PREDICTING MOOSE BROWSE PRODUCTION USING THE NORTH-WESTERN ONTARIO FOREST ECOSYSTEM CLASSIFICATION

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ABSTRACT: High browse production is a key factor for quality moose habitat, and in this study we test the utility of a forest ecosystem classification system to predict the density and biomass of browse in standing timber, and the regrowth response of browse species following timber harvest. The 38 vegetation- and 22 soil-types of the Northwestern Ontaro Forest Ecosystem Classification were grouped *a priori* into Treatment Units (TUs) according to their expected ability to produce browse, and we tested the hypothesis that all groups produced browse equally, before and after harvest. We sampled for browse density using a nearest-neighbour, plotless sampling technique, and extrapolated current annual growth by using regressions of plant dimensions to clipped annual growth dry weight. We ranked each TU according to observed density and inferred preference of browse species, and also tested if existing and commonly available forest resource inventory (FRI) data could successfully assign forest stands to TUs without the need for on-ground data collection. TU 1 (hardwood and mixedwood) and TU 2 (balsam fir-white spruce conifer and mixedwood) had highest browse density ($P < 0.0001$), current annual growth ($P < 0.001$), and overall browse habitat suitability. The magnitude of response of browse density to timber harvest differed across TUs, with browse density in TUs 1 and 2 increasing 2-3 times following harvest, but increasing little or not at all for other TUs. Substantial congruence occurred between the field-determined TUs and airphoto-based FRI estimated TU classifications (83% overlap), although the classifications did differ ($P = 0.018$). Some TUs could not be differentiated because of the absence of information on understory vegetation in the FRI data.

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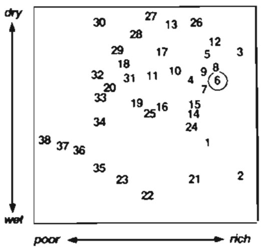
Regional forest ecosystem classifications are being developed across North America (e.g., Corns and Annas 1986, Kotar *et al.* 1988, Sims *et al.* 1989, Beckingham *et al.* 1996), and they offer the potential to assist resource planners in predicting forest structure and composition, or the ecological response of a site to forest management treatments (Racey *et al.* 1989). For example, wildlife planners may be able to use groupings of classification units to predict both the density and biomass of moose browse in standing timber, and the regrowth of browse following timber harvest. In an age of diminishing resources and increasing demands for knowledge and information, resource planning agencies will benefit if they can develop simple predictive models by encoding knowledge of expected vegetation responses under specific site conditions. Cost of data collection and management is also a factor in evaluating a classification's cost-effectiveness, and classifications that require intensive field work may not always be effective. It is thus important to determine the minimum data requirements for successfully applying the classification.

The Northwestern Ontario Forest Ecosystem Classification (NWO FEC), (Sims *et al.* 1989) defines 38 vegetation types (V-types) and 22 soil types (S-types) based on vegetation composition and structure as well as soil characteristics. A sample V-type factsheet is shown in Fig. 1. *A priori* group-

V6

Trembling Aspen (White Birch) - Balsam Fir / Mountain Maple

General Description (n=68): Hardwood mixedwood stands with balsam fir as the main conifer tree species. The canopy is typically diffuse and two-tiered with aspen or aspen-birch in the overstory and balsam fir constituting a secondary stratum. The understory is generally herb and shrub rich with *Acer spicatum*, *Aralia nudicaulis* and *Aster macrophyllus* often abundant. Occurring mainly on deep, fresh, well to rapidly drained, upland mineral soils.



Overstory Species

balsam fir 10
trembling aspen 10
white birch 7
white spruce 3
black spruce 2
jack pine 1

Common Understory Species

Shrubs: balsam fir, Acer spicatum, Rubus pubescens, trembling aspen, Diervilla lonicera, Corylus cornuta, Linnaea borealis, Lonicera canadensis, Sorbus decora, Rosa acicularis

Herbs: Aralia nudicaulis, Streptopus roseus, Maianthemum canadense, Cornus canadensis, Clintonia borealis, Aster macrophyllus, Viola renifolia, Trientalis borealis, Galium triflorum, Mitella nuda, Anemone quinquefolia

Mosses: Pleurozium schreberi, Plagiomnium cuspidatum, Rhytidiadelphus triquetrus, Ptilium crista-castrensis

Forest Floor Cover

Broadleaf litter: 81 Moss: 7 Wood: 7

Soil / Site Characteristics

Soil Groups:	(dp d-f) 8, (dp m) 1, (mod dp) 1
Thickness of Organic Layer:	[LFH] - (6-15) 6, (1-5) 3, (16-25) 1
Surface Texture:	c. loamy 4, silty 2, f. sandy 2, clayey 1, f. loamy 1
C Texture (when present):	c.loamy 4, f. sandy 2, silty 2, clayey 1, c. sandy 1
Moisture Regime / Drainage:	fresh 8, dry 1, moist 1 / well 5, rapid 4, poor 1
Mode of Deposition:	morainal 5, lacustrine 2, glaciofluvial 2, fluvial 1

Comments: Some stands may key to this Type solely as a result of herb richness *(Astemac ≥ 10%)*. Balsam fir is frequently abundant in the shrub layer. **V6** differs from **V7**, and is similar to **V8**, primarily on the basis of *Acer spicatum* abundance. **V6** occurs more frequently in the NC Region than in the NW.

