Avian response to willow height growth (*Salix* spp.) in Yellowstone's Northern Range

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Abstract. Willows appear to be increasing in height growth in portions of the Northern Range of YNP for the first time in several decades. This may be a consequence of climate change or a trophic cascade where presence of wolves reduces elk density and increases woody plant growth. Regardless of the cause, the recent "release" of willow in the Northern Range may have important consequences for the recolonization of bird species dependant on this habitat type. This report summarizes the results for one year of a three year study investigating 1) change in willow since 1997/1998; 2) willow species composition and percent cover; and 3) differences in willow and riparian dependant bird species abundances in three willow stand types. This report details results for objectives 2 and 3 for 2006. We surveyed bird species diversity and abundance and willow species composition and cover in protected (tall, unbrowsed) stands, released (formerly heavily browsed) stands and suppressed (short, heavily browsed) stands. We found tall stands had 3 times the percent cover of short stands and twice that in recently tall stands. Willow species richness was significantly greater in protected stands than in released or suppressed stands, but released and protected stands were similar in willow community composition. Wilson's warbler, song sparrow and warbling vireo were significantly more abundant in protected stands. Yellow warbler and willow flycatcher abundance did not differ between protected and released stands. Common yellowthroat was significantly more abundant in released stands. The results indicate that willow and riparian dependent bird species are expanding in the Northern Range in association with the increased height growth of some willow communities. Further research should examine nest success for those species common to protected and released stands to determine population viability between stand types. Additionally, future research should establish the relative role of wolves and climate in driving willow change.

Introduction

Riparian zones have long been recognized as crucial components of the landscape performing a variety of ecological functions such as stream bank stabilization, maintaining nutrient balances, and providing habitat for wildlife (Groshong, 2004). Riparian vegetation in the arid west comprises < 1% of the landscape and although rare, healthy riparian zones are an exceptionally species-rich habitat containing as much as 80% of the local avian diversity (Dobkin et al., 1998; Berger et al., 2001). The

conservation of healthy riparian areas is vitally important in maintaining several bird species dependant on this habitat type in the western states.

In Yellowstone National Park's (YNP) Northern Range (NR) deciduous wetland woody vegetation has been highly suppressed since the early 1900's (Ripple and Beschta, 2003). Recruitment of aspen (*Populus tremuloides*) (Romme et al., 1995) and cottonwood (*Populus* spp.) into adult size age classes has been rare (Ripple and Beschta, 2003) and willow cover (*Salix* spp.) has declined by 50% during this time (Houston, 1982). The loss and low stature of deciduous woody vegetation has been attributed to factors including elk (*Cervus elaphus*) herbivory, loss of beaver (*Castor canadensis*), fire, and/or climate change (YNP, 1997).

Since 1997/1998 however, YNP biologists have observed that some willow stands in the NR are expanding in height. This is supported by Ripple and Beschta (2003) who found increased height growth in six of eight cottonwood and willow stands between 1998 and 2002. A study using high spatial resolution imagery in the NR found that riparian vegetation including willow, alder (*Alnus* spp.) and cottonwood increased in areal extent in the Lamar River-Soda Butte Creek confluence between 1995 and 1999 (Groshong, 2004).

This "release" of woody vegetation coincides with the reintroduction of wolves (*Canis lupus*) in 1995 and 1996. Smith et al. (2003) and Smith (2005) suggested that the expansion of deciduous woodlands is the result of a "trophic cascade" where predation by wolves has altered the density and foraging habits of elk resulting in reduced herbivory and increased growth of deciduous woody plants. Support for the trophic cascade hypothesis is given by experimental evidence from Banff National Park. Hebblewhite et

al. (2005) found the presence of wolves indirectly and positively impacted willow growth by reducing elk density and consequently, increasing habitat for willow obligate bird species. This hypothesis has stimulated considerable interest and research in how top level predators may drive "top-down" controls on ecosystem function and biodiversity and has renewed interest in reintroducing carnivores in locations where they were extirpated by humans to restore ecosystem function (Berger et al. 2001).

An alternative hypothesis is that willow growth is due to warmer growing season temperatures. The release of deciduous vegetation coincides with years of above average annual temperatures and relatively long growing seasons (Groshong, 2004). It is speculated that willow growth is limited by the number of days in the growing season with temperatures above freezing and that the recent growth is a result of climate warming (Despain personal communication, 2005).

Regardless of the causes of willow height increases, the recent expansion may lead to changes in patterns of avian diversity and could have important consequences for willow and riparian dependant species in the NR such as yellow warbler (*Dendroica petechia*), common yellowthroat (*Geothlypis trichas*), Wilson's warbler (*Wilsonia pusilla*), willow flycatcher (*Empidonax traillii*), warbling vireo (*Vireo gilvus*) and song sparrow (*Melospiza melodii*). The current dynamics on the NR present a unique opportunity to better understand how diversity of bird populations and communities may respond to changes in deciduous woody habitats as driven by climate or trophic cascades.

