ASSESSMENT OF CRUCIAL MOOSE WINTER HABITAT IN WESTERN WYOMING

Megan A. Smith[1], Steve Kilpatrick[2], Brenda Younkin[1], Leigh Work[1] and Doug Wachob[1]

[1]Conservation Research Center, Teton Science Schools, 700 Coyote Canyon Rd, Jackson, WY 83001; [2]Wyoming Game and Fish Department, Jackson Regional Office, PO Box 67, Jackson, WY 83001

ABSTRACT: Over the past 2 decades wildlife managers in Wyoming have documented that moose (*Alces alces shirasi*) populations within the 8 herd units in western Wyoming are declining; habitat condition is believed most responsible for decline in at least 1 herd unit. As the first component of a larger effort to systematically assess moose winter range throughout Wyoming, we assessed the winter habitat of the Jackson and Sublette moose herds in 2007-2009. Habitat was assessed with a landscape approach using 1) habitat mapping, 2) photo-documentation of willow and aspen communities, 3) risk/succession assessment of aspen stands, and 4) detailed vegetation monitoring using Live Dead Index transects. In the Jackson Moose Herd Unit a total of 105,574 acres (~42,740 ha) were evaluated and delineated into 403 habitat patches with specific vegetative data collected on 52 transects. In the Sublette Moose Herd Unit a total of 48,617 acres (~19,685 ha) were assessed and delineated into 301 habitat patches with detailed vegetation data collected on 54 transects. Treatment prioritizations were made based on vegetative data that indicated that willow (*Salix spp*.) and aspen (*Populus spp.*) habitats were over used and/or in decline in both study areas. The majority of willow regeneration was not escaping the browse zone of moose. Succession in many aspen patches had advanced to include conifers, but regenerating aspen was not growing beyond the browse zone. These habitat inventories and assessments will be used as a template for enhancing moose winter habitat in Wyoming. Management implications and cooperative strategies between wildlife and habitat managers are discussed.

ALCES VOL. 47: 151-162 (2011)

Key words: aspen, habitat management, Live Dead Index, moose, willow, winter habitat.

In 2005 the Wyoming Game and Fish Department (WGFD) listed the Shiras moose (*Alces alces shirasi*) as a species of greatest conservation need (NSS3) based on habitat and population declines (WGFD 2005). Wyoming moose presumably immigrated from Montana and Idaho in the 1850s growing to ~2,600 moose statewide by 1950 (Houston 1968). The 2008 post-season, statewide population estimate was ~7,700 moose with a population objective of ~13,800 moose (WGFD 2009). The 2008 Jackson Herd Unit represented 13% and the Sublette Herd Unit 62% of the statewide population; the Sublette Herd Unit is the largest in Wyoming.

Habitat quantity and quality were recognized to strongly influence moose in western Wyoming as early as the 1950s (Harry 1957, Houston 1968, Wigglesworth et al. 2004), yet their preferred aspen (*Populus spp.*) and willow (*Salix spp.*) winter habitats are also heavily used by elk (*Cervus elaphus*), mule deer (*Odocoileus hemionus*), and cattle (*Bovis spp.*). Prolonged and elevated browsing pressure causes decline in shrub production, and a larger proportion of new growth is unavailable to browsing species due to protective architecture and chemical defensive responses to overbrowsing (Seaton 2002). Informative studies and historical overviews of moose and habitat in Wyoming are provided by numerous authors (Houston 1968, Hnilicka et al. 1994, Brimeyer et al. 2004, Wigglesworth and Wachob 2004, Becker 2008, Becker et al. 2010).

Moose in the Jackson Herd Unit currently have among the lowest pregnancy rates in North America (Berger et al. 1999). Berger (2004) found that 60% of female mortality from 1995-2004 in Jackson Hole was due to malnourishment and suggested that the regional population decline was linked to habitat degradation; a strong relationship exists between nutrition and recruitment in moose (Boertje et al. 2007). Becker (2008) provided further evidence that habitat quality was a primary factor limiting population growth in the Jackson Herd Unit.

Both quantity and quality of forage are important for moose survival, and throughout the year moose depend on willow, aspen, and conifer habitats (Franzmann and Schwartz 2007). Because canopy cover provides important thermal refuge, spatial distribution of forage and thermal cover is an important aspect of moose habitat. Moose migrate to lower elevations with less snow pack and easier mobility and access to forage in winter, often occupying willow riparian zones (Houston 1968, Wigglesworth and Wachob 2004). Crucial winter range, as defined by WGFD, is critical to a population's ability to maintain adequate productivity to meet population objectives, and in1993 crucial winter range accounted for only 10.1% of occupied moose habitat in Wyoming (Hnilicka and Zornes 1994). Since crucial winter range is limited by its presence and availability, the quantity and quality of forage available in these areas is critically important to moose.

