Biodiversity and Culturally Significant Plants of the Palouse Prairie

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Authorization to Submit Dissertation

This dissertation of Cleve Davis, submitted for the degree of Doctorate of Philosophy Environmental Science with a Major in Environmental Science and titled “Biodiversity and Culturally Significant Plants of the Palouse Prairie,” has been reviewed in final form. Permission, as indicated by the signatures and dates below, is now granted to submit final copies of the College of Graduate Studies for approval.

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Abstract

This dissertation presents three manuscripts that assess the impacts of non-native grass invasion to biodiversity and identifies the social importance of conserving native flora on the Palouse Prairie. The Palouse Prairie is located northern Idaho and southeastern Washington where it has been estimated that less than 1% of the prairie remains and invasive non-native grasses are reducing the biodiversity. The manuscripts are entitled: "Effects of Non-native Grass Invasion and Landscape Structure on Plant and Pollinator Diversity in the Palouse Prairie of the Columbia Basin, USA"; "Biological Soil Crusts in Relation to Topography, Soil Depth, Non-native Grass Invasion, and Native Plant Diversity on the Palouse Prairie Grassland;" and "Social Values of Culturally Significant Plants on the Palouse Prairie".

The first manuscript identified relationships between native plant and bee pollinator diversity with landscape elements and non-native grass invasion. The analysis was done using a multi-scale approach. Five variables were found to be significant at predicting plant and pollinator diversity, which included: non-native grass cover, area-weighted mean patch size, patch richness, useful pollinator habitat, and distance to water. A negative relationship of annual non-native grass cover to native plant diversity was found to be significant.

The second manuscript focused upon biological soil crust (BSC) and non-native grass invasion by assessing the relationship with native plant diversity, elevation, aspect, soil depth, and slope. Using regression soil depth was found to be inversely related to BSC cover and native plant diversity positively related to BSC cover. We attributed these findings to the ability of BSC and native plants to thrive upon environmentally stressed soils better than non-native grasses. Nonnative grass cover was also found to be inversely related to native plant diversity. This finding was attributed to biotic resistance of native plant communities.

The third manuscript focused upon valuing the importance of culturally significant plants using interviews and sample surveys. The purpose of the study was to identify potential social support to conserve culturally significant plants. The study found that Native Americans interviewed and 36% of the respondents from the community considered culturally significant plants valuable.

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Dedication

This body of work is dedicated to several special people in my life who sacrificed to help me fulfill this educational pursuit. To my gorgeous and intelligent wife, Dawn D. Davis, your contributions to our lives are beyond any words I can express. To my beautiful daughter, Lilianna Big Tree Nolan, your humor and positive outlook has made my life more fulfilling and fun. My eldest daughter, Rheannon A. Davis, your help during the hottest time of year in 2013 was a cherishing time for me. To my dad, Joe Davis Jr., you are simply the best man I know. I love you all and am truly grateful to have each of you in my life.

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Abstract

Aims

To identify effects and linkages of native plant and pollinator diversity with landscape elements and varying levels of non-native grass invasion.

Location

The highly endangered Palouse Prairie grassland of the Columbia River Basin, covering approximately 3,800 km^2 of northern Idaho and southeastern Washington (46°84’N, 117°09’W).

Methods

Vascular plant species data were collected along 12-m length transects with 0.125 m^2 quadrats with randomized sample design (*n*=104), using a standardized assessment method. Bee pollinator species were collected using traps and aerial netting with randomly located plots (*n*=29), using a standardized collection method. Landscape metrics were derived from a 2013 Landsat 8 cover classification and 2011 high resolution aerial photography. The association between plant and pollinator diversity with non-native grass invasion and landscape metrics was determined using a multi-scale approach. A multivariate multiple linear regression stepwise procedure was used to identify significant variables related to predicting native plant and pollinator diversity. Correlations among the significant variables were assessed using a biplot developed from principal components. In addition, simple linear regression was used to assess relationship between non-native grass invasion and native plant diversity.

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[1] To be submitted to Diversity and Distributions

Results

Five variables were found to be significant at the 0.05 alpha level for predicting plant and pollinator diversity: non-native grass cover, area-weighted mean patch size, patch richness, useful pollinator habitat, and distance to water. Plant and pollinator diversity were positively correlated with patch richness, useful pollinator habitat, and distance to water. Non-native grass cover and area weighted mean patch size were negatively correlated with plant and pollinator diversity. A negative relationship of annual non-native grass cover to native plant diversity was found to be significant at 0.05 alpha level. The study generated a broad scale land cover classification of approximately 3,800 km^2 of the Palouse Prairie landscape with an overall accuracy of 0.64.

Main Conclusions

The research approach enabled assessment of links for plant and pollinator diversity to landscape elements and non-native grass invasion. The results can be used to support the development of regional native plant and pollinator conservation strategies. At a landscape scale management focused upon preventing non-native grass spread, increasing patch heterogeneity and area size of useful pollinator habitat would likely improve biodiversity conservation in a highly endangered ecosystem.

Keywords

Biodiversity, conservation biogeography, land cover, multi-scale approach, multivariate multiple linear regression, Palouse Prairie, spatial patterns, landscape elements, non-native grasses, *Arrhenatherum elatius*, *Ventenata dubia*, *Bromus tectorum*

Introduction

Economic incentives and increasing demand for agricultural products have resulted in large losses of natural vegetation (Scherr & McNeely, 2008). This type of loss has occurred in the Palouse Prairie region of northern Idaho and southeastern Washington, where it has been estimated that less than 1% of the natural grassland remains (Noss & Peters, 1995). Although agricultural production in the Palouse region is highly important for supporting and maintaining the agriculturally dependent rural communities and economies, what little remains of the Palouse Prairie grassland is critical for maintaining native species of local and global importance (Black *et al*., 2000). Anticipated continuing demands for agricultural production in this region will require measures to preserve its native habitats and the species they harbor. Approaches to do so should integrate ecological and social processes with food production and the provision for biodiversity conservation. This need is acute worldwide, including the Palouse region.

It is likely that humankind has had a presence on the Palouse Prairie for at least 12,000 years (Black *et al*., 2000). Some of the earliest records of humankind in North America have been uncovered in the nearby basalt canyons along the Snake River, which forms the southern border of the Palouse Prairie (Chatters, 2004; Breckenridge, 2009). When Euro-Americans first entered the region in 1805, it was inhabited by Palouse (*Naha'ùumpùu*), Nez Perce (*Niimìipuu*), Spokane (*Sqeliz*), and Coeur d'Alene (*Schi̱tsu'umsh*) peoples (Palmer, 1998; Sprague, 1998; Walker, 1998; Frey, 2001; Scheuerman & Finley, 2008). Subsistence practices of the indigenous population relied upon hunting, fishing, and gathering, as well as low-impact utilization of native plant species (Black *et al.,* 2000). The gathering of edible and medicinal plants was and continues to be an important cultural ecosystem service the Palouse Prairie supplies to the indigenous population. When the horse was introduced in the 1700s, indigenous use of the area expanded to stock raising (Black *et al.,* 2000). However, by 1860 the indigenous population was drastically reduced by war, disease, and famine that came with Euro-American colonization (Sprague, 1998).

Subsequent to the arrival of Euro-Americans the Palouse Prairie underwent a profound transformation. The land use practices of Euro-Americans differed dramatically from those of the American Indian (Black *et al.,* 2000). Initially, Euro-Americans used the Palouse Prairie for pasture and grew fruit crops (Williams, 1991). Eventually, competition from areas better suited for fruit production and high returns for investments in wheat facilitated a switch to grain farming (Williams, 1991). Since 1900 it has been estimated that 94% of the grasslands and 97% of the wetlands in the Palouse Prairie have been converted into crop or pasture (Black *et al.,* 2000). The region is now considered to be one of the most productive grain-growing areas in the United States (Duffin, 2005).

Although ecologists had not thoroughly investigated the vegetation of the Palouse Prairie until after a large majority of the region was converted to cropland (Looney & Eigenbrode, 2012), it is believed to have supported a diverse mosaic of bunchgrasses and wildflower prairies interspersed with wetlands, thickets, and forest patches (Daubenmire, 1942). It is unknown if any species of wildlife and plants became extinct during the extensive conversion to cropland, but today the Palouse Prairie grassland is habitat for several endemic or species with limited range. *Driloleirus americanus*, the giant Palouse earthworm, was recently rediscovered by University of Idaho scientists in 2005 (Sánchez de León & Johnson-Maynard, 2009). It is the only known species of earthworm native to the Palouse Prairie and appears to be associated with intact prairie (Xu *et al.,* 2013).

Seven rare plant species are also known to occur within the Palouse Prairie including: *Silene spaldingii*, *Astragalus arrectus*, *Calochortus nitidus*, *Cirsium brevifolium*, *Pyrrocoma liatriformis*, *Trifolium plumosum* var. *amplifolium*, and *Aster jessicae*. *Silene spaldingii* is currently listed as threatened under the Endangered Species Act due to habitat loss from human development and habitat degradation associated with grazing and the spread of invasive non-native plants. The other five taxa are monitored by the Washington Natural Heritage Program or the Idaho Fish and Game due to species conservation concerns. Additionally the Palouse region likely supports populations of the rare bumble bee *Bombus occidentalis*, which is thought to be near extinction (Rao & Stephen, 2007; Hatten *et al.,* 2013; Rhoades, unpublished data).

Although direct loss of habitat from agricultural and, more recently, urban development are driving factors for imperilment of native flora (Goldberg *et al.*, 2011), the most severe impacts to remaining patches of Palouse Prairie are degradation by invasive non-native species, particularly non-native grasses (Hill *et al.,* 2012; Goldberg *et al.*, 2011; Hanson *et al.,* 2008). Invasive non-native plants can alter ecosystem processes, contribute to the loss of native plant and wildlife, and reduce economic, cultural, and aesthetic values that native ecosystems provide (Radosevich *et al.,* 2007; Mack & D'Antonio, 1998; Vitousek 1990). Introduced species can also alter the distribution patterns of pollinator services, and structure and stability of plant communities (Richardson & Pyšek, 2000; Bartomeus *et al.,* 2010, Bartomeus *et al.,* 2008). There are currently seven problematic exotic grass species on the Palouse Prairie. Five of these are annual grasses: *Ventenata dubia*, *Bromus tectorum, B. hordeaceus, B. racemosus* and *Vulpia myuros.* The two perennials are *Poa pratensis* and *Arrhenatherum elatius*. *Ventenata dubia* is a native of southern Europe, western Asia, and northern Africa. In the United States, this plant was first documented in Washington State in 1952 and is now found throughout the northwest and northeast states of the United States (Scheinost *et al.,* 2008), including many Palouse Prairie remnants (Ingwell & Bosque-Pérez, 2015).

Considering the high diversity and cover of flowering plants on the Palouse Prairie, pollination is clearly essential for both the persistence and resilience of these plant communities. Land use, pesticide use, and the introduction of non-native species are believed to have diminished pollinator services, but the impact of these factors is largely unknown. Habitat loss and fragmentation negatively impact pollinators by reducing population size and increasing isolation of fragmented populations respectively. Looney and Eigenbrode (2012) found that most of the potential remnants of the Palouse Prairie are than 2 ha in size with high perimeter-area ratios. Furthermore, only a few large prairie clusters exist near rivers and rocky buttes in the region (Looney & Eigenbrode, 2012). Fragmentation is also known to increase genetic drift, inbreeding depression, and the potential for extinction through demographic stochasticity (Kearns *et al.,* 1998). Fragmentation has also likely contributed to diminishing native plant diversity, since invasive plant spread often increases with disturbances. Understanding how fragmentation and invasive plant spread impacts plant-pollinator interactions is necessary to identify linkages between diversity, as well as for the conservation of biodiversity (Ebeling *et al.,* 2008). Identifying these links is necessary for developing goals and objectives to maintain biological diversity on the Palouse Prairie, which is focus of this study. As pollination and native plant communities do not supply ecosystem services to existing crops on the Palouse Prairie, feasible goals and objectives for biodiversity conservation would at best have no immediate upon the region's agricultural production. Longer term, many agronomists promote cropping system diversification for the region, including canola and other oilseed *Brassica* crops, which can benefit from pollination. Long term agricultural resilience of the region may well require adequate pollinator populations to succeed.

The overall aim of this study was to identify linkages of native plant and pollinator diversity with landscape elements and varying levels of non-native grass invasion. To address this aim we hypothesize that the total number of patches, patch contagion index, area-weighted mean patch size, Simpson's patch diversity index, patch richness, and cover estimates of non-native grass invasion are useful to predict native plant and pollinator diversity. Patch contagion index is a measure of aggregation that subsumes both dispersion and interspersion (McGarigal *et al.*, 2012). The patch area-weighted mean patch size metric is the area-weight mean patch size of patches of the corresponding class type, where the proportional area of each patch is based on total class area (McGarigal *et al.*, 2012). Patch richness is the number of patch types present regardless of the relative cover of each patch type (McGarigal *et al*., 2012). Simpsons' patch diversity index is a statistic that quantifies patch diversity at a landscape level and represents the probability that any two grid cells selected at random would be different patch types (McGarigal *et al.*, 2012). We also hypothesized that the invasion of annual non-native grass reduced native plant diversity. The second objective was to identify potential synergistic relationships among these variables to identify possible strategies to conserve biodiversity in a region with community that is mostly dependent upon agricultural production.

Methods

Study Area

The study area is the Palouse Prairie grassland in the northern Idaho and southeastern Washington in the central region of the Columbia River basin (46°84'N, 117°09'W; Fig.I.1). We are defining a Palouse Prairie patch as untilled native grassland or naturalized grassland steppe and thickets of hawthorn (*Crataegus douglasii*) or other native, non-forested habitat in the region. Although descriptions of the Palouse Prairie grassland cover vary in geographical extents, we have adopted a definition for the region consistent with a core area in northern

Idaho and southeastern Washington similarly described by Caldwell (1961). This region includes grassland as native and naturalized steppe vegetation on gently rolling basalt plateaus and foothills with elevations ranging from approximately 331-1,250m. The geology of this region is characterized as Miocene Columbia River basalts mantled with windblown silt or loess (DeGrey & Link, 2007). The soil is particularly rich and composed of volcanic ash that originates from volcanoes in the Cascades and loess that likely originated from glaciations to the north (Breckenridge, 2009). At some places the loess can be up to 75 m meters in depth (Busacca 1989). The hills often form a distinct alignment with steep north-facing slopes and flattened south-facing slopes (Breckenridge, 2009).

The study area is part of the Temperate Steppe division (Bailey, 1998) and has a semi-arid climate with an average annual precipitation of 600 mm (Western Regional Climate Center 2015). Evaporation exceeds precipitation during the months from June through September. The average annual max temperature of the region is 14.5°C and average annual minimum temperature 2.5°C (Western Regional Climate Center 2015). Approximately, 40 percent of the precipitation occurs from November-January. A graphical summary of average annual climatic variables is provided in Fig. I.2.

Multi-scale Approach

This study linked plot-based data of both pollinator species richness and plant species composition with landscape metrics. The landscape metrics were derived from a land cover classification, aerial photography, and distance from water. As a first step, a spatial dataset of remnant patches of Palouse Prairie grassland was developed by merging three existing polygon shapefiles using ESRI ArcGIS 10.1 software (ESRI 2012). The existing datasets were created through heads-up digitization of what could be discerned as remnant patches of native grassland vegetation using 2011 aerial imagery obtained from the National Agricultural Imagery Program. The data sources merged included: Looney & Eigenbrode (2012), Hill *et al.,*(2012), and unpublished 2013 GIS dataset of United States Fish & Wildlife Service and the Palouse Conservation District. The remnant patch polygon shapefile was corrected by the authors based upon field inventories during the 2012 and 2013 field seasons. Sample prairie sites represented a range of sizes and shapes with a mean patch size of 39.1 hectares and standard deviation of 72.7 hectares. The smallest patch size was 0.2 hectares with the largest at 299 hectares.

Plot-based data were collected from a total of 26 remnant prairie patches in Latah County, Idaho and Whitman County, Washington. With the exception of two patches in Washington, (i.e., Steptoe Butte and Kamiak Butte), all patches were privately owned. An example of plot layout and sample locations within the study areas is provided in Fig. I.3. Permission to sample on privately owned land was obtained prior to sampling. Although we strove to select sites randomly, site selection was constrained by whether permission could be obtained to access a site. With the exception of cemetery every patch where access was granted was sampled. To prevent spatial autocorrelation, pollinator sampling sites were located ≥1 km from any other pollinator sampling site. Using these constraints, a total of 29 study sites were sampled within the 26 remnants.

Pollinator Data

Sampling methods for bees were adapted and modified from published reports (Steffan-Dewenter *et al.*, 2002; Stephen & Rao, 2007; Neame *et al.*, 2012). Bees were sampled between May and July of 2012 and 2013. Insects were collected using blue vane traps, colored pan traps, bee bowls, and aerial netting. Traps were placed at each site four times each year of collection and left open for about 24 hrs. Both blue vane traps and bee bowls were filled with a solution of soapy water. Daily trap placement on a given sampling date began once the temperature reached 12°C and stopped before 18:00 hours. Trap contents were strained to remove insects from the soapy water and the insects were placed in Whirlpaks (Naco, Salida, CA) with 95% ethanol before being cleaned, dried and pinned for identification. Insects were also netted on flowers within 30m of the trap location for 5-minute periods during both trap placement and collection each of the four times traps were placed. This resulted in a total of 40 minutes of netting per site for the season. Netted insects were placed in vials on ice and stored at -20°C before pinning. Since trap effectiveness varied based on surrounding land cover, rarefied species richness was calculated with species accumulation curves using the R packages ‘vegan’ (Oksanen *et al.*, 2015).

Plant Species Data

Plant species cover, including biological soil crusts, were estimated at each of the pollinator trap sites following Daubenmire's (1959) canopy-coverage method. Sample units were 0.50 by 0.25 m rectangular quadrats and transect direction was obtained randomly using a random number generator. The long axis of the quadrat frame was oriented away from the transect line. Within in each quadrat, we recorded foliar percent cover of species in classes on the following scale: 0, 1 = 0.01-5%, 2 = 5-12.5%, 3 = 12.5-25%, 4 = 25-50%, 5 = 50-75%, 6 = 75-100%. The mid-point value of these cover class estimates was used to determine cover by species. Only one observer was used to make estimations.

Plant species data were collected in May-July during 2012 and 2013 when a majority of plant species could be easily identified. Transect orientation of all plots was chosen randomly. Species were identified in the field or collected and identified by comparison with herbarium specimens at the University of Idaho Stillinger and Washington State University Marion Ownbey herbaria. To account for plant species variability surrounding pollinator trapping sites, 77 additional plots were established using a random design stratified by aspect and elevation. Both aspect and elevation are major drivers affecting plant species composition on the Palouse Prairie (*Hanson et al.*, 2008). To the extent possible these sites were spread proportionally to the access area available with linear combinations of the random variables of aspect and elevation. Tabulations of the number of plots by aspect, elevation, and soil depth are provided in Table I.1. Overall, a total of 104 plots were sampled or 1,248 quadrat frames were read to determine cover by species.

The following variables were calculated after data collection using the R software environment for statistical computing and graphics (R Core Team 2014): total cover of non-native grass species (NNGRS) in each plot and Shannon's diversity index for total flora and native species. The Shannon's diversity index was chosen because it is more sensitive than the Simpson diversity index to the presence of rarer species (Hill 1973). To better assess the variability of plant species diversity around pollinator trapping sites, all Shannon's diversity index calculations within 1km of trapping sites were averaged. Averaged Shannon's diversity index calculations surrounding each trapping site are identified as H. Cover values for non-native grasses were calculated in a similar manner to estimate non-native grass cover surrounding trapping sites. Fig. I.3 depicts the location of the 29 pollinator trapping site (red) and additional 75 plant composition study sites (blue).

Spatial Data

To examine the question of how lost opportunities for plant-pollinator interactions are affected by fragmentation it was necessary to create a broad scale classification of land cover types. Image analysis of Landsat 8 imagery was completed using Exelis ENVI 5.1 (ENVI 2013). Imagery from April 25, 2013, June 28, 2013, and July 14, 2013 was downloaded from the Earth Explorer website. Each image file was calibrated to radiance and reflectance using Radiometric Calibration and FLAASH Atmospheric Correction tools. A mosaic of the image files was created by the date of acquisition which resulted in three image mosaics. The three image mosaics were then fused into a single image file. This resulted in a single image file with a total of 21 bands representing different dates over the growing season in 2013. Although the Landsat 8 images have a level 1 T-terrain correction, the fused image file was checked for alignment using National Agricultural Imagery Program (NAIP) (USDA 2013) with 0.5 meter spatial resolution. Based upon visual inspection of alignment it was determined that georectification was not needed for the Landsat Level 1 T-terrain corrected image files.

To reduce spatial variability for the image classification, the remnant patches polygon shapefile was used as a mask of the fused Landsat 8 image file. Two separate classifications were then carried out to delineate land cover types within the study region. One classification focused upon the agricultural matrix surrounding Palouse Prairie patches and the other focused upon the patches themselves.

In regard to the agricultural matrix, image classification training sites were based upon crop type present during the 2013 growing season. The agricultural types included: wheat (*Triticum aestivum*), lentil (*Lens culinaris*), garbanzo (*Cicer arietinum*), peas (*Pisum sativum*), and rapeseed (*Brassica napus*). The cover types of native or naturalized vegetation within the agricultural matrix included: perennial grassland, annual grassland, native grassland and conifer. Dominant species of the perennial grassland cover type included non-native grasses such as *P. pratensis, A. elatius, Bromus inermis,* and *Phleum pratensis.* The annual grassland cover type was visually dominated by *V. dubia*, *B. tectorum, B. hordeaceus*, *B. racemosus,* and *V. myuros.* In general, data on the presence of native grassland within the agricultural matrix were unavailable. Therefore, the native grassland cover type was identified as native if it appeared, to be predominantly native grasses, forbs, and shrubs, when viewed through binoculars (Nikon Monarch 10x40). Urban/bare ground cover type included asphalt, concrete, bare ground, gravel, shingles, and steel siding. The conifer cover type usually included closed canopy stands of *Pseudotsuga menziesii, Abies grandis*, *Picea engelmannii*, *Pinus contorta*, *Pinus ponderosa,* and *Picea pungens.*

For the Palouse Prairie patch image file, training sites with greater than 50% cover of *V. dubia*, *B. tectorum, B. hordeaceus*, *B. racemosus,* and *Vulpia myuros* were used for the annual grassland cover type. Training sites with greater than 50% cover of *Poa pratensis* and *Arrhenatherum elatius* were used for perennial grassland cover type. Training sites for shrub had greater than 50% cover of *Crataegus douglasii* Lindl. and *Physocarpus malvaceus.* Native grassland training sites had cover of *Pseudoroegneria spicata, Danthonia californica, Danthonia intermedia, Festuca idahoensis* greater than 30%. Training sites for biological soil crust cover type had greater than 50% cover of biological soil crusts. Training sites with greater than 60% forb cover were used for the forb cover type.

The agricultural matrix image file was classified into ten land cover types and the Palouse Prairie patch image file was classified into seven types. The Supervised Classification (Maximum Likelihood Classification) tool of Exelis ENVI 5.1 (ENVI 2013) was used to classify land cover types within both image files. The cover types for the agricultural matrix included: urban/bare ground, peas, lentil, garbanzo bean, grain, perennial grassland, native prairie, annual grassland, rapeseed, and conifer. The seven cover types classified in the patch image file included: shrub, annual grassland, conifer, native grassland, perennial grassland, forb, and biological soil crusts. Based upon a preliminary accuracy assessment and due to the spectral similarity between classes, the biological soil crust, forb, and native grassland cover types were all subsequently recoded as native grassland for the Palouse Prairie patch image file. The resultant image file for the patch classification included four classes (i.e., annual grassland, conifer, native grassland, and perennial grassland).

The final two raster files of the patch and agricultural matrix image files were then exported as a polygon using the Raster to Feature tool of ESRI ArcMap 10.1 (ESRI 2012). The merged patch polygon file was then used as a mask of the agricultural matrix file. The Palouse Prairie patch classification file was then merged with the masked Agricultural matrix file to create a single image file with two separate and distinct classifications. The polygon file was then converted into a raster file using the Feature to Raster tool and exported as Geotiff with a 30 m pixel size.

A thematic accuracy assessment was carried out for both classifications separately. As access in the study region is extremely limited, study plots not used in the classification process were used in the accuracy assessment. Ground control points (GCPs) were also used in the accuracy assessment. GCPs were obtained using a cluster sample spread throughout the study region. GCPs that were inaccessible from roadways with public lands were verified using Nikon 10x40 Monarch binoculars and Range Finder. A total of 257 GCPs were used on the accuracy assessment of the Palouse Prairie patch classification image file.

