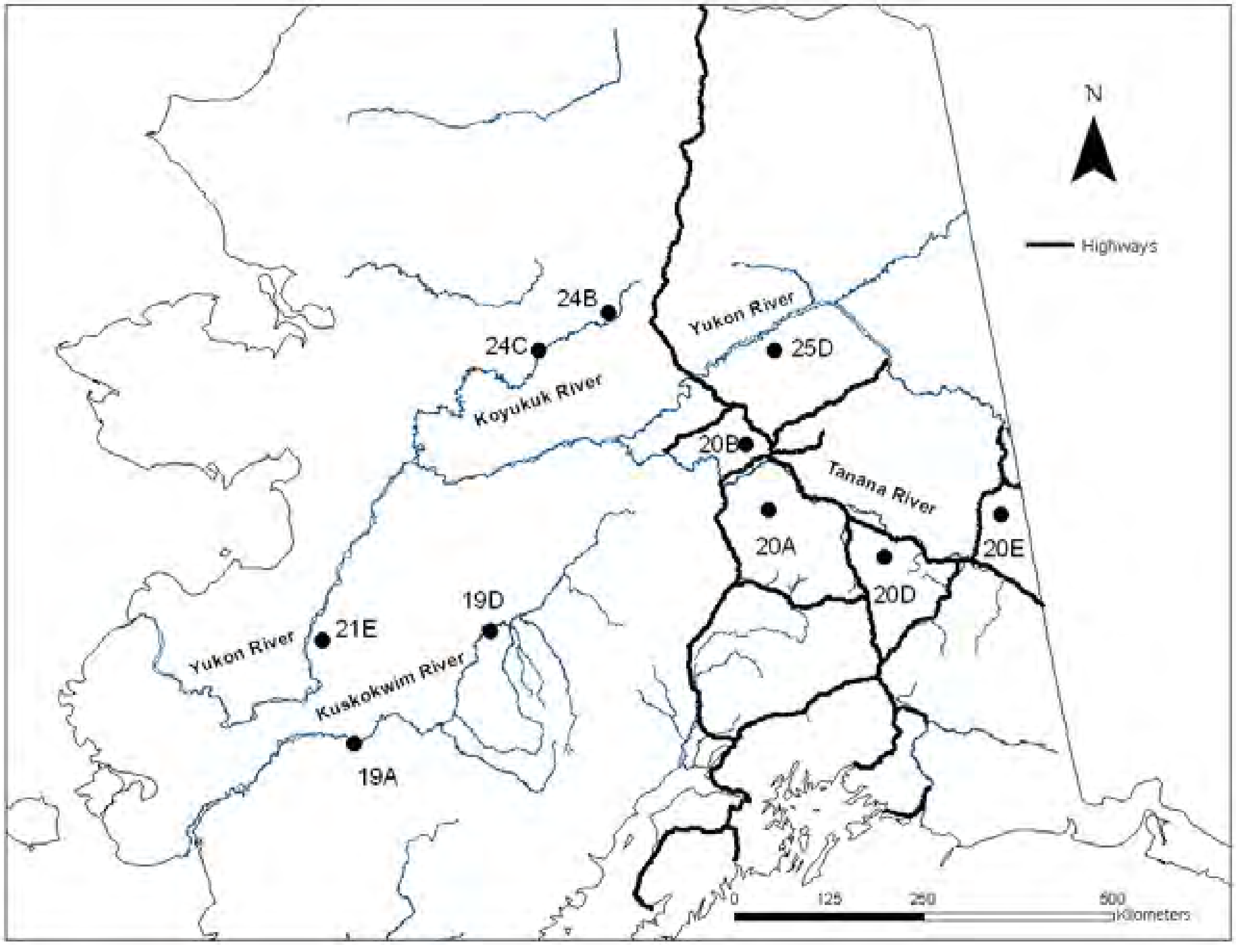


FIGURE 1 Location of 10 study areas identified by game management unit where browse production and its removal by moose were sampled during 2000–2007 in Interior Alaska

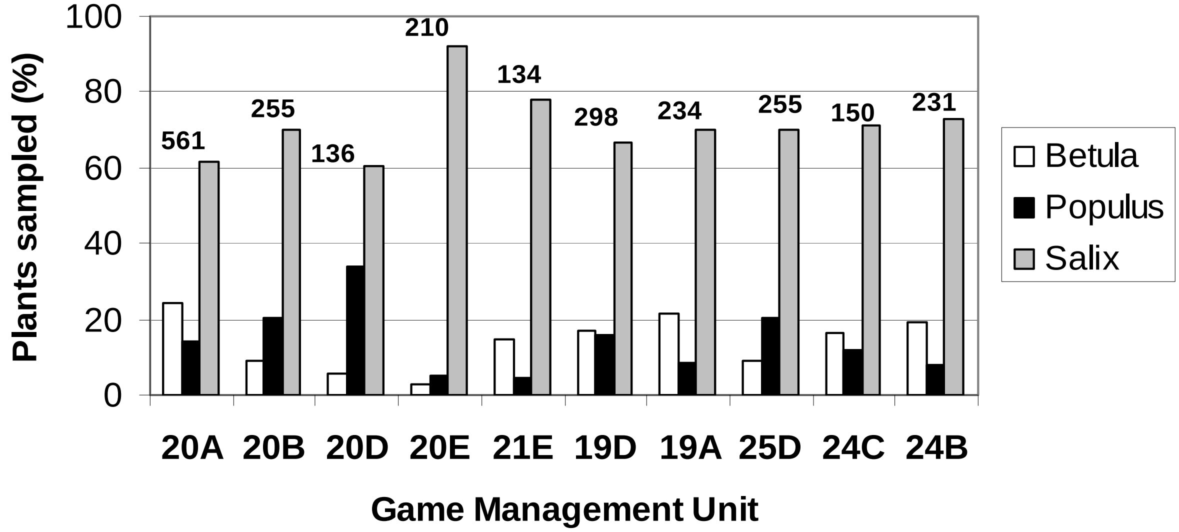
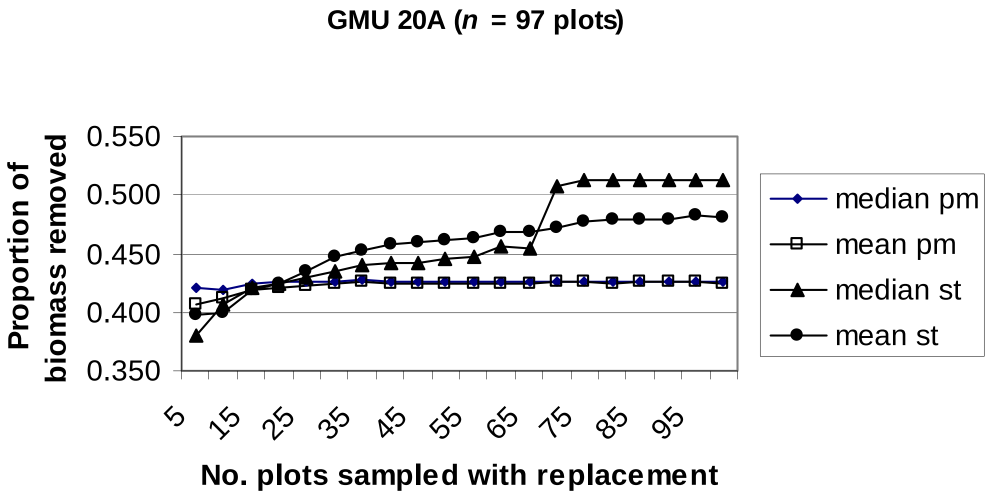


FIGURE 2 Genera composition of browse plants sampled to estimate biomass removed by moose browsing among 10 game management units of Interior Alaska, 2000–2007. Sample size is listed above the bars. *Cornus stolonifera* was also sampled in Unit 19D (n = 2) and Unit 21E (n = 6).

a



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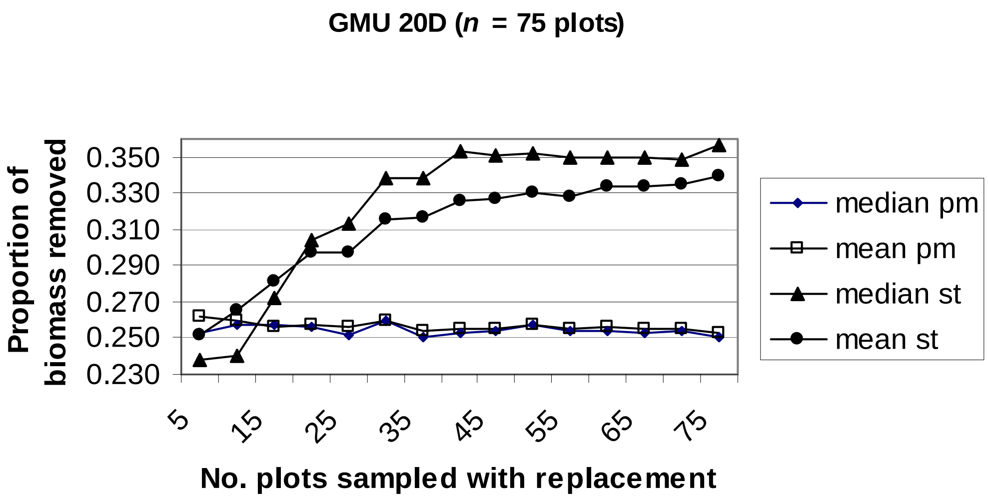
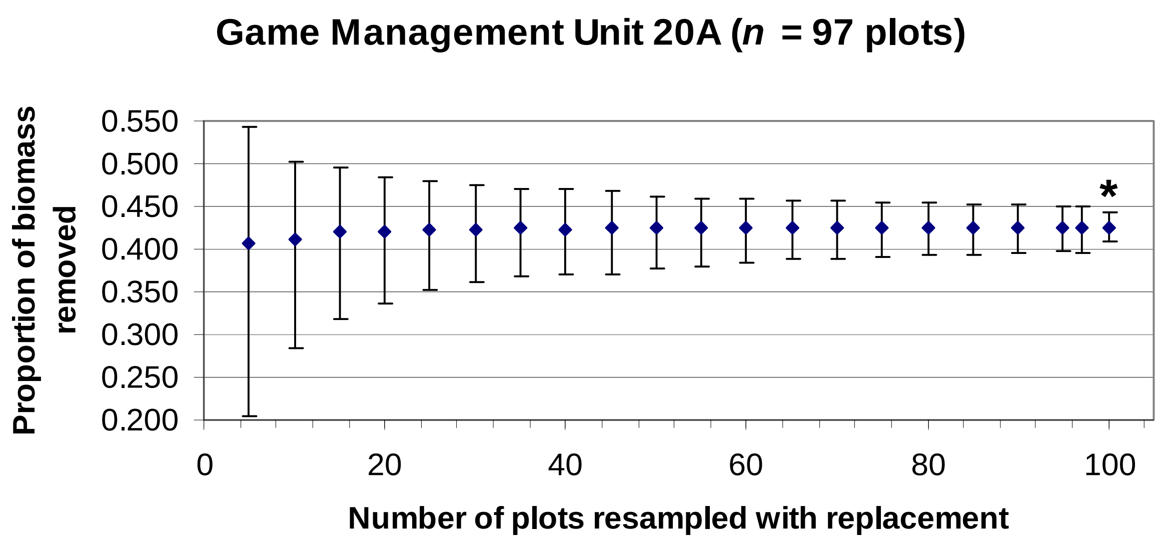


FIGURE 3 Estimates of browse removal by moose as a function of sample size in Game Management Units (Unit) 20A (a) and 20D (b) in Interior Alaska, 2000 and 2007, respectively. Bootstrap estimates of mean and median proportion of biomass removed (resampling with replacement, 1000 iterations) were done at the plant mean (pm) level from sampled twigs only and at the species total (st) level from sample data extrapolated to plot species composition.

a



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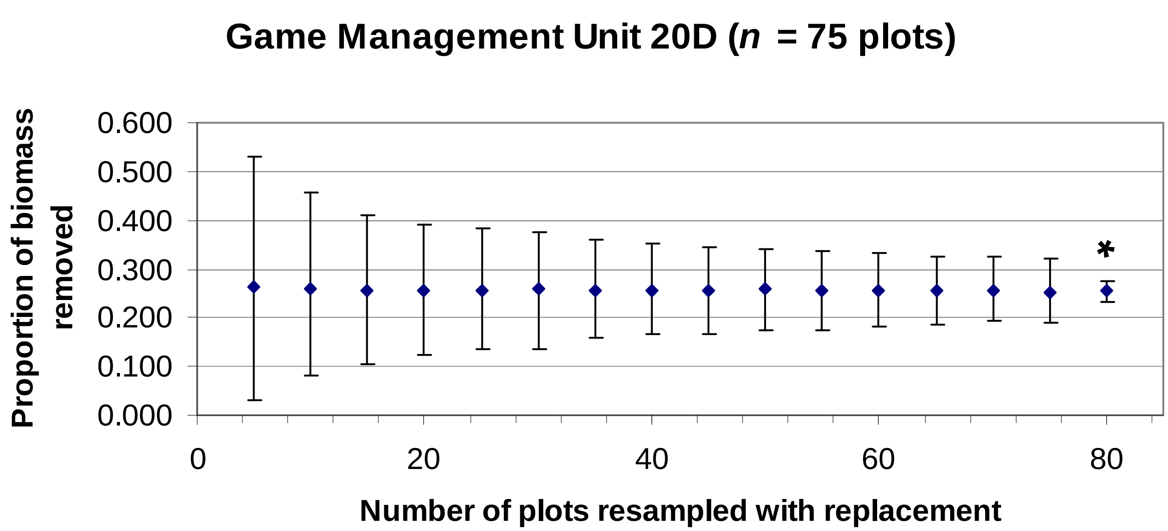


FIGURE 4 Simulated effect of number of plots sampled on mean and 95% confidence limit for proportion of browse biomass removed (sampled twigs only) by moose in Game Management Unit 20A (a) and Game Management Unit 20D (b) in Interior Alaska. Estimates at each sample size were derived by bootstrapping with 1000 iterations except for the last in each series (*), which was the deterministic estimate and confidence interval at the actual sample size.

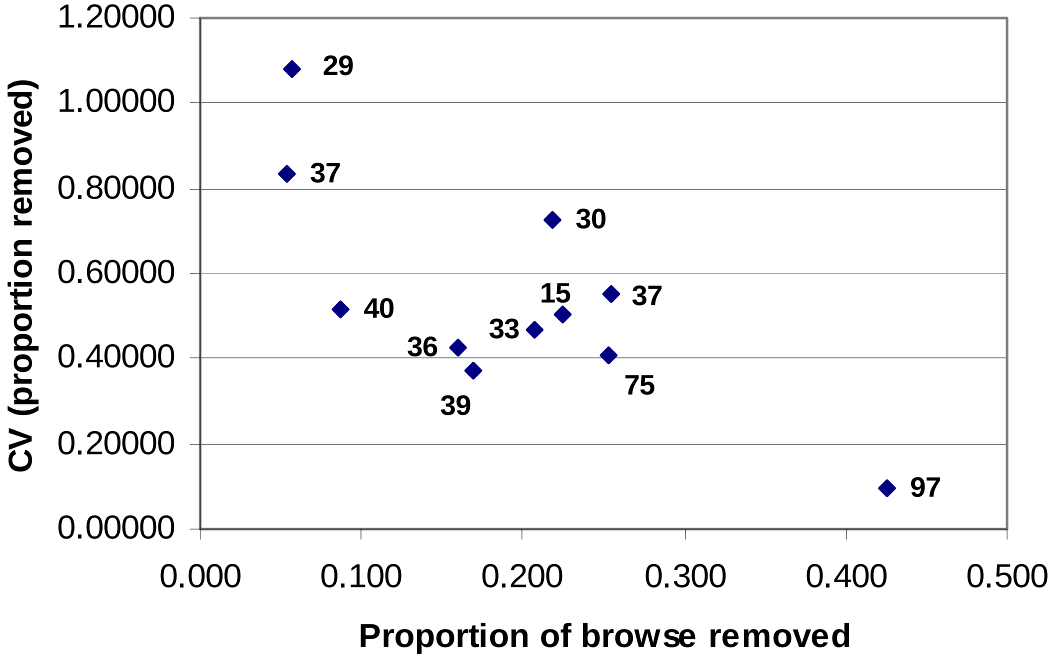


FIGURE 5 Relationship between the proportion of browse removed (sampled twigs only) by moose and its coefficient of variation (CV = [s.e./mean]*100) for 10 study areas in Interior Alaska, 2000–2007. Estimates were derived by bootstrapping, with number of plots resampled shown for each study area.

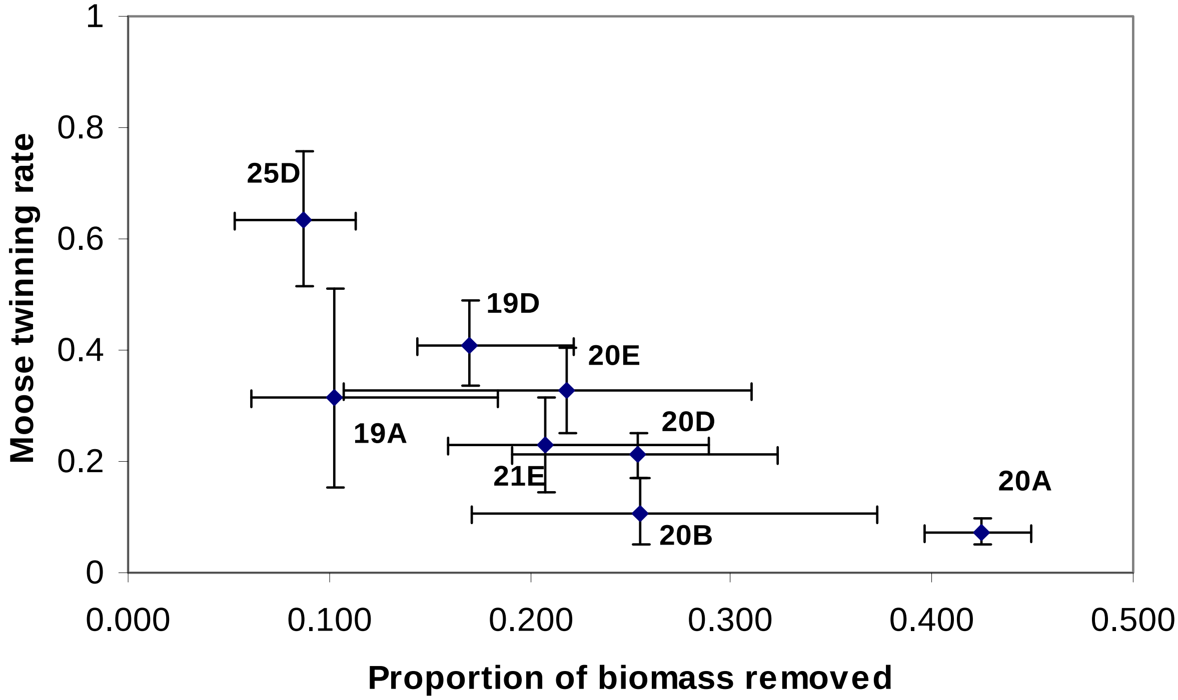
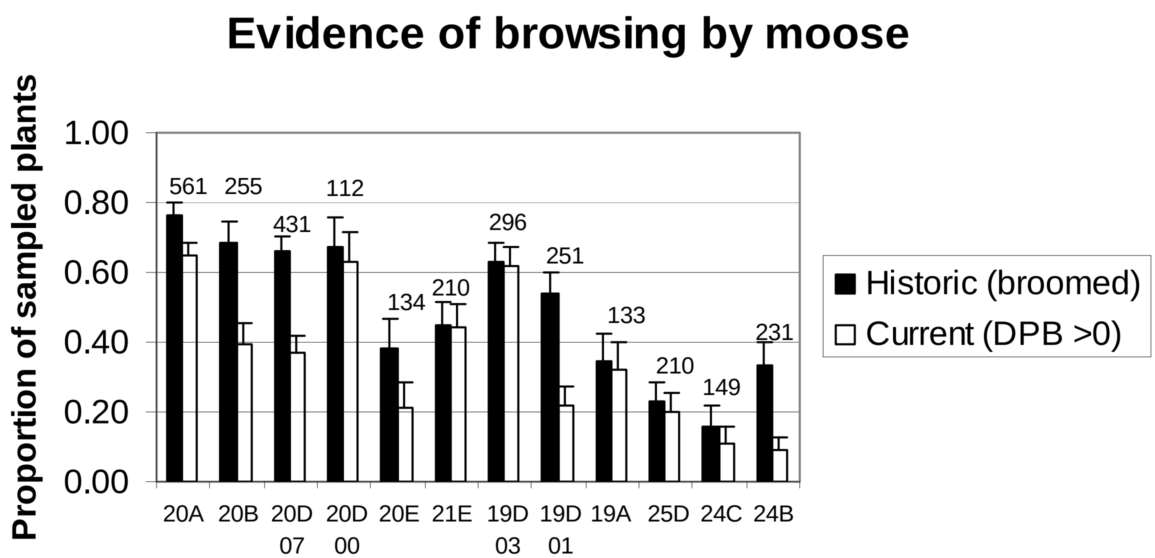


FIGURE 6 Relationship between proportion of CAG browse biomass removed (sampled twigs only) by moose and proportion of cow moose with twin calves for 8 study areas in Interior Alaska, 2000–2007. Estimates were derived by bootstrapping, and error bars indicate bootstrap 95% confidence limits.

a



b

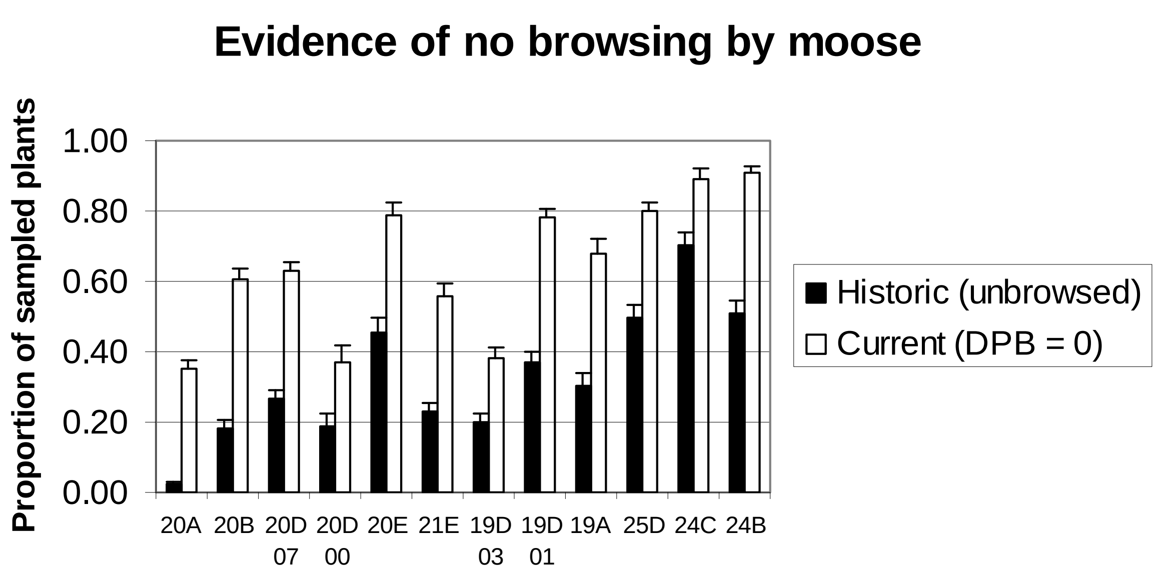


FIGURE 7 Proportion of plants with (a) evidence of browsing based or (b) lack of browsing based on growth form (see methods) and proportion of plants browsed in the current year among game management units in Interior Alaska, 2000–2007. Broomed index (a) is number of broom plants divided by the sum of broomed and browsed plants (i.e., all browsing). Binomial confidence interval (95%) is shown above bars, and number of plants sampled is shown in Table 1.

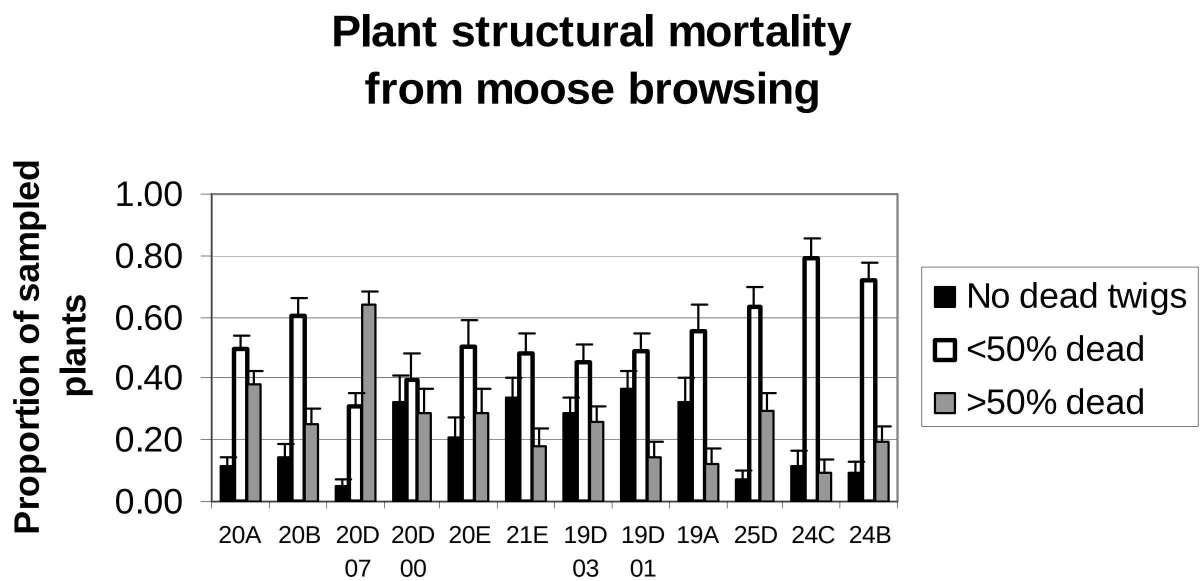


FIGURE 8 Proportion of plants with no twig mortality, less than half of biomass dead, and more than half of biomass dead as a result of moose browsing among game management units in Interior Alaska, 2000–2007. Binomial confidence interval (95%) is shown above bars, and number of plants sampled is shown in Table 1.

TABLE 1 Sampling effort for moose browse surveys by game management unit in Interior Alaska, 2000–2007

Unit	Year(s)	Sites[b]	*n* Plots	*n* Plants	*n* Twigs	Plot cover type (% total)[a] Tall shrub	Open forest	Closed forest
20A Flats	2000	–[c,d]	48	326	3405	--	--	--
20A Hills	2000	–[c,d]	49	235	2504	--	--	--
20A Total	2000	–[c,d]	97	561	5909	--	--	--
20B	2007	–[e]	37	255	2336	8	22	70
20D Flats	2007	50[d]	46	285	2752	39	6	55
20D Hills	2007	38[d]	29	152	1560	86	11	3
20D Total	2007	88[d]	75	437	4312	59	4	37
20D	2000–2001	–[e]	15	113	1100	--	--	--
20E	2006	71	30	135	1422	37	30	3
21E	2006	77	32	210	1606	74	19	6
19D	2003	78[d]	39	298	2377	72	9	19
19D	2001	69[d]	36	251	2420	53	25	22
19A	2006	75	27	134	1249	48	41	4
25D	2000	–[f]	40	210	2360	--	--	--
24C	2007	48	29	150	1592	38	41	21
24B	2007	64	37	231	2350	62	32	5

[a] Low shrub plots with browse above snow occurred in Units 19A (n = 2), 20E (9), and 21E (1).
[b] Number of sites visited by helicopter, some of which had no browse above snow.
[c] Helicopter access and pre-sampling reconnaissance described in Seaton (2002).
[d] Access by snowmachine or road vehicle to some plots.
[e] Access by snowmachine, ATV, or road vehicle to all plots.
[f] Access by boat to all plots.

TABLE 2 Percent frequency of microhistological plant fragments in fecal pellets collected during capture of 25 adult cow (≥1 yr old) and 15 short-yearling cow (<1 yr old) moose in March 2001 in eastern Unit 19D

Browse type	Adult cows	Female short-yearlings
Alnus stem	10.7	4.1
Betula leaf	--	0.2
Betula stem	15.9	26.0
Populus stem	5.8	3.7
Salix hair	2.2	1.1
Salix leaf	3.3	8.2
Salix stem	61.8	56.0
Shrub leaf	0.3	--
Total	99.7	99.3

TABLE 3 Mean production of current annual growth and browsing removal of woody biomass by moose, reported by game management unit in Interior Alaska, 2000–2007. Per-plot estimates are derived from sampled twig data extrapolated to plot composition.