Pierce and Peek (1984) and Osko et al. (2004) found that moose habitat preferences are not fixed but change with the relative abundance of available habitat. In south central Montana, Van Dyke et al. (1995) found that moose select aspen over lodgepole pine (*Pinus contorta*) in all seasons, and prefer wetland shrub areas (willows) in winter and spring. Conifer communities are considered marginal winter habitat but are used extensively in areas with limited willow habitat (Pierce and Peek 1984). The loss of 50% of Wyoming's aspen since the 1800s (Kilpatrick 2006), and the historical decline of willow throughout assessed crucial winter ranges (Harry 1957, Houston 1968), indicate that preferred winter habitat of moose in Wyoming has declined continually in quality and quantity.

Over the past 2 decades wildlife managers in Wyoming have documented that moose populations were declining in 8 western Herd Units (Brimeyer and Thomas 2004, Becker et al. 2010). Low forage quality and moderate physical condition of moose are primary contributors to the decline in at least one herd unit (Becker 2008, Becker et al. 2010). The objective of this study was to generate a baseline assessment of crucial winter habitat with a standardized habitat quality index. To initiate an assessment of winter range throughout Wyoming, winter habitat in the Jackson and Sublette Herd Units, the 2 largest in the state, were assessed in 2007-2009. Particular focus was given to management priorities based on vegetation data for aspen and willow communities within both.

STUDY AREA

The habitat assessment was focused on crucial winter habitat in Jackson Herd Unit #103 and Sublette Herd Unit #105 in western Wyoming (Fig. 1). The study areas were chosen based on their designation as crucial moose winter range. The Jackson Herd Unit included public land associated with major drainages between Buffalo Valley and the Gros Ventre River, and the Sublette Herd Unit included public and private land from the Upper Green River west to the Hoback Basin and south to LaBarge Creek. Crucial winter range in this area included major drainages and adjacent upland aspen habitats. Public lands were managed by Grand Teton National Park, the Bureau of Land Management's Pinedale Field Office, and the Bridger-Teton National Forest.

METHODS

Habitat condition was assessed with a coarse landscape approach to cover the area efficiently by mapping habitat, extensive photo-documentation of willow and aspen communities, and risk/succession assessment of aspen stands followed by detailed browse level monitoring using Live Dead Index (LD) transects. Fieldwork was conducted in summer and fall of 2007-2008 in the Jackson Herd Unit and June- September 2009 in the Sublette Herd Unit. An emphasis was placed on rapidly covering the landscape during habitat mapping. Browse level, vegetation monitoring, and LD transects involved more detailed data collection from fixed locations within a habitat patch. All field data were entered directly into Dell X30 Pocket PCs. Garmin model 76CX Global Positioning System (GPS) units were used to mark and store waypoints and tracks in the field.

Habitat Patch Mapping

Habitat patches were defined as areas of similar vegetation types and condition within a discrete area. Color-adjusted MRSID digital aerial photography (2006 and 2009) field maps were used to identify patches (NAD 1983 UTM Zone 12). The photos were adjusted in color to improve reliable identification of shrubland communities. Patch boundaries were hand-drawn on maps in the field and later digitized over aerial imagery using ArcGIS. Minimum patch size was 20 acres (8.1 ha) for willow and 10 acres (4.05 ha) for aspen with at least 10% aspen canopy cover (ocular estimate; S. Kilpatrick, WGFD, pers. comm.). Smaller proximate patches were combined into multi-part patches to create sampling areas larger than the minimum patch size. General vegetative and ecological data recorded for each willow patch included:

1. 3 dominant overstory (shrub) species,
2. 3 dominant understory species,
3. similar patches identification numbers,
4. general site description,
5. detailed assessment of desired outcomes and potential management recommendations,
6. notes on historic conditions and land use practices when available, and
7. qualitative assessment of overall animal use and the ungulate dominating the use (subjective and relative to other patches).

Other data collected in aspen patches included:

1. estimated canopy cover,
2. generalized browse level (variation on WGFD 5-stem methods [S. Kilpatrick, pers. comm.]),
3. aspen community type (Mueggler 1988),
4. presence/absence of 5 risk factors for aspen-dominated stands (adapted from Campbell and Bartos 2001):
   1 = conifer cover (understory and overstory) >25%,
   2 = aspen canopy cover <40%,
   3 = >10% aspen are standing dead,

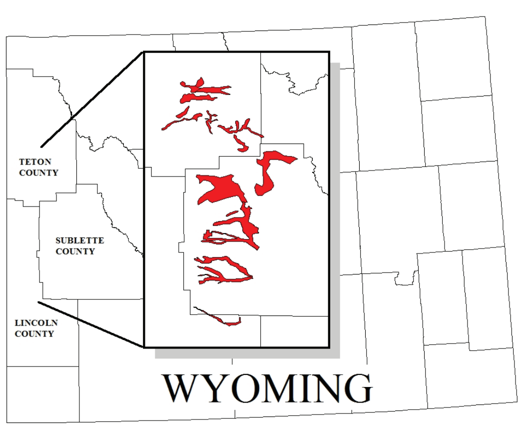

Fig. 1. The location of crucial moose winter habitat studied in western Wyoming, 2007-2009. The Jackson Herd Unit #103 was in Teton County and the Sublette Herd Unit #105 was in Sublette and Lincoln County.