Fig. 1. Description of vegetation-type 6, which is 1 of 38 vegetation-types defined in the northwestern Ontario Forest Ecosystem Classification (Sims *et al.* 1989). Vegetation-type is identified using a dichotomous key in which herb, shrub, and overstory vegetation layers are inspected in a 10 m by 10 m plot. Type description includes a general description of vegetation and soil characteristics, an ordination diagram identifying location of all vegetation-types on dominant axes of soil moisture and richness, a schematic silhouette diagram of typical overstory, understory, and substrate conditions, and summaries of common understory vegetation, forest floor cover, soil/site characteristics, and comments.

ings of vegetation- and soil-types, termed Treatment Units (TUs), have been formulated (Racey *et al.* 1989). TUs are aggregations of vegetation and soil types that are expected to respond similarly to a given silvicultural treatment regime (Racey *et al.* 1989). Racey *et al.* (1989) developed specific interpretations of TUs in terms of their suitability to produce moose browse which represent an hypothesis of the relationship between FEC units and browse productivity. As an example application of how FEC classifications can be used to predict browse production, we empirically tested the success of northwestern Ontario TUs to discriminate sites in terms of browse density and current annual growth (kg/ha), before and after timber harvest, and calculate expected biomass production for each TU. Using published selection ratings for moose browse (Cumming 1987), we calculate a browse habitat suitability index based on density and biomass of individual browse species. We then apply the index across a 2-dimensional ordination space to model expected browse habitat suitability across a range of site soil-moisture and nutrient-availability conditions in northwestern Ontario.

The Ontario Forest Resource Inventory (FRI), the standard used in Ontario for forest management planning, is based on air-photo interpretation of overstory vegetation, and exists for all active forest management units. Ability to use these inventory data to estimate FEC types or TUs would enhance the cost-effectiveness of applying FEC in resource planning. In comparison with FRI systems, which are based on air-photo interpretations of overstory vegetation, FEC systems typically require relatively detailed field level survey of herb, shrub, and overstory vegetation to determine vegetation-types, and soil depth, moisture, and texture information to determine soil-types. Mapping FEC types for an entire management unit will be expensive and time consuming. Overstory composition, however, can be viewed as a long-term integrator of site conditions, and therefore, predictions of browse production based on FEC-derived TUs may overlap with predictions based on FRI-derived TUs. To test this hypothesis we develop an algorithm to assign sites to TUs based on FRI data, and test for deviations from site classifications based on field vegetation- and soil-type data.

STUDY AREA

The study was undertaken in northwestern Ontario at with sampling generally concentrated in the vicinity of seven areas ranging from north of Lake Superior (87°1'W, 49°35'N) to north of Lake of the Woods (93°34'W, 50°30'N). Overstory vegetation ranged from pure, even-aged jack pine (*Pinus banksiana*) located on dry glacial outwash sands to highly productive aspen (*Populus tremuloides*)- balsam fir (*Abies balsamea*)- white spruce (*Picea glauca*) mixedwoods located on fresh and moist silty and fine-loamy lacustrine soils. The area has a long history of disturbance from both wildfire and timber management, and disturbed areas are allowed to regenerate naturally or artificially (*e.g.,* aerial seeding and hand planting).

METHODS

Seven TUs, modified from Racey *et al.* (1989), were sampled (Table 1). These Treatment Units were assembled based on an *a priori* assumption that the V-types and S-types would have similar browse production potential, based upon expected productivity associated with common soil texture, moisture regime, soil depth and plant species composition. Only stands greater than 40 years of age or cut 5 - 12 yrs before 1991 were selected, in part to ensure a relatively stable forest condition for sampling and avoid rapidly changing conditions during early establishment, and stand closure. V-Types are best determined using the NWO FEC identification keys (Sims *et al.* 1989) on relatively mature stands. FEC vegetation-types were

Table 1. Treatment unit[a] (TU) descriptions in terms of northwestern Ontario Forest Ecosystem Classification (FEC) vegetation- and soil-types (Sims *et al.* 1989).

