THE EFFECTS OF WOODY VEGETATION ENCROACHMENT AND REMOVAL WITHIN A COASTAL FEN

By

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ABSTRACT

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Early successional wetland habitat is being lost in temperate regions worldwide as a result of changes in disturbance regimes that allow for the establishment and dominance of woody species. In particular, this phenomenon is pronounced in fens, which harbor high numbers of rare herbaceous species that require early successional habitat. I investigated the relationship between woody vegetation encroachment and herbaceous species diversity within a Northern California coastal fen that has been undergoing encroachment by woody vegetation for ca. 80 years by recording species richness and cover data from 338 permanent plots throughout the fen. I also investigated the effect of a woody vegetation removal treatment on herbaceous species richness, non-native and special status botanical species occurrences by comparing the same plots before and after treatment. Before treatment, lower species richness was associated with higher woody vegetation cover and height along with higher litter cover and no special status botanical species were observed in areas with complete canopy closure. In addition, I found a significant reduction in herbaceous species richness with 65% woody vegetation cover resulting in, on average, a 50% loss of herbaceous species. Following woody vegetation removal, herbaceous species richness increased across the fen with the greatest increases

within areas that experienced more than 50% woody vegetation cover removal that were nearer the edge of encroaching vegetation. In addition, special status botanical species occurrences increased by 43% and non-native species occurrences increased by 71% after treatment. The results of this study suggest that the re-introduction of disturbance, specifically the removal of woody vegetation and litter accumulation, is likely essential to maintain herbaceous species diversity and persistence of special status species populations in coastal fens. Furthermore, disturbance can have mixed effects on sensitive vegetation communities, with the potential for promoting non-native species invasion that may require follow-up treatments to prevent unintended degradation of sensitive vegetation communities. Lastly, I developed a monitoring plan for the continued study of the fen to document changes in vegetation cover and composition for five years following the treatment. Results from the continued monitoring of the site should direct additional treatment and study.

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INTRODUCTION

Wetlands are among the most threatened ecosystems in the world with half of global wetland area having been lost over the last two centuries (Duffy 2011; Davidson 2014; Van Meter 2015). The loss of wetlands has been most concentrated in temperate regions where industrialization, transportation projects, and agricultural development has been particularly intensive (Tiner 1984; Armentano 1986; Turner 1991; Mattingly 1994; Gibbs 2000; Brinson 2002; Gutzwiller 2011). For example, portions of southern and eastern Europe, the southeastern United States, and California have lost an estimated 90% of their wetlands primarily in the last 150 years (Hefner 1984; Dahl 2004; Finlayson 1999; Dark 2006) resulting in a loss of species diversity from these regions (Euliss etal. 1999; Brinson 2002; Van Meter 2015; Duffy 2011). Much of the wetland loss within these regions has resulted from the conversion of wetlands to agricultural use, urban development, and roadway construction. To a lesser yet increasing extent, wetlands have also been lost or severely altered due to changes in disturbance regimes, in particular changes in fire return intervals and fire behavior. Changes in grazing patterns, reductions in fire return intervals, and changes in fire behavior can result in the loss of wetland habitat particularly in areas such as California, the southeastern United States, and central Europe (Hobbs 1992; Gusewell 2004; Martin 2009, Bart 2016).

In response to historical and on-going loss of wetland habitat, many wetland areas within North America and Europe have been set aside for conservation through land purchases and increased regulatory protection (Dahl 2006; Duffy 2011). Physical

disturbance, including timber harvest and livestock grazing, are usually excluded from protected wetlands. Fire exclusion, especially within the vicinity of populated areas, has impacted the natural disturbance regimes of many wetland ecosystems within the state of California (Hobbs 1992; Bowles 1996). Disturbance is an important component of many ecosystems, and many plant communities are entirely dependent on some disturbances (Pickett and White 1985). For example, in the absence of disturbance many wetland systems become increasingly dominated by woody vegetation (Godwin 1974; Christy 1979; Bowles 1996; Gusewell 2004; Middleton 2006; Warren 2007). Woody vegetation encroachment, and often the associated transition towards drier soils is occurring in many wetland types resulting in a marked decline in herbaceous species richness and cover (Bowles 1996; Gusewell 2004; Middleton 2006; Taft 2014; Taylor 2018). Many rare herbaceous wetland species are dependent on early successional conditions, and as such, are increasingly at risk of extirpation from protected, undisturbed wetlands (Gibbs 2000; Van Meter 2015). For example, wetlands in the southern Appalachian Mountains, which harbor a disproportionate number of special status species, are currently being impacted by woody vegetation encroachment and dominance (Warren 2007), and herbaceous dominated wetlands in Switzerland, previously used for grazing, are losing herbaceous species diversity following a cessation of agricultural use (Matthias 2001; Gusewell 2004). The loss of habitat dominated by herbaceous species within many protected wetlands is of particular concern as these areas were set aside as refugia for wetland dependent species in the face of historic wetland loss (Johnston 2007).

Woody vegetation encroachment is more pronounced in fen wetlands as compared to other wetland types such as bogs (Johnson 1996; Van den Broek 2006). Fens are generally recognized as being early successional wetlands (Gorham and Rochefort 2003; Baker 1972) and as such support early successional plant communities (Leppig 2002). In addition, fens are described as peatlands (i.e., sites where plant growth exceeds decomposition) with slightly acidic to even alkaline soils as a result of through-flowing water. These characteristics makes fens species rich, productive, and subject to organic matter accumulation and hydrologic change (Baker 1972; Erman 1977; Leppig 2004; Weixelman 2009; Granath 2010). However, in the absence of disturbance the rapid plant growth, high sediment input, and minimal decomposition of organic material often allows for aggressive growth of woody vegetation (Wilson 1986; Hausman 2007; Johnston 2009). In several studies, repeated disturbance was necessary to prevent fens from transitioning to drier, woody species dominated systems; fire was found to maintain prairie fen diversity (Bowles 1996), and mowing of Swiss fens every three years was found to maintain or increase herbaceous species diversity (Gusewell 2004). Like other wetland types, fire exclusion and changes in grazing practices and forest management have resulted in fens transitioning, often rapidly, to drier habitats that support species-poor communities dominated by woody species (Christy 1979; Bowles 1996; Leppig 2002; Gusewell 2004; Bencie 2007; Taylor 2018). In some cases of late seral fens, where early successional habitat has been lost to woody vegetation encroachment but still contain fen soils and hydrology, could potentially transition back to early successional conditions following significant disturbance.

Fen habitat is relatively uncommon in California where it primarily occurs at higher elevations (Leppig 2004; Sikes 2013). At lower elevations, it is known from locations along the immediate coast of Northern California (Baker 1972; Leppig 2002), with additional fens along the pacific coast north of California (Christy 1979, Christy 2005). As a result of their uncommon distribution and favorable conditions for plant growth, fens are known to harbor a high diversity of uncommon or rare botanical species and vegetation communities (Rubtzoff 1953; Baker 1972; Barry and Schlinger 1977; Christy 1979; Leppig 2002; Leppig 2004; Bencie 2007). Early successional fen habitat with diverse plant assemblages are very uncommon along the coast and are known from only a few select locations such as Big Lagoon Bog.

Big Lagoon Bog is a peatland fen along the north coast of California and represents an uncommon habitat that supports numerous rare plant species (Leppig 2002; Leppig 2004; Smith 2014). A total of 90 plant species have been recorded from Big Lagoon Bog prior to this study (Leppig 2002; Smith 2014). Of the 90 species recorded, 11 are considered special status species in California (Leppig 2002; Leppig 2004; CNDDB 2019, CNPS 2020), representing approximately 12% of the species diversity present within the fen. Of the 11 special status species reported from Big Lagoon Bog, three (*Carex leptalea* Wahlenb. (bristle-stalked sedge, Cyperaceae), *Juncus nevadensis* var. *inventus* (L.F. Hend.) C.L. Hitchc. (dune rush, Juncaceae), *Vaccinium uliginosum* L. *occidentale* (A. Gray) Hulten (western blueberry, Ericaceae)) are presumed to be extirpated from the site and another, *Lycopodiella inundata* (L.) Holub (inundated bog club-moss, Lycopodiaceae), is in immediate risk of extirpation. *Lycopodiella inundata* is

a circumboreal species known from two locations in the state of California (CNDDB 2019) representing peripheral populations that are likely genetically and ecologically distinct from more central populations (Leppig and White 2006). The population of *L. inundata* within Big Lagoon Bog has been slowly decreasing and now consists of a few individuals in a single location within the fen (Gordon Leppig, personal communication). *Viola pulustris* L. (alpine marsh violet, Violaceae), *Drosera rotundifolia* L. (round-leaved sundew, Droseraceae), and *Carex buxbaumii* Wahlenb. (Buxbaum's sedge, Cyperaceae) are wetland dependent species restricted to coastal or montane wetlands in California (Baldwin 2012) and *Sphagnum* moss is known from only a few disparate locations along the coast of California (CNDDB 2019). In fact, many of the special status plant populations recorded from Big Lagoon Bog are isolated peripheral populations (Leppig 2002; Leppig 2004; CNDDB 2019, CNPS 2020) and therefore likely possess distinct genetic and ecological characteristics (Leppig and White 2006) making their preservation all the more urgent. All of the rare botanical species reported from Big Lagoon Bog require early successional open habitat (Baldwin 2012).

A marked and progressive decline in open habitat within Big Lagoon Bog and other pacific northwest fens has been documented due to encroachment by woody vegetation for at least the last four decades (Christy 1979; Leppig 2004; Christy 2005, Bencie 2007). It is estimated that 60% of the open early successional habitat in Big Lagoon Bog has been lost as a result of woody vegetation encroachment. A progressively faster rate of woody vegetation encroachment has been observed within Big Lagoon Bog and in other similar habitats throughout the surrounding region (Christy 1979; Christy

2005, Bencie 2007). Many similar fens along the coast have been completely eliminated in the last 10-20 years due to woody vegetation encroachment and progression to forested habitat (Christy 1979; Leppig 2002; Christy 2005, Bencie 2007, Imper 2016). Of the 19 fens along the Pacific Coast studied by Christy in 1979, 15 were experiencing invasion by woody vegetation, and open, early successional habitat was found to be disappearing as a whole (Christy 1979).