To determine landscape effects upon pollinator and native plant diversity, a 1 km distance surrounding each of the integrated study plots was extracted from the Palouse Prairie land cover classification. The 1 km distance was used because this is considered the estimated foraging distance for bee pollinators (Gathmann & Tscharntke, 2002; Zurbuchen *et al.,* 2010). Each of the subregions was then imported into Fragstats 4.2 (McGarigal *et al.,* 2012) for spatial pattern analysis. Using Fragstats 4.2 (McGarigal *et al.,* 2012), the total number of patches, patch contagion index, area-weighted mean patch size, Simpson's patch diversity index, and patch richness were calculated.

In addition to the land cover metrics calculated with Fragstats 4.2 (McGarigal *et al.,* 2012), the percent of useful pollinator habitat within 1.25 km of each trapping site was calculated using 2011 NAIP aerial imagery (USDA 2011). Useful pollinator habitat included prairie patches, naturalized vegetation around homes, fields or land enrolled in the Conservation Reserve Program left fallow long enough to regain some plant diversity, and streams that are typically dominated by both native and non-native perennial grasses, shrubs, forbs, and trees.

As pollinators forage for water at sources close to their nesting sites, the nearest distance from water was included as a variable for each trapping site. Nearest distance from water sources was calculated by measuring the distance in meters from either a perennial stream or existing ponds. Stream data was obtained from the U.S. Geological Survey in cooperation with Federal and state agencies, and Northwest Indian Tribes (Davis & Thiel 1990). Ponds were identified using the 2013 NAIP aerial imagery.

Data Analysis

The R software environment for statistical computing and graphics (R Core Team 2014) was used for data analysis. Response variables of the analysis included: the averaged value of Shannon's Diversity Indices by plant species cover measurements for all plots within 1 km of pollinator trapping sites (H); and rarefied richness for pollinators (RARE). Since the study sought to understand the relationship between the two diversity dependent variables (H and RARE), a multivariate multiple linear regression backward stepwise procedure regressed H and RARE against non-native grass cover, total number of patches, patch contagion index, patch area-weighted mean, Simpson's patch diversity index, patch richness, LN1250, and distance to water. In this analysis multivariate refers to the dependent variables and multiple pertains to the independent variables. The multivariate model was $Y = XB + \Xi$, where Y is n x p, X is n x $(q + 1)$ x p. The notation Ξ is the vector length of p x n.

The model assumes:

1. E(Y) = XB or $E(\Xi) = 0$
2. $cov(y_i) = \Sigma$ for all $i = 1,2,\ldots,n$, where y'_i is the ith row of Y.
3. $cov\left(y_i, y_j\right) = 0$ for all $i \neq j$.

The purpose of this stepwise selection of variables was to find the most important variables related to the biological diversity of both the plant and pollinator communities and to determine the mathematical form of these relationships. Specifically, the analysis was used to identify which variables are useful for predicting diversity and their relative importance. Linear regression was also used to assess if H was reliable in predicting RARE.

Principal component analysis (PCA) of the R package 'psych' (Revelle 2014) was used as a reduction technique to transform the larger number of correlated variables into a smaller set of uncorrelated variables. The variables included in this analysis included: RARE, H, patch area-weighted mean, patch richness, LN1250m, non-native grass cover, and distance to water. An eigenvalue criterion of one was used identify the number of components to retain. Fig. I.4 displays the scree plot with parallel analysis showing that two components are necessary for summarizing the dataset. The Promax rotation was used to make the loading matrix more interpretable, as the components generated by the initial unrotated solution were difficult to interpretable. PCA rotation is an important step as initial solutions are often arbitrary and uninterpretable linear combinations of the true latent variables (Dien 2010)

To understand the influence of annual grasses on native plant diversity, cover estimates of non-native annual grasses were pooled to create an annual grass cover variable for each plot. A total of 87 plots had annual grass cover values. Diversity of native plants was then calculated using Shannon's Diversity Index based upon cover estimates. Native plant diversity was treated as the response variable and annual grass cover was the independent variable. Linear and nonlinear (arcsin square root transformation) regression analysis was used to determine the relationship of nonnative annual grasses to native plant diversity. The *lm* function of R was used to evaluate the fit. The linear model without transformation of the data overall had a higher multiple R^2-value (0.076) compared with the non-linear model (0.068).

Results

A total of 264 species of vascular plants, lichens, bryophytes, and fungi were observed within a total of 104 plots across 26 remnant patches. Of these, cover values were recorded for 239 species of vascular plants, 12 lichens, 13 bryophytes, 1 fungus, 1 club moss and 1 liverwort species. Of the vascular plants a total of 68 species (28%) were non-native to the region. *Ventenata dubia, B. tectorum*, and *Lactuca serriola* were the three most frequently observed non-native plant species measured in the plots. The 20 most frequent non-native plant species are provided in Table I.2. The top three most frequent native species included: *Achillea millefolium*, *Symphoricarpos albus*, and *P. spicata* (Table I.3). The threatened species, *S. spaldingii* was observed in two plots at the Kramer Prairie remnant, Washington. The rare plant species *P. liatriformis* (2 plots), *C. brevifolium* (2 plots), and *A. arrectus* (5 plots) were also encountered within plant study plots.

At least 136 species of bees in 24 genera and 5 families were identified out of 6,742 individuals collected on the Palouse in 2012. Some of the most abundant species include the sweat bees *Agapostemon angelicus*, *A. virescens*, *Halictus tripartitus* and *Lasioglossum sisymbrii* comprising 4.2%, 5.8%, 8.4% and 5.7% of total collected individuals respectively. Other abundant species include the small carpenter bee *Ceratina nanula* (3%) and the mason bee *Osmia trevoris* (5.2%). Ten females of the rare *B. occidentalis* were recovered (0.014% of collected individuals) at 6 locations.

Overall, accuracy of the land cover classification of approximately 380,000 hectares of the Palouse Prairie was 0.64 with a Kappa of 0.59. The error matrix is provided in Table I.4. The producer's accuracy and user's accuracy assessment (Jensen 2005) and associated classification omission and commission errors are provided in Table I.5. The analysis had greater than 70% user's and producer's accuracy for the Urban/Bare Ground, Grain, and Conifer type. The analysis had less than 70% user's and producer's accuracy for the Perennial Grass type. The other cover types had either a high or low user's and producer's accuracy. For example, the Native type had a producer's accuracy of 44 percent and user's accuracy of 91%. The Annual Grass type had 79 percent producer's accuracy and 45% user's accuracy. The number of hectares of land cover types within the study region and percent by land cover type is provided in Table I.6. Fig. I.5 provides an example of the classification for the Steptoe Butte region of the Palouse Prairie in Washington State.

Based upon the multivariate multiple linear regression backward stepwise procedure significant variables identified for both H and RARE at the 0.05 alpha level included: non-native grass cover, patch area-weighted mean, patch richness, LN1250m, and distance to water (Table I.7). Table I.8 lists the values of the significant variables identified in the stepwise procedure. Using *lm* function of R, the linear model of H to predict RARE was found to be significant (p-value 0.002, $R^2 = 0.297$).

The standardized loadings based upon the correlation matrix that resulted from the principal component analysis are provided in Table I.9. The first component accounts for .40% of the variance in the variables and the second component accounts for 27% of the variance. Combined the two components account for 67% of the variance total. The biplot of principal components 1 and 2 (Fig. I.6). The bioplot was used to visually appraise the structure of the data matrix. It shows inter-unit distances and indicates clustering of units as well as displaying both variances and correlations of variables (Gabriel, 1971). The biplot shows non-native grass cover and area-weighted mean patch size being negatively correlated with H and RARE. Patch richness, LN1250, and distance to water were positively correlated with both H and RARE.

In regard to the separate analysis of assessing the relationship with native plant diversity and non-native annual grass cover, the results of the linear fit modeling the Shannon Diversity Index of native plants (H.native) by non-native annual grass cover (AnnGrs) is provided in Table I.10. Annual grass cover was found to be significant at predicting Shannon Diversity Index of native plants. However, the model only had a multiple R^2 value of 0.07591.

Discussion

Despite significant habitat loss and fragmentation, substantial biodiversity of plant and pollinator species continues to persist on the Palouse Prairie grassland. This study examined factors associated with this diversity to identify potential strategies to promote its conservation. Without assessments of this biodiversity, we may miss management opportunities among ecosystem processes and increase the risk of incurring unnecessary ecological trade-offs (Bennett *et al.,* 2009). Non-native grass cover, area-weighted mean patch size, patch richness, LN1250, and distance to water were associated with pollinator and plant diversity. Under the assumption that these relationships are causal, the findings indicate that actions that prevent or reduce the cover of non-native grass and increase the size and diversity of patches would likely have positive effects upon pollinator and plant. The study also provides indication that biodiversity may benefit through payment for ecosystem services programs, such as the Conservation Reserve Program (CRP) of the United States Department of Agriculture. Area increases of lands enrolled in the CRP and naturalized vegetation along roads, field margins, and residential areas was positively correlated with native plant ($\rho_{X,Y} = 0.60$) and pollinator diversity $\rho_{X,Y} = 0.57$).

There was a weak positive correlation ($\rho_{X,Y} = 0.17$) between distance to water and pollinator diversity and plant diversity ($\rho_{X,Y} = 0.44$). This finding is likely attributed to plot location usually being located on hilltops and ridges at relatively large distances from streams and drainages. Furthermore, some of the larger and more diverse patches sampled were actually located on the top of some of the highest hills and ridges on the region (e.g., Steptoe and Butte, Washington and Paradise Ridge, Idaho).

Conclusions

The spread of annual exotic grasses and tall oatgrass is likely to continue in the region and, based on the correlations we observed, this could contribute to decreases in plant diversity on the Palouse Prairie. As an example, the understory of a *Physocarpus malvaceus* site on Kamiak Butte is dominated almost exclusively by *A. elatius*. Although the existing *P. malvaceus* shrub is taller than the *A. elatius,* approximately half of the community is dominated by *A. elatius* and the other half is dominated almost exclusively by *P.malvaceus.* Seven other alien species present, which include *Ventenata dubia,* comprise another 10 percent of the community. Therefore, it is hard to imagine this community type changing a great deal without some major intervention. Furthermore, two drier and warm plots a short distance away on Kamiak butte, were found to have very high cover values for *A. elatius, V. dubia, B. hordeaceus,* and *Centaurea solstitialis.* Each of these species are highly invasive (Wilson & Clark, 2001; Humphrey & Schupp, 2001, Nyamai *et al.,* 2011; Mciver *et al.,* 2009) and represent a severe impediment to restoring the native plant community.

Herbicide application to reduce invading plant species must be considered carefully because of the potential adverse effects on wildlife (Freemark & Boutin 1995, Herbert *et al.,* 2014) and potential negative externalities to society though pesticide pollution (Radosevich *et al.,* 2007). Control of invasive plants has to also consider subsequent effects upon pollinators. *Centaurea solstitialis* is known to be an attractive source of pollen and nectar resource to native bees and integrates well into the ecosystem (Mciver *et al.,* 2009). Nonetheless, prevention of the spread of new invaders is important, and factors that facilitated past invasions need to be considered when designing policies to prevent spread of new invaders. If social, cultural and economic gains to landowners are sufficient to compensate for either the externalities or the financial costs associated with application, then it may be beneficial to implement pesticide treatments through an integrated weed management program (Sharma & Singh, 2014). Optimally, the program should consider effects upon plant-pollinator interactions, and if possible integrate biological, cultural, mechanical and chemical treatment methods that improve or at least do not harm to these interactions (Kearns *et al.,* 1998). Conserving species richness should also be viewed as tool in the integrated weed management program to increase invasion resistance (Qakley & Knox, 2013). Assuming diversity is more resistant to invasion; integrated weed management would likely have the largest impact on maintaining native biodiversity and slowing biological invasion most effectively on the patches identified in Table I.11, which were the most diverse.

This study detected a negative correlation ($\rho_{X,Y} = -0.11$) among the variables non-native grass and pollinator richness. This negative correlation suggests that invasion of non-native grasses reduces pollinator diversity on the Palouse Prairie. Bartomeus *et al.,* (2008) reported pollinator community richness was similar in plots invaded and non-invaded plots, but did not consider the impacts of non-native invasive grasses. Although impacts of invasive entomophilous plants on native bees have been studied (Stout and Morales, 2009; Bartomeus et al., 2008; Molina-Montenegro *et al.,* 2008; Larson *et al.,* 2006), we were unable to find a single published article that assessed the impacts of non-native grass invasion on pollinators. There were also associations observed between bee species richness and the amount of natural land (LN1250m) and patch richness, and this finding supports other observations on the importance of habitat availability (Carvalheiro et al. 2010; Öckinger and Smith, 2007; Kim *et al.,* 2006) and plant richness (Ebeling *et al.,* 2008).

Efforts by the landowners, institutions, and government agencies should consider practices and policies that contribute to increasing native plant diversity, increase patch heterogeneity and habitat. Improving and establishing more diverse cover types around homes, along roads, and field margins would likely have positive effects upon plant and pollinator diversity.

Social support for restoration actions could be increased by using native plant materials known to be of ethnosignificance or supply aesthetic values to the local community. These plant species can provide both ecological function and supply cultural benefits to the community. For example, the use of *Cammasia quamash*, a plant of high ethnosignificance to Native Americans in the region, would likely have high support in the region due to heritage values this plant supplies to local community. Biologically diverse areas of the Palouse Prairie may also be important to local communities for other reasons than just natural diversity (Donovan et al., 2009).

Although this study focused upon two widely used indicators of regional biodiversity (plant and pollinator), other metrics including the biodiversity of mammals, birds, and soil organisms should also be assessed to understand linkages between biodiversity and ecosystem services on the Palouse Prairie. Conversion to agriculture has greatly diminished the grassland ecosystem in the Palouse, potentially contributing to its vulnerability to invasion by non-native plants. Although several parks are present within the core area of the Palouse Prairie, there is currently no grassland preserve that exists and no formal protection is afforded to the rare prairie species that thrive on private lands. Establishment and proper management of natural areas, habitat or niches would help ensure critical elements for habitat or ecosystem services that cannot be provided in areas under production. Optimally, these areas should also be managed to benefit the local community through economic sustainability and cultural services (e.g., interpretation, educational, aesthetic) values. However, any conservation effort will need to recognize that rural communities are key stewards of biodiversity and ecosystem services.

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Biosketch

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Table I.1: Number of plots by aspect and elevation category for plant species cover estimates.

		Aspect				
		NE	NW	SE	SW	Row Sum
Elevation	$\leq 850m$	15	12	4	8	39
	$> 850\ m \leq 950\ m$	8	8	9	12	37
	> 950	3	5	9	11	28
	Column Sum	26	25	22	31	104

Table I.2: Frequency of non-native (exotic) plant species observed within 104 plots in the Palouse Prairie of northern Idaho and southeastern Washington. Non-native grass species indicated by (*).

Scientific Name	**Frequency**
**Ventenata dubia*	78
**Bromus tectorum*	61
Lactuca serriola	40
**Bromus hordeaceus* ssp. *hordeaceus* (*Bromus mollis*)	35
**Bromus racemosus* (*Bromus commutatus*)	34
**Poa pratensis*	28
Valerianella locusta	26
Tragopogon dubius	24
Myosotis arvensis	23
Draba verna	22
**Vulpia myuros*	19
**Arrhenatherum elatius*	18
Vicia villosa	17
**Bromus sterilis*	16
**Poa bulbosa*	15
Anthriscus caucalis	13
Hypericum perforatum	13
Cirsium arvense	10

Scientific Name	Frequency
**Bromus arvensis* (*Bromus japonicus*)	10
Rumex acetosella	9

Table I.3: Frequency of native plant species and biological soil crusts (i.e., bryophyte and lichen) observed within 104 plots in the Palouse Prairie of northern Idaho and southeastern Washington.

Scientific Name	Frequency
Achillea millefolium	64
Symphoricarpos albus	61
Pseudoroegneria spicata	55
Epilobium brachycarpum	54
Galium aparine	49
Lomatium dissectum	45
Festuca idahoensis	43
Microsteris gracilis	43
Balsamorhiza sagittata	37
Brachythecium albicans	36
Madia gracilis	30
Potentilla gracilis	29
Lupinus sericeus	28
Claytonia perfoliata ssp. *perfoliata*	27

Scientific Name	**Frequency**
Cladonia pocillum	27
Geranium viscosissimum	26
Syntrichia ruralis	25
Poa secunda	24
Geum triflorum	24
Hieracium scouleri var. *albertinum*	22

Table I.4: Error matrix of the classification map derived from Landsat 8 data fusion of the core area of Palouse Prairie region in Northern Idaho and Southeastern Washington. Type corresponds to actual cover types and class corresponds to land cover classifications.

		TYPE										
		Annual Grass	Conifer	Garbanzo	Grain	Lentil	Peas	Perennial Grass	Rapeseed	Native	Urban/ Bare Ground	Row Total
CLASS	Annual Grass	26	3	0	0	0	0	6	0	23	0	58
	Conifer	0	23	0	0	0	0	1	0	1	0	25
	Garbanzo	0	0	5	0	1	0	1	3	1	0	11
	Grain	2	1	1	11	2	0	3	6	3	1	30
	Lentil	0	0	0	0	4	0	0	1	0	0	5
	Peas	0	0	0	0	0	2	0	0	0	0	2
	Perennial Grass	3	2	1	0	1	1	25	3	13	1	50
	Rapeseed	0	0	0	0	0	0	0	15	0	0	15
	Native	2	0	0	0	0	0	1	0	32	0	35
	Urban/ Bare Ground	0	1	0	0	0	0	2	0	0	23	26
	Column Total	33	30	7	11	8	3	39	28	73	25	257

Table I.5: Producer's accuracy and user's accuracy assessment and associated omission and commission errors of the classification map of the Palouse Prairie derived from three Landsat 8 imagery scenes.

	Producer's Accuracy	**Omission Error**	**User's Accuracy**	**Commission Error**
Annual Grass	0.79	0.21	0.45	0.55
Conifer	0.77	0.23	0.92	0.08
Garbanzo	0.71	0.28	0.45	0.54
Grain	1	0	0.37	0.63
Lentil	0.5	0.5	0.8	0.2
Peas	0.67	0.33	1	0
Perennial Grass	0.64	0.36	0.5	0.5
Rapeseed	0.53	0.46	1	0
Native	0.44	0.56	0.91	0.08
Urban/ Bare Ground	0.92	0.08	0.88	0.11

Table I.6: Estimated hectares and percent of land cover types derived from Landsat 8 data fusion. Estimates represent the entire study region of the Palouse Prairie.

Cover Type	Hectare	Percent
Annual Grassland	18,677.79	4.9
Conifer	27,227.61	7.2
Garbanzo	35,502.57	9.3
Grain	194,910.2	51.3
Lentil	12,786.39	3.4
Native Grassland	6,362.82	1.7
Peas	7,294.77	1.9
Perennial Grassland	54,730.8	14.4
Rapeseed	965.7	0.3
Urban/Bare Ground	21,477.15	5.6
TOTAL	**379,935.8**	**100**

Table I.7: Partial Λ-values results of the multivariate multiple linear regression backward elimination of variables. Variables at step four are all retained because each Λ has a value less than the lower critical values of Wilks' Λ (0.849), α = 0.05.

Step	Non-native grass Invasion (NNGRS)	Total Number of Patches (NP)	Contagion (CONTAG)	Patch Area-Weighted Mean (AREAM)	Patch Simpson's Diversity Index (SIDI)	Patch Richness (PR)	Useful Pollinator Habitat (LN1250)	Distance to Water (WATER)
1	0.691	0.917	0.931	0.816	0.985	0.907	0.816	0.679
2	0.676	0.905	0.878	0.726		0.855	0.794	0.669
3	0.538		0.828	0.660		0.778	0.692	0.638
4	0.533			0.634		0.648	0.592	0.530

Table I.8: Dataset of variables found to be significant for predicting plant (H) and pollinator diversity (RARE) using a multiple multivariate backward stepwise procedure by trapping site (SITE). Significant variables identified include: estimated non-native grass cover within 1km of trapping sites (NNGRS), area-weighted mean patch size (AREAAM), patch richness (PR), percent of useful pollinator habitat within 1.25 km (LN1250), and distance (m) to nearest source of water (WATER).

SITE	H	RARE	NNGRS	AREAAM	PR	LN1250	WATER
239	0.9653	14.16375	69.271	243.6497	7	11.8392	2179
566	2.1012	27.48489	41.23118	42.1519	8	14.4654	434
238	1.534	17.0076	8.021	122.0871	7	12.1101	712
1211a	1.70865	25.45068	58.19013	39.7123	9	14.2617	1527
1211	1.68337	24.88552	50.3438	60.281	7	14.4127	1345
492	2.0569	32.14604	43.438	56.7379	9	14.4972	684
848	1.498	30.43883	64.583	115.4714	8	13.2292	693
828	2.0208	30.69641	60.938	84.0805	10	13.8804	158
933	2.08295	29.15405	60.9375	120.1985	7	12.9631	1535
942	2.3188	26.25686	36.875	82.4597	7	12.0897	2457
199	2.328425	34.09259	13.94525	149.8157	9	14.2279	1305
1516	2.1304	33.39904	26.6874	53.2208	7	14.7181	450
801	2.127167	24.68847	21.875	112.5779	7	13.397	1201
529a	2.5545	35.77495	13.724	41.6684	9	13.9903	799
529b	2.283375	26.25612	32.57825	36.967	7	13.9801	1332
543	0.8651	24.47257	85.417	114.9755	7	12.5263	471

SITE	H	RARE	NNGRS	AREAAM	PR	LN1250	WATER
303	0.9432	30	79.167	252.1453	8	12.6317	302
987	1.919367	22.09273	54.96533	47.3022	9	13.9663	209
988	1.72005	30.86734	45.78125	42.4523	9	14.1159	35
1100	1.962875	29.03592	26.302	68.968	9	13.731	94
1091	2.436657	40.49718	34.76171	97.9084	10	14.522	1072
1571b	2.244664	25.51412	42.08336	43.4885	8	14.7275	1759
1571a	2.23797	33.67768	41.2395	48.1593	8	14.672	1082
1571	2.42148	30.14721	37.6252	63.473	7	13.959	2950
114	1.3745	22.69372	53.125	126.4956	8	12.936	127
734	2.20648	22.41041	42.5628	68.5847	7	13.9521	239
979	1.9718	29.75393	56.771	128.5849	8	12.8596	2030
929	1.6873	20.67558	2.292	18.2245	7	13.3641	542
196	1.6728	23.05853	51.042	57.731	9	12.333	227

Table I.9: Standardized loadings based upon the correlation matrix that resulted from principal component analysis. Standardized loadings based upon the correlation matrix that resulted from principal component analysis. Principal component 1 and principal component 2 contain component loadings, which are the correlations of the observed variables with the principal components. Component communalities identify the amount of variance in each variable that is explained by the component. The uniqueness of the component represents the amount of variance not accounted for by the component.

	PC1	**PC2**	**Communalities**	**Uniquenesses**
H	0.81	0.22	0.80	0.20
RARE	0.24	0.74	0.69	0.31
NNGRS	-0.71	0.15	0.47	0.53
AREAAM	-0.74	0.09	0.58	0.42
PR	-0.19	0.95	0.84	0.16
LN1250	0.62	0.45	0.73	0.27
WATER	0.74	-0.37	0.55	0.45

Table I.10: Output results of the linear regression analysis modeling the Shannon diversity index of native plants by non-native annual grass invasion for 104 plots. Results had a residual standard error of 0.5907 on 85 degrees of freedom with a multiple $R^2$of 0.07591.

	Coefficient Estimate	**Standard Error**	**t-value**	**p-value**
Intercept	2.013649	0.097381	20.678	2e-16
Non-native Annual Grass Cover	-0.007140	0.002702	-2.642	0.0098

Table I.11: Remnant patches and pollinator trapping sites with highest native plant and pollinator diversity.