TU	Vegetation-Types	Common Soil-Types	Expected browse production	N	Description
1	V4,V5, V6, V9	S2, S3, S4, S5, S6, S7, S8, SS6	High	41	**Hardwood and Mixedwood** Stands range from white birch or pure aspen dominated to aspen mixed with white birch, balsam fir, jack pine, black spruce or white spruce. The understory is usually productive with a dense, tall and low shrub layer. Soils are deep, and either moderately dry to very fresh, or moist to very moist.
2	V14,V15	S3, S4, S5, S6, S7, S9, S10	Moderate/High	37	**Balsam Fir-White Spruce Conifer and Mixedwood** An extremely variable mixed-wood type. The canopy, comprising mainly balsam fir or white spruce, may contain a mixture of several species. The understory varies from shrub rich to moderately herb and shrub poor. Usually on deep, fresh to moist mineral soils, but encompassing a wide range of soil and site conditions.
3	V20,V31, V32, V33, V37	S1, S2, S3, S4, S7, S8, S9, SS5, SS6, SS8, SS3	Low	33	**Black Spruce-Jack Pine / Feathermoss** Even-aged, black spruce and jack pine stands with a poor to moderately well developed shrub layer. Feathermoss cover is often high. Soil conditions variable.
4	V18, V29, V32	S1, S2, S3, SS2	Low	25	**Jack Pine / Feathermoss**. - Typically even-aged jack pine or jack pine-black spruce stands with extensive feathermoss ground cover. Relative to other mixedwoods, understory tends to be herb and shrub poor. Occurring on upland, fresh to dry, coarse-textured mineral soils.
5	V17	S1, S2, S3, S4, SS6	Low/Moderate	27	**Jack Pine/ Shrub Rich** - Jack pine stands with some trembling aspen component and a generally rich, diverse low shrub component. Scattered feathermoss patches may at time be extensive. Ericaceous shrubs can be a major component of the low shrub layer, particularly in northwestern Ontario. Occurring on upland, fresh to dry, coarse-textured mineral soils.
6	V30	S1, S2, S3, SS1, SS2, SS4, SS6	Low	27	**Jack Pine - Black Spruce / Blueberry / Lichen (V30)** - Sparse jack pine and/or black spruce stands. The understory is open with scattered clumps of black spruce shrubs. *Vaccinium* spp. predominate in the herb / dwarf shrub layer. The forest floor is characterised by abundant lichen cover. Usually occurring on shallow, sandy or rocky sites.
7	V33,V36, V37	S7, S9, S12S, SS8, SS9, S12F	Low	21	**Black Spruce / Wet Organic** - Typically black spruce / Sphagnum associations on organic soils. Occurring on wet, poorly drained sites.

[a] In Racey *et al.* 1989, TU 1 = B and C, 2 = D, 3 = E, 4 = F, 5 = G, 6 = I, and 7 = J2.

assigned to cut stands based on inspection of residual woody debris, moss and herb layers, soil moisture, adjacent stand composition, and stand composition records. The authors modified a previous interpretation by Racey *et al.* (1989) to suggest an expected ranking of browse production from from each of the seven TUs (Table 1).

We used Cumming's (1987) summary of 16 years of browse selection studies in Ontario, studies by Belovsky and Jordan 1978, Crête and Jordan 1982, McNicol *et al.* 1980, Irwin 1985, Peek *et al.* 1976, and Thompson and Vukelich 1981, and local experience to select the following commonly available plant species that range from high to low preference by moose: june berries (*Amelanchier* spp.), mountain ash (*Sorbus americana*), red osier dogwood (*Cornus stolonifera*), trembling aspen (*Populus tremuloides*), willow (*Salix* spp.), white birch (*Betula papyrifera*), mountain maple (*Acer spicatum*), beaked hazel (*Corulus cornuta*), balsam fir (*Abies balsamea*), pin cherry (*Prunus pensylvanica*), green alder (*Alnus stricta* var. *crispa*) and speckled alder (*A. incana* var. *rugosa*).

Plant density and dimensions were sampled from July through September 1991. Each sampling site consisted of 3, 100 m adjoining transect lines, and 30 starting points were located at 10 m intervals along the 300 m line (Fig. 2a). The 100 m transects were usually positioned at right angles, forming the 3 legs of a "U". The "U" shape was modified on some sites to ensure the sampling was done within the desired site condition. The initial starting point for the first transect was located at least 50 m from a stand edge, cutover boundary or road right of way. From each of these starting points the distance (cm) to the nearest eligible plant species was measured following the corrected point distance sampling technique described by Laycock and Batcheler (1975). Distance to the location where the stem emerged from the soil was recorded only if an eligible species of shrub >0.5 m in height was encountered. If distance was ≥ 5 m away, distance was recorded as 5 m to avoid extreme distance measures and avoid the same plants being sampled from more than 1 starting point. The number of usable sample sites within each of the 7 TUs varied from 21-41 sites; overall there were 259 sample sites, of which 211 were used providing a total of $211 \cdot 30 = 6330$ potential plant distance and canopy measurements. Some of the original sample sites that had chemical tending treatments applied were not used in the analysis.