Within Big Lagoon Bog, the dramatic increase in woody vegetation is directly linked to a cessation of disturbance. Historically, the area may have experienced natural and human caused fire events, and large elk herds and beaver may have provided a check on woody vegetation growth. In addition, tsunami events have been recorded in the area which would have greatly impacted Big Lagoon Bog as evidenced by tsunami sediment deposits (Gordon Leppig, personal communication). The area surrounding the fen was logged in the late 1800s and converted to farmed and grazed lands which continued through the 1930's. Grazing ceased in the late 1930's or early 1940's with the construction of nearby vacation homes, and this appears to be linked with the establishment of woody vegetation (Don Tuttle, personal communication). Lastly, a roadway was constructed in the 1960's on top of fill across the mouth of the fen which mutes hydrologic connection to Big Lagoon. This may affect salinity, water movement and wave action within Big Lagoon Bog and may have aided in the growth of woody vegetation.

The primary objective of my study was to investigate the impacts of woody vegetation encroachment on herbaceous species richness and cover within Big Lagoon

Bog. Specifically, this study aimed to quantify the relationship between woody vegetation encroachment and herbaceous species richness. In addition, this study aimed to update the botanical species lists for Big Lagoon Bog and map areas of highest herbaceous species diversity and rare species occurrences. To do this, I established permanent plots along transects within Big Lagoon Bog to obtain uniform coverage across the entire fen. In each plot, I recorded all herbaceous species and cover for each herbaceous species, as well as cover measures of non-living components such as thatch, litter, and large woody debris. In addition, species richness, cover, and average height of woody vegetation were recorded within each plot. Transects and plot locations were established so that plots can be revisited in subsequent years to allow for long-term monitoring and assessment of conditions within the fen. The data from these plots were used to develop statistical models that predict thresholds for the loss of herbaceous species richness and determine potential methods for restoration.

MATERIALS AND METHODS

Study Site

Big Lagoon Bog is a 1.3 ha peatland situated within a shallow depression on the southwest corner of Big Lagoon (Fig. 1). Big Lagoon is a brackish embayment at the mouth of Maple Creek and separated from the Pacific Ocean by a sand barrier that is typically breached in winter months by storm water affecting the water level and salinity of the lagoon. Water levels within Big Lagoon directly affect the water levels within Big Lagoon Bog. However, a gravel road constructed across the lower portion of the fen in 1963 appears to have muted inflow of water from Big Lagoon. A small perennial stream flows through Big Lagoon Bog from southeast to north that originates in forests dominated by *Sequoia sempervirens* (D. Don) Endl. (coast redwood, Cupressaceae) in the upper watershed and *Picea sitchensis* (Bong.) Carriere (Sitka spruce, Pinaceae) in the lower watershed. The upper watershed is managed for timber production while the lower portions of the watershed – including Big Lagoon Bog – are primarily located within public lands including Big Lagoon County Park and Humboldt Lagoons State Park. Currently, the area directly surrounding the fen is dominated by an 85 year old even-age *P. sitchensis* forest that dates back to a cessation in grazing. Woody shrub and tree encroachment is occurring from all sides of Big Lagoon Bog and radially from numerous points within the fen (D Imper, G Leppig, D York, pers. comm.).

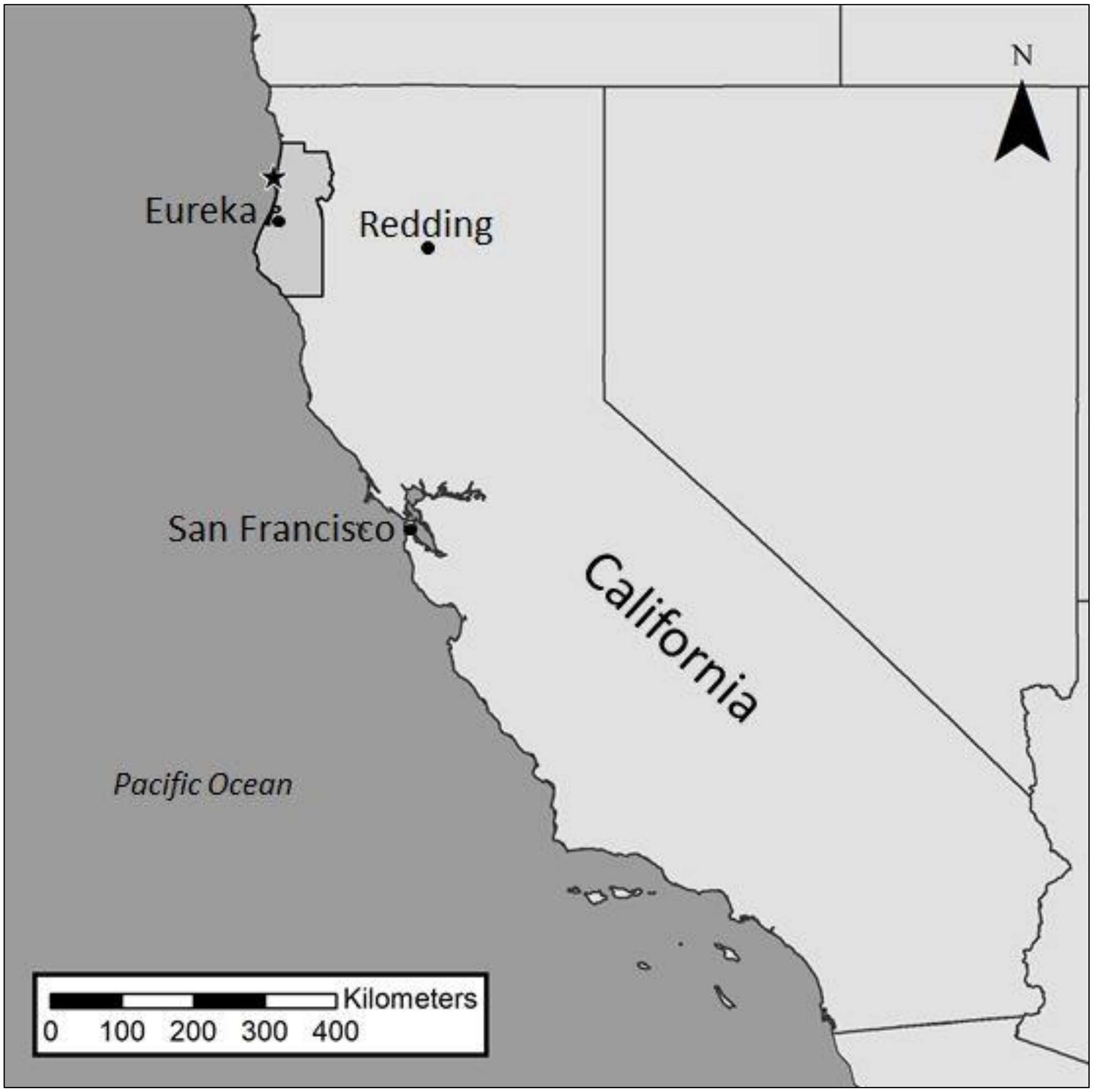

Figure 1. Location of Big Lagoon Bog within Humboldt County, California, USA as denoted by the star. Map created in the Geospatial Information System ArcMap (10.6.1).

Data Collection

I established a total of 25 transects by evenly dividing the length of Big Lagoon Bog from north to south and developing transects running west to east across the fen to ensure that the entire fen was adequately sampled (Fig. 2). I drove marked PVC pipe stakes into the forest soils at the edge of the fen at both ends of each transect to ensure the transects can be relocated during any subsequent monitoring. I verified the initial origin (starting point) on the western side of the fen for Transect 1 in the field using a measuring tape and triangulating from two predetermined hard points visible on aerial imagery which included the road to the campground and a corner of the nearest vacation home. The origin was further verified using a Trimble 6T GPS unit. The same method was used on the eastern side of the fen using the campground road as hard points for establishing the end point of Transect 1. Following establishment of the beginning and end points of the first transect, I established the remaining 24 transects using the first transect as a base-line and measuring the distance to the next transect start and end point. Each successive transect was placed 12 m from the previous transect with start and end points placed just outside of the fen and recorded using the Trimble 6T GPS unit. Transects were numbered from 1 to 25 heading north to south. Each transect had its origin on the western edge of the fen and its largest plot numbers on the east side of the fen. All transect start and end points were installed and recorded prior to tape measure and plot placement on any of the transects.

I collected plant community composition and species dominance data using 1x1 m quadrats randomly placed along transects. I ran a tape measure between the start and end point of the transect so that plot locations could be recorded and revisited for the duration of the study and any subsequent monitoring. A narrow swath of vegetation was cleared using a machete and loppers to place the tape measure in a straight line across the fen while attempting to minimize impacts to surrounding vegetation so as not to influence vegetation cover data. I offset plots from the tape measure to collect undisturbed vegetation data.