Table 1. Adaption of Campbell and Bartos (2001) risk/succession key used to prioritize aspen stands for treatment. It is assumed that aspen occurs at a density of at least 20 mature trees per acre (0.4 ha).

Category	Description	Rank
1	a. Conifer species comprise at least half of the relative canopy cover (of overstory present, conifer species comprise at least 50%).	Highest priority
	b. Aspen comprises more than half of the total canopy cover.	2
2	a. Aspen canopy cover is less than 40% absolute canopy cover; *and* sagebrush, usually a dominant understory species, exceeds 15% cover	High priority
	b. Not as above.	3
3	a. Conifer cover (including overstory and understory) exceeds 25%.	Moderate to high priority
	b. Conifer cover is less than 25%.	4
4	a. Aspen regeneration (5 to 15 feet tall) is less than 500 stems per acre. See *note above.	Moderate priority
	b. Aspen regeneration exceeds 500 stems per acre.	5
5	a. Any two of the following three risk factors are represented: 1 - Aspen canopy cover is less than 40% absolute canopy cover. 2 - Greater than 10% aspen are standing dead (replaced dominant aspen trees are greater than 100 years old). 3 - Sagebrush cover exceeds 10% absolute canopy cover.	Low to moderate priority
	b. Two of the three risk factors in 5a are not represented.	6
6	a. One of the three risk factors in 5a is represented.	Low priority
	b. None of the risk factors above are represented.	Candidate for properly functioning condition

4 = aspen regeneration <500 stems (5-15 feet tall or 1.5-4.6 m) /acre (0.4 ha), and
5 = sagebrush cover >10%, and

5. risk/succession assessment adaptation (Campbell and Bartos 2001, Table 1).

Monitoring Transects

Transect locations were not assigned randomly; rather, they were selected to represent the typical vegetation (willow) or community type and risk/succession assessment (aspen) within a patch and across patches with similar vegetative characteristics. The number of transects in each area was determined using the guidelines of 1 transect/600 acres (~243 ha) and at least 3 transects /willow area and 1 transect/8 aspen patches.

Transects with 20 sampling points spaced at 5-pace intervals were placed in the center of patches to avoid transition areas. Transects varied in length; if the edge of a willow stand was reached before 20 points were gathered, the transect was moved 5 paces perpendicular to the original transect and additional points were sampled parallel to and in the opposite direction of the original bearing. The start and end point locations of transects were recorded for future transect repetition.

Live Dead Sampling Technique

The Live Dead (LD) Index method was used to quantify browsing pressure within a patch (Keigley et al. 2002). One species of willow was sampled at all points within willow areas; this species was a dominant and preferred species based on ocular use estimates (Keigley 2006). By using a preferred species as an indicator, we assumed that less preferred species were of condition at least equal to or better than the sample species (Keigley, USGS, pers. comm.). Booth's willow (*S. boothii*) was measured in the Sublette study area, and Booth's, Geyer (*S. geyeriana*), and Drummond's (*S. drummondiana*) willows were measured in the Jackson area. Wolf's willow (*S. wolfii*) which does not grow >1 m high (Dorn and Dorn 1997), coyote willow (*S. exigua*), and other rhizomatous species were not sampled.

The nearest individual plant encountered was selected at each point. If the closest individual encountered was outside of the browse zone (50-200 cm), the next nearest stem was examined; this was continued until a suitable stem (within the browse zone) was encountered. All individuals rejected for measurements were recorded as either above or below the browse zone. The height of the base of the tallest live current year's annual growth ring (H_L), the height of the tip of the tallest dead annual increment that had been browsed (H_D), and the leader length (LL) were measured (Keigley et al. 2009, Fig. 2). The distance from the height of the base of the current year's growth (H_L) to the annual growth increment below was measured as the 2008 leader length. This was done throughout the season to remain consistent between study areas because fieldwork was begun prior to mid-July. For quaking aspen (*P. tremuloides*), a suitable ramet was defined as within the browse zone (50-200 cm) and <5 cm diameter. Additionally, ramets with diameter >5 cm were considered escaped from the browse zone and not recorded.

