

Survey and Characterization of Montane Willow Habitat in the Wild Basin Area of Rocky Mountain National Park

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INTRODUCTION

Rocky Mountain National Park (RMNP) in north-central Colorado encompasses nearly 108,000 hectares (ha) of high-elevation forest, shrublands, meadows, and alpine tundra and rocklands. Several large ungulate species, including Rocky Mountain elk (*Cervus elaphus*) and Shiras moose (*Alces alces shirasi*), are among the numerous species of wildlife found in RMNP. Elk and moose frequent riparian shrublands, meadows, and wetlands, feeding on verdant herbaceous growth and woody plants, such as willow (*Salix* spp.), birch (*Betula* spp.) and alder (*Alnus* spp.), but they also make extensive use of the RMNP's upland shrubs and grasslands, subalpine forest, and alpine habitats. Wetlands, including riparian shrublands, harbor significant diversity of plants, insects, birds, and amphibians, as well as a majority of the rare or imperiled plant species in RMNP (Grace et al. 2016), but riparian shrublands make up only 2% of the RMNP landscape (Salas et al. 2005). In recent decades, a significant amount of research has been devoted to investigating the cause of declines in riparian shrublands and aspen communities in RMNP. Among factors that have been identified as affecting willow and aspen habitats in the park, both directly and indirectly, are elk herbivory, altered hydrology (particularly loss of beaver) and fire regimes, human disturbance, and climate change (Baker et al. 1997, Singer et al. 1998, Alstad et al. 1999, Hessler 2002, Peinetti et al. 2002, Zeigenfuss et al. 2002, Baker et al. 2005, Binkley 2008, Kaczynski et al. 2014, Kaczynski and Cooper 2015, Grace et al. 2016)

Ungulate herbivory can positively and negatively affect the plant communities upon which they depend (Hobbs 1996, Zeigenfuss et al. 2002, Schoenecker et al. 2004). Removal of small to moderate amounts of plant material during the growing season can lead to increased plant productivity and release of suppressed buds which can lead to taller and fuller plant canopies. Intense levels of browsing and grazing, however, can remove photosynthetic plant structures reducing the ability of the plant to store energy for future growth and lead to plant canopy dieback, stunted plant heights that are subject to further herbivory, and eventual stem and plant death. In addition to effects from the removal of plant material by ungulates, plants may suffer physical breakage associated with trampling and rubbing, detrimental effects from soil compaction, and effects on the entire plant community due to changes in those species targeted by ungulates (e.g., changes in species composition due to decline of target species, changes in the physical environment due to loss of shading/increase in light when overstory plants decline, etc.).

Elk in RMNP

Elk are native to RMNP but were extirpated from the area by the late 1800s. They were reintroduced to the area in 1913–1914, and the elk population in the park grew to the point that park staff actively managed the herd from 1944 until 1968 (Stevens 1980). In 1969, the active control of elk numbers was discontinued, and the population was allowed to regulate its numbers naturally, although hunting still occurred outside park boundaries. After management by natural regulation was begun, the herd increased from approximately 500–600 animals to a high point ranging from 2,800 to 3,500 between 1997 and 2001 (Lubow et al. 2002), with roughly 1,100 elk wintering primarily inside the park boundary. During this same period, there was an increase in the human population in the Estes Valley outside the park, which also provides elk range. Concerns from park managers, scientists, and the public, regarding the condition of vegetation (particularly willow and aspen) in the park and conflicts between elk and humans, both inside and outside the park, prompted studies of the effects of elk herbivory in RMNP (Singer and Zeigenfuss 2002, Monello et al. 2006).

Many years of research indicated that high elk densities in RMNP were resulting in suppression of willow growth, both in height and areal cover, and conversion of tall willow stands to short willow (Singer et al. 1998, Peinetti et al. 2002, Zeigenfuss et al. 2002). Willow is the dominant woody shrub on most low-elevation shrubby wetland and riparian areas in RMNP. Heavy browsing inhibited the ability of many winter-range willows to reproduce because few willow plants on the primary elk winter range produced seed. Suitable seedling establishment sites and seedling survival was limited due to downcutting of stream channels and associated lowering of the water table combined with elk browsing (Gage and Cooper 2005).

The findings of these research studies helped lead to the development and implementation of an elk-vegetation management plan (EVMP) for RMNP in 2008 (National Park Service 2007). The purpose of the EVMP is to guide management actions in the park during a 20-year period to reduce the impacts of elk on vegetation and restore, to the extent possible, the natural range of variability in the elk population and affected plant communities. Objectives include restoration and maintenance of sustainable montane riparian willow habitat on the primary winter range; and maintenance or improvement of the condition of riparian willow on the primary summer range. The wintering elk population objective in the EVMP is 600–800 animals. In the years since implementation of the EVMP elk populations have declined due to many factors; however, the elk winter range is still heavily used by migrating elk that pass through in spring and fall as they transition from low-elevation winter range outside the park to high elevation summer range within RMNP. Wintering elk population size inside the park from 2014 to 2018 has ranged from 170–320 animals (Ketz et al. 2016; N.T. Hobbs, Colorado State University, unpublished data).

Moose in RMNP

Historical records indicate that moose, typically bulls, were occasionally observed in northern Colorado but it was suspected that they wandered in from Wyoming and never established a stable population. In 1978, the Colorado Division of Wildlife (now Colorado Parks and Wildlife) began reintroduction of moose to the North Park area of the Routt National Forest located approximately 25 km NW of the Kawuneeche Valley of RMNP (Kufeld and Bowen 1996, Colorado Parks and Wildlife 2013). Additional moose were introduced to other areas of western Colorado over the years (Colorado Parks and Wildlife 2013). By 1980, a single moose was reported in the Kawuneeche Valley and by 1988, moose were wintering on the west side of the Park (Dungan and Wright 2005). In the past 5 years increasing numbers of moose have also been observed on the east side of RMNP. Moose have now been sighted in every drainage on the east side and park managers have recognized the need to learn more about moose population growth and the long-term effects of the moose population on other animal species and habitats within RMNP. In 2017, RMNP researchers began a study of moose populations, movements, and habitat use using moose fitted with GPS collars.