Patch Number	Tapping Site	H	RARE
	529a	2.55	35.77
	529b	2.28	26.26
1516	1516	2.13	33.4
1571	1571	2.42	30.15
	1571a	2.23	33.68
	1571b	2.24	25.51
566	566	2.10	27.48
492	492	2.06	32.15
1091	1091	2.44	40.5
1100	1100	1.96	29.03
199	199	2.33	34.09

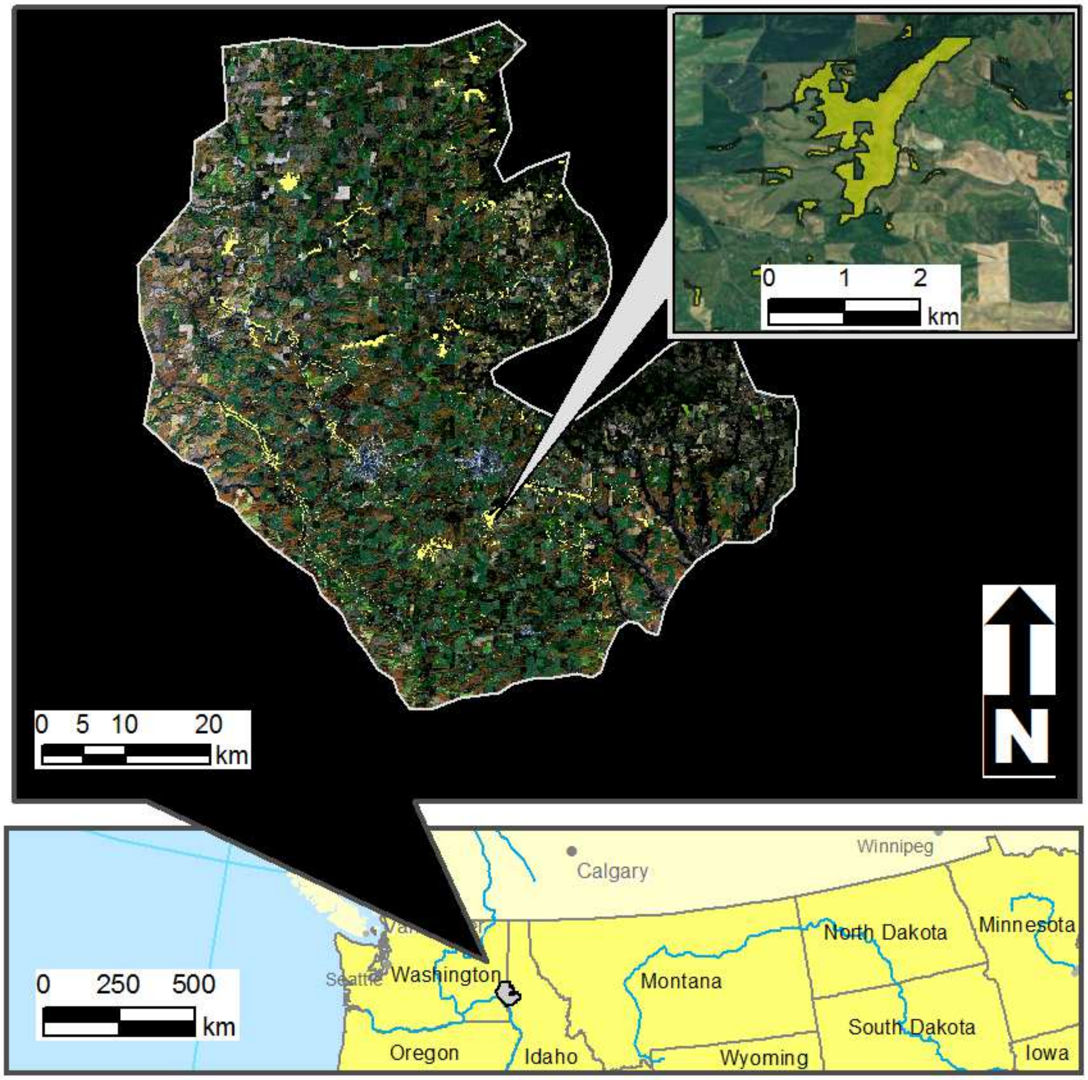

Fig. I.1: Overview of the core area of the Palouse Prairie grassland in northern Idaho and southeastern Washington at varying scales. Bottom scale shows the location of the region at the continental scale. Center map at 1:800,000 scale shows agricultural matrix and patches of Palouse Prairie. Upper right map at 1:100,000 scale shows the Paradise Ridge remnant, one of the largest remnants within the study area.

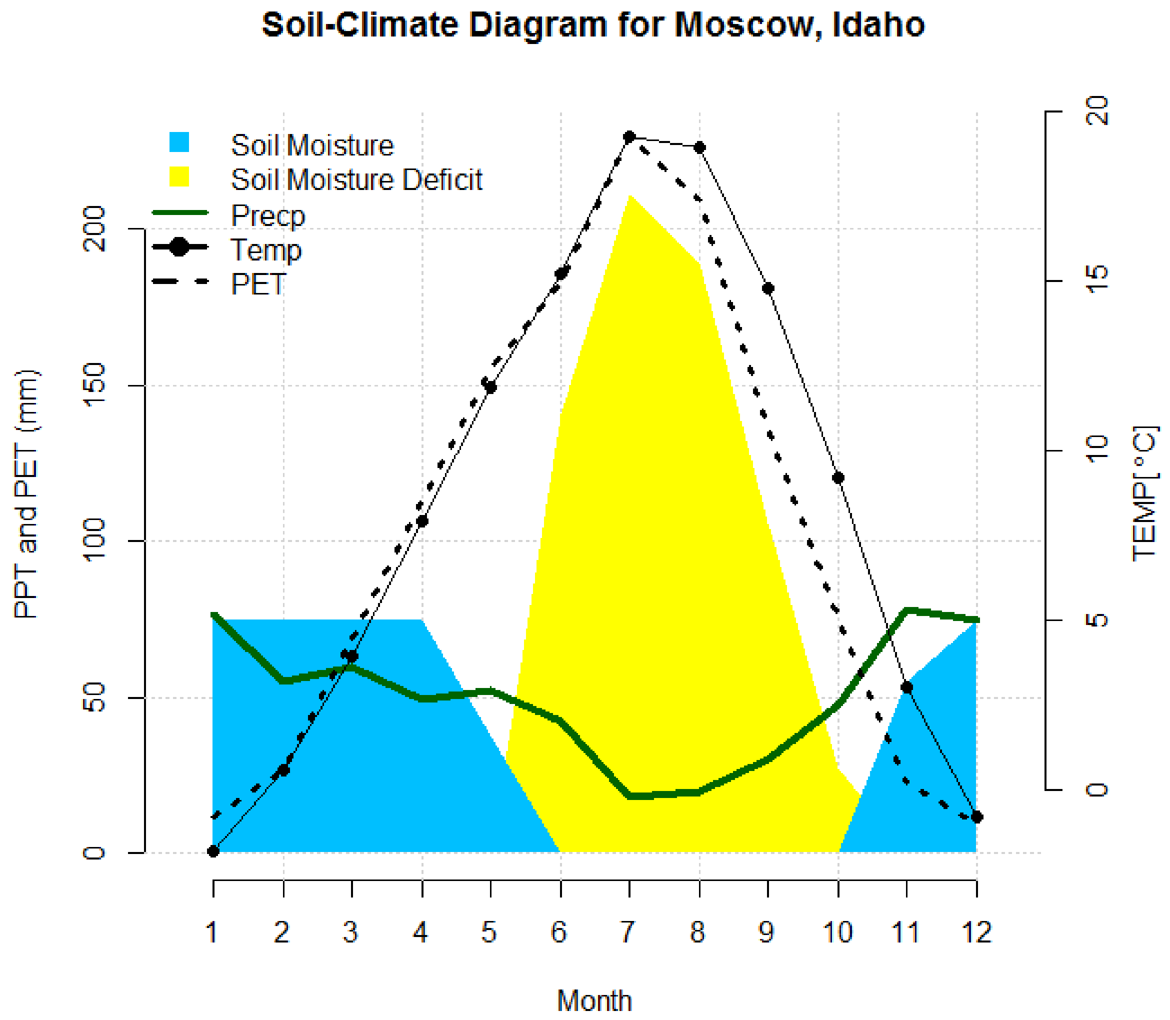

Fig. I.2: Diagram of generalized soil and climate conditions in the Palouse Prairie near Moscow, Idaho. The region is characterized as having a xeric soil moisture regime with warm, dry summers and cool, moist winters. Average air temperature (TEMP) and precipitation (Precp) were based upon 120 years of climate records (Western Regional Climate Center 2013). Potential evapotranspiration (PET) data were obtained using the mean alfalfa reference evapotranspiration data (University of Idaho 2012).

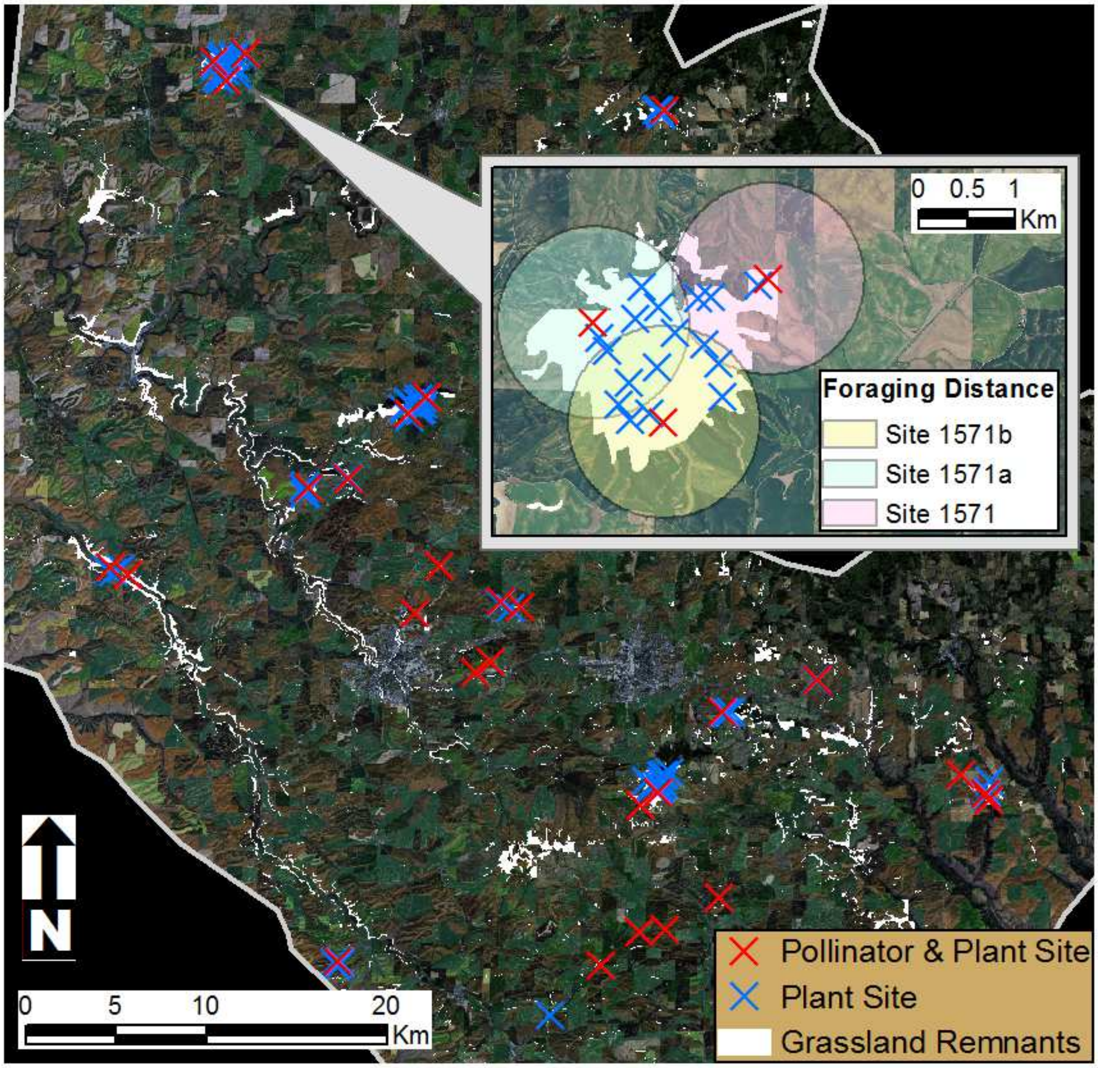

Fig. I.3: Map depicting pollinator/plant (red) and plant composition (blue) study site locations within agricultural matrix of the Palouse Prairie core area. Inset map (scale 1:100,000) depicts assumed 1 km pollinator foraging distance surrounding the integrated study site at Steptoe Butte, Washington.

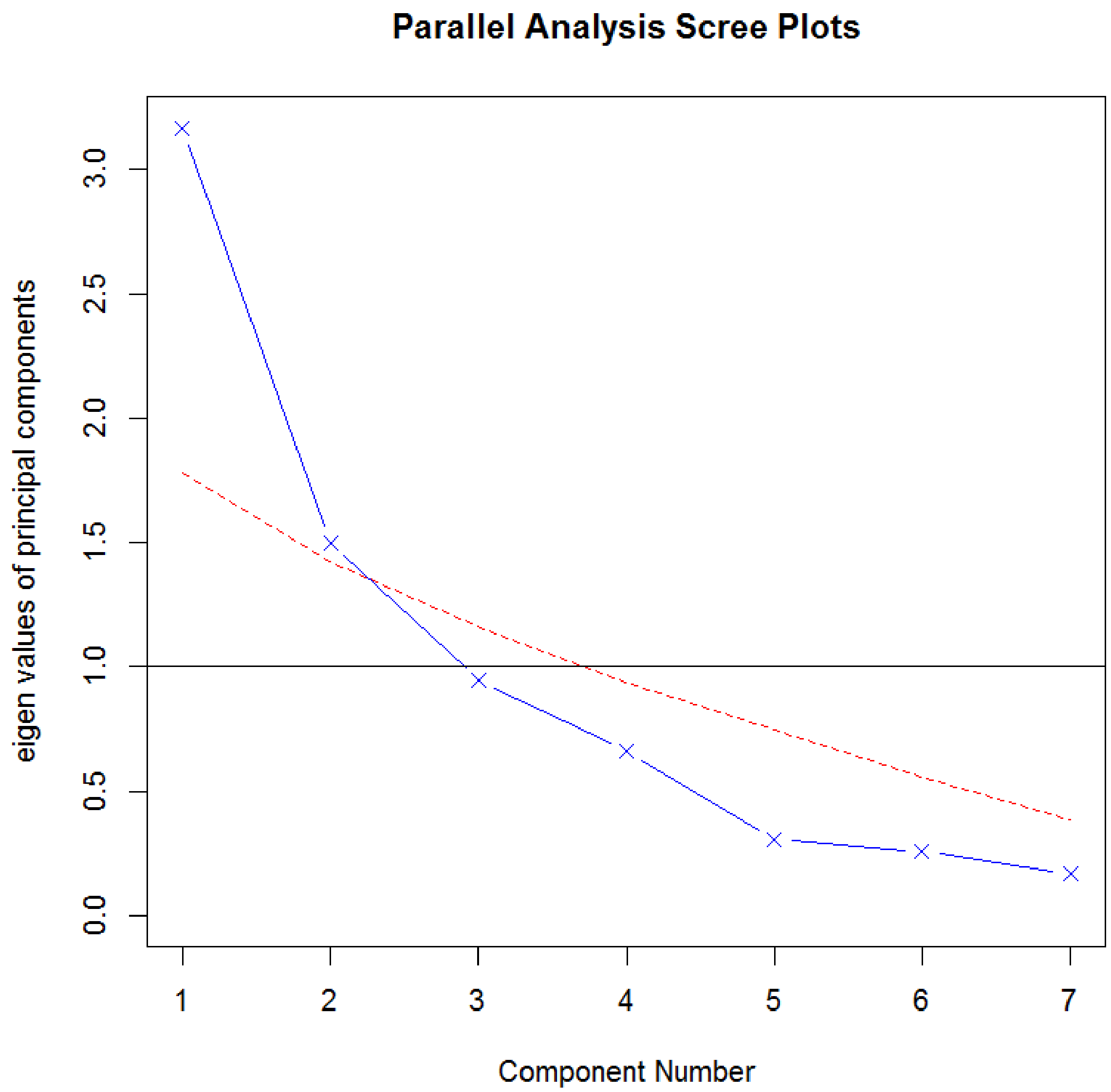

Fig. I.4: Assessment of the number of principal components (PC) to retain for the native plant and pollinator biodiversity on the Palouse Prairie. The parallel analysis suggests that the number of components to retain is 2 (eigenvalue criteria of 1). Blue cross line represents the PC of the actual data. The red hash line represents the PC of the resampled data.

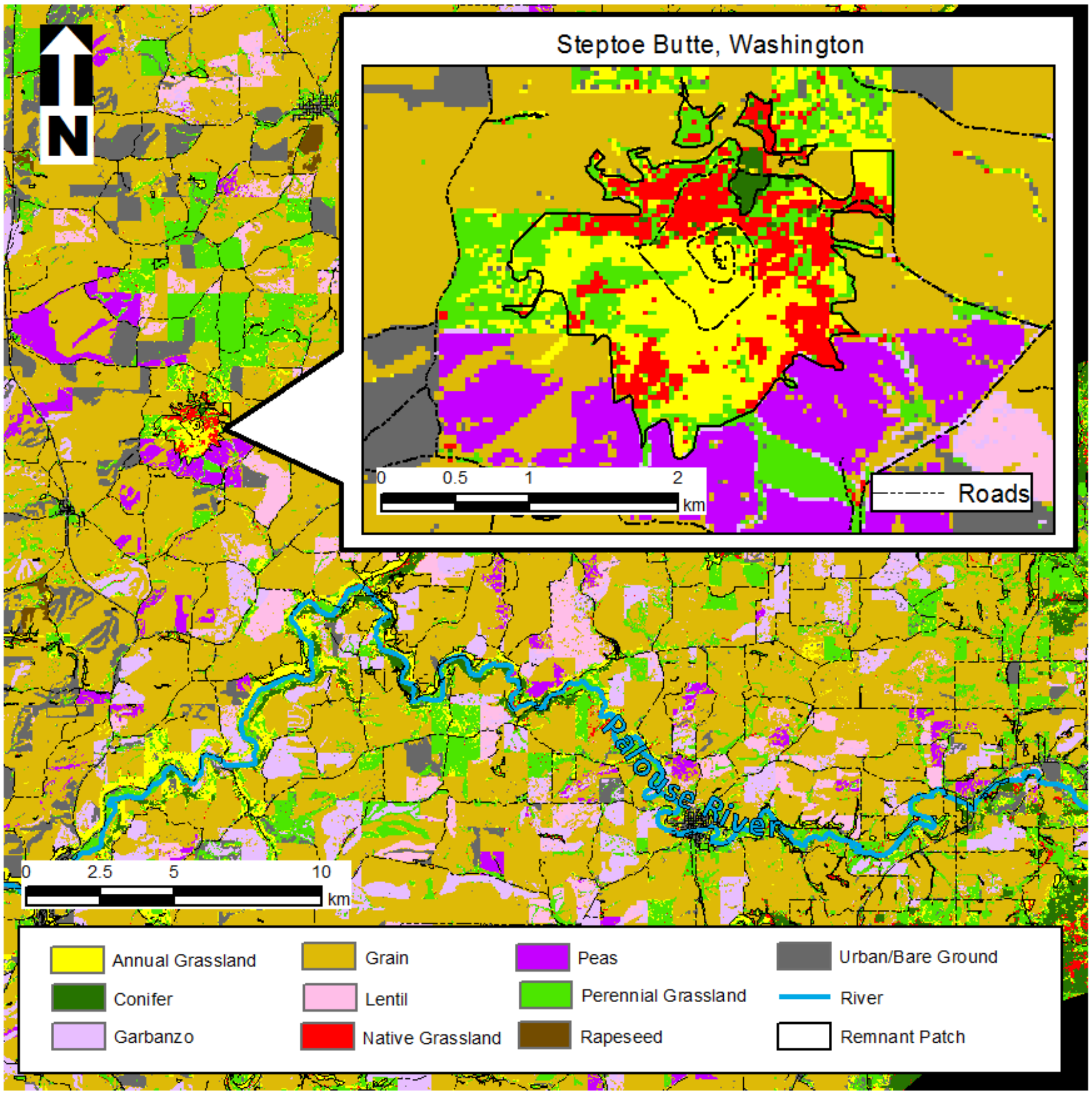

Fig. I.5: Land cover classification of the Palouse Prairie region near Steptoe Butte, Washington. Classification was based upon three fused Landsat 8 images acquired 25 April 2013, 28 June 2013, and 14 July 2013.

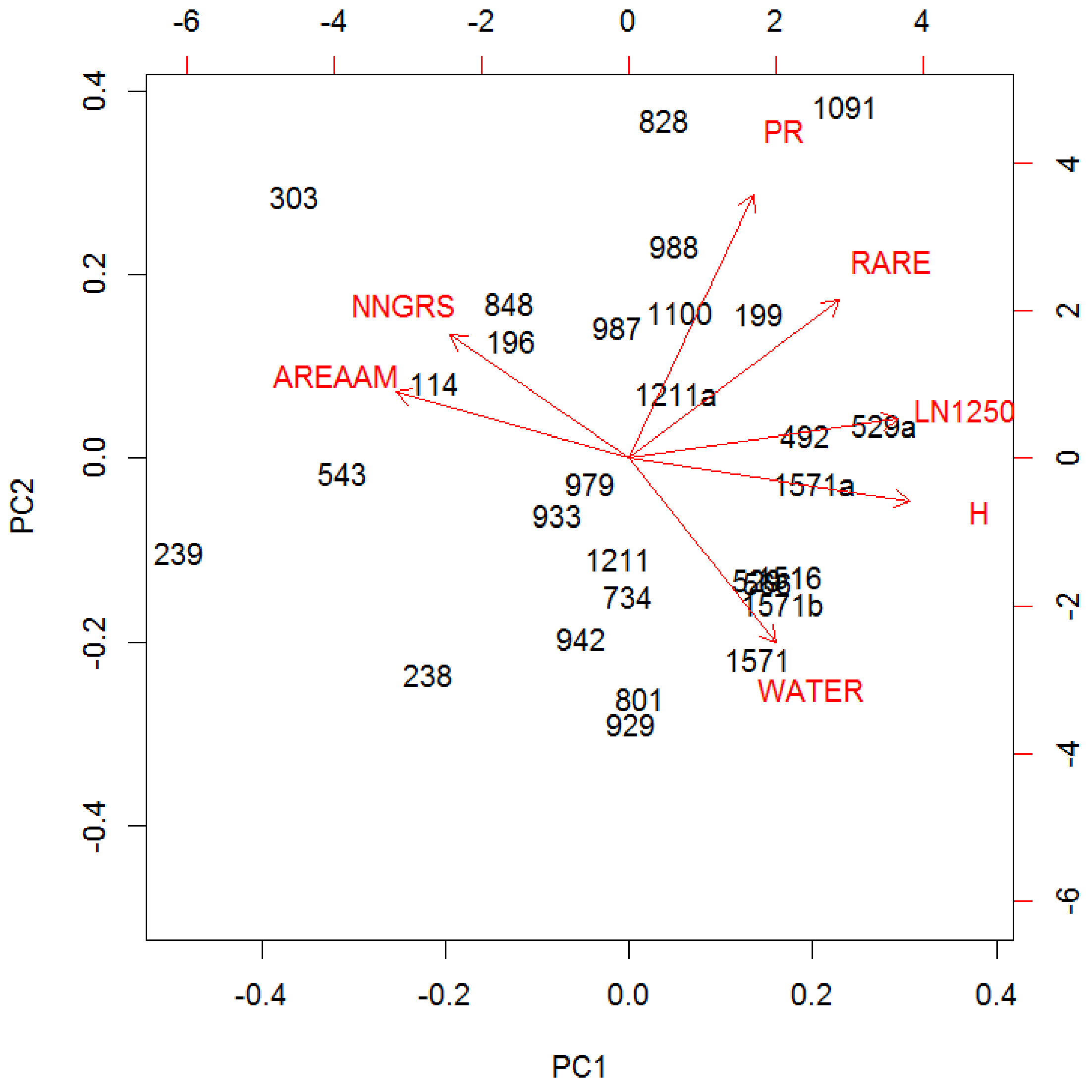

Fig. I.6: Biplot of Principal Components 1 and 2. Numbers represent assigned site numbers, 29 total.

Chapter II: Biological Soil Crusts in Relation to Soil Depth, Aspect, Slope, Non-native Grass Invasion, and Native Plant Diversity on the Palouse Prairie Grassland[2]

Cleve Davis, Roger Rosentreter, Timothy S. Prather

Abstract

We studied biological soil crust (BSC) communities and non-native grass invasion on the Palouse Prairie landscape of the Columbia Basin, and assessed the relationships between BSC and non-native grass cover to native plant diversity, elevation, aspect, soil depth, and slope. In 104 plots spread across a variety of topographies with varying soil depths, we found 27 BSC species and 20 non-native grass species. Using regression we found soil depth to be inversely related to BSC cover, and native plant diversity to be positively related to BSC cover. We attributed the findings to shallower soils having lower available water holding capacity and higher temperatures than deeper soils. We also found nonnative grass cover to be inversely related to native plant diversity. We attributed this finding to biotic resistance of native Palouse Prairie grassland.