I collected data from July 11, 2018 to August 16, 2018, during the time when herbaceous species are most easily identified. I recorded all vascular plant species and the relative percentage canopy cover of each species within every plot. Species did not have to be rooted within a plot to contribute to cover percentages. Individual species and their corresponding percentage cover were recorded within either herb stratum or woody stratum. The herb stratum included relative cover percentages for litter, thatch, large woody debris (LWD), bare ground, water, and *sphagnum* in addition to relative cover percentages by non-woody plant species for a total of 100%. Litter was defined as dead material derived from woody vegetation, while thatch was defined as dead material derived from herbaceous vegetation. The woody vegetation stratum included all woody vegetation cover within and above the quadrat including trees and shrubs of any size. Cover included the relative percentage cover by each woody species for a total less than or equal to 100%. Overlapping woody vegetation could lead to inflated cover estimates that would influence the analysis on the effect of total woody vegetation cover on

herbaceous species cover and species richness. To address this, total woody vegetation cover was estimated followed by estimates for individual woody species cover. Areas of direct overlap were excluded to prevent double counting and inflating woody vegetation cover. Also recorded were incidental occurrences (outside of plots) of special status species and species recorded as being invasive by the California Invasive Plant Council (Cal-IPC 2020) as well as the beginning and end of fen soils in relation to the start and end points of each transect to record distance influence on woody vegetation encroachment.

Data Analyses

I created Generalized Linear Models (GLMs) to assess the relationship between woody vegetation encroachment and herbaceous species richness. Histograms and correlation tests of the variables were conducted prior to development of a suitable model to determine multicollinearity. I used ANOVA to assess which variables were significant and therefore appropriate for use in the model. Subsequently, GLMs were created using percent woody vegetation cover, percent litter cover, distance from the edge of the fen, woody vegetation height, and woody vegetation species richness as predictors of herbaceous species richness. GLMs were created assuming non-normally distributed data and the Poisson function for herbaceous species richness. Hypothesis tests including goodness of fit, residuals, dispersion, and significance of terms were conducted on the models in addition to Akaike's Information Criteria (AIC). Several different model iterations were developed prior to the creation of the model that best fit the data using the

above tests. The predicted values from the model and those from the data set were graphed to display the predictive power of the model and compare observed values to values predicted by the created model. Following model creation, predicted outputs were visually displayed to show the relationship between the predictor variables and herbaceous species richness. GLM creation and data analysis was conducted using R version 3.5.2 (R core team 2018). Visual display of the model outputs were created using the “visreg” package in R version 3.5.2 (R core team 2018).

RESULTS

A total of 87 species were observed within Big Lagoon Bog over the course of this study (Appendix A). Of these, 79 species (91%) were present within the study plots. 11 species previously unrecorded for Big Lagoon Bog were observed during the 2018 data collection effort which consisted primarily of common species that occur within the vicinity of the fen including the invasive *Hedera helix* L. (English ivy, Araliaceae). Of the total species observed, 22 were woody species and 65 were herbaceous or non-vascular species, of which eight were special status species and 11 were non-native species (Appendix A). While the 87 species observed in this study is less than the 90 previously reported from Big Lagoon Bog, the difference in species observed in this study and those previously reported (14 species) is likely a result of differences in study area. This study did not include species occurring outside of the extent of organic fen soil or portions of the fen north of the access road (Fig. 2). In addition, some species such as the Sierra rush or the western blueberry have not been recorded from Big Lagoon Bog for several decades (Leppig 2002).

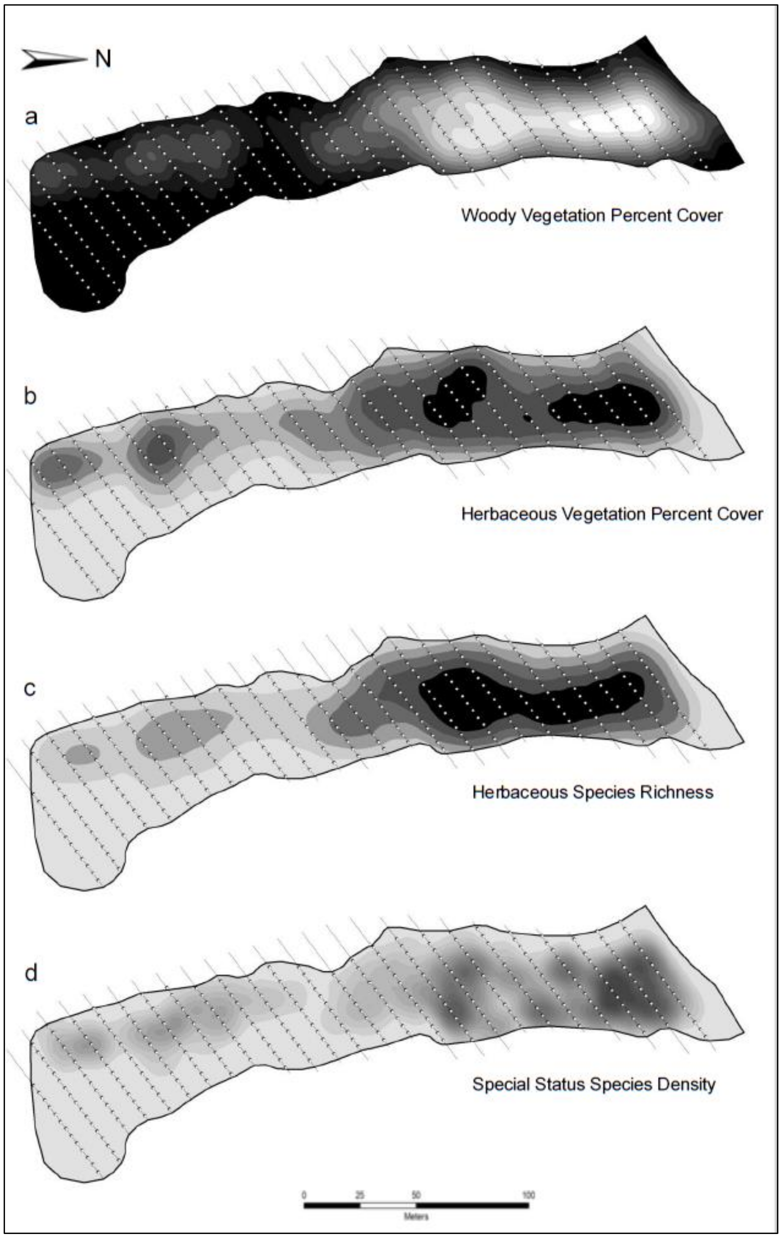

Figure 2. Heat maps of Big Lagoon Bog showing the percent cover of woody and herbaceous plants (panels a and b), herbaceous species richness (panel c), and the density of special status species (panel d). Transect and plot locations are shown as they were located within the fen. The fen boundary was determined by the edge of organic fen soil. Highest cover and density are depicted by the darkest color, and lowest cover and density are depicted by the lightest color

Within the 1x1 m study plots, average species richness was 8.4 species across the entire fen (range = 1 to 21). Plots contained an average of 3.8 woody species and 4.6 herbaceous species. The most diverse plot with 21 species was located in the center of the fen where the stream, which is channelized throughout the woody species dominated portions of the fen, fans out into shallow surface flowing water (Fig. 2, panel c). The least diverse locations within Big Lagoon Bog were within the southeastern portion of the fen under dense *P. sitchensis* cover which in several instances was the only species present within the plot (Fig. 2, panel c).

Eight of the 11 special status species previously recorded in Big Lagoon Bog were observed during the study while the three remaining special status species (*C. leptalea*, *J. nevadensis* var. *inventus* and *V. uliginosum*) were not observed. Special status species density was closely related to herbaceous species richness and cover. The highest density of special status species occurred in the north-central portion of the fen, as well as a small area in the southwestern portion of the fen, corresponding to a small remnant opening (Fig. 2, panel d).

Dominant species included primarily woody species; *P. sitchensis* exhibited the highest level of total average cover within the fen (19%) and was present in 52% of the plots. *Rubus ursinus* Cham. & Schltdl. (California blackberry, Rosaceae) was the most frequently occurring species and was observed in 62% of the plots with a total average cover of 3.4% within the fen (Table 1). Other woody dominants included *Morella californica* (Cham. & Schltdl.) Wilbur (California wax myrtle, Myricaceae; 10.9% average cover), *Ledum glandulosum* (Piper) Harmaja (Western Labrador tea, Ericaceae;

10.5% average cover), and *Spiraea douglasii* Hook. (Douglas spiraea, Rosaceae; 4.8% average cover; Table 1).

Dominant herbaceous species included *Struthiopteris spicant* (L.) F.W. Weiss (deer fern, Blechnaceae; 9.1% average cover), *Lysichiton americanus* Hulten & H. St. John (yellow skunk-cabbage, Araceae; 6.9% average cover) and *Calamagrostis nutkaensis* (J. Presl) Steud. (Pacific reed grass, Poaceae; 5.1% average cover; Table 1).

Of the 11 non-native species observed on site, five of them are recorded as invasive by the California Invasive Plant Council (Cal-IPC 2020). *Rubus armeniacus* Focke (Himalayan blackberry, Rosaceae), *Hypocheris radicata* L. (Hairy cat's-ear, Asteraceae), and *Cortaderia jubata* Stapf (jubata grass, Poaceae) were most prevalent of the invasive species observed. However, the non-invasive non-native *Eleocharis pachycarpa* E. Desv. (broad fruit spikerush, Cyperaceae) was the most abundant non-native species exhibiting 1.4% total average cover followed by *Danthonia decumbens* (L.) DC. (mountain heathgrass, Poaceae) with 2.2% total average cover.

Table 1. The 12 most abundant taxa found in the study of Big Lagoon Bog. Abundance is the average percent cover of the species within study plots. Frequency of occurrence is the percentage of study plots in which a species was observed.