		Production (kg/ha)		Removal (kg/ha)	
Unit	Year	$\bar{x}$	95% CI	$\bar{x}$	95% CI
20A[a] Flats	2000	173.05	9.04	59.83	4.73
20A[a] Hills	2000	744.88	154.32	414.06	84.34
20A[a] Total	2000	477.07	78.08	238.77	21.76
20B	2007	76.59	8.30	30.57	3.59
20D Flats	2007	71.67	7.56	25.04	4.14
20D Hills	2007	22.69	2.15	8.02	1.31
20D Total	2007	52.33	4.65	18.32	2.56
20D	2000–2001	32.69	6.60	4.86	0.71
20E	2006	63.37	20.78	13.75	4.24
21E	2006	260.52	21.68	66.23	6.77
19D	2003	671.60	50.53	135.91	12.55
19D	2001	200.86	18.69	36.84	4.80
19A	2006	87.96	10.02	12.50	2.38
25D	2000	181.12	14.13	17.10	2.61
24C	2007	51.41	5.06	4.39	1.42
24B	2007	22.36	1.38	2.01	0.44

[a] Seaton (2002:Table 7) excluded plots 353 and 481 with extremely high production from Unit 20A foothills (Appendix E), but they are included in these estimates.

TABLE 4 Estimates of browse removed by moose (sampled twigs only) reported by game management unit in Interior Alaska, 2000–2007. Frequency of browsing diameter on twigs (DPB) exceeding the current annual growth (CAG), frequency of plots where no DPB was sampled, and estimates for proportion of biomass removed are based on sampled twigs only (plant mean level in R program output). Twinning rate is estimated from aerial observation in late May over multiple years (see methods for details).

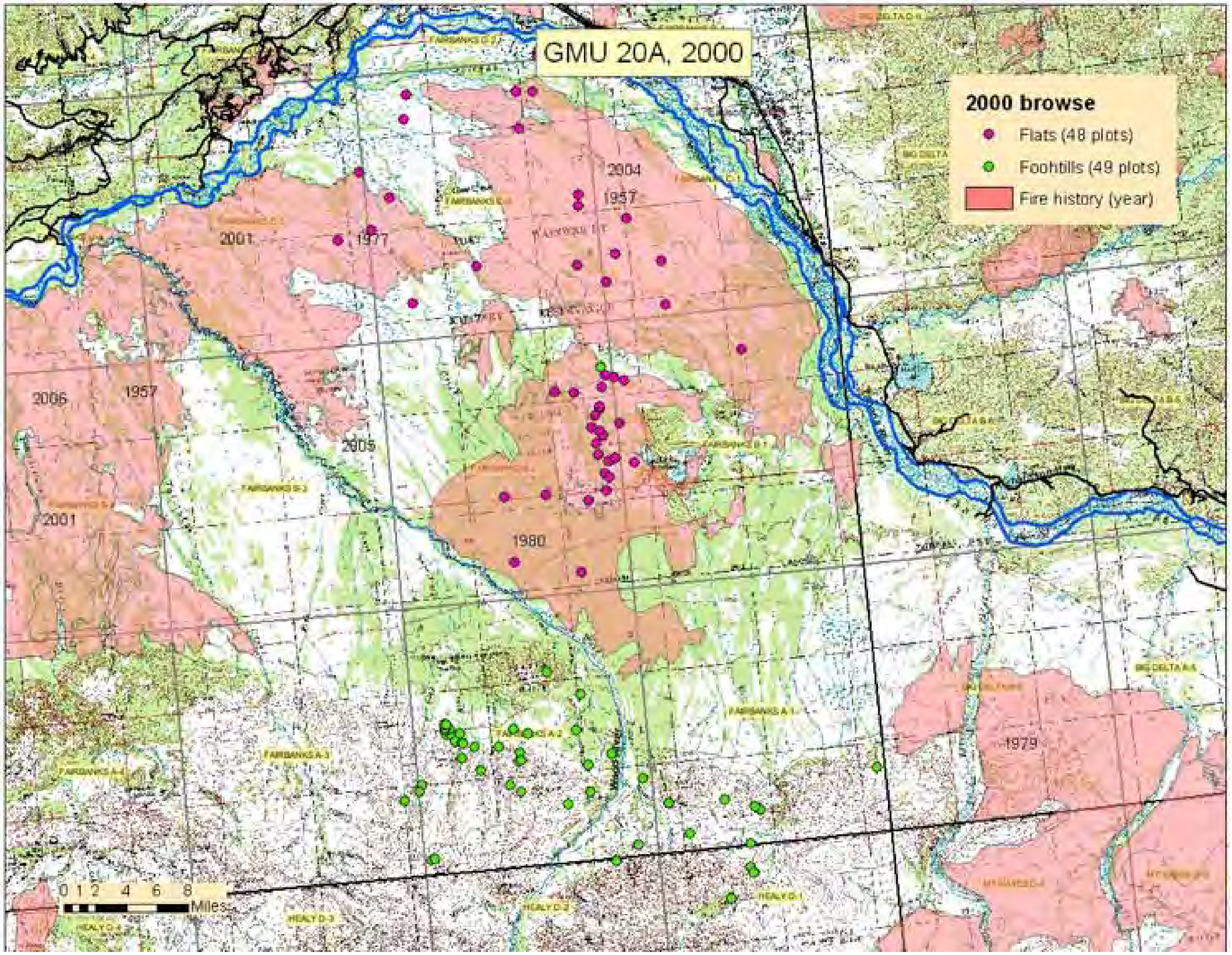
				Bootstrap[a] proportion browse biomass removed		Deterministic[b] proportion browse biomass removed		Bootstrap moose twinning rate[c]		
Unit	Year	Plots no DPB twigs (%)	Twigs DPB >CAG (%)	$\bar{x}$	95% CI	$\bar{x}$	95% CI	$\bar{x}$	95% CI	*n* Yr
20A Flats	2000	0	--	0.414	0.366, 0.456	0.415	0.037			
20A Hills	2000	14	--	0.433	0.394, 0.462	0.435	0.034			
20A Total	2000	7	--	0.425	0.397, 0.449	0.426	0.017	0.072	0.049, 0.097	9
20B	2007	24	17.0	0.255	0.171, 0.373	0.251	0.045	0.108	0.053, 0.170	3
20D Flats	2007	30	26.8	0.227	0.159, 0.306	0.223	0.029			
20D Hills	2007	45	11.7	0.302	0.169, 0.392	0.304	0.044			
20D Total	2007	36	21.2	0.253	0.191, 0.323	0.254	0.021	0.212	0.172, 0.253	7
20D	2000–2001	13	12.6	0.225	0.156, 0.294	0.227	0.030			
20E	2006	53	18.7	0.218	0.108, 0.311	0.219	0.032	0.327	0.253, 0.404	4
21E	2006	44	3.9	0.208	0.159, 0.289	0.203	0.026	0.228	0.146, 0.316	3
19D	2003	10	7.0	0.170	0.144, 0.222	0.160	0.015	0.409	0.335, 0.488	4
19D	2001	47	19.1	0.159	0.112, 0.195	0.160	0.024			
19A	2006	52	9.4	0.103	0.061, 0.184	0.084	0.021	0.317	0.154, 0.510	2
25D	2000	55	1.0	0.087	0.054, 0.113	0.088	0.010	0.636	0.513, 0.756	2
24C	2007	72	20.3	0.057	0.022, 0.095	0.055	0.010			
24B	2007	73	18.2	0.054	0.023, 0.079	0.053	0.010			

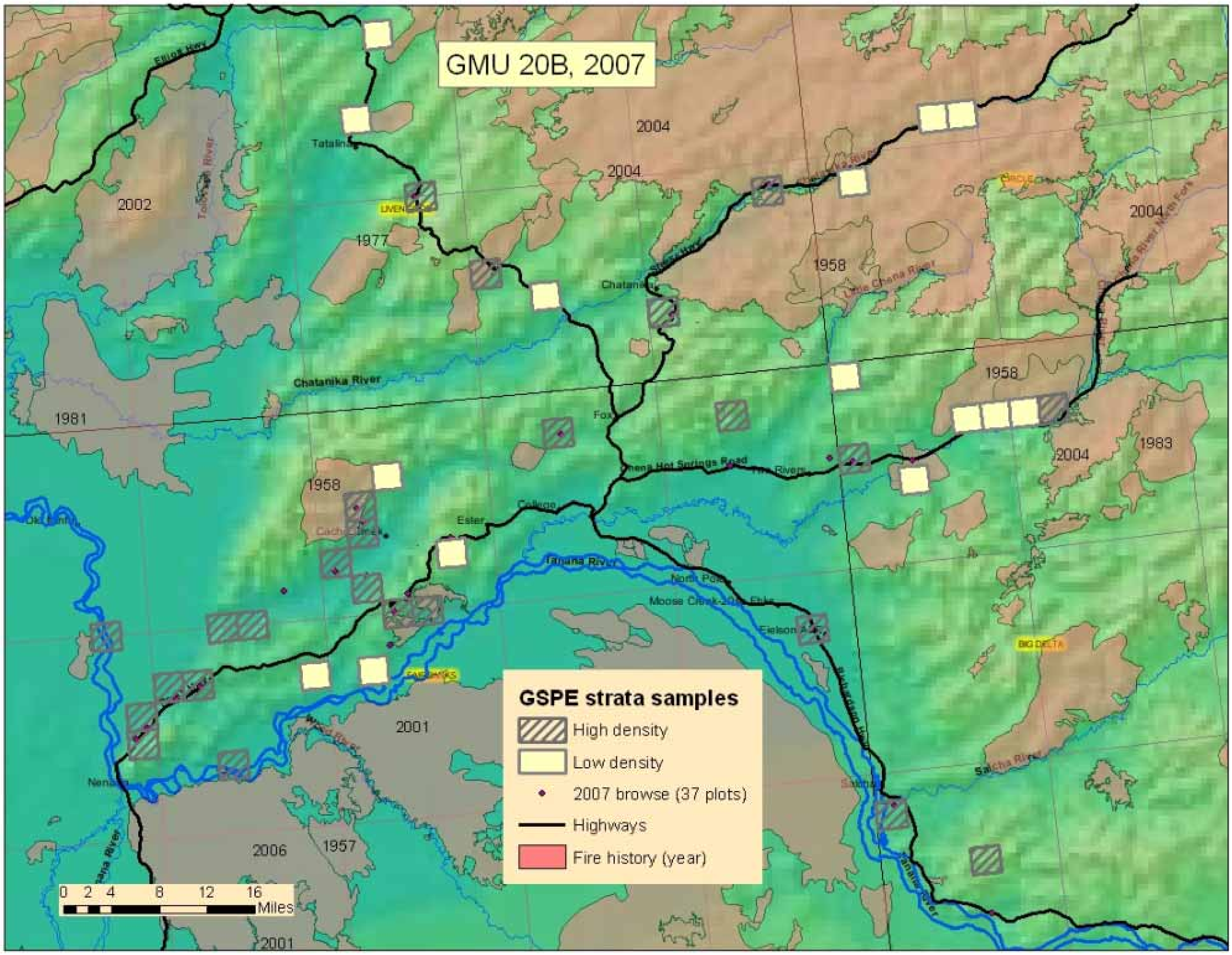
[a] Resampling with replacement from total number of plots (1000 iterations) for bootstrap estimates of mean and variance using formulas in Seaton (2002). Confidence interval produced with the percentile bootstrap method may be asymmetrical.

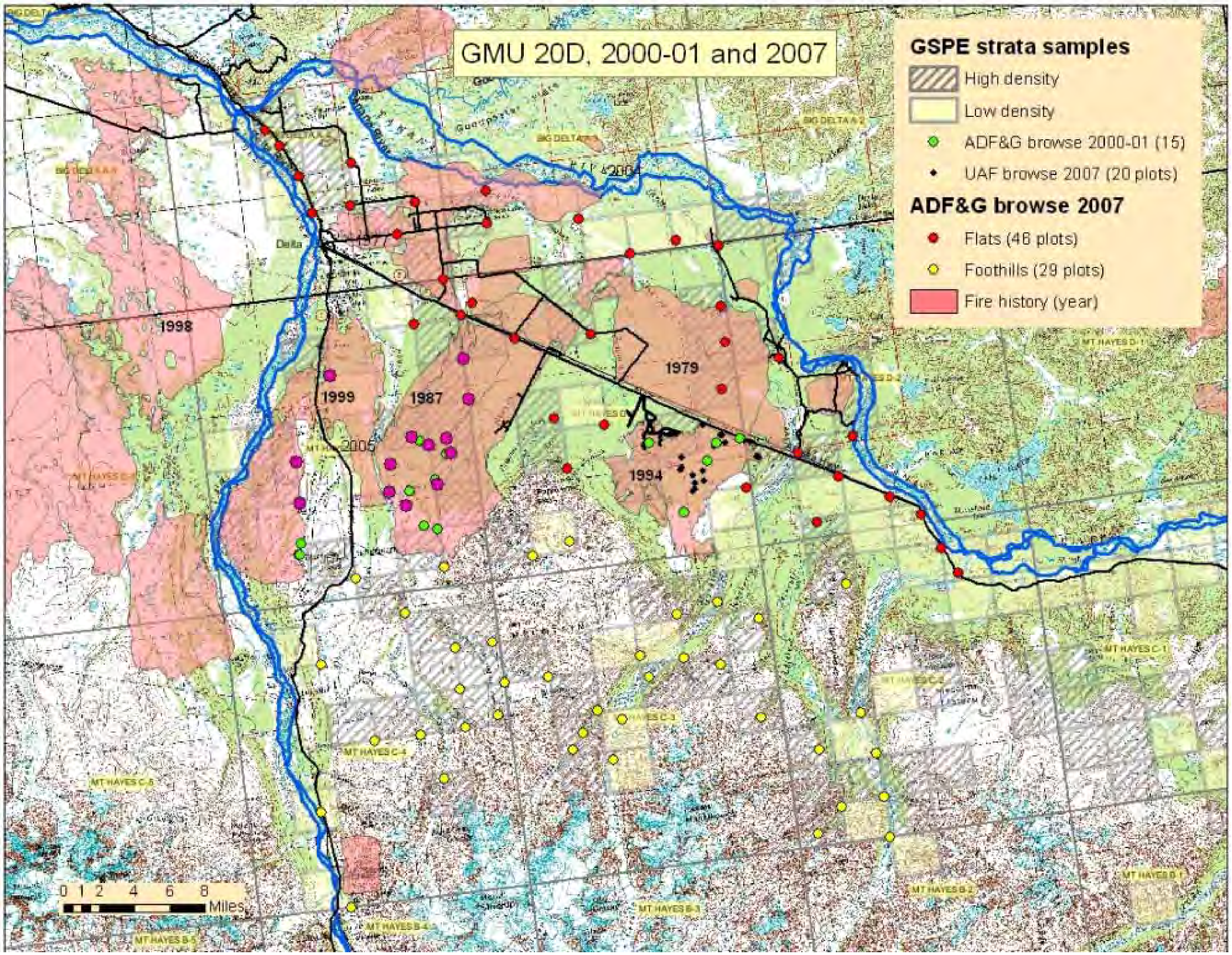
[b] Calculated using formulas in Seaton (2002). Delta method for variance estimation produced symmetrical confidence interval.

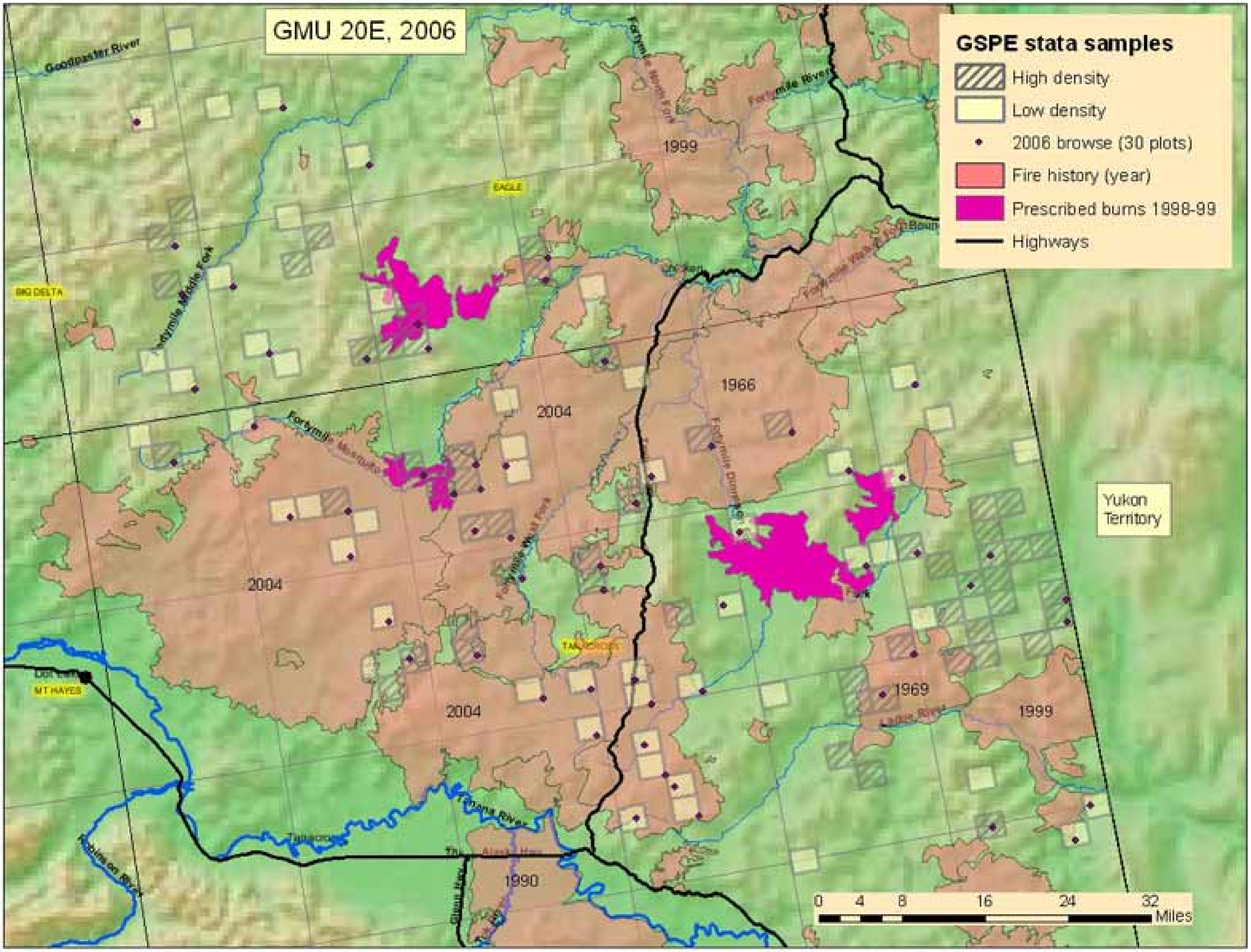
[c] Resampling with replacement (10,000 iterations) for bootstrap estimates of mean and variance. Confidence interval produced with the percentile bootstrap method may be asymmetrical.

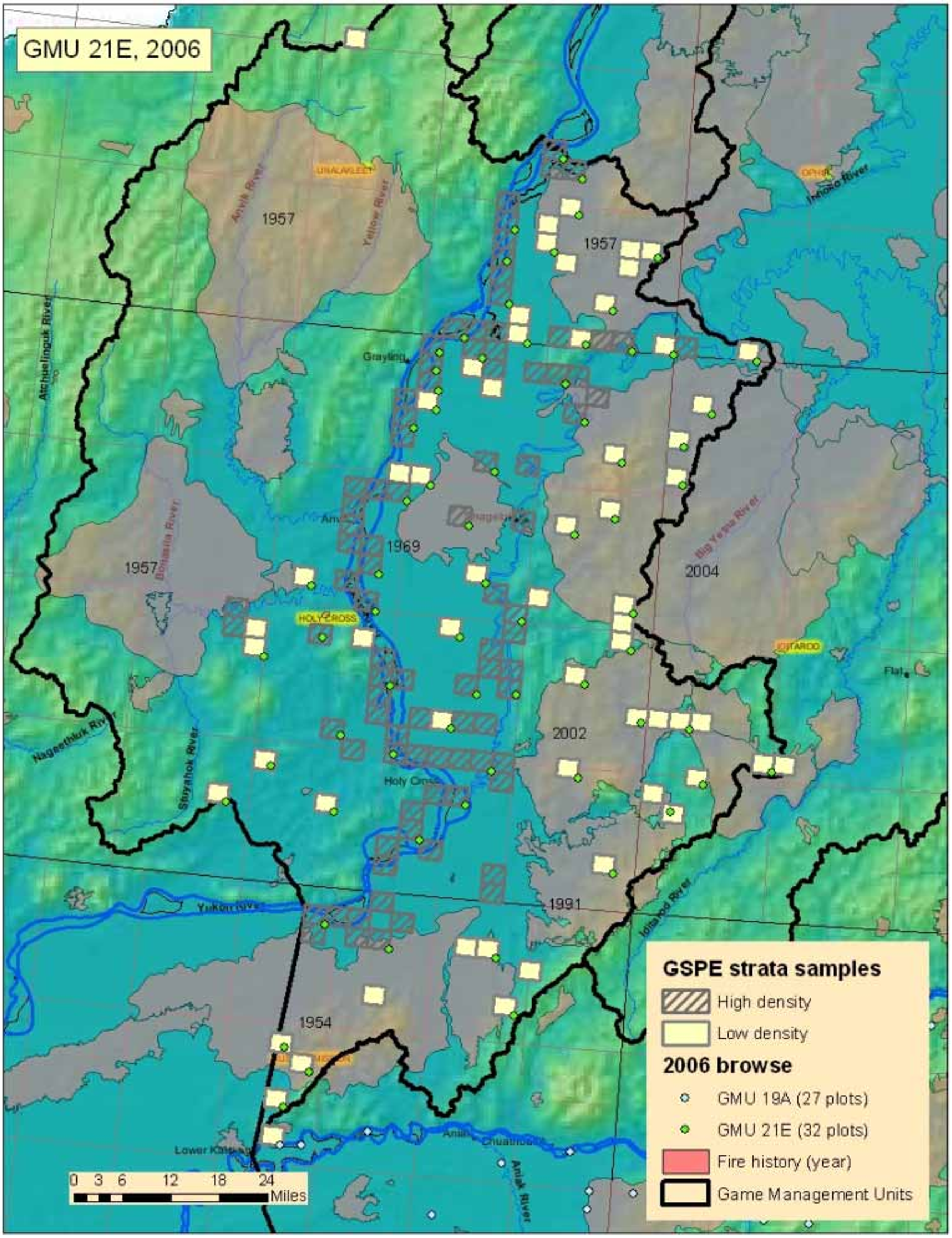
APPENDIX A Location of sample strata (high or low moose density cells) and sampled 30-m diameter plots for estimating production and removal of moose browse in 9 study areas of Interior Alaska, 2000–2007. No plot locations were collected in Game Management Unit (GMU) 25D on the Yukon Flats. Roads and the year and location of major fires are shown.

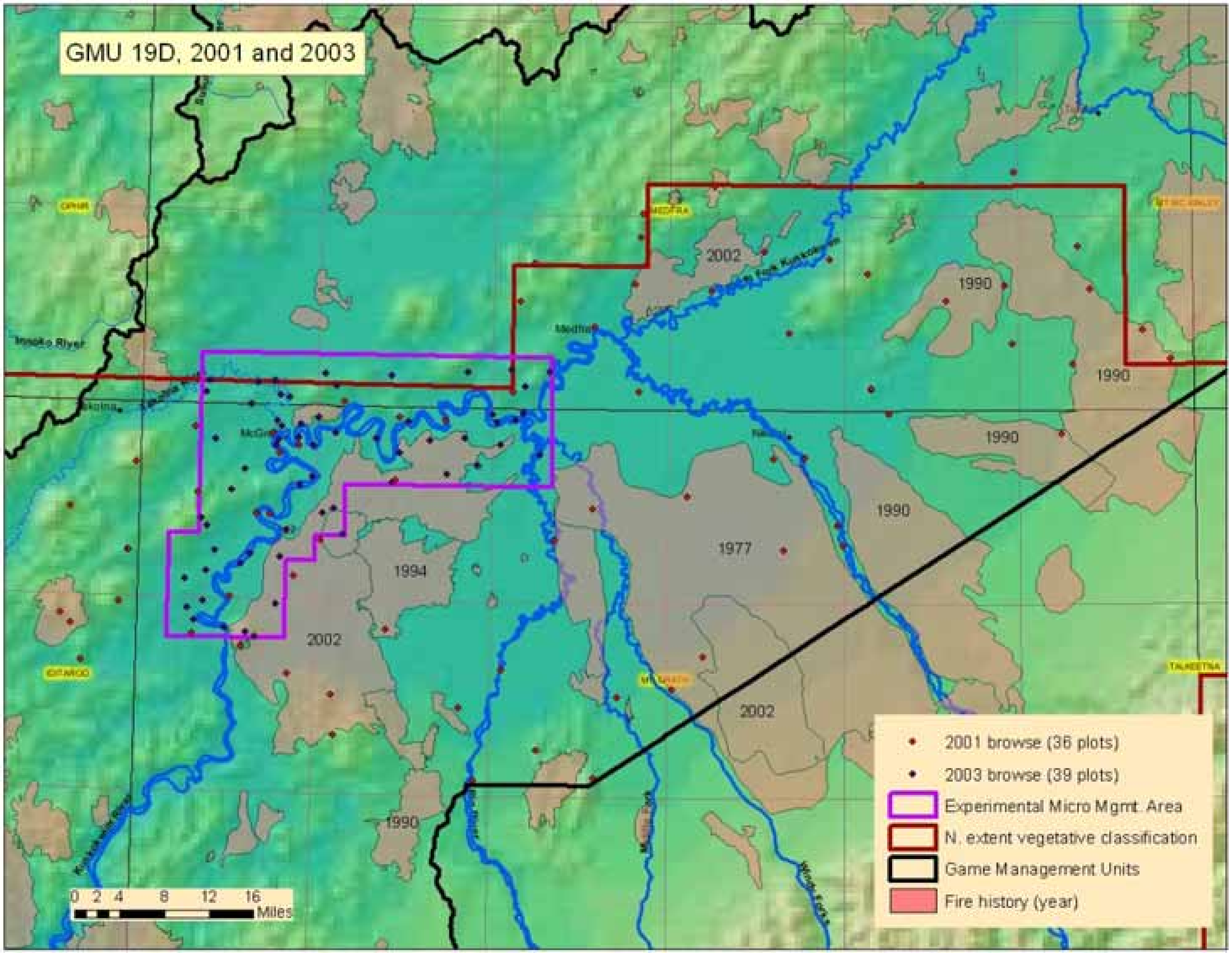


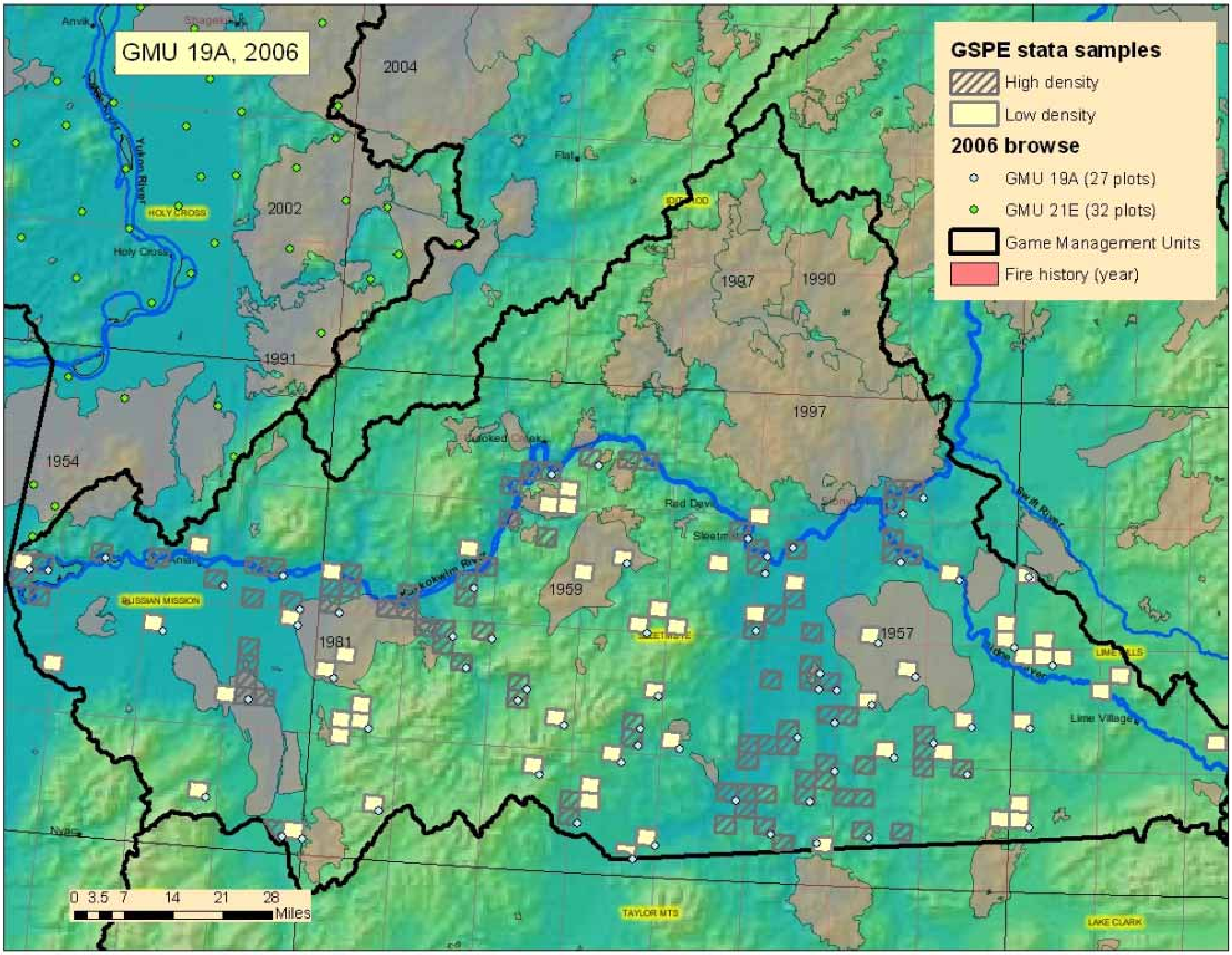

GMU 20B, 2007
GSPE strata samples
High density
Low density
2007 browse (37 plots)
Highways
Fire history (year)
0 2 4 8 12 16
Miles
Elliott Hwy
Chatanika River
Tanana River
Salcha River
Fox
Ester
College
North Pole
Eielson AFB
Nenana
2004
2002
1977
1958
1981
1983
2001
2006
1957