Live Dead Index Analysis

Transect calculations followed protocols of Keigley et al. (2009). The LD Index was calculated as LD = H_L - H_D (Fig. 2). An LD Index ~0 indicated that browsing was preventing growth beyond the plant's height of mechanical protection (protection from older stems and twigs). A negative LD Index (considerably <0) indicated that the plant was browsed beyond its annual growth and was in decline. A positive LD Index (considerably >0) indicated that growth was uninhibited by browsing. LD Index values were compared with the standardized LD Index threshold of 50 cm recommended by Keigley et al. (2009). This threshold presumably indicates whether shrubs are capable of growing through the browse zone (>50 cm threshold) or not (<50 cm threshold). The threshold should be adjusted to include area-sensitive, potential growth-stature values, species-specific differences, and specific management objectives, rather than used as a permanent standardized index.

Adaptive Methodology

The methods outlined above are further described in Smith and Younkin (2010). Because of refinements in methodology made after the first field season, certain techniques employed for the Jackson Herd Unit differed from those used in the Sublette Herd Unit. Specifically:

1. The shrub species assessed on transects in the Jackson Herd Unit included willow, aspen, cottonwood (*P. angustifolia*), blue spruce (*Pinus*

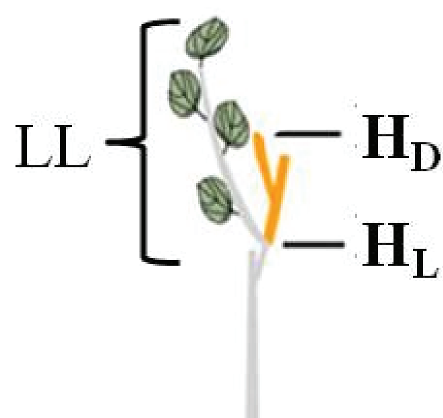

Fig. 2. Illustration of Live Dead Index measurements used to assess moose winter habitat in western Wyoming; H_D = height of dead, H_L = height of live, and LL = leader length.

pungens), and sagebrush (*Artemisia spp.*). Transects included >1 species measured per transect (Sublette had 1 species/transect); therefore, transect data were grouped to achieve 20 measured plants of the same species for LD Index calculations. The individual species were Booth's willow, Drummond's willow, Geyer willow, and aspen.

2. An important distinction of the Sublette Herd Unit data was that "percent browsed" plants was defined as the number of stems with an H_D/total number of stems ("percent intensely browsed" in Keigley et al. [2009]). Thus, to allow more site-specific analysis, "percent browsed" was calculated by transect in the Sublette Herd Unit versus grouping in the Jackson Herd Unit.
3. Leader length was not measured in the Jackson area.
4. The browse zone was defined as 35-200 cm in the Jackson Unit (50-200 cm in Sublette Herd Unit).
5. Aspen risk/succession assessment was not conducted in aspen stands in the Jackson Herd Unit.

RESULTS

A total of 105,574 acres (~42,740 ha) were evaluated in the Jackson Herd Unit with habitat enhancement prescriptions recommended for 91,488 acres (~37,040 ha). A total of 403 moose habitat patches were mapped with specific vegetative data collected on 52 LD transects within these patches; 33 were in willow, 16 in quaking aspen, and 1 each in cottonwood, blue spruce, and sagebrush communities. In the Sublette Herd Unit a total of 48,617 acres (~19,685 ha) were assessed and enhancement prescriptions were recommended on 34,835 acres (~14,105 ha). A total of 301 habitat patches were mapped with detailed vegetation data collected on 53 LD transects; 26 in willow and 27 in quaking aspen communities. Overall, willow and aspen communities were generally not reaching their potential height and structure due to excessive browsing in both the Sublette and Jackson Herd Units. Aspen communities were composed of stands in all categories of risk for losing their aspen component and succeeding to a conifer community.

Jackson Herd Unit

Transect data were grouped to achieve 20 measured plants of the same species for LD Index calculations. Browsing pressure was defined as the percent of plants having an LD Index that is less than or equal to the threshold LD value of 50 cm (R. Keigley, USGS, pers. comm.). The mean LD Index values for Booth's willow ranged from -10.5-22.6 cm ($\bar{x}$ = 8.8 ± 3.7 cm). Browsing pressure for Booth's willow ranged from 82-100% ($\bar{x}$ = 94 ± 2%). The Live Dead Index values for aspen ranged from -10.4-26.1 cm ($\bar{x}$ = 6.2 ± 5.9 cm); browsing pressure ranged from 65-100% ($\bar{x}$ = 87 ± 6%; Table 2).

Sublette Herd Unit

Transect data was collected on 1 species per transect (Booth's willow or quaking aspen), therefore LD Index calculations pertain to individual transects rather than groups of transects. The LD Index values for Booth's willow ranged from 1.0-55.3 cm ($\bar{x}$ = 12.9 ± 2.1 cm); browsing pressure ranged from 20-100% ($\bar{x}$ = 89 ± 0%). The LD Index values for aspen ranged from 1.2-53.5 cm ($\bar{x}$ = 21.4 ± 2.9 cm); browsing pressure ranged from 20-95% ($\bar{x}$ = 60 ± 0%; Table 2).