Ungulates in Wild Basin

Research on ungulate use in RMNP has often been prompted by changes in a species' population within the park, such as for bighorn sheep (*Ovis canadensis*), or perceived impacts on vegetation communities, such as for elk. As a result, research on willow and aspen communities has focused on the east side core elk winter range (Stevens 1980, Singer and Zeigenfuss 2002, Zeigenfuss et al. 2008), alpine willow (Stevens 1980, Zeigenfuss 2006), and more recently on the Kawuneeche Valley (Kaczynski et al. 2014). Areas that were perceived as having “healthy”

vegetation and few ungulates often received less attention due to limited research funds and staffing and the need to focus resources on locations where critical declines in habitat condition were occurring. The Wild Basin willow area was perceived as having little to no elk use and as a result was not included in research on other willow areas on the east side of the park. Unlike the declining beaver populations documented on the elk winter range, beaver were still very active in the area up through 2011 (Mitchell et al. 2000, Scherer et al. 2011). One result of the active beaver community and minimal ungulate browsing was a healthy willow community that had no perceived need for research into habitat decline or intervention to restore or maintain habitat condition. Over the past decade, however, moose have begun to move over the Continental Divide into drainages on the east side of RMNP and Wild Basin is no exception. Elk have been observed in Wild Basin during the fall as recently as October 2018. The potential for ungulate-induced changes on one of the few remaining high condition willow wetlands in RMNP prompted the effort described here to gather some baseline information on the status of Wild Basin willow and ungulate impacts on this community. Our objectives are to gather basic information on species composition and general condition (canopy cover, shrub height, browse utilization, ungulate use) of Wild Basin willow habitats and compare this condition with data gathered from willow communities elsewhere in RMNP that are experiencing various combinations of elk and moose herbivory, season of browsing, and ungulate densities. This information can be used to determine: how the current moose population may be affecting willow in Wild Basin; whether there is a need for additional or more intensive data collection to fill information gaps; the location and timing of additional data collection; and a minimum baseline condition for comparison to future data.

AREA OF INTEREST

The area of interest is a large riparian area along North St. Vrain Creek in the Wild Basin area in southeastern RMNP (fig. 1). The area encompasses roughly 35 ha of riparian shrub habitat that is dominated by willow species and has a large component of river birch and alder; approximately 1.2 ha of old and active beaver ponds that currently hold water for some portion of the year; and 0.75 ha of herbaceous wetlands. Two aspen stands extend into the riparian shrub



Current beaver activity in Wild Basin includes dams on the main channel of N. St. Vrain Creek as well as ponds and dams on side channels.

zone along the northern edge of the willow. The willow area is surrounded by conifer and aspen forest and a few dry meadows.

Wegener and others (2017) describe the area as beaver-influenced with dams within side-channels and backwaters that impound large volumes of water upstream. The frequent breaching, rebuilding, relocation, and abandonment of these dams has resulted in a complex floodplain of aquatic habitats that include “overflow side-channel, relic side-channels, backwater ponds, and shallow open-water marshes” (Wegener et al. 2017). Wetland habitat is fed by water both from the river and groundwater and the water table in some areas is seasonally high but declines

throughout the summer as many side-channels, ponds, and wetlands become dry, while it remains high in other areas—particularly in areas of current beaver activity. Wegener and others (2017) reported mean annual temperature of 5°C, with a winter average of -4°C and summer average of 14°C for the 27 years of recorded temperature data from 1988 to 2015 at the Copeland Lake snowpack telemetry (SNOTEL #412). Elevations range from 2532 m to 2550 m.

Although the area has been the subject of much hydrologic and geomorphologic research (Wohl et al. 2004, Wohl and Cadol 2011, Polvi 2012, Wohl 2013, Wegener et al. 2017), little data on vegetation appears to have been gathered. Three sites were established as part of the effort to create and validate a park-wide vegetation cover map (fig. 1; Salas et al. 2005). These sites were located at the east end of the area. Data gathered included species presence, height/functional stratum, and cover (Salas et al. 2005). In 2008, the National Park Service's Vital Signs Monitoring Program established a survey site at the west end of the area as part of their Wetland Ecological Integrity (WEI) program (fig. 1; Schweiger et al. 2015a). Among the measurements recorded at this site are woody and herbaceous species composition, woody plant structural components, and some browse metrics. This site was remeasured in 2014 and 2017. The NPS Vital Signs Program is in the process of establishing a sentinel site complex in Wild Basin as well (fig. 1). This complex will consist of ~10 sites that will measure the same metrics as the survey site but will be spread throughout the wetland in selected areas to capture the variability in site conditions. The WEI survey and sentinel sites each have ground water wells to monitor hydrologic conditions associated with each site. However, establishment and baseline measures for all sites within basin will not be complete until approximately 2020. In addition to the WEI sites, the Rocky Mountain Network has also established one Stream Ecological Integrity site in the wetland and 6 sites upstream (Schweiger et al. 2015b).

Mitchell and others (2000) surveyed the area for beaver activity in November 1999 from the park boundary at County Road 84W to the first RMNP bridge crossing North St. Vrain Creek. Streams were surveyed by foot to locate current and past beaver activity, including lodges, bank dens, food caches, dams, trails, cuttings, stumps, scent mounds, scat, and sightings. Data were recorded for riparian shrub use by ungulates, canopy cover of riparian shrubs, species composition of riparian shrubs, river channel condition and suitability for beaver, and river channel width. Scherer and others (2011) also visited the area in 2009-2010 to survey beaver occupancy.