The overall objectives of this 3 year study are to 1) determine the extent to which willow cover has changed in the NR since 1997/1998 using field data, aerial photographs and/or satellite imagery; 2) determine willow species composition and percent cover in

each of three stand types: protected, released and suppressed; and 3) determine how bird abundance and diversity vary between stand types for six focal species known to be willow and riparian dependant species in the NR: yellow warbler, common yellowthroat, Wilson's warbler, willow flycatcher, warbling vireo and song sparrow. This annual report summarizes the results of objectives 2 and 3 for 2006.

We predict that protected stands, with little observed changes in height growth since 1997/1998, will contain the greatest diversity and abundance of willow and riparian dependant species. Released stands, which have shown considerable changes in height growth since 1997/1998, will be less diverse with fewer individuals of willow and riparian dependant species than protected stands and that these species will be absent from highly suppressed willow stands. Knowledge of avian species composition and abundance in willow of varying height and extent may aid in identifying the nature at which willows need to be in order to maintain healthy densities of riparian songbirds in the NR.

Methods

Study Region and Stand Type Characteristics

The study region is located in Yellowstone National Park's Northern Range, adjacent Gallatin National Forest, and Tom Miner Basin. The landscape is dominated by shrub steppe and grasslands varying in elevation from 1500 m to 3209 m in elevation (Savage, 2005) and is characterized by long, cold winters (-4.9ºC) and short, cool summers (15ºC) (YNP, 1997). Riparian willow habitats account for ~ 0.4% of the landscape in the NR (Houston, 1982). Willow stands were selected with the aid of park

staff biologists based on the following criteria: 1) willow stands along a riparian corridor or seep; 2) willow that occupies at least 50% of a 40m point count circle and 3) ease of access (see Appendix A for a list of site locations).

Willow stands were categorized as protected, released or suppressed based on historical browsing and growth patterns. Suppressed sites are actively grazed on a regular basis by elk and other ungulates and are < 1 m in height; released stands are generally 1-2 m in height, are growing vigorously and show little evidence of recent browsing; protected stands are generally > 2 m in height and show little browsing due to being within the confines of a fenced exclosure, in areas where deep snow limits winter browsing, or in areas where hunting inhibits elk browsing.

Willow Species Composition and % Cover

Site level characteristics of willow such as % willow cover and species composition were determined using the Robel pole method (Robel et al., 1970). At each 10 m interval starting from the center of each stand the percent willow cover and willow species have been identified in each of 11 height classes (0.5 m intervals) in each of the cardinal directions for a total of 16 samples per point count location. Analysis of variance and community level variables were used to test significant differences between stand types in % willow cover and species composition.

Avian Abundance and Diversity

Birds were sampled across the 3 willow stand types using standard point count techniques. Three rounds of point counts were conducted for each point count location from June – July of 2006. Several bird community variables were calculated using formulae from Magurran (2004). Mean and variation in abundance of each bird species

detected and community level variables have been summarized by willow community type. Analysis of Variance tests will be used to determine statistical differences in vegetation and bird variables among willow community types.

Results

Willow species composition and % cover

Twelve species of willow were identified among the three stand types as well a hybrid between Geyer and Lemmon's willow (Table 1; see Appendix B for Latin names). Willow species richness and the Shannon-Weaver diversity index, a measure of abundance and evenness, was significantly greater ($p < 0.0000$) in protected stands, but not between released and suppressed stands. The Simpson's diversity index, a measure of dominance, was not significantly different between stand types.

Of the twelve species, 4 occurred in all three willow communities (Booth, Drummond's, Geyer and Wolf's willow) (Table 1). Three species, Drummond's ($p < 0.0051$), Missouri ($p < 0.0002$), and Lemmon's willow ($p < 0.0000$) were encountered significantly more frequently in protected stands than in released and suppressed stands. There was no difference in the frequency of occurrence between protected and released stands for Booth and Wolf's willow. Geyer willow was not significantly different between stand types. Sandbar willow ($p < 0.0000$) occurred significantly more frequently in short stands than in either protected or released stands. Bebb ($p < 0.0256$) and plane-leaf willow ($p < 0.0492$) differed significantly between protected and suppressed, but not between released and suppressed stands. No willow species showed statistically greater frequency of occurrence in released than in suppressed or protected stands.

Table 1: Summary of willow species frequency of occurrence between stand types. Under 'Differences', those separated by spaces are significantly different. Species names are listed in Appendix B.