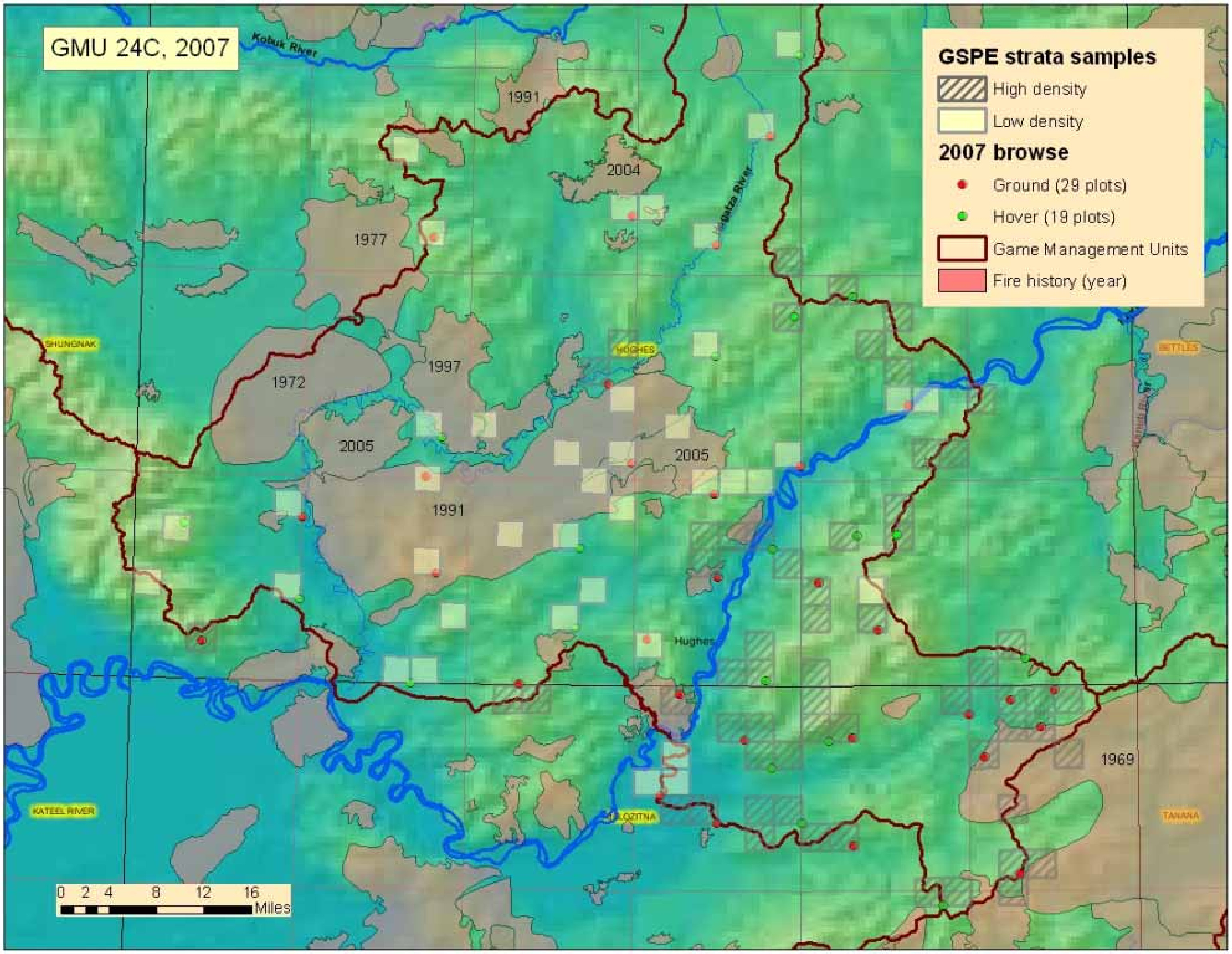

GMU 20D, 2000-01 and 2007
GSPE strata samples
High density
Low density
ADF&G browse 2000-01 (15)
UAF browse 2007 (20 plots)
ADF&G browse 2007
Flats (46 plots)
Foothills (29 plots)
Fire history (year)
1998
1999
1987
1979
1994
2005
2004
1977
Delta
0 1 2 4 6 8
Miles

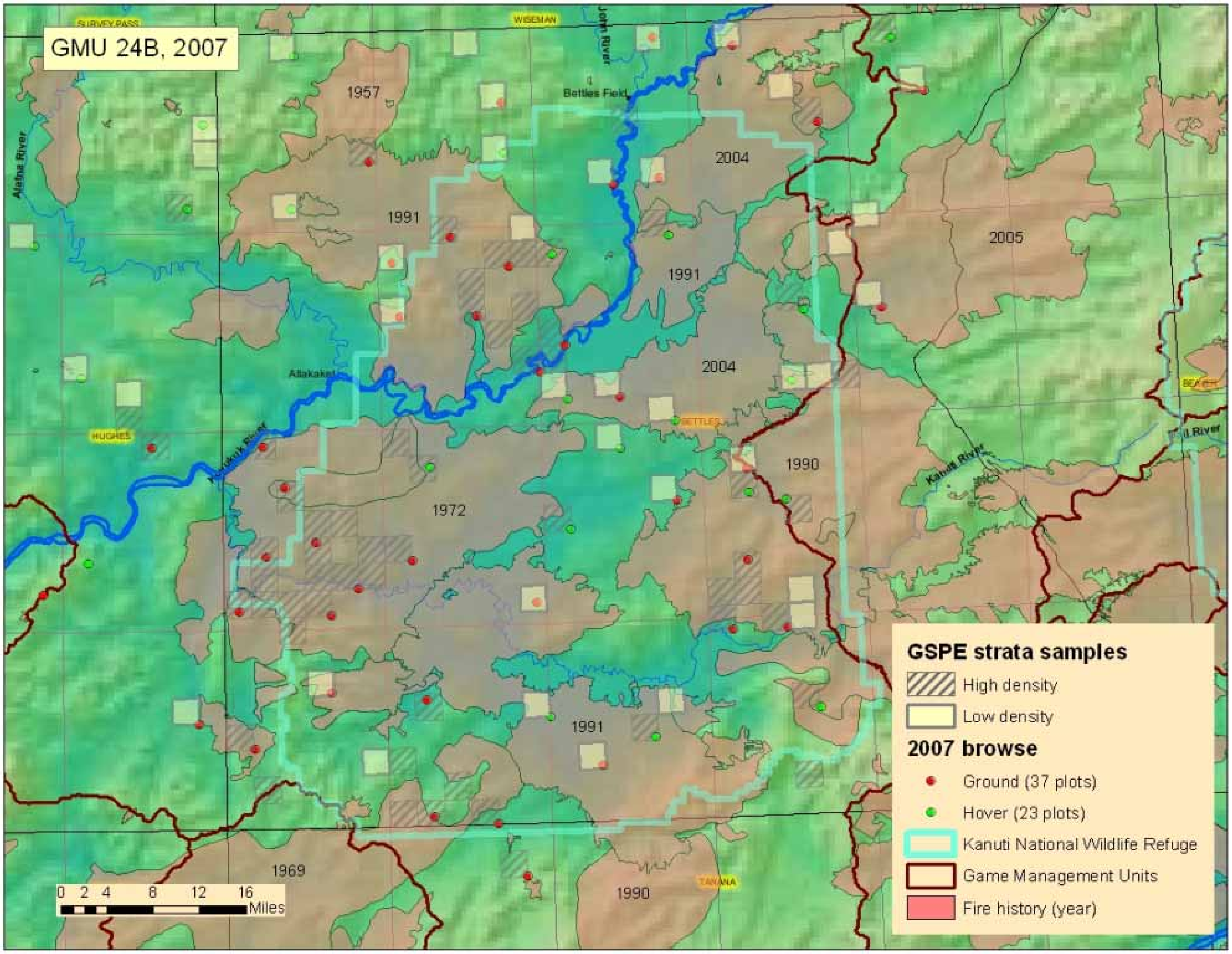

GMU 20E, 2006
GSPE stata samples
High density
Low density
2006 browse (30 plots)
Fire history (year)
Prescribed burns 1998-99
Highways
Yukon Territory
Goodpaster River
Fortymile River
Fortymile Middle Fork
Fortymile North Fork
Tanana River
1999
1966
2004
2004
2004
1969
1999
1990
0
4
8
16
24
32
Miles


GMU 21E, 2006
1957
1957
1957
1969
2004
2002
1991
1954
Grayling
Holy Cross
Yukon River
Innoko River
Big Yetna River
Iditarod River
Anvik River
Yellow River
Bonasila River
Nageethluk River
Stuyahok River
Atchuelinguk River
Anvik River
GSPE strata samples
High density
Low density
2006 browse
GMU 19A (27 plots)
GMU 21E (32 plots)
Fire history (year)
Game Management Units
0 3 6 12 18 24
Miles


GMU 19D, 2001 and 2003
Innoko River
McGrath
Medfra
Nikolai
2002
1990
1990
1990
1990
1977
1994
2002
2002
1990
0 2 4 8 12 16
Miles
2001 browse (36 plots)
2003 browse (39 plots)
Experimental Micro Mgmt. Area
N. extent vegetative classification
Game Management Units
Fire history (year)


GMU 19A, 2006
GSPE stata samples
High density
Low density
2006 browse
GMU 19A (27 plots)
GMU 21E (32 plots)
Game Management Units
Fire history (year)
2004
2002
1991
1954
1987
1990
1997
1959
1981
1957
Anvik
Yukon River
HOLY CROSS
Holy Cross
Flat
Crooked Creek
Red Devil
Sleetmute
Kuskokwim River
Aniak
RUSSIAN MISSION
SLEETMUTE
Swift River
Lime Village
Nyac
TAYLOR MTS
LAKE CLARK
0 3.5 7 14 21 28
Miles


GMU 24C, 2007
Kobuk River
GSPE strata samples
High density
Low density
2007 browse
Ground (29 plots)
Hover (19 plots)
Game Management Units
Fire history (year)
1991
2004
1977
1972
1997
2005
2005
1991
1969
Hughes
0 2 4 8 12 16
Miles

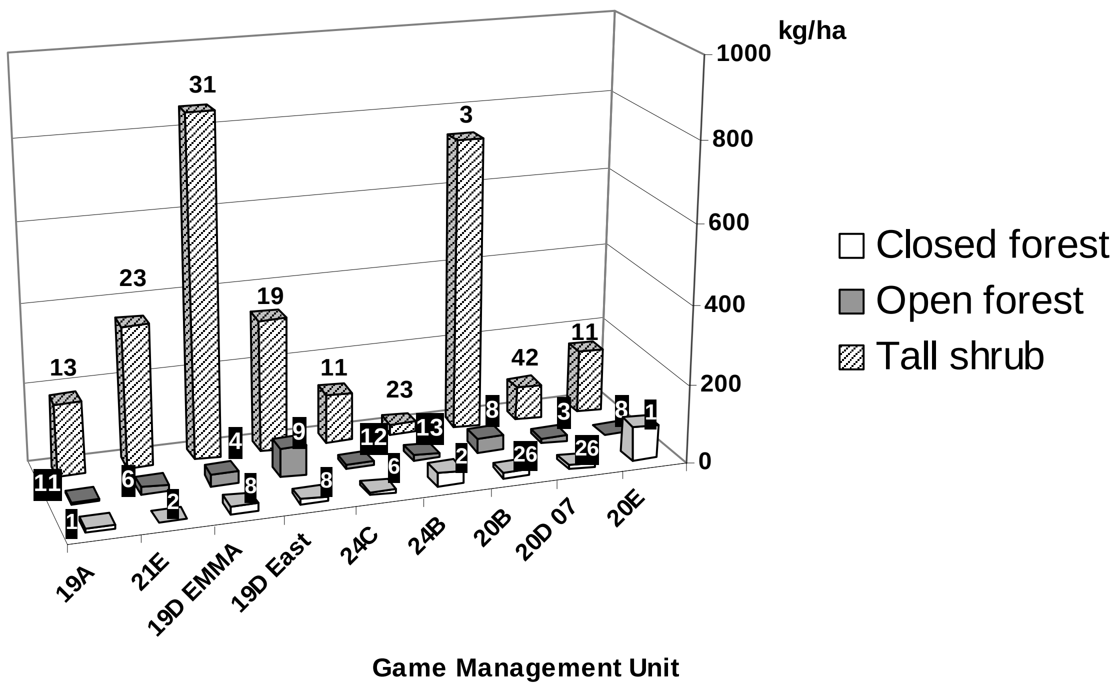

GMU 24B, 2007
1957
Bettles Field
John River
WISEMAN
2004
1991
2005
1991
Alatna River
Allakaket
2004
HUGHES
Koyukuk River
BETTLES
1990
Kanuti River
1972
1991
1969
1990
TANANA
0 2 4 8 12 16
Miles
GSPE strata samples
High density
Low density
2007 browse
Ground (37 plots)
Hover (23 plots)
Kanuti National Wildlife Refuge
Game Management Units
Fire history (year)

APPENDIX B Regression coefficients to predict dry matter (g) from twig diameter (mm) of moose browse species by game management unit in Interior Alaska, 2000–2007. Samples sizes in Unit 20A were larger because of research design to contrast Tanana Flats from Alaska Range foothills (Seaton 2002). For a species with <100 pairs collected in a unit, we pooled data from the nearest unit for calculations. Using log transformed data for the regression equation, drymass = $e^a * e^{mse/2} *$ diameter^b where *a* is intercept and *b* is slope. The terms $e^a * e^{mse/2}$ are listed as parameter "a" in Seaton (2002:Table 3).

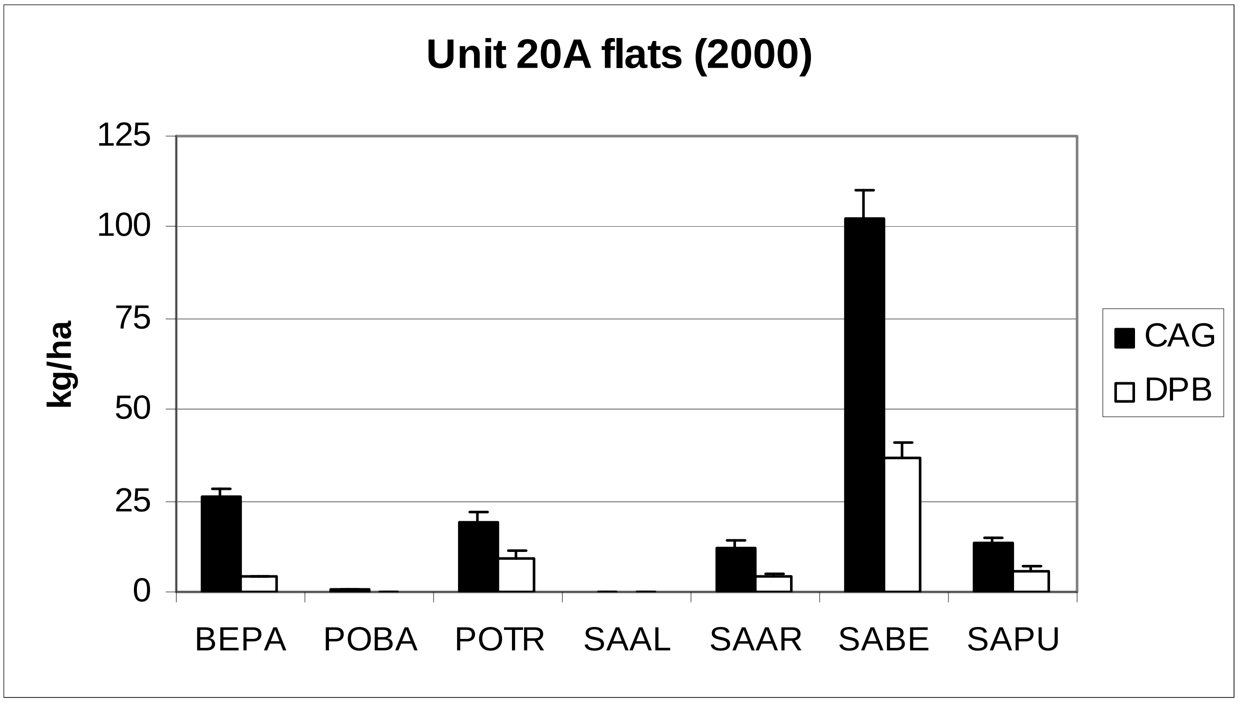
Species	Unit	Intercept	Slope	MSE	*n*	r-squared
Betula neoalaskana	19A	-4.352	3.344	0.134	59	0.928
Betula neoalaskana	19D	-3.273	2.967	0.107	55	0.972
Betula neoalaskana	20A	-3.914	3.338	0.124	259	0.974
Betula neoalaskana	20B	-3.911	3.296	0.140	154	0.968
Betula neoalaskana	21E	-3.519	2.829	0.097	25	0.763
Betula neoalaskana	25D	-3.721	3.204	0.146	50	0.972
Cornus stolonifera	21E	-5.427	4.023	0.180	61	0.896
Populus balsamifera	19A	-3.420	2.677	0.068	72	0.974
Populus balsamifera	19D	-3.335	2.705	0.080	111	0.968
Populus balsamifera	20A	-3.392	2.792	0.100	217	0.947
Populus balsamifera	20B	-3.285	2.831	0.095	100	0.952
Populus balsamifera	25D	-5.082	3.660	0.074	10	0.990
P. tremuloides	20A	-3.087	2.694	0.105	259	0.970
P. tremuloides	20B	-2.907	2.440	0.098	112	0.947
P. tremuloides	25D	-4.160	3.139	0.132	100	0.973
Salix alaxensis	19A	-5.645	3.763	0.259	209	0.925
Salix alaxensis	19D	-4.439	3.264	0.192	129	0.953
Salix alaxensis	20A	-4.558	3.304	0.275	751	0.903
Salix alaxensis	20B	-4.210	3.274	0.184	225	0.950
Salix alaxensis	20E	-4.574	3.308	0.271	751	0.905
Salix alaxensis	21E	-6.154	3.882	0.117	95	0.974
Salix alaxensis	25D	-4.326	3.318	0.161	104	0.963
S. arbusculoides	19A	-3.860	3.076	0.105	58	0.969
S. arbusculoides	20A	-3.575	3.284	0.158	123	0.963
S. arbusculoides	20B	-3.574	3.283	0.158	123	0.963
S. arbusculoides	20E	-3.712	3.276	0.223	89	0.947
S. arbusculoides	21E	-3.780	3.294	0.211	37	0.940
S. arbusculoides	25D	-3.604	3.135	0.095	109	0.980
S. bebbiana	19A	-3.878	3.224	0.128	345	0.966
S. bebbiana	19D	-3.889	3.233	0.129	288	0.965
S. bebbiana	20A	-3.880	3.225	0.128	345	0.966
S. bebbiana	20B	-4.000	3.356	0.139	167	0.973
S. bebbiana	25D	-3.286	2.987	0.091	100	0.980
S. glauca	19A	-5.279	3.514	0.192	91	0.921
S. glauca	20D	-3.132	1.713	0.123	4	0.717
S. glauca	20E	-5.250	3.585	0.326	127	0.866
S. interior	19D	-3.578	3.014	0.125	96	0.969

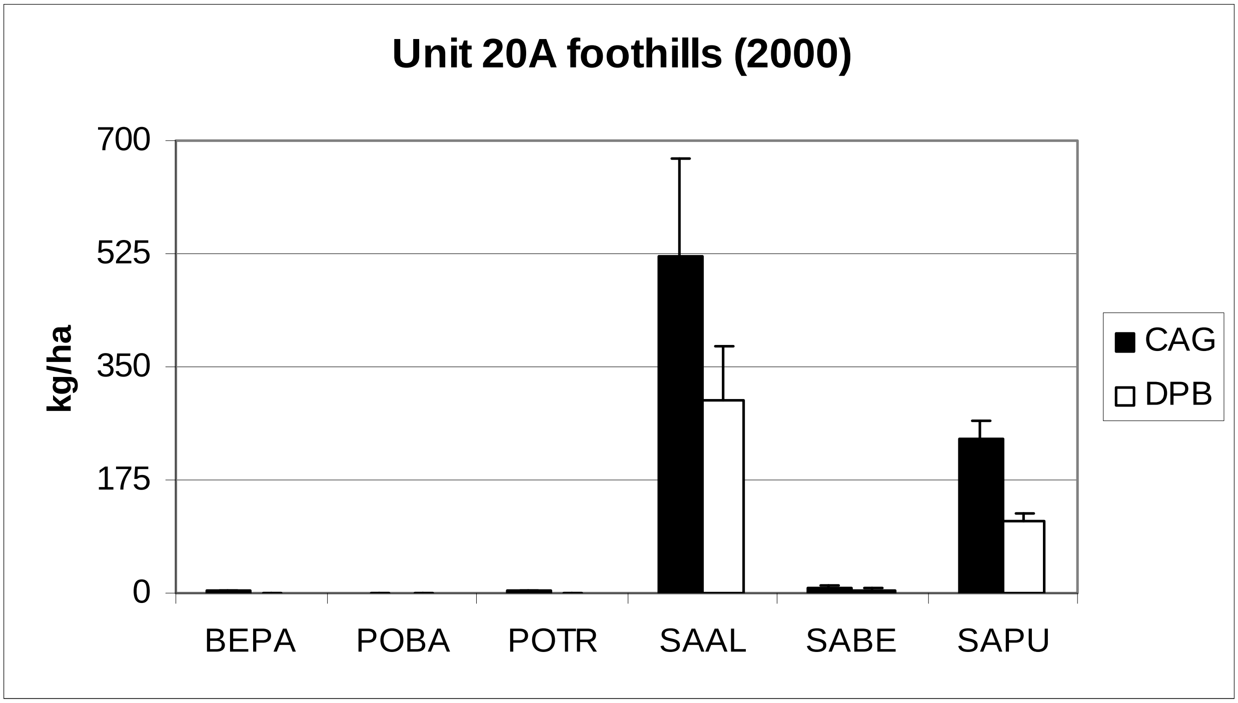
Species	Unit	Intercept	Slope	MSE	*n*	r-squared
S. pulchra	19A	-3.907	2.894	0.389	40	0.824
S. pulchra	19D	-3.203	2.844	0.166	69	0.963
S. pulchra	20A	-3.449	3.010	0.225	637	0.936
S. pulchra	20B	-3.439	2.993	0.196	274	0.938
S. pulchra	20E	-4.816	3.581	0.277	148	0.926
S. pulchra	21E	-4.428	3.527	0.183	100	0.954
S. Richardsonii	20B	-4.750	3.074	0.251	31	0.902
S. Richardsonii	20D	-4.751	3.074	0.242	32	0.903

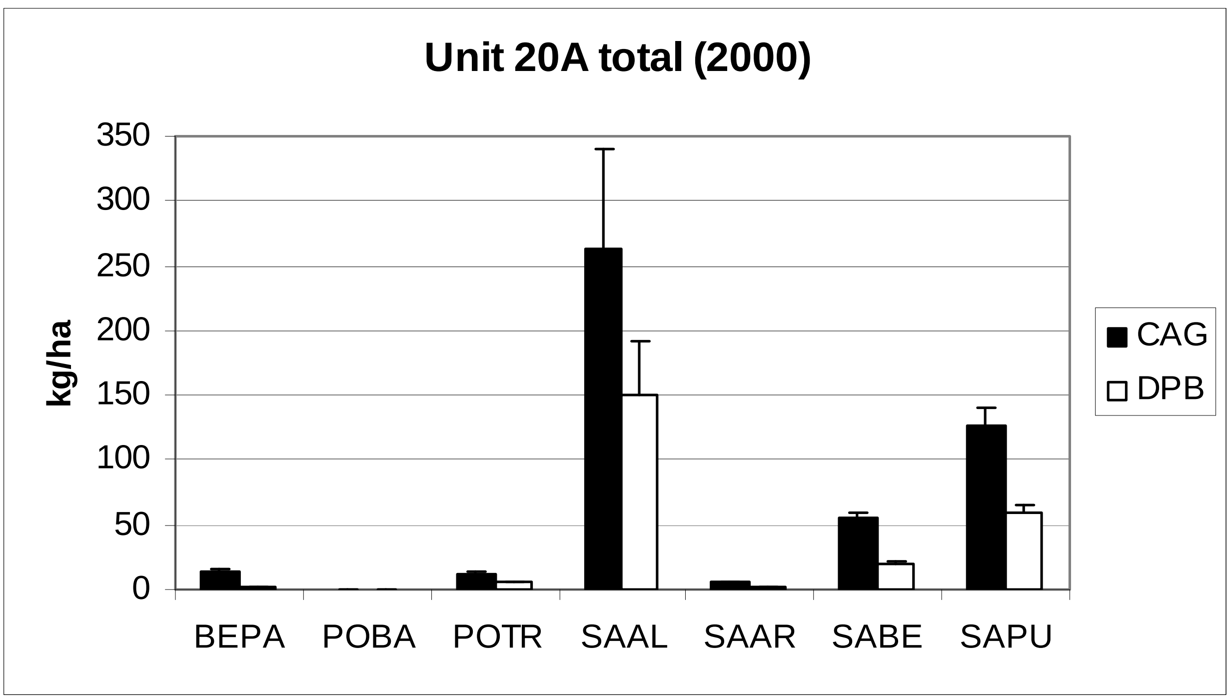
APPENDIX C Mean production per plot of moose browse among cover types by game management unit in Interior Alaska, 2001–2007. Weighted mean (95% CI) across all units by type: Tall shrub = 302.2 kg/ha (66.3), open forest = 21.0 (4.7), closed forest = 13.3 (1.6). Number of plots is shown above bars.