The average percent browsing was plotted against the average LD Index for individual transects to provide a visual representation of recent browse history. For willow transects (all Booth's willow), the majority was classified as in an impending loss of structural diversity; 6 transects fell within the region where further monitoring is needed, 1 was above the 50 cm

Table 2. Summary results of Live Dead (LD) and browse transects performed in moose winter habitat in the Jackson and Sublette Herd Units in western Wyoming, 2007-2009. Dominant species were Booth's willow (SABO), Geyer willow (SAGE), Drummond's willow (SADR), and aspen (POTR).

	# of Transects	LD (cm) $\bar{x}$ ± SE (range)	% Browsing ($\bar{x}$ ± SE)
Jackson Herd Unit			
Willow Transects			
SABO	9	8.8 ± 3.7 (-10.5-22.6)	94 ± 2
SAGE	3	22.5 ± 5.0 (15.3-32.2)	83 ± 8
SADR	1	11.6	96
Aspen Transects			
POTR	6	6.2 ± 5.9 (-10.4-26.1)	87 ± 6
Sublette Herd Unit			
Willow Transects			
SABO	26	12.9 ± 2.1 (1.0-55.3)	89 ± 0
Aspen Transects			
POTR	27	21.4 ± 2.9 (1.2-53.5)	60 ± 0

threshold, and 1 (on USFS land) was within the region of benign browsing (Fig. 3). For aspen transects the majority fell within the area where further monitoring was needed, 3 were in an impending loss of structural diversity, and a few fell in the region of benign browsing (Fig. 4).

The aspen risk/succession assessments were done on 213 patches representing 27,503 acres (~11,135 ha). By area, the majority (56%) was within the moderate-highest risk categories for losing the aspen component; only15% was in the low to low-moderate categories. Nearly a third (29%) was classified in the candidate for properly functioning condition (Fig. 5).

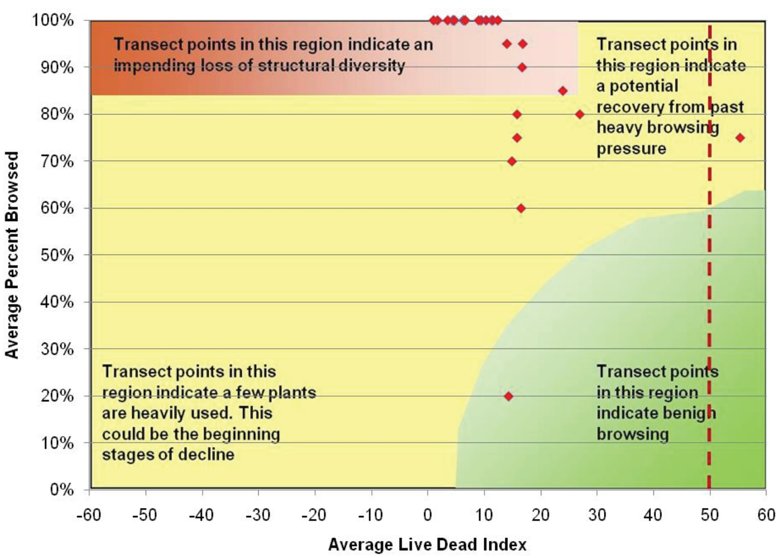

Fig. 3. The relationship between the Live Dead Index and browsing level that illustrates the relative condition and history of winter browse on Sublette willow transects in western Wyoming. The dotted line indicates the standardized threshold of 50 cm; values <50 indicate growth has not escaped through the browse zone (Keigley et al. 2002).

DISCUSSION

Historically, most moose habitat treatments in western Wyoming have been done opportunistically and were site-based rather than at the landscape scale using a methodical, systematic approach. This opportunistic approach lacked the systematic assessment of existing habitat conditions across the landscape necessary for prioritizing treatment locations, prescriptions, desired outcomes, and continued monitoring.

Currently, moose habitat management in Wyoming is moving toward a landscape scale approach that integrates habitat components, game management, and stocking rates into long-term management plans. Our baseline data provide the template and initial phases for the habitat component of these long-term, landscape scale planning efforts.

Our initial findings support the results of others that long-term, high browsing levels negatively influence willow and aspen productivity (Bowyer and Bowyer 1997). Our data indicated that willow and aspen communities were generally not reaching their potential height and structure due to excessive browsing. Additionally, aspen communities were composed of stands in all categories of risk for losing their aspen component and succeeding to a conifer community. Ultimately, negative feedback loops between population size and forage are possible consequences of high browsing levels (Bowyer and Bowyer 1997). Our moose habitat inventory in western Wyoming has provided a much needed template to accurately assess habitat conditions and appropriately manage for the high quality habitat necessary to sustain moose populations into the future.