	Protected		Released		Suppressed		p-value	
Species	Mean	Std. Err.	Mean	Std. Err.	Mean	Std. Err.	$\alpha = .05$	Differences
Bebb willow	0.00	0.00	0.10	0.08	0.38	0.15	0.0256	P,R S,R
Booth willow	1.64	0.36	1.38	0.30	0.02	0.09	0.0004	P,R S
Drummond's willow	0.91	0.22	0.55	0.20	0.08	0.05	0.0051	P R,S
Sierra willow	0.14	0.10	0.00	0.00	0.00	0.00	NS	
Missouri willow	1.82	0.63	0.10	0.08	0.00	0.00	0.0002	P R,S
sandbar willow	0.00	0.00	0.17	0.11	2.15	0.40	0.0000	P,R S
Geyer willow	0.55	0.37	1.03	0.35	0.08	0.05	NS	
hybrid:Geyer/Lemmon's	0.18	0.13	0.07	0.07	0.00	0.00	NS	
Pacific willow	0.00	0.00	0.07	0.05	0.12	0.08	NS	
Lemmon's willow	3.64	0.72	0.07	0.05	0.00	0.00	0.0000	P R,S
plane-leaf willow	0.23	0.11	0.07	0.05	0.00	0.00	0.0492	P,R R,S
false mountain willow	0.32	0.19	0.00	0.00	0.04	0.04	NS	
Wolf's willow	0.82	0.22	0.62	0.17	0.08	0.05	0.0064	P,R S
Richness	3.73	0.30	2.17	0.27	1.38	0.21	0.0000	P R,S
Shannon-Weaver index	1.01	0.09	0.57	0.09	0.30	0.08	0.0000	P R,S
Simpson index	0.62	0.05	0.57	0.07	0.54	0.09	NS	

Protected, released, and suppressed stands differed significantly ($p < 0.000$) in overall percent willow cover until 2.5 m, above which tall stands showed significantly more willow cover than released and suppressed stands (Figure 1, Table 2). Percent willow cover was less than 5% for suppressed stands above 1 m. In released stands percent willow cover was less than 5% above 2 m and above 3 m for protected stands. Mean willow cover in protected stands was over 3 times willow cover in suppressed stands and twice that in released stands. All three stand types differed significantly in cover richness ($p < 0.0000$) and mean cover ($p < 0.0000$). Variation in cover richness was highest in suppressed stands and lowest in protected stands. Variation in mean willow cover was lowest in protected stands, but not significantly different between released and suppressed stands ($p < 0.0002$).

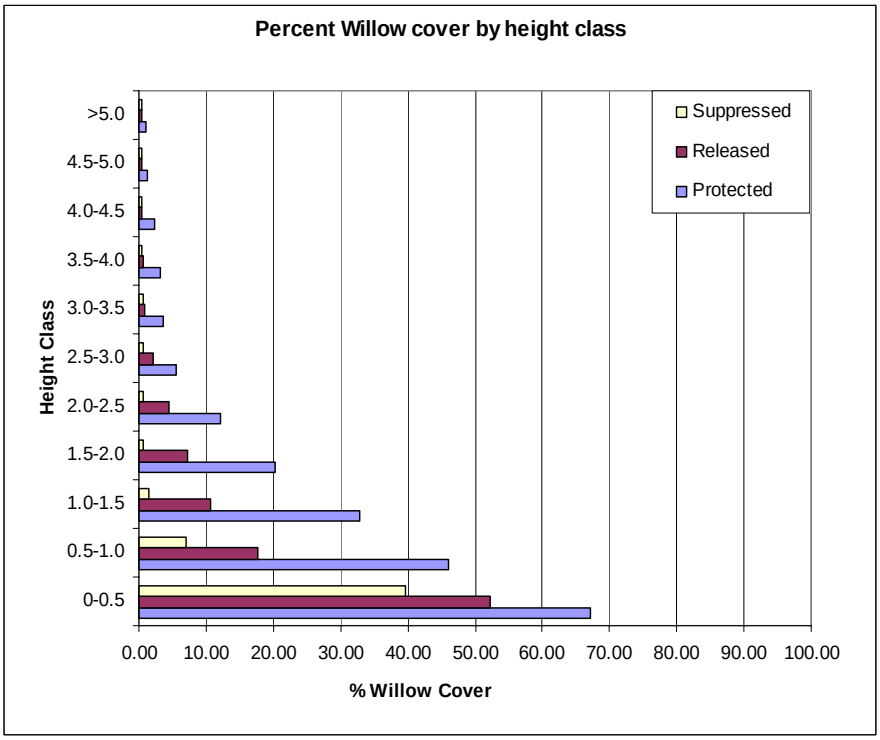

Figure 1:Distribution of overall willow cover by height class

Table 2: Percent overall willow cover by height class. Under 'Differences', those separated by spaces are significantly different.