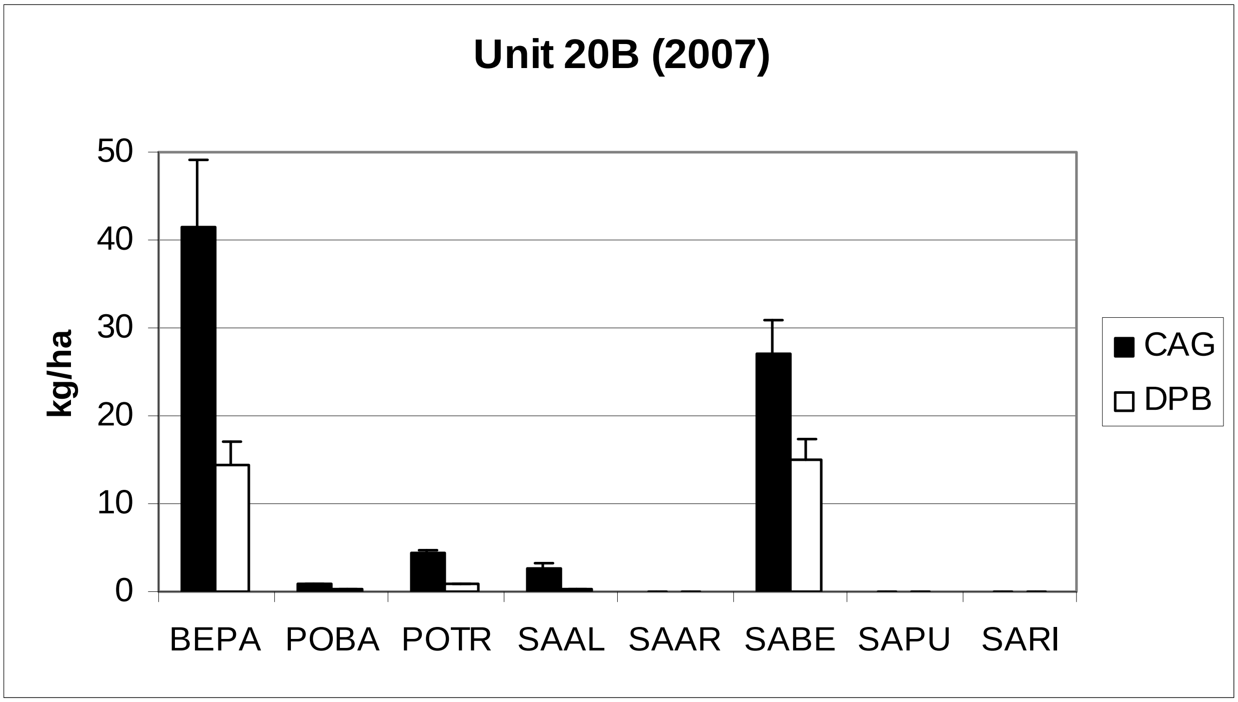


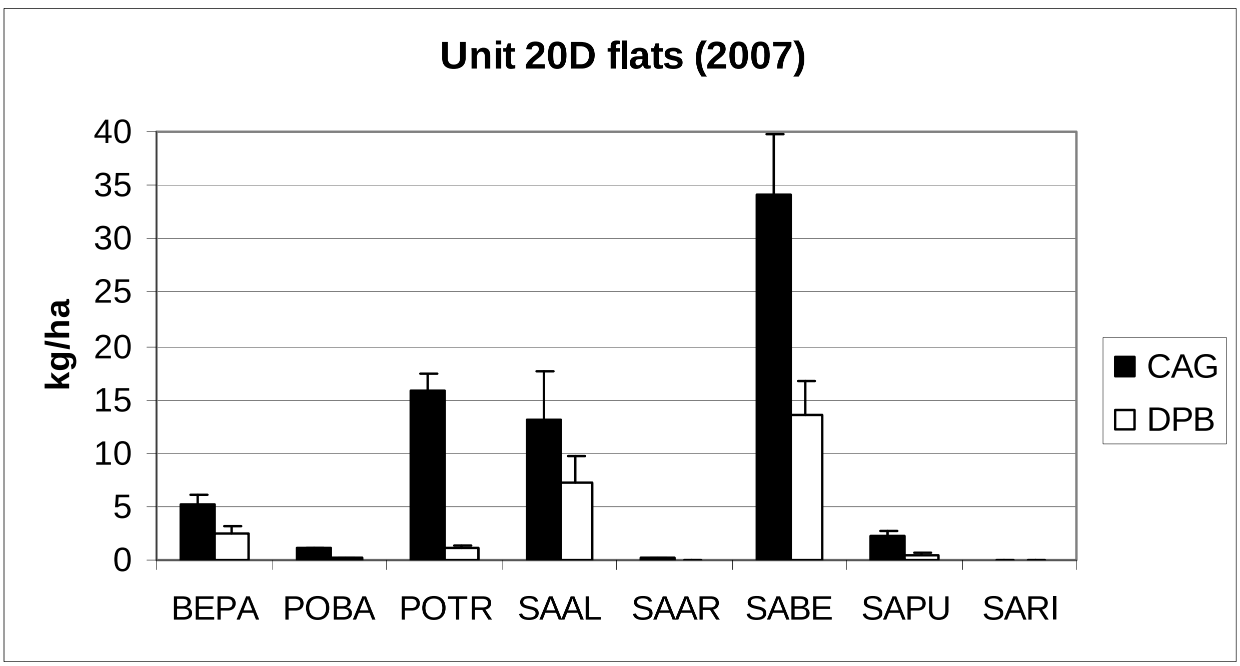
APPENDIX D Mean browse production (CAG) and biomass removed by moose (DPB) among plant species in game management units in Interior Alaska, 2000–2007. Estimates are sampled twigs extrapolated to plot species composition for the study area ("site total" in R program output) and corrected to a per-plot basis by unit (Table 3). Error bars are 95% confidence limits. Estimates for Unit 20A include 2 plots with extremely high production in the foothills (353 and 481 in Appendix E) not presented by Seaton (2002:Table 7). Number of plants sampled is shown Table 1. Note differences in *y*-axis scale. Species codes: BENE (*Betula neoalaskana*), COST (*Cornus stolonifera*), POBA (*Populus balsamifera*), POTR (*P. tremuloides*), SAAL (*Salix alaxensis), SAAR (S. arbusculoides), SABE (S. bebbiana*), SAGL (*S. glauca*), SAIN (*S. interior*), SARI (*S. richardsonii*), and SAPU (*S. pulchra*).

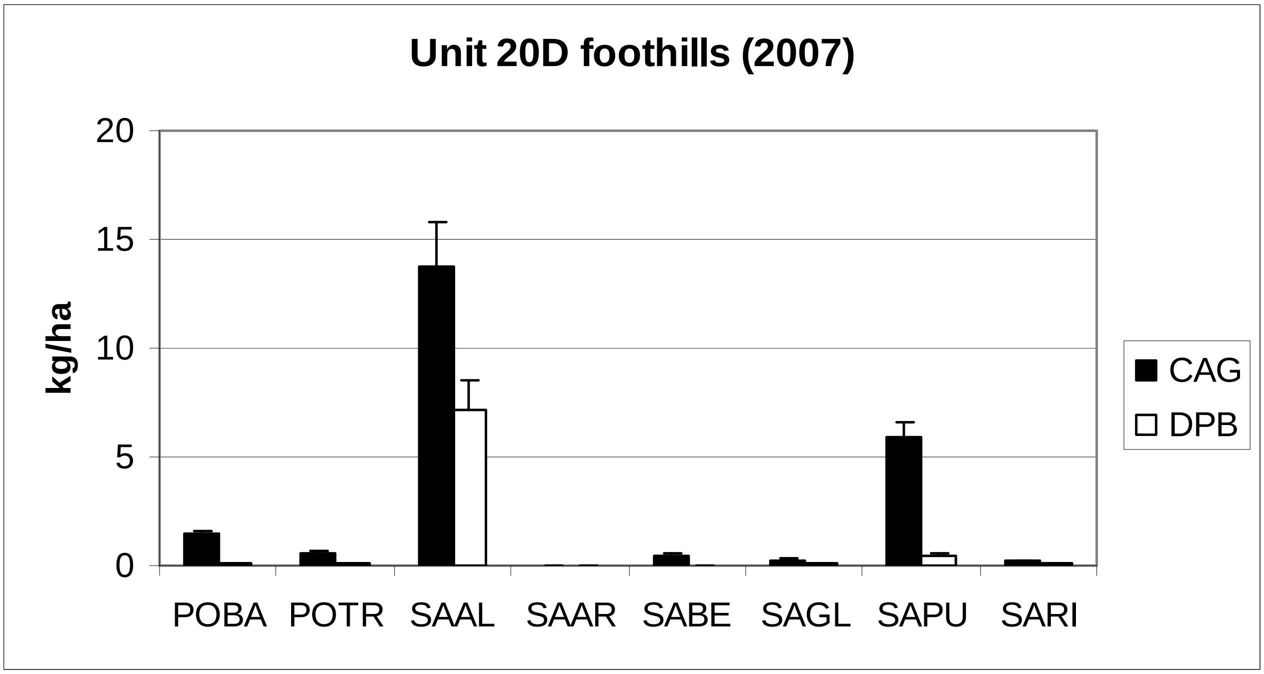


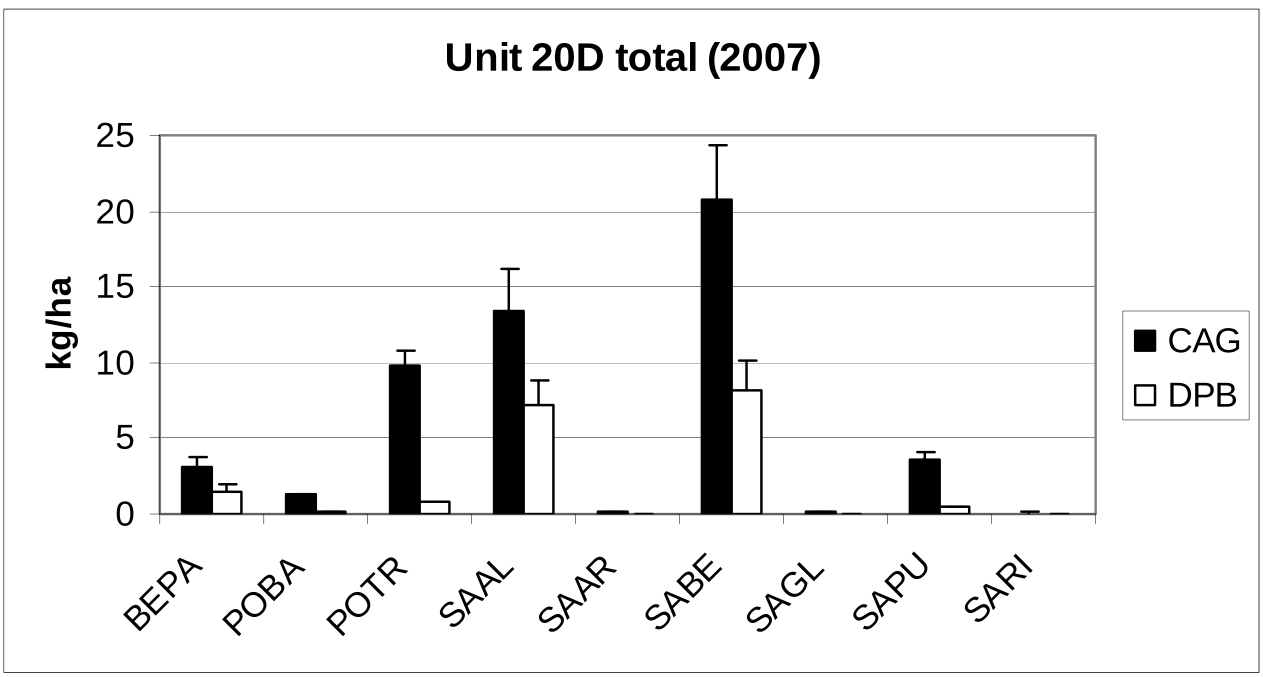

Unit 20A foothills (2000)
kg/ha
700
525
350
175
0
BEPA
POBA
POTR
SAAL
SABE
SAPU
CAG
DPB

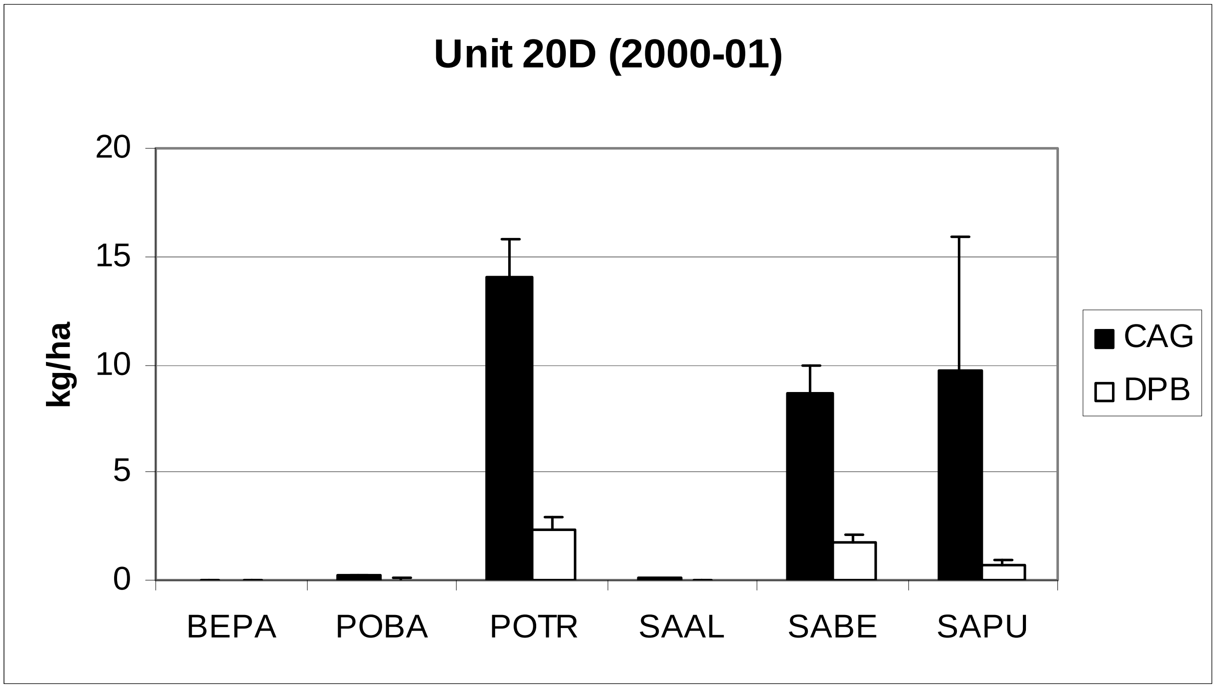

Unit 20A total (2000)
kg/ha
350
300
250
200
150
100
50
0
BEPA
POBA
POTR
SAAL
SAAR
SABE
SAPU
CAG
DPB

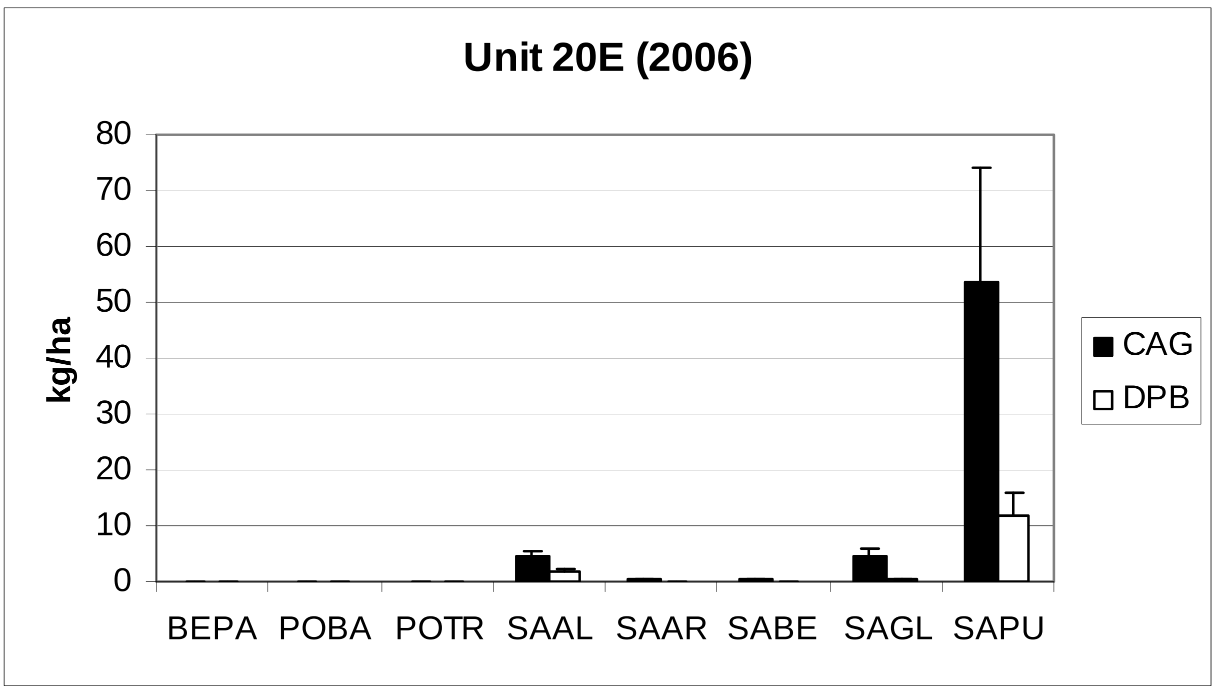

Unit 20B (2007)
kg/ha
50
40
30
20
10
0
BEPA
POBA
POTR
SAAL
SAAR
SABE
SAPU
SARI
CAG
DPB

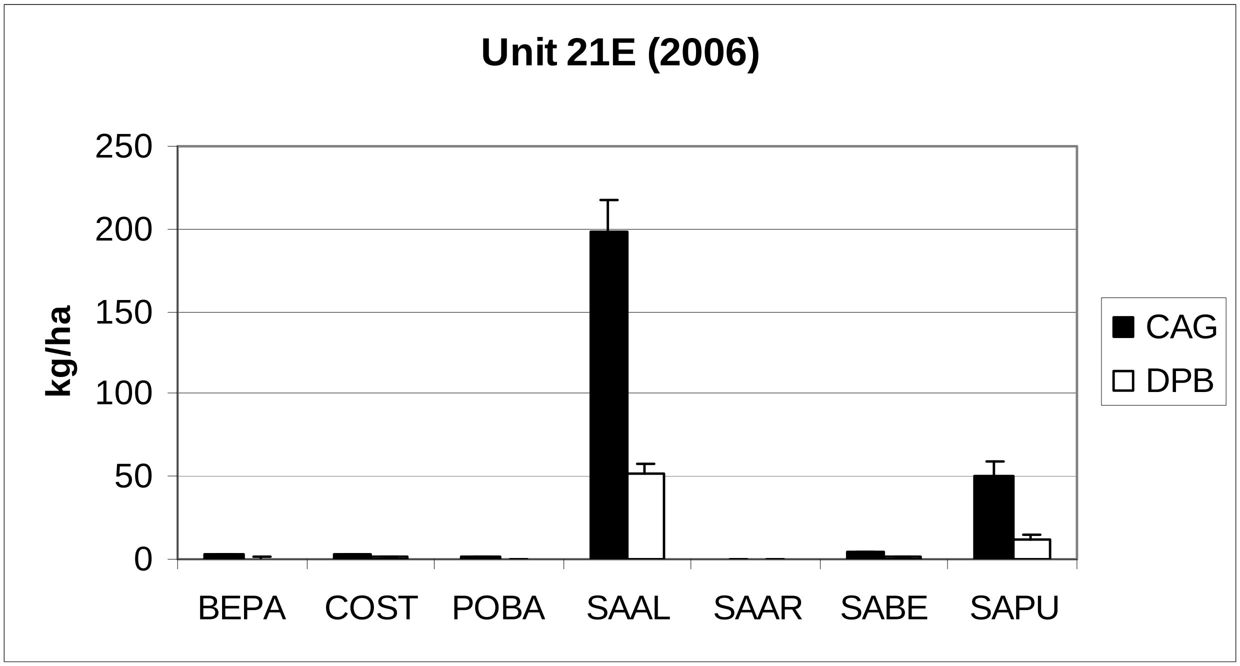

Unit 20D flats (2007)
kg/ha
40
35
30
25
20
15
10
5
0
BEPA
POBA
POTR
SAAL
SAAR
SABE
SAPU
SARI
CAG
DPB

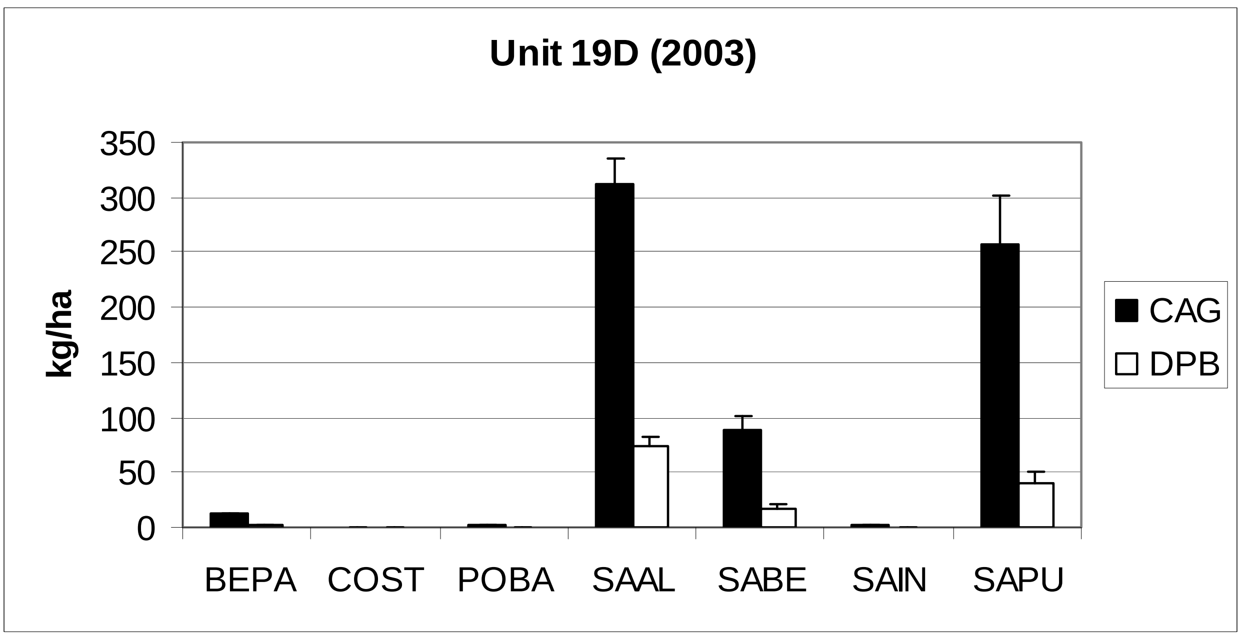

Unit 20D foothills (2007)
kg/ha
20
15
10
5
0
POBA
POTR
SAAL
SAAR
SABE
SAGL
SAPU
SARI
CAG
DPB

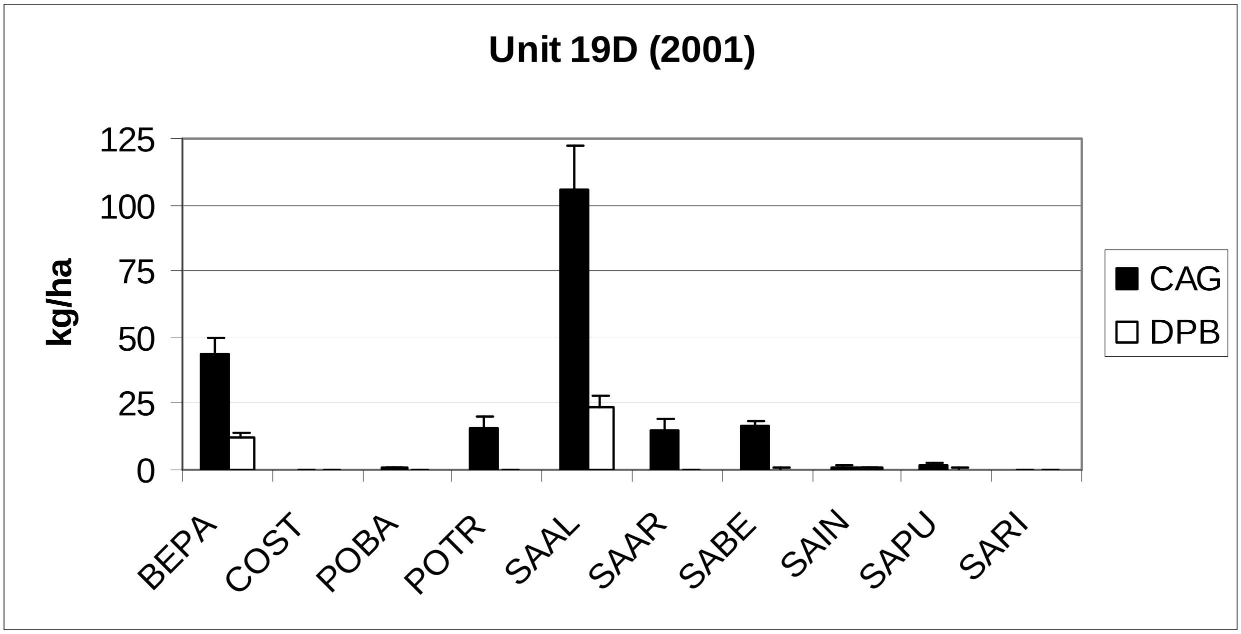

Unit 20D total (2007)
kg/ha
25
20
15
10
5
0
BEPA
POBA
POTR
SAAL
SAAR
SABE
SAGL
SAPU
SARI
CAG
DPB