Scientific Name	Common name	Abundance (% cover of fen)	Frequency of Occurrence (% of plots)	Functional group
Picea sitchensis	Sitka spruce	19%	52%	woody, tree
Morella californica	California wax-myrtle	10.9%	45%	woody, shrub
Ledum glandulosum	western labrador tea	10.5%	60%	woody, shrub
Struthiopteris spicant	deer fern	9.1%	57%	Herbaceous, fern
Lysichiton americanus	skunk cabbage	6.9%	42%	Herbaceous, herb
Calamagrostis nutkaensis	pacific reed grass	5.1%	35%	Herbaceous, graminoid
Sphagnum sp.	sphagnum	4.9%	25%	Herbaceous, non-vascular
Spiraea douglasii	Douglas spirea	4.8%	41%	woody, shrub
Salix hookeriana	coast willow	3.8%	12%	woody, tree
Malus fusca	Oregon crab apple	3.8%	11%	woody, tree
Rubus ursinus	California blackberry	3.4%	62%	woody, vine
Gaultheria shallon	salal	2.6%	29%	woody, shrub

Woody vegetation height within Big Lagoon Bog was primarily between 0 and 10 m with a few plots containing woody vegetation over 10 m representing mature *P. sitchensis* on the eastern and western edge of the fen. Average woody vegetation height

was 2.78 m which included open areas with very little woody vegetation cover. Woody vegetation cover ranged between 0% and 100% cover, with very few plots containing 0% cover. The average woody vegetation cover across the entire fen was 69.3%; however, woody vegetation was most dense along the edges of the fen and within the entire southeastern portion of the fen (Fig. 2, panel a). Herbaceous species cover ranged between 0% and 100% cover, with few plots recording 100% cover by herbaceous species. The average herbaceous species cover across the entire fen was 41%. Herbaceous species cover was highest in the north central portion of the fen where woody vegetation cover was lowest (Fig. 2, panel b).

A Generalized Linear Model (GLM) to describe the relationship between herbaceous species richness and woody vegetation encroachment was developed that utilized percent woody vegetation cover, percent litter cover, distance from the edge of the fen, woody vegetation height, and woody vegetation species richness as predictors of herbaceous species richness (Table 2 and Table 3). The model was a good predictor of the relationship between these variables and herbaceous species richness within Big Lagoon Bog and met the hypothesis test, dispersion (0.98), and goodness of fit criteria ($P > 0.22$) for a GLM (Table 2). Aikeke's Information Criteria (AIC) indicated that the model using these predictor variables was better than models using fewer variables (Table 2).

The model indicated that increased woody vegetation cover, woody vegetation height, and increased litter cover are negative predictors of herbaceous species richness. For example, increasing woody vegetation cover to 65% woody vegetation results in a

50% reduction in herbaceous species richness (Table 3, Fig. 3, panel a). Increasing litter cover to 58% litter results in a 50% reduction of herbaceous species richness (Fig. 3, panel 2). Increasing woody vegetation height of 16 m results in a 50% reduction of herbaceous species richness (Fig. 3, panel c). The model also indicated that distance from the edge of the fen and woody vegetation species richness are positive predictors of herbaceous species richness (Table 3). For example, increasing the distance from the edge of the fen to 35m results in a 50% increase in the number of herbaceous species. Likewise, the presence of seven woody vegetation species results in a 50% increase of herbaceous species richness (Fig. 3, panel 5).

Table 2. GLM for predicting herbaceous species richness in Big Lagoon Bog. The full model included the following predictors: Woody Vegetation Cover, Litter Cover, Distance from the edge of the Fen, Woody Vegetation Height, and Woody Vegetation Species Richness. Diagnostic tests confirm the suitability of the full model.

Model: HerbRichness ~ Woody Cover + Litter + Distance + Woody Height + Woody Richness, family=poisson	
Full AIC Reduced AIC	1310.4 1441.5
Full model dispersion Goodness of fit	0.98 *P* >0.22

Table 3. GLM for predicting herbaceous species richness in Big Lagoon Bog. All variables were significant predictors of herbaceous richness.

	Estimate	SE	z	*P*-value
Intercept	2.2003	0.0869	25.310	<0.0001
Woody Vegetation Cover	-0.0106	0.0014	-7.843	<0.0001
Litter Cover	-0.0124	0.0015	-8.434	<0.0001
Distance from Edge of Fen	0.0107	0.0036	2.975	0.0029
Woody Vegetation Height	-0.0446	0.0129	-3.460	0.0005
Woody Vegetation Richness	0.0542	0.017612	3.079	0.0021

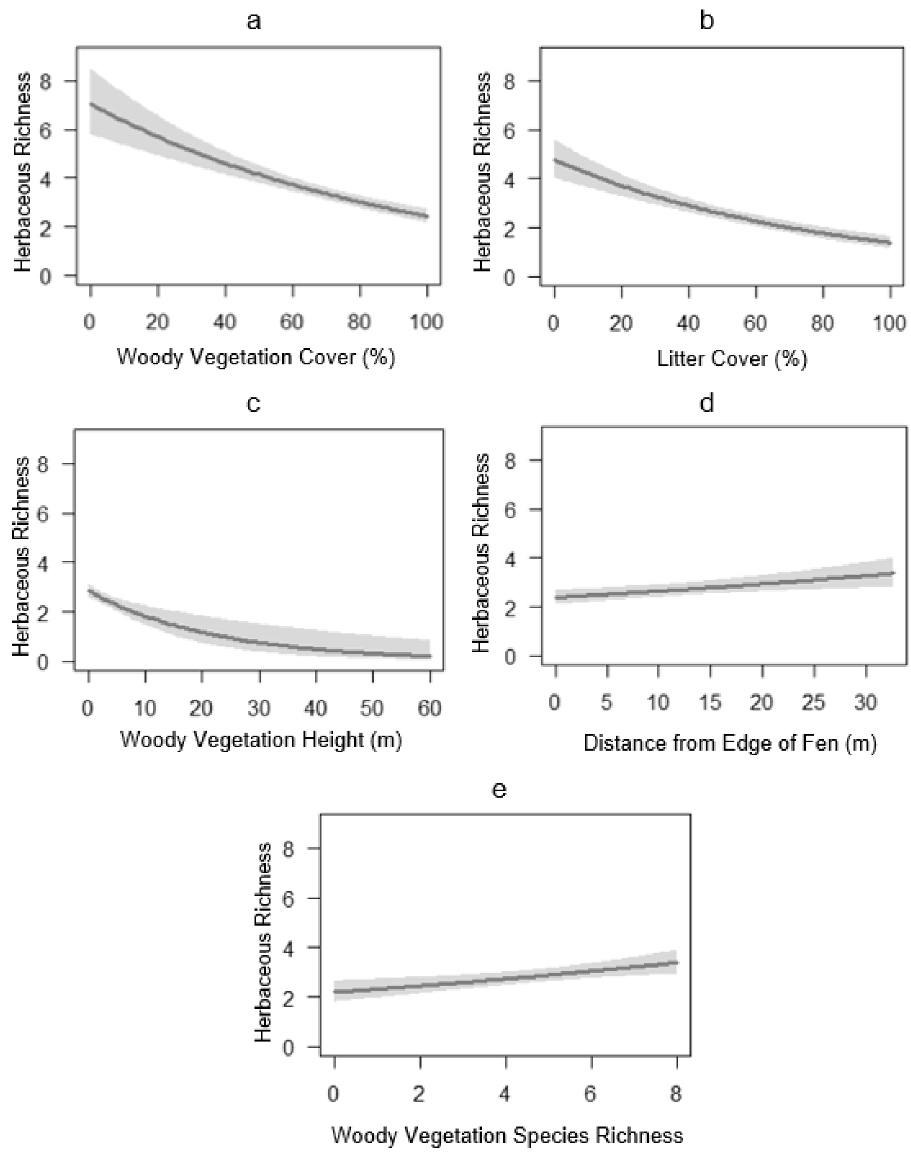

Figure 3. Graphical representation of the response of herbaceous species richness to five predictor variables: (a) Woody Vegetation Cover, (b) Litter Cover, (c) Woody Vegetation Height, (d) Distance from the Edge of Fen, and (e) Woody Vegetation. Richness measures are estimated using the GLM described in detail in the text. Line is the mean predicted using the model; gray shaded area is the confidence interval.

DISCUSSION

This study provides strong evidence that woody vegetation encroachment has been a primary driver of herbaceous species loss in Big Lagoon Bog. Furthermore, if encroachment continues, decreases in herbaceous species diversity will likely continue to occur across additional parts of the fen. Several components of woody vegetation encroachment that I measured influenced herbaceous species diversity including woody vegetation cover, litter cover, woody vegetation height, distance from the edge of the fen, and woody vegetation species richness. These processes are likely to be occurring at numerous other similar coast fen habitats that are known to be decreasing in size due to encroachment. This study can be used to estimate the thresholds that exist for maintaining herbaceous species diversity in fens and wetlands currently in the process of woody vegetation encroachment, and my methodologies can be applied to other fens. In addition, this study suggests that the removal of woody vegetation may be a viable restoration technique within fens and other wetland types currently being impacted by woody vegetation encroachment due to the absence of disturbance.

Woody vegetation cover and woody vegetation height were found to have a strong negative relationship with herbaceous species richness and cover (Fig. 2 and Fig. 3, panel a, panel b, and panel c). Using the model I produced, 65% woody vegetation cover results in a 50% loss of herbaceous species, while a woody vegetation height of 16 m results in a 50% loss of herbaceous species. This later relationship is likely a result of decreasing light availability and increasing competition with herbaceous species in the

understory (Coomes and Grubb, 2000). Woody vegetation height can also be a measure of the age of woody vegetation. Litter cover is a direct result of woody vegetation encroachment with increasing woody vegetation encroachment supporting increased litter deposition. The decrease in herbaceous species richness associated with increasing litter cover is likely a result of changes in soil conditions (Diemer etal. 2001); primarily a loss of exposed soils. Many of the herbaceous species present within the fen appear to require bare organic soils for germination, and increasing litter deposition will raise the substrate level above the water table creating dry conditions that are not suitable for wetland dependent species germination or persistence (Diemer etal. 2001). Litter is likely to suppress diminutive herbaceous species such as *sphagnum* and *D. rotundifolia*.

Distance from the edge of the fen and increased woody vegetation species richness were strongly associated with increasing herbaceous species richness. Herbaceous species richness was found to be highest in the center of the fen where woody vegetation cover was low to non-existent and the water table is at or near the soil surface (Fig. 3, panel c). Woody vegetation is less dense in the center of the fen allowing for a greater number of herbaceous species to persist.

