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Invasive Plant Science and Management

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Comparison of visual estimation and line-point intercept vegetation survey methods on annual grass–invaded rangelands of Wyoming

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Research Article

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Abstract

Scientists and natural resource managers require suitable vegetation survey methods to assess the success of rangeland restoration projects. Visual estimation and point intercept methods are commonly used to evaluate vegetation cover. This study compared the performance of one visual (quadrat-based) and two line-point intercept (LPI, canopy and basal) methods to assess biodiversity and cover and to estimate biomass production on sites invaded by introduced annual grasses across Wyoming, USA. Greater species richness and higher Shannon index values were measured in quadrats, while introduced annual and native perennial graminoid cover values were higher in LPI canopy in general. Overall, these outcomes indicate quadrats as the most suitable survey method when biodiversity monitoring is the primary objective, while suggesting LPI canopy when monitoring vegetation cover is prioritized. Finally, our regression models indicated quadrat-based estimates as the most reliable to predict introduced annual and native perennial graminoid biomass.

Introduction

One of the most important components of ecological restoration projects is monitoring of plant communities. Effective monitoring allows land managers to estimate potential changes in community structure and processes over the time, providing a rationale to evaluate the effectiveness of restoration treatments (D'Antonio and Meyerson 2002; Davies et al. 2021; Mealor et al. 2013; Sutter 1996). Therefore, choosing an appropriate monitoring methodology becomes a high-priority decision for scientists and natural resource professionals involved in restoration and adaptive management (Mealor et al. 2013). In the western United States, introduced annual grasses, such as bromes (*Bromus* spp.), ventenata [*Ventenata dubia* (Leers) Coss.], and medusahead [*Taeniatherum caput-medusae* (L.) Nevski], have invaded large areas, displacing native species and altering ecosystem structure and function (Jones et al. 2018; Monaco et al. 2017). Extensive efforts are underway to restore native rangeland ecosystems across the western United States, aiming to reestablish native species; eradicate invasive species; implement best management practices; and ultimately restore ecosystem structure, composition, stability, and functionality (D'Antonio and Meyerson 2002; Davies 2011; DiTomaso et al. 2010; Humphrey and Schupp 2004).

To track restoration goals, monitoring must rely on dependable sampling techniques capable of reliably and consistently detecting spatial and temporal changes in vegetation structure (Chen et al. 2009; Kopecký and Macek 2015; Sutter 1996), with particular attention to vegetation cover, productivity, species richness, and diversity (Elzinga et al. 2009; Herrick et al. 2005; Seefeldt and Booth 2006). These indicators are closely associated with habitat quality, resilience to invasion, grazing, erosion potential, and climate change (Herrick et al. 2012; Pyke et al. 2002). Particularly, plant cover is a key indicator of rangeland condition, and it can be efficiently measured and assessed (Booth and Tueller 2003). Furthermore, researchers and managers have collaborated to produce standardized protocols to obtain repeatable, statistically defensible, and comparable data (Herrick et al. 2010; Wirth and Pyke 2007).

Among the various vegetation sampling techniques described in the scientific literature, visual assessment methods such as Daubenmire and other size quadrats, and line-point intercept (LPI) methods are often used to assess cover at the species or functional group level (Thacker et al. 2015). Several authors have compared the two methods, trying to identify the most efficient way to sample plant cover both in greenhouse experiments and natural ecosystems (Dethier et al. 1993; Floyd and Anderson 1987; Gregg 2006; Herrick et al. 2005; Hulvey et al. 2018;

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Management Implications

Introduced annual grasses have caused severe ecological damage in native rangeland ecosystems across the western United States, and considerable efforts have been made to control introduced species and reestablish native species. However, without an appropriate survey method, it is difficult to evaluate the success of weed management and restoration projects. Visual estimation and line-point intercept (LPI) methods are commonly used to estimate vegetation cover, and researchers have often debated which method is the most reliable. In our study, we compared species richness, diversity (Shannon index), cover, and biomass estimates from one visual (quadrat-based) and two LPI (canopy and basal) methods in four sites in Wyoming, USA. Greater species richness and Shannon index values were measured with quadrats, while both introduced and native graminoid cover was higher in LPI canopy, except for two sites with similar results. Biomass regression models developed using quadrat-based estimates were more reliable than the others. Because quadrats outperformed LPI canopy in number of species and biodiversity and performed at least as well for graminoid cover, quadrats should be the preferred method. However, quadrats may be subject to observer bias in visually estimating cover, while LPI is considered nonbiased. When operators measure species incidence (presence or absence) and cover estimation is secondary, quadrats become bias free. Therefore, visual estimation methods should be adopted when biodiversity is prioritized, while LPI canopy should be used when estimation of cover is the main goal. Generally, we think that cover represents a fast and reliable method to estimate graminoid biomass, and our results indicated quadrat-based estimates produced the most accurate results in terms of coefficient of determination, but these outcomes might be influenced by the fact that the biomass clippings used to develop the models were obtained from the same quadrats.

Karl et al. 2016; Martyn et al. 2015; Thacker et al. 2015). In these studies, the two methods were evaluated for rangeland habitat management and conservation, with an emphasis on greater sage-grouse [*Centrocercus urophasianus* (Bonaparte, 1827)] habitat monitoring (Hulvey et al. 2018; Karl et al. 2016; Martyn et al. 2015; Thacker et al. 2015). However, we have found no comparative studies focused on informing decisions around management of invasive annual grasses in rangelands. Quantitative information about pre- and posttreatment conditions is particularly needed, as the demand for more precise data on rangeland condition and restoration effectiveness has increased, while financial resources for monitoring remain, unfortunately, limited (Davies et al. 2020, 2021). Pretreatment assessments help land managers develop effective management strategies, while posttreatment monitoring evaluates whether plant communities are shifting in the desired direction to meet management goals and objectives —optimizing resources invested in the management strategy (Mealor et al. 2013). In ongoing discussions with the Wyoming Invasive Grasses Task Force, land managers posed the question of which monitoring methods were best suited to evaluate "recovery potential" (the potential for desirable plants to respond favorably to annual grass control) before annual grass control and to capture plant community response to annual grass treatments. We were concerned that different monitoring techniques may yield inconsistent data regarding species richness, diversity, and cover, affecting the ability to detect changes in the vegetation community response to restoration treatments.

The main goal of this study was to compare three sampling techniques (quadrat based, LPI canopy, and LPI basal) to assess plant community diversity and cover and to estimate biomass production on sites invaded by introduced annual grasses. The specific objectives were to (1) quantify species richness in relation to introduced annual graminoid cover, (2) determine species diversity in terms of the Shannon-Weiner index, (3) measure differences in vegetation cover, and (4) assess the relationship between plant cover (by method) and biomass production of cheatgrass (*Bromus tectorum* L.) and native perennial graminoids. We were particularly interested in how these sampling approaches, as typically employed in the field, performed in characterizing vegetation in pre- and posttreatment conditions.