Densities were estimated for each site using the density point distance (dpd) (Warren and Batcheler 1979). This method is termed BBCI in Table 1 of Engeman et. al (1994:1771). In a simulation experiment evaluating the performance of 25 plotless density estimators under 6 spatial dispersion patterns, 4 sample sizes and 4 population densities, Engeman *et al.* (1994) found that the Batcheler-Bell closest individual (BBCI) density estimator (dpd in this study) performed reasonably well, although it was not the best of all point distance methods. Specifically, the density point distance method had a lower error (in all but 1 distribution) than the corrected point density, even when the samples were clumped. Because the dpd method works reasonably well under most spatial dispersion patterns encountered in this study we did not calculate density separately for each plant species. Accelerated bootstrap estimates (Efron 1982, Dixon 1993) were used to calculate 95% confidence intervals for median stem density (1000 resamples). ANOVA was used to test for main effects and interactions of TU (1-7) and harvest (cut and uncut) on $\log_e$ transformed density, and Student-Newman-Keuls multiple-range procedure was used to test for differences among TUs within a harvest treatment.

For each shrub, the diameter of the stem was measured to the nearest millimetre, and

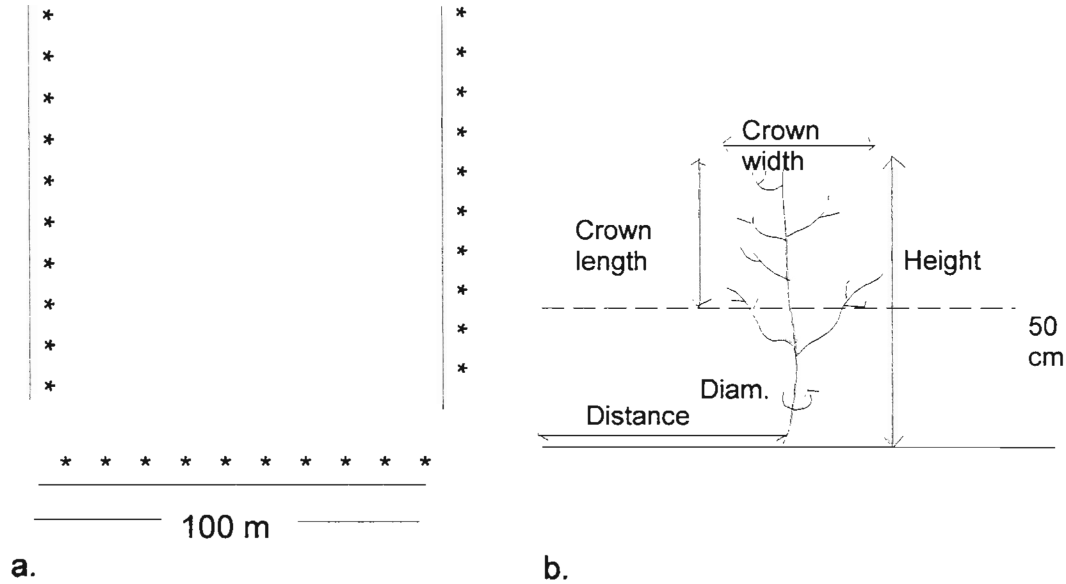


Fig. 2. (a) Typical layout of starting points for point-density measurements. Each sample site has 3 transects and a total of 30 starting points; (b) plant stem and canopy measurements that were taken for every plant. Clippings of current annual growth were taken from a subset of plants, and multiple log-linear regressions of expected current annual growth with these plant dimensions established.

height to the nearest centimetre (shrubs $\geq$ 3 m in height were recorded as 3 m). Crown length was determined as the vertical distance between the lowest browsable twig or 0.5 m (whichever was higher) and the top of the terminal twig or 3 m (whichever was lower) (Fig. 2b). Crown width was the maximum horizontal distance across the crown and between 0.5 and 3.0 m in height. For each plant species, we calculated empirical regressions of current annual growth (CAG) of twigs versus crown dimensions.

Clipping of CAG for regressions took place after leaf fall, September and October 1991, and annual twig biomass production estimates were based on twigs from clipped shrubs in each species. To ensure samples were taken from plants over a range of heights, the field team searched sample site locations for shrubs of each species in each of the three height categories; <1 m, 1 - 2 m, and > 2 m. For each selected plant, all twig CAG between 0.5-3.0 m above ground was clipped, without leaves, and placed into labelled plastic bags. Prior to clipping in the field, stem diameter, height, crown length and crown width was measured. Clippings were placed in a freezer at -3 °C until drying. Clipping were placed in a paper bag and oven dried for 48 hr at 65°C. Dried material was weighed to the nearest 0.01 g.

Linear regression was used to extrapolate the $\log_e$ of plant dimensions (by species) to the $\log_e$ of CAG for all stems measured, using a method similar to Marshall *et al.* (1990), and average CAG was calculated for each sample site. Average biomass for each sample site was a derived variable, calculated as the product of average density and CAG. We did not conduct formal tests of significance, but did provide empirically derived (boot-strapped) estimates of 95% confidence of the median.