Increasing woody species richness reflects the earliest stages of woody vegetation encroachment. Many woody vegetation seedlings may be present in plots with low woody vegetation cover and high herbaceous species richness signaling the beginning of woody vegetation encroachment. Over time, as the woody species mature, fewer species will be present within a square meter as some become shaded and others become dominant. Plots with the highest number of woody species therefore indicate pre-

encroachment or early successional conditions within Big Lagoon Bog with high herbaceous species diversity. Plots within these locations frequently had 15 or more herbaceous species present and close to 100% cover by herbaceous species. Dominant herbaceous species within these portions of the fen varied; however, *C. nutkaensis* and *Deschampsia cespitosa* ssp. *cespitosa* (L.) P. Beauv (tufted hairgrass, Poaceae) were common dominants.

Areas of the fen with the highest species diversity were also found to harbor the highest special status species densities. Special status species were found only in locations with little to no woody vegetation cover and were completely absent from locations with woody vegetation canopy closure (Fig. 3, panel d). This absence would suggest that as a group, special status species may be more sensitive to woody vegetation encroachment than some of the generalist herbaceous species and will likely be the first species to be extirpated from the fen following moderate woody vegetation canopy closure. Special status botanical species are often restricted to very specific habitat conditions (Mouillot et al, 2013) restricting them to small, select portions of the fen. When these areas become dominated by woody species, conditions change so that the area is no longer suitable for the support of the special status species previously found at that location. An example of this is *C. leptalea*, which was last observed within the fen in 2012 in an area now dominated by a closed woody vegetation canopy. Similarly, *L. inundata* was historically observed in several locations throughout the fen but is now restricted to a few individuals within a remnant opening surrounded by a closed woody canopy. My study indicates that continued woody vegetation encroachment will likely

result in the extirpation of special status species from Big Lagoon Bog, in addition to the majority of the herbaceous species that are currently found within the fen.

The results from this study have implications for the future of fens and other herbaceous dominated wetlands in California and other temperate climates. Herbaceous species diversity and special status species persistence within many protected fens and wetlands are in jeopardy as a result of changes in disturbance regimes which have allowed for the establishment and dominance of woody species. Without the return of disturbance to these systems to maintain open, early successional habitat it is likely that a complete shift to woody species domination will occur at the expense of herbaceous species diversity and cover as has been observed at other fens in North America, Europe (Bowles 1996; Matthias 2001; Warren 2007), and locally. The loss of herbaceous species diversity has been qualitatively observed in coastal fens within the Pacific Northwest as a result of woody vegetation encroachment (Baker 1972; Christy 1979; Bencie 2007, Imper 2016), however no new observations have been made in these fens to determine their condition at the present time. More recent observations in European fens have indicated a loss of herbaceous species diversity that continues as woody vegetation becomes more pervasive (Matthias 2001; Gusewell 2004; Middleton 2006), and herbaceous species richness has decreased in grasslands and savannas worldwide as a result of woody vegetation encroachment (Ratajczak 2012). Special status species occurrences are frequently the result of random introductions (Leppig 2004; Sikes 2013); therefore, it may be difficult to restore special status species diversity within fens and wetlands once the herbaceous layer is severely degraded or lost.

A restoration treatment of Big Lagoon Bog consisting of the removal of woody vegetation has been conducted following the completion of this study. It will take several years, at the least, to assess the effectiveness of this restoration effort. It may be that woody vegetation removal can reset succession within partially encroached wetland systems; however, it is unclear how effective it will be in restoring herbaceous diversity within fens and wetlands that have been impacted by a greater degree of woody vegetation encroachment. The loss of herbaceous species richness may be permanent if restoration efforts are conducted following complete canopy closure and extirpation of herbaceous species from the site.

The results from this study suggest that woody vegetation removal is a potential restoration method in fen and wetland habitat undergoing woody vegetation encroachment. The earlier woody vegetation removal treatment is conducted prior to canopy closure, the more likely a high level of herbaceous species diversity and early successional habitat can be maintained. The study also suggests that woody vegetation removal should be accompanied by litter removal through burning or manual removal as the presence of litter will likely prevent the germination of some herbaceous species. Woody vegetation cover and height and litter cover negatively affected herbaceous species richness; therefore the removal of woody species and litter prior to the extirpation of herbaceous species may be sufficient in resetting succession within encroached fens and wetlands, thereby maintaining or restoring herbaceous species richness and dominance.

CHAPTER 2: INITIAL RESPONSE OF VEGETATION TO A RESTORATION TREATMENT WITHIN A NORTHERN CALIFORNIA FEN

INTRODUCTION

Woody plant encroachment is a widely documented global phenomenon that alters ecosystems and reduces herbaceous plant productivity (Brudvig 2007; Limb 2014, Joyce 2014, Maestre 2016). Woody vegetation encroachment is occurring in grasslands, savannahs, woodlands, and wetlands (Brudvig 2007), and results in large, often permanent shifts in community composition (Beisner 2003; Brudvig 2007, Granath 2010), including declines in herbaceous species richness (Bowles 1996; Güsewell 2004; Middleton 2006; Joyce 2014; Taft 2014; Taylor 2018). Many ecosystems undergoing woody vegetation encroachment have already been lost or significantly altered as a result of historical and on-going urban, agricultural, and infrastructure development (Zedler 2001, Duffy 2011). In addition, changes in disturbance regimes has led to increases in woody vegetation with similar impacts of reducing herbaceous diversity. Disturbance, in particular fire, grazing, and flooding is an important component of many plant communities (Pickett and White 1985; Middleton 2006; Limb 2014) and these disturbance events are often what prevented large scale woody vegetation encroachment historically (Brudvig 2007).

Wetland habitat is particularly vulnerable to degradation by woody vegetation encroachment because woody plants can produce marked changes in hydrology, sediment input, and disturbances (Erwin 2009; Saintilan 2015). In wetlands, woody vegetation encroachment contributes to a decline in herbaceous species diversity by increasingly monopolizing limiting resources such as light, space, nutrients, and water (Warren 2007;

Ratajczak 2012). Degradation of wetlands is of critical importance because wetlands provide critical ecosystem services (Clarkson 2018) and are among the most threatened ecosystems in the world; wetlands cover ~6% of the Earth's surface (Erwin 2009) and half of global wetland area has been lost over the last two centuries (Duffy 2011; Davidson 2014; Van Meter 2015). Some areas within California and Europe, for instance, have lost up to an estimated 90% of their wetlands, primarily during the last 150 years (Hefner 1984; Dahl 2004; Finlayson 1999; Dark 2006), and this has resulted in a loss of species diversity from these regions (Euliss et al. 1999; Brinson 2002; Van Meter 2015; Duffy 2011). More recently, in response to the loss of wetland habitat, many wetland areas within North America and Europe have been set aside for conservation through land purchases and increased regulatory protection (Dahl 2006; Duffy 2011). Anthropogenic disturbances, including timber harvest and livestock grazing, are usually excluded from protected wetlands. More importantly, wildfire, cultural burning, flooding and other natural physical disturbances are also typically excluded which impacts the natural disturbance regimes of many wetland ecosystems set aside for preservation (Hobbs 1992; Bowles 1996). In the absence of disturbance, many wetland systems become increasingly dominated by woody vegetation and experience a loss of herbaceous richness (Godwin 1974; Christy 1979; Bowles 1996; Güsewell 2004; Middleton 2006; Warren 2007). The loss of habitat dominated by herbaceous species within protected wetlands is of particular concern as these areas are acting as refugia for wetland dependent species – almost always herbaceous species – in the face of historic wetland loss (Johnston 2007).

The dramatic surge in woody vegetation encroachment into wetlands has led to an increase in calls to reverse the trend using restoration efforts (Zedler 1996; Matthews 2010). Reintroduction of fire has been used with more frequency to restore areas experiencing woody vegetation encroachment (Simenstad 2006, Brudvig 2007); however, re-introduction of fire into encroached systems may not be effective due to opposition by adjacent land owners (Simenstad 2006), changes in fuel loading that increase the intensity of fire, or the increased resistance of large trees to prescribed fire (Brudvig 2007; Limb 2014). These systems represent an alternative steady state that may be nearly impossible to restore with a simple re-introduction of disturbance (Beisner 2003; Brudvig 2007). In these systems, manual removal of encroaching species might be more effective in restoring pre-encroached conditions (Brudvig 2007; Limb 2014). If these encroached wetlands are to be properly restored, restoration efforts cannot be seen as a one-time event, but rather a long-term commitment (Smit 2004, Zedler 2000).

Woody vegetation encroachment is more pronounced in fen wetlands as compared to other wetland types such as bogs or wet meadows (Johnson 1996; Van den Broek 2006). Fens are recognized as being early successional wetlands (Gorham and Rochefort 2003; Baker 1972) and as such, support early successional plant communities (Leppig 2002). In addition, fens are described as peatlands (i.e., sites where plant growth exceeds decomposition), with slightly acidic or alkaline soils as a result of through-flowing water. These characteristics make fens species rich, productive, and subject to organic matter accumulation and hydrologic change (Baker 1972; Erman 1977; Leppig 2004; Weixelman 2009; Granath 2010). However, in the absence of disturbance, the

rapid plant growth, high sediment input, and minimal decomposition of organic material allow for aggressive growth of woody vegetation (Wilson 1986; Hausman 2007; Johnston 2009). In several studies, repeated disturbance was necessary to prevent fens from transitioning to drier, woody species dominated systems. For instance, fire was found to maintain prairie fen diversity (Bowles 1996) and mowing of Swiss fens every three years was found to maintain or increase herbaceous species diversity (Güsewell 2004). Like other wetland types, fire exclusion and changes in grazing practices and forest management have resulted in fens rapidly transitioning to drier habitats that support species-poor communities dominated by woody species (Christy 1979; Bowles 1996; Leppig 2002; Güsewell 2004; Bencie 2007; Taylor 2018).