Unit 20D (2000-01)
20
15
10
5
0
kg/ha
BEPA
POBA
POTR
SAAL
SABE
SAPU
CAG
DPB

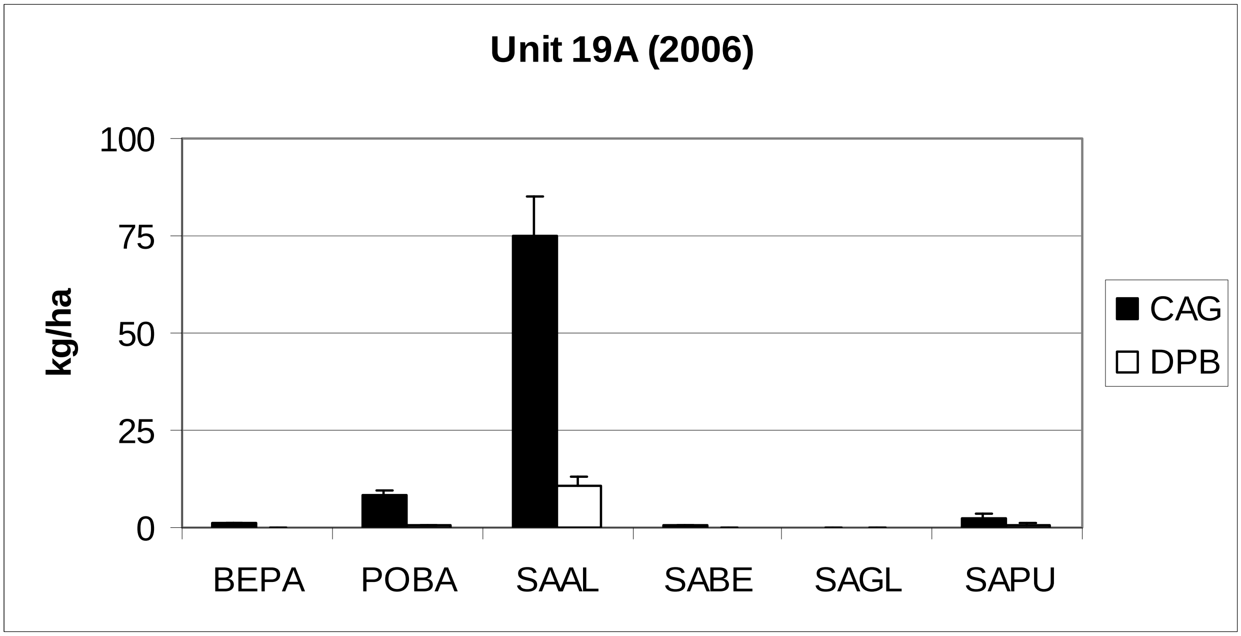

Unit 20E (2006)
80
70
60
50
40
30
20
10
0
kg/ha
BEPA
POBA
POTR
SAAL
SAAR
SABE
SAGL
SAPU
CAG
DPB


Unit 21E (2006)
kg/ha
250
200
150
100
50
0
BEPA
COST
POBA
SAAL
SAAR
SABE
SAPU
CAG
DPB

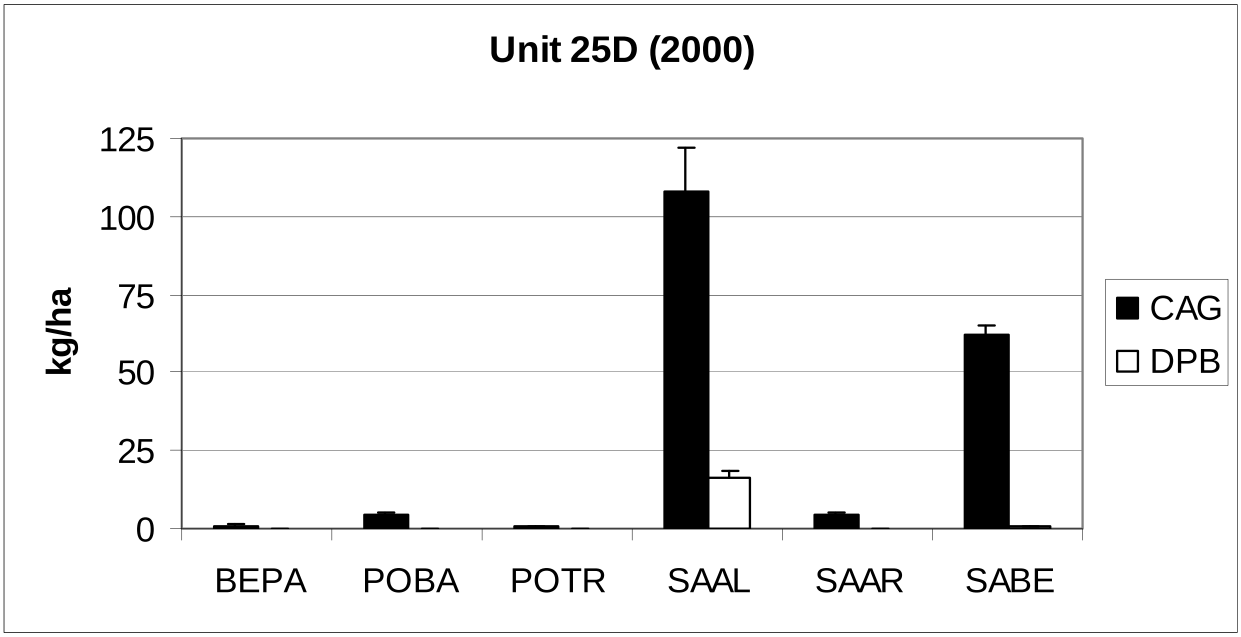

Unit 19D (2003)
kg/ha
350
300
250
200
150
100
50
0
BEPA
COST
POBA
SAAL
SABE
SAIN
SAPU
CAG
DPB

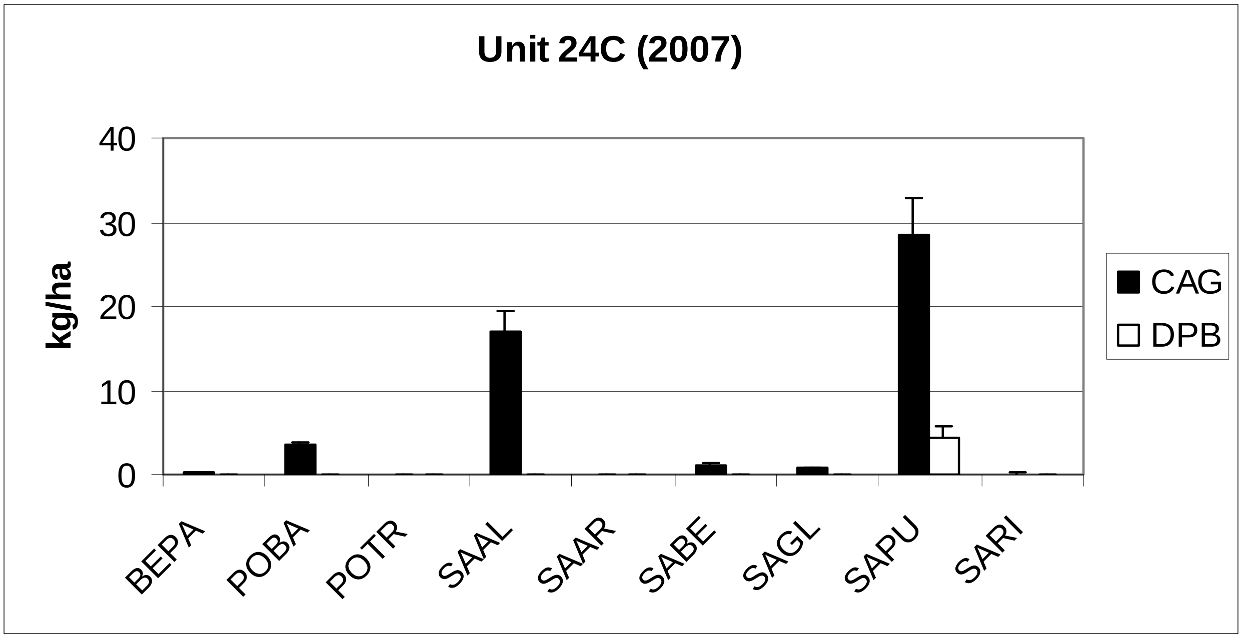


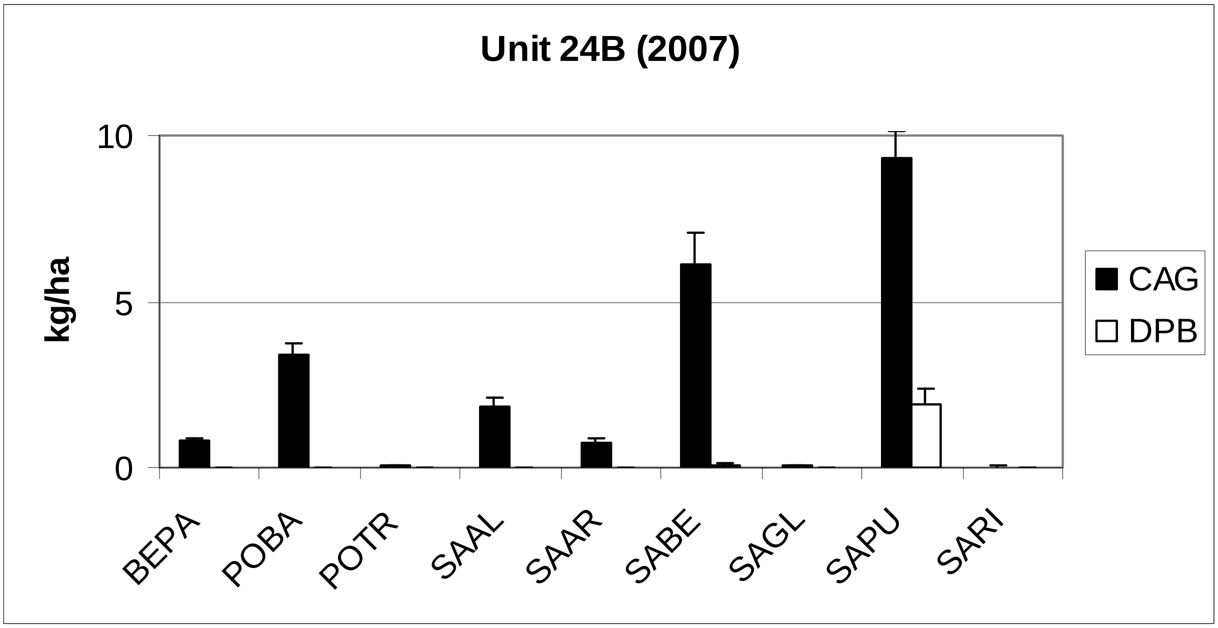
Unit 19D (2001)
kg/ha
125
100
75
50
25
0
BEPA
COST
POBA
POTR
SAAL
SAAR
SABE
SAIN
SAPU
SARI
CAG
DPB



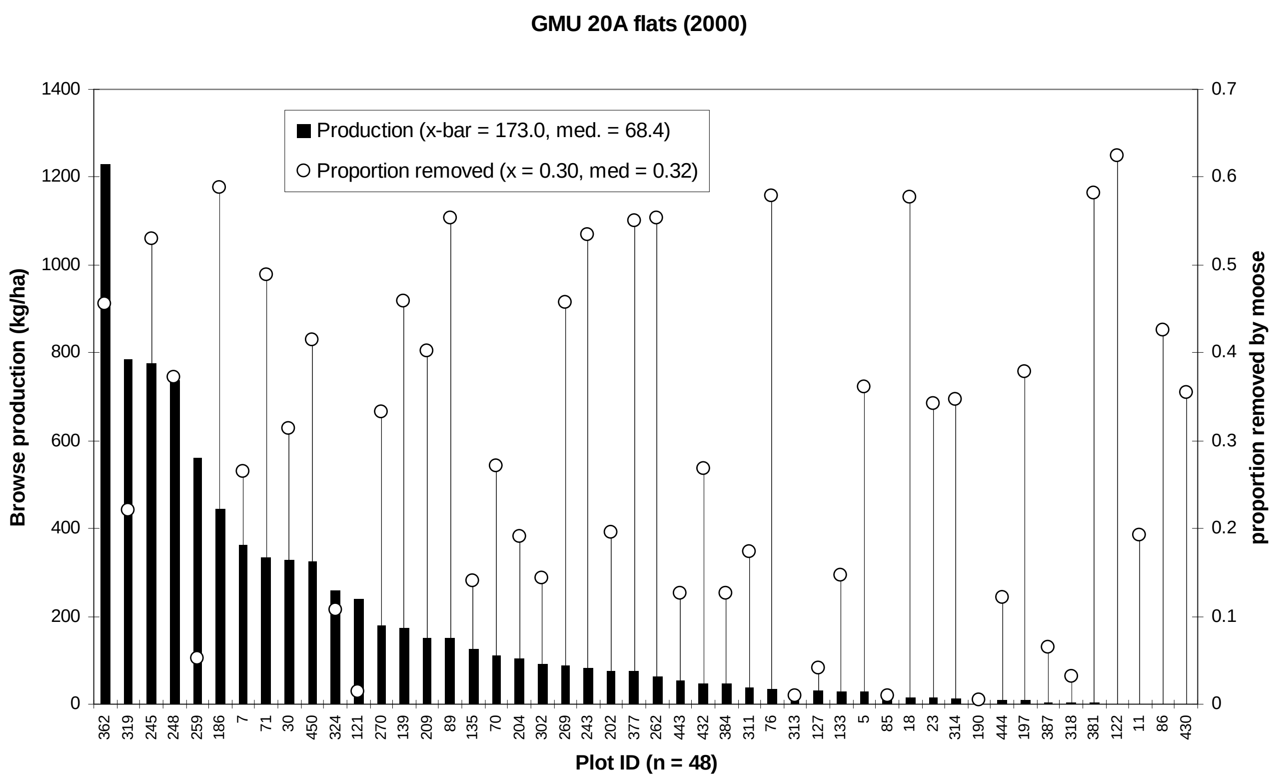
Unit 19A (2006)
kg/ha
100
75
50
25
0
BEPA
POBA
SAAL
SABE
SAGL
SAPU
CAG
DPB


Unit 25D (2000)
kg/ha
125
100
75
50
25
0
BEPA
POBA
POTR
SAAL
SAAR
SABE
CAG
DPB

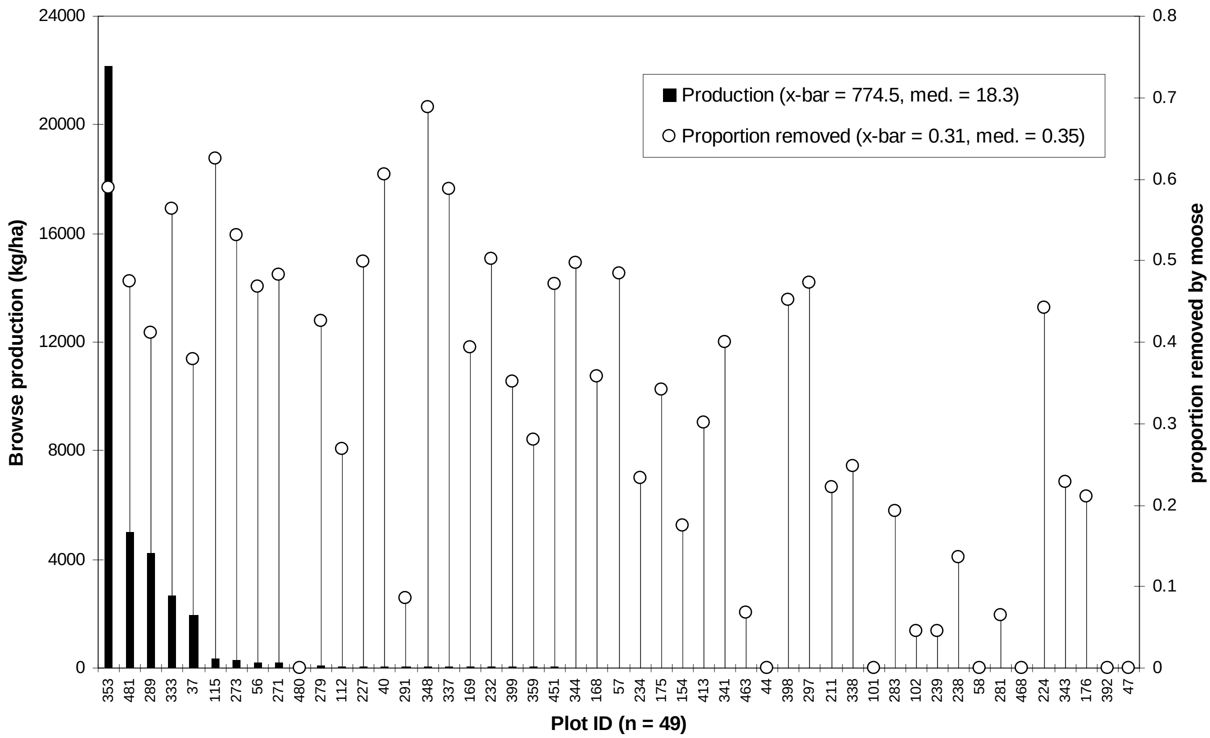

Unit 24C (2007)
kg/ha
40
30
20
10
0
BEPA
POBA
POTR
SAAL
SAAR
SABE
SAGL
SAPU
SARI
CAG
DPB


Unit 24B (2007)
10
5
0
kg/ha
CAG
DPB
BEPA
POBA
POTR
SAAL
SAAR
SABE
SAGL
SAPU
SARI

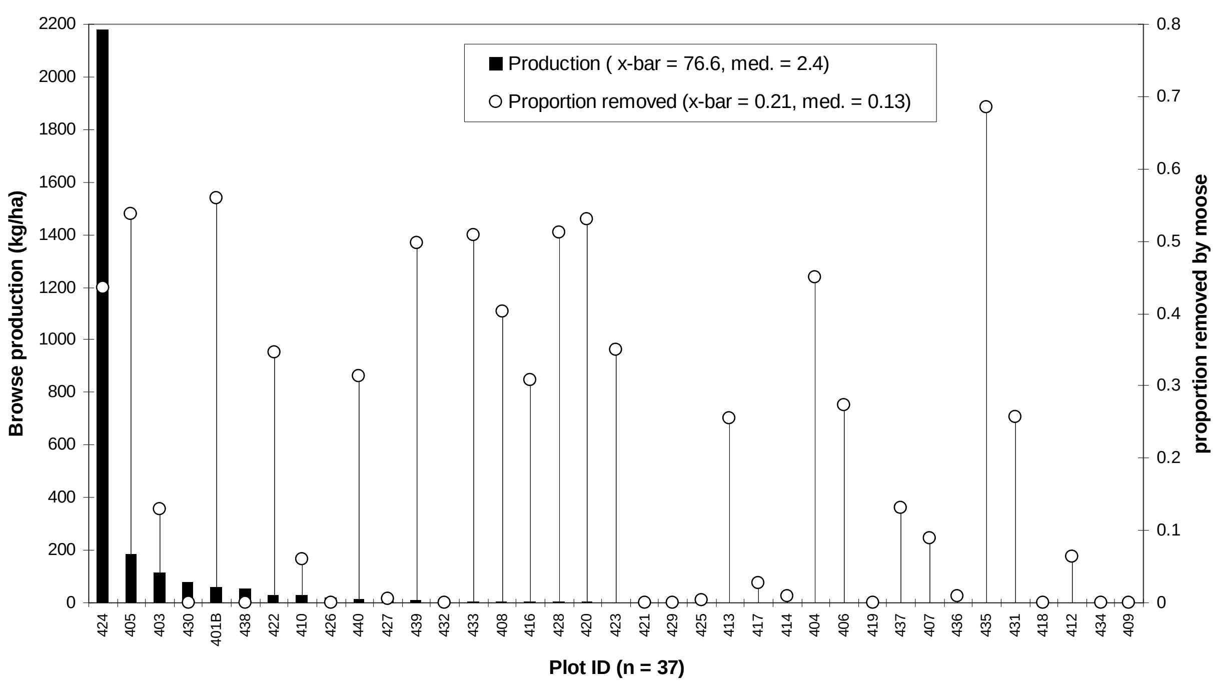
APPENDIX E Browse production (ranked in decreasing order left to right) and the proportion of browse biomass removed by moose among 30-m diameter plots, by game management unit in Interior Alaska, 2000–2007. Production and removal were extrapolated from sampled twigs to species composition at the plot level ("species total" in R program output) as an index to landscape diversity. In Unit 19D plot IDs the first letter indicates stratum (C = closed forest, O = open forest, T = tall shrub, W = subjectively chosen willow bar) and a second letter indicates alternative plots chosen when site did not match imagery classification. Note strong disparity between mean and median production for foothills plots and difference in production scale between the foothills and flats strata in Units 20A and 20D.

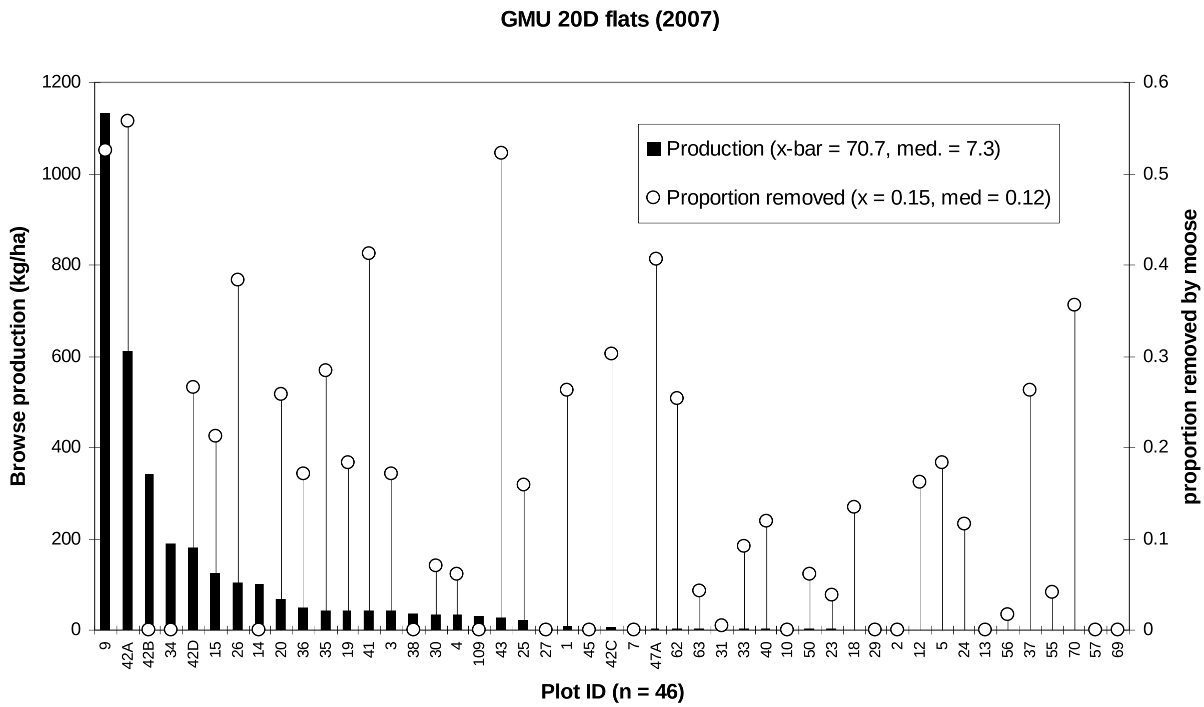


GMU 20A foothills (2000)

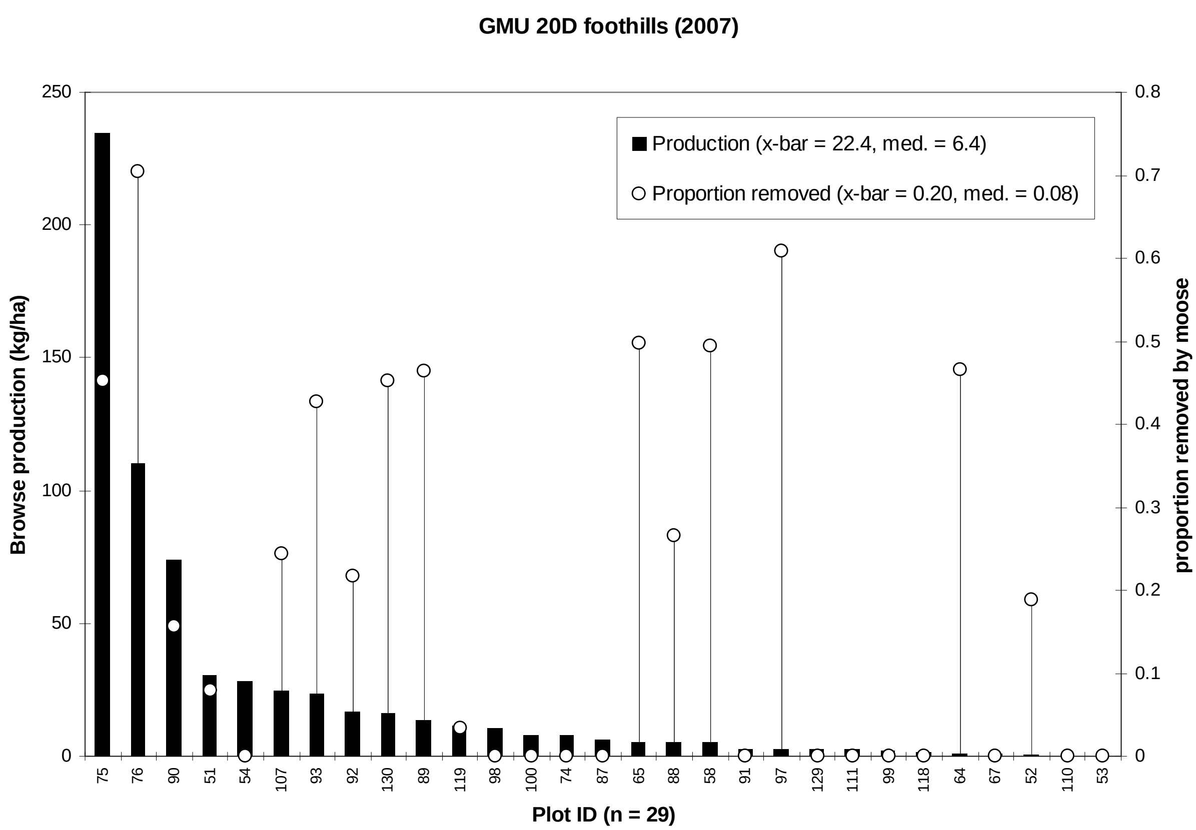


GMU 20B (2007)

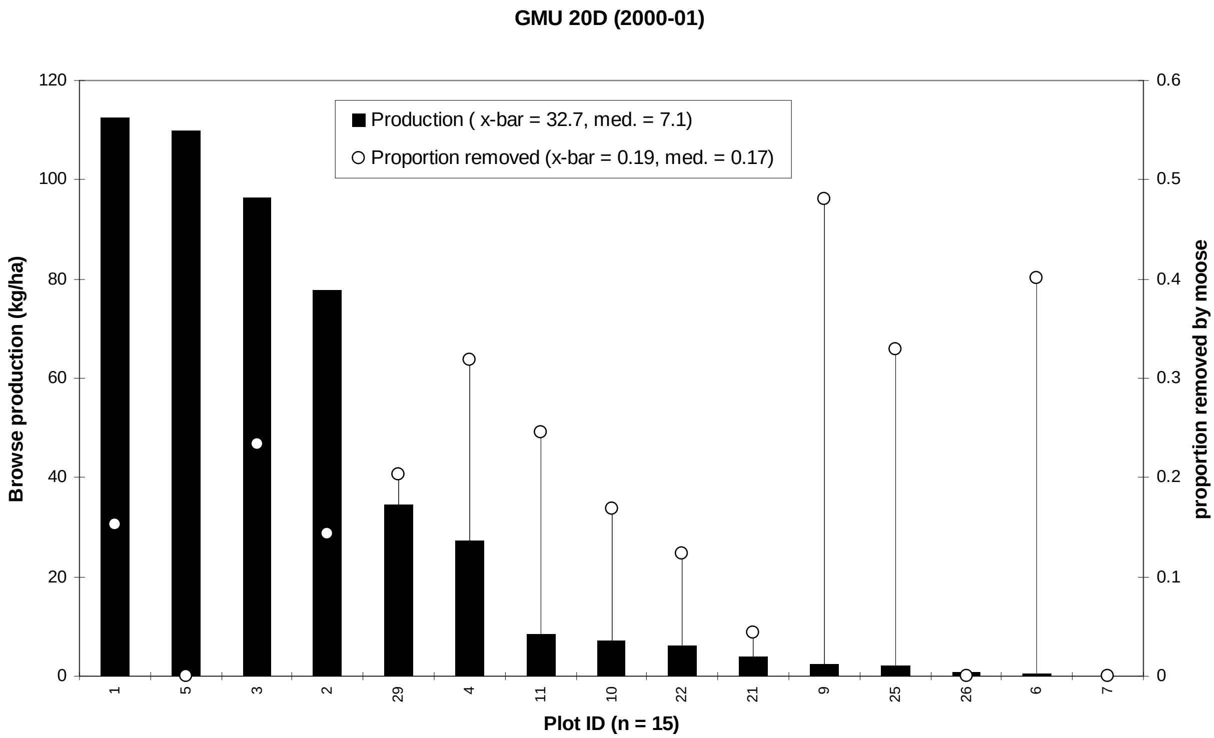


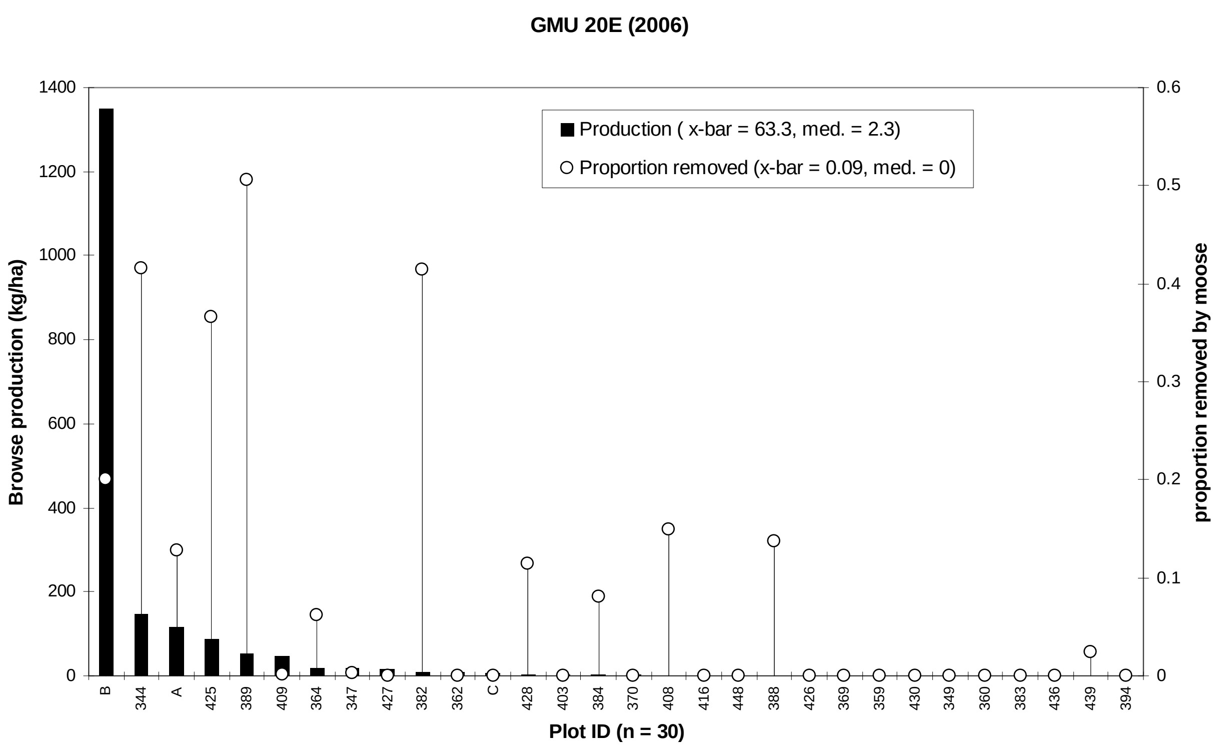


GMU 20D flats (2007)
Browse production (kg/ha)
proportion removed by moose
Production (x-bar = 70.7, med. = 7.3)
Proportion removed (x = 0.15, med = 0.12)
Plot ID (n = 46)