Quantitative and qualitative information from our assessment protocol allowed us to prioritize treatment areas based on patch level observations, measurements on LD Index transects, and aspen risk-succession assessments. Specific prioritization and management recommendations based on vegetative data by patch are available (Younkin et al. 2008, Smith et al. 2010). The LD Index data are pivotal because they provide quantitative and qualitative measures of browse pressure (Keigley et al. 2001). For example, if LD Index values are low and patch level observations also indicate an area of low quality habitat, that area would be prioritized for treatment and further evaluation; the converse would have a low priority for treatment. In areas with low LD Index values, habitat treatments should account for historical and current use of the habitat by multiple species. Areas with moderate LD Index values and favorable patch level observations are good candidates for future monitoring to provide a temporal picture of management implications, such as exist in the Sublette Herd Unit (Table 2).

The LD Index for an individual stem can change with diverse environmental conditions and browsing pressure between growing seasons. Therefore, graphically combining the average percent browsed stems with the average LD Index by transect provides a historical perspective of community structure and browse pressure over time (R. Keigley, pers. comm.). If managers plot the average

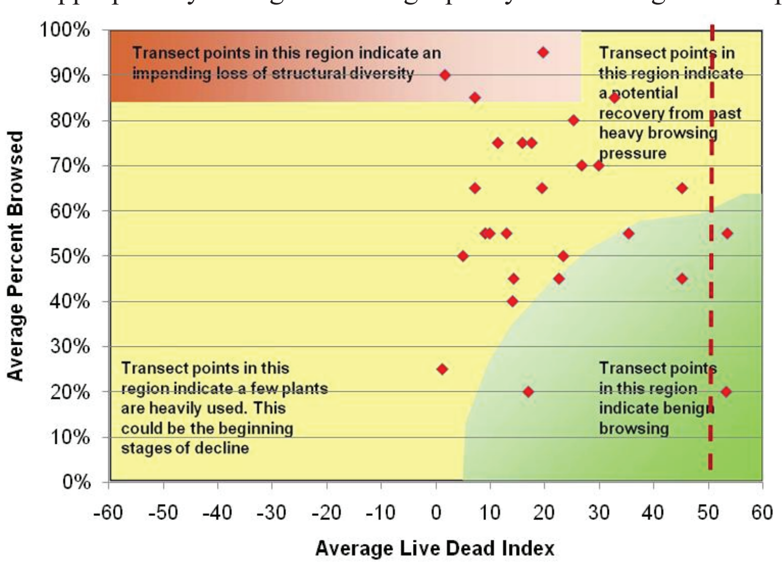

Fig. 4. The relationship between the Live Dead Index and browsing level that illustrates the relative condition and history of winter browse on Sublette aspen transects in western Wyoming. The dotted line indicates the standardized threshold of 50 cm; values <50 indicate growth has not escaped through the browse zone (Keigley et al. 2002).

percent browsed stems against the average LD Index values for multiple years, they will acquire an interpretation of the community's health based on its ability to attain potential height structure and sustained recruitment, and provide the basis for habitat treatments and adjusting populations or stocking rates accordingly. Figures 3 and 4 provide the foundation for this temporal analysis, as well as a current assessment of the trend in the Sublette Herd Unit. Many of the willow transects had 100% browsing pressure and a low LD index demonstrating an impending loss of structural diversity. Moving these areas toward sustainable habitat will require a cooperative effort between habitat and population managers.

The Campbell and Bartos' (2001) quantitative risk-succession assessment methodology provides an additional analysis from which managers can make aspen-related management decisions. These assessments indicate the composition of an aspen stand and help assess treatment priority for maintaining aspen communities; high risk means late succession and high priority for treatment to maintain aspen. Aspen is seral to conifers in western Wyoming and most aspen ramets were not able to grow through the browse zone (i.e., had low LD values). If an area has a low LD Index and a moderate to highest risk assessment, treatments and/or adjustments in population management are needed; there is less need for management adjustments with a high LD and a low risk assessment. If the 2 indices are moderate, more monitoring and a temporal component are needed. While 56% of the Sublette aspen stands fall within the moderate to highest risk categories, all 3 scenarios occurred demonstrating that historic management actions (e.g., stocking rates) should be considered.

Aspen communities require a disturbance event such as fire for regeneration and the establishment of age class diversity across the landscape. Such treatments promote regeneration but are ineffective if excessive browsing exists (Campbell and Bartos 2001). Therefore, domestic stocking levels must be evaluated and coordinated before treatment actions are initiated. Techniques such as temporary fencing of an aspen community post-treatment may limit browsing of aspen from livestock and allow ramets to escape through the browse zone. Before implementing habitat treatment, habitat and population managers should consider follow-up and long-term management decisions such as fencing, game population levels, domestic stocking rates, season of use, and harvest strategies. For example, cattle grazing is a dominant land use that could reduce winter forage available to moose in the Sublette Herd Unit. It is imperative that management of cattle grazing and moose habitat be coordinated to address the effects of browsing and promote overall rangeland health. Livestock producers need to be included during the initial planning stages to gain their input, trust, and support if habitat treatment objectives are to be met, especially over the long-term.