Materials and Methods

Locations

We compared vegetation monitoring methods focused on annual grass invasion impacts to plant community composition and pretreatment assessments at four sites in Wyoming: Hyattville Pinedale, Saratoga, and Sheridan (Figure 1). Topographic, climate, and soil characteristics varied among sites and are listed in Table 1. The Hyattville, Pinedale, and Saratoga sites are located within the Cold Desert level II EPA ecoregion, while Sheridan is located within Temperate Prairies. The most prevalent soil series were Neville (Entisols) and Teensleep (Aridisols) in Hyattville, Pinedale (Mollisols) and Noclios (Alfisols) in Pinedale, Dranburn and Kilgore (both Mollisols) in Saratoga, and Workfa (Aridisols) and Samday and Shingle (Entisols) in Sheridan (Soil Survey Staff 2014).

Native vegetation across the study sites consisted of sagebrush species, such as silver sagebrush (*Artemisia cana* Pursh), prairie sagewort (*Artemisia frigida* Willd.), and mountain big sagebrush [*Artemisia tridentata* Nutt. ssp. *vaseyana* (Rydb.) Beetle], associated with native perennial grasses, including western wheatgrass [*Pascopyrum smithii* (Rydb.) Á. Löve], needle-and-thread grass [*Hesperostipa comata* (Trin. & Rupr.) Barkworth], Idaho fescue (*Festuca idahoensis* Elmer), bluebunch wheatgrass [*Pseudoroegneria spicata* (Pursh) Á. Löve], and Sandberg bluegrass (*Poa secunda* J. Presl). Common introduced annual grasses included *B. tectorum*, Japanese brome (*Bromus arvensis* L.), soft brome (*Bromus hordeaceus* L.), smooth brome (*Bromus inermis* Leyss.), rattlesnake brome (*Bromus briziformis* Fisch. & C.A. Mey.), and *V. dubia*. All sites except Hyattville have had livestock grazing excluded for many years, whereas the Hyattville site was moderately grazed as part of a rotational grazing system through recent history. All sites except the Sheridan site had burned previously, but no burns had occurred within 10 yr before the current research being conducted.

Experimental Design

Because we were particularly interested in evaluating information gathered from three different vegetation monitoring methods across a broad range of annual grass abundance, the overall sampling scheme was developed to be analyzed within an experimental regression framework. Response variables were treated

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Table 1. Descriptive details for four Wyoming sites (each ~30 ha) where annual grass vegetation sampling methods were evaluated.[a]

Site	Location	Elevation	Slope	Texture	MAP	pH	EC	OM	ppm		
									NO_3-N	P	K
		m	%		mm		ds^{-1}	%			
Hyattville	44.140°N, 107.529°W	1,381	4.89	Sandy loam/sandy clay loam	260	7.7	1.7	2.7	2.4	15.3	192.2
Pinedale	42.851°N, 109.690°W	2,299	22.9	Sandy clay loam	350	6.1	0.4	3.1	2	17.2	150.5
Saratoga	41.478°N, 106.644°W	2,367	10.66	Sandy clay loam	455	7	0.4	2.7	2.8	13.4	233.9
Sheridan	44.847°N, 107.050°W	1,241	24.5	Sandy loam	430	6.9	0.5	3.3	2.4	15.3	192.2

[a]Mean annual precipitation (MAP) was calculated using PRISM climate group data (www. https://prism.oregonstate.edu/). Soil texture, pH, electrical conductivity (EC), organic matter (OM), NO_3-N, P, and K were based on multiple samples aggregated across each field site to a depth of 20 cm.

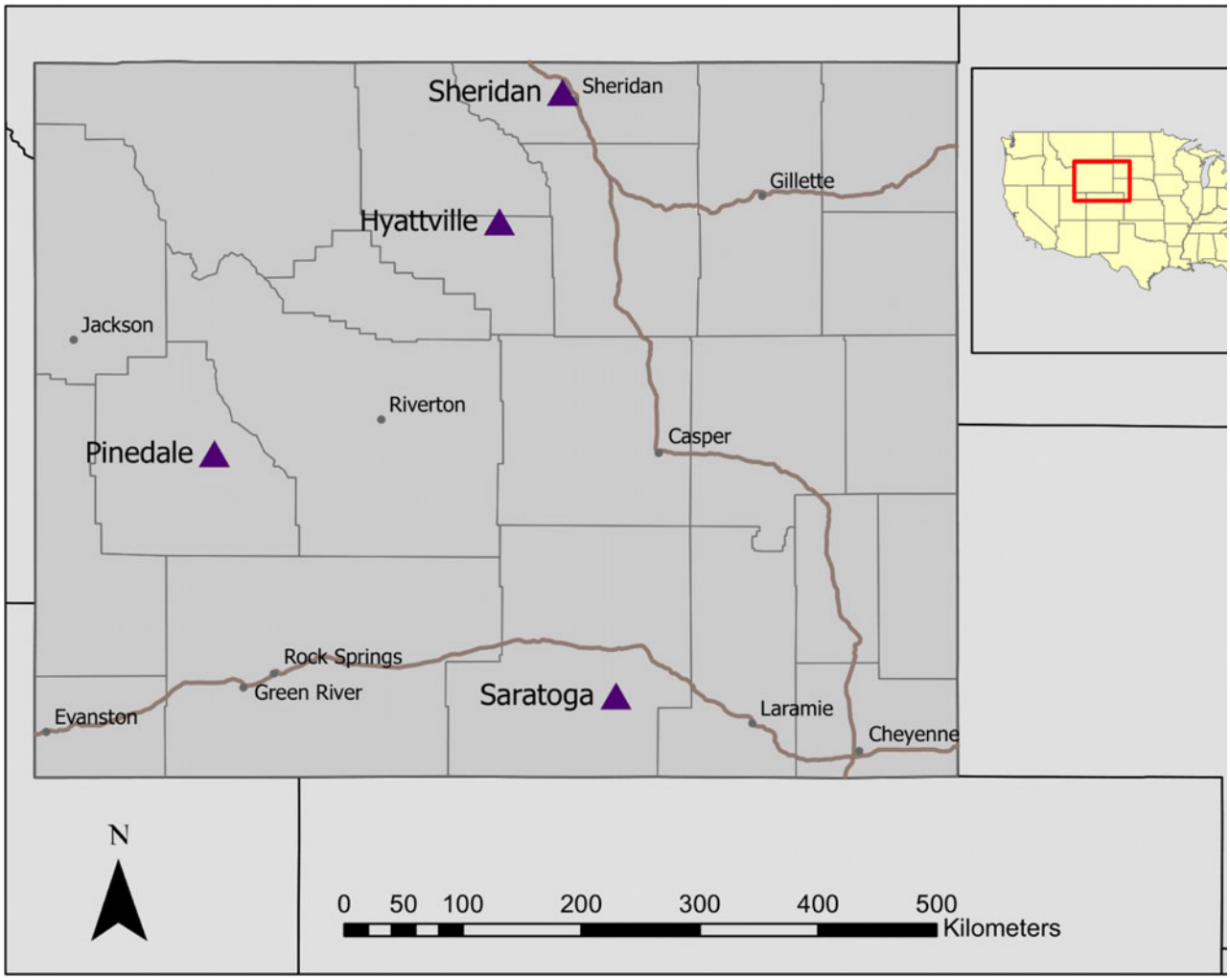


Figure 1. Locations of the four study sites in Wyoming, USA.