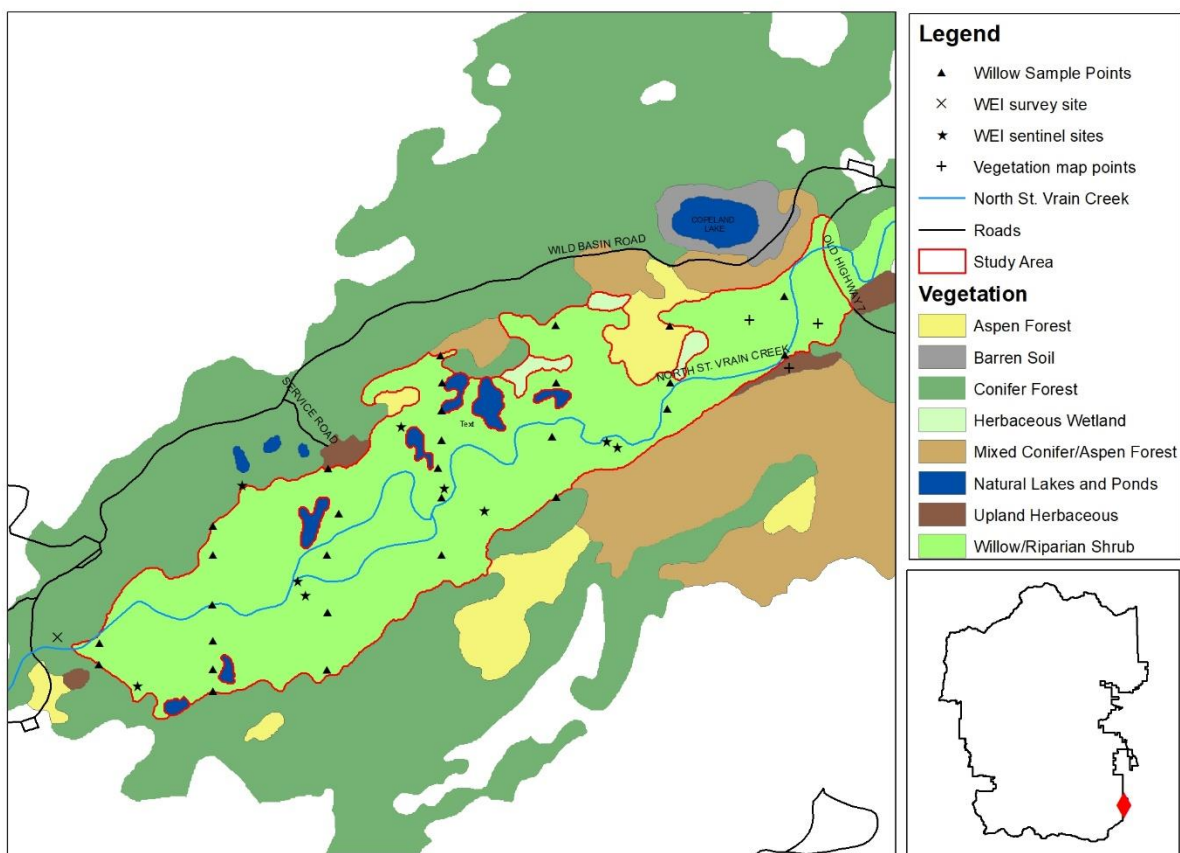


Figure 1. Locations of the willow area surveyed in 2018 and other sites where vegetation data has been collected in Wild Basin, Rocky Mountain National Park, Colorado.

METHODS

We searched the NPS Integrated Resource Management Applications (IRMA) database for past studies conducted on vegetation and (or) wildlife in the Wild Basin and other similar areas of the park. We conducted scientific literature and web searches for information on studies of moose ecology specifically in Colorado and throughout the Rocky Mountains. We used this information to inform discussions with researchers in hydrology, wetland ecology, and wildlife biology who have knowledge of the area of interest or related studies. Based upon these discussions, we determined that our focus should be on issues related to willow condition and ungulate browsing because current studies could not provide adequate information for Wild Basin regarding these topics.

From September 22 through September 24, 2018, we canvassed the area of interest to determine the best means to survey the habitat. We determined that a systematic sampling would be the most efficient method to survey the area with the limited time and field assistance that was available. The original design was to sample points spaced 20 m apart along transects that followed UTM easting lines (which are oriented in a north-south direction). These UTM transects were spaced 200 m between transects. On September 25–27, 2018, we returned to the

area with NPS field crews to begin measuring sites. After the initial two days of sampling, we found that the time it took to navigate to sites and complete measurements would not allow us to cover the entire area if we sampled sites using 20–25 m spacing. As a result, the spacing of sites for the remaining sites was increased to 40–50 m along the UTM transects. We were not able to measure some sites due to the presence of bull moose and the risk associated with aggressive moose behavior during the rutting season; therefore, a few sites are spaced between 80 and 100 m apart along the UTM transect lines. The NPS field crew completed the survey on October 2, 2018.

We navigated to selected sites using an Arrow GPS linked to an iPad/iPhone. This GPS setup allowed us to obtain sub-meter accuracy for recording beginning and end points of each transect line (Appendix A). We placed a 5-m transect line alternating due east (90° using declination-corrected compass bearing) or due west (270°) from the start point on the UTM line. At each site we recorded information on general site conditions, including: whether the site appeared to be generally wet or dry based on herbaceous and shrub species present; signs of ungulates (tracks, scat, animals, bedding sites, browsing) and when known, whether sign was from elk, moose, or both; signs of current beaver activity that were affecting the site; and notes on any other relevant information that might influence the site. We measured all trees and shrubs whose canopies intercepted the vertical plane of a measuring tape stretched from 0 to 5 m. For each measured plant, we recorded: the species, whether the plant was a tree or shrub, the canopy intercept length, maximum live height, maximum dead height, estimate of percent of standing stems that were completely dead, estimate of 3-D canopy that was dead, whether there was evidence of current or past leaf stripping or browsing into older wood (older than current year's growth), estimated percent browsing using a test method developed by Danielle Johnston of Colorado Parks and Wildlife, estimated percent of current year twigs showing signs of ungulate browsing, and browse architecture of the plant following the methods of Keigley and others (2002, see Appendix B). Willow displaying arrested or retrogressed browse architecture are indicative that these plants are experiencing moderate to intense browsing (arrested) or a gradual change from light-to-moderate browsing to intense browsing (retrogressed), while plants with uninterrupted browse architecture are experiencing minimal to no browsing. For plants where a small portion of the plant was significantly taller than most of the rest of the plant canopy, we also recorded a typical live height for the lower part of the canopy. A complete protocol for field sampling is included in Appendix B.

We calculated average canopy cover as the amount of the transect line intercepting a shrub canopy divided by 5 m (total transect length). Mean heights, canopy cover, and percent dead were calculated for each species by site and then averaged over all sites to get means for the area. All statistical analyses were performed using R version 3.5.1 (The R Foundation for Statistical Computing, <https://www.r-project.org/>).

RESULTS

We surveyed 29 sites located throughout the area of interest during the four-day sampling effort (fig. 1). The 29 sites ranged from forest-meadow edge habitats to dense riparian willows. We recorded 14 tree or shrub species in our survey sites, including 6 willow species (table 1). Baseline shrub/tree canopy cover ranged from 0 to over 100% (overlapping canopies) and

averaged $84 \pm 10\%$. Willow accounted for $59 \pm 9\%$ of average canopy cover across Wild Basin and was the dominant species followed by alder (5%), birch (4%), lodgepole pine (4%), common juniper (4%) and aspen (3%). Willow canopy cover was slightly higher at sites near the main channel of N. St. Vrain Creek, averaging 71% willow cover at sites within 20 m of the stream.

Only three sites (11%) were currently influenced by beaver as evidenced by recent cuttings or active dams. An additional 25% of sites showed evidence of past beaver activity, though this number may be higher as evidence of past cuttings and dams were not always easy to find due to heavy grass cover. There was great variety in age of inactive dams and old cut stumps but quantifying the age of past beaver activity was beyond the scope of this survey. The remainder of sites showed no evidence of recent beaver activity but may have had past influence from beaver dams and removal of shrub and tree stems. Our general observation is that most of the Wild Basin willow area has been influenced by beaver in the past. This observation agrees with Mitchell and others (2000) who observed “Dams of various ages and states of disrepair [were found] throughout the surveyed area. Many old beaver ponds that are now stagnant are filling in with grasses and algae.”

Table 1. Shrub species recorded on 29 transects measured in Wild Basin, Rocky Mountain National Park, September 2018.