An index of habitat suitability for browse was calculated from density by weighting individual browse species according to expected moose selection (Cumming 1987:138). The browse habitat suitability index (BHSI) was defined as:

$$BHSI_j = \sum_{i=1}^{n} (SD_j \bullet PC_i \bullet BP_i) / 1000$$

where j is the jth TU, i is the ith browse species, n is the number of browse species, SD is total stem density (stems/ha), PC is % composition of browse species within a TU, and BP is browse selection value. An extrapolation of $BHSI_j$ was overlaid on the original northwestern Ontario FEC ordination (Sims *et al.* 1989) of vegetation-types. TUs in terms of vegetation-types were delineated on the ordination.

For each sampling site the overstory tree percent composition, up to a limit of 5 species, was recorded from FRI mapsheets, which are based on air-photo interpretation at scales of 1:15,840 or 1:20,000. From these data, and the field-based measurements of vegetation-type and TU, an algorithm was developed to assign sample sites to TUs based on the overstory composition. The success of this classification was tested using a Wilcoxan matched-pairs signed-ranks test, where TU was the paired-variable.

RESULTS

Beaked hazel, mountain maple and trembling aspen dominated the percent species composition of TU 1, while balsam fir and mountain maple dominated TU 2 (Table 2). Green alder and willow were common in TUs 3-7, and pin cherry was common in units 3-6. White birch occurred frequently in TU 5, and speckled alder was the most frequently occurring deciduous species in TU 7. Balsam fir biomass differed the most between harvested and unharvested sites, and dominated TUs 1 and 2, where it accounted for 62 and 98% of total biomass, respectively. Median densities for harvested sites ranged from 327 - 13,493 stems/ha for TUs 6 and 1, and for unharvested sites ranged from 172 - 5,653 stems/ha for TUs 3 and 1, respectively (Table 3). Densities were greater in the harvested sites (F = 8.58, 1,238 df, P < 0.001) and differed among TUs (F = 25.0, 6,238 df, P < 0.0001), with interaction occurring between TU and harvesting (F = 3.60, 6,238 df, P < 0.001). For both harvested and unharvested treatments, TUs 1 and 2 were consistently highest in density, with TU 5 third in rank.

Step-wise multiple-regressions of CAG with plant stem dimensions were significant (P < 0.0004 to P < 0.0001) for all 12 species, with R^2 ranging from 0.530 to 0.888 (Table 4). Median CAG biomass per hectare for harvested sites ranged from 0.9 - 123.7 kg/ha for TUs 6 and 2, and for unharvested ranged from 1.1 - 206.0 kg/ha for TUs 3 and 1, respectively (Table 5).

Mean density was weighted by moose browse selection and the proportion of stems within each species (BHSI). TUs 1 and 2 were consistently highest, followed by TU 5 (Table 3). Balsam fir was very dense in the unharvested TU 2 sites (756 g/stem), so consequently this TU had a lower BHSI value in the unharvested than harvested condition. Browse habitat suitability for unharvested forest sites, by TU, was extrapolated onto the FEC ordination of vegetation-types (Fig. 3). Axes are interpreted in terms of general soil moisture and nutrient availability. TUs and vegetation-types associated with greater soil nutrient availability and dry to fresh soil moisture regime (Racey *et al.* 1989) are generally expected to produce more browse than other site conditions.

The algorithm to assign TUs on the basis of overstory composition resulted in the same TU as the FEC field-based classification in 204 out of 246 cases, however the two TU classifications did differ (P=0.018). Lack of understory information in the FRI database meant that not all TUs could be uniquely identified; consequently TUs 3 and 7 and TUs 4 and 6 were grouped (Table 6). Thirteen of the 259 sites could not be classified into any TU by this algorithm. The algorithm was applied to forested polygons within a sample FRI mapsheet, 1500 km^2 in area (Fig.

Table 2. Percent species composition of browse stems and average current annual growth (CAG) across treatment units, for northwestern Ontario, 1991.

Study Species	Percent Browse Stems by Treatment Unit								
	1	2	3	4	5	6	7	Average CAG (g/stem)	Selection Rating[a]
balsam fir	7	17	3	2	8	2	16	327.1	0.62
speckled alder	6	9	17	4	4	0	25	35.7	0.2
trembling aspen	20	10	12	10	14	8	7	11.3	1.3
mountain ash	0	1	1	1	1	1	1	10.3	1.61
white birch	2	6	8	8	12	8	6	9.3	1.18
green alder	4	1	10	22	13	24	13	8.2	0.4
pin cherry	3	5	15	14	18	11	2	7.8	0.52
willow	6	7	26	29	15	39	21	5.5	1.26
red osier dogwood	5	4	1	0	1	0	4	4.4	1.56
beaked hazel	19	8	0	1	2	1	0	3	0.89
mountain maple	17	28	2	2	6	1	1	2.9	1.01
june berry	9	4	5	8	6	4	5	1.6	1.66

[a]Selection rating for all species (except green and speckled alder) based on Table 3, Cumming (1987 : 138).