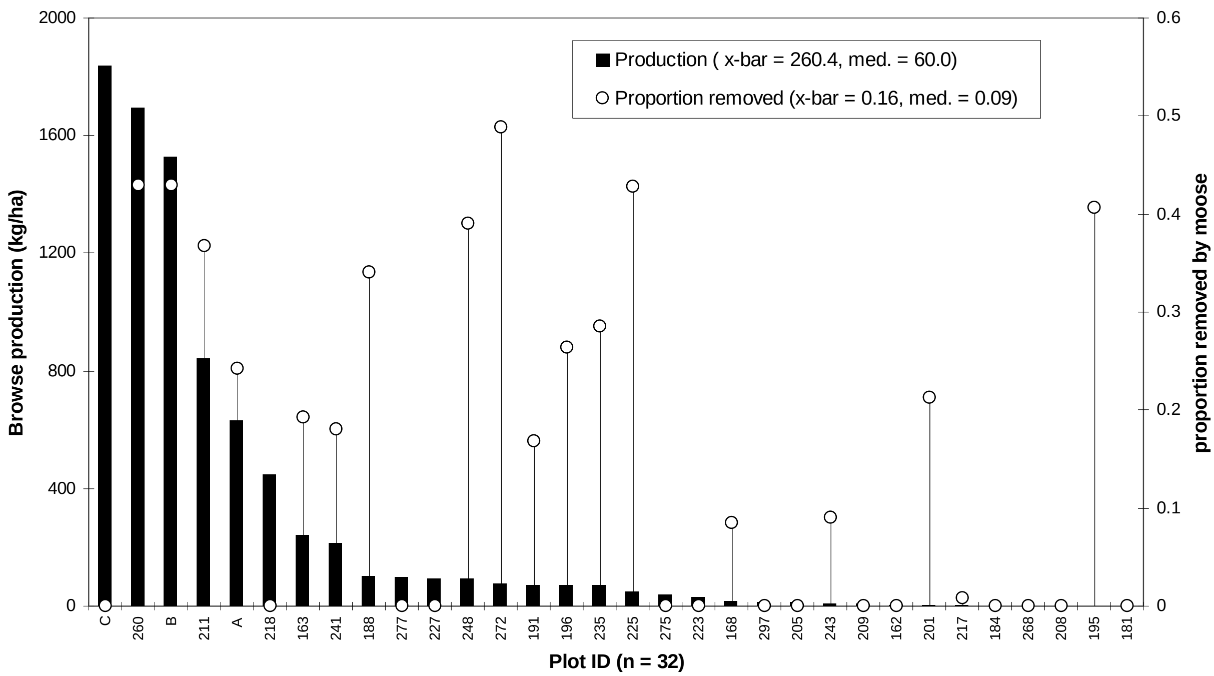


GMU 20D foothills (2007)
Browse production (kg/ha)
proportion removed by moose
Production (x-bar = 22.4, med. = 6.4)
Proportion removed (x-bar = 0.20, med. = 0.08)
Plot ID (n = 29)

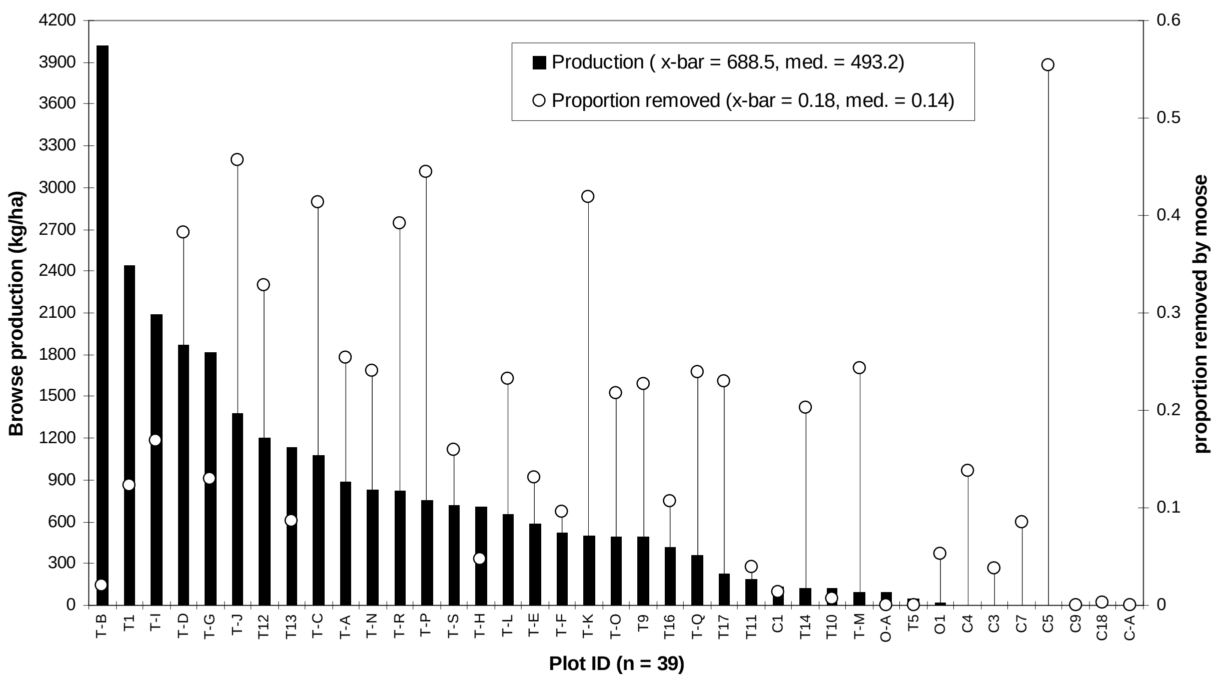

GMU 20D (2000-01)
Production (x-bar = 32.7, med. = 7.1)
Proportion removed (x-bar = 0.19, med. = 0.17)
Browse production (kg/ha)
proportion removed by moose
Plot ID (n = 15)
1
5
3
2
29
4
11
10
22
21
9
25
26
6
7

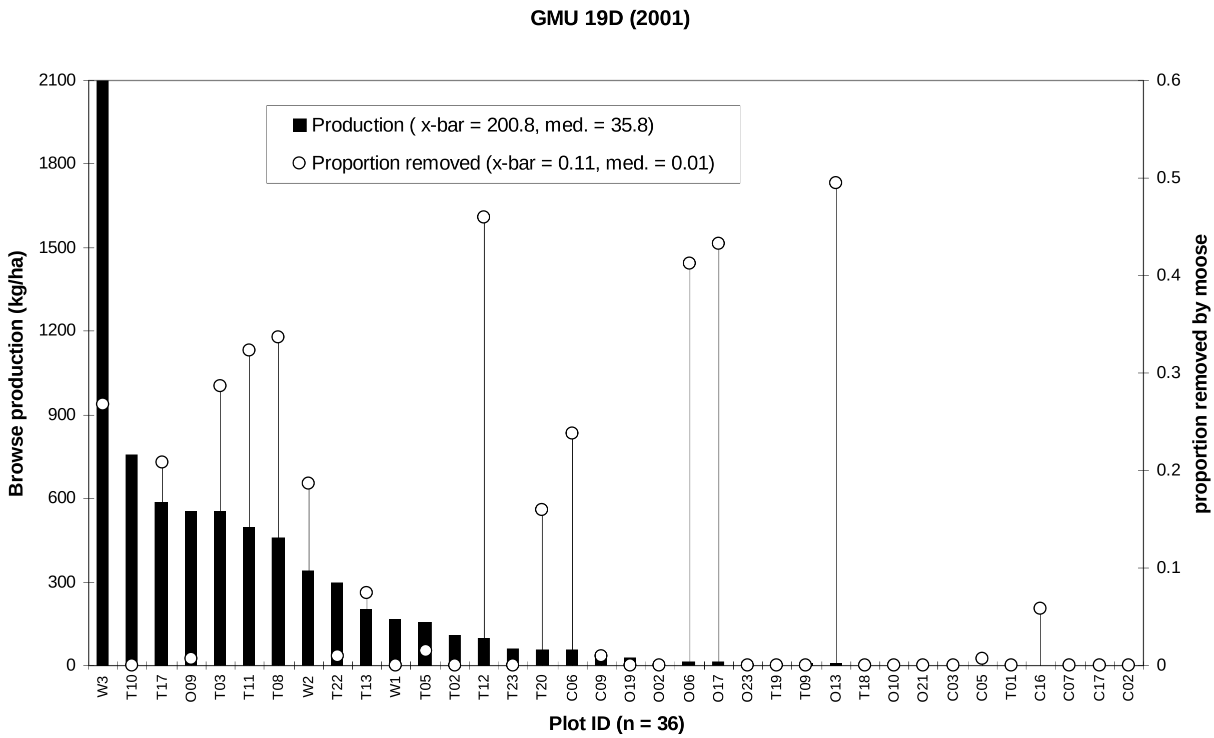

GMU 20E (2006)
Production (x-bar = 63.3, med. = 2.3)
Proportion removed (x-bar = 0.09, med. = 0)
Browse production (kg/ha)
proportion removed by moose
Plot ID (n = 30)
B
344
A
425
389
409
364
347
427
382
362
C
428
403
384
370
408
416
448
388
426
369
359
430
349
360
383
436
439
394

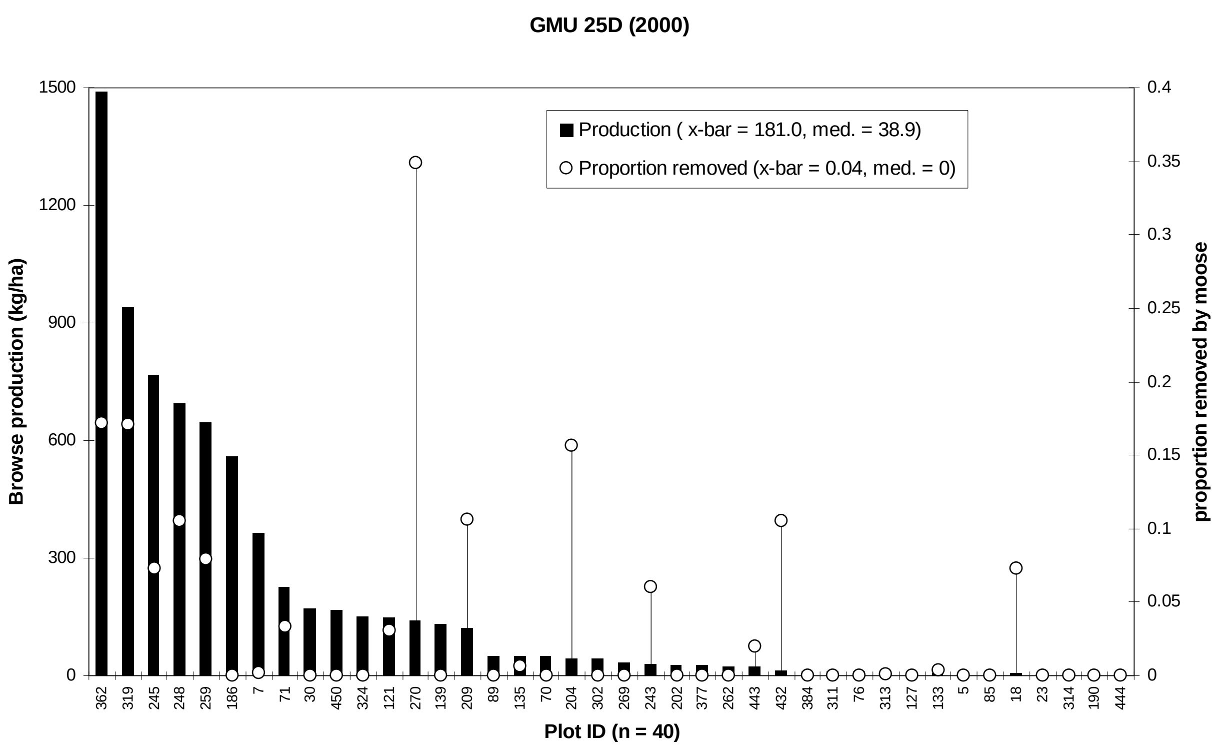
GMU 21E (2006)

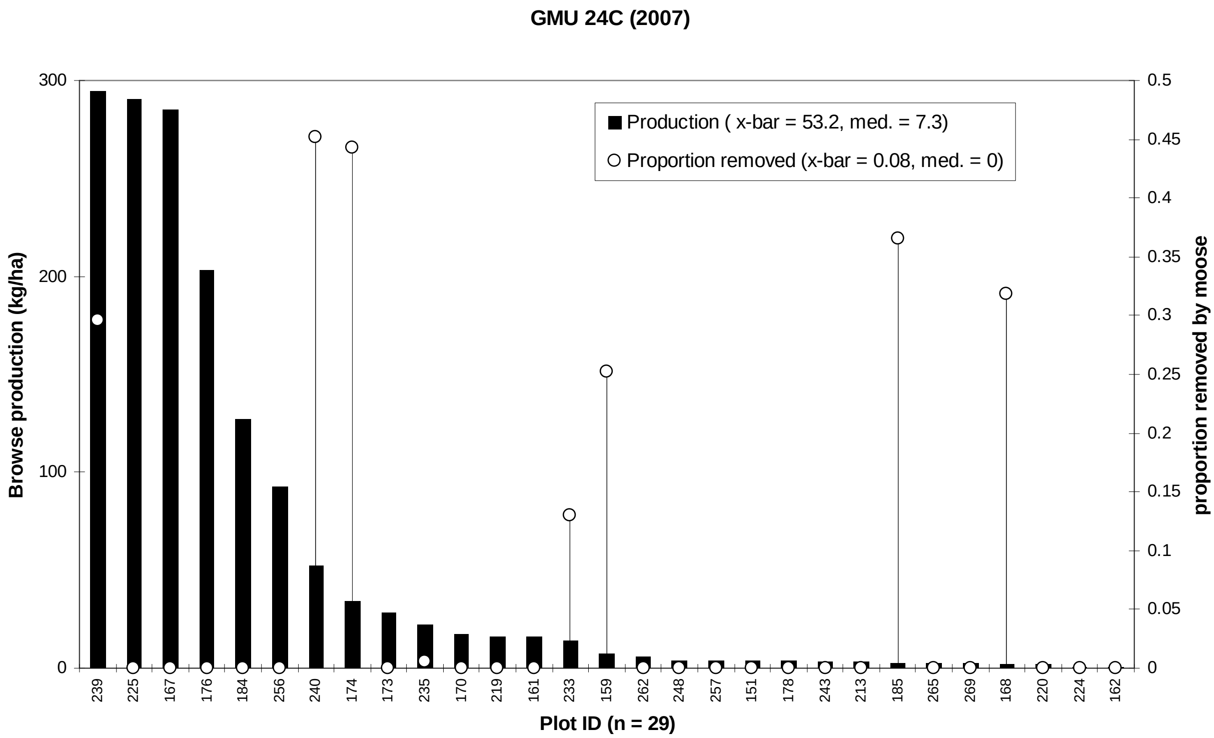


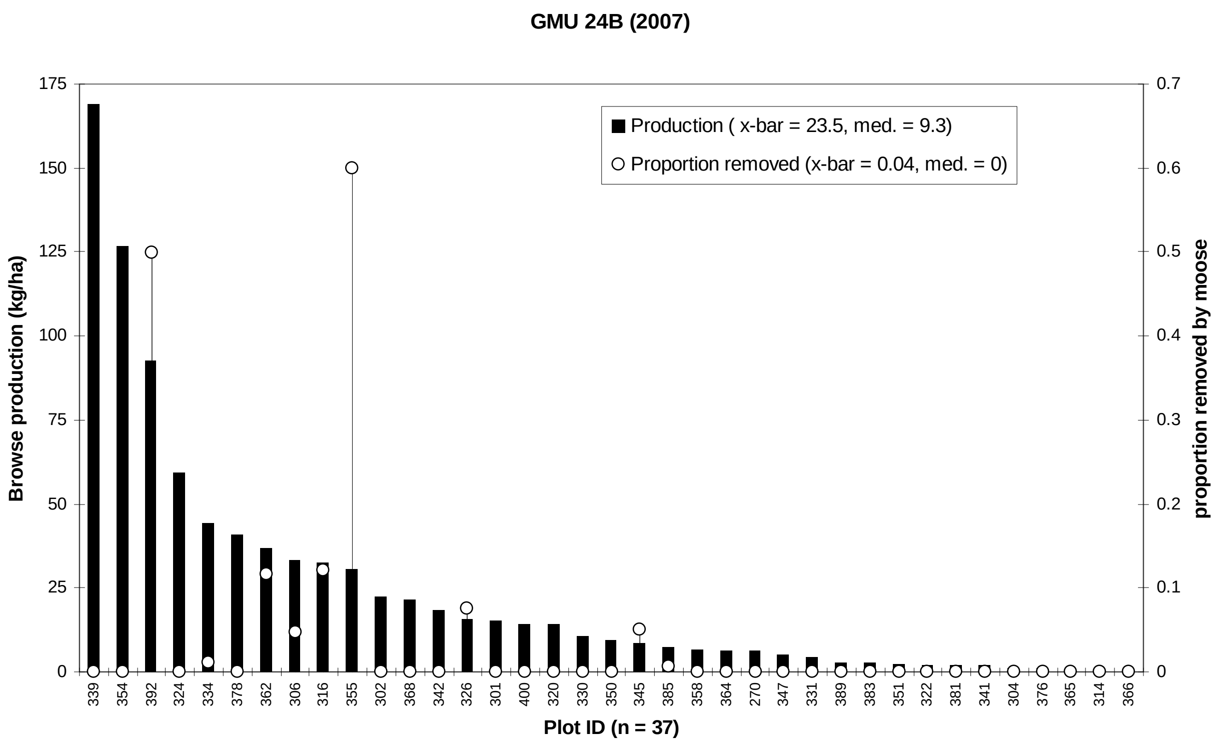
GMU 19D (2003)




GMU 19D (2001)
Production (x-bar = 200.8, med. = 35.8)
Proportion removed (x-bar = 0.11, med. = 0.01)
Browse production (kg/ha)
proportion removed by moose
Plot ID (n = 36)
W3 T10 T17 O09 T03 T11 T08 W2 T22 T13 W1 T05 T02 T12 T23 T20 C06 C09 O19 O02 O06 O17 O23 T19 T09 O13 T18 O10 O21 C03 C05 T01 C16 C07 C17 C02

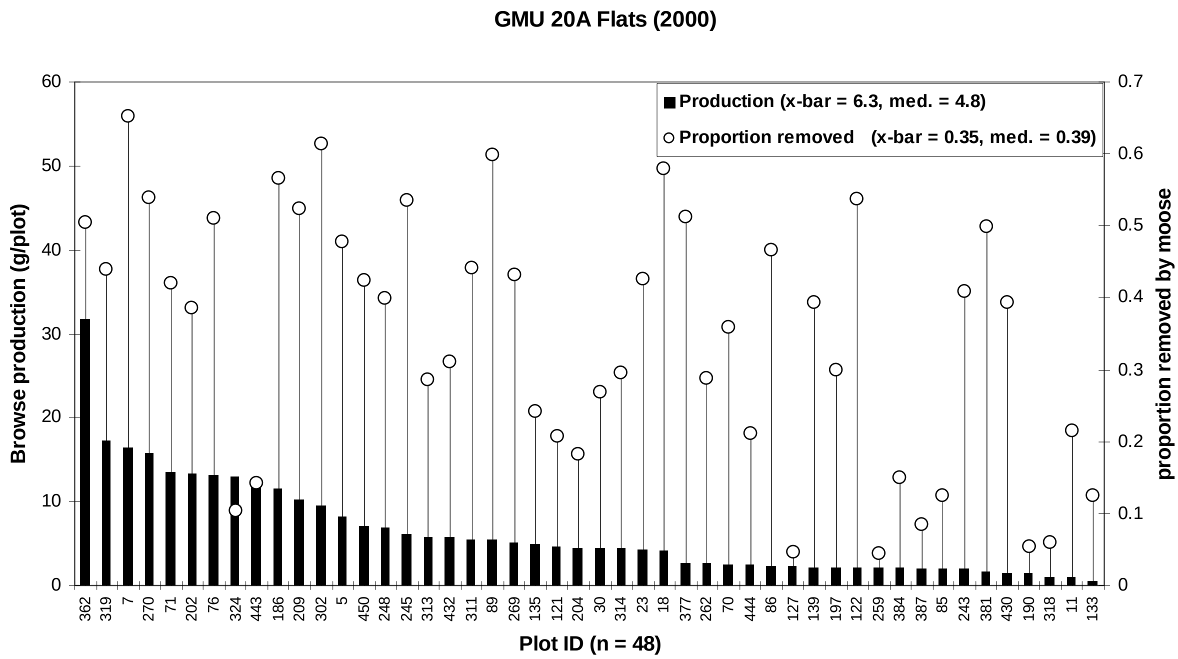

GMU 25D (2000)
Production (x-bar = 181.0, med. = 38.9)
Proportion removed (x-bar = 0.04, med. = 0)
Browse production (kg/ha)
proportion removed by moose
Plot ID (n = 40)
362 319 245 248 259 186 7 71 30 450 324 121 270 139 209 89 135 70 204 302 269 243 202 377 262 443 432 384 311 76 313 127 133 5 85 18 23 314 190 444

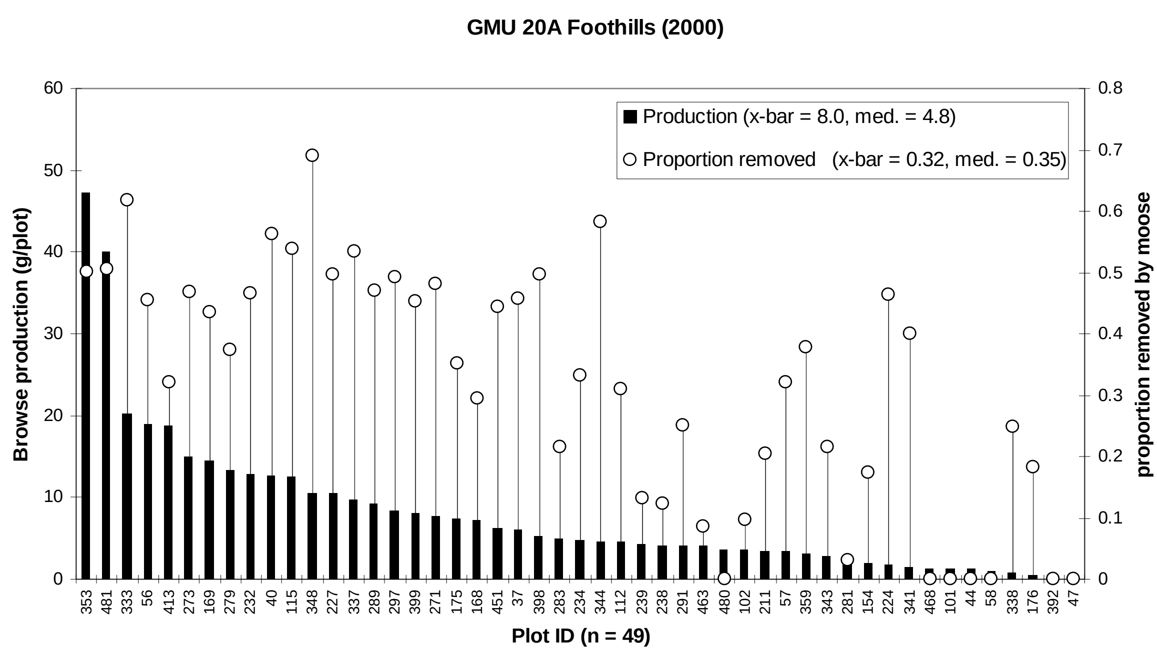

GMU 24C (2007)
Production (x-bar = 53.2, med. = 7.3)
Proportion removed (x-bar = 0.08, med. = 0)
Browse production (kg/ha)
proportion removed by moose
Plot ID (n = 29)


GMU 24B (2007)
Production (x-bar = 23.5, med. = 9.3)
Proportion removed (x-bar = 0.04, med. = 0)
Browse production (kg/ha)
proportion removed by moose
Plot ID (n = 37)

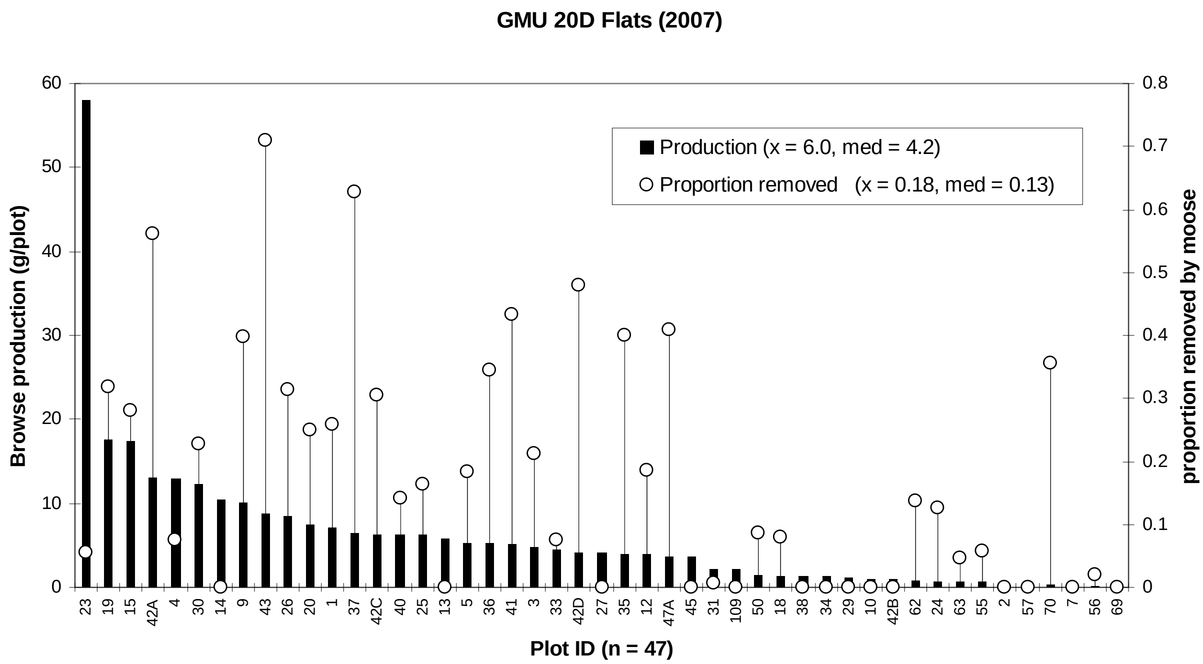
APPENDIX F Browse production (ranked in decreasing order) and the proportion of browse biomass removed by moose among 30-m diameter plots in topographic strata (flats and foothills) of Game Management Units 20A (a) and Unit 20D (b). Production and removal were estimated from sampled plants only ("plant mean" in R program output) to characterize component data of mean proportion of browse removed (Fig. 4). Compare differences in order of plots and relative distribution in level of production and removal between these graphs and corresponding graphs of plant data extrapolated to plot composition (Appendix E).