Keywords

Biological Soil Crusts, Soil Depth, Invasive Grasses, Non-native Grasses

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[2] To be submitted to the Journal of Arid Environments

Highlights

The findings of this study identified a significant inverse relationship between BSC percent cover and soil depth on the Palouse Prairie of northern Idaho and southeastern Washington. A significant positive relationship was also identified between BSC percent cover and native plant diversity. We also detected no significant relationship between BSC cover and non-native grass invasion on the Palouse Prairie. However, outliers and many plots with zero percent cover of BSC contributed to a violation of normality assumptions. In a second model, native plant diversity was found to be significantly inversely related to non-native grass invasion. Based upon residual plots, normality assumptions for the relationship between native plant diversity and non-native grass invasion appeared to hold. This finding supports the diversity-resistance hypothesis

Introduction

Biological soil crusts (BSC) are intertwined assemblages of lichens, bryophytes, fungi, cyanobacteria, bacteria, green algae, and soil particles (Belnap et al., 2001). They can often be found on the surface of undisturbed soils in arid and semiarid habitats (Hernandez and Sandquist, 2001; Serpe et al., 2006), and can be particularly abundant in winter-cold regions of the world (Belnap et al., 2001). In western North America, they can be major components of desert regions between the Rocky Mountains and Sierra Nevada (Rosentreter and Belnap, 2001). At the community scale, BSC cover and composition is highly influenced by landscape position, vegetation, and microsite characteristics (Dettweiler-Robinson et al., 2013; Ponzetti et al., 2007). BSC are ecologically recognized for providing an important service in the conservation of soil from wind and water erosion (Belnap, 2003), and can contribute to increasing the availability of nitrogen and other minerals for vascular plants (Ponzetti et al., 2007;Castillo-Monroy et al., 2010). BSC are also known to be sensitive to physical disturbances, fragmentation, trampling, fire, alterations of plant communities, and recreational disturbances (Ponzetti et al., 2007; Tabeni et al., 2014).

Certain crust species have been attributed to preventing some forms of annual non-native grass invasion (Hernandez and Sandquist, 2011). This observation can be considered a form of biotic resistance, which is the ability of a resident community to reduce or regulate the invasion of other species (Levine et al., 2004; Byun et al., 2013). However, we found only one study that attributed biotic resistance of invasive plants to BSC (Hernandez and Sandquist, 2011) and currently no research exists that assesses the relationship of BSC to soil depth.

Therefore, we sought to identify the relationships of topographical features, native plant diversity, and soil depth with non-native grass and BSC cover. To examine the effects of invasion and diversity resistance we looked at the relationship between native plant diversity and non-native grass cover (NNGS) and BSC cover. As physical attributes are also known to influence species composition (Belnap et al., 2001; Hanson et al., 2008; Ponzetti et al., 2007; Root et al., 2011), we also sought to identify the relationship of how topographical elements and site characteristics related to NNGRS and BSC cover. Our hypothesis was that these factors were significant at predicting BSC and NNGRS cover.

The focus of this study was on Palouse Prairie grassland which is located within the heart of the Columbia Basin of the Pacific Northwest in the United States (46°84'N, 117°09'W; Fig.II.1). Although descriptions of the geographic extent of the Palouse Prairie grassland vary, our definition of the region is similar with the core area in northern Idaho and southeastern Washington described by Caldwell (1961). The study region is characterized by rolling basalt plateaus and foothills with a semi-arid climate. The Palouse loess deposits are unique in that they are considered the deepest and most continuous loess deposits in northwestern United States (Busacca 1989). The soils of this region can be up to 75m deep (Busacca 1989). In regard to climate of this region, evaporation exceeds precipitation during the months from June through September. The average annual precipitation is 600 mm (Western Regional Climate Center 2015). Approximately, 40% of the precipitation occurs from November-January (1893-2015). The average annual maximum temperature of the region is 14.5°C and average annual minimum temperature 2.5°C (Western Regional Climate Center 2015).

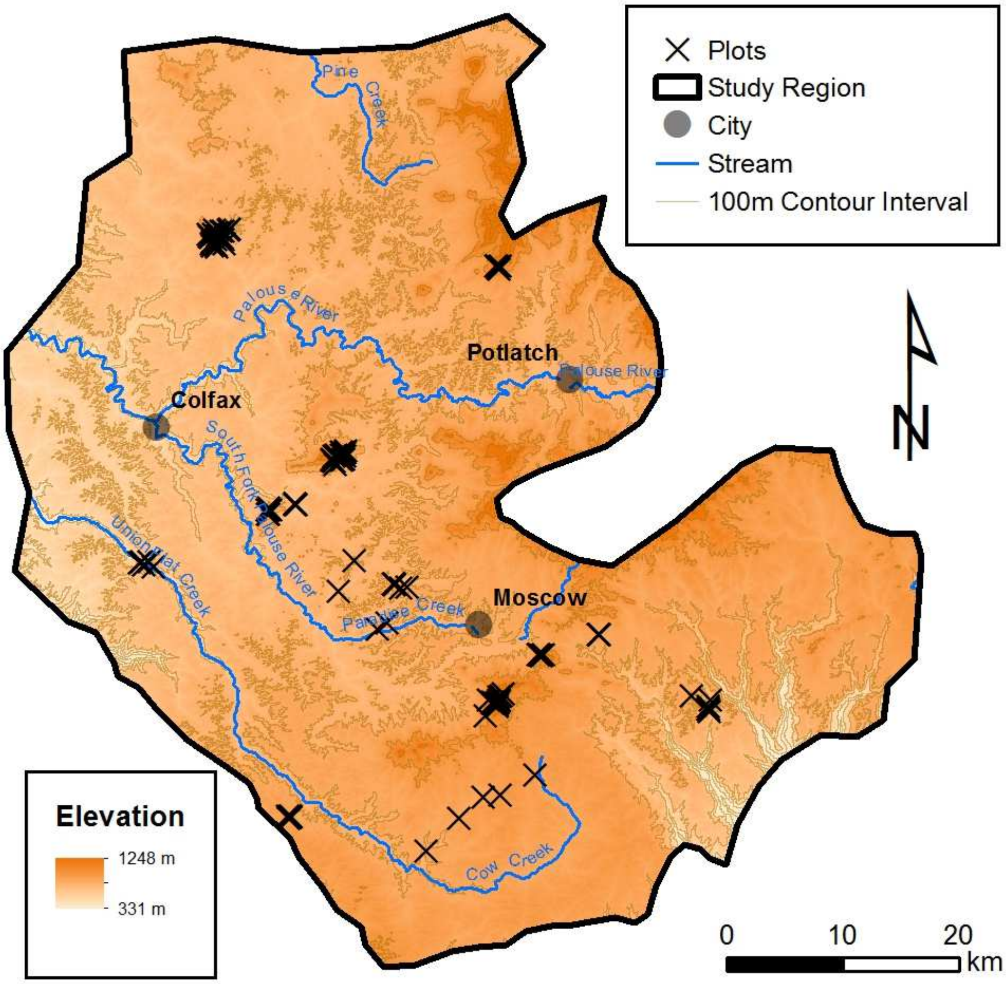


Fig. II.1: Palouse Prairie region in northern Idaho and southeastern Washington. Background shows topography and plot locations.

Historically, the Palouse Prairie grassland is believed to have been a mosaic of bunchgrasses and wildflower prairies interspersed with wetlands, thickets, and forest patches (Daubenmire, 1942). Dominant native bunchgrasses of the region include *Pseudoroegneria spicata* and *Festuca idahoensis*. As a result of profound agricultural conversion and non-native weed spread, the natural Palouse Prairie is believed to be only one tenth of one percent of its former extent (Noss and Peters, 1995). Today, seven rare plant species can be found within the region and these species include: *Silene spaldingii*, *Astragalus arrectus*, *Calochortus nitidus*, *Cirsium brevifolium*, *Pyrrocoma liatriformis*, *Trifolium plumosum* var. *amplifolium*, and *Aster* *jessicae*. *Silene spaldingii* is currently listed as threatened under the Endangered Species Act. There are no known rare BSC species known from the Palouse Prairie.

Currently, the most severe impact to remaining grassland patches of Palouse Prairie is the invasion of non-native plants, particularly non-native grasses (Goldberg et al., 2011; Hill et al., 2012). The most problematic of these species include five species of annual grasses: *Ventenata dubia*, *Bromus tectorum, B. hordeaceus, B. racemosus* and *Vulpia myuros;* and two perennials grasses, *Poa pratensis* and *Arrhenatherum elatius*. At least one of the grassland patches was used for livestock grazing historically. However, recent livestock or other agricultural uses of the study plots were not apparent during field sampling.

Materials and Methods

A Palouse Prairie patch was defined as land that did not appear to be modified to a large extent by physical disturbances (e.g., plowing). These patches typically supported both native and naturalized non-native plant species. Permission to sample on privately owned land was obtained prior to sampling since all but; Steptoe Butte and Kamiak Butte are privately owned. Plot data were collected from a total of 26 prairie patches in Latah County, Idaho and Whitman County, Washington. Vascular plant, lichen, bryophyte, liverwort, and fungi cover were measured following a canopy-coverage method (Daubenmire 1959).

Sample units were 0.50 by 0.25 m rectangular quadrats. Transect direction was obtained randomly using a random number generator. The long axis of the quadrat frame was oriented away from the transect line. Within in each quadrat, we recorded percent cover of species in classes on the following scale: 0, 1 = 0.01-5%, 2 = 5-12.5%, 3 = 12.5-25%, 4 = 25-50%, 5 = 50-75%, 6 = 75-100%. Only one observer was used to make cover estimates.

Cover estimates were made from May through July during 2012 and 2013 when a majority of plant species could be easily identified. Transect orientation of all plots were chosen randomly. Species were identified in the field or collected and identified by comparison with herbarium specimens. Initially, 29 sites were located randomly spaced at least 1 km apart. An additional 73 sites were established using a random design stratified by aspect and elevation, which were thought to influence community composition due to changes in soil moisture and irradiation. With the exception of one very small and diverse remnant, no two sampled sites were located within 60 meters of each other. Site selection was constrained by whether permission could be obtained to access a site and size of patches. Using these constraints, a total of 102 plots (i.e., 1,200 quadrat frames) were sampled within 26 grassland patches of varying size and shape. The largest patch was 299 ha and smallest was 0.25 ha. The mean patch size was 37.8 ha. Tabulations of the number of plots by aspect and elevation in relation to soil depth and slope are provided in Appendix 1. To the extent possible study sites were spread proportionally to strata area available (i.e., aspect and elevation).

For each plot, elevation, latitude and longitude were measured using a GPS unit. Topographic position (slope and aspect) was measured in degrees using clinometer and compass. North aspects are typically more moist and cooler than southern aspects on the Palouse Prairie. Therefore, aspect measurements were transformed with the cosine function to yields results in values close to 1 being northward and values close to -1 southward. Values of close to 0 are either east or west. Positive values represent eastward slopes and negative values represent westward slopes. A total of 12 cover measurements were collected per plot and averaged for BSC and species groups (e.g., non-native grasses), as well as individual species. Soil depth was estimated to the nearest cm using a 1.25m soil probe measured every three meters along the transect line. Thus, a total of four measurements were obtained to estimate the average soil depth per study plot.

The following variables were calculated after data collection using the R software environment for statistical computing and graphics (R Core Team 2014): total cover of BSC and non-native grass (NNGRS) species and Shannon's diversity index (H) for native flora within each plot. H was calculated based on species cover value estimates present. The H metric was chosen because it is more sensitive than other diversity indices to the presence of rarer species (Hill 1973). Total cover of BSC and NNGRS was estimated using the mean of mid-point values of cover class estimates.

Data Analysis

As topographical elements and site characteristics are known to influence BSC communities and biotic invasion (Belnap et al., 2001; Hanson et al., 2008; Ponzetti et al., 2007; Root et al., 2011), we hypothesized that H, topographical elements, and soil depth would be significant factors useful for predicting BSC and NNGS percent cover. Therefore, the first linear model aimed at identifying important factors that can predict BSC and the second model sought to identify important factors to predict NNGRS. Independent variables for the first model included: NNGRS, H, aspect, elevation, soil depth, and slope. The second model independent variables included: BSC, H, aspect, elevation, soil depth, and slope. The regression model utilized had the form

$$\widehat{Y_\iota} = \hat{\beta}_0 + \hat{\beta}_1 X_{1i} + \cdots + \hat{\beta}_k X_{ki} \; i = 1 \cdots n$$

where *n* is the number of observations and k is the number of predictor variables. The model assumes the dependent variable is normally distributed, Y_i values are independent of each other, and that the dependent variable is linearly related to the independent variables. When compared with non-transformed cover estimates, the arcsin square root transformation improved the model fit (adjusted R-square value). All cover value estimates were transformed using the arcsin square root transformation. The *plotmeans()* function of the *gplots* package was also used to show differences in categories of soil depth (i.e., 1 = less than or equal to 25 cm; 2 = greater than 25 and less than 100 cm; 3 = greater than 100 cm) and BSC cover.

Results and Discussion

Biological Soil Crust

A total of 27 BSC species were encountered within 61 of the 104 plots (Table II.1). Of these, 13 are bryophytes, 1 is a club moss, 1 is a fungus, 12 are lichens, and 1 is a liverwort. Three bryophytes could not be identified. We collected a total of 116 voucher specimens.

Table II.1: Biological soil crusts encountered during the study and life form type.

Scientific Name	**Life Form**
Brachythecium albicans	Bryophyte
Bryum argenteum	Bryophyte
Ceratodon purpureus	Bryophyte
Dicranum tauricum	Bryophyte
Funaria hygrometrica	Bryophyte

Scientific Name	**Life Form**
Grimmia Montana	Bryophyte
Homalothecium aeneum	Bryophyte
Homalothecium nevadense	Bryophyte
Orthotrichum speciosum	Bryophyte
Polytrichum piliferum	Bryophyte
Syntrichia ruralis	Bryophyte
Selaginella densa	Club moss
Camarophyllus pratensis	Fungus
Cladonia sp.	Lichen
Cladonia fimbriata	Lichen
Cladonia pocillum	Lichen
Cladonia verruculosa	Lichen
Collema sp.	Lichen
Diploschistes muscorum	Lichen
Lepraria sp.	Lichen
Lepraria cacuminum	Lichen
Leptogium lichenoides	Lichen
Peltigera didactyla	Lichen
Peltigera rufescens	Lichen
Polychidium muscicola	Lichen
Cephaloziella divaricata	Liverwort

The residual plots (Fig.II.2) for the first model reflect a difference in the standard deviations among the sites, and dispersion of the residuals varied considerably across the study plots. The normal Q-Q probability plot indicates a skewed and nonnormal distribution of observations. The values above the line in the upper right-hand corner of the figure are residuals with positive values larger than expected from standard normal distribution. The Residuals vs. Leverage plot identifies three data points that may have undue influence on the regression relationship. Each of these three data points had high BSC cover (18-61%) and high non-native grass cover (15-57%).

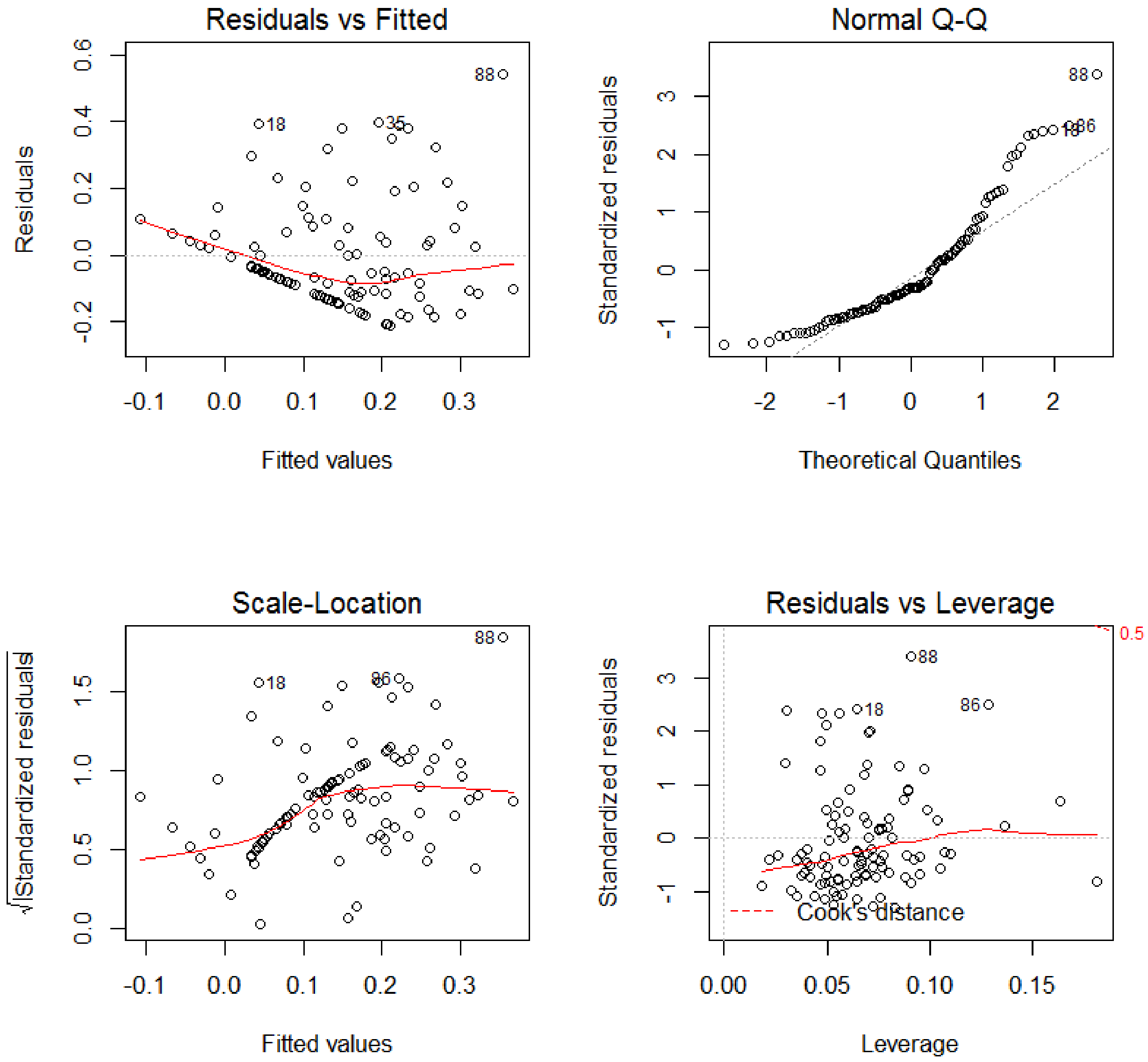


Fig. II.2: Diagnostic plots for the regression of arcsin square root transformed biological soil crusts cover by: arcsin square root transformation of non-native grass cover, cosine transformed aspect, Shannon's diversity index (H), elevation, soil depth, and slope.

Based upon the linear model soil depth and H were significantly associated with BSC cover at the 0.05 alpha level (Table II.2). Soil depth had a negative coefficient which indicates as soil depth increases BSC decreases. The coefficient for H was positive which indicates as H increases, BSC also increases. The model had an adjusted R-squared value of 0.2106, and residual standard error of 0.1677 with 97 degrees of freedom.

Table II.2: Ordinary least squares regression output results modeling arcsin square root transformed biological soil crusts cover by: arcsin square root transformation of non-native grass cover, cosine transformed aspect, Shannon's diversity index (H), elevation, soil depth, and slope. The model had a residual standard error of 0.1677 on 97 degrees of freedom in predicting the transformed BSC cover value using the variables in the model.

Coefficient	**Estimate**	**Standard Error**	**t-value**	**p-value**
Intercept	0.1182	0.1644	0.719	0.4740
Non-native Grass Cover (Arcsin square root transformation)	-0.0449	0.0614	-0.730	0.4671
Aspect (Cosine transformation)	0.0263	0.0222	1.182	0.2401
H	0.0769	0.0325	2.371	0.0197
Elevation	-0.0004	0.0002	-0.265	0.7917
Soil Depth	-0.0014	0.0004	-3.372	0.0011
Slope	0.0031	0.0019	1.604	0.1119

The H and soil depth were identified as being significant variables at the 0.05 alpha level when modeling biological soil crust cover. However, the diagnostic residual plots of this model indicated a violation of assumptions and non-normal data distribution. The variation measured in the model of BSC percent cover against H is provided Fig. II.3.

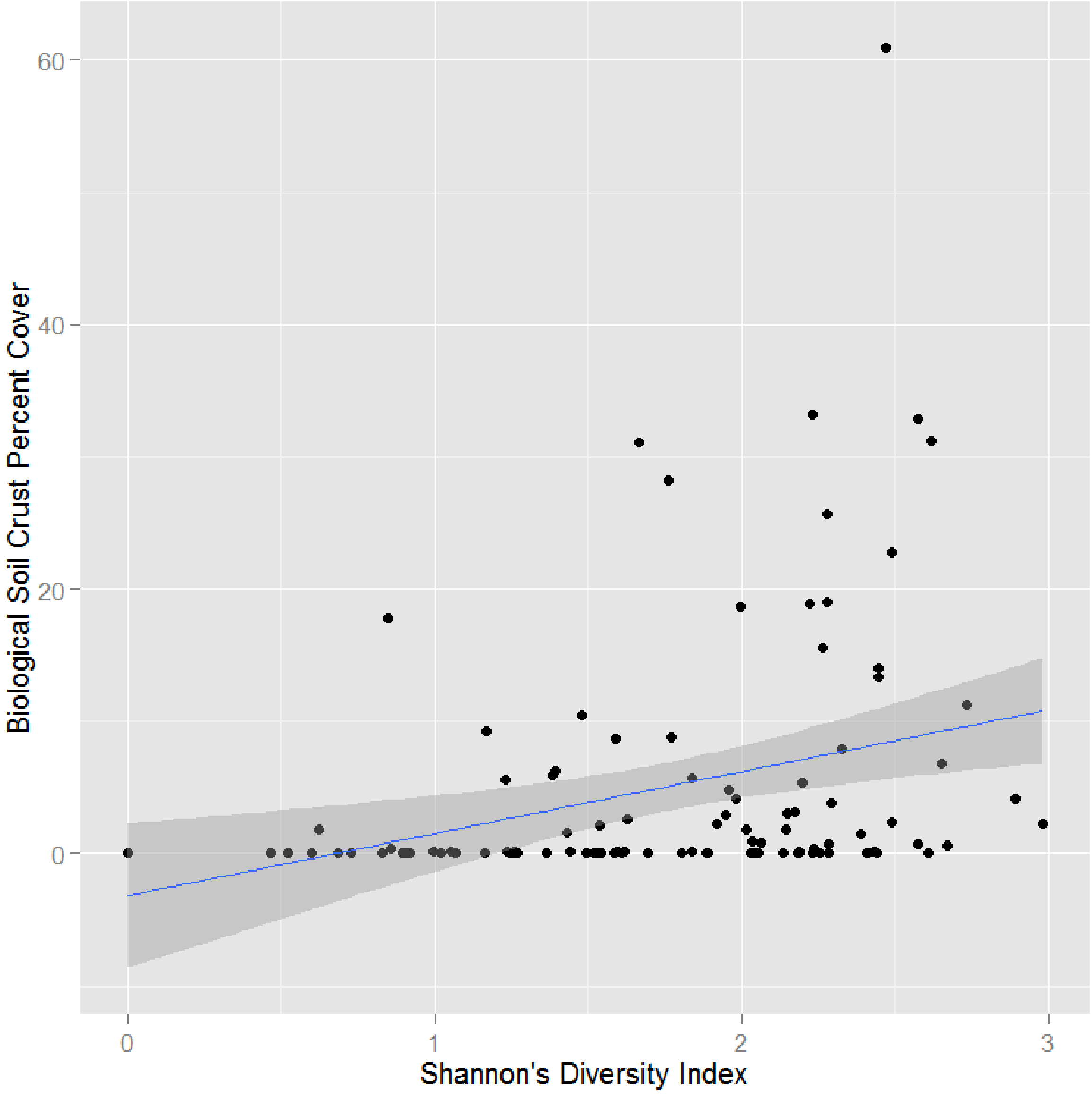


Fig. II.3: Plot displays Shannon's Diversity Index values (x-axis) against biological soil crust percent cover (y-axis). Plot has been fitted with best fit line (blue line). Shaded region represents 95% confidence level of linear model.

A scatter plot of BSC percent cover against soil depth is provided Fig. II.4. High BSC percent cover values at soil depths greater than 87 cm deviate from other observations in the sample. The plot of BSC means by soil depth categories (i.e., 1 = less than or equal 25 cm; 2 = greater than 25 and less than 100 cm; 3 = greater than 100 cm) indicates that BSC cover is similar at the depths greater than 25 cm (Fig. II.5). The plot means graphic also shows that shallow soils support higher cover of BSC. Pairwise group comparisons confirm this at the 0.05 alpha level.

Despite the trend that decreasing soil depth and increasing native plant diversity were significantly related to increasing BSC cover, the assumption of normality was issue with the linear model and the analysis of variance modeling soil depth categories.