Table 3. Browse habitat suitability index (BHSI), and median density[a] (stems/ha) in the harvested and unharvested sites, by treatment unit, northwestern Ontario, 1991.

Harvested					Unharvested				
TU	*N*	BHSI[b]	Density	SNK[c]	TU	*N*	BHSI	Density	SNK
1	15	459	13,494	A	1	26	404	5,653	A
2	18	208	5,541	A	2	19	186	2,165	B
5	14	90	2,101	B	5	13	91	1,339	B
3	20	16	1,394	B	4	11	27	1,153	B C
4	14	31	1,261	B	6	9	17	518	C
7	9	15	561	B	7	12	15	189	D
6	18	20	327	C	3	13	19	172	D

[a]Medians are back-transformations of $\log_e$ transformed densities, i.e., geometric means.
[b]BHSI are weighted means of density, with weighting based on moose browse selection values and relative percent composition for individual plant species.
[c]Densities with same class letter are not significantly different based on Student - Newman - Keuls test, F = 14.1, df = 6, 101, $P < 0.0001$ for harvested, and F = 20.5, df = 6, 96, $P < 0.0001$ for unharvested.

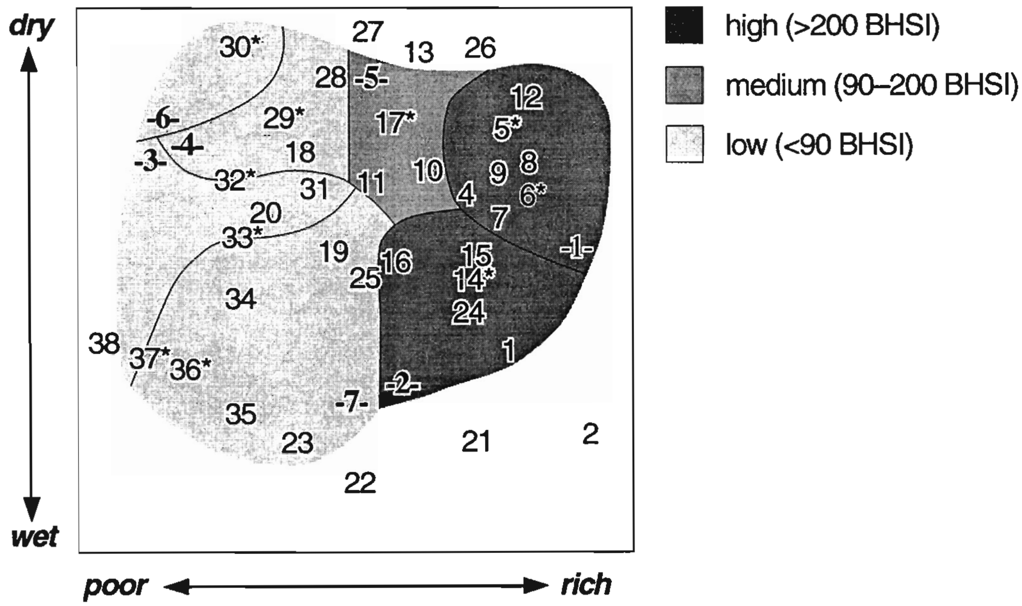


Fig. 3. Rankings of expected browse CAG for unharvested forest sites extrapolated to the ordination of northwestern Ontario forest ecosystem classification system (Sims et al. 1989) vegetation types. Axis labels represent an interpretation of ordination factors in terms of general moisture and nutrient availability for the y and x axes, respectively. Solid lines delineate treatment units (TU) and shading identifies level of expected browse habitat suitability index (BHSI) within the ordination space. Bold numbers identify TUs, plain numbers vegetation types, and asterisks vegetation types sampled in this study. Extrapolations were not extended to those vegetation types not shaded.

4). The algorithm was successful at classifying TUs for 93.8% of the forested landbase, and consequently the majority of the digitised polygons could be assigned predicted CAG biomass (kg/ha) values.

DISCUSSION

Our *a priori* ranking of treatment units in terms of browse production (Table 1) successfully predicted which sites with standing timber would be the best producers of moose browse. This success was expected, as the assignment of FEC vegetation-types is in large part based on the richness of the understory shrub and herb layer. The more interesting result, however, is how well TUs predict browse production following timber harvest. In terms of browse density and BHSI, the rankings of the top 3 TUs (1, 2, and 5) remained the same both before and after timber harvest, although the magnitude of the response to harvesting differed among TUs. This result means that resource planners can use pre-harvest information to successfully predict the response of browse plant species to timber harvest, and assign relative browse production values to the forested land base.