My study was conducted at Big Lagoon Bog in northern California; a rare peatland fen habitat that supports numerous rare plant species (Leppig 2002; Leppig 2004; Smith 2014). A total of 90 plant species have been recorded from Big Lagoon Bog prior to this study (Leppig 2002; Smith 2014). Of the 90 species recorded, 11 are considered special status species in California (Leppig 2002; Leppig 2004; CNDDB 2019, CNPS 2020), representing approximately 12% of the species diversity present within the fen. Three of the special status species – *Carex leptalea* Wahlenb. (bristle-stalked sedge, Cyperaceae), *Juncus nevadensis* var. *inventus* (L.F. Hend.) C.L. Hitchc. (dune rush, Juncaceae), and *Vaccinium uliginosum* L. subsp. *occidentale*) (A. Gray) Hulten (western blueberry, Ericaceae) – are presumed to be extirpated from the site, and another species, *Lycopodiella inundata* (L.) Holub (inundated bog club-moss, Lycopodiaceae), is in immediate risk of extirpation. *Lycopodiella inundata* is a

circumboreal species known from only two locations in the state of California (CNDDB, 2019) representing peripheral populations that are likely genetically and ecologically distinct from more central populations (Leppig and White 2006). The population of *L. inundata* within Big Lagoon Bog has been slowly decreasing and now consists of a few individuals in a single location within the fen (G. Leppig, pers. comm.). In addition, *Viola pulustris* L. (alpine marsh violet, Violaceae), *Drosera rotundifolia* L. (round-leaved sundew, Droseraceae), and *Carex buxbaumii* Wahlenb. (Buxbaum's sedge, Cyperaceae) are wetland dependent species restricted to coastal or montane wetlands in California (Baldwin 2012) and *Sphagnum* moss is known from only a few disparate locations along the coast of California (CNDDB 2020). In fact, many of the special status plant populations recorded from Big Lagoon Bog are isolated peripheral populations (Leppig 2002; Leppig 2004; CNDDB 2019, CNPS 2020) and therefore likely possess distinct genetic and ecological characteristics (Leppig and White 2006) making their preservation all the more urgent. All of the rare botanical species reported from Big Lagoon Bog require early successional open habitat (Baldwin 2012; Flora of North America 2020).

A marked and progressive decline in open habitat within Big Lagoon Bog has been documented due to encroachment by woody vegetation for at least the last four decades (Christy 1979; Leppig 2004; Bencie 2007). Over that time period ~60% of the open early successional habitat in Big Lagoon Bog has been lost as a result of woody vegetation encroachment. A progressively faster rate of woody vegetation encroachment has been observed within Big Lagoon Bog and in other similar habitats throughout the surrounding region (Christy 1979; Christy 2005; Bencie 2007). Many similar fens along

the coast have been completely eliminated in the last 10-20 years due to woody vegetation encroachment and progression to forested habitat (Christy 1979; Leppig 2002; Christy 2005; Bencie 2007). Of the 19 fens along the Pacific Coast studied by Christy in 1979, 15 were experiencing invasion by woody vegetation, and open, early successional habitat was found to be disappearing as a whole (Christy 1979; Christy 2005). It is likely that without some sort of woody vegetation removal treatment, or reintroduction of consistent disturbance regimes, this early successional habitat and the rare species it supports will soon be lost.

Within Big Lagoon Bog, the dramatic increase in woody vegetation is directly linked to a cessation of disturbance. Historically, the area may have experienced natural and human caused fire events, and large elk herds and beaver may have provided a check on woody vegetation growth. Tsunami events have been recorded in the area which would have greatly impacted Big Lagoon Bog as evidenced by tsunami sediment deposits (Gordon Leppig, personal communication). The area surrounding the fen was logged in the late 1800s and converted to farmed and grazed lands which continued through the 1930s. Grazing ceased in the late 1930's or early 1940's with the construction of nearby vacation homes, and this appears to be linked with the establishment of woody vegetation (Don Tuttle, personal communication). Lastly, a roadway was constructed in the 1960's on top of fill across the mouth of the fen which mutes hydrologic connection to Big Lagoon. This may affect salinity, water movement, and wave action within Big Lagoon Bog and may have aided in the growth of woody vegetation.

The primary objective of my study was to investigate the initial response of vegetation to a woody vegetation removal treatment within Big Lagoon Bog. Specifically, this study aimed to assess the response of herbaceous species to the woody vegetation removal treatment as well as the response of the woody vegetation to the treatment. Of particular concern is the response of special status species to the treatment as well as the rate of non-native species introductions or increases in non-native species cover within the treated areas. To do this, I established permanent plots along transects within Big Lagoon Bog prior to treatment in which I recorded species richness and cover as well as cover measures of non-living components such as thatch, litter, and large woody debris prior to treatment. The pre- and post-treatment data from these plots were used to develop statistical models that predict herbaceous species response to the treatment and to make recommendations about future restoration efforts.

MATERIALS AND METHODS

Site Description

Big Lagoon Bog is a 1.3 ha fen located in the southwest corner of Big Lagoon (Fig. 1) in coastal northern California. Big Lagoon is a brackish embayment at the mouth of Maple Creek separated from the Pacific Ocean by a sand barrier that is typically breached in winter months by storm water affecting the water level and salinity of the lagoon. Water levels within Big Lagoon directly affect the water levels within Big Lagoon Bog. Coastal northern California has a strong maritime climate with cool consistent year-round temperatures, persistent fog, and high precipitation levels, creating ideal conditions for peat development and suitable refugia for species found more commonly in northerly climates. A small unnamed perennial stream flows through Big Lagoon Bog from southeast to north that originates in forests dominated by *Sequoia sempervirens* (D. Don) Endl. (coast redwood, Cupressaceae) in the upper watershed and *Picea sitchensis* (Bong.) Carriere (Sitka spruce, Pinaceae) in the lower watershed. The upper watershed is managed for timber production while the lower portions of the watershed – including Big Lagoon Bog – are primarily located within public lands comprised of Big Lagoon County Park and Humboldt Lagoons State Park. Currently, the area directly surrounding the fen is dominated by an 85 year old even-aged *P. sitchensis* forest that dates back to a cessation in grazing. Summer vacation homes constructed in the 1930s exist to the west of the fen preventing the use of some restoration methods such

as prescribed fire. Woody shrub and tree encroachment is occurring from all sides of Big Lagoon Bog and radially from numerous points within the fen (D. Imper, G. Leppig, D. York, pers. comm.).

Data Collection

I evenly divided the length of Big Lagoon Bog from north to south resulting in the establishment of 25 transects 12 m apart. Transects were positioned from west to east across the fen (Fig. 2). I used marked PVC pipe stakes at both ends of each transect to facilitate the relocation of transects during post-treatment data collection and monitoring. I verified the initial origin (starting point) on the western side of the fen for Transect 1 in the field using a measuring tape and triangulating from the corner of the nearest vacation home and the road to the campground both of which were visible on aerial imagery. The origin was further verified using a Trimble 6T GPS unit. The same method was used on the eastern side of the fen using the campground road as a hard point for establishing the end point of Transect 1. Next, I established the remaining 24 transects using the first transect as a baseline and measuring the distance to the next transect start and end point. Each successive transect was placed 12 m from the previous transect with start and end points placed just outside of the fen and recorded using the Trimble 6T GPS unit. Transects were numbered from 1 to 25 heading north to south. Each transect had its origin on the western edge of the fen and its largest plot numbers on the east side of the fen.

I collected pre-treatment data from July 11, 2018 to August 16, 2018, and post treatment data from July 11, 2019 to August 16, 2019 during the time when herbaceous species are most easily identified. During pre-treatment data collection a narrow swath of vegetation was cleared using a machete and loppers to place the tape measure in a straight line across the fen while attempting to minimize impacts to surrounding vegetation. I offset plots from the tape measure to collect undisturbed vegetation data. During both pre- and post-treatment monitoring, I recorded all vascular plant species and the relative percentage canopy cover of each species within every plot. Species did not have to be rooted within a plot to contribute to cover percentages. Individual species and their corresponding percentage cover were recorded within either herb stratum or woody stratum. The herb stratum included relative cover percentages for litter, thatch, large woody debris (LWD), bare ground, water and *sphagnum* in addition to relative cover percentages by non-woody plant species such that all plant and abiotic elements summed to 100%. The woody vegetation stratum included all woody vegetation cover within and above the quadrat including trees and shrubs of any size, and this included re-sprouting woody species or woody species seedlings observed during the post treatment monitoring. Cover included the relative percentage cover by each woody species for a total less than or equal to 100%. Overlapping woody vegetation could lead to inflated cover estimates that would influence the analysis on the effect of total woody vegetation cover on herbaceous species cover and species richness. To address this, total woody vegetation cover was estimated followed by estimates for individual woody species cover; areas of direct overlap were excluded to prevent inflation of woody vegetation

cover estimates. Also recorded was the beginning and end of fen soils in relation to the start and end points of each transect to record distance influence on woody vegetation encroachment.