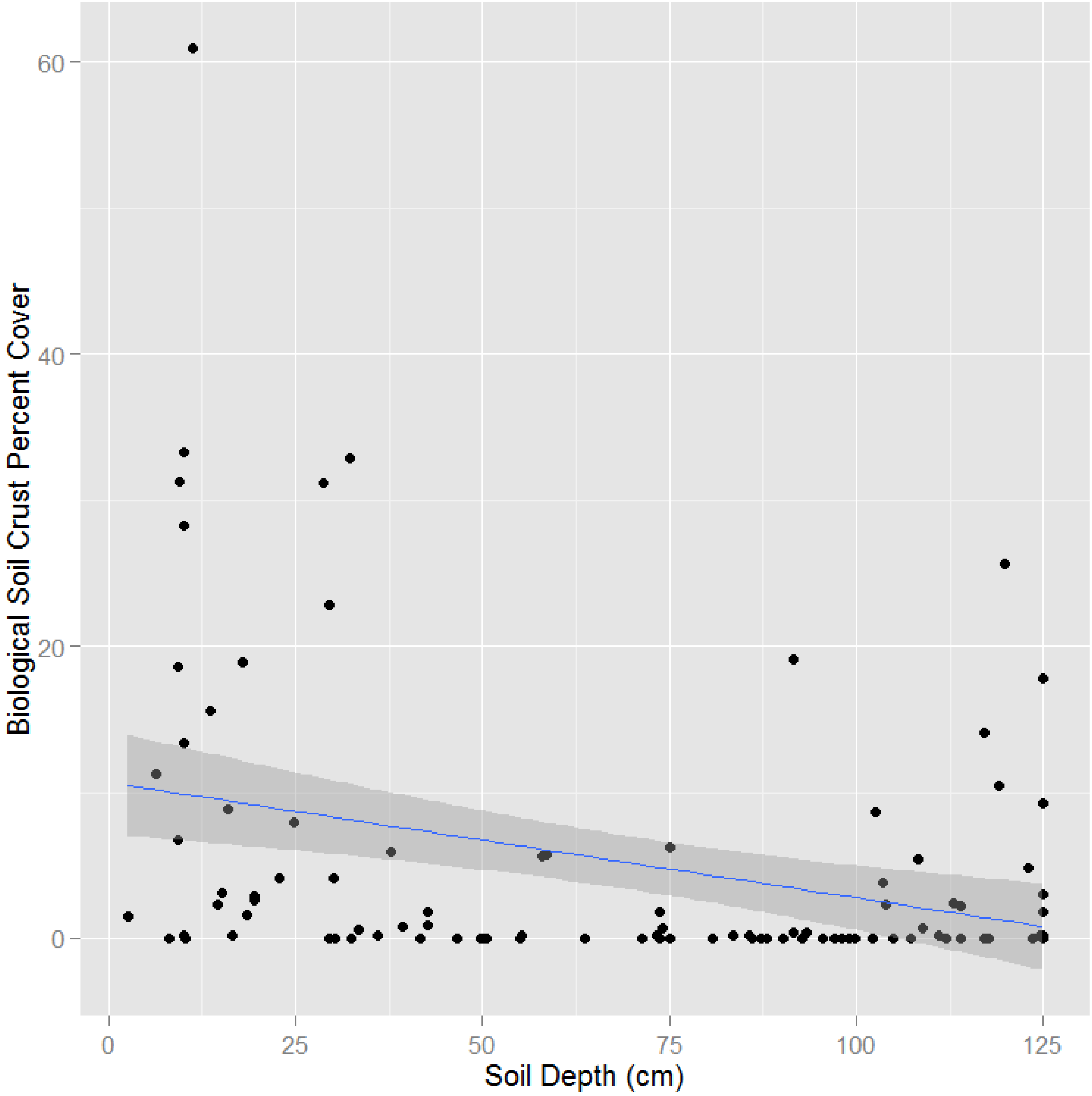


Fig. II.4: Plot displays soil depth values (x-axis) against biological soil crust percent cover (y-axis). Each plot has been fitted with best fit line (blue line). Shaded region represents 95% confidence level of linear model.

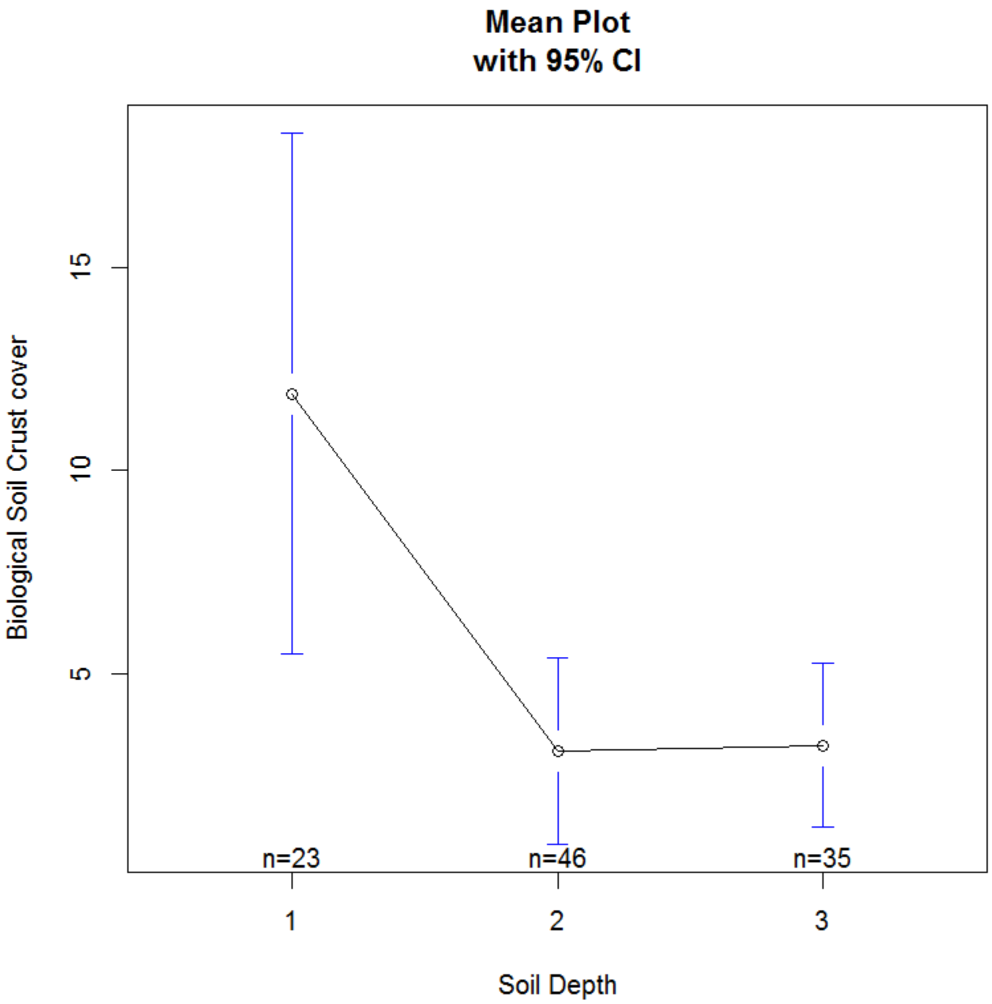


Fig. II.5: Treatment group means with 95% confidence intervals for three soil depth categories (i.e., 1 = less than or equal 25 cm; 2 = greater than 25 and less than 100 cm; 3 = greater than 100 cm).

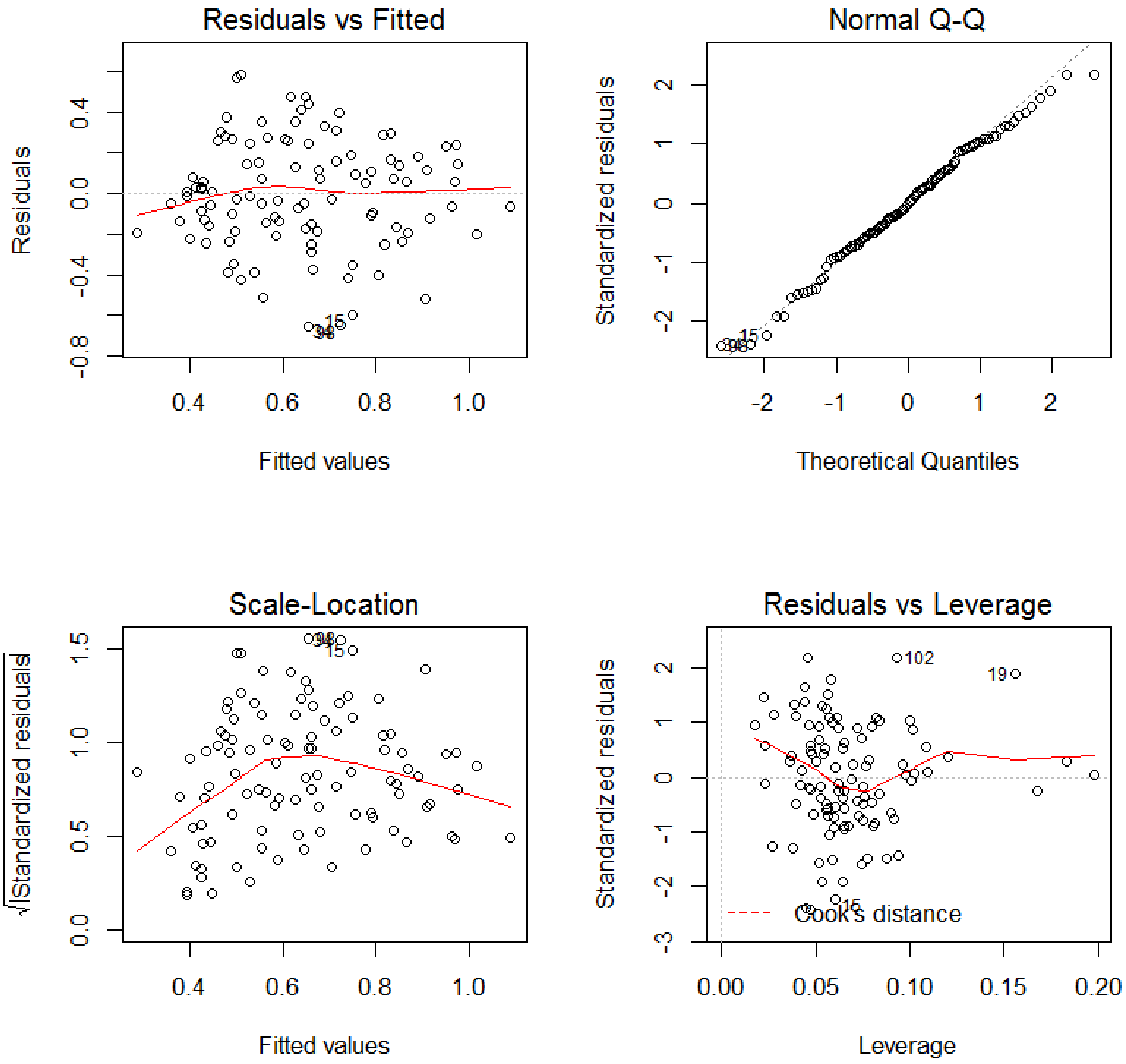
Non-native Grass

Non-native grass cover was observed within all plots and invasion into the Palouse Prairie is extensive and widespread. The plot frequency of non-native grass species is provided in Table II.3. Of these non-native grass species, 11 were annual and 9 perennial.

Table II.3. Plot frequency of non-native (exotic) grass species observed within 104 plots in the Palouse Prairie of northern Idaho and southeastern Washington. Perennial non-native grass species indicated by (*).

Scientific Name	**Plot Frequency**
Ventenata dubia	78
Bromus tectorum	61
Bromus hordeaceus ssp. *hordeaceus* (*Bromus mollis*)	35
Bromus racemosus (*Bromus commutatus*)	34
*Poa pratensis**	28
Vulpia myuros	19
*Arrhenatherum elatius**	18
Bromus sterilis	16
*Poa bulbosa**	15
Bromus arvensis (*Bromus japonicus*)	10
*Phleum pretense**	8
Taeniatherum caput-medusae	8
Apera interrupta (*Agrostis interrupta*)	7
*Bromus inermis**	5
Bromus briziformis (*Bromus brizaeformis*)	3
Bromus sp.	2
*Agrostis stolonifera**	1
*Dactylis glomerata**	1
*Phalaris arundinacea**	1
*Thinopyrum intermedium**	1

The diagnostic plots to investigate agreement between the data and the model are provided in Fig. II.6. The residual verses fitted and Square Root Standardized residual plots shows relatively homogeneous error variance. The Normal Q-Q or normal quantile plot of residuals lies on a straight line indicates normal probability. The Residuals vs. Leverage plot identifies three data points may be having undue influence on the regression relationship.



II.6. Diagnostic plots for the ordinary least squares regression modeling transformed arcsin square root transformation of non-native grass cover by arcsin square root transformation of biological soil crust cover, aspect, Shannon's diversity index (H), elevation, soil depth, and slope.

Based upon the linear model H was found to be significant at predicting non-native grass cover at the 0.01 alpha level (Table II.4). Overall, our model had adjusted R-squared value of 0.2629, and residual standard error of 0.2764 on 97 degrees of freedom.

Table II.4: Ordinary least squares regression output results modeling transformed arcsin square root transformation of non-native grass cover by arcsin square root transformation of biological soil crust cover, aspect, Shannon's diversity index (H), elevation, soil depth, and slope. The model had a residual standard error of 0.2764 on 97 degrees of freedom in predicting the transformed nonnative grass cover value using the variables in the model.

Coefficient	Estimate	Standard Error	t-value	p-value
Intercept	0.9386	0.2544	3.6900	0.0004
Biological Soil Crust Cover (Arcsin square root transformation)	-0.1218	0.1669	-0.7300	0.4671
Aspect (Cosine transformation)	-0.0026	0.0369	-0.0720	0.9430
H	-0.2677	0.0478	-5.5990	<0.0001
Elevation	0.0004	0.0003	1.3410	0.1829
Soil Depth	-0.0005	0.0007	-0.6220	0.5353
Slope	-0.0044	0.0031	-1.3910	0.1674

H had a negative coefficient which indicates as H increases, non-native grass cover decreases. BSC cover and soil depth were not significant factors at predicting NNGRS cover at the 0.05 alpha level. The variation measured in the model of H against percent cover against NNGRS is provided Fig. II.7.

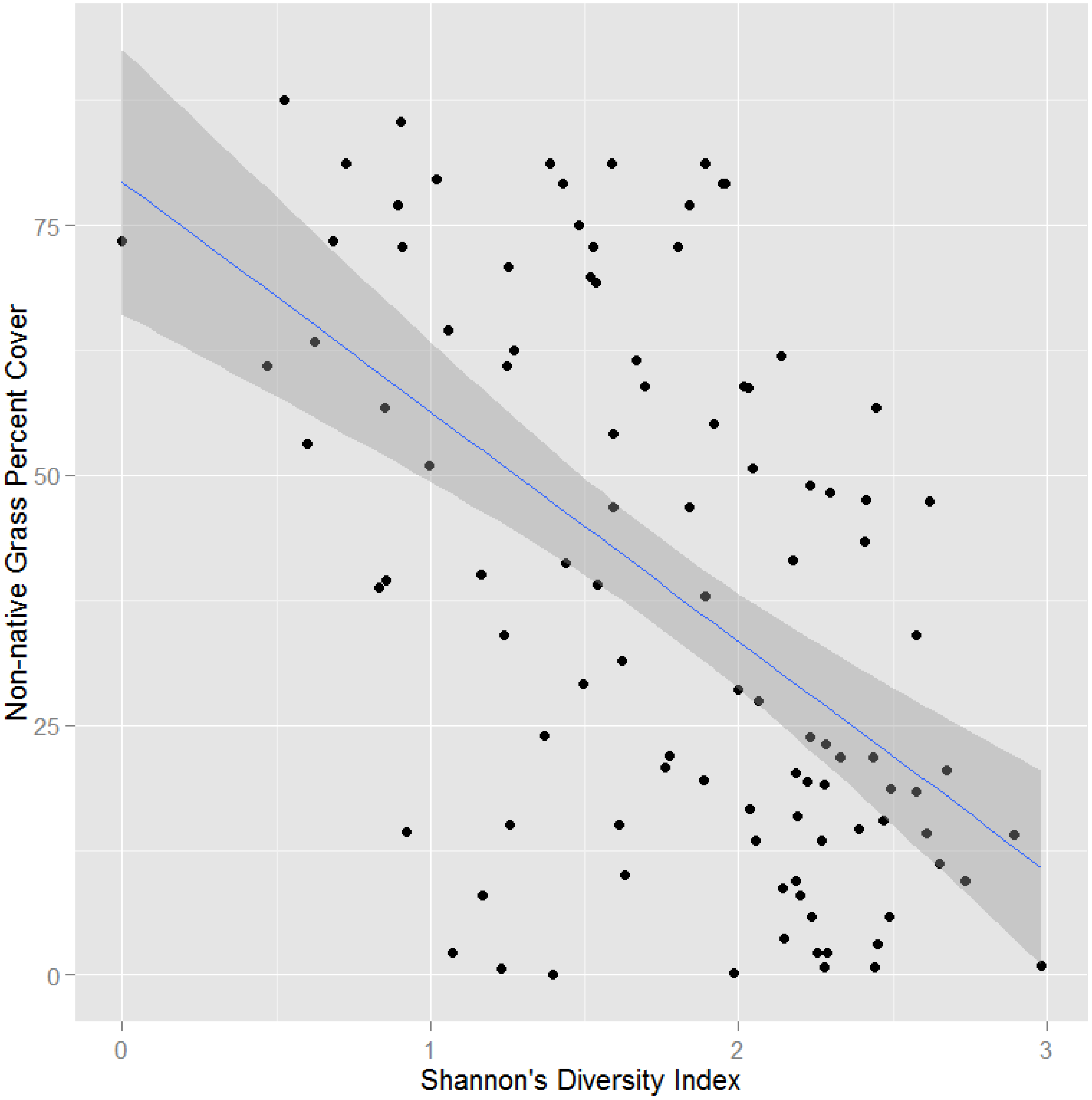


Fig. II.7: Scatter plot matrix of Shannon's diversity index of native plant cover (x-axis) against total non-native grass cover (y-axis). Each plot has been fitted with best fit line (blue line). Shaded region represents 95% confidence level of linear model.

Conclusions

Although soil temperature was not measured it is possible that BSC have greater tolerance than vascular plants to shallow soils, which likely have lower available water holding capacity and experience higher temperatures than the deeper soils of the Palouse region. Native plant diversity was also positively correlated with biological soil crust cover, and this too may be attributed to the native flora having greater tolerance for low soil moisture levels and higher soil temperature than exotics to the Palouse. Surface rock of shallow soils may also have acted as an armoring mechanism that protected BSC from past disturbances associated with livestock grazing.

Greater BSC cover on shallower soils is also consistent with patterns reviewed by Belnap et al. (2001a). Although assumptions of normality were an issue with our analysis, this study did identify a relationship with biological soil crusts and soil depth. We also detected no significant relationship between BSC cover and non-native grass invasion on the Palouse Prairie; a finding not consistent with conclusions made by Kaltenecker et al. (1999) and Serpe et al. (2006) that BSC significantly reduces seed germination. Nonetheless our results are partly supported by Dettweiler-Robinson et al., (2013) who found that lichen cover did not appear to impede *B. tectorum*, and further that *B. tectorum* appeared to negatively affect lichen cover at early and late successional stages. In our system, BSC and native plant diversity cover may be insufficient to prevent the invasion by non-native grasses, which in turn may be capable of reducing and degrading native plant and BSC communities. The profound invasion of *V. dubia* may be further explained by the small seed size of this grass, which could allow it to penetrate the BSC and germination, a possibility that merits further investigation.

The finding that native plant diversity is negatively related to non-native grass invasion supports the diversity-resistance hypothesis proposed by Elton (1958), which predicts a positive relationship between species diversity and biotic resistance. Our data only permit detection of correlations and cannot ascertain the processes that account for these, including native plant community resistance to invasion. Nonetheless, because the native grasses of the Palouse Prairie, which primarily includes *Pseudoroegneria spicata* and *Festuca idahoensis* bunchgrasses, have differing traits to those of annual non-native grasses and rhizomatous perennial grasses such as *P.pratensis,* they may not be resistant to invasion. The ability of non-native grasses to exploit unoccupied niches or available resources may be a factor related to the invasion success of non-native grasses (Davis et al. 2000). Niche-based community assembly or limiting similarity theory maintains communities are more resistant to invasion by non-native species if they contain native species with similar characteristics (Abrams 1983; Fargione et al., 2003; Emery 2007; Kimball et al., 2014). Therefore, restoration actions that consider competition interactions among native functional groups and invasive plants would like have higher success, especially at biological diverse sites.

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Appendix 1: Plot Tabulations

Table II.5: Number of plots by soil depth and aspect category for biological soil crusts variables.

		Soil Depth			
		$\leq 25\ cm$	> 25 $\leq 100\ cm$	$> 100\ cm$	Row Sum
Aspect	NE	2	12	12	26
	NW	5	8	12	25
	SE	4	12	6	22
	SW	12	14	5	31
	Column Sum	23	46	35	104

Table II.6: Number of plots by soil depth and elevation category for biological soil crust variables.

		Soil Depth			
		$\leq 25\ cm$	> 25 $\leq 100\ cm$	$> 100\ cm$	Row Sum
Elevation	$\leq 850m$	7	16	16	39
	$> 850\ m \leq 950\ m$	6	13	18	37
	> 950	10	17	1	28
	Column Sum	23	46	35	104

Table II.7: Number of plots by slope and aspect category for biological soil crust variables.

		Slope			
		$\leq 15^{\circ}$	$> 15.01^{\circ}$ $\leq 25^{\circ}$	$> 25^{\circ}$	Row Sum
Aspect	NE	8	8	10	26
	NW	5	12	8	25
	SE	6	12	4	22
	SW	16	13	2	31
	Column Sum	35	45	24	104

Table II.8: Number of plots by slope and elevation category for biological soil crust variables.

		Slope			
		$\leq 15^{\circ}$	$> 15.01^{\circ}$ $\leq 25^{\circ}$	$> 25^{\circ}$	Row Sum
Elevation	$\leq 850m$	9	12	7	28
	$> 850\ m \leq 950\ m$	14	16	9	39
	> 950	12	17	8	37
	Column Sum	35	45	24	104

Chapter III: Social Values of Culturally Significant Plants on the Palouse Prairie[3]

Cleve Davis, Kevin Decker, Rodney Frey, Ed Galindo, Timothy S. Prather, Nilsa A. Bosque-Pérez, Sanford D. Eigenbrode, Paul R. Rhoades, and Chris M. Baugher

Abstract

Although economic valuations of ecosystem services can account for externalities and be useful for conveying costs, these valuations can be considered inadequate by certain stakeholders or when viewed from certain social perspectives. This study sought to assess the importance value of culturally significant plants on the Palouse Prairie in northern Idaho and southeastern Washington through interviews and surveys. The purpose of the study was to identify potential social support for the conservation of culturally significant plants on the Palouse Prairie. A mail survey and semi-structured interviews found that Native Americans of the region and 36 percent of the respondents from the local population considered culturally significant plants valuable.

Introduction

The ecosystem services framework involves quantifying and valuing conditions and processes through which natural ecosystems and biodiversity sustain, benefit, and fulfill human life. The global benefits of ecosystem services (ES) are enormous because human societies could not exist without them (Daily 1997). Ecosystem services can include provisioning, regulating, habitat, supporting, cultural and amenity services (Sarukhán and Whyte 2005; de Groot et al. 2010). Scientists and policy makers are increasingly describing ecosystems and biodiversity as “environmental capital” or “natural capital” (Holdren et al. 2011; Kareiva et al. 2011). Economic valuations of ES can be used to prioritize conservation (van Berkel and Verburg 2012). In the absence of these valuations ES are not fully being valued in markets nor appropriately quantified in economic terms, and therefore not adequately incorporated into policy decisions (Constanza et al. 1997). Accounting for value of ES may help guide society

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[3] To be submitted to Journal of Northwest Anthropology

to account for degradation and loss of these services (Pascual et al. 2010). The approach and need to quantify and value ES is widely accepted by scientists and policy makers (Daniel et al. 2012).

Placing an economic value upon ecosystem service components and functions can account for some externalities (i.e., uncompensated environmental effects of production and consumption that affect consumer utility and enterprise cost outside the market mechanism), and help to prioritize, assess tradeoffs, and convey the costs to decision makers. But strictly economic valuations may be considered inadequate or insensitive to the perspectives of certain stakeholders with differing social views (Burger 2011; Johansson-Stenman 1998). For example, certain stakeholders or individuals who consider the natural environment to be sacred may reject the notion of quantifying how much they would be willing to pay, or give up in order to sustain a particular ES (Chan et al. 2012). Indeed, for many Indigenous cultures economic valuations are viewed as part of the colonial process premised on commoditization of the natural world and hence fundamentally unacceptable. This has been a criticism of economic valuations of ES, especially cultural services (Chan et al. 2012). How to value ES in a manner that is sensitive to these social and cultural perspectives but compatible with global economic forces is a significant challenge.