differently based on the question being addressed. Approximate plot density was 6 plots ha^{-1}, which was higher sampling density than many management programs would install, but sampling at this density allowed us to develop sample-based species accumulation curves at each site to understand the relationship between the number of sample locations and detection of species richness (Colwell and Coddington 1994; Magurran 2004). Our sampling approach also allowed us to evaluate site-level vegetation characteristics using the three monitoring methods as categorical predictor variables.

Vegetation Surveys and Data Collection

We collected vegetation data at the Saratoga and Pinedale field sites from June 22 to July 1 in 2015, and at the Hyattville and Sheridan field sites from June 6 to 17 in 2016. At each field site, we sampled

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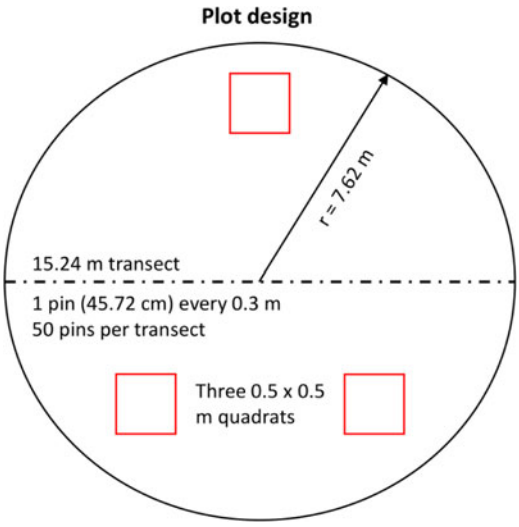


Figure 2. Plot design.

areas of approximately 33 ha that contained a broad range of *B. tectorum* abundance. After preliminary site mapping for annual grass cover, we established plots that represented *B. tectorum* cover across each site ranging from absence (0% cover) to dominance (cover equal to or greater than 50%). A total of 627 circular plots ($r = 7.62$ m) were established in the four sites, divided as follows: 219 plots at Hyattville (73 per each sampling method), 192 plots at Pinedale (64 per each sampling method), 198 plots at Saratoga (66 per each sampling method), and 180 at Sheridan (60 per each sampling method).

At each plot, we collected plant cover via LPI and quadrat-based methods. Three 0.5 by 0.5 m (0.25-m^2) quadrats were randomly placed inside every circular plot, and a 15.24-m transect was established along the plot as well (Figure 2). We collected LPI data (canopy and basal cover) at 50 points (each represented by a 45.72-cm-long by 0.2-cm-diameter pin) placed at 0.3-m intervals along the transect, assessing cover at the species level with the addition of litter, rock, and bare ground as additional cover categories. We visually estimated species-level quadrat cover data in the three randomly placed quadrats by assigning values for each species into one of seven cover classes: (1) 0%, (2) 1% to 5%, (3) 5% to 25%, (4) 25% to 50%, (5) 50% to 75%, (6) 75% to 95%, and (7) 95% to 100%. Vegetation visual cover assessment was done independently by individual species, enabling vertical overlapping and therefore allowing cover values greater than 100%. LPI estimation was conducted recording the numbers of times that a species was "hit" by the pin dropped vertically to the ground. Then, percent cover was calculated by dividing the number of hits for each species by 50 (total number of sampling points along each transect) and multiplying the result by 100. A canopy "hit" is defined when the pin intercepts any part of the plant (leaves or stems) that can intercept raindrops or provide shade from vertical sunlight (gaps not included). A basal "hit" occurs when the pin intercepts the plant basal cover, defined as the area of the ground surface covered by the basal part of plants. Generally, basal cover is considered most stable, because it does not vary as much in relation to climatic variation or grazing.

Vegetation cover assessment was performed by the same observer to ensure consistency; therefore, observer 1 assessed the vegetation cover in the quadrats, observer 2 in the transects (LPI canopy and basal). Within the three quadrats, we clipped and bagged all current-year aboveground herbaceous biomass for *B. tectorum* and native perennial graminoids. Biomass samples were dried in a forced-air oven at 60 C for 72 h, weighed to the nearest milligram, and pooled by plot. Within each site, 15 soil cores (20 cm) were collected and sent to the laboratory (www.wardlab.com) to measure soil pH, electroconductivity (EC), total organic matter (OM), nitrate-nitrogen (NO_3-N), P, and K. Soil pH and EC were quantified using a 1:1 soil–water solution, while soil OM was estimated by loss-on-ignition. NO_3-N was determined using a flow-injection analyzer. K (ammonium acetate) and P (Mehlich-3) were assessed using the inductively coupled plasma-optical emission spectrometry method.

Species Richness and Diversity

We computed species richness (S) and Shannon index (H') (Hayek and Buzas 2010; Jost 2006, 2007; Magurran 2004) from vegetation cover collected using the three methods. To calculate species richness, vegetation cover was converted into species incidence (presence/absence of a species in form of 1 or 0 respectively), and then each species value was summed to obtain the total number of species per plot. The Shannon index was calculated using vegetation cover as species proportion as follows:

$$H' = -\sum_{i=1}^{N} p_i \ln p_i \quad [1]$$

where p_i represents the relative proportion of the ith species.

We used species richness data to generate sample-based species accumulation curves per each survey method within each site, which describe the cumulative number of species discovered in a community as a function of sampling effort, defined as cumulative number of samples (Colwell and Coddington 1994; Magurran 2004). We plotted sample-based species accumulation curves indicating the number of sampling units (circular plots) on the x axis, and the cumulative number of species on the y axis (Gotelli and Colwell 2001, 2011). The number of species in a plot was measured by aggregating the species detected in the three quadrats for the quadrat-based method and the number of species hit by pins along the transects for the LPI methods.

Data Analyses

ANOVA was conducted to test for differences in species richness, Shannon index, species cover, and grass biomass at $\alpha = 0.05$ significance level. Vegetation survey method, site, and their interaction were used as fixed effects. When ANOVA indicated significant effects, means separations were performed using Tukey's honest significant difference test. We performed simple linear regression analyses between (1) *B. tectorum* aboveground biomass and its percent cover and (2) native perennial graminoid biomass and their relative percent cover and tested significance with analysis of covariance.