Our index of browse habitat suitability was a weighted mean of stem density, with weighting based on published studies of browse selection by moose in Ontario. Rankings of BHSI among TUs were similar, but not identical to rankings for mean density. Although weighting density values by browse selection may enhance the predictive precision of estimating browse habitat suitability, rankings of TUs by density values alone are still reasonably close to the more detailed BHSI rankings. Estimates of browse

Table 4. Regression equations for calculating current annual growth biomass in northwestern Ontario, 1991.

Species	*N*	Regression Equations[a]	R^2	*P*
balsam fir	10	LL * 1.581+ LD * 1.802 - LW * 1.465 +1.795	0.888	0.0004
beaked hazel	89	LL * 1.076 + LD * 1.905 - LW * 0.082 - LH * 1.891 + HC * 0.675 + 5.678	0.703	<0.0001
dogwood	60	LL * 0.616 + LD * 1.247-1.566	0.530	<0.0001
green alder	79	LL * 0.568 + LD * 1.407-1.499	0.604	<0.0001
june berry	73	LL * 1.863 + LD * 1.358 - LH * 2.817 + 6.192	0.614	<0.0001
mountain ash	36	LL * 0.48 + LD * 2.268 - 1.483	0.876	<0.0001
mountain maple	75	LL * 0.807 + LD * 0.819 - 2.995	0.701	<0.0001
pin cherry	90	LL * 1.355 + LD * 1.628 - LH * 1.447 + HC * 1.341 + 2.222	0.558	<0.0001
speckled alder	72	LL * 0.811 + LD * 2.25 - LH * 1.80 + 5.89	0.615	<0.0001
trembling aspen	96	LL * 1.574 + LD * 0.78 - LH * 1.144 + 0.167	0.597	<0.0001
white birch	91	LL * 1.532 + LD * 1.276 - LH * 1.52 + HC * 0.897 + 1.897	0.750	<0.0001
willow	113	LL * 0.78 + LD * 1.281 - LW * 0.082 - HC * 0.839 - 2.25	0.764	<0.0001

[a] LD= log(diameter); LH= log (height); LW = log (width); LL = log (length); HC= height class

Table 5. Median[a] browse production (kg/ha) in harvested and unharvested treatment units, northwestern Ontario, 1991.

Treatment unit	Harvested				Unharvested			
	N	Median	LCL	UCL	N	Median	LCL	UCL
1	15	123.7	77.6	157.1	26	206.0	91.4	282.8
2	18	66.8	26.9	129.1	19	79.4	48.0	127.4
3	20	17.4	2.7	37.3	13	1.1	0.5	2.4
4	14	13.8	1.2	32.8	11	7.7	2.8	16.2
5	14	21.6	10.6	43.1	13	40.2	7.6	62.3
6	18	0.9	0.4	2.7	9	11.5	0.8	22.9
7	9	8.2	0.9	29.9	12	3.9	1.1	8.1

[a]Medians are calculated from original data, and 95% confidence limits are based on accelerated bootstraped estimates (Efron 1982, Dixon 1993), with 1000 resamples for each treatment unit/harvest combination.

density for unharvested sites predict habitat suitability of the existing vegetation structure, whereas estimates for browse regrowth following harvest predict site capability for future browse production.

Estimates of browse production are derived values from the product of averaged sample-site stem density and predicted CAG,

Table 6. Algorithm to assign treatment units based on forest resource inventory species composition[a] data, northwestern Ontario, 1991.

Treatment unit	Formation[b]
1	po + bw $\geq$ 5
2	sb + sw + bf + (pj if < 3) $\geq$ 5 AND po + bw $\geq$ 1 AND po + bw < 5
3 and 7	(sb + pj $\geq$ 9 AND sb $\geq$ 5) OR sb $\geq$ 9
4 and 6	sb + pj $\geq$ 9 AND pj $\geq$ 5
5	pj $\geq$ 3 AND bw + po $\geq$ 2

[a]po = trembling aspen, bw = white birch, sb = black spruce, sw = white spruce, bf = balsam fir, pj = jack pine