Woody Vegetation Removal

Woody vegetation removal was conducted from September 12, 2018 to October 17, 2018 by the California Conservation Corps (CCC). All woody vegetation within the fen with a diameter at breast height (DBH) under 30 cm were removed. Removal of woody vegetation required four weeks of work by crews of 9 to 17 individuals. Chain saws, polesaws, string trimmers, lopers and polaskis were used for vegetation removal. Areas with lower growing woody vegetation were removed with a string trimmer although special status herbaceous species were specifically avoided in these areas which often required the use of selective removal of woody vegetation using loppers. All debris was carried, not dragged, and dispersed within the *P. sitchensis* forest east of the fen. While the majority of large cut material was removed, there were portions of the fen that had woody debris which was not removed resulting in a thick layer of litter and residual large woody debris. Areas with substantial populations of special status species were flagged and avoided as were individual occurrences of special status species. In addition, areas with mucky or saturated soils were protected using temporary placement of plywood for the duration of work and debris removal. Lastly, species recorded as being invasive by the California Invasive Plant Council (Cal-IPC) were targeted for removal. These included *Rubus armeniacus* Focke (Himalayan blackberry, Rosaceae) and

Cortaderia jubata (Lemoine) Stapf (jubata grass, Poaceae) which were cut and covered by weedmat to prevent re-growth. Smaller herbaceous invasive species such as *Hypochaeris radicata* L. (hairy cat's-ear, Asteraceae) were treated with the stringed trimmer.

Data Analyses

I created Generalized Linear Models (GLMs) and Generalized Additive Models (GAMs) to assess the relationship between woody vegetation removal and herbaceous species response, special status species response, and non-native species response. I defined the herbaceous species response as the change in herbaceous cover and species richness between pre- and post-treatment monitoring. Specifically, the change in percent woody vegetation cover, change in litter cover, distance from the edge of the fen, and change in woody vegetation height were used as predictors of herbaceous species response, special status species response, and non-native species response. I defined non-native species was as all species occurring within the fen that are not native to the north California coast region including species recorded by Cal-IPC as being invasive as well as non-invasive, non-native species. Histograms and correlation tests of the variables were conducted prior to development of a suitable model to determine multicollinearity. I used ANOVA to assess the significance of each predictor variable to determine suitability for use in modeling. Subsequently, GLMs were created for each response variable of interest which included the change in herbaceous species richness, change in non-native species cover, and change in special status species cover. GLMs were created assuming

normally distributed data and the Gaussian function for herbaceous species richness, special status species cover, and non-native species cover. GAMs were not investigated further due to overfitting of the data. Hypothesis tests including goodness of fit, residuals, dispersion, and significance of terms were conducted on the models in addition to Akaikes Information Criteria (AIC). GLM creation and data analysis was conducted using R version 3.5.2 (R core team 2018). Visual display of the model outputs was created using the "visreg" package in R version 3.5.2 (R core team 2018).

RESULTS

Within the 1x1 m study plots, average species richness pre-treatment was 8.4 species across the entire fen (range 1 to 21). Pre-treatment plots were composed of an average of 3.8 woody species and 4.6 herbaceous species of which 4.2 herbaceous species were native and 0.4 were non-native. The most diverse plot (21 species) was located in the center of the fen where the stream, which is channelized throughout the woody species dominated portions of the fen, fans out into shallow surface flowing water (Fig. 2). The least diverse locations within Big Lagoon Bog were within the southeastern portion of the fen under dense *P. sitchensis* cover which in several instances was the only species present within the plot.

Following treatment, the mean increase in herbaceous species richness was 1.7 (range -4 to 9) species per m^2 plot. Native herbaceous species accounted for 1.4 additional species, while non-native species accounted for 0.3 additional species per plot after treatment. The greatest increases of herbaceous species were found in areas that were formerly encroached, within 4 m of the woody vegetation encroachment edge, and that experienced greater than 50% woody vegetation cover removal. Plots with losses in herbaceous species richness occurred throughout the fen, however, most were in areas with little vegetation removal in the northern portion of the fen. Plots were composed of a modest average of 0.095 additional woody species (range -4 to 5), and this reflected the addition of seedlings of woody species in plots.

Special status species cover for plots that included these species in pre-treatment monitoring decreased slightly by 0.32% (range -53% to 59%). In contrast, the number of plots containing special status species in pre-treatment monitoring (119 plots) increased 43% to 170 plots in post-treatment monitoring. When including multiple special status occurrences within individual plots, the total special status observations increased from 229 pre-treatment to 314 post-treatment plots representing a 37% increase in total special status species observations. *Sphagnum* moss accounted for the majority of special status species increases occurring in 83 plots pre-treatment and increasing to 129 plots post-treatment (55% increase). The majority of the *Sphagnum* increases consisted of small *Sphagnum* starts observed throughout the treated area but were concentrated in the southeast portion of the fen. *Viola palustris* exhibited the second highest increase from 30 occurrences pre-treatment to 45 occurrences post treatment (50% increase). Other special status species seedlings were observed in treated areas, but these accounted for a lesser portion of the increase in special status occurrences observed (see Table 4 for special status species response). *L. inundata* was not observed within plots but was observed in one location outside of the plots. No change in cover or occurrence for this species was observed following treatment.

Table 4. Response of special status species to the woody vegetation removal in the first year following treatment. Observations are the number of study plots in which each species was observed, change in abundance is the pre-treatment to post-treatment percent increase (or decrease) of study plots in which the species was observed.

Scientific Name	Common name	Functional group	Pre-treatment observations	Post-treatment observations	% Change in abundance
Carex buxbaumii	Buxbaum's sedge	Herbaceous, graminoid	30	36 (+6)	20%
Carex viridula ssp. *viridula*	green yellow sedge	Herbaceous, graminoid	19	21 (+2)	11%
Drosera rotundifolia	round-leaved sundew	Herbaceous, forb	26	36 (+10)	38%
Lathyrus palustris	marsh pea	Herbaceous, forb	19	14 (-5)	-26%
Lycopodiella inundata	inundated bog club-moss	Herbaceous, fern	0 (not obs. in plots)	0 (not obs. in plots)	0
Lycopus uniflorus	northern bugleweed	Herbaceous, forb	17	30 (+13)	76%
sp.	*Sphagnum* species	Herbaceous, non-vascular	83	129 (+46)	55%
Viola palustris	alpine marsh violet	Herbaceous, forb	30	45 (+15)	50%

A total of 15 non-native species were observed within Big Lagoon Bog: four of which were not observed pre-treatment. Within plots, non-native species cover increased an average of 2.36% (range 35% decrease to 66% increase). Occurrences increased from 89 plots containing non-native species pre-treatment to 152 plots post treatment (71% increase). Four herbaceous species accounted for the majority of the increase, including

Hypochaeris radicata (7 pre-treatment to 46 post-treatment plots), *Danthonia decumbens* (34 pre-treatment to 44 post-treatment plots), *Eleocharis pachycarpa* (79 pre-treatment to 89 post-treatment plots), and *Senecio minimus* (1 pre-treatment to 20 post-treatment plots) (Table 5). When including multiple non-native species occurrences within individual plots, the total non-native species observations increased from 135 pre-treatment to 228 post-treatment observations (69% increase).

Woody vegetation height within Big Lagoon Bog was between >0 and 10 m and the average woody vegetation cover across the entire fen was 69.3% pre-treatment. Woody vegetation removal treatment resulted in a 52% reduction from 69.3% to 33.0% cover, with the remaining woody vegetation cover consisting of vegetation around the edge of the fen including mature *P. sitchensis* as well as regrowth of cut vegetation.

Table 5. Response of non-native species to the woody vegetation removal in the first year following treatment. Observations are the number of study plots in which each species was observed; change in abundance is the percent increase (or decrease) of study plots in which the species was observed.

Scientific Name	Common name	Functional group	Pre-treatment observations	Post-treatment observations
Aira caryophyllea	silver hairgrass	Herbaceous, graminoid	1	0 (-1)
Anthoxanthum odoratum	sweet vernal grass	Herbaceous, graminoid	6	9 (+3)
Cortaderia jubata	jubata grass	Herbaceous, graminoid	1	0 (-1)
Danthonia decumbens	mountain heathgrass	Herbaceous, graminoid	34	44 (+10)
Eleocharis pachycarpa	broad fruit spikerush	Herbaceous, graminoid	79	89 (+10)
Festuca myuros	six-weeks grass	Herbaceous, graminoid	0	1 (+1)
Galium parisiense	wall bedstraw	Herbaceous, forb	0	4 (+4)
Hedera helix	English ivy	woody, vine	1	0 (-1)
Holcus lanatus	velvet grass	Herbaceous, graminoid	1	0 (-1)
Hypochaeris radicata	hairy cat’s ear	Herbaceous, forb	7	46 (+39)
Lotus corniculatus	bird-foot trefoil	Herbaceous, forb	1	1 (0)
Rubus armeniacus	Himalayan berry	woody, vine	1	0 (-1)
Senecio minimus	coastal burnweed	Herbaceous, forb	1	20 (+19)
Senecio vulgaris	common groundsel	Herbaceous, forb	0	3 (+3)
Sonchus oleraceus	sow thistle	Herbaceous, forb	0	5 (+5)

The change in woody vegetation cover (pretreatment to post-treatment) was found to be a significant predictor of changes in herbaceous species richness (Table 6). The GLM indicated that herbaceous species richness increased with increasing levels of woody vegetation removal (0.013 herbaceous species increase for every percent of vegetation removal, Table 6, and Fig. 4 panel a). The same model was run using only native herbaceous species richness with similar results; however, native herbaceous species richness was less impacted by woody vegetation removal with 0.008 native herbaceous species increase for every percent of woody vegetation removal (Fig. 4 panel g). Change in litter cover (pretreatment to post-treatment) and change in herbaceous species richness (pretreatment to post-treatment) were the only significant predictors of a change in special status species (Table 7). Specifically, the model indicated that special status species cover increased with increasing levels of thatch removal and litter removal (20% increase in percent special status cover for every percent of thatch removal (Fig. 4, panel b), 10% increase in percent cover for every percent of litter removal (Fig. 4, panel c)). The model also indicated that herbaceous species richness is a strong predictor of special status species cover (Table 7 and Fig. 4, panel d) which did not change when only native herbaceous species richness was used. Change in woody vegetation cover and distance from the edge of the fen were found to be the only significant predictors of a change in non-native species cover (Table 8). Specifically, the model indicated that non-native species cover decreased with increasing levels of woody vegetation removal (Fig. 4, panel e) and increased with increasing distance from the edge of the fen (Fig. 4, panel f).