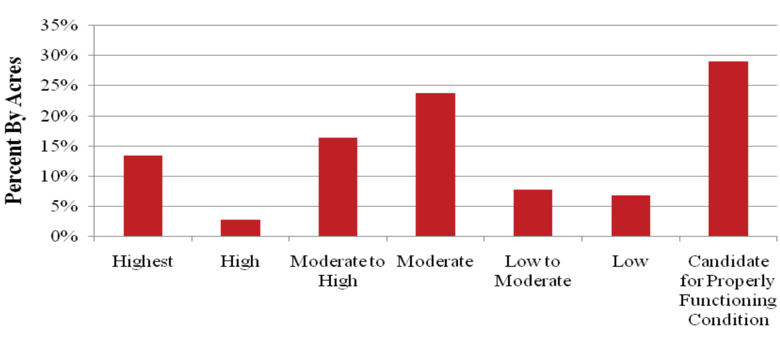

Fig. 5. Distribution of area (%) within the 7 categories of aspen risk/succession in the Sublette Herd Unit in western Wyoming. The majority was in moderate-highest risk categories.

Management Implications

Management implications resulting from our work are twofold.

First, our habitat assessment methodology provides the opportunity for moose population and habitat managers to coordinate management techniques to ensure healthy sustainable moose populations and the habitats moose depend upon (Boertje et al. 2007, Boertje et al. 2009). In Alaska, removal rate of browse biomass >35% indicated low nutritional status of moose, and reduced twinning rate, pregnancy rate, and body weight of short-yearling moose (Boertje et al. 2007). Seaton (2002) classified forage plants by the architecture they acquired from browsing: 1) broomed, 2) browsed, and 3) unbrowsed. He postulated that low twinning rates were related to a high proportion of broomed plants and that monitoring plant architecture may be a valuable and easily monitored index of moose condition; however, his methods did not allow for relating browsing rates and willow community health. The LD index methodology and graphical analysis provides managers with not only an assessment of browsing pressure, but also an assessment of browse community sustainability.

Future studies should analyze the relationship between average annual moose density on winter range and existing LD indices. This analysis would support long-term landscape management plans that incorporate habitat and population indices. Our preliminary analysis of moose density and LD indices indicated a moderately strong correlation (Smith, unpublished data). Refining the analysis to incorporate habitat use by other ungulates and additional analysis of winter moose counts has promise and deserves evaluation. With this habitat assessment template, managers now have the opportunity to develop correlations between the LD index and population indices (e.g., twinning rates). Management strategies based on such analysis and indices will assist managers in maintaining sustainable moose habitats and populations.

We also provided baseline habitat indices for numerous moose wintering areas from which managers can now formulate prioritized treatment and monitoring plans. Equipped with baseline habitat assessment information, moose population and habitat managers in western Wyoming are now challenged with including relationships among population performance and habitat indices, multiple species (domestic and wild) effects, and private and public land management/use practices into long-term management strategies.

ACKNOWLEDGEMENTS

We gratefully acknowledge the thoughtful supervision and oversight of this project by the Habitat Section of the Wyoming Game and Fish Department. The information and insights provided by Phil Baigas, Gary Butler, Bill Gerhart, and Jill Miller were crucial to the design of the project and the utility of our results. We also appreciate the useful information and knowledge of the landscape provided by Gary Fralick of the WGFD and Mack MacFarland and Sarah Dewey of Grand Teton National Park. The guidance with methods and background information provided by Richard Keigley was critical to the success of this project. The following Conservation Research Center staff contributed to the completion of this project. Fieldwork and data management were conducted by Jeremie Artery, John Clare, Nick Fortin, Morgan Graham, Rebecca Mann, Jennifer McCabe, Jennifer McGarvey, Kerry Quinton, and Christopher Reynolds. Maps and geodatabases were created by Morgan Graham. Report writing for the Jackson area was done by Leigh Work. Funding was generously provided by the WGFD, Wyoming Wildlife and Natural Resources Trust, and the Wyoming Governor's Big Game License Coalition.

REFERENCES

Becker, S. A. 2008. Habitat selection, condition, and survival of shiras moose in northwest Wyoming. M.S. Thesis, University of Wyoming, Laramie, Wyoming, USA.

______, M. J. Kauffman, and S. H. Anderson.

2010. Nutritional condition of adult female Shiras moose in northwest Wyoming. Alces 46: 151-166.

Berger, J. B. 2004. Does predation drive moose population declines in northwest Wyoming - a ten year study. Wildlife Conservation Society. Final report to Wyoming Game and Fish Commission, Cheyenne, Wyoming, USA.