	Protected		Released		Suppressed		p-value	Differences
Height Class	Mean	Std. Error	Mean	Std. Error	Mean	Std. Error	α = .05	
0-0.5	67.21	1.59	52.25	1.48	39.67	1.45	0.0000	P R S
0.5-1.0	46.13	2.12	17.78	1.37	7.01	0.78	0.0000	P R S
1.0-1.5	32.87	2.08	10.66	1.20	1.54	0.36	0.0000	P R S
1.5-2.0	20.26	1.79	7.29	1.02	0.74	0.21	0.0000	P R S
2.0-2.5	12.15	1.42	4.45	0.78	0.71	0.21	0.0000	P R S
2.5-3.0	5.58	0.97	2.22	0.49	0.71	0.21	0.0000	P R,S
3.0-3.5	3.73	0.83	0.91	0.22	0.71	0.21	0.0000	P R,S
3.5-4.0	3.19	0.73	0.69	0.19	0.50	0.00	0.0000	P R,S
4.0-4.5	2.26	0.59	0.53	0.03	0.50	0.00	0.0000	P R,S
4.5-5.0	1.36	0.41	0.50	0.00	0.50	0.00	0.0036	P R,S
>5.0	1.08	0.32	0.50	0.00	0.50	0.00	0.0187	P R,S
coverrich	5.91	0.47	4.85	0.31	2.50	0.27	0.0000	P R S
meancover	17.80	1.17	8.89	0.62	4.83	0.31	0.0000	P R S
coverrichcv	38.50	2.84	42.79	2.05	67.50	3.52	0.0000	P,R S
meancovercv	24.95	1.91	48.62	4.30	51.69	5.84	0.0002	P R,S

Lemmon's and Missouri willow in protected stands showed < 5% cover above 5 m and 3 m respectively (Figure 2). Booth and Geyer willow showed < 5% cover above 4 m in protected stands, but showed less than 5% cover above 3 m in released stands (Figure 2, 3). Drummond's willow was taller in released stands than in suppressed stands showing < 5% cover above 3 m in released and < 5% above 2 m in protected stands (Figure 2, 3). Wolf's willow did not exceed 1 m in protected or released stands (Figure 2, 3). Two species frequently encountered in suppressed stands, Bebb and sandbar willow, showed < 5% cover above 1 m (Figure 3).

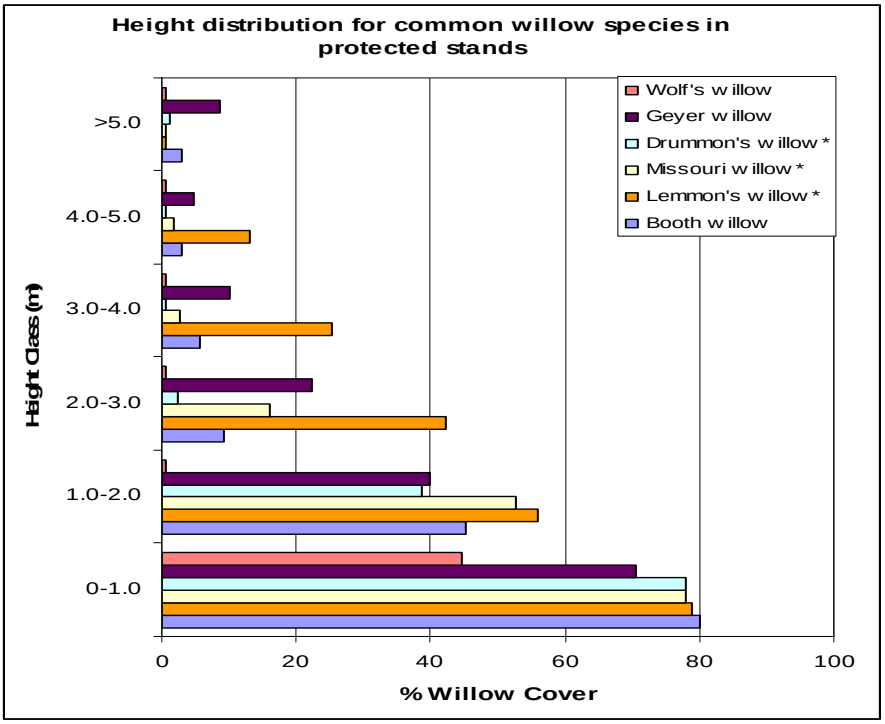

Figure 2: Percent cover by height class for common (>10 occurrences) willow species in protected stands. * denotes species significantly associated with protected stands.