Shannon index and sample-based species accumulation curves with 95% confidence intervals were estimated using the R package VEGAN (Oksanen et al. 2020). Curves with overlapping confidence intervals were considered the same. All statistical analyses were performed using R (R Core Team 2021), and the plots were produced using the GGPUBR package (Kassambara 2020).

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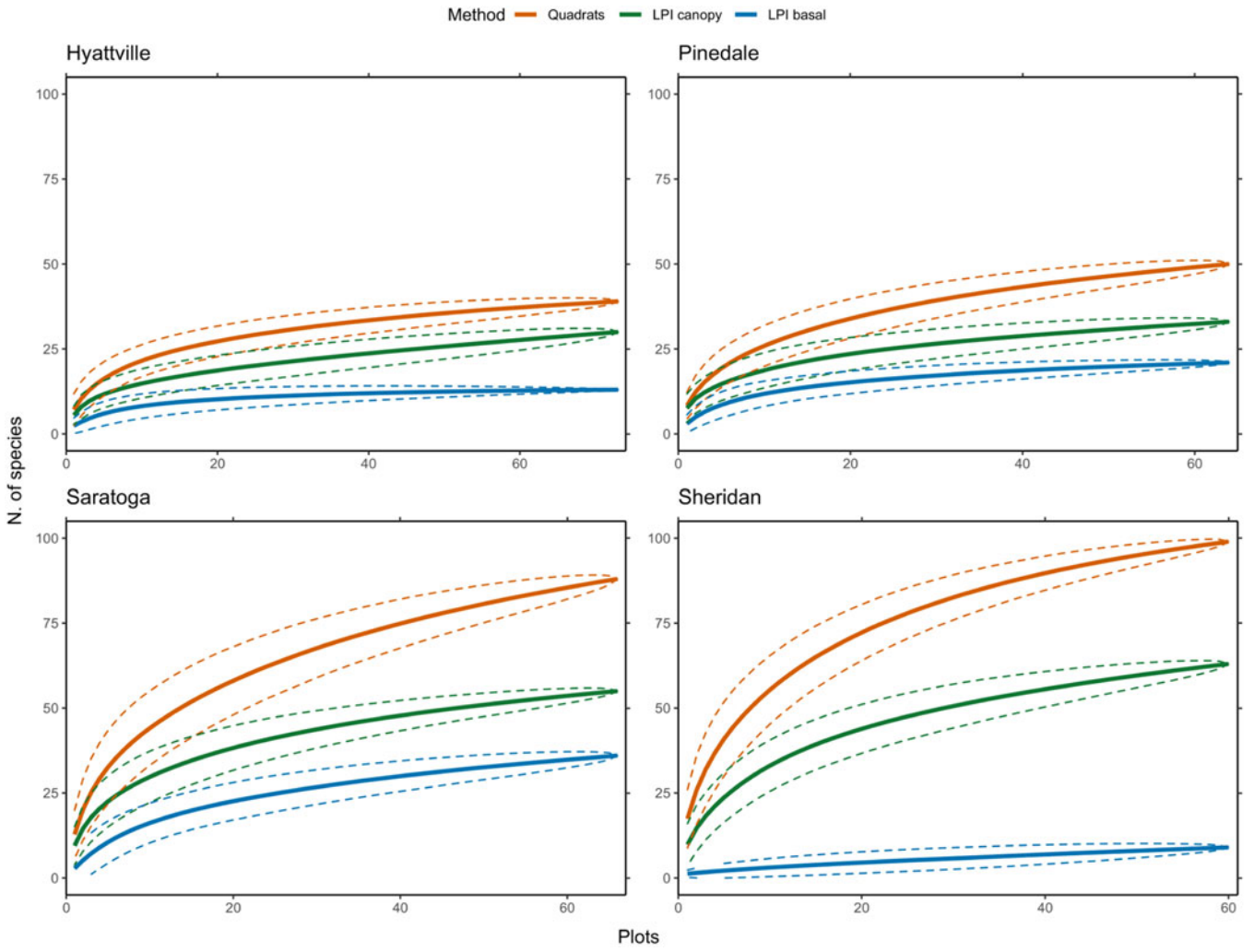


Figure 3. Sample-based species accumulation curves (solid lines) and 95% confidence intervals (dashed lines) for the three sampling methods in the four study sites. LPI, line-point intercept.

Results and Discussion

Species Richness and Diversity

Results suggested that vegetation survey methods differed in the overall number of species detected, as shown by sample-based species accumulation curves (Figure 3). Quadrat-based estimates detected a higher number of species in all four sites, followed by LPI canopy and LPI basal. ANOVA results (Figure 4, Supplementary Table S2) reflected the outcomes of sample-based species accumulation curves, indicating differences among methods within each site for both species richness and Shannon index. These differences were more evident at Sheridan and Saratoga, where richer and more even communities grew. Means and relative standard errors for species richness and Shannon index are indicated in Table 2. Generally, quadrats outperformed both LPI methods in detecting the number of species and measured more diverse and equally distributed communities in terms of Shannon index.

Our results were similar to those from other studies based on the contrast of point intercept versus visual cover methods (Etchberger and Krausman 1997; Godínez-Alvarez et al. 2009; Kinsinger et al. 1960; Stohlgren et al. 1998; Symstad et al. 2008). The reason for these differences lies in the tendency of point intercept methods to miss less frequent and rare species: a species must be hit by at least one pin to be recorded, and the likelihood of this occurrence decreases with cover (Friedmann et al. 2011; Mamet et al. 2016). Moreover, it is well documented that increasing the sampling area and the minimal scale sampled will increase species richness (Palmer and White 1994; Rapson et al. 1997). Korb et al. (2003) measured a direct correlation between area sampled and number of species detected, with the low number of species captured in the point intercept transect (0.1 m^2), followed by the Daubenmire transect (4 m^2), the belt transect (500 m^2), and a modified-Whittaker plot (1,000 m^2), indicating a direct correlation between sampling area and ability to detect new species. In our study, quadrats had the higher sampling area compared