Willow Species		Other Shrub/Tree Species	
Common Name	Scientific Name	Common Name	Scientific Name
Bebb willow	<i>Salix bebbiana</i>	Thinleaf alder	<i>Alnus incana</i>
Shortfruit willow	<i>Salix brachycarpa</i>	Water birch/Red birch	<i>Betula occidentalis</i>
Drummond’s or blue willow	<i>Salix drummondiana</i>	Common juniper	<i>Juniperus communis</i>
Geyer willow	<i>Salix geyeriana</i>	Lodgepole pine	<i>Pinus contorta</i>
Park willow	<i>Salix monticola</i>	Quaking aspen	<i>Populus tremuloides</i>
Planeleaf or diamondleaf willow	<i>Salix planifolia</i>	Wild rose	<i>Rosa woodsia</i>
		Raspberry	<i>Rubus deliciosus</i>
		Common snowberry	<i>Symphoricarpos albus</i>

We observed signs of ungulate presence, including tracks, scat, evidence of browsing and grazing, and numerous bedding sites, throughout the survey area and at all survey sites. Evidence of both elk and moose was observed at nearly 60% of the sites, moose sign alone was observed at 25% of the sites. At only one site (<5% of total sites) we found no apparent signs of moose but did observe signs of elk. At the remaining sites, there were signs of ungulate use but whether those signs were from moose or elk was not clearly discernible. Although, moose were the only ungulates observed in the area during our survey, elk scat was present, particularly in drier areas toward the middle of the survey area and along the boundary between forest edge habitat and the wetland area. In many of these same areas, numerous bedding sites gathered together and typical in size and number for elk, as well as elk tracks, appeared to support the conclusion that elk were present in small groups. One site along the southeast edge of the study area had plants that

appeared to have been browsed for many years, likely beyond the length of time that moose have been a regular presence in the area (fig. 2).



Figure 2. Willow along southeast edge of Wild Basin willow area displaying evidence of long-term browsing, likely pre-dating moose arrival to the area.

Willow condition

Mean live willow height was 227 ± 22 cm (range 10 – 448 cm) and mean height of dead stems was 182 ± 27 cm. Percent dead willow stems and percent dead willow canopy were both roughly $19 \pm 4\%$. Mean estimated browse utilization on willow was $24 \pm 5\%$ but observed twig use ranged from 0 to 80%. Roughly 21% of willow displayed an arrested browse architecture (indicative of moderate to heavy ungulate browsing, fig. 3), 22% displayed a retrogressed architecture (indicative of a change from light to moderate or heavy browsing, fig. 3), and 56% displayed an uninterrupted browse architecture (indicative of light or no browsing, fig. 3). Browse utilization was similar on willow displaying arrested and retrogressed browse architectures ($40 \pm 6\%$ and $41 \pm 5\%$ respectively) and greater than for willow with uninterrupted architecture ($11 \pm 2\%$). Mean heights of willows with uninterrupted browse architecture (298 ± 17 cm) were more than 2.5 times greater than those with arrested browse architecture (85 ± 7 cm). Nearly three-quarters of willow that we measured had signs of past or recent leaf stripping and 64% of willow showed signs of past or current browsing into older wood (fig. 4).



Figure 3. Wild Basin willows displaying arrested browse (left), retrogressed (center), and uninterrupted (c) browse architecture.



Figure 4. Examples of browsing into older wood (left) and leaf stripping (right) on Wild Basin willows.

Other browse species

Several other woody species showed signs of browsing by ungulates. We observed that browse utilization on birch was equal to that of willow at 24%. Browse utilization on aspen was roughly 11%. All other species had 3% or less of their twigs browsed. Half of the birch measured had an arrested or retrogressed browse architecture. No species other than birch (and willow) showed impacts of ungulate browsing on plant architecture.

DISCUSSION

Overall, the condition of willow in Wild Basin is among the best condition we've observed for low elevation willow in RMNP. The willow in many places is very thick with high canopy cover, tall heights, and low levels of utilization. However, there are many indicators that these willows are experiencing increasing levels of herbivory (as we will describe below) and, in some parts of Wild Basin, may be at the start of a declining trend. To put these results in context with willow trend throughout RMNP, we compare the current condition of Wild Basin willow with past data from the area, and also with willow data collected throughout the park over the past three decades.

Comparisons with other Wild Basin data

Mitchell and others (2000) described area on the north side of the stream as very dense willow with numerous beaver channels, whereas more alder and birch were found on the south side. Fresh beaver cuttings and dams of various ages and states of disrepair were found throughout the surveyed area. Many old beaver ponds were stagnant and filling in with grasses and algae. The willows were described as very dense and browsing by ungulates was minimal with no obvious browsed leaders on most plants. No sign of moose or elk on the N. St. Vrain drainage was mentioned in the report. The authors speculated that the dense willow and very wet and marshy conditions possibly restricted elk movements in the area. Channel width ranged from 0.5–7 m with a braided main channel and numerous flowing side channels. The main channel was characterized as rocky and typically too swift for damming, but side channels and braids were soft and muddy and provided adequate habitat for beaver. Total canopy cover of riparian shrubs except for water was reported as 90–100%, mainly dense willow. Species composition was reported as 90% willow, 5% aspen, and 5% birch.

In contrast, the 2018 survey indicated a large increase in ungulate use. Whereas the 1999 survey reported minimal ungulate browsing (Mitchell et al. 2000), we estimated an average of 24% of twigs on most willows were browsed and utilization was as high as 80% on some individual willows. During the 2018 survey, we observed abundant moose sign in the form of tracks, scat, browsing, bedding sites, and visual observation of moose, as well as considerable scat, tracks and bedding sites of elk. Willow canopy cover was as much as 30% lower than that observed in 1999, but that may be



During the 2018 survey, we found many beaver ponds that were not holding water throughout the season (top), though areas near the active dams had ponded water (bottom).

due to differences in methods between the two surveys. Mitchell and others (2000) surveyed a route that followed the stream and side channels where beaver occupancy was likely and they estimated canopy cover and species composition. The 2018 survey covered the entire wetland basin, including edge areas that had more open canopies and included upland species such as juniper, pine, Douglas-fir, rose, and snowberry, and the 2018 survey also used a method that directly quantified canopy cover instead of estimating. We performed an analysis of the 2018 data that included only sites within 20 m of the stream, but found these sites only accounted for ~10% difference in estimates of willow cover. Estimates of aspen and birch canopy cover were similar in 2018 to those observed in 1999.

The single Wetland Ecological Integrity (WEI) survey site established by the Rocky Mountain Network (ROMN) of the NPS Vital Signs monitoring program is located at the edge of the willow habitat at the west end of the area (fig. 1). This site is part of a park-wide monitoring effort and therefore is not necessarily representative of the Wild Basin area as a whole. Browse utilization metrics are not equivalent between our 2018 survey and the ROMN methods because we measured percent of all *twigs* browsed while ROMN measured percent of *stems* (including all twigs on those stems) showing evidence of browsing, including rubbing, stripping, in various height stratum of the plant canopy. But the ROMN WEI survey site provides important insight into trends over the past decade in the Wild Basin area.