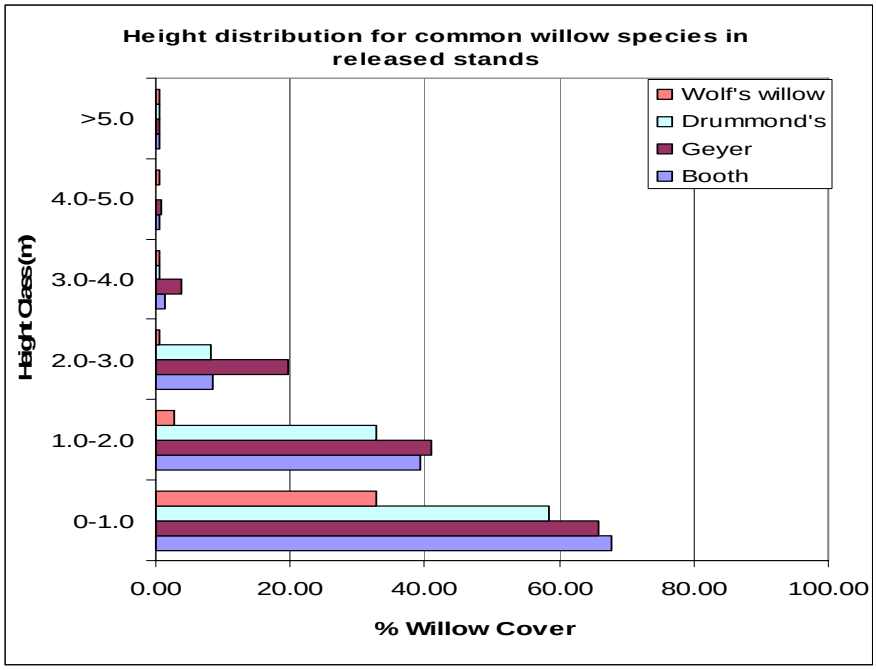

Figure 3: Percent cover by height class for common (>10 occurrences) willow species found in released stands.

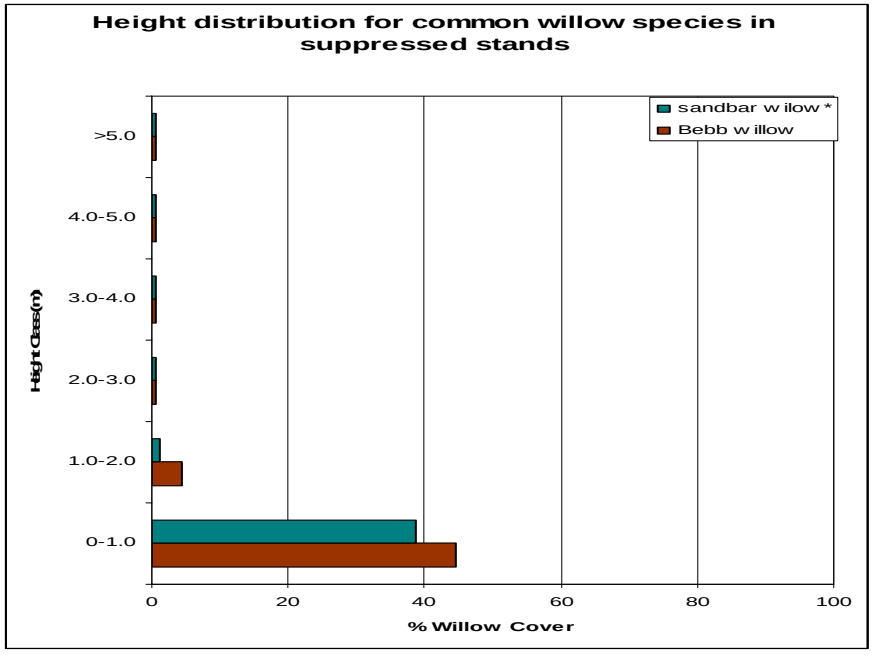

Figure 4: Percent cover by height class for common (>10 occurrences) willow species found in suppressed stands. * denotes species significantly associated with suppressed stands.

A total of 44 bird species were observed among the three stand types excluding flyovers (Table 3; see Appendix C for Latin names). Of the 44 species observed, 19 were observed at least 5 times and analyzed statistically, but all were included in diversity measures. Overall, bird species richness and both measures of diversity were greatest in protected stands and lowest in suppressed stands ($p < 0.000$).

Of the six focal species, 5 occurred in both protected and released stands. There was no difference between protected and released stands for yellow warbler ($p < 0.0000$) and willow flycatcher ($p < 0.0371$). Song sparrow ($p < 0.0000$) and warbling vireo ($p < 0.0001$) were significantly more abundant in protected stands than in released stands. Wilson's warbler was found only in protected stands ($p < 0.0000$). Common yellowthroat was significantly more abundant in released stands than in either of the other two stand types ($p < 0.0000$).

Among other species significantly more abundant in protected stands were MacGillivray's warbler, brown-headed cowbird, dusky flycatcher and lazuli bunting. MacGillivray's warbler, dusky flycatcher and lazuli bunting are associated with wet, willow thickets with dense undergrowth in the region while brown-headed cowbirds are associated with ecotones and brushy thickets. Brewer's blackbird was significantly more abundant in released stands than protected or suppressed stands ($p < 0.0031$).