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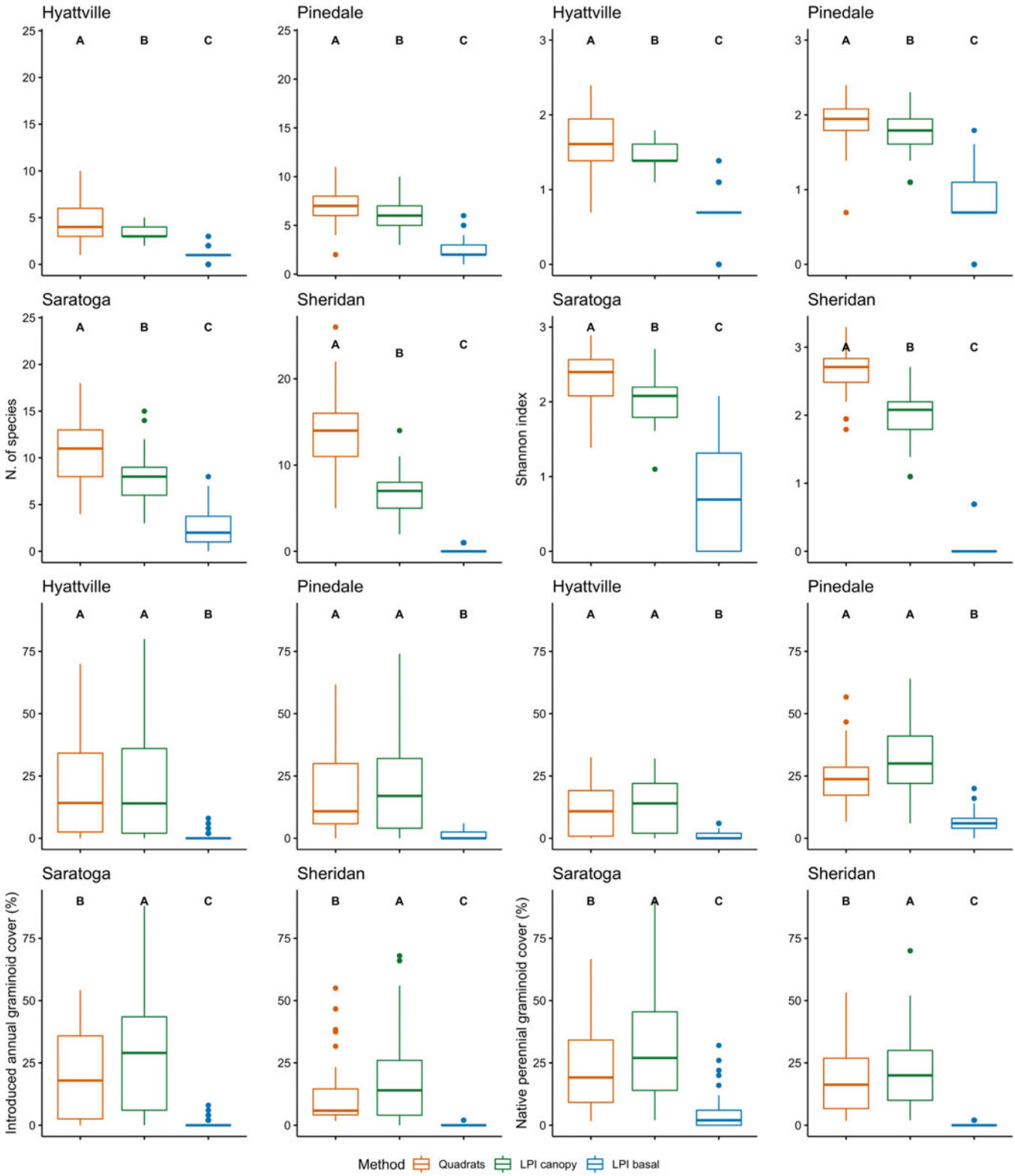


Figure 4. Box plots of number of species, Shannon index, introduced annual, and native perennial graminoid percent cover in the four sites. The lower and the upper parts of the box represent the first quartile (Q1) and the third quartile (Q3) respectively. The horizontal line denotes the median, the whiskers the upper and lower extremes, and the dots the outliers. Different letters indicate differences between vegetation survey methods within a site.

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Table 2. Mean (±SE) and sample size relative to number of species, Shannon index, and graminoid percent cover in the four study sites.

Location	Method[a]	Variable	*N*	Mean (±SE)
Hyattville	Quadrats	Introduced annual graminoid cover	73	19.48 (±2.26)
		Native perennial graminoid cover		11.01 (±1.17)
		No. of species		4.66 (±0.23)
		Shannon index		1.67 (± 0.04)
	LPI canopy	Introduced annual graminoid cover	73	20.00 (±2.27)
		Native perennial graminoid cover		13.18 (±1.17)
		No. of species		3.38 (±0.12)
		Shannon index		1.45 (±0.03)
	LPI basal	Introduced annual graminoid cover	73	0.71 (±0.19)
		Native perennial graminoid cover		1.26 (±0.19)
		No. of species		1.08 (±0.09)
		Shannon index		0.66 (±0.05)
Pinedale	Quadrats	Introduced annual graminoid cover	64	16.93 (±1.86)
		Native perennial graminoid cover		24.01 (±1.18)
		No. of species		6.81 (±0.20)
		Shannon index		1.89 (±0.03)
	LPI canopy	Introduced annual graminoid cover	64	20.91 (±2.33)
		Native perennial graminoid cover		32.09 (±1.76)
		No. of species		5.95 (±0.20)
		Shannon index		1.75 (±0.03)
	LPI basal	Introduced annual graminoid cover	64	1.38 (±0.25)
		Native perennial graminoid cover		6.28 (±0.48)
		No. of species		2.61 (±0.14)
		Shannon index		0.87 (±0.06)
Saratoga	Quadrats	Introduced annual graminoid cover	66	19.91 (±2.09)
		Native perennial graminoid cover		22.48 (±1.93)
		No. of species		11.00 (±0.44)
		Shannon index		2.34 (±0.04)
	LPI canopy	Introduced annual graminoid cover	66	27.30 (±2.74)
		Native perennial graminoid cover		31.21 (±2.70)
		No. of species		8.06 (±0.29)
		Shannon index		2.05 (±0.04)
	LPI basal	Introduced annual graminoid cover	66	0.78 (±0.20)
		Native perennial graminoid cover		4.36 (±0.81)
		No. of species		2.30 (±0.24)
		Shannon index		0.69 (±0.08)
Sheridan	Quadrats	Introduced annual graminoid cover	60	10.89 (±1.45)
		Native perennial graminoid cover		18.44 (±1.74)
		No. of species		14.07 (±0.52)
		Shannon index		2.67 (±0.04)
	LPI canopy	Introduced annual graminoid cover	60	17.57 (±2.19)
		Native perennial graminoid cover		21.60 (±1.83)
		No. of species		6.80 (±0.32)
		Shannon index		2.00 (±0.05)
	LPI basal	Introduced annual graminoid cover	60	0.03 (±0.03)
		Native perennial graminoid cover		0.27 (±0.09)
		No. of species		0.20 (±0.05)
		Shannon index		0.14 (±0.04)

[a]LPI, line-point intercept.

with the LPI methods, confirming the species–area correlation highlighted in past studies. The limited number of measured points in LPI methods decreased the likelihood of detecting rare species. Because of this issue, some authors regarded LPI not suitable when monitoring biodiversity (Korb et al. 2003; Leis 2003; Prosser et al. 2003; Stohlgren et al. 1995). Therefore, we suggested that visual methods are more appropriate when the assessment of total number of species, species evenness, and biodiversity are the priorities.