Several willow plants were measured in the ROMN WEI site in 2008, 2014 and 2017, though changes in measurement methods (from a plot-based sample to a transect-based sample) and death of plants led to differing numbers between the early samples and 2017 sample. Mean percent of plant stems showing evidence of ungulate browsing increased from no noted browsing in the lower canopy (below 2 m height) of one plant in 2008, to roughly 20-25% of stems showing browsing below 2 m height by 2014. No browsing in the lower canopy was documented in 2017. Browsing at 2-3 m height was evident on up to 14% of stems of this plant in 2008 but data indicated a decrease in 2014, and then an increase to 45% of stems by 2017. On another plant, ROMN documented browsing on 100% of stems in the 2-3 height stratum in 2017. All willows had evidence of browsing above 3 m, ranging from 4% to 12% of stems across all plants, in 2008 and 2014. In 2017, browsing was documented on 100% of stems above 3 m height, but only on a single plant. The lack of browsing above 3 m on any other plants in 2017 may be a result of the aforementioned changes in methods or plant survival. Absolute cover of willow at the ROMN WEI site increased from 83% in 2008 to over 100% in 2014, then dropped to 26% in 2017. Relative cover—cover of willow as a proportion of all vegetation cover—declined by nearly half from 0.33 in 2008 to 0.19 in 2017 and this decrease occurred between the 2014 (relative cover = 0.40) sample and the 2017 sample.

Our interpretation of this data is that it indicates an increase in browsing from 2008 to 2017, likely attributable primarily to moose given the height at which the browsing has occurred. The high browsing numbers observed by ROMN in 2017 compared to the much lower numbers in our 2018 survey does not indicate a significant decrease in browsing between 2017 and 2018, but likely reflects differences in assessment methods. Ungulate impacts should not be interpreted from a single site nor a single year as browsing patterns are greatly influenced by weather, ungulate density and population size, and distribution of preferred browse species. This site is very helpful in documenting an increase in ungulate browsing pressure and a decrease in willow cover over the last decade. However, the new sentinel complex of sites should allow better inference to the entire Wild Basin area and should provide a good picture of changing conditions on select areas into the future.

Elk Winter Range Comparisons

Approximately 20 km north of Wild Basin, the RMNP elk winter range is located inside the park to the west and northwest of the town of Estes Park, Colorado, has been subject to heavy concentrations of elk for over 50 years. Comparisons of the Wild Basin willow condition in 2018 to measured willow condition at various levels of elk browsing provides context for status of Wild Basin willow on the spectrum of ungulate use and effects from ungulate herbivory.

On elk winter range areas, willow offtake in Moraine Park and Horseshoe Park was collected as part of a study conducted 1994–1998 (Singer et al. 2002). The wintering elk population in the park at the time of the research was over 1000 animals. Browse utilization using measures (not estimates) of percent twig use in summer and winter were collected as part of this research (table 2). Browse use on willow on the winter range in the mid-1990s was due to elk browsing alone. Moose were not observed on the winter range in 1994–1998. Summer browse utilization by elk alone that was observed at this time was similar to the use observed in Wild Basin in 2018 (table 2) from both moose and elk. Signs of deer use (observations, tracks, scat) in both cases were minimal or not evident. Currently, there is no winter browse use data from Wild Basin willows to compare with winter rates elsewhere in the park.

Table 2. Ungulate browse utilization in Wild Basin during summer 2018 compared to elk winter range willow browse utilization in the past 25 years. Data from Singer et al. (2002), Zeigenfuss et al. (2011), Zeigenfuss and Johnson (2015), and Linda Zeigenfuss, unpublished data.

	Year						
	1994	1995	1996	1998	2008	2013/2014*	2018
	Winter Browse Utilization (%)						
Core elk winter range	63	64	57	49	85	55	
Noncore elk winter range					52	35	
Wild Basin							
	Summer browse utilization (%)						
Core elk winter range		25	33	23	37	14	
Noncore elk winter range					14	4	
Wild Basin							24

*Summer browse values are from 2014, winter values are from 2013.

Browse utilization has also been measured on the entire elk winter range (including Moraine Park, Horseshoe Park, Beaver Meadows, Hidden Valley, Cow Creek, and Hallowell Park) as part of the EVMP monitoring program (Zeigenfuss and Johnson 2015). Browse utilization on the winter range (as measured by percent of twigs browsed) was measured at the end of winter from 2008 to 2013 and some twig use measures were collected in summer 2014 as well (Zeigenfuss and Johnson 2015). Summer twig use on the elk winter range in 2014 was lower (14% core winter range and 4% non-core winter range) than what we observed in the 2018 Wild Basin Survey (24%). In 2014, field notes indicate that moose browsing/scat was only observed in the Hidden Valley area. Summer browsing on Wild Basin willows in 2018 is much

lower than observed elk winter range values in winters 2008 and 2013. This is not surprising, given that most elk were present on the winter range between September and May.

Willow heights and canopy cover in Wild Basin were greater than those observed on the elk winter range from 2008–2013 (table 3), though average willow heights in Wild Basin are close to the maximum heights (the mean across all EVMP sites of the tallest willow height at each individual site) observed on the non-core winter range. The non-core winter range is the part of the winter range that is most like Wild Basin in terms of willow condition and ungulate browse pressure prior to the arrival of moose.

Table 3. Height and canopy cover of willows measured in Wild Basin during summer 2018 compared to elk winter range willow browse utilization 10 years. Data from Zeigenfuss et al. (2011) and Zeigenfuss and Johnson (2015).

	Location			Wild Basin
	Noncore winter range	Core winter range, unfenced	Core winter range, fenced	
	Average willow height (cm) $\pm$ standard error			
2008	143 $\pm$ 23	85 $\pm$ 18	47 $\pm$ 12	
2013	200 $\pm$ 23	89 $\pm$ 18	83 $\pm$ 12	
2018				227 $\pm$ 22
	Maximum willow height (cm) $\pm$ standard error			
2008	185 $\pm$ 28	121 $\pm$ 25	60 $\pm$ 14	
2013	239 $\pm$ 28	116 $\pm$ 25	98 $\pm$ 14	
2018				279 $\pm$ 26
	Percent canopy cover $\pm$ standard error			
2008	29 $\pm$ 5	20 $\pm$ 4	17 $\pm$ 5	
2013	37 $\pm$ 5	22 $\pm$ 4	24 $\pm$ 5	
2018				59 $\pm$ 9

Comparisons to Kawuneeche Valley

The Kawuneeche Valley on the west side of RMNP is the only place in the park that has had both moose and elk browsing for an extended period. Therefore, comparisons between Wild Basin and Kawuneeche Valley may provide some insights into the possible future of Wild Basin if exposed to moderate to heavy levels of ungulate browsing, declining beaver populations, and extended drought. We caution, however, that Wild Basin willows may not respond to conditions in the same way as the Kawuneeche Valley because of differences in: 1) history of human disturbance of vegetation and hydrology between the two areas (Grace et al. 2016), 2) season and intensity of elk use, and 3) effects of drought and weather patterns. The Colorado River through the Kawuneeche Valley was also surveyed for beaver use in October 1999 by Mitchell and others (2000). They observed moderate (10% – 40%) to heavy (40% – 60%) browsing in the Kawuneeche Valley from Onahu Creek to the Colorado River trailhead and only light browsing (<10% was observed from Onahu Creek to the southern boundary of RMNP. Based on data found in Kaczynski (2013) estimates of browse intensity in Kawuneeche Valley in 2011 were between 35% and 40%. Current Wild Basin willow browsing rates (24%) are much lower than Mitchell et al. (2000) or Kaczynski (2013) estimates and are also lower than data collected during summer 2014 in the Kawuneeche Valley (49%; Zeigenfuss, unpublished data).