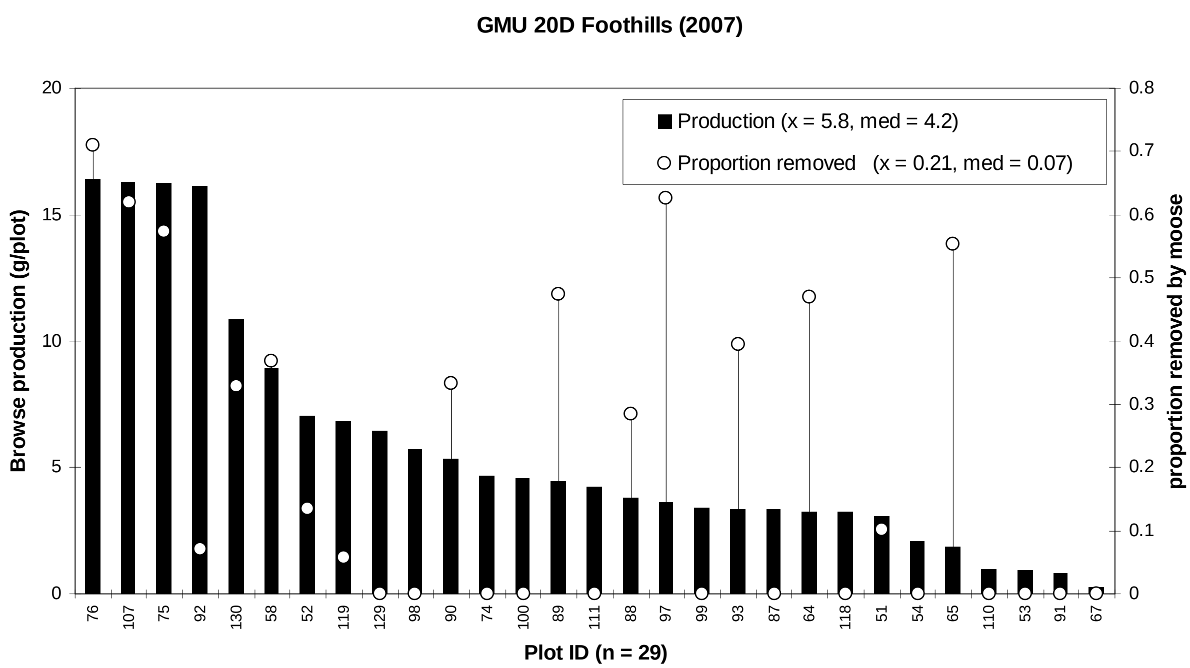
a



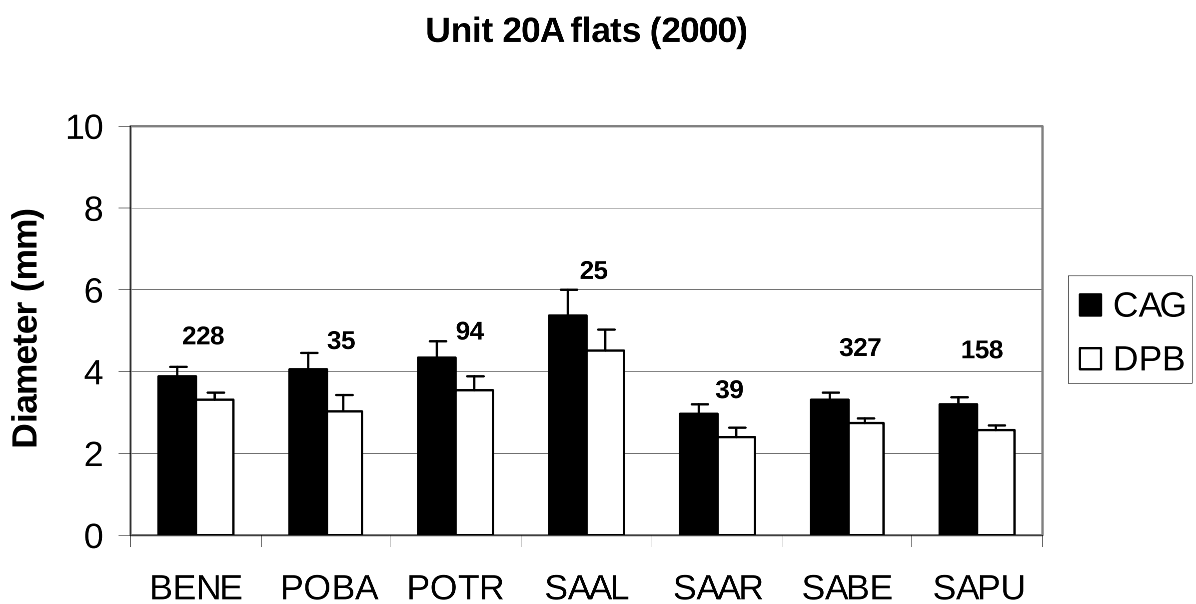


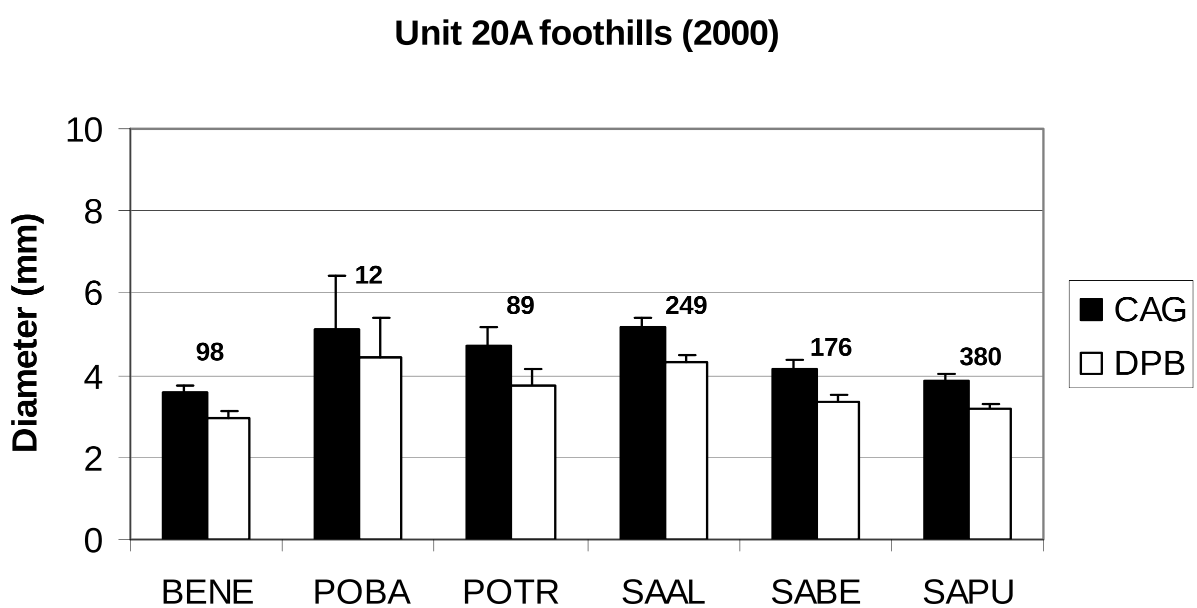
b


GMU 20D Flats (2007)
Production (x = 6.0, med = 4.2)
Proportion removed (x = 0.18, med = 0.13)
Browse production (g/plot)
proportion removed by moose
Plot ID (n = 47)
23 19 15 42A 4 30 14 9 43 26 20 1 37 42C 40 25 13 5 36 41 3 33 42D 27 35 12 47A 45 31 109 50 18 38 34 29 10 42B 62 24 63 55 2 57 70 7 56 69

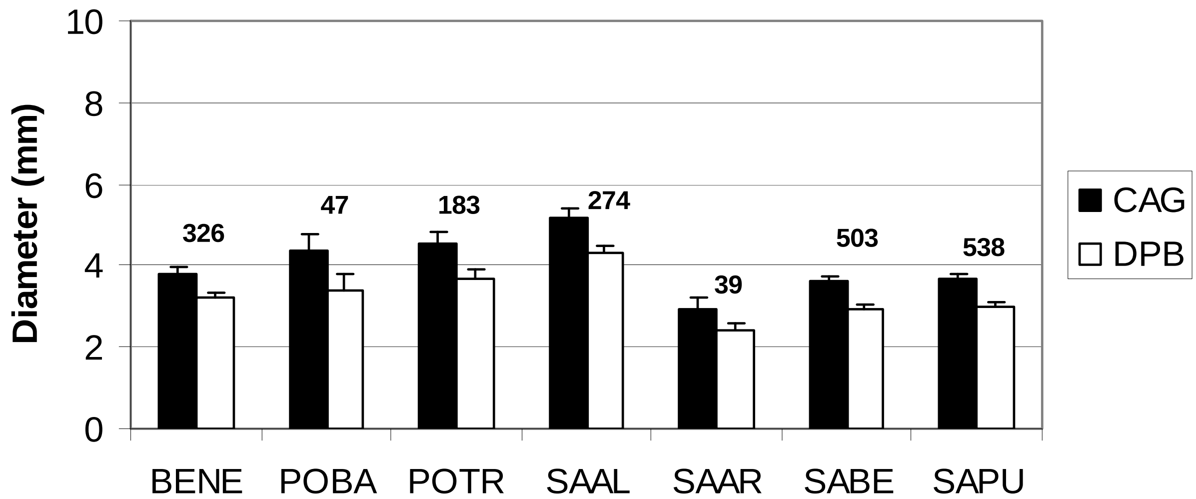

GMU 20D Foothills (2007)
Production (x = 5.8, med = 4.2)
Proportion removed (x = 0.21, med = 0.07)
Browse production (g/plot)
proportion removed by moose
Plot ID (n = 29)
76 107 75 92 130 58 52 119 129 98 90 74 100 89 111 88 97 99 93 87 64 118 51 54 65 110 53 91 67

APPENDIX G Mean diameter of current annual growth (CAG) and diameter at point of moose browsing (DPB) among plant species sampled, by game management unit in Interior Alaska, 2000–2007. Error bars are 95% confidence limits, and sample size (*n* twigs, DPB > 0) is shown above bars. Calculations are from sampled twigs only ("plant mean" level in R program output). See Appendix D for abbreviation codes of plant species.

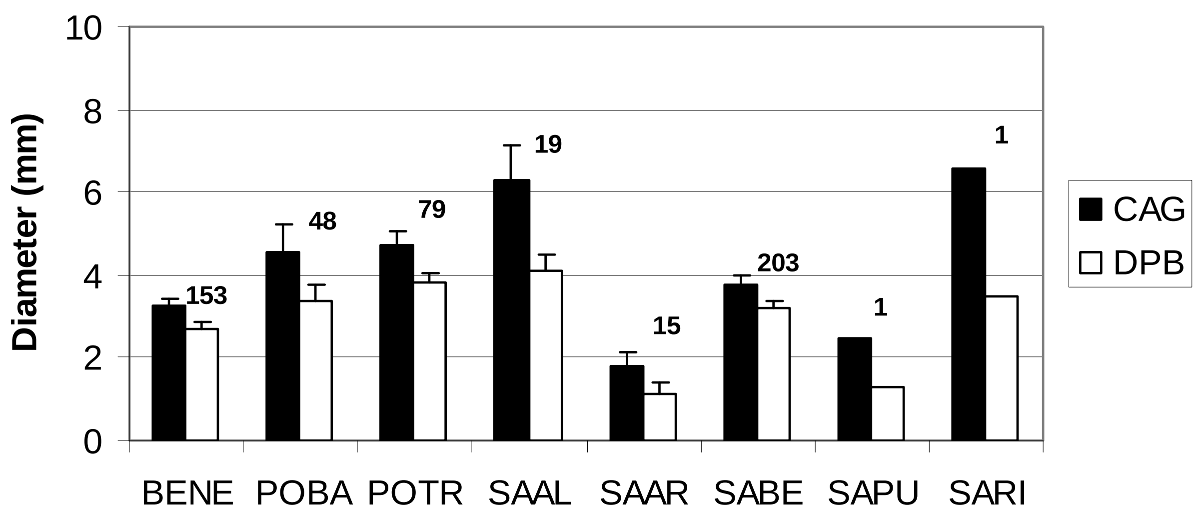


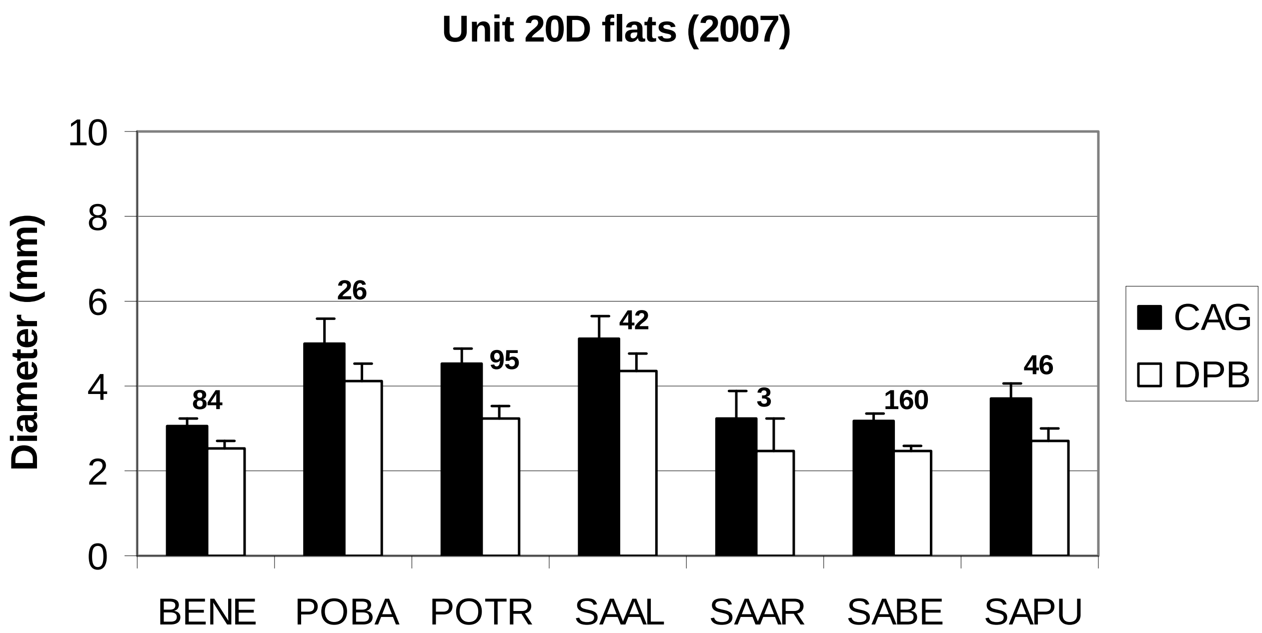


Unit 20A total (2000)

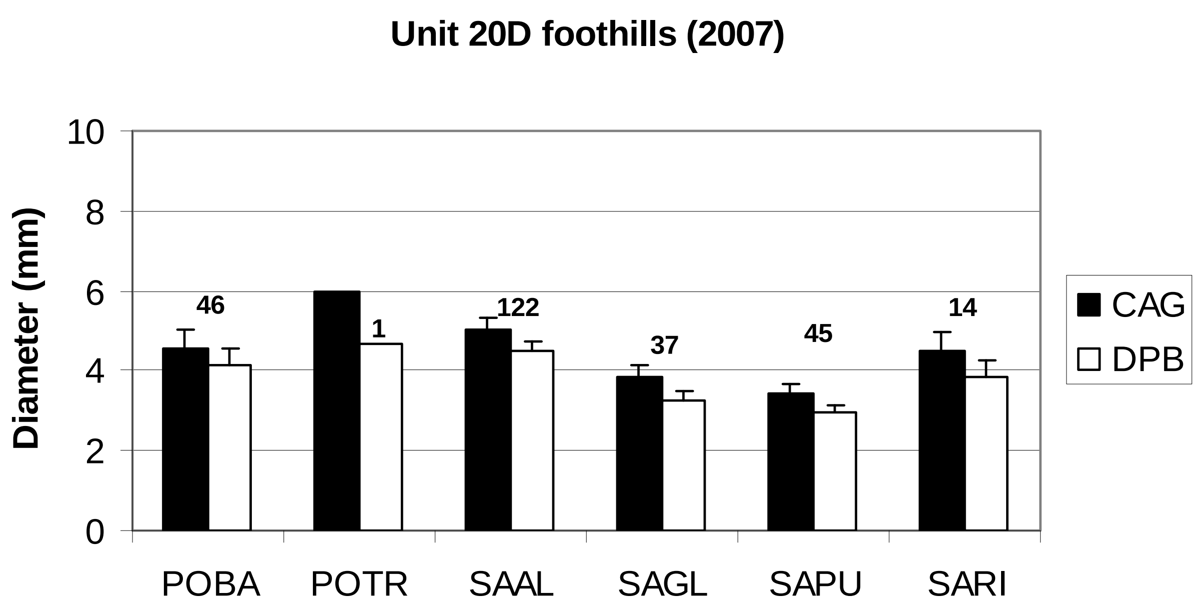


Unit 20B (2007)

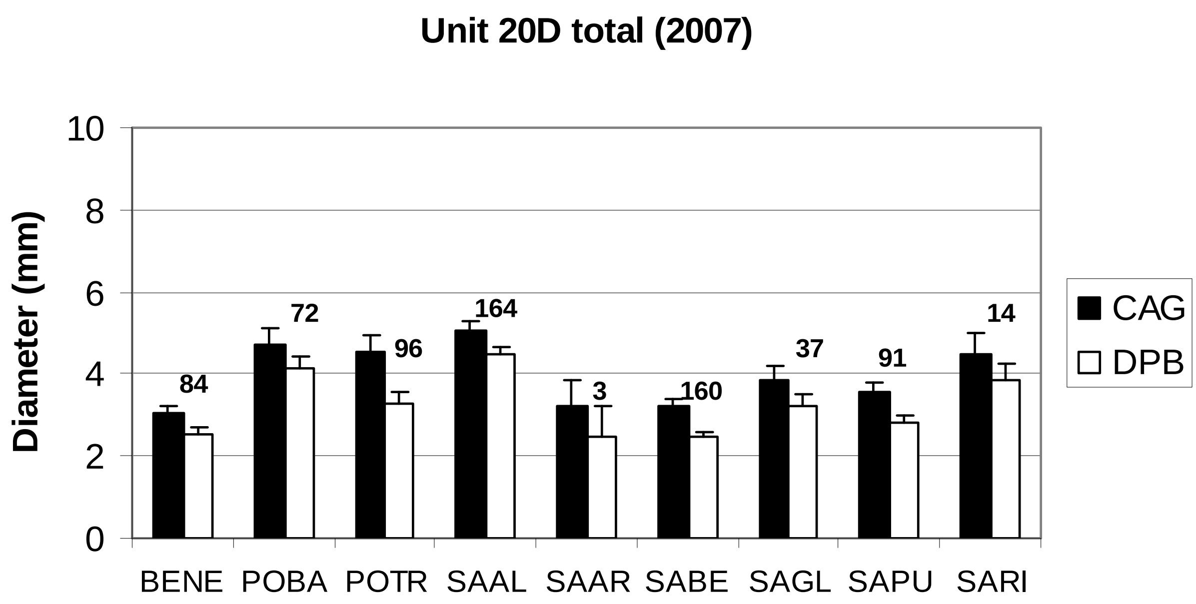




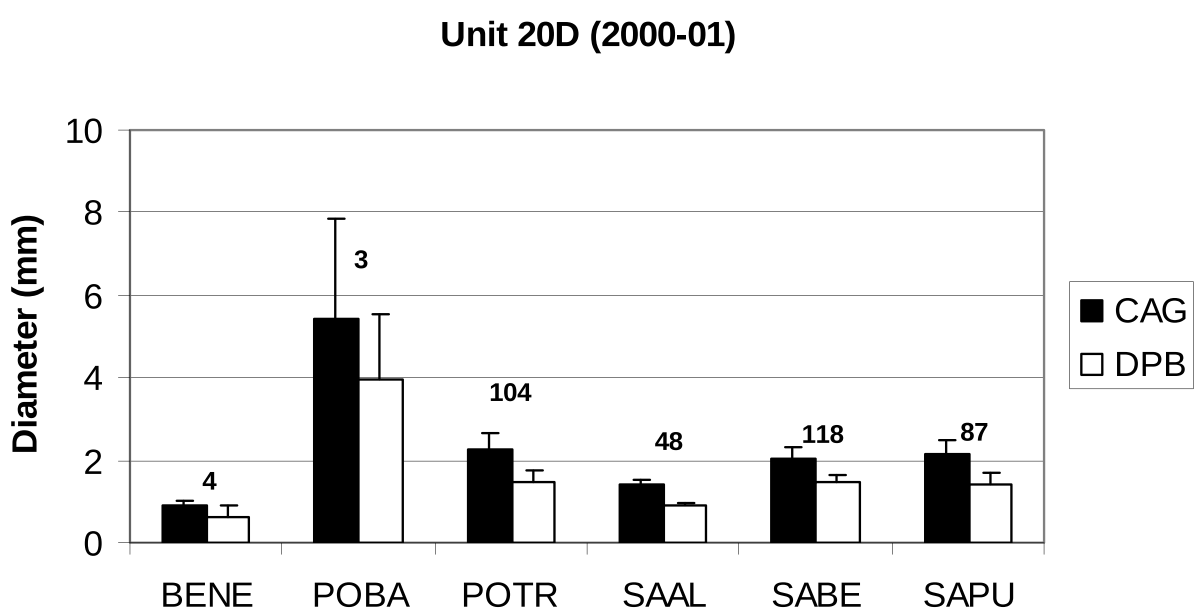
Unit 20D flats (2007)
Diameter (mm)
10
8
6
4
2
0
26
42
95
46
84
3
160
BENE
POBA
POTR
SAAL
SAAR
SABE
SAPU
CAG
DPB



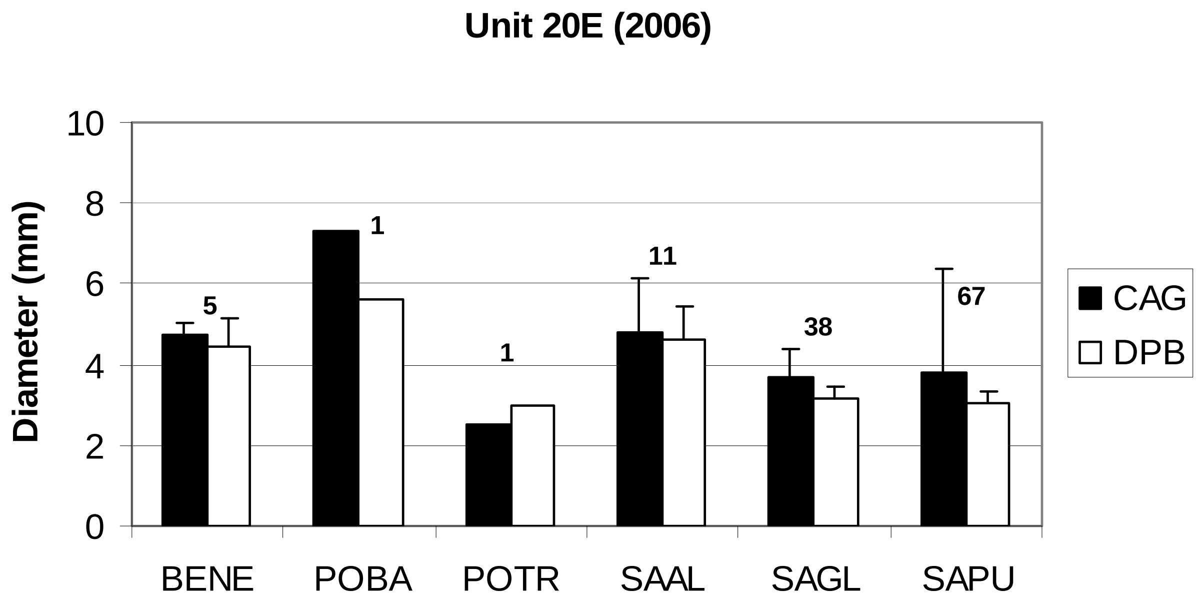
Unit 20D foothills (2007)
Diameter (mm)
10
8
6
4
2
0
46
1
122
37
45
14
POBA
POTR
SAAL
SAGL
SAPU
SARI
CAG
DPB

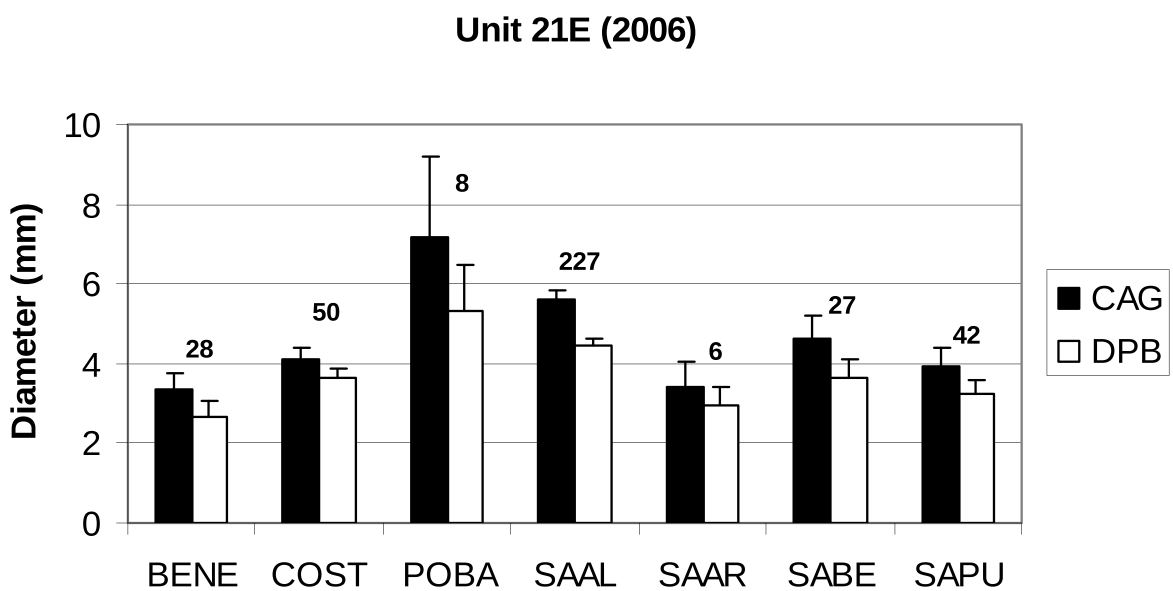


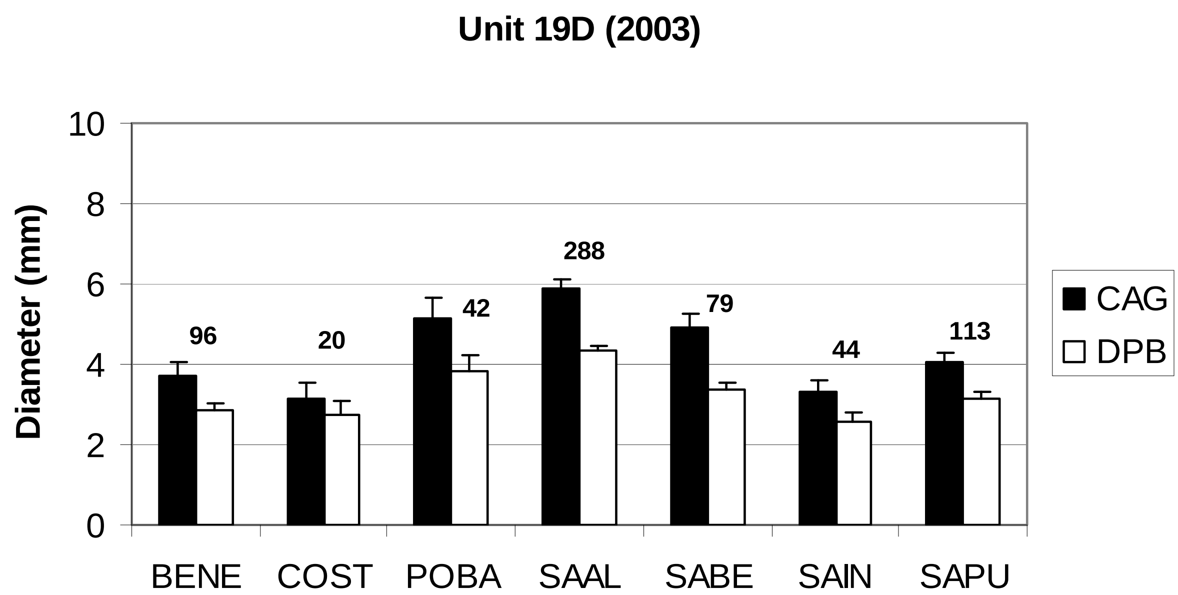
Unit 20D total (2007)
Diameter (mm)
10
8
6
4
2
0
84
72
96
164
3
160
37
91
14
BENE
POBA
POTR
SAAL
SAAR
SABE
SAGL
SAPU
SARI
CAG
DPB

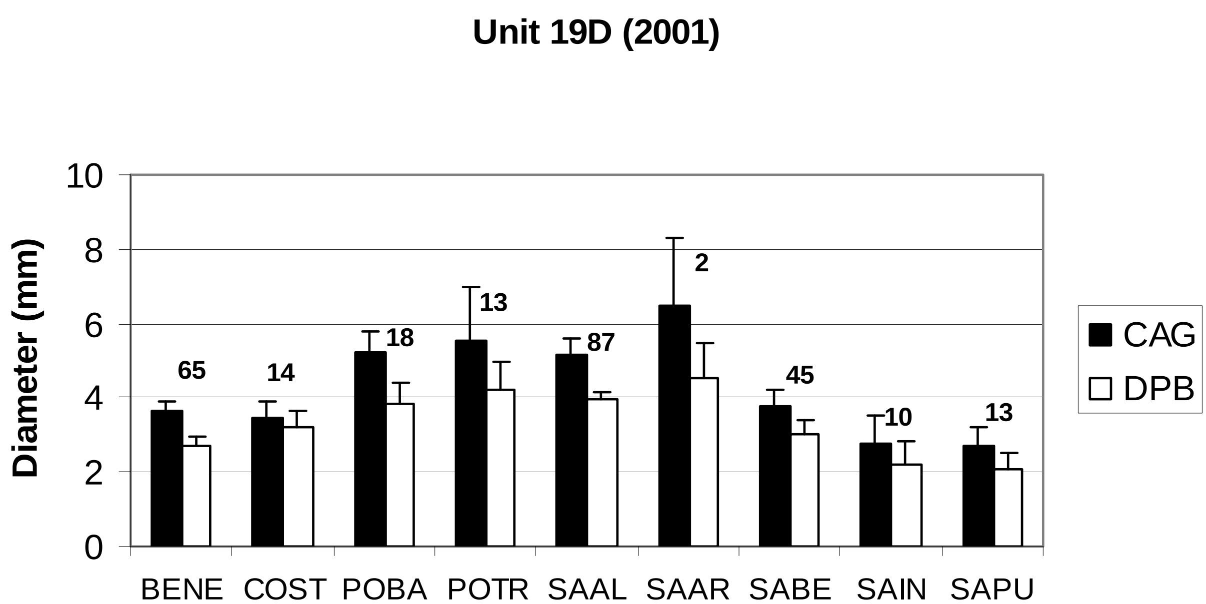


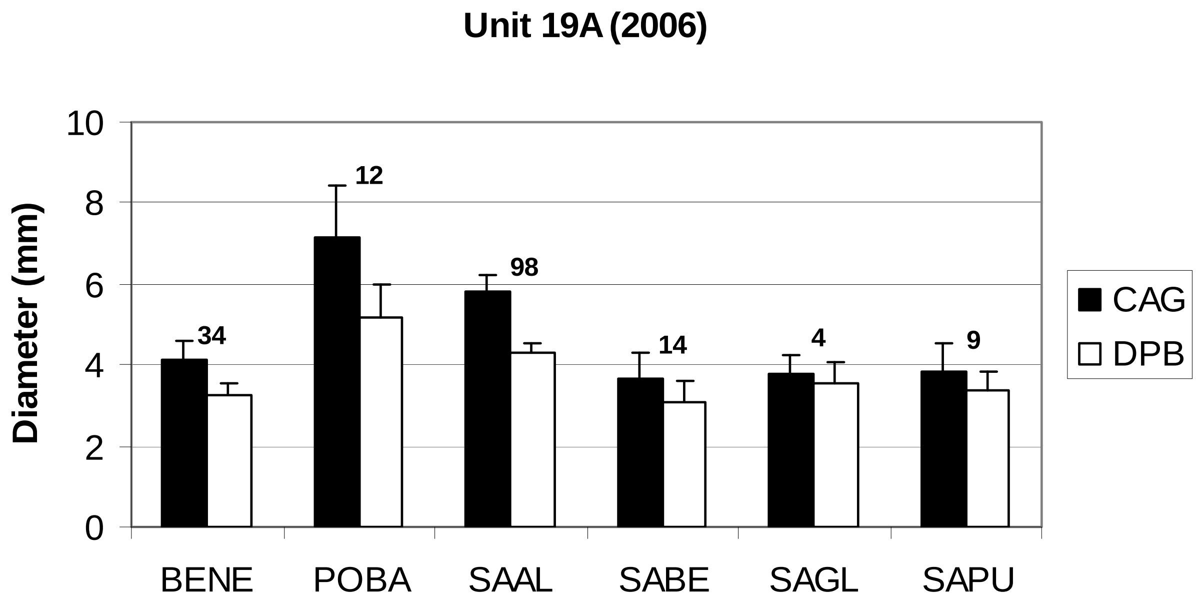
Unit 20D (2000-01)
Diameter (mm)
10
8
6
4
2
0
4
3
104
48
118
87
BENE
POBA
POTR
SAAL
SABE
SAPU
CAG
DPB