Introduced Annual and Native Perennial Graminoid Cover

There were differences in cover of introduced annual graminoid cover between quadrats and LPI basal, quadrats and LPI canopy, and quadrats and LPI basal at all sites, but not between quadrats and LPI canopy at Hyattville and Pinedale (Figure 3; Table 2). At the remaining two sites, all three methods differed from one another, with higher cover levels detected by LPI canopy. For native perennial graminoid cover, there were differences

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Table 3. Introduced annual graminoid mean percent cover by species indicated by site and survey method.

Site	Method[a]	Species mean cover (%)					
		Bromus briziformis	*Bromus hordeaceus*	*Bromus arvensis*	*Bromus tectorum*	*Polypogon monspeliensis* (L.) Desf.	*Ventenata dubia*
Hyattville	Quadrats	0.00	0.00	0.19	19.28	0.00	0.00
	LPI canopy	0.00	0.00	0.00	20.00	0.00	0.00
	LPI basal	0.00	0.00	0.00	0.71	0.00	0.00
Pinedale	Quadrats	0.00	0.00	0.00	16.93	0.00	0.00
	LPI canopy	0.00	0.00	0.00	20.91	0.00	0.00
	LPI basal	0.00	0.00	0.00	1.38	0.00	0.00
Saratoga	Quadrats	0.00	0.00	0.00	19.91	0.00	0.00
	LPI canopy	0.00	0.00	0.00	27.30	0.00	0.00
	LPI basal	0.00	0.00	0.00	0.73	0.00	0.00
Sheridan	Quadrats	0.03	0.01	3.39	6.69	0.03	0.74
	LPI canopy	0.00	0.00	5.37	11.57	0.00	0.63
	LPI basal	0.00	0.00	0.00	0.03	0.00	0.00

[a]LPI, line-point intercept.

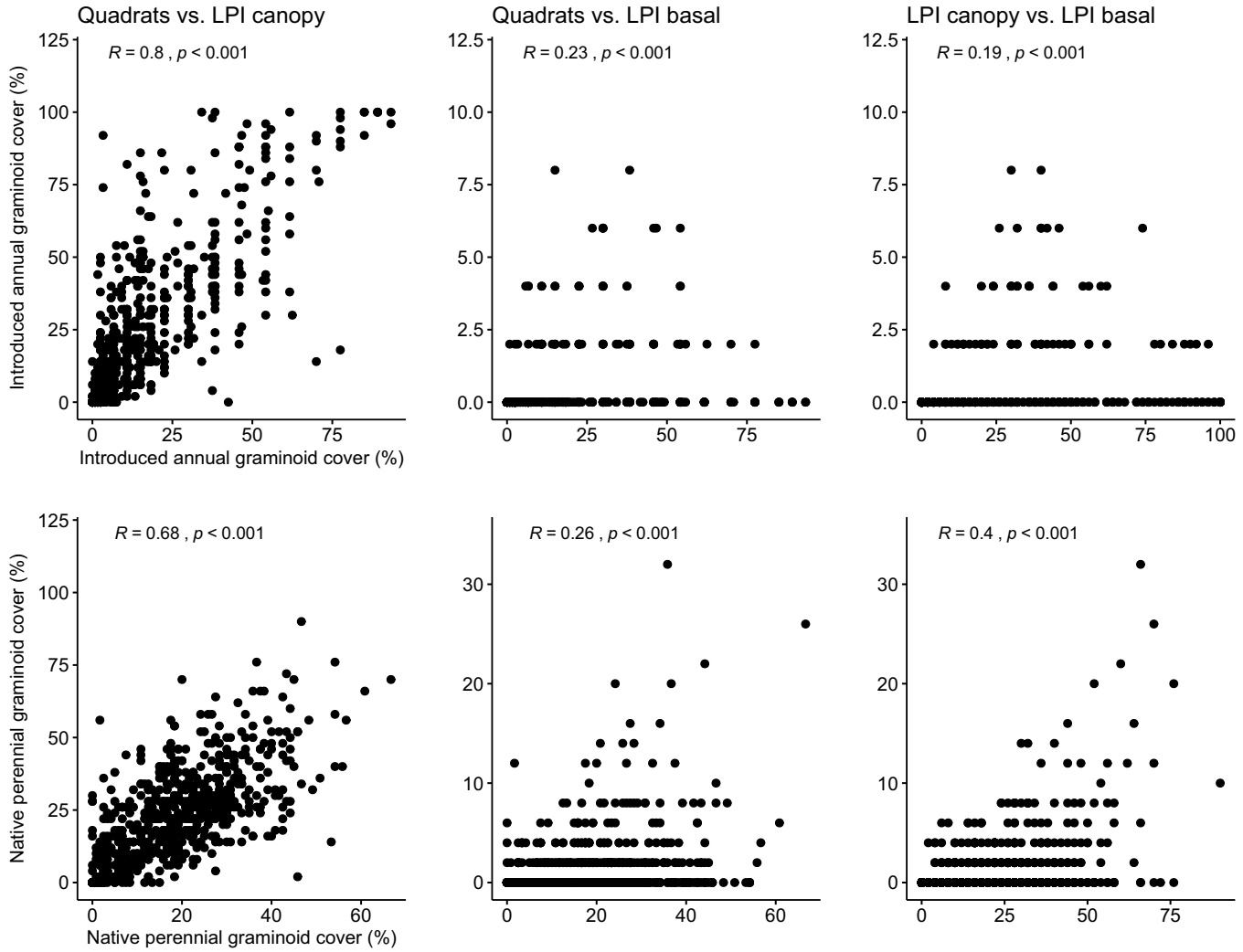


Figure 5. Scatter plots and Pearson's correlation coefficient between the three methods relative to introduced annual and native perennial graminoid percent cover. LPI, line-point intercept.