Mitchell and others (2000) estimated willow cover generally as >50% in most of the Kawuneeche Valley, but as low as 10% in some areas, and never reaching as high as 90%. In many sections, willow was confined to areas along the river. Alder accounted for as much as 15% of species composition in some areas. Using aerial photo analysis, Kaczynski and others (2014) found a 40% decrease in willow cover from 2001 to 2005. Willow heights in Wild Basin are taller (227 ± 22 cm) than those recorded for unbrowsed willow in the Kawuneeche Valley in 2009-2011 (209 cm; Kaczynski et al. 2014) and in 2014 (Zeigenfuss and Johnson 2015). It should be noted, however, that the Zeigenfuss and others' data were taken from one location in the Kawuneeche Valley, while Kaczynski's data was from three locations in the Valley.

CONCLUSIONS

The condition of the Wild Basin willow area appears to be exceptionally good, particularly in comparison to other low elevation willow areas in RMNP. It stands out spectacularly as one of the few remaining unprotected thriving willow stands on the east side of RMNP. The long history of minimal ungulate browsing and apparently minor human manipulation of the hydrology in this area (though some ditching and water transfer has occurred in the past) makes it an excellent reference site and we believe park managers should make all attempts possible to preserve an intact and functioning riparian shrub community in this area.

There is no doubt that conditions in the area have changed over the past 10 years as moose have become established on the landscape. Over the past 35 years, summer and winter temperatures have increased and summer precipitation has decreased (Fassnacht et al. 2018). Currently, shrub canopy cover, particularly willow canopy cover, remains high. However, the 43% of willow displaying arrested or retrogressed browse architecture indicates that many of the willows we measured are experiencing moderate to intense browsing (arrested) or a gradual change from light-to-moderate browsing to intense browsing (retrogressed). Particularly in drier sites and sites along the edge of the Wild Basin willow area, we observed plant structure that was similar to remnant "tall" willow observed in Moraine Park in 1994. Several recent dry summers may further increase the stress on willows that might otherwise withstand current levels of browsing. We believe these observations should serve as bellwethers to the possible future condition of this willow community, particularly if there are increases in ungulate browsing pressure from moose and/or elk, declining beaver populations, and extended hot and dry summer conditions that stress these willows.

There are many gaps in the information necessary to fully assess the potential future health of Wild Basin willow including: data on the elk and moose populations using this part of Wild Basin; the current status of beaver in the area compared to past beaver populations; and data on vegetative cover change in the riparian areas of Wild Basin over the past half century. The response of willow to some factors cannot be easily predicted but if the appropriate information is available, existing models can be employed to predict a range of potential responses to varying conditions. These factors include the potential for sapsucker (*Sphyrapicus nuchali*)-mediated *Cytospora* infection to impact willow heights if ungulate browsing increases; responses of willow to long-term weather variabilities, including increasing year-round average temperature, increased severity and length of droughts, and changes in timing and accumulation of winter snowpack; responses to changes in beaver-mediated hydrologic effects due to increases

or decreases in beaver occupancy and activity in the area; and the response of willow habitat to different growth rates of ungulate populations given interspecific competition between moose and elk.

NPS biologists and managers are currently addressing some of these needs in other parts of RMNP and adding data collection on Wild Basin willow could be wrapped into current studies and monitoring if funding and staffing resources allow. At a minimum, it would be useful to have some idea of the number of elk and moose regularly using the area and a determination of whether this use is seasonal or year-round. Ideally, this could be done by deploying some GPS collars on Wild Basin moose, but it may be cost prohibitive to get an adequate sample of collared moose. However, deploying even 10 collars would be valuable for spatially defining aerial survey units that could be used to estimate moose population numbers from unmarked animals. Collared moose could also be used to determine habitat use and seasonal migration patterns. Alternatively, other methods, such as adding Wild Basin to existing aerial survey flights, using aerial thermal imaging cameras, or performing ground surveys of the area might be possible but would likely net little return for the effort, particularly for ground surveys. Currently, RMNP is testing aerial thermal imaging cameras to determine whether it can be used successfully to survey moose populations.

Fecal pellet plots which are cleared then revisited could provide information on season of use, ungulate species presence, spatial distribution, and relative ungulate density. Fecal plots could be a lower cost option because they could provide some of the needed information and would be easy and relatively cheap to set up. Data collection may be able to be performed by citizen scientist volunteers. Ungulate population size could not be calculated in this manner, but an index to relative density of use could be assessed. Trail cameras are another option requiring relatively less cost, particularly if camera units are already available. Cameras that are strategically placed could collect information on ungulate species, season of use, and potentially information on how each species browses on individual plants. They could also be used to gather more detailed information on ungulate populations, but such an effort would require a greater investment in design and equipment because more cameras would be required.

The extent and intensity of winter ungulate browsing could be assessed by attempting to relocate and remeasure the 29 transects visited here again in spring, ideally spring of 2019. As noted earlier, a single year of data collection would not necessarily give an accurate picture of mean winter use over a longer period, but it would identify whether browsing is occurring primarily in summer or year-round. It would take some time to relocate the plots because the survey was not set up with permanent site markers. However, the sub-meter accuracy GPS locations and the summer species and intercept data could facilitate relocating these plots. Even if these plots could not ideally be repeated in the exact location, a spring survey would still provide valuable information on overwinter browse use in Wild Basin. At a larger and more extensive level, placing 5–10 new EVMP monitoring plots in Wild Basin could help provide a better picture of Wild Basin willow condition into the future and will help document trends occurring at these sites. The EVMP willow monitoring measurements (Zeigenfuss et al. 2011) could also possibly be piggybacked on the WEI sentinel complex sites as they are built on a similar sub-plot design.

RMNP resources management staff has been attempting to revisit the sites of the Scherer et al. (2011) survey and repeat the survey methods. The methods of the 2011 survey differed substantially from the Mitchell et al. (2000) survey and we recommend also repeating the Mitchell methods since they include estimates of ungulate browsing and willow cover. We would recommend that this be completed in Wild Basin as soon as possible to document whether beaver use in this area has changed substantially over the past 2 decades.

Some aerial photo data does exist and might be used to assess change in willow and other riparian shrub cover since the 1950s. We would recommend that RMNP pursue use of this data to determine any significant changes to shrub cover (see Kaczynski 2013) and channel length, width, and areas of ponded water, to investigate patterns where this change has occurred and match them with ground surveys targeted at collecting information from existing shrubs or their remnants (stumps, dead stems, plant architecture, current browse utilization, height, past beaver cuttings) to determine factors contributing to cover changes. As an example, many large dead and dying birch were observed in the east end of the Wild Basin willow area. An aerial photo analysis might help determine when these birches recruited and when they started to die, and these events could be linked to a timeline of other events, such as climate conditions, to speculate driving factors behind the regeneration and decline of this apparent cohort of birch. Such an analysis could provide valuable information on long-term trends in shrub cover and could also help pinpoint areas where future decreases or increases in shrubs might be expected.