Savannah sparrow was the only species more abundant in suppressed stands than in either protected or released stands ($p < 0.0000$). Lincoln's sparrow, red-winged blackbirds, and white-crowned sparrow were found in all three willow stand types with no significant differences in their abundances. Only 3 fox sparrows were observed

during surveys, but all 3 occurred in protected stands. There were no differences in the abundance of gray catbirds between stand types; however none occurred in short stands.

Table 3: Abundances of species and community variables within the classes of willow sampled. * after species code denotes species detected less than 5 times and not analyzed statistically. Under 'Differences', letters refer to the willow type and those separated by spaces are significantly different. Species codes are listed in Appendix C.

	Tall		Recently Tall		Short		p-value	
Species	Mean	Std. Err.	Mean	Std. Err.	Mean	Std. Err.	$\alpha = .05$	Differences
AMCR*	0.02	0.02	0.00	0.00	0.00	0.00		
AMRO*	0.26	0.08	0.43	0.11	0.13	0.07		
BBMA*	0.14	0.09	0.05	0.05	0.00	0.00		
BCCH*	0.23	0.07	0.00	0.00	0.00	0.00		
BGGN*	0.02	0.02	0.00	0.00	0.00	0.00		
BHCO	0.49	0.11	0.18	0.11	0.00	0.00	0.0016	P, R,S
BRBL	0.19	0.06	1.78	0.42	1.41	0.58	0.0031	R P,S
BWTE*	0.00	0.00	0.00	0.00	0.03	0.03		
CAHU*	0.00	0.00	0.03	0.03	0.00	0.00		
CHSP*	0.05	0.03	0.03	0.03	0.00	0.00		
CONI*	0.02	0.02	0.00	0.00	0.00	0.00		
COSN	0.26	0.08	0.30	0.10	0.50	0.17	NS	
COYE	0.95	0.23	2.23	0.24	0.34	0.15	0.0000	R P,S
DEJU*	0.05	0.03	0.00	0.00	0.00	0.00		
DUFL	0.49	0.14	0.08	0.06	0.00	0.00	0.0009	P R,S
FOSP*	0.07	0.04	0.00	0.00	0.00	0.00		
GBHE*	0.00	0.00	0.03	0.03	0.00	0.00		
GRCA	0.09	0.04	0.03	0.03	0.00	0.00	NS	
GTTO*	0.07	0.04	0.00	0.00	0.00	0.00		
GWTE*	0.05	0.03	0.00	0.00	0.03	0.03		
HAWO*	0.00	0.00	0.03	0.03	0.00	0.00		
KILL*	0.00	0.00	0.00	0.00	0.06	0.06		
LAZB	0.28	0.10	0.03	0.03	0.00	0.00	0.0055	P R,S
LISP	2.79	0.31	2.28	0.37	1.94	0.39	NS	
MGWA	0.60	0.12	0.00	0.00	0.00	0.00	0.0000	P R,S
NOFL*	0.05	0.03	0.03	0.03	0.00	0.00		
PISI*	0.02	0.02	0.05	0.03	0.00	0.00		
RCKI*	0.05	0.05	0.00	0.00	0.00	0.00		
RNSA*	0.05	0.03	0.00	0.00	0.00	0.00		
RUGR*	0.07	0.04	0.00	0.00	0.00	0.00		
RUHU*	0.00	0.00	0.03	0.03	0.00	0.00		
RWBL	0.12	0.06	1.05	0.40	0.94	0.40	NS	
SAVS	0.26	0.11	1.55	0.41	4.28	0.66	0.0000	P R S
SORA*	0.02	0.02	0.08	0.04	0.00	0.00		
SOSP	1.63	0.28	0.75	0.18	0.00	0.00	0.0000	P R S
SPSA	0.33	0.12	0.08	0.04	0.38	0.12	NS	
WAVI	0.84	0.17	0.28	0.14	0.00	0.00	0.0001	P R,S
WCSP	0.23	0.10	0.18	0.09	0.03	0.03	NS	
WEME	0.02	0.02	0.10	0.05	0.16	0.08	NS	
WIFL	0.47	0.16	0.48	0.16	0.00	0.00	0.0371	P,R S
WIWA	1.19	0.25	0.00	0.00	0.00	0.00	0.0000	P R,S
YHBL*	0.02	0.02	0.08	0.06	0.00	0.00		

YRWA*	0.05	0.03	0.00	0.00	0.00	0.00		
YWAR	2.67	0.30	2.45	0.28	0.03	0.03	0.0000	P,R S
richness	7.35	0.27	5.63	0.27	3.16	0.22	0.0000	P R S
Shannon's Index	1.79	0.04	1.48	0.05	0.89	0.07	0.0000	P R S
Simpson Index	0.86	0.01	0.79	0.01	0.59	0.04	0.0000	P R S

Discussion

Protected, released and suppressed stands differed in % willow cover, height growth and willow species composition. All willow species found in this study are facultative or obligate wetland shrubs and can reach maximum heights between 3 m and 12 m (USDA-NRCS, 2007; see Appendix B for individual species height potential). None of the willow species in this study reached maximum height potential except for Geyer willow in protected stands. Nevertheless, protected willow stands were taller, had significantly greater mean willow cover and more willow species than released and suppressed willow stands. There was no difference in willow species richness or the Shannon-Weaver diversity index between released and suppressed stands. In protected stands Drummond's, Lemmon's and Missouri willow were encountered more frequently than in released and suppressed stands.