[b]Numbers represent stand proportions $\cdot$ 10^{-1}

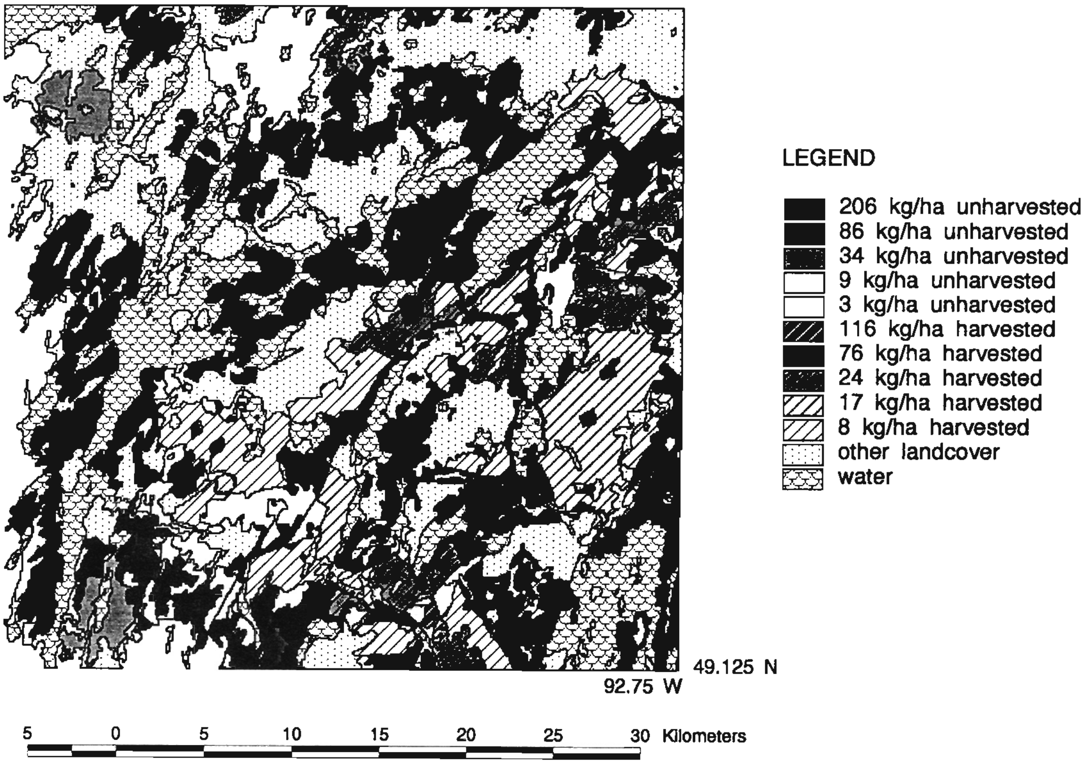


Fig. 4. Map of expected annual browse production (kg/ha), derived from Forest Resource Inventory map of overstory percent composition. Map is created by assigning a treatment unit to each polygon using the algorithm of Table 6. Darker shades indicate higher browse production, and diagonal hatching indicates recently harvested sites.

so should be viewed only as 1st order approximations. Nonetheless they provide coarse estimates of browse production that could enhance the ability of moose habitat models (e.g., Allen *et al.* 1987) to estimate suitability and carrying capacity. Understory balsam fir in mature trembling aspen stands contributed to the high biomass in TUs 1 and 5, and consequently caused some bias that should be considered for regions where moose do not select balsam fir as a browse species.

The extrapolation of BHSI values for TUs across a 2-dimensional ordination space of the northwestern Ontario FEC (Sims *et al.* 1989) provides a model of expected browse habitat suitability, following timber harvest, for most site conditions encountered in northwestern Ontario. The model provides a clearly stated and testable link between forest ecosystem structure (vegetation composition and structure) and function (food production for moose). In general, those sites with vegetation communities associated with well drained soils and greater nutrient availability had higher BHSI values, and those sites with less nutrient availability, regardless of soil moisture, had lower BHSI values. Because the index values are weighted by browse selection ratings, species with low ratings (e.g., balsam fir and alder spp.) do not unduly influence the BHSI values, although they do influence estimates of CAG.

Although classification of sites into TUs based on detailed community vegetation composition, including moss, herbs, shrubs, and overstory provides a more precise link between community structure and ecosystem processes (e.g., nutrient availability), classification of TUs based on overstory vegetation alone produced reasonably close approximations of the field-based TU classifications. This is in part because of the large influence overstory vegetation plays in the assignment of NWO FEC vegetation-types and the development of understory vegetation attributes. We demonstrated that an algorithm can emulate the classification of TUs for modelling purposes where ground-based TU data is not available. In this study, TUs 3 and 7 and TUs 4 and 6 could not be discriminated using FRI overstory vegetation alone, but both these pairs had similar browse densities based on FEC classifications, and both were of very low density and BHSI values.

MANAGEMENT IMPLICATIONS

Forest ecosystem classifications provide a relatively simple tool to characterize soil and vegetation site conditions. Our results indicate that aggregating sites with similar conditions of soil moisture, drainage, texture, and vegetation overstory, shrub, and herb composition into management-oriented treatment units will allow resource planners to successfully predict relative availability of moose browse and the response of moose browse species to timber harvest.

The ability to use browse density, CAG and BHSI values based on FRI-derived data is important from a practical habitat modelling and management perspective, as most GIS forest resource inventories are based on air-photo interpretations of overstory composition. Extrapolating these existing inventories into maps of browse habitat suitability and production requires an established link between overstory composition and predicted browse habitat suitability and production, before and after harvest. The 83% classification congruence rate found in this study will be sufficient for some, but not all management purposes.

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