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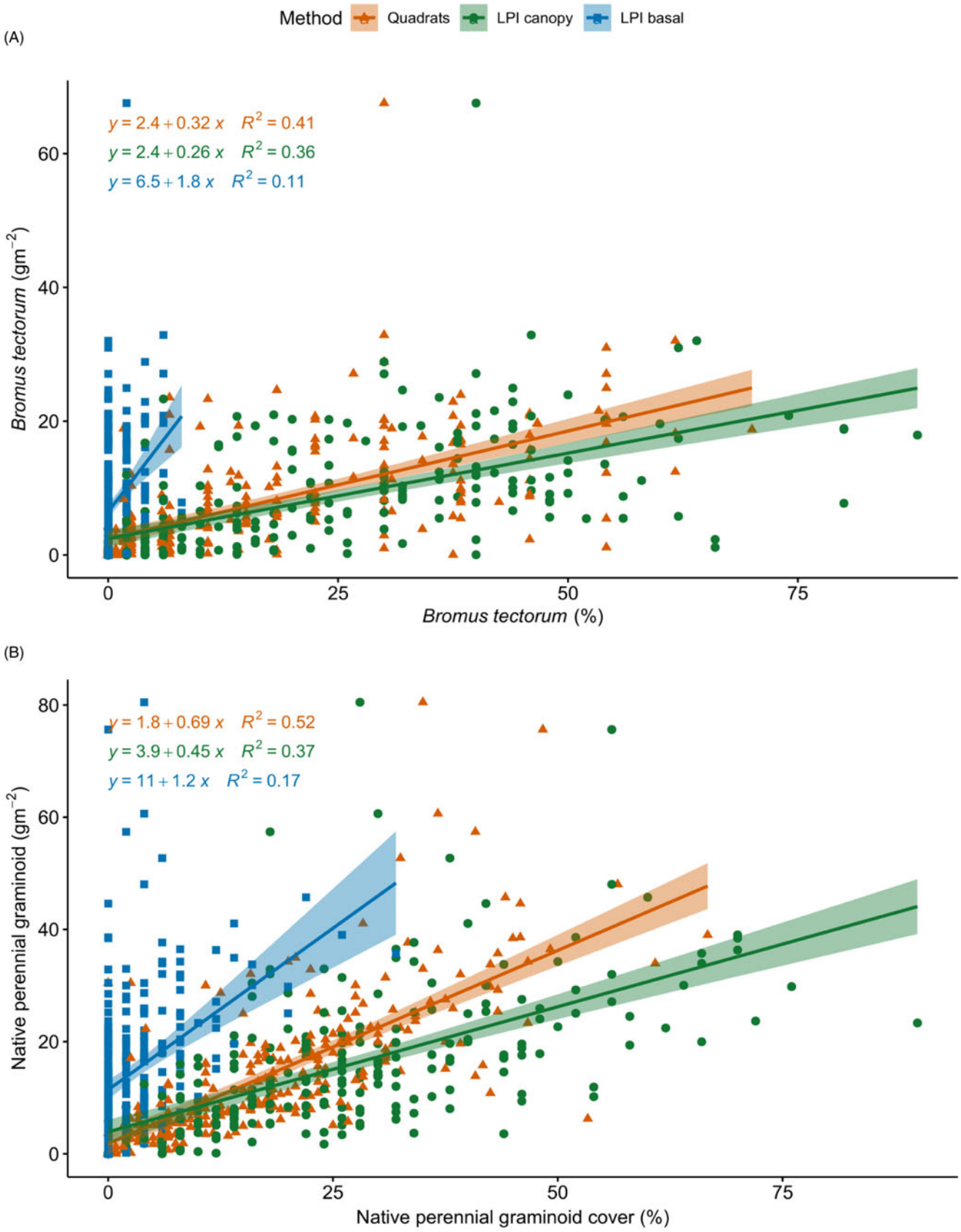


Figure 6. Scatter plots of (A) *Bromus tectorum* biomass against its percentage cover and (B) native perennial graminoid biomass against its percentage cover. Simple regression models were fit for each vegetation survey method. LPI, line-point intercept. LPI, line-point intercept.

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Table 4. Simple regression parameters for quadrat and line-point intercept (LPI) canopy and basal survey methods.

Method	Dependent variable	Coefficient	Estimate	SE	*t*-value	P-value	R^2
Quadrats	*Bromus tectorum* biomass	Intercept	2.4	0.59	4.15	0.0000	0.41
		Slope – *B. tectorum* cover	0.32	0.02	12.95	0.0000	
	Native perennial graminoid biomass	Intercept	1.8	0.98	1.87	0.0628	0.52
		Slope – Native perennial graminoid cover	0.69	0.04	16.33	0.0000	
LPI canopy	*B. tectorum* biomass	Intercept	2.4	0.63	3.86	0.0001	0.36
		Slope – *B. tectorum* cover	0.26	0.02	11.72	0.0000	
	Native perennial graminoid biomass	Intercept	3.9	1.11	3.50	0.0005	0.37
		Slope – Native perennial graminoid cover	0.45	0.04	12.15	0.0000	
LPI basal	*B. tectorum* biomass	Intercept	6.5	0.57	11.42	0.0000	0.11
		Slope – *B. tectorum* cover	1.8	0.32	5.58	0.0000	
	Native perennial graminoid biomass	Intercept	11	0.89	12.86	0.0000	0.17
		Slope – Native perennial graminoid cover	1.2	0.16	7.22	0.0000	

between quadrats and LPI basal, quadrats and LPI canopy, and quadrats and LPI basal at all the sites, but not between quadrats and LPI canopy at the Hyattville and Sheridan sites. The other two sites had differences between LPI canopy and the other methods, with LPI canopy detecting higher cover values than the other two methods. Our outcomes were in part consistent with other studies in which point intercept methods yielded higher grass cover values than quadrats (Korb et al. 2003; Thacker et al. 2015). Generally, point-based methods are considered more objective and precise than visual-based techniques, because they use pins (rather than a visual estimation) to detect points of contact of plant species (Bonham 2013; Dethier et al. 1993; Elzinga et al. 2009), while visual estimation techniques may be subject to bias, because the observers need to mentally integrate the cover of individual species (Bonham 2013; Elzinga et al. 2009; Floyd and Anderson 1987; Godínez-Alvarez et al. 2009; Hanley 1978; Korb et al. 2003; Sykes et al. 1983). On the other hand, our results indicated no differences between quadrats and LPI canopy, partially supporting the recommendation of other authors (Korb et al. 2003; Leis 2003; Prosser et al. 2003; Stohlgren et al. 1995).

Our outcomes suggested that quadrats should be the recommended method when trained observers are employed. In our study, highly trained personnel conducted the vegetation cover assessment, which can explain the consistency between point- and visual-based methods. This homogeneity in results can be evinced by the correlation coefficients for introduced annual and perennial native graminoid cover measured with method versus LPI canopy—0.8 and 0.68, respectively (Figure 5)—suggesting consistency in visual cover assessment. The level of training of the surveying crew can affect the quality of measurements using visual methods. Anderson and Kothmann (1982) recommended that observers practice reading cover for species before sampling to increase consistency and precision. We think that the LPI method remains the most successful and least biased method to monitor changes in vegetation cover, although similar results can be achieved with visual methods when properly trained personnel are employed.