Released and protected stands contained a similar species assemblage, but released willows were reduced in frequency of occurrence and percent cover. Wolf's willow has a naturally short growth form and was $\leq$ 1 m tall in all stand types in this study. Willows in suppressed stands were well below their maximum height potential and were generally less than 1 m tall. Sandbar willow, a disturbance adapted species which prefers coarse soils, was significantly more associated with suppressed stands than released or protected. The prevalence of this species on suppressed sites as compared with protected and released suggest poorer quality soils less able to retain moisture

important to willow growth. Bebb willow was also a common species in suppressed stands although not significant. Neither of these species was found in protected stands and only rarely in released stands.

It has been suggested that elk herbivory is the proximate factor leading to differences in height growth between suppressed and released or protected stands while changing climate conditions and local water table variability are the ultimate factors affecting willow growth (Singer, 1994; Bilyeu, 2006). In a study comparing suppressed, intermediate and tall willows in the NR suppressed willows were found to be growing on sites with lower growth potential than tall and intermediate sites and as a result showed reduced defense compounds thereby increasing their palatability to elk and other ungulates (Singer, 1994).

Recent willow growth may be partially attributed to better growth potential in released sites than in suppressed sites. Better growth potential in conjunction with reduced browsing as a result of lower elk density since wolf reintroduction and possible behavioral modifications of elk induced by wolves could have allowed willow to increase in height growth in some locations.

The results of this study support our initial predictions that protected willow stands would contain greater bird diversity and abundance of willow and riparian dependant species than released stands and that suppressed stands are unable to support these species with the exception of common yellowthroat. Common yellowthroat were significantly greater in released stands and although commonly found in willow and riparian areas throughout their range they are not typically found in tall riparian vegetation and are likely responding to dense growth of low vegetation commonly found

in released stands in this study. Song sparrows and warbling vireos were significantly more abundant in protected than released stands. While differences in the abundance of yellow warbler and willow flycatcher were not significant between protected and released stands, their abundance was greater in protected stands. Wilson's warbler was found only in protected stands. Although gray catbirds are often associated with streamside vegetation, they were rare in the willow communities studied here and may be restricted to lower elevation sites outside YNP.

Given willow community similarity and differences in height growth, % cover and frequency of occurrence of willow between released and protected stands it appears that willow and riparian dependant species are responding to habitat structure and willow density rather than to willow species present. Although we did not directly measure willow density, frequency of occurrence indicates willow density is greater in protected than released and suppressed stands. The results of this study indicate that willow species in suppressed stands are currently unable to reach their maximum height potential consequently preventing the colonization of willow and riparian dependant bird species in this community type.

Several studies relating bird species richness and diversity to structural modification of willow induced by ungulate browsing support our results. In YNP, abundance of Wilson's warbler, yellow warbler, willow flycatcher and warbling vireo were greater in lightly browsed, tall willow stands as opposed to short, heavily browsed willow stands (Jackson, 1992). Interestingly, willow stands within exclosures contained few species, especially willow and riparian dependant species indicating a curvilinear relationship between the level of browsing and bird species richness (Jackson, 1992). In

our study black-billed magpie and lazuli bunting were commonly found in exclosed willow stands while no willow and riparian dependant species were found in these stands with the exception of one Wilson's warbler observation made early in the season when birds were likely still establishing territories. In Grand Teton National Park approximately 50% of willow bird species were reduced in density or absent in areas where browsing by moose was high (GTNP) (Berger et al., 2001). Structural modifications of willow induced by moose browsing inhibited colonization of gray catbird and MacGillivray's warbler and reduced nesting density for willow flycatcher, yellow warbler and fox sparrow (Berger et al., 2001). In contrast, bird and nesting density were greater in areas where browsing by moose was relatively low in Bridger-Teton National Forest (Berger et al., 2001).

Conclusions

The results of this study indicate that willow and riparian dependant bird species are beginning to recolonize released willow stands in the NR. Continued expansion of willow in the NR will likely lead to increased population viability for those species dependant on this habitat type. Future research should attempt to determine population viability through studies of nest success for those species common to protected and released stands. Knowledge of avian nest success between these stand types would aid in identifying the nature at which willows need to be in order to maintain healthy densities of riparian songbirds in the NR. Additionally, it is important to better understand factors driving willow release and consequences for biodiversity to better inform the debate concerning restoration of large carnivores and future research should attempt to

determine the relative role of wolves and climate change in driving willow growth in the NR.