Ideally, installation of 6-10 research exclosures as part of a well-designed experimental study might be useful in preserving habitat that is in good condition while testing the effects of removal of ungulate herbivory starting at a time when browse utilization is still sustainable; i.e. before willow decline is widespread and evident. While research exclosures were erected in the 1990s in the Kawuneeche Valley where there are both elk and moose, data collection was spotty and there are so few exclosures (3) that statistical inference is very minimal. Exclosure studies have several drawbacks, however, including expense in construction and maintenance of fences and data collection efforts. Therefore, any efforts to use research exclosures should be carefully considered and a good study design is critical.

While it is promising that the Wild Basin willow community is in generally good condition, to take no action to monitor its condition could risk delaying management actions that reverse or mitigate damage until conditions have deteriorated beyond recovery or require expensive restoration efforts. This is the situation that the EVMP is meant to address and execution of the elk and vegetation monitoring programs is time-consuming and costly. Careful intervention and monitoring of Wild Basin willow can help RMNP avoid similar expensive efforts and preserve a remaining piece of high-quality park habitat.

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APPENDIX A—UTM locations of the beginning and end points for each 5-m transect measured in the Wild Basin Willow Survey, September 2018. UTM locations are North American Datum 1983, Zone 13N.

Date Collected	Point ID	Description	Comments	UTM Easting	UTM Northing
9/25/2018	WB1-0	Start line WB1		453199	4451409
9/25/2018	WB1-5	End line WB1		453204	4451408
9/25/2018	WB2-0	Start line WB2		453200	4451447
9/25/2018	WB2-5	End line WB2		453196	4451445
9/25/2018	WB3-0	Start line WB3		453399	4451362
9/25/2018	WB3-5	End line WB3		453404	4451363
9/25/2018	WB4-0	Start line WB4		453399	4451401
9/25/2018	WB4-5	End line WB4		453394	4451401
9/25/2018	WB5-0	Start line WB5		453399	4451451
9/25/2018	WB5-5	End line WB5		453404	4451451
9/25/2018	WB6-0	Start line WB6	Shifted point due to river and log jam located at original point	453398	4451514
9/25/2018	WB6-5	End line WB6		453393	4451515
9/25/2018	WB8-0	Start line WB8		453399	4451601
9/25/2018	WB8-5	End line WB8		453395	4451601
9/25/2018	WB9-0	Start line WB9		453399	4451651
9/25/2018	WB9-5	End line WB9		453404	4451651
9/26/2018	WB10-0	Start line WB10		453601	4451751
9/26/2018	WB10-5	End line WB10		453606	4451751
9/26/2018	WB26-0	Start line WB26		453797	4451949
9/26/2018	WB26-5	End line WB26		453801	4451950
9/26/2018	WB25-0	Start line WB25		453800	4451901
9/26/2018	WB25-5	End line WB25		453795	4451902
9/26/2018	WB24-0	Start line WB24		453799	4451853
9/26/2018	WB24-5	End line WB24		453804	4451852
9/26/2018	WB23-0	Start line WB23		453799	4451801
9/26/2018	WB23-5	End line WB23		453794	4451801
9/26/2018	WB22-0	Start line WB22		453793	4451752
9/26/2018	WB22-5	End line WB22		453798	4451750
9/26/2018	WB13-0	Start line WB13		453599	4451601
9/26/2018	WB13-5	End line WB13		453595	4451602
9/26/2018	WB11.5-0	Start line WB 11.5	Taken without Arrow GPS	453619	4451672
9/26/2018	WB11.5-5	End line WB11.5	Taken without Arrow GPS	453608	4451671
9/27/2018	WB39-0	Start line WB39		454398	4452053

Date Collected	Point ID	Description	Comments	UTM Easting	UTM Northing
9/27/2018	WB39-5	End line WB39		454393	4452053
9/27/2018	WB41-0	Start line WB41		454400	4451950
9/27/2018	WB41-5	End line WB41		454404	4451949
9/27/2018	WB35-0	Start line WB35		454194	4451855
9/27/2018	WB35-5	End line WB35		454189	4451856
9/27/2018	WB36-0	Start line WB36		454199	4451901
9/27/2018	WB36-5	End line WB36		454204	4451901
9/27/2018	WB29-0	Start line WB29		454000	4451901
9/27/2018	WB29-5	End line WB29		453995	4451901
9/27/2018	WB27-0	Start line WB27		453999	4452001
9/27/2018	Wb27-5	End line WB27		453994	4452002
9/27/2018	WB31-0	Start line WB31		453992	4451807
9/27/2018	WB31-5	End line WB31		453997	4451809
9/27/2018	WB33-0	Start line WB33		453999	4451702
9/27/2018	WB33-5	End line WB33		453994	4451701
9/27/2018	WB19-0	Start line WB19		453799	4451601
9/27/2018	WB19-5	End line WB19		453804	4451601
9/27/2018	WB21-0	Start line WB21		453799	4451700
9/27/2018	WB21-5	End line WB21		453794	4451701
10/4/2018	WB17-0	Start line WB17		453599	4451400
10/4/2018	WB17-5	End line WB17		453594	4451401
10/4/2018	WB15-0	Start line WB15		453599	4451500
10/4/2018	WB15-5	End line WB15		453595	4451502
10/4/2018	WB38-0	Start line WB38		454198	4452000
10/4/2018	WB38-5	End line WB38		454203	4452001