Cultural services are well-recognized component of ES, but are not well defined nor integrated with the broader ES framework (Daniel et al. 2012). Sarukhán and Whyte (2005:40) define cultural services as “nonmaterial benefits people obtain from ecosystems through spiritual enrichment, cognitive development, reflection, recreation, and aesthetic experiences”. Cultural services can also have some level of intangibility and typically difficult to quantify monetarily or biophysically (Milcu et al. 2013, Daniel et al. 2012). The criticism of assigning monetary values to cultural services arises because these values are typically not reflected in economies and not marketable (Carpenter et al. 2009; Martín-López et al. 2008), thus difficult to concisely value.

To address the inadequacy of a strictly economic valuation of cultural ES, Chan et al. (2012) proposed a multi-metric approach that included non-monetary variables. Therefore, our study sought to value cultural ES using a non-monetary approach that examines culturally significant plants through local community expression. The focus area of the study was the

Palouse prairie region of northern Idaho and southeastern Washington (Fig. III.1). In this study we defined culturally significant plants as: any native plant, lichen, moss, or fungus that can be used for food, teas, medicine, in ceremonies, or materials used in artisan craft.

Culturally significant plants can provide cultural, provisioning services, regulating, and habitat support services. In regard to cultural services, culturally significant plants can represent a legacy of biophysical features and intangible attributes inherited from past generations and bestowed for future generations. It is also well known that Native Americans utilize culturally significant plants in religious ceremonies, as religious symbols, or as items of inspiration or spiritual enrichment (Moerman 1998; Stewart 1987). Culturally significant plants and plant communities can also provide aesthetic beauty or natural scenery. They can also be classified as a provisioning ES by providing a source of wild food, medicine, and raw materials. Culturally significant plants and communities can also be considered a regulating ecosystem services through carbon sequestration. They can also provide services to regulate soil erosion and contribute to soil fertility. As many culturally significant plants are part of the native plant community they also play role in providing habitat and supporting services to wildlife.

Culturally significant plants were selected as focus for assessing ES value using a non-monetary approach, as they do not fit well into any one category of ecosystem services. Furthermore, the Palouse region was once considered a vast garden for culturally significant plants by the native inhabitants (Scheuerman and Finley 2008), thus a focus on these plants for assessing their cultural ES value using a non-monetary approach is particularly appropriate. Therefore, the goal of the study was to identify potential social synergies that could be used to influence conservation of culturally significant plants on the Palouse prairie. A social synergy is the interaction of social elements or common values that when combined produce a total effect that is greater than the sum of the individual elements or contributions to achieve a desired outcome.

Study Region

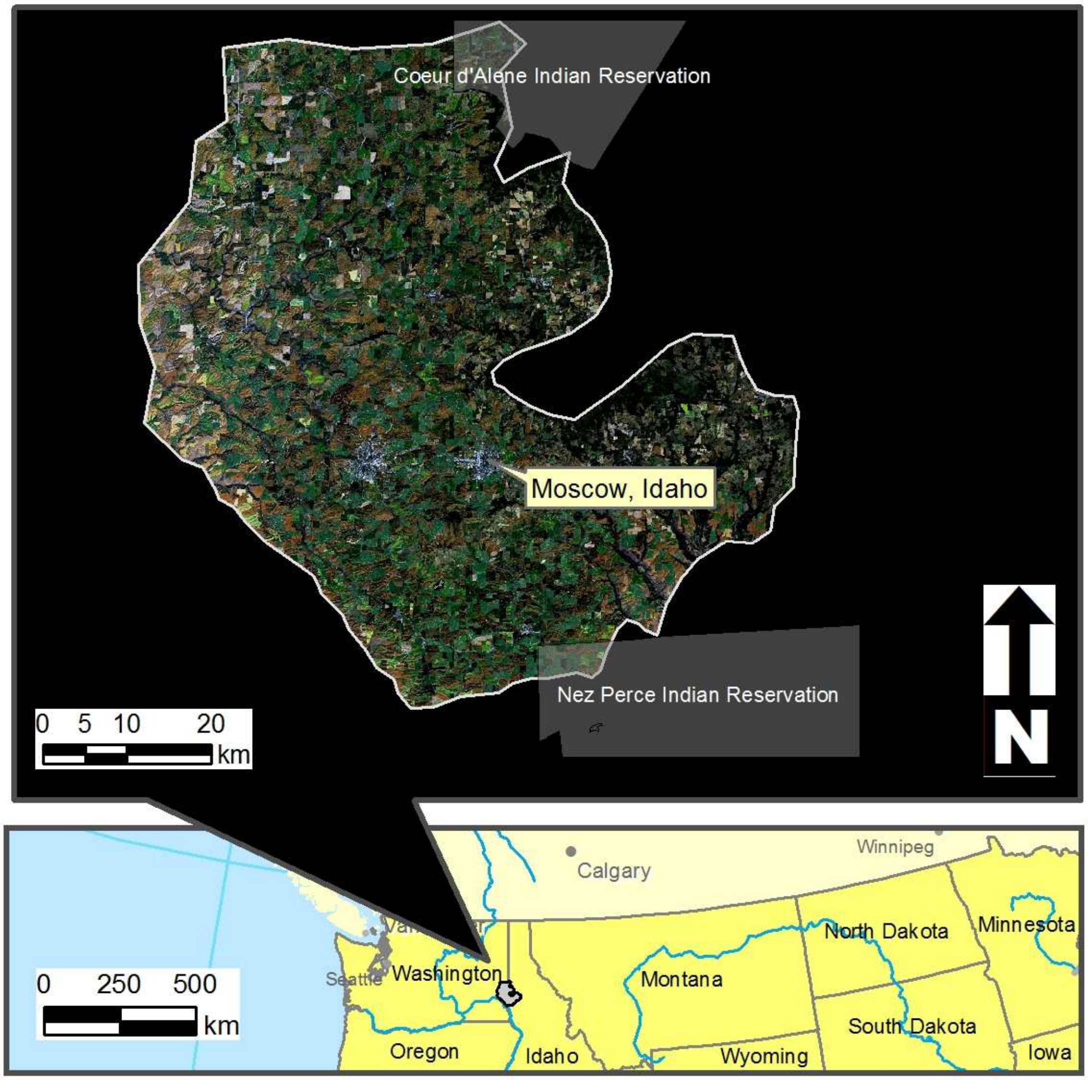


Fig. III.1: The core area of the Palouse prairie region in northern Idaho and southeastern Washington at two scales. Center map at 1:900,000 scale shows agricultural matrix and portions of the Coeur d'Alene and Nez Perce Reservations. The map at the bottom shows the location of the region at the continental scale (1:25,000,000).

The Palouse Prairie grassland is critically endangered because most of its former extent is now dedicated almost exclusively to rainfed farming, mostly grain and pulse crops (Looney and Eigenbrode 2012; Donovan et al. 2009; Hanson et al. 2008). The Palouse region has an extensive and significant prehistory. Some of the earliest records of humankind in North America have been uncovered in the nearby basalt canyons along the Snake River, so it is likely that there has been some human presence in the Palouse Prairie for at least 12,000 years (Chatters 2004; Black et al. 2000; Breckenridge 1986). When Lewis and Clark of the Corps of Discovery entered the region in 1805, the region was inhabited by Palouse (*Naha'ùumpùu*), Nez Perce (*Niimìipuu*), Spokane (*Sqeliz*), and Coeur d'Alene (*Schitsu'umsh*) peoples (Walker 1998; Sprague 1998; Scheuerman and Finley 2008; Frey 2001). The Palouse and Nez Perce speak the Sahaptin language and are culturally related.

Subsistence practices of the Indigenous populations were based upon hunting, fishing, and gathering, as well as low-impact agriculture of native plant species (Black et al. 2000). The Palouse Prairie was particularly important for the gathering of edible and medicinal plants by the Indigenous populations (Sprague 1998; Frey 2001; Scheuerman and Finley 2008). The seasonally wet meadows and prairies of the Palouse Prairie supported high densities of the edible blue camas (*Camassia quamash*). When the horse was acquired in the 1700s, use of the area by Indigenous people diversified to stock raising (Black et al. 2000). However, most of the Indigenous population was severely reduced in size by 1860 through war, disease, and famine that resulted from Euro-American invasion and settlement (Sprague 1998).

In the late 1800s, the Palouse Prairie underwent an extensive and profound transformation. Euro-Americans used the region in a dramatically different from that of the Indigenous peoples (Black et al. 2000). Initially, Euro-Americans pastured livestock and grew tree fruits (Williams 1991). Within a few decades, competition from areas better suited for fruit production and high returns for wheat production drove a nearly complete transition to grain farming (Williams 1991). Since 1900 it has been estimated that as little as one tenth of one percent of the Palouse Prairie grassland remains (Noss and Peters 1995). Today, the region is considered to be one of the United States' most productive dryland farming areas (Duffin 2005). What remains of the natural Palouse Prairie is considered an endangered ecosystem (Noss and Peters 1995), and a large majority of it under private ownership (Black et al. 2000).

Valuations of culturally significant and wild plants involve ascribing value to a particular species using an index scoring system or economic valuation. Existing valuation methods are often based upon attributes the researchers identify as being most important to, usually, an Indigenous hunter-gather society that make primary subsistence upon the natural environment. Little attention has been directed at valuing the importance of culturally significant plants using an integrated analysis of both Indigenous and non-Indigenous communities of a region which is a focus of this study. Although very little natural grassland remains in the Palouse region this study was aimed at determining if culturally significant plants in the Palouse Prairie supplied value to the local community, including Native American Tribes. Through a regional population study we tested the hypothesis that culturally significant plants provide no value (i.e., less 10 percent through sample survey) to the local community due to the reduced extent of natural vegetation and its inaccessibility to the local community.

Methods

The overall approach for this analysis included conducting semi-structured interviews with Nez Perce Tribal members to gain a better understanding of Indigenous eco-cultural priorities, concerns, and perspectives of the Palouse Prairie; as well as an analysis of sample survey responses by the local Palouse Prairie community. Information gathered via interviews was used to develop survey questions for a quantitative survey of the regional population that included both the Indigenous and non-Indigenous community. Requests were also made to conduct semi-structured interviews Coeur d'Alene Tribe; however formal participation was not obtained within the established time frame. Nonetheless, meetings were held with Coeur d'Alene Tribal members and professionals involved in Natural and Cultural Resource Management in 2012 and 2013 to gain participation in the study. The Nez Perce and Coeur d'Alene Reservations span portions of what we are defining as the core area of the Palouse Prairie landscape.

Semi-structured Interviews

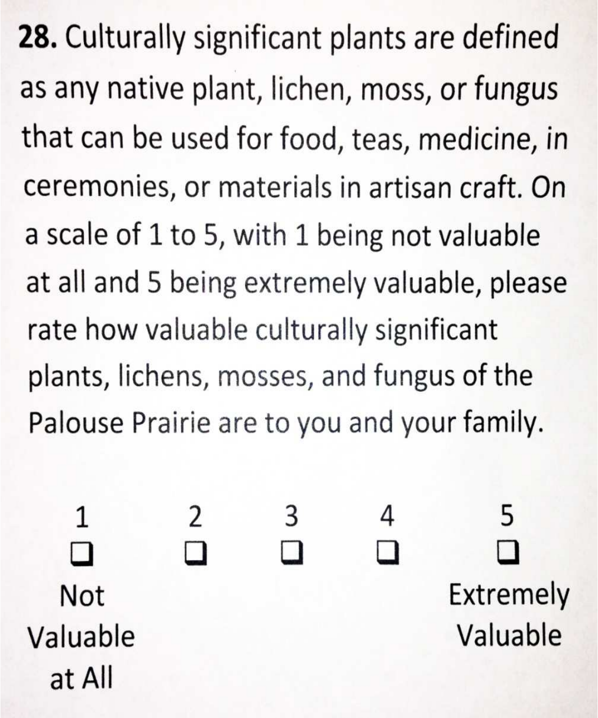
The purpose of the semi-structured interviews was to: 1) identify opportunities and barriers for ecosystem conservation, 2) understand traditional methods and locations of cultural use of the Palouse Prairie, 3) identify barriers to cultural use, and 4) understand Native American views and perspectives on the stewardship and sustainability of local plant resources. Six semi-structured interview sessions were conducted with Nez Perce Tribal members who were identified by the local community as being knowledgeable of traditional language and culture. The interviews took place in 2012 and 2013 on the Nez Perce Reservation in northern Idaho.

Two meetings were held with Coeur d’Alene Tribal representatives, which included interaction with a Coeur d’Alene Councilman, Cultural Resources Director, Natural Resources Director, Coeur d’Alene Lake Management and Educational Outreach Program Manager to gain approval to conduct the semi-structured interviews. The research permit with the Nez Perce Tribe was approved on June 26, 2012 by the Nez Perce Tribe Executive Committee. The interview protocol was approved as offering no significant risks to human subjects by the University of Idaho Institutional Review Board on August 27, 2012. Although new ideas and discussions repeatedly occurred, the questions posed in semi-structured interviews were standardized and provided in Appendix 2

Maps were also created of the Palouse Prairie and interviewees were encouraged to use the maps for reference during the interview. Responses to questions and notes of discussions were documented in writing and later coded based upon theme of the response. As part of the Nez Perce Research Permit, the Tribe was provided an opportunity to review information summarized and a draft of this manuscript to ensure protection of sensitive information of the Tribe. This included two reviews of electronic versions of the manuscript and a printed hard copy delivered to the Cultural Department of the Nez Perce Tribe. The Cultural Department requested more information be provided about the shared language of various Nez Perce bands and consideration of several existing publications. There was no requirement to meet with the Circle of Elders or Tribal Cultural Committee Review.

Sample Survey

Based upon interviews three survey questions were developed related to valuing culturally significant plants as part of a more comprehensive survey aimed at valuing ES on the Palouse Prairie. In additions to assessing the value of culturally significant plants, two questions on the appropriateness of using a dollar amount to inform conservation decisions and the respondent’s heritage connection with the Palouse Prairie were developed. Respondents were asked to rate the importance of culturally significant plants on a scale of 1 to 5, with 1 being not valuable at all to themselves and their families and 5 being extremely valuable to themselves and their families (Fig. III.2). Due to response rate, the value rating was recoded as follows: value scores of 1-2 were considered Not Valuable, value score 3 was considered Neutral, and value score of 4-5 were considered Valuable.

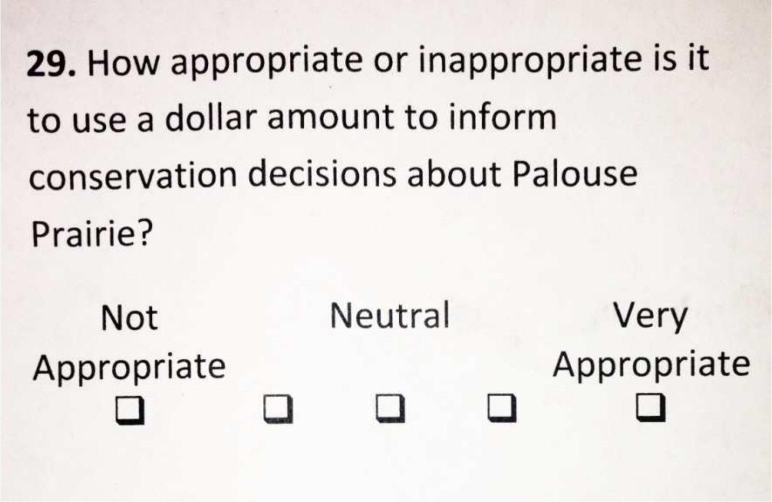


28. Culturally significant plants are defined as any native plant, lichen, moss, or fungus that can be used for food, teas, medicine, in ceremonies, or materials in artisan craft. On a scale of 1 to 5, with 1 being not valuable at all and 5 being extremely valuable, please rate how valuable culturally significant plants, lichens, mosses, and fungus of the Palouse Prairie are to you and your family.

1	2	3	4	5
☐	☐	☐	☐	☐
Not Valuable at All				Extremely Valuable

Fig. III.2: Question 28 of the Palouse Prairie sample survey instrument identifying how culturally significant plants were valued.

A question was also developed to assess the adequacy of using a dollar amount to inform conservation decisions about the Palouse Prairie (Fig. III.3). This question asked “How appropriate or inappropriate is it to use a dollar amount to inform conservation decisions about the Palouse Prairie?”, and was rated on scale of 1 to 5, with 1 as being “Not Appropriate”, 3 “Neutral”, and 5 “Very Appropriate”. From this point forward this variable is referred to as “dollar appropriateness”.

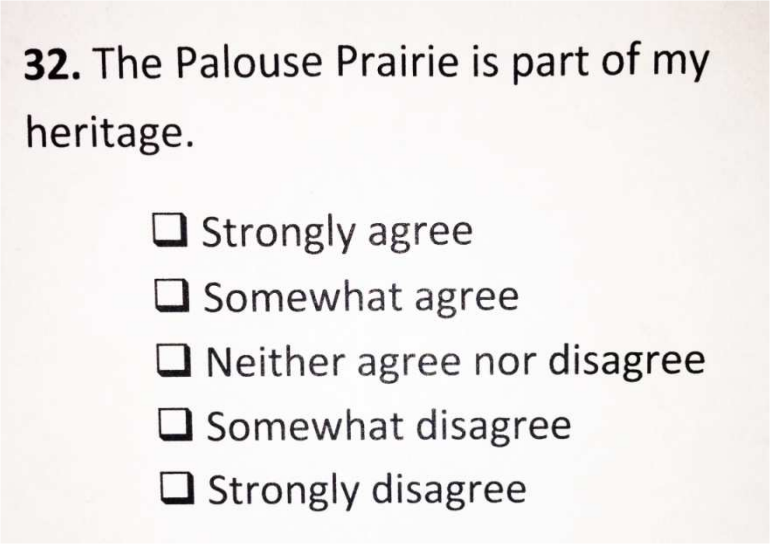


29. How appropriate or inappropriate is it to use a dollar amount to inform conservation decisions about Palouse Prairie?

Not Appropriate ☐ ☐ Neutral ☐ ☐ Very Appropriate ☐

Fig. III.3: Question 29 of the Palouse Prairie sample survey instrument identifying how appropriate or inappropriate is it to use a dollar amount to inform conservation decisions about Palouse Prairie.

A question was also posed in the survey to identify if the respondent considered the Palouse Prairie as part of their heritage (Fig. III.4). Respondents were also asked to identify if they “strongly agree”, “somewhat agree”, “neither agree nor disagree”, “somewhat disagree”, and “strongly disagree” with the statement “The Palouse Prairie is part of my heritage”. From this point forward this variable is referred to as “Heritage”.



32. The Palouse Prairie is part of my heritage.

- ☐ Strongly agree
- ☐ Somewhat agree
- ☐ Neither agree nor disagree
- ☐ Somewhat disagree
- ☐ Strongly disagree

Fig. III.4: Question 32 of the Palouse Prairie sample survey instrument identifying how the respondent rated their heritage.

Demographic profile information was also collected to identify the respondents: age category, gender, education level, income level, and political view. Age of the respondent was collected with the question, “What year were you born (YYYY)?” with a blank space for the respondent to fill in. Response was then categorized by taking the age difference from the year of 2014 and tabulating the number of responses within the age categories: 18-25, 25.01-35, 35.01-45, 45.01-55, 55.01-65, and 65.01-93. Male or female gender was identified by the respondent selecting a box with “Male” or “Female” below the question “What is your gender?”. Political view was collected with the question, “On a scale of 1 to 7 where 1 is very liberal, 4 is moderate and 7 is very conservative, how would you described your political views?”. Education level of the respondent was collected with question “What is the highest grade or year of school you completed?”. The respondent could identify education level by selecting the appropriate box with the following categories: “12th grade or less, no diploma”, “High school graduate or GED”, “Some college, no degree”, “Associate’s degree”, “Bachelor’s degree”, “Graduate or professional degree”. Gender, political view, income level, education level, heritage, age category, and dollar appropriateness were verified for homoscedasticity using the Bartlett test and Fligner-Killeen test (alpha 0.05). An eighth demographic factor, “ethnicity/race”, could not be assessed statistically because of a low response rate from minority groups and heteroscedasticity of the data.

The population sampled was people residing within the core area of the Palouse Prairie. This area included all of Latah County, Idaho and Whitman County, Washington. One thousand three hundred households were drawn proportionate to the population size in the two counties. Samples of 100 households were also drawn from Plummer (Benewah County, Idaho), Worley (Kootenai County, Idaho), and Lapwai (Nez Perce County, Idaho) for a total of 300 additional samples. Therefore the frame of this study was an address based sample of 1,600 residents in the Palouse Prairie area. Addresses were purchased from Survey Sampling Inc. of Connecticut. The address purchase was done to capture the perspectives of hard-to-reach populations such as ethnic minorities and those of lower socio-economic status. The towns of Plummer, Worley, and Lapwai are located within the Nez Perce and Coeur d’Alene Indian Reservations. Data collection was conducted by the University of Idaho Social Science Research Unit using a modified Dillman method (Dillman et al. 2008; Dillman 1978). This method has proven useful for increasing response rates (Hoddinott and Bass 1986).

The modified method included four stages. At the first stage, a preselected postcard was mailed to all 1,600 households with a notification to expect a survey letter with an internet link to a web-based survey. The postcard with the world-wide-web based survey link followed within a few days. From this sample, 208 were returned as undeliverable. A $1.00 incentive was sent a week and half later to all non-responsive households to complete the survey. A paper survey with prepaid return envelope was sent to all remaining non-respondents as a final measure to increase response rate. Overall, the sampling strategy resulted in 241 surveys completed online and 180 completed paper copies for a total of 421 completed surveys ($n = 421$).

The sample survey was administered during the summer in a region with two large universities nearby. As a result the sample does not necessarily conform to the population demographics of the region when school is in session. Therefore, the sample mostly represents the perspectives of permanent residents of the region. No weighting was used to compensate for the difference between the sample and the population.

Data Analysis

Survey data were analyzed using the R program version 3.1.1. The analysis focused on the effect of seven demographic factors: Gender, Political View, Income Level, Education, Heritage, Age Category, and Dollar Appropriateness. Therefore, we tested seven factors measured on a scale ranging from Not Valuable (1), Neutral (2), and Valuable (3).

The ordered logistic regression (OLR) was executed using the *polr* command from the MASS package to estimate a model. This analysis is a proportional odds logistic regression to assess how demographic factors influenced the assessed importance of valuing culturally significant plants. P-values were calculated by comparing the regression t-value against the standard normal distribution. The logistic model used to show the function of the probabilities results in a linear combination of parameters is

$$ln\left(\frac{prob\ (event)}{(1-prob(event))}\right) = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_k X_k \ .$$

The logit in this case is the ratio of the number of people who placed a value (i.e., Not Valuable, Neutral, Valuable) on culturally significant plants against those who held a different value. The resulting coefficients on the OLR model tell how much the logit changes based on the values of the predictor variables. The purpose of the model was to identify the relationship between value placed on culturally significant plants by gender, political views, income level, education, heritage, age category, and appropriateness of using a dollar value in conservation decisions related to valuing the importance of culturally significant plants.

Proportional probabilities were calculated independently upon predictor variables found to be significant. This was done by using the *polr* command fitting the value category by the variables found to be significant. These variables included: gender, income, political view, heritage, and appropriateness of using dollar value in conservation decisions. Model predictions were done using *predict* command of the Stats package of R.

Results

Interviews

The number of times reoccurring themes and issues identified during interviews with Nez Perce Tribal members is provided in Table III.1. The use, knowledge, and importance of natural foods and traditional culture to interviewees were articulated during interviews. It was also revealed through the interviews that the epistemology of interviewees guided uses and views of the natural world and Palouse Prairie. One interviewee stated that, “The elders say the importance of one plant or animal should not be called out over another. All are important”. Another interviewee stated that, “When you die and your body decays to dust you return to mother earth. This is why the Nez Perce think land is sacred”. Another major theme and issue identified through the interviews was that there is a perceived difference in culture between Indigenous and non-Indigenous people. One interviewee stated:

> The dominant society wants to make the world like Europe. What is there you want to protect? Our natural foods and medicines are important to protect. Once these are gone they are irreplaceable. Where else can you get the natural foods? Nowhere. All our land, food, fish, and forest have been taken away.

Another interviewee stated, “Whiteman thinks only certain points in the system are important, when the whole system is important”. There was concern that natural foods and medicines are being lost through environmental degradation and agricultural production activities. The loss due to and concern about using natural foods and medicines that had been exposed to pesticides (e.g., herbicides) was also identified by the interviewees. There is perception that when pesticides are applied that “poison is still there”.

The Palouse Prairie also represented a sense of place for several of the interviewees, either through knowledge of traditional use or features at a particular location. For example, the region now known as Moscow, Idaho, was known by Sahaptin speaking people as *Tatxinme* the “Fawn Place”. It was called the fawn place because it was a known fawning area for deer. It was also an important trading place for Indigenous people. There is also a very old oral tradition on Steptoe Butte and how the butte was once used to escape a flood. Several of the interviewees also stated that in the past the Palouse Prairie was also important for horse pasture.