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Appendix A: Site locations

Willow community type	Site Name	# point counts
Tall (n = 43)	Eagle Creek	5
	Lamar West Exclosure	1
	Mammoth Exclosure	2
	Tom Miner Basin	16
	Willow Flats North	7
	Willow Flats South	12
Recently Tall (n = 40)	Blacktail	8
	Crystal Creek	4
	East Blacktail	2
	Elk Tongue	11
	Lamar Creek	7
	Lamar Picnic	2
	Lower Slough	1
	N. Blacktail	3
	Pebble Creek	2
Short (n = 32)	E. Crystal Creek	2
	Lamar Confluence	6
	Lamar Flats	5
	Middle Slough Creek	2
	Round Prairie	10
	Soda Butte	5
	Upper Slough	2
total		115

Appendix B: Willow common and Latin names (USDA, NRCS, 2007)

Common Name	Latin Names	Maximum Height Potential (m)
Bebb willow	*S. bebbiana*	3.5
Booth's willow	*S. boothii*	7.5
Drummonds willow	*S. drummondiana*	3.5
Sierra willow	*S. eastwoodii*	3
Missouri willow	*S. eriocephala*	12
sandbar willow	*S. exigua*	3
Geyer willow	*S. geyeriana*	4.5
Hybrid	*S. geyeriana/lemmonii*	NA
Pacific willow	*S. lasiandra*	7.5
Lemmon's willow	*S. lemmonii*	4.5
Plane leaf willow	*S. planifolia*	2.5
False mountain willow	*S. psuedomonticola*	5.5
Wolf's willow	*S. wolfii*	2

Appendix C: Bird species codes

Species code	Common name	Latin Name
AMCR	American Crow	*Corvus brachyrhynchos*
AMRO	American Robin	*Turdus migratorius*
BBMA	Black-billed Magpie	*Pica hudsonia*
BCCH	Black-capped Chickadee	*Poecile atricapilla*
BGGN	Blue-gray Gnatcatcher	*Polioptila caerulea*
BHCO	Brown-headed Cowbird	*Molothrus ater*
BRBL	Brewer's Blackbird	*Euphagus cyanocephalus*
BWTE	Blue-winged Teal	*Anas discors*
CAHU	Calliope Hummingbird	*Stellula calliope*
CHSP	Chipping Sparrow	*Spizella passerine*
CONI	Common Nighthawk	*Chordeiles minor*
COSN	Common Snipe	*Gallinago gallinago*
COYE	Common Yellowthroat	*Geothlypis trichas*
DEJU	Dark-eyed Junco	*Junco hyemalis*
DUFL	Dusky Flycatcher	*Empidonax oberholseri*
FOSP	Fox Sparrow	*Passerella iliaca*
GBHE	Great Blue Heron	*Ardea Herodias*
GRCA	Gray Catbird	*Dumetella carolinensis*
GTTO	Green-tailed Towhee	*Pipilo chlorurus*
GWTE	Green-winged Teal	*Anas crecca*
HAWO	Hairy Woodpecker	*Picoides villosus*
KILL	Killdeer	*Caradrius vociferous*
LAZB	Lazuli Bunting	*Passerina amoena*
LISP	Lincoln's Sparrow	*Melospiza lincolnii*
MGWA	MacGillivray's Warbler	*Oporornis tolmiei*
NOFL	Northern Flicker	*Colaptes auratus*
PISI	Pine Siskin	*Carduelis pinus*
RCKI	Ruby-crowned Kinglet	*Regulus calendula*
RNSA	Red-naped Sapsucker	*Sphyrapicus nuchalis*
RUGR	Ruffed Grouse	*Bonasa umbellus*
RUHU	Rufous Hummingbird	*Selasphorus rufus*
RWBL	Red-winged Blackbird	*Agelaius phoeniceus*
SAVS	Savannah Sparrow	*Passerculus sandwichensis*
SORA	Sora	*Porzana Carolina*
SOSP	Song Sparrow	*Melospiza melodii*
SPSA	Spotted Sandpiper	*Actitis macularia*
WAVI	Warbling Vireo	*Vireo gilvus*
WCSP	White-crowned Sparrow	*Zonotrichia leucophyrs*
WEME	Western Meadowlark	*Sturnella neglecta*
WIFL	Willow Flycatcher	*Empidonax traillii*
WIWA	Wilson's Warbler	*Wilsonia pusilla*
YHBL	Yellow-headed Blackbird	*Xanthocephalus xanthocephalus*
YRWA	Yellow-rumped Warbler	*Dendroica coronata*
YWAR	Yellow Warbler	*Dendroica petechia*