Introduced Annual and Native Perennial Graminoid Cover Biomass

Among invasive annual graminoids, *B. tectorum* was the most abundant species in terms of cover (Table 3), and we included a list of native perennial graminoids in Supplementary Table S1. For quadrats, there were significant direct linear relationships between *B. tectorum* cover (%) and its aboveground biomass and between native perennial graminoid cover (%) and aboveground biomass (Figure 6; Table 4). The relationship was similarly positive for LPI methods, but with lower R^2 values. Slopes were different: greater for LPI basal with an exception for the native perennial graminoid model. In all models, LPI basal overestimated aboveground biomass. When simple regression models were fit separately according to the sites, the coefficient of determination increased in some cases (Figure 7), and the analysis of covariance (Table 5) revealed a cover by method by site interaction only for the native perennial graminoid cover model. Overall, quadrats delivered a better estimate of aboveground grass biomass in terms of coefficient of determination, probably because biomass clippings were obtained directly from the quadrats. Cover has been regarded as a fairly effective, fast, inexpensive, and nondestructive method to estimate aboveground biomass (Abella 2020; Axmanová et al. 2012; Casady et al. 2013; Chieppa et al. 2020; Flombaum and Sala 2007; Goslee 2020; Humphrey 1985). Site characteristics, such as precipitation, elevation, soil, and topography, may affect aboveground biomass productivity and were recommended to be taken into account when developing biomass-predicting models (Abella 2020; Abella et al. 2012; Beatley 1966). In our study only the native perennial graminoid cover model presented a cover by method by site interaction indicating different regression slopes, while similar slopes were obtained for *B. tectorum* models, suggesting an inconsistent effect of site characteristics. However, exploring the effect of site characteristics may help to generate and calibrate site-specific models, considering site productivity.

Finally, another potential issue is the use of fixed number cover classes and the minimum number of cover classes necessary for reliable biomass estimation (Abella 2020). We agree that the use of finer-resolution cover classes may improve the reliability of biomass estimation. We recommend the use of visual methods and LPI canopy methods as estimators when the assessment of aboveground biomass is involved.

Generally, visual cover estimation and LPI canopy methods yielded consistent and comparable data regarding native and nonnative graminoid cover and biomass prediction. Both methods are suited to evaluate the desirable vegetation recovery potential in response to restoration treatments, and their selection should be based on management's objectives. We recommend visual cover estimation methods when the priority is centered on biodiversity monitoring, while we suggest LPI canopy to detect changes in vegetation cover because of its objectivity and lack of bias.

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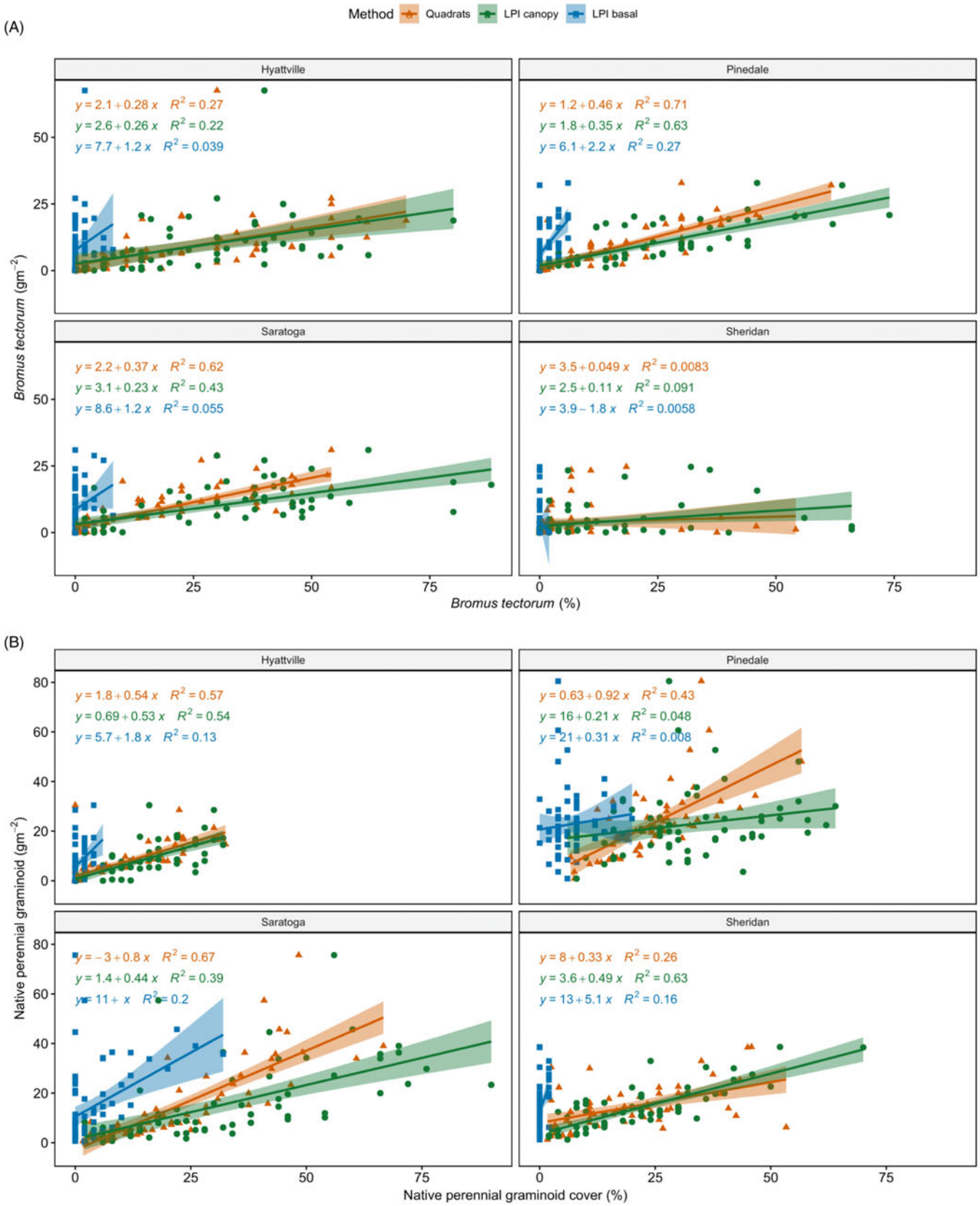


Figure 7. Scatter plots of (A) *Bromus tectorum* biomass against its percentage cover and (B) perennial graminoid biomass against its percent cover. Simple regression models were fit for each vegetation survey method within each site. LPI, line-point intercept.

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Table 5. Analysis of covariance table relative to simple regression models fit by sites. Covariates: *Bromus tectorum*, introduced annual, and native perennial graminoid percent covers. Grouping variables: vegetation survey method and site.

Variable	Predictor	Effect	df	*F*	P-value
B. tectorum biomass	*B. tectorum* cover	Cover	1	215.847	0.0000
		Method	2	35.756	0.0000
		Site	3	7.923	0.0000
		Cover*method	2	12.759	0.0000
		Cover*site	3	7.197	0.0001
		Method*site	6	1.824	0.0917
		Cover*method*site	6	1.080	0.3731
		Residuals	725		
Native perennial graminoid biomass	Native perennial graminoid cover	Cover	1	282.929	0.0000
		Method	2	70.190	0.0000
		Site	3	26.745	0.0000
		Cover*method	2	13.197	0.0000
		Cover*site	3	2.197	0.0871
		Method*site	6	1.158	0.3272
		Cover*method*site	6	5.167	0.0000
		Residuals	725		

Supplementary material. To view supplementary material for this article, please visit https://doi.org/10.1017/inp.2021.36

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