Of all the plant species identified by the interviewees camas was mentioned the most. Loss of camas due to agricultural practices (plowing, livestock grazing) and activities (pesticide use) was a major concern. Due to the loss of camas and worry of ingesting pesticides access to “pure” camas has diminished. One interviewee stated that traditional harvesting of camas is beneficial to camas because the digging tills up the soil. The traditional method of harvesting camas by the Nez Perce is to do so after seed ripening (late summer), and dropping seed into the disturbed soil after harvesting bulbs. Another interviewee stated that only large bulbs are harvested and smaller bulbs are left to grow.

Nez Perce elders expressed the importance of educating tribal youth in traditional language and culture, but there is some concern about sharing the knowledge with outsiders. Access to harvesting and use of natural foods and medicines is becoming more difficult due to development, landownership, and spread of invasive non-native species. Tribal members are traveling further to find harvest locations, usually on public land, that have not been impacted by agricultural activities. Due to the losses associated with agricultural production and invasive species there is a need for restoration and more sustainable use of the landscape.

There is also a perception that climate change has impacted water availability and has made wind and temperature more extreme. Oral traditions maintain that rivers used to freeze over and now they never freeze over. There is also a perception that climate change is altering the seasons and harvest times of natural foods and medicines.

There is a perceived lack of support of Tribal interests by local non-Indian politicians and federal land managers, and tribal members continue to exercise off-reservation treaty rights on both federal and private lands. One Tribal member also expressed the desire to reconnect to the Palouse Prairie through hunting, fishing and gathering.

Table III.1: The number of Palouse Prairie issues and themes identified as priority or concern during interviews with Nez Perce Tribal members.

Theme/Issue	**Number of Times Mentioned by Interviewees**
Importance of Treaty Right consultation	1
Importance of protecting traditional knowledge	1
Desire to reconnect to Palouse Prairie	1
Tactics of colonization	1
Importance of horse pasture	2
Exercise of off-Reservation Treaty Rights	2
Degradation/loss of water	2
Dominant society failure to acknowledge impacts upon Native Americans and ecosystem	2
Seasonal uses	3
Invasive species	3
Pesticide use	3
Need for restoration	3
Traditional methods to promote natural replenishment	3
Climate change	3
Maintenance of Treaty Rights	3
Self-belief(s)	3
Natural medicines	4

Theme/Issue	**Number of Times Mentioned by Interviewees**
Loss of access	5
Importance of educating Tribal members of traditional knowledge and language	6
Camas	7
Sense of place	7
Degradation/loss of traditional cultural landscape	9
Tribal epistemology (i.e., All of the natural environment is important/connected, Lessons from Animals/Nature, Gifts from Creator)	9
Differences in culture among Natives and non-Natives	10
Traditional uses, practices, and values	12
Importance and names of natural foods	19

Although some of the respondents stated that all native plant or animal species are considered important, some species specifically identified as being culturally significant are provided in Table III.2. Native American's interviewed also identified several locations on the Palouse Prairie where culturally significant plants can be harvested.

Table III.2: List of specific native plants[1] of the Palouse Prairie identified as culturally significant to the Nez Perce Tribe during 2011 and 2012 semi-formal interviews.

Life Form Type	Scientific Name	Name Used by Interviewee
Bryophyte	Unknown	*Hoopop,* Pine moss
Vascular Plant	*Camassia quamash*	*Quem'es*, camas
Unknown	Unknown	Indian tea
Vascular Plant	*Vaccinium membranaceum*	Huckleberry
Vascular Plant	*Lomatium cous*	*Cous cous*
Vascular Plant	Unknown	*Qeqeite*
Fungus	Unknown	*Hepau*
Vascular Plant	Unknown	*Weim,* Celery
Vascular Plant	*Balsamorhiza sagittata*	*Pask*
Vascular Plant	Unknown	*Tetineze,* Shiners
Unknown	Unknown	Mountain tea
Vascular Plant	*Allium* sp.	Onion
Fungus	*Morchella* sp.	Morels

[1] Although these species were specifically identified during the interviews, Nez Perce Tribal members adhere to oral tradition that all native plants and animals are important.

Sample Survey

Likert plots were used to show sample survey results by demographic groupings (i.e., age category, gender, education level, income level, and political view), heritage, and dollar appropriateness.

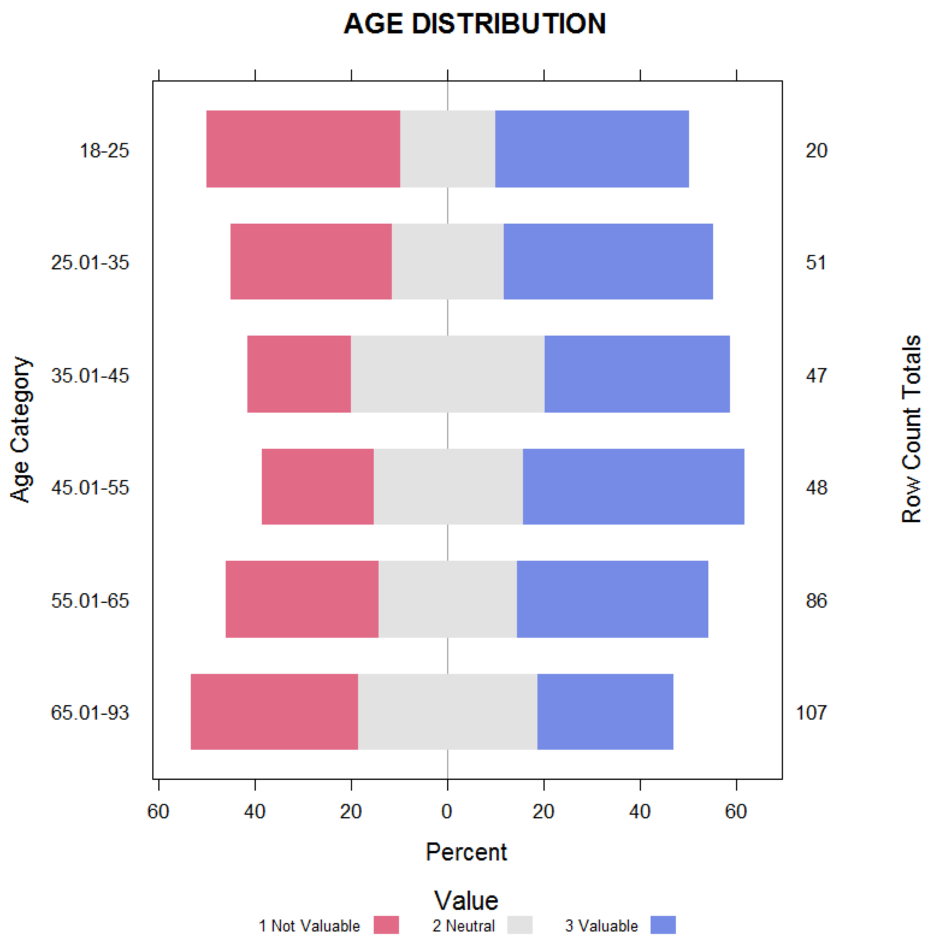


Fig. III.5:The Likert plots show rating scale by age category value choices of culturally significant plants. Row count totals by category are provided on the right y-axis label of the Likert plots. Percentage of respondents' choice by value rating is provided on the x-axis. The stated value of culturally significant plant is identified by color. Red indicates respondents who considered culturally significant plants as being not valuable. White indicates the percentage of respondents who placed a neutral value upon culturally significant plants. Blue identifies the percentage of respondents who identified culturally significant plants as valuable.

The age distribution, category of "45.01-55" had the highest percentage of respondents who considered culturally significant plants as valuable, while the age-category of "65.01-93" years had the lowest (Fig. III.5).

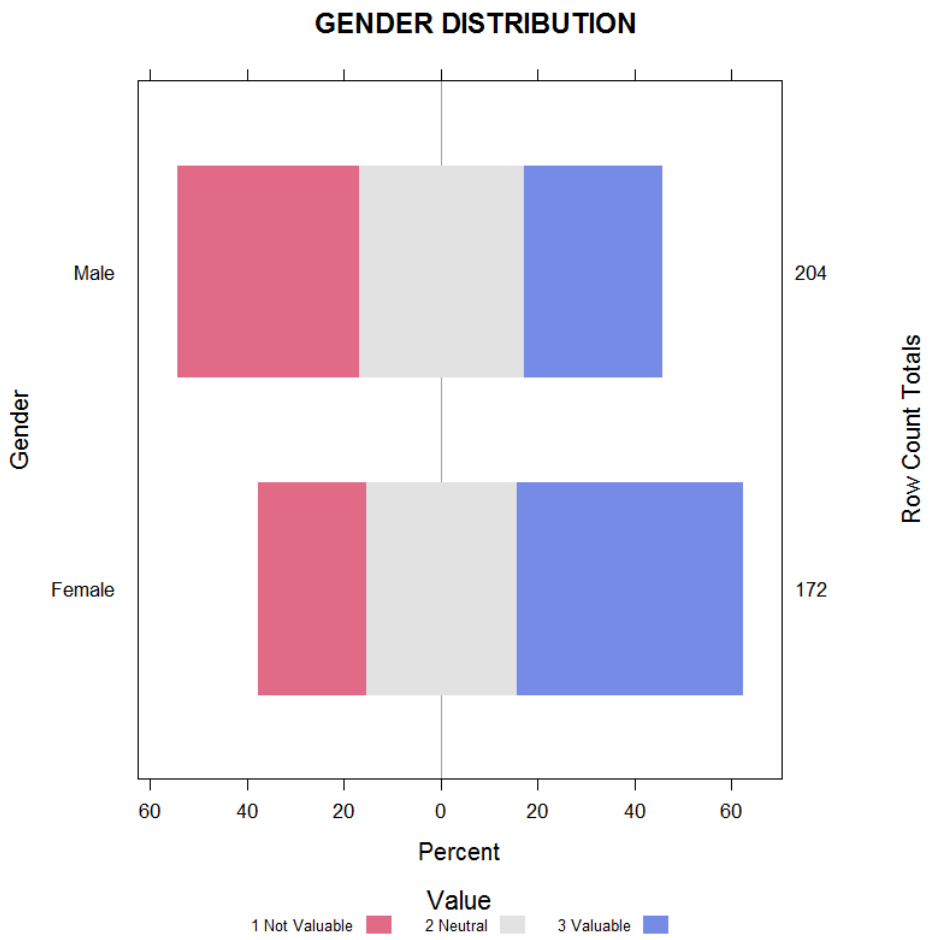


Fig. III.6:The Likert plots show rating scale by gender category value choices of culturally significant plants. Row count totals by category are provided on the right y-axis label of the Likert plots. Percentage of respondents' choice by value rating is provided on the x-axis. The stated value of culturally significant plant is identified by color. Red indicates respondents who considered culturally significant plants as being not valuable. White indicates the percentage of respondents who placed a neutral value upon culturally significant plants. Blue identifies the percentage of respondents who identified culturally significant plants as valuable.

Female respondents had a higher percentage that considered culturally significant plants as valuable (Fig. III.6). Males were nearly equally divided between not valuable, neutral, and valuable.

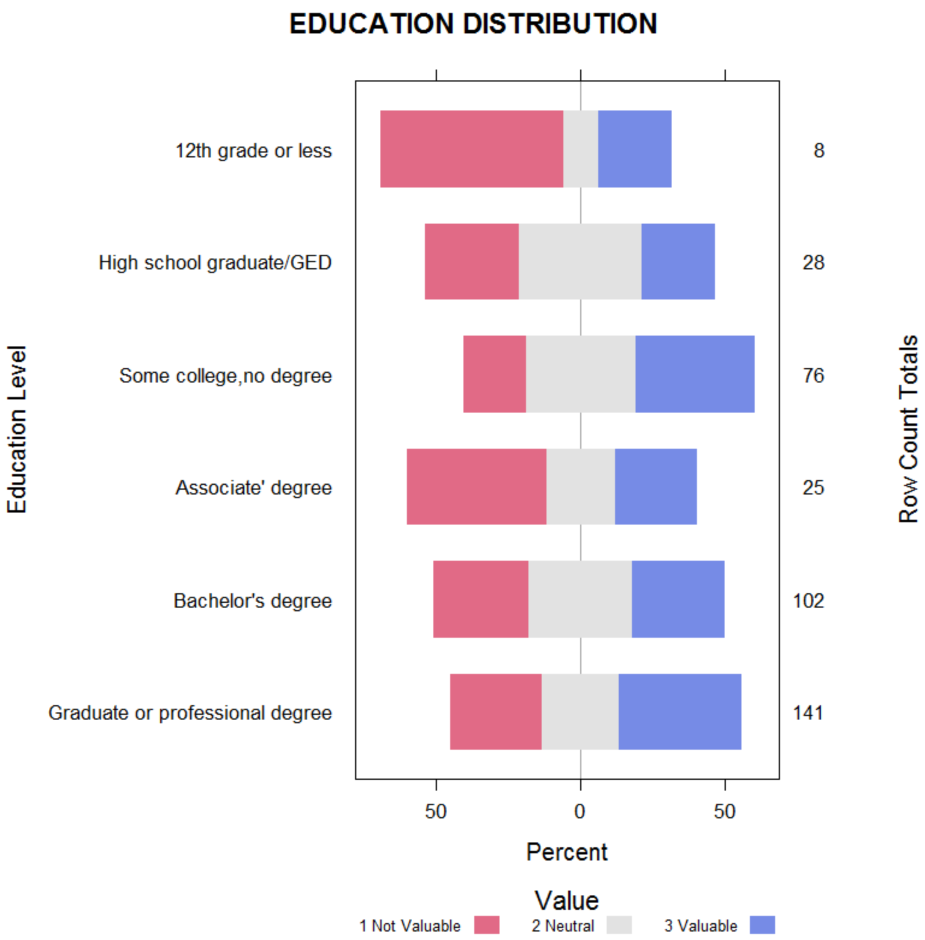


Fig. III.7:The Likert plots show rating scale by education level value choices of culturally significant plants. Row count totals by category are provided on the right y-axis label of the Likert plots. Percentage of respondents' choice by value rating is provided on the x-axis. The stated value of culturally significant plant is identified by color. Red indicates respondents who considered culturally significant plants as being not valuable. White indicates the percentage of respondents who placed a neutral value upon culturally significant plants. Blue identifies the percentage of respondents who identified culturally significant plants as valuable.

Within the education category (Fig. III.7) the group that had "Some College, No Degree" had the highest percentage that consider culturally significant plants valuable, while those with "12th Grade or Less" of "High School Graduate/GED" had similar lowest percentage.

Fig. III.8:The Likert plots show rating scale by income level value choices of culturally significant plants. Row count totals by category are provided on the right y-axis label of the Likert plots. Percentage of respondents' choice by value rating is provided on the x-axis. The stated value of culturally significant plant is identified by color. Red indicates respondents who considered culturally significant plants as being not valuable. White indicates the percentage of respondents who placed a neutral value upon culturally significant plants. Blue identifies the percentage of respondents who identified culturally significant plants as valuable.

Overall, the value of culturally significant plants increased with income to the "$25,000-$34,999", but decreased with increasing income levels thereafter (Fig. III.8). Among income level categories those with household incomes of "$25,000-34,999" had the highest percentage considering culturally significant plants valuable, while those with the highest income (i.e., "greater than $100,000").

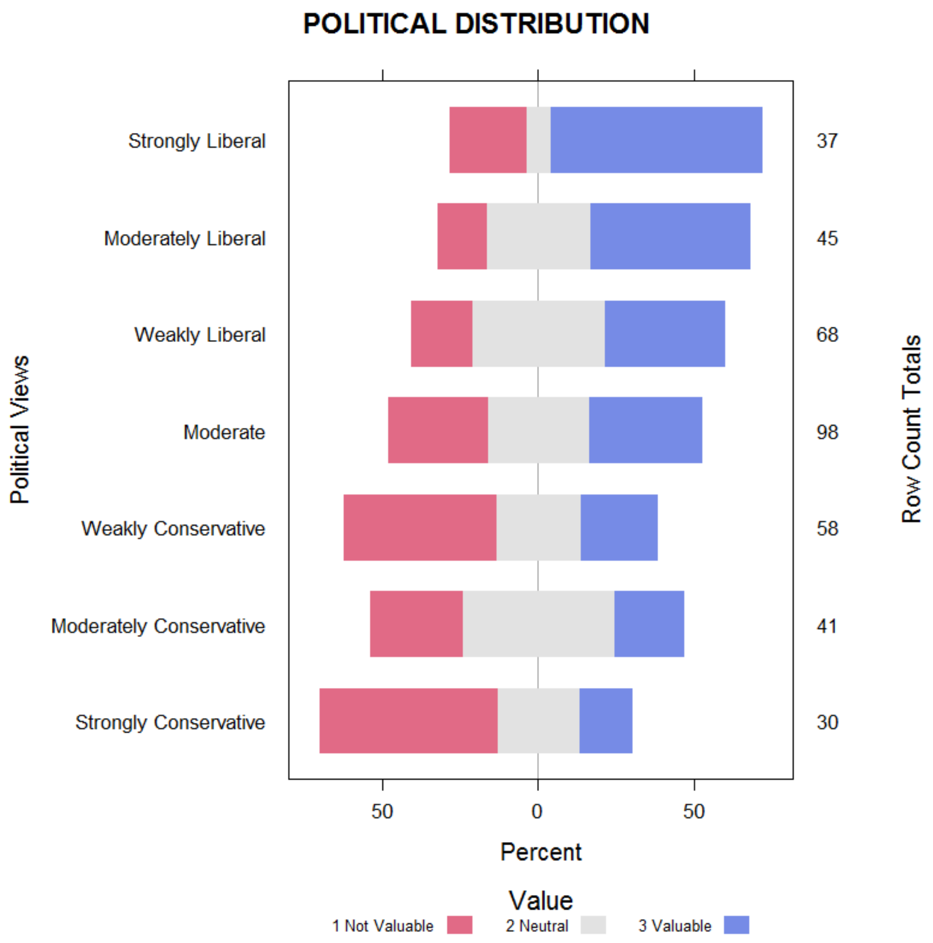


Fig. III.9:The Likert plots show rating scale by political view value choices of culturally significant plants. Row count totals by category are provided on the right y-axis label of the Likert plots. Percentage of respondents' choice by value rating is provided on the x-axis. The stated value of culturally significant plant is identified by color. Red indicates respondents who considered culturally significant plants as being not valuable. White indicates the percentage of respondents who placed a neutral value upon culturally significant plants. Blue identifies the percentage of respondents who identified culturally significant plants as valuable.

In general, individuals with liberal views are typically characterized as being tolerant of prejudice or bigotry, possess favorable views to governmental progress or reform, and support maximum individual freedoms. Individuals with conservative political views are inclined to maintain the existing or traditional order, respect for traditional institutions and opposed to attempts to achieve social change through legislation or publicly funded programs. Among the political view demographic (Fig. III.9), the "Strongly Liberal" category had the highest percentage of respondents who considered culturally significant plants as valuable, while the "Strongly Conservative" group had the lowest.

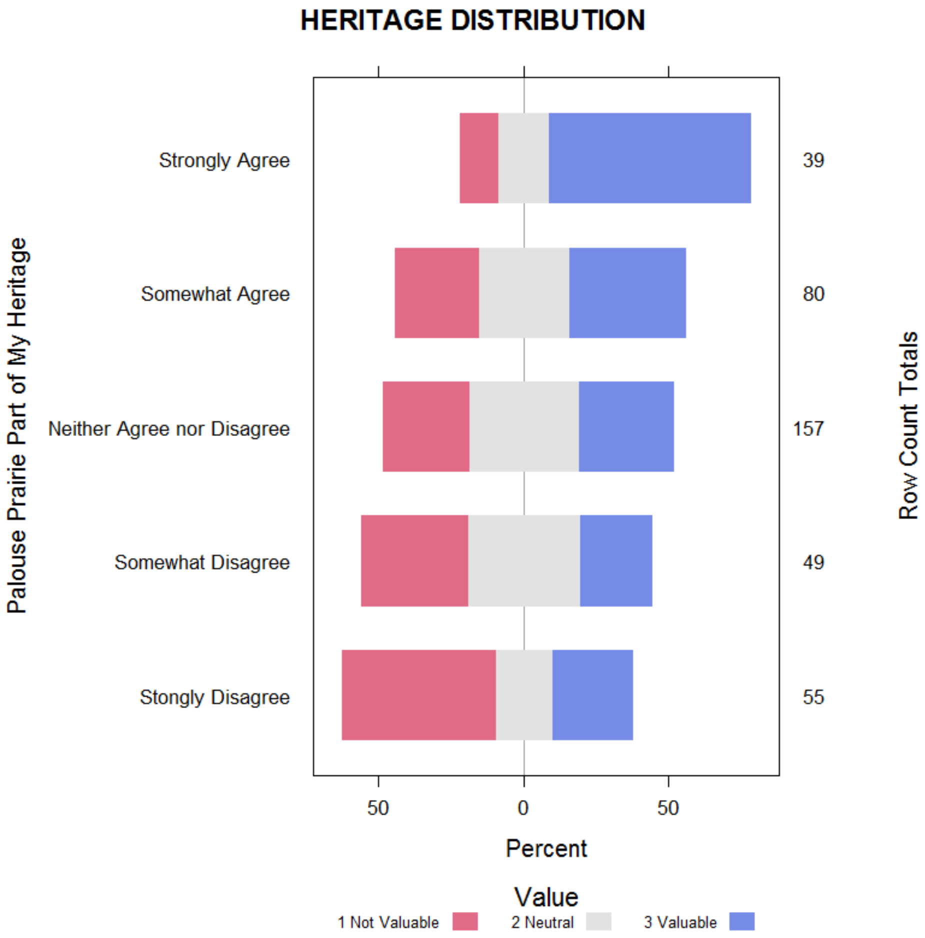


Fig. III.10:The Likert plots show rating scale by heritage value choices of culturally significant plants. Row count totals by category are provided on the right y-axis label of the Likert plots. Percentage of respondents' choice by value rating is provided on the x-axis. The stated value of culturally significant plant is identified by color. Red indicates respondents who considered culturally significant plants as being not valuable. White indicates the percentage of respondents who placed a neutral value upon culturally significant plants. Blue identifies the percentage of respondents who identified culturally significant plants as valuable.

Those respondents who strongly agreed that the Palouse Prairie was part of their heritage had the highest percentage who considering culturally significant plants valuable, while those who "Somewhat Disagreed" had the lowest (Fig. III.10).

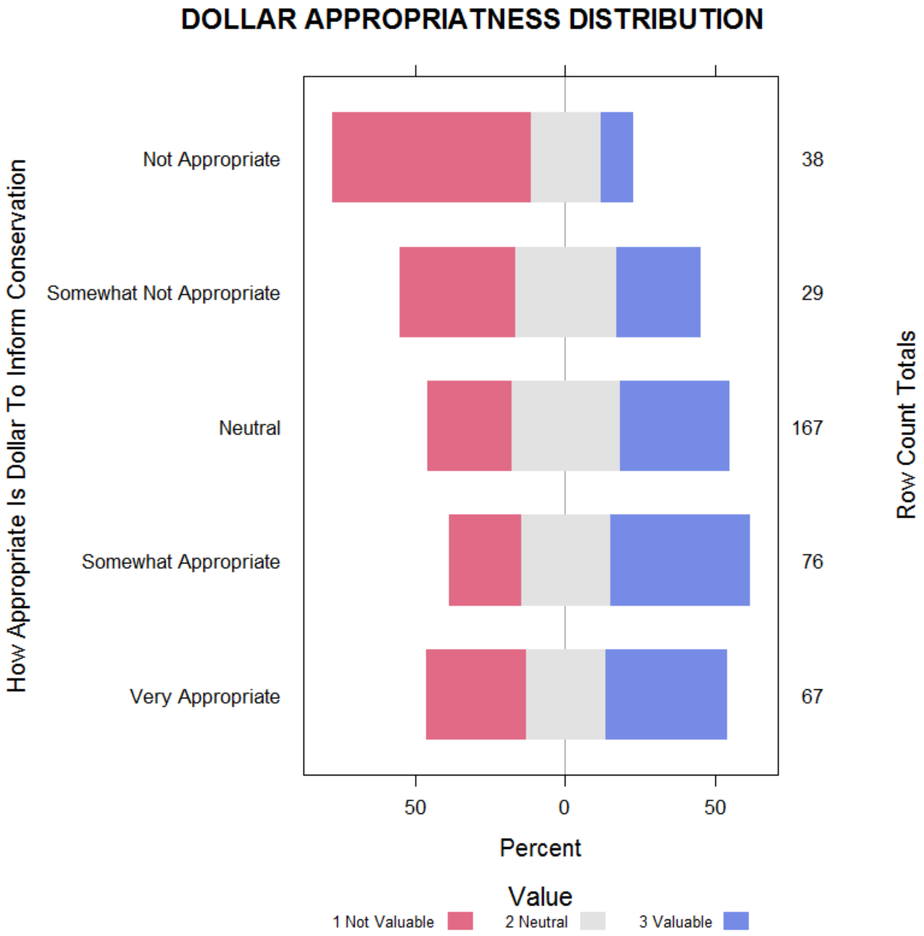


Fig. III.11:The Likert plots show rating scale by dollar appropriateness value choices of culturally significant plants. Row count totals by category are provided on the right y-axis label of the Likert plots. Percentage of respondents' choice by value rating is provided on the x-axis. The stated value of culturally significant plant is identified by color. Red indicates respondents who considered culturally significant plants as being not valuable. White indicates the percentage of respondents who placed a neutral value upon culturally significant plants. Blue identifies the percentage of respondents who identified culturally significant plants as valuable.