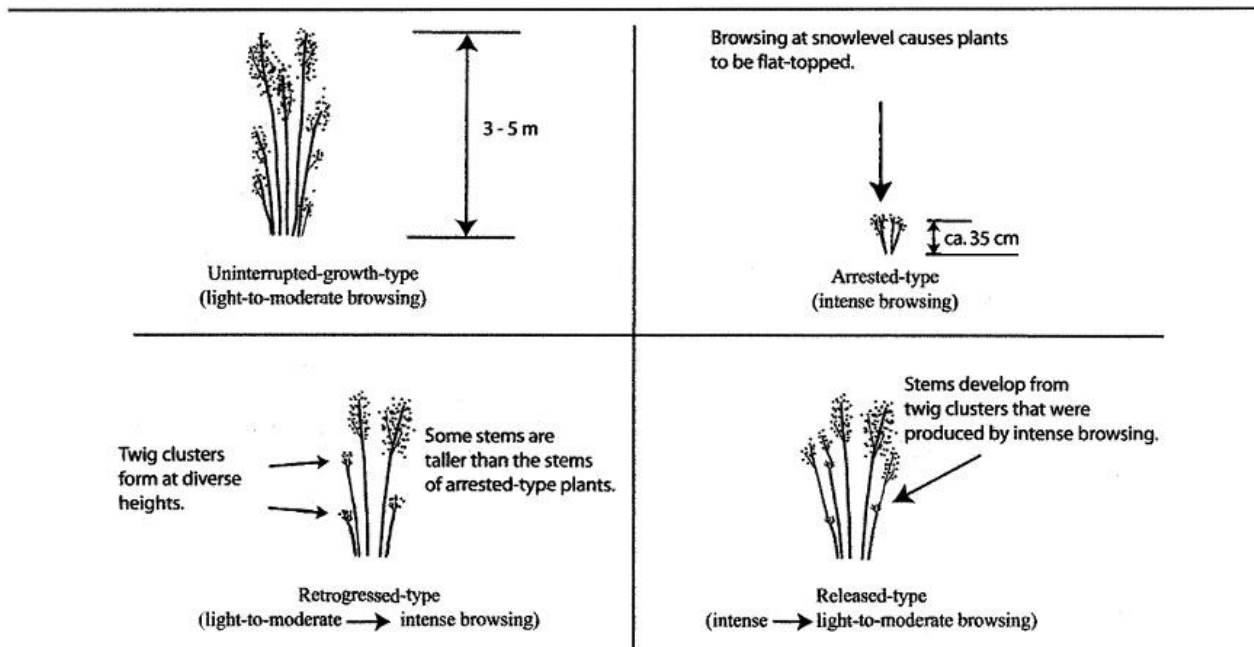
APPENDIX B--Wild Basin Willow Survey Protocol

1. Navigate to selected site from Wild Basin willow points file using the Arrow GPS and iPad/iPhone.
2. Get as close as possible to site and place start point of line intercept transect using chaining pin and 50 m measuring tape. Mark waypoint on GPS with point number plus start point distance. For example, the beginning of site 41 would be WB41-0.
3. Extend the measuring tape 5 meters directly east or west based on the line bearing indicated in the GPS point file using a compass that is corrected with the appropriate magnetic declination.
4. Pin the tape beyond the 5 m mark and mark the waypoint on the GPS at the 5m mark on the tape with the site number plus the endpoint distance. For example, WB41-5.
5. Using the Wild Basin Willow Survey sheet, enter the date and proceed to the columns on pg1 and fill out accordingly. Measure all trees and shrubs whose canopies intercept the vertical plane of the tape from 0-5 m:
 - a. Pt—Add the point number (in example above this would be 41)
 - b. Plant—Number measured plants at the point consecutively starting at 1. This helps ensure the correct plant is identified on pg. 2 of the survey sheet. Start over at one for the next point.
 - c. SP—Enter the four-letter species code for each plant—e.g., SABE (*Salix bebbiana*), SADR (*S. drummondiana*), SAGE (*S. geyeriana*), SAMO (*S. monticola*), SAPL (*S. planifolia*), ALIN (*Alnus incana*), BEOC (*Betula occidentalis*), BEGL (*Betula glandulosa*), POTR (*Populus tremuloides*), etc.
 - d. Shrub intercept start—The first point along the measuring tape where an individual shrub or tree canopy intercepts the plane extending vertically from the measuring tape. Be sure to look up. Measured to the nearest 0.05 m
 - e. Shrub intercept end—The point along the measuring tape where the canopy of the individual shrub or tree canopy no longer intercepts the vertical plane extending from the measuring tape. Measured to the nearest 0.05 m.
 - f. Max live height—the maximum live height of the plant being measured. This is the tallest height of the whole plant, not the just the section of the plant that intercepts the measuring tape. Measured to the nearest cm.
 - g. Average live height (CONDITIONAL)—this measure is only used for plants showing a retrogressed browse architecture where only a few stems on the plant are tall and a large portion of the canopy is at a much shorter height. In these cases, add a canopy height measure that approximates the typical height of the lower canopy. Measured to the nearest 1 cm. Mark N/A if the plant not strongly retrogressed.
 - h. Maximum dead height—this is the height of the tallest completely dead stem. If the plant has no completely dead stems this can be marked N/A.
 - i. Height base tallest CAG—REMOVED—we will not use this measure—do not record.
 - j. Percent dead stems—this is a visual percentage of the percent of all individual stems on a plant that are completely dead. This does not include stems that are

completely laying down or separated from the living part of the plant. If there are no dead stems on the plant, this number will be 0. Can be measured in 1% increments but often will be estimated in 5% intervals.

- k. Percent dead canopy—this is a visual estimate of the amount of 3-D canopy that is dead. Measured in 1% increments.
 - l. Beaver sign—note beaver cuttings, food caches, and dams that affect the point. If there are a lot of past beaver signs (old stumps or dams or dried up ponds), preface this sign with a “P” for past. This needs only be recorded once for each point.
 - m. Ungulate sign—note sign of ungulates by species in the near vicinity of the point. Sign may include scat, prints, animal observations, bed sites, etc. If you are able to determine ungulate species use the appropriate code to note this. This needs only be recorded once for each point.
6. Go to pg. 2 of data sheet and fill out accordingly:
- a. Pt—See above
 - b. Plant—See above.
 - c. Leaf stripping—note any signs of leaf stripping on twigs—this can include previous years’ twigs. Use Y/N.
 - d. Browsed 2nd year or older—note any sign of current or past browsing into wood older than current year browsing.
 - e. Ocular browse (DBJ)—An estimate of browse use following the Bilyeu Johnston method. This describes how much of the *current year* leaves and stems have been removed by *summer* browsing. Look at the tips of the shoots and look for fresh bite marks. These can be distinguished from older bite marks because the color of the bite mark will be pinkish or tan rather than grey. Consider how many of them you find as well as how deep the bites were- is the diameter at the bite mark small, so that just the tip of the current year shoot was removed, or is the diameter bigger and occurring in wood older than one year, so that a current year shoot, plus some older wood and possibly some smaller side shoots were all removed in one bite? Keep in mind that plants typically grow their biggest shoot at the apex of the plant, and that herbivores prefer to eat these biggest shoots. Then take a stab at what percentage of leaves and shoots were removed. Here are some benchmarks to help:
 - i. 5%- only one to a few nibbles of shoot tips;
 - ii. 10% -- several nibbles of shoot tips;
 - iii. 30% -- many nibbles plus a few bites into older wood;
 - iv. 50% -- many nibbles, and/or several bites into older wood, and most branches having some browsing evident;
 - v. 70% --many bites into older wood, the only intact shoots occurring deep within the plant where they had protection from herbivory by woody branches above.

- vi. If you are really stuck, you can use numbers in between or above benchmarks; they are guides.
- f. Estimated twig use—a visual estimate of the percent of current year's twigs that show evidence of browsing. Include upper parts of the canopy—even if they seem out of reach. It is reasonable that this estimate may be very different from the preceding estimate.
- g. Browse architecture—Choose one of the four browse architectures described by Keigley et al. (2002) following the graphic below:



- h. Notes: Add information on notes for the site and note here whether the willow is a tree with a defined, inflexible trunk or a shrub.

Wild Basin Willow Survey

Date:

[illegible]

NOTES:

[illegible]