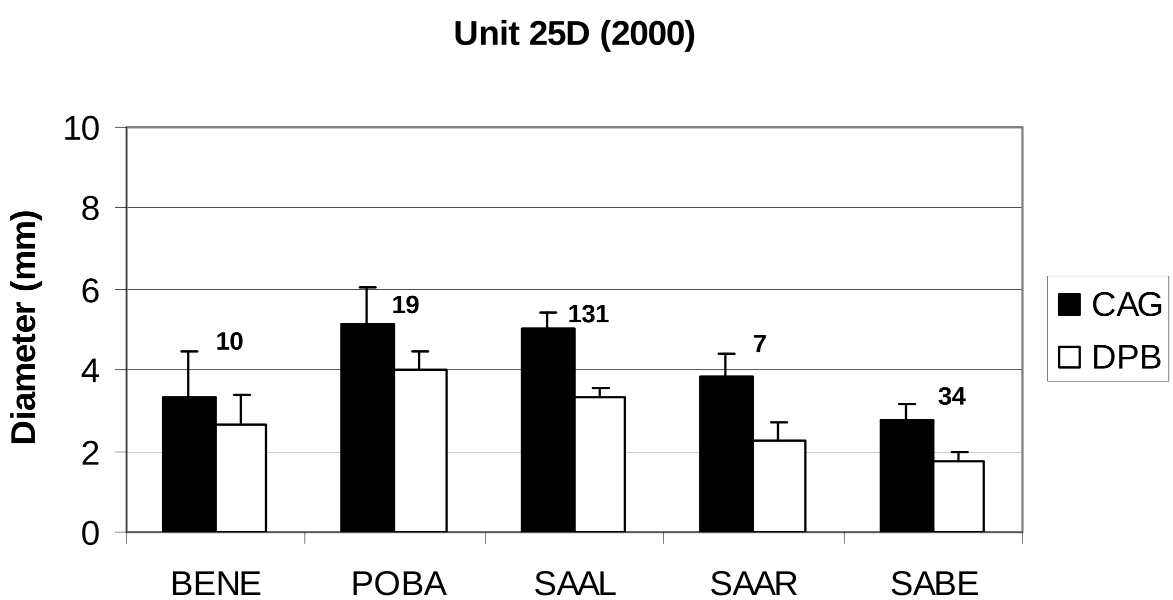

Unit 20E (2006)
Diameter (mm)
10
8
6
4
2
0
5
1
1
11
38
67
BENE
POBA
POTR
SAAL
SAGL
SAPU
CAG
DPB

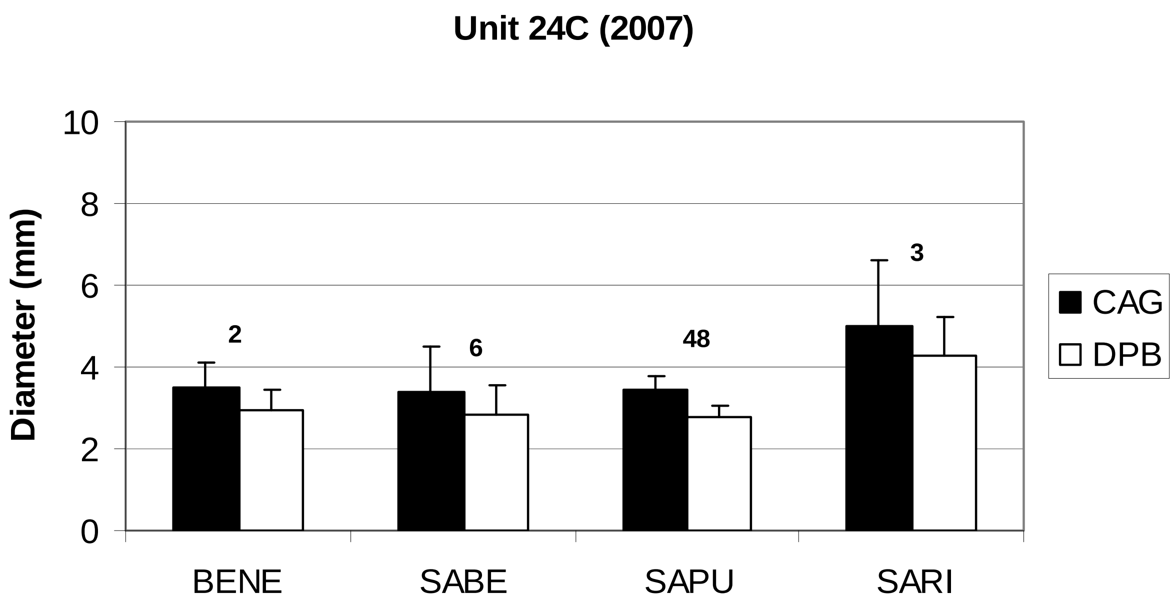

Unit 21E (2006)
Diameter (mm)
10
8
6
4
2
0
28
50
8
227
6
27
42
BENE
COST
POBA
SAAL
SAAR
SABE
SAPU
CAG
DPB

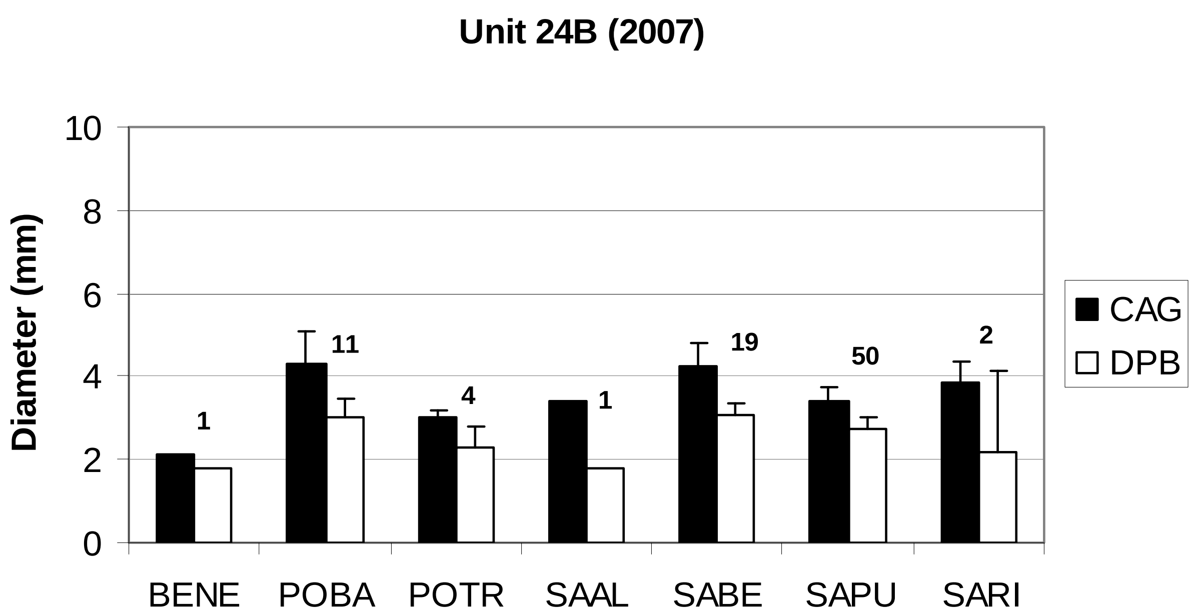

Unit 19D (2003)
Diameter (mm)
10
8
6
4
2
0
96
20
42
288
79
44
113
BENE
COST
POBA
SAAL
SABE
SAIN
SAPU
CAG
DPB


Unit 19D (2001)
Diameter (mm)
10
8
6
4
2
0
65
14
18
13
87
2
45
10
13
BENE
COST
POBA
POTR
SAAL
SAAR
SABE
SAIN
SAPU
CAG
DPB


Unit 19A (2006)
Diameter (mm)
10
8
6
4
2
0
12
98
34
14
4
9
BENE
POBA
SAAL
SABE
SAGL
SAPU
CAG
DPB


Unit 25D (2000)
Diameter (mm)
10
8
6
4
2
0
19
131
10
7
34
BENE
POBA
SAAL
SAAR
SABE
CAG
DPB


Unit 24C (2007)
Diameter (mm)
10
8
6
4
2
0
2
6
48
3
BENE
SABE
SAPU
SARI
CAG
DPB


Unit 24B (2007)
Diameter (mm)
10
8
6
4
2
0
1
11
4
1
19
50
2
BENE
POBA
POTR
SAAL
SABE
SAPU
SARI
CAG
DPB

APPENDIX H Example of deterministic output from R program with added calculations (in bold) of production (CAG) and removal (DPB) in g/707 m^2 plot and proportional removal of moose browse at 4 summary levels for Unit 20D in 2007. Only the last 2 lines of output are shown for each summary level (sum of records is count). DPB of zero indicates lack of browsing for plant or plot.

PLOTID	PLANTID	SPECIES	SUMMARY	CAG	CAG.var	DPB	DPB.var		
24	98	BEPA	plant mean	0.156198	0.000136773	0	0		
25	99	SABE	plant mean	0.154356	0.000613765	0	0		
			Sum	**449.1954**	**165.4749172**	**114.0953**	**12.4723**	**removal**	**0.2540**[a]
				Variance	**0.000866501**[b]		**0.000475**		**0.0001**[c]
				Count	**437**		**162**	**95%CL**	**0.0210**[d]
24	98	BEPA	plant total	3.748763	0.078781487	0	0		
25	99	SABE	plant total	8.489566	1.85664052	0	0		
			Sum	**11782.46**	**93689.75202**	**3547.037**	**29321.24**	**removal**	**0.3010**
98	ALL	SAAL	species mean	6.034007	0.568231734	0	0		
99	ALL	SAAL	species mean	14.66448	2.857211226	0	0		
			Sum	**4465.655**	**12094.48309**	**1307.287**	**3579.607**	**removal**	**0.2927**
98	ALL	SAAL	species total	12.06801	2.272926934	0	0		
99	ALL	SAAL	species total	131.9803	231.4341093	0	0		
			Sum	**281135.4**	**162642801.9**	**98418.62**	**49185509**	**removal**	**0.3501**
				Variance	**6947.874832**		**6807.683**		**0.0009**
				Count	**153**		**85**	**95%CL**	**0.0580**
			Kg/ha =	**53.02**[e]					

[a] Proportional removal = DPB / CAG * 100.
[b] Variance [CAG] = (Sum[CAG.var]) / (Count) ^{2}.
[c] Variance [percent removal] by Delta method = (Sum[DPB.var]) / (Sum[CAG]) ^{2} + [(Sum[DPB]) ^{2} / (Sum[CAG]) ^{4}] * (Sum[CAG.var]).
[d] 95% CL = 1.96 * Variance [percent removal] $^{0.5}$.
[e] Average browse production for the study area (kg/ha) is the sum of CAG at the species total level multiplied by 0.01414427 and divided by the number of plots sampled in this Unit (*n* = 75). Tally for species total level is the same as for a fifth level of “site total” shown in the program output but not in this table.

APPENDIX I Data collection and processing procedures for browse surveys

Seaton (2002) described the protocols of sampling and data collection and developed data sheets for field plots and lab measurements (Appendix K). We subsequently contracted development of software written in R language (Appendix J) to read a Microsoft Access database with an entry screen that matches the field form. Below are additional guidelines for planning and conducting surveys, lab measurements, and data entry into an electronic database.

1) Field data collection

Cold weather often hinders use of field computers, so we used field forms (Appendix J) with an enclosed clipboard for storage. Before leaving the plot, cross check that all preferred browse species for which measurements have been taken have a tally under PREF.

To describe a 30-m diameter plot in the field, we placed the 2-m pole calibrated at 0.1-m increments in the plot center. We placed marks roughly 5 cm apart on a pencil as a rangefinder for 15-m radius. (To calibrate, we stood 15 m from the vertical 2-m pole, held the pencil to your side at arm's length, sighted down an arm, and lined up the 2 marks on the pencil with brightly painted or flagged marks at the 1-m and 2-m marks on the pole.) The pole was placed vertically at the plot center so the observer could walk a circle to define the plot boundary (flagging was required after snow was gone). When vegetation was sparse, distance was confirmed for individual plants near the plot boundary to save time.

Counts of twigs on sampled plants and plants by species are expansion factors for estimating production at the plot level, thus can introduce multiplication errors. If 2 or more people are counting, they must coordinate definitions of an individual plant for grouping counts (e.g., clump = 10 plants) when visually estimating high numbers of stems. Dividing the circle into quadrants if uniform or stratifying by stem density (low and high) helps to improve accuracy. Training should involve visual estimates followed by counting to verify or calibrate visual estimates.

Plant height is measured as is (includes bending by snow). If 30 diameter measurements for a species is not possible on the plot because of fewer than 3 plants, it is acceptable to get >10 measurements from one plant. If numerous single-stem plants are measured (e.g., 1- or 2-yr-old feltleaf cohort on active floodplain) because they are the only growth form in the stand, they need to be entered as individual plants (diameters) using the same height, dead class, and architecture form (make note and use a single column on data sheet). The plant count by species for the plot must distinguish between single-stem young plants and older multiple-stem plants on the data sheet because they are different multipliers.

2) Lab procedure for mass-diameter of twigs

If you are developing mass-diameter relationships, keep plant leader samples frozen until analysis to prevent desiccation. Label species, study area, and date on a diagonal cut end or tag in the field. A data sheet (Appendix J) helps guide measurements in the lab. Use dial calipers to find location of whole millimeter diameters on the leader for clipping with hand shears or a sharp knife. Weigh successively smaller sections of leaders on an electronic balance. Oven drying samples and other technique details are found in cited methods.

3) Error checking in database

The Microsoft Access database has entry forms for tables configured similar to field data sheets. When proofing data entry, key multipliers to check are the count of preferred plants (by species) in each plot and the twig count per sampled plant. Lack of a plant (species) count when a species is reported under twigs will cause an error, as will a blank under number of twigs (the latter reported as “NA” in the output spreadsheet created by the R software; Appendix I). Having a blank in the Twig Data table for diameter at point of browsing (DPB) instead of 0.0 will cause reporting as “NA.” Always use the “save” option after corrections are made. Inadvertent blanks on the data sheets for number of twigs can be entered in the database with an average from the other plants of the same species for that plot.

For any species listed in the Plant Data and the Twigs Data tables, there must be the corresponding species in the Lab Wetmass and Diameter and the Wet Weight Conversion tables (mass-diameter regression and dry weight correction, respectively). If not, “NA” will be reported for plants (species) lacking the corresponding data in the output spreadsheet. If necessary, import regression and dry weight data from the nearest study area where it exists. A separate column for “Plot_GMU” (Game Management Unit) should specify origin of browse mass and diameter data; there must be an exact match of plot ID between the 2 tables (Wetmass and Wet Weight) to avoid “NA.”

Importing mass-diameter data from another study area can be done as a table export from the source Access file, renaming the table with the source study area. Once field names are confirmed to exactly match those of the receiving table (add or delete fields if necessary), export a second table within the same (recipient) database that will contain only the species needed after you delete unnecessary records of species you already have. It is helpful to print out the relationships diagram for a recent dataset for cross-checking tables and records in older datasets. Note the source study area in the “zone” field for posterity, which requires creating a column in Excel and pasting into the zone field. Then append the needed species onto the Lab Wetmass and Diameter table by cutting and pasting (as append option) into the last (blank) record.

If a different willow species is added the plant count section of Access (e.g., SAGL), you should verify that the column TOTSAGL exists in the SITE table and the counts are reported, or there will be an “NA” reported for some of the totals in the output.

APPENDIX J Instructions for using R program to estimate browse production and removal

Download a copy of the R statistical package found at http://www.r-project.org/. You'll also need to download and install the RODBC package. The R program code for calculating browse metrics (moosebrowse_1.0.zip), along with the Access database framework and field and lab data sheets, can be obtained from the senior author (tom.paragi@alaska.gov). Create a single folder in which to store the R code, the .RData workspace, Access database files, and output files.

To calculate mass-diameter regression, dry weight adjustment, and estimates of biomass production (CAG) and biomass removed by browsing (DPB), you must first install the library file into R. After starting R, at the ">" command prompt type "**utils:::menuInstallLocal()**" and hit return to select the program code (moosebrowse_1.0.zip). Installation of the library is done once and need not be repeated. At the > prompt, enter "**library(moosebrowse)**" to load program and help files (must be entered at the prompt each time you wish to execute the moosebrowse library of routines). For full documentation, type any of the following at the prompt:

?analyze.browse.data
?run.reference.regression
?predict.drymass
?multilevel.summary
?bootstrap.summary

For default calculations, type "**analyze.browse.data()**" and select an Access database file when prompted. The code will perform the deterministic calculations for production and removal and produces 3 comma delimited (*.csv) spreadsheets in the same directory as the Access database with a prefix of the same file name (2 additional spreadsheets from bootstrapping):

[filename]Browse.csv = production, removal, and variance estimates at multiple summary levels
[filename]TWIG.csv = production and removal for each twig measured
[filename]RR.csv = regression parameters for each plant species in the study area
[filename] st_BS.csv = species total bootstrapping results
[filename] pm_BS.csv = plant mean bootstrapping results

Entry options for the main routine "analyze.browse.data" are listed below with defaults:

analyze.browse.data(file, file.out = T, bootstrap = F, plot.diameter = 30, nbootstrapSamples = 1000, nplotidSample = 5, version = F)

> <u>file</u> is the Access database with field data
> <u>file.out=T</u> writes 5 files of results otherwise results not written to files
> <u>bootstrap=F</u> does not perform bootstrapping and bootstrap files are not written (otherwise <u>bootstrap=T</u> performs bootstrap)
> <u>plot.diameter=30</u> notes diameter of plots (m)
> <u>nbootstrapSamples = 1000</u> is number of bootstrap replications
> <u>nplotidSample = 5</u> is number of plots to sample for each bootstrap replication
> <u>version = F</u> (otherwise when version=T it outputs date of program constructions)

If any output fields CAG or DPB in the Browse spreadsheet contain “NA” you will need to correct errors in the database (see section 3 of Appendix I) and run the program again. Deterministic estimates of production and removal and 95% confidence limits can be calculated at multiple summary levels in the spreadsheet output (Appendix H). Bootstrap estimates at the summary levels of “plant mean” (sampled twigs only) and “species total” (sampled twigs of a species extrapolated to all plants of a species in a plot) may be obtained by typing “**analyze.browse.data(,,T,,,#)**” where # is the number of plots you wish to resample with replacement for bootstrapping (typically the total number of plots sampled in study area). Bootstrap runs may take several minutes depending on computer processing speed. After several runs you may receive an error message about memory limit, in which case you simply quit program R, restart it, and reload the program code to continue. In addition to the spreadsheet output, frequency distributions of bootstrapping results are generated in a popup screen. The bootstrapping graphs are another way to examine the effect of extrapolating sampled twig data to the plot species composition (e.g., Fig. 2).

The output spreadsheet from the function “analyze.browse.data” also produces estimates by summary levels of “plant total” (sampled twigs extrapolated to total twigs on sampled plants) and “species mean” (total twigs extrapolated to all plants of a species in a plot) in the Browse spreadsheet. Cell values for the first 4 summary levels are grams per plot (30 m diameter = 707 m^2). Subsequent calculations can be done on this raw output for percent removal and confidence intervals (Appendix H). Each summary level beyond plant mean is subject to bias during extrapolation; e.g., sample all 3 plants of one species in a plot but only 3 of 1,000 plants in another plot. Seaton (2002:73) estimated production and removal at the species total level to allow modeling of forage intake for Unit 20A. We used the “plant mean” level as the least biased index for comparing proportional biomass removed with twinning rate (Table 4) but recommend the “species total” level as the most inclusive index to landscape variability for characterizing browse production at the Unit or study area scale (Table 3).

Three additional summary levels (“site total,” “plot total,” and “study area”) are provided in the Browse spreadsheet for further analysis. These 3 summary levels extrapolate sample data to plot composition. Additional fields (CAG2, CAG2.se, DPB2, DPB2.se) are estimates of production and removal in kg/ha and its standard error. Note that cell values for the level “plot total” are grams/plot, whereas cell values for “site total” and “study area” are grams/all plots, which must be multiplied by the number of plots in the study area for a per-plot value.

APPENDIX K Example of data forms for field (plots) and lab (mass-diameter) measurements in our browse surveys (next 3 pages). The conceptual definitions of architecture on the back of the field form have been modified to more precise terms (see methods).

plot ID: 130 Unit 20D
lat/lon:
date: 5 Apr 07
crew: CTS TEP
strat class: TS
slope: —
aspect:
snow dep.: 0.7 | Bark stripping? Y N | sp?
diameters in mm or inches/100

PREF	number	#broken
Saal	40	
Sapu		
Sabe		
SaRi	8	
Sa__		
Bepa		
Potr		
Poba	6	

NONPREF	number	mean height	# broken or browsed
spruce			
tam			
alder	15	2	
D birch			

Species	Saal	Saal	Saal	Pobe	Pobe	Pobm
#twigs	22	16	25	9	7	56
dead class	M	M	M	L	M	M
height	1.5	1.5	1.6	2.0	1.5	2.0
architect	BM	BM	BM	BM	BM	BM

	CAG	DPB	CAG	DPB	CAG	DPB	CAG	DPB	CAG	DPB	CAG	DPB
1	3.0	—	3.6		3.1		5.9	—	3.1		3.3	—
2	5.9	5.9	2.2		2.8		5.2	—	2.8		4.5	2.8
3	4.8	4.8	3.2		3.1		7.4	(5.9)	3.0		2.7	—
4	5.4	4.6	3.0		4.0		5.0	5.0	2.2		9.6	(7.2)
5	2.8	2.8	2.4		3.0		5.1	5.1	3.7		4.4	—
6	4.3	4.3	1.8		3.8		3.2	3.2	3.6		3.0	—
7	2.5	—	1.6		2.1		4.2	—	4.4		3.3	—
8	2.0	—	2.0		2.4		5.8	—			3.0	—
9	2.4	—	2.3		2.8		4.0	—			2.5	—
10	3.2	3.2	4.4	(3.8)	6.1	(4.9)					2.0	—
11											2.9	—
12											3.0	—
13											5.1	—
14											2.4	—
15												
16												
17												
18												
19												
20												
21												
22												
23												
24												
25												
26												
27												
28												
29												
30												

NOTES
burn?
drifting?
moose preferences
succession stage?

subalpine bench above
[illegible]
SaRi: sample taken

Circle the DPB measurement if it is believed to be older than CAG

Architecture classes (browsing history of the plant, includes this year, and all visible evidence of past years)
broomed- past browse pressure has altered the growth of the plant (broken main stem OR most of the CAG twigs rise from lateral twigs that are the result of browsing)
unbrowsed- no evidence of past browsing
browsed- evidence of past browsing, but hasn't significantly altered the growth of the plant

	Plant 1	Plant 2	Plant 3	Plant 4	Plant 5	Plant 6
Species	SaRi	SaRi	SaRi	SaRi		
#twigs	15	15	5	30		
dead class	L	L	L	M		
height	1.5	1.4	1.5	1.2		
architect	UN	UN	UN	UN		

	CAG	DPB	CAG	DPB	CAG	DPB	CAG	DPB	CAG	DPB	CAG	DPB
1	2.8		4.5		2.2		2.8					
2	2.2		2.5		2.2		2.2					
3	2.0		2.7		2.0		2.0					
4	1.6		2.5		1.8		2.5					
5	2.3		2.7		3.2		2.7					
6	1.5		3.0									
7	1.8		2.9									
8	1.9		2.0									
9	1.5		1.8									
10	2.4		2.0									
11												
12												
13												
14												
15												
16												
17												
18												
19												
20												
21												
22												
23												
24												
25												
26												
27												
28												
29												
30												

Dead classes (amount of dead material that comprizes a plant)
X= no dead
L= less dead than live material
M= more dead than live material

STEPS IN SURVEY
1. Locate center of plot
2. Locate boundary of plot
3. If no pref plants, pick alt
4. Snow depth
5. Choose random distance and direction from center to start measuring closest plant of each pref species
6. Turn head and grab stem on plant
7. Measure 10 twigs starting at terminal end of that stem
8. height, # twigs, spp, arch.
stems only between 0.5m and 3.0m
9. Choose next random distance and direction from center for other plants to measure
9.5. Goal is 30 twigs/ spp
10. Estimate # of all woody browse plants by species in plot

TIPS
*Pref plant has CAG twigs between 0.5m and 3m
*Bepa, Saal, Sabe, etc., can be nonpref plants if they are too tall
*measure plant height from ground

twig mass regression data form.xls

Location	ID	Species	range	10mm	9mm	8mm	7mm	6mm	5mm	4mm	3mm	2mm	1mm	
24	334	Sagl										0.23	–	
												0.17	–	
												0.23	–	
24	130	SaRi										0.07		
												0.04	–	
									3,09	2.24	0.55	0.06		
					15.48	6.09	4.48	3.40	2.41	0,92	0.56	0.14		
										1.62	0.41	0.13		
											0.62	0,13		S
												0.22	–	
											0.55	0,03		
											0.67	0,08		
											0.32	0,06		
											0.53	0.15		S
											0.27	–	–	
												0,17	–	
												0,13	–	
												0,13		
												0.13	–	
2A	334	Saal					16.23	10.08	3.29	1.35	0.35	0.06		
										2.25	1.17			
									3.59	2.64	0.70			
							16.12	9.86	4.82	1.57	0.18			S
										3.06	1.25	0.06		
						19.68	14.18	11.23	4.00	1.61	0.46			S
						~~14.46~~	~~9.22~~			2.27	0.71			
							15.36	6.98	3.35	1.08		–	–	S
								10,46	4.76	1.49	0.28			
											0.81			
									4.89	2.64	0.78	0.06		
											1.16	0.12		S
										2.98	0.65	0.09		S
										2.39	1.61	0.05		

1)locate the largest single-stem diameter
2)cut twig at even mm
3)weigh twig

4)cut same twig at next smallest diameter (mm), repeat #3
5)find another large single-stem and start a new row
6) make one wet wieght conversion for each collection location

The Federal Aid in Wildlife Restoration Program consists of funds from a 10% to 11% manufacturer's excise tax collected from the sales of handguns, sporting rifles, shotguns, ammunition and archery equipment. The Federal Aid program allots funds back to states through a formula based on each state's geographic area and number of paid hunting license holders. Alaska receives a maximum 5% of revenues collected each year. The Alaska Department of Fish and Game uses federal aid funds to help restore, conserve and manage wild birds and mammals to benefit the public. These funds are also used to educate hunters to develop the skills, knowledge and attitudes for responsible hunting. Seventy-five percent of the funds for this report are from Federal Aid.

ADF&G Photo/Tom Paragi

Federal Aid in Wildlife Restoration
Grants W-33-4, 5, 6 and 7
Project 5.10