Respondents who selected “Somewhat Appropriate” for using a dollar amount to inform conservation decisions about the Palouse Prairie had the highest percentage that considered culturally significant plants valuable, while those that selected “Not Appropriate” had the lowest (Fig. III.11).

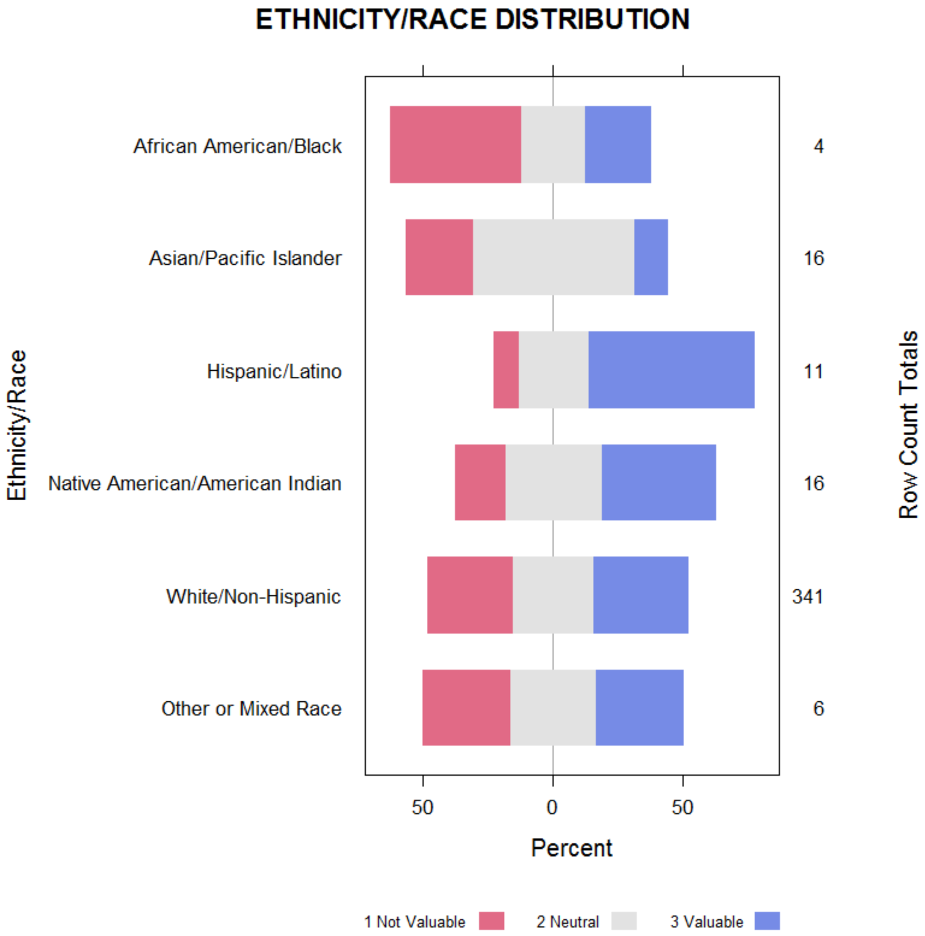


Fig. III.12:The Likert plots show rating scale by ethnicity/race value choices of culturally significant plants. Row count totals by category are provided on the right y-axis label of the Likert plots. Percentage of respondents' choice by value rating is provided on the x-axis. The stated value of culturally significant plant is identified by color. Red indicates respondents who considered culturally significant plants as being not valuable. White indicates the percentage of respondents who placed a neutral value upon culturally significant plants. Blue identifies the percentage of respondents who identified culturally significant plants as valuable.

In regard to ethnicity/race group (Fig. III.12), the "Hispanic/Latino" category had the highest percentage of respondents who considered culturally significant plants as valuable, while the "Asian/Pacific Islander" group had the lowest.

Overall 384 individuals or 36 percent of all respondents to the survey considered culturally significant plants as valuable and 64 percent were equally divided between neutral and not-valuable. In other words, one-third of the population in Latah County, Idaho, Whitman County, Washington, and three towns (e.g., Plummer, Worley, and Lapwai) located on Native

American Reservations consider culturally significant plants valuable. The OLR output modeling the value of culturally significant plants by Age Category, Education Level, Female Gender, Income, Political View, Heritage, and Dollar Appropriateness is provided in Table III.3. The estimates of the two intercepts (cutpoints) are provided in Table III.4.

Table III.3: Ordered logistic regression output modeling value of culturally significant plants by Age Category, Education Level, Female Gender, Income, Political View, Heritage, and Dollar Appropriateness. Output includes coefficient table including the value of each coefficient, standard error, t-value, estimated p-value, and 95% confidence intervals.

Factor	Coefficient Value	Standard Error	t-value	p-value	2.5%	97.5%
Age Category	-0.01194	0.07332	-0.1628	0.8706	-0.1561	0.1318
Education Level	0.09393	0.08294	1.1325	0.2574	-0.0688	0.2569
Female Gender	0.58374	0.22883	2.5510	0.0107	0.1365	1.0346
Income	-0.18625	0.06240	-2.9847	0.0028	-0.3097	-0.0647
Political View	-0.28513	0.06947	-4.1046	<0.0000	-0.4231	-0.1503
Heritage	-0.41513	0.10037	-4.1362	<0.0000	-0.6150	-0.2208
Dollar Appropriateness	0.25683	0.09963	2.5778	0.0099	0.0623	0.4536

Table III.4: Cut-point intercepts for ordered logistic regression modeling value of culturally significant plants by Age Category, Education Level, Female Gender, Income, Political View, Heritage, and Dollar Appropriateness. Output includes the value of each coefficient, standard error, t-value, and estimated p-value.

Intercept	Coefficient Value	Standard Error	t-value	p-value
Valuable | Neutral	-2.0722	0.8576	-2.4165	0.0157
Neutral | Not Valuable	-0.5147	0.8506	-0.6052	0.5451

The odds ratios and confidence intervals for the significant factors are provided in Table III.5. Based upon the OLR model a change in gender from male to female, the odds of valuing culturally significant plants as “Valuable” versus “Neutral” or “Not Valuable” were 1.8 times greater, given that all of the other variables in the model are held constant. Likewise, the odds of valuing culturally significant plants as “Valuable” or “Neutral” versus “Not Valuable” is 1.8 times greater for females, holding all of the other variables in the model constant. The second highest odds ratio was dollar appropriateness; as a dollar appropriateness level moved 1 unit, the odds of moving from “Valuable” to “Neutral” or “Not Valuable” (or from the “Valuable” and “Neutral” categories to the “Not Valuable” category) was 1.3 time greater. Income had a moderate odds ratio of 0.8. The lowest odds ratios were Heritage and Political View, with an odds ratio of 0.7.

Table III.5: Odds ratios and lower and upper confidence intervals.

Factor	**Odds Ratio**	**2.5%**	**97.5%**
Female Gender	1.7927	1.1462	2.8139
Income	0.8301	0.7337	0.9374
Political View	0.7519	0.6550	0.8605
Heritage	0.6603	0.5406	0.8019
Dollar Appropriateness	1.2928	1.0642	1.5740

Based upon the estimated response probabilities for gender (Table III.6), males had the highest probability for considering culturally significant plants as not valuable”. Females had the highest probability for considering culturally significant plants as valuable. This means that among the gender demographic females tend to value culturally significant plants more than males. Therefore, the finding supports a sex-specific difference in ethnobotanical valuation.

Table III.6: Estimated response probabilities for gender.

Culturally Significant Plants	**Male**	**Female**
Not Valuable	0.37	0.22
Neutral	0.34	0.32
Valuable	0.29	0.46

The estimated response probabilities indicate lower income levels place a higher value upon culturally significant plants than higher income levels (Table III.7). The “<$15,000” income level group had the highest response probability for considering culturally significant plants as valuable. While the lowest income level group valued culturally significant plants the most the highest income level group valued culturally significant plants the least. The political view analysis suggests culturally significant plants within the study area are mostly a good valued by poor.

Table III.7: Estimated response probabilities by income level.

Culturally Significant Plants	**<$15,000**	**$15,000-$24,999**	**$25,000-$34,999**	**$35,000-$49,999**	**$50,000-$74,999**	**$75,000-$99,999**	**>$100,000**
Not Valuable	0.19	0.22	0.25	0.28	0.32	0.37	0.41
Neutral	0.28	0.29	0.31	0.32	0.32	0.32	0.31
Valuable	0.53	0.49	0.44	0.40	0.35	0.31	0.28

The estimated probabilities according to political views are provided in Table III.8. Overall, there was a strong difference in response between the liberals and conservatives. Based upon the estimated response probabilities, "Very Liberal" respondents had the highest probability for considering culturally significant plants as valuable, while "Very Conservative" respondents had the lowest probability for valuing culturally significant plants. The political view analysis suggests that culturally significant plants are mostly valued by individuals with liberal political views, the value of culturally significant plants decreases considerably with conservatism.

Table III.8: Estimated response probabilities for political view.

Culturally Significant Plants	**Very Liberal**	**Liberal**	**Moderate Liberal**	**Moderate**	**Moderate Conservative**	**Conservative**	**Very Conservative**
Not Valuable	0.14	0.18	0.24	0.30	0.38	0.46	0.54
Neutral	0.27	0.31	0.33	0.35	0.34	0.33	0.29
Valuable	0.59	0.51	0.43	0.35	0.28	0.21	0.17

The estimated response probabilities for valuing culturally significant plants in relation to how respondent rated their heritage affiliation to the Palouse Prairie is provided in Table III.9. The response probabilities for considering culturally significant plants as valuable were highest for respondents who selected “Strongly Agree” that the Palouse Prairie was part of their heritage and lowest for the “Strongly Disagree” group. The analysis on heritage affiliation with the Palouse Prairie suggests that those who consider it to be part of their heritage value culturally significant plants the most, while those who do not consider the Palouse Prairie as part of their heritage value culturally significant plants the least.

Table III.9: Estimated response probabilities that the Palouse Prairie is considered part of the respondent’s heritage.

Value of Culturally Significant Plants	**Strongly Agree**	**Somewhat Agree**	**Neither Agree Nor Disagree**	**Somewhat Disagree**	**Strongly Disagree**
Not Valuable	0.16	0.23	0.31	0.41	0.51
Neutral	0.28	0.32	0.34	0.33	0.30
Valuable	0.56	0.45	0.35	0.26	0.19

The estimated response probabilities for valuing culturally significant plants for the question that examined how the respondent felt about basing conservation decisions upon a dollar amount is provided in Table III.10. The response probability for considering culturally significant plants as valuable was highest for those respondents who selected “Very Appropriate” for using a dollar amount to inform conservation decisions. The response probability was lowest for those individuals who considered it “Not Appropriate” to use a dollar amount to inform conservation decisions.

Table III.10: Estimate response probabilities on how appropriate or inappropriate it is to use a dollar amount to inform conservation decisions about the Palouse Prairie.

Value of Culturally Significant Plants	Not Appropriate	Somewhat Not Appropriate	Neutral	Appropriate	Very Appropriate
Not Valuable	0.49	0.42	0.34	0.27	0.21
Neutral	0.30	0.32	0.33	0.32	0.30
Valuable	0.21	0.26	0.33	0.41	0.49

Discussion

Interviews

Although little remains of the natural Palouse Prairie grassland, this study found that Native Americans of the region, as assessed through semi-formal interviews, and 36% of the general population surveyed considered culturally significant plants, lichens, mosses, and fungi of the Palouse Prairie to be valuable. Plant species such as camas were repeatedly identified as being important to the Nez Perce. The Nez Perce also conveyed during interviews that the importance of plants must be viewed in broader context of its function and contribution to the ecosystem. Furthermore, resource policy should consider input from Native Americans, as their knowledge, values, and use of the ecosystem may contribute to replenishment of natural plant foods and ecosystem services. For example, the Nez Perce method of harvesting camas after seed set and replanting of seed after harvesting disturbance or the practice of only taking the larger bulbs and replanting of the smaller bulbs. In some instances ecosystem conservation initiatives of Western Societies may be too quick to strictly exclude Native American human uses, without fully understanding how the practices or use contributes to ecosystem function and resiliency. The urgency of adopting aspects of traditional ecological knowledge of Native Americans into modern policy development may be a powerful tool to combat the profound and widespread ecocide and pollution we are experiencing today (Wildcat 2009).

Sample Surveys

Ethnobotanical valuations among people are thought to be dependent upon many factors. These factors can include: ethnicity, gender, age, education level, religious and cultural beliefs, abundance and usefulness of plant species, social status, income level, profession or role in the community and at home, mental capacity, as well as control and access to natural resources (Holt 2005, Ayantunde et al. 2008; Sop et al. 2011). Although we could not test for differences between ethnicity, we did find gender specific differences in how the local community valued culturally significant plants. The gender difference finding could be attributed women's roles in the local community or at home, and profession (Voeks 2006; Rangel de Almeida et al. 2010). However, further research would be necessary to identify why there was a difference between genders.

There was a valuation difference among differing income levels, as individuals in lower income classes placed a higher value upon culturally significant plants. Our finding is similar to the finding of Benz et al. (2000) who identified the most marginal of the communities in Manantlan, Mexico who used a wider diversity of plants and had more uses of individual species. However, our finding was different in that we assessed how varying income levels valued cultural significant plants as whole. As the approximately one third of the local community considered culturally significant plants as valuable, further research towards identifying individual species of the local community and their uses would be highly important for conservation purposes.

We were unable to find any valuation of culturally significant plants that assessed how political views influenced value choices. Based upon surveys from the World and European Values Surveys, Neumayer (2004) found left-wing orientations embraced pro-environmental issues. If valuing culturally significant plants is considered pro-environmental, our findings that self-identified liberals value culturally significant plants more than conservatives support the findings of Neumayer (2004). We were also unable to find any published study that valued culturally significant plants by assessing how the respondent self-identified heritage connection with the study area. Our findings suggest that individuals with a heritage connection with a region will value culturally significant plants higher than those who do not have such a connection. In regard to the valuation of culturally significant plants based upon how the respondent felt about basing conservation decisions upon a dollar amount, individuals who valued culturally significant plants are also concerned about costs associated with conservation. As a result, conservation costs are an important factor to consider during policy development to conserve culturally significant plants.

Conclusions

Existing valuation systems of culturally significant plants are often based upon one or more of the following attributes: number of potential uses, number of participants identifying a particular species, utilitarian purposes, taste appreciation, perceived quality, financial benefits provided, contingent valuations, marginal costs, time and travel spent harvesting and processing, selling price on the market, and value in local markets (Hunn 1982; Turner 1988; Stoffle et al. 1990; Phillips et al. 1994; Pieroni 2001; Godoy et al. 1993; Cocks and Wiersum 2003; Reyes-García et al. 2006; Thomas et al. 2009). Many of these studies have made an attempt to prioritize value to individual species, and focus on how a single social group (e.g., indigenous hunter gatherer society) values a plant taxon. Furthermore, little attention has been directed at valuing the importance of culturally significant plants using an integrated analysis of both Indigenous and non-Indigenous communities of a region.

Existing methods for prioritizing the value of an individual plant taxon in itself represents an epistemological difference between Western Societies and Indigenous people. For example, similar to the findings in this study Turner (1988:274) noted that when inquiring to a knowledgeable elder which plants are most important the elder responded “I’d pick them all – they’re all important”. On the other hand, existing valuation methods and research developed by Western scientists, which are often done in response to development, go to great efforts to define cultural significance of a plant taxon based upon the researcher’s perceived role it plays within a particular culture. This study was unique in that it did not make a distinction in value for an individual plant taxon and considered a broader group of stakeholders that included both the dominant non-Indian society and local responses and perspectives of Native American Tribes.

Based upon the findings of this study, social support to conserve culturally significant plants exists among females, Nez Perce Tribal members, individuals will liberal political views, people who consider the Palouse Prairie as being part of their heritage, and people within lower income classes. However, any conservation effort must recognize that the agricultural-dependent community of region as the primary steward of biodiversity for the region (Scherr and McNeely 2008). Optimally, it would be preferable to develop conservation initiatives that would result in co-benefits for biodiversity conservation, production, and local peoples (Scherr and McNeely 2007). There is an urgent to seek means to integrate agricultural production and biodiversity conservation on the Palouse Prairie in a way that can meet the demands for both agricultural products and ecosystem services.

One potential strategy towards conserving biodiversity on the Palouse Prairie is to implement institutional mechanisms to coordinate initiatives towards achieving biodiversity conservation, agricultural production, and livelihood objectives on a landscape scale (Scherr and McNeely 2008). For example, Nez Perce Tribal members identified several locations along major roadways and natural areas on the Palouse Prairie were camas continues to thrive. These areas could be recognized as important features of the cultural and natural heritage of the region, justifying their management as remnants of biodiversity beneficial to the local community, including Native American Tribes. As part of management of culturally significant plants and biodiversity, the local community could also consider impacts associated with agricultural inputs and make efforts to minimize environmental pollution. This is especially important considering that some of the Native Americans interviewees identified a concern about the harvesting of natural foods that have been exposed to pesticides or pollution. Another potential strategy to benefit biodiversity and culturally significant plants of the region would be to analyze at a landscape scale existing and potential habitat networks that can be enhanced to improve ecosystem integrity, structure, and function (Freemark et al. 2002; Scherr and McNeely 2008). For example, plantings of desirable native species along roadways and field margins could promote habitat connectivity and have little or no impact upon agricultural production. Where possible these networks could be targeted within existing patches with highest biodiversity or natural areas.

Ecological conservation policy should be careful to not adopt a worldview that sees “humankind as the ultimate measure of value” (Wildcat 2009:34), and respect should be provided to other forms of life. Chan et al. (2012) recommend using a multi-metric approach to value cultural services. Therefore, our hope was to facilitate a valuation through semi-formal interviews and sample survey of the local Palouse population that can be more representative and thus more readily accepted by the diverse stakeholders of the Palouse Prairie. We feel this study addresses a knowledge gap in how a broader group of stakeholders value culturally significant plants. Based upon the findings of this study, the importance of conserving culturally significant plants should not be overlooked and when possible incorporated into policy development. Policy development should also not overlook the sophisticated knowledge and philosophies of Indigenous peoples, and the role this knowledge can serve to protect ecosystem services, biodiversity, and culture (Wildcat 2009; Cajete 2000).

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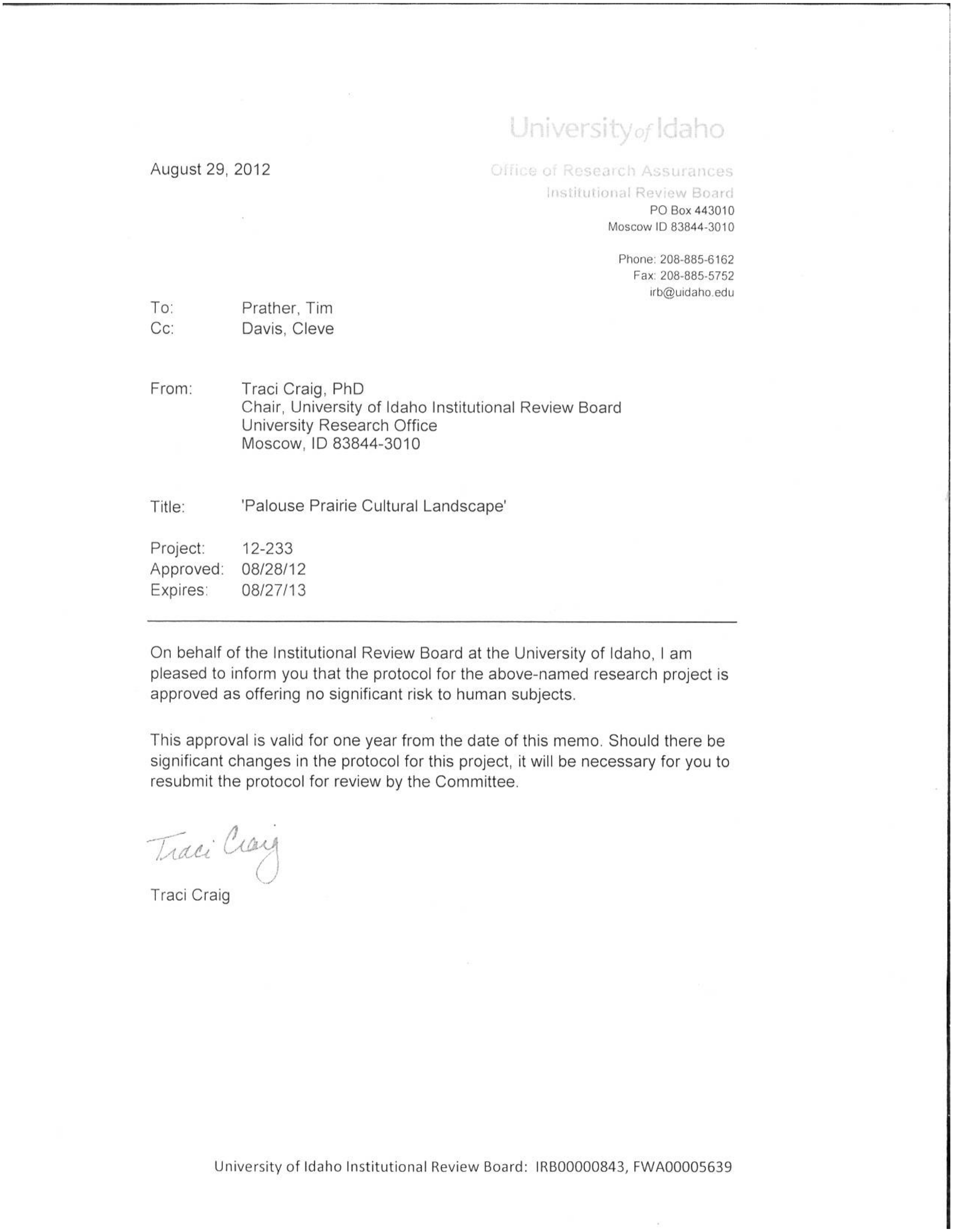
First Author's Professional Description

Cleve Davis is currently employed as the Environmental Coordinator of the Shoshone-Bannock Tribes and Ph.D. Candidate in the Environmental Science Program at the University of Idaho. His current research interests include: assessing social-ecological phenomena towards developing sustainable land use management policy; development of scientific graphics; and identifying opportunities towards incorporating Indigenous perspectives into the sciences.

Appendix 1: Internal Review Board Letter



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August 29, 2012

To: Prather, Tim
Cc: Davis, Cleve

From: Traci Craig, PhD
Chair, University of Idaho Institutional Review Board
University Research Office
Moscow, ID 83844-3010

Title: 'Palouse Prairie Cultural Landscape'

Project: 12-233
Approved: 08/28/12
Expires: 08/27/13

On behalf of the Institutional Review Board at the University of Idaho, I am pleased to inform you that the protocol for the above-named research project is approved as offering no significant risk to human subjects.

This approval is valid for one year from the date of this memo. Should there be significant changes in the protocol for this project, it will be necessary for you to resubmit the protocol for review by the Committee.

Traci Craig

Traci Craig

University of Idaho Institutional Review Board: IRB00000843, FWA00005639

Appendix 2: Semi-structured Interview Questions

1. What is your tribal affiliation?
2. Tell me a little about yourself?
3. What is your age?
4. What native plants and animals are important to you and your family?
5. Why are these native plants and animals important to you or your family?
6. What is the Indian language name of these plants and animals?
7. What language are you speaking?
8. Have you ever tried to access natural places, such as native grasslands or forests, on the Palouse Prairie?
9. Would you be interested in accessing natural places, such as native grasslands or forests, on the Palouse Prairie?
10. What can you tell be about the traditional use of the Palouse Prairie?
11. Do you farm or pasture livestock on the Palouse Prairie?
12. Most of the natural Palouse Prairie is in agriculture and only small patches of native grassland remain. What is your opinion on conserving what remains of the native grassland?
13. Over your lifetime have you noticed any unusual changes to the weather or regional climate? If so, do you foresee these changes affecting your life or traditions?
14. Do you know of anyone else who would be knowledgeable about Palouse Prairie and traditional customs of the Tribe?
15. Do you have anything else you want to say about the Palouse Prairie?