______, J. W. Testa, T. Roffe, and S. Montfort. 1999. Conservation endocrinology: a noninvasive tool to understand relationships between carnivore colonization and ecological carrying capacity. Conservation Biology 13: 980-989.

Boertje, R. D., M. A. Keech, D. D. Young, K. A. Kellie, and C. T. Seaton. 2009. Managing for elevated yield of moose in interior Alaska. Journal of Wildlife Management 73: 314-327.

______, K. A. Kellie, C. T. Seaton, D. D. Keech, D. D. Young, B. W. Dale, L. G. Adams, and A. R. Aderman. 2007. Ranking Alaska moose nutrition: signals to begin liberal antlerless harvests. Journal of Wildlife Management 71: 1494-1506.

Bowyer, R. T., and J. W. Bowyer. 1997. Effects of previous browsing on the selection of willow stems by Alaskan moose. Alces 33: 11-18.

Brimeyer, D. G., and T. P. Thomas. 2004. History of moose management in Wyoming and recent trends in Jackson Hole. Alces 40: 133-143.

Campbell, R. B., and D. L. Bartos. 2001. Aspen ecosystems: objectives for sustaining biodiversity RMPS-P-18. USFS Intermountain Research Station, Fort Collins, Colorado, USA.

Dorn, R. D., and J. L. Dorn. 1997. Rocky Mountain region willow identification field guide. United States Forest Service, Denver, Colorado, USA.

Franzmann, A. W., and C. C. Schwartz. 2007. Ecology and Management of the North American Moose, 2nd edition. Smithsonian Institution Press, Washington, D. C., USA.

Harry, G. B. 1957. Winter food habits of moose in Jackson Hole, Wyoming. Journal of Wildlife Management 21: 53-57.

Hinilicka, P., and M. Zornes. 1994. Status and management of moose in Wyoming. Alces 30: 101-107.

Houston, D. B. 1968. The Shiras Moose in Jackson Hole, Wyoming. Technical Bulletin No. 1. Grand Teton Natural History Association, Moose, Wyoming, USA.

Keigley, R. B. 2006. Application of monitoring methods. *in* J. Kraft, editor. Proceedings of the Regional Moose Workshop, 22-23 August 2006, Jackson, Wyoming, USA.

______, M. R. Frisina, and C. W. Fager. 2001. Assessing browse trend at the landscape level. Montana Department of Fish, Wildlife and Parks, Helena, Montana, USA.

______, ______, and ______. 2002. Assessing browse trend at the landscape level part 1: preliminary steps and field survey. Rangelands 24: 28-38.

______, J. Warren, and W. J. King. 2009. A multi-refuge program to evaluate the effect of ungulate browsing on habitat. United States Fish and Wildlife Service, Denver, Colorado, USA.

Kilpatrick, S. 2006. State's management and habitat concerns related to moose. *in* J. Kraft, editor. Proceedings of Regional Moose Workshop, 22-23 August 2006, Jackson, Wyoming, USA.

Mueggler, W. F. 1988. Aspen community types of the intermountain region GTR-INT-250. USFS Intermountain Research Station, Ogden, Utah, USA.

Osko, T. J., M. N. Hiltz, R. J. Hudson, and S. M. Wasel. 2004. Moose habitat preferences in response to changing availability. Journal of Wildlife Management 68: 576-584.

Pierce, D. J., and J. M. Peek. 1984. Moose habitat use and selection patterns in north-central Idaho. Journal of Wildlife Management 48: 1335-1343.

Seaton, C. T. 2002. Winter foraging ecology of moose in the Tanana Flats and Alaska Range foothills. M.S. Thesis, University of Alaska Fairbanks, Fairbanks, Alaska, USA.

Smith, M.,and B. Younkin. 2010. Sublette Moose Habitat Assessment: Upper Green River to LaBarge Creek. Teton Science Schools, Jackson, Wyoming, USA.

Van Dyke, F., B. L. Probert, and G. M. Van Beek. 1995. Seasonal habitat use characteristics of moose in south-central Montana. Alces 31: 15-26.

Wyoming Game and Fish Department (WGFD). 2005. A Comprehensive Wildlife Conservation Strategy for Wyoming. Cheyenne, Wyoming, USA.

______. 2009. Statewide Annual Wildlife Report. Pinedale, Wyoming, USA.

Wigglesworth, R. R., and D. G. Wachob. 2004. Historical and Present Habitat Conditions on the Jackson Hole, Wyoming Moose Winter Range. Report to Wyoming Game and Fish Department. Conservation Research Center of Teton Science Schools, Jackson, Wyoming, USA.

Younkin, B., L. Work, D. G. Wachob, and M. Graham. 2008. Jackson Moose Herd Habitat Assessment. Final Report to Wyoming Game and Fish Department. Conservation Research Center of the Teton Science Schools, Jackson, Wyoming, USA.