Table 6. GLM for predicting the response of herbaceous species richness to the woody vegetation removal treatment. Model 1 included change in woody vegetation cover as a predictor of the change in herbaceous species richness. Model 1: Δ herbaceous species richness ~ Δ woody vegetation cover, family=Gaussian. Model 1 AIC: 1460.8; Model 1 dispersion: 4.36.

	Estimate	SE	z	*P*-value
Intercept	1.2040	0.1609	7.481	<0.0001
Δ Woody Vegetation Cover	-0.0131	0.0032	-4.153	<0.0001

Table 7. GLM for predicting the response of special status species cover to the woody vegetation removal treatment. Model 2 included change in thatch and litter cover as well as the change in herbaceous species richness as predictors of a change in special status species cover. Model 2: Δ special status species cover ~ Δ Thatch + Δ Litter + Δ herbaceous species richness, family=Gaussian. Full Model 2 AIC: 2390.4; Reduced Model 2 AIC: 2404; Model 2 dispersion: 67.8.

	Estimate	SE	z	*P*-value
Intercept	-0.6217	0.6149	-1.011	0.313
Δ Thatch	-0.2030	0.0283	-7.174	<0.0001
Δ Litter	-0.1006	0.0240	-4.184	<0.0001

	Estimate	SE	z	*P*-value
Δ herbaceous species richness	0.8382	0.2111	3.971	<0.0001

Table 8. GLM for predicting the response of non-native species cover to the woody vegetation removal treatment. Model 3 included change in woody vegetation cover and distance from the edge of the fen as predictors of the change in non-native species cover. Model 3: Δ non-native species cover ~ Δ woody vegetation cover + distance to fen edge, family=Gaussian. Full Model 3 AIC: 2372.7; Reduced Model 3 AIC: 2377.8; Model 3 dispersion: 64.52

	Estimate	SE	z	*P*-value
Intercept	1.9686	0.9180	2.145	0.0327
Δ woody vegetation cover	0.0415	0.1216	3.414	0.0007
distance to fen edge	0.1442	0.0540	2.671	0.0079

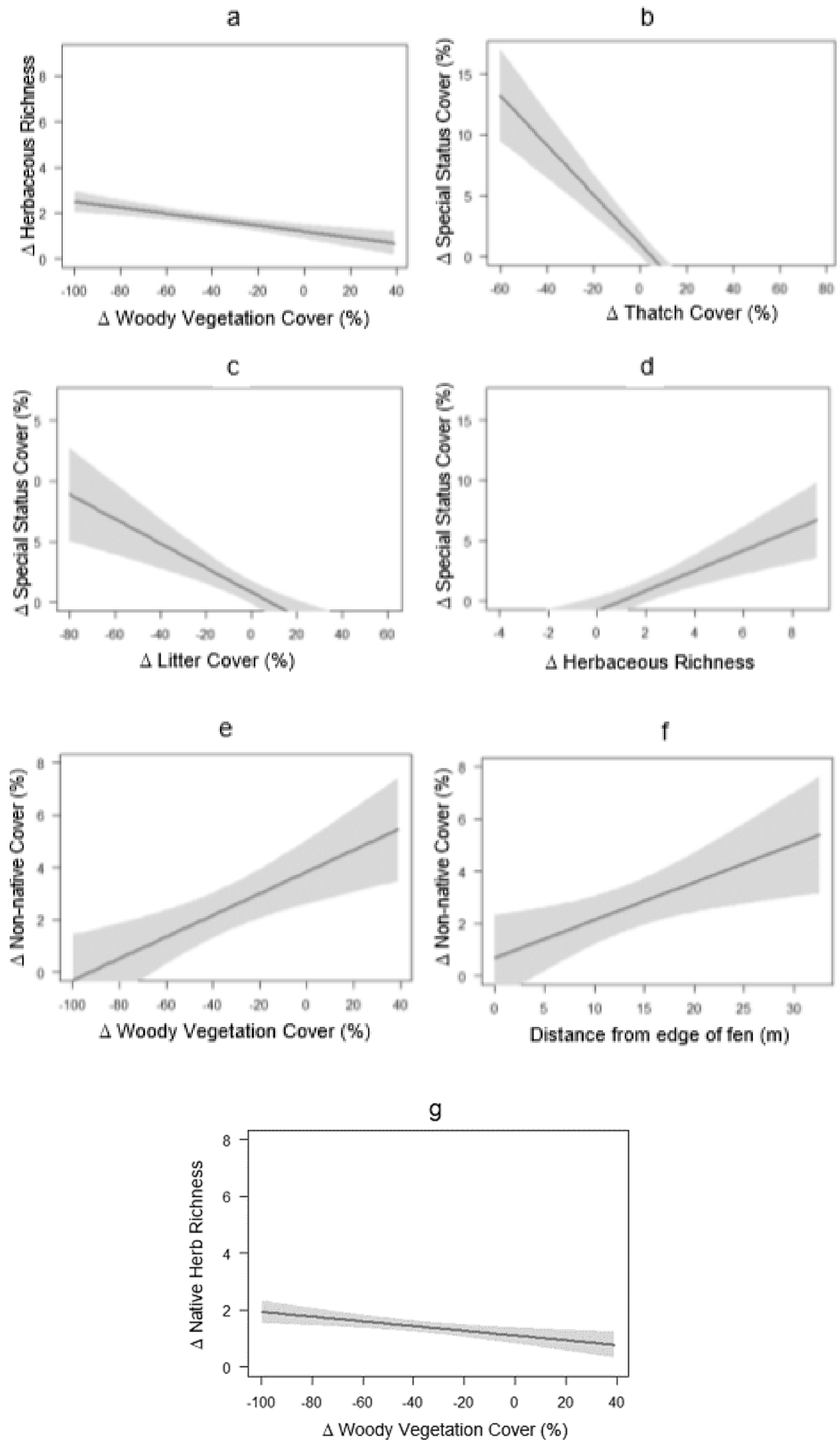
a
Δ Herbaceous Richness
Δ Woody Vegetation Cover (%)
b
Δ Special Status Cover (%)
Δ Thatch Cover (%)
c
Δ Special Status Cover (%)
Δ Litter Cover (%)
d
Δ Special Status Cover (%)
Δ Herbaceous Richness
e
Δ Non-native Cover (%)
Δ Woody Vegetation Cover (%)
f
Δ Non-native Cover (%)
Distance from edge of fen (m)
g
Δ Native Herb Richness
Δ Woody Vegetation Cover (%)

Figure 4. Graphical representation of Generalized Linear Modelling methods described in detail in the text. (a) Model 1: Change in herbaceous species richness as a result of woody vegetation removal, (b) Model 2: Change in special status species cover as a result of thatch removal, (c) Model 2: Change in special status species cover as a result of litter removal, (d) Model 2: Change in special status species cover as it relates to the change in herbaceous species richness, (e) Model 3: Change in non-native species cover as a result of woody vegetation removal, and (f) Model 3: Change in non-native species cover as it relates to distance from the edge of the fen. Line is the mean predicted using the model, gray shaded area is the confidence interval.

DISCUSSION

Fens are known to harbor a high diversity of special status botanical species and plant communities as a result of varied hydrology and favorable conditions for plant growth (Rubtzoff 1953; Baker 1972; Barry and Schlinger 1977; Christy 1979; Leppig 2002; Leppig 2004; Bencie 2007, Bart 2016). The diversity of herbaceous species, their limited distributions and high rate of woody vegetation encroachment make California fens a priority for woody vegetation removal restoration efforts. My study indicates that manual removal of woody vegetation may be an effective restoration tool for fens experiencing woody vegetation encroachment, but that restoration treatment cannot be viewed as a one-time effort. I found herbaceous species richness increased immediately following woody vegetation removal, and special status species occurrences increased dramatically. In addition, my study indicates that non-native species cover and occurrences also increase dramatically following treatment potentially threatening the success of the restoration program. Because of this, future studies will be necessary to determine the long-term effect of woody vegetation removal treatment on herbaceous species diversity, special status species occurrences, and non-native species cover.

The Generalized Linear Model developed to predict the effect of woody vegetation removal on herbaceous species richness indicated that a minimum of 77% of woody vegetation removal is needed for an increase of one herbaceous species per m^2 (Table 6 and Fig. 4, panel a). This prediction is representative of an average across the entire fen in my study. When excluding non-native species from the herbaceous species

richness measurement used in the model, the effectiveness of woody vegetation removal decreases indicating that non-native species are driving some of the herbaceous species richness increase resulting from wood vegetation removal. The amount of change in woody vegetation cover was found to be the only significant predictor of increased herbaceous species richness with or without non-native species in the analysis. This model highlights the effectiveness of woody vegetation removal on increasing herbaceous species richness; however, it also indicates that some of the herbaceous species richness increases observed as a result of woody vegetation removal are driven by non-native species. It must be noted that this may represent a short-term transitory response that does not reflect the final vegetation response to the treatment as has been seen in other studies (Mathews 2010).

Locations near the edge of woody vegetation encroachment may represent areas that were only recently dominated by encroaching woody species and/or may represent limits to seed dispersal within the first year. Herbaceous species richness increases were greatest in locations with greater than 50% woody vegetation cover removal and within approximately 4.0 m of the pretreatment edge of woody vegetation. Previous research indicates that the greatest wetland restoration benefits can be achieved by leveraging benefits from existing natural conditions including proximity to intact hydrology and diverse natural communities that can facilitate re-colonization (Horvath 2017; Morimoto 2017). By conducting woody vegetation removal prior to complete encroachment and extirpation of herbaceous species, restoration of early successional, herbaceous dominated wetland habitat can be more reliable and easier to achieve (Morimoto 2017).

The results from my study mirror these conclusions as the locations nearest the intact herbaceous dominated communities were those that responded most dramatically to the treatment. It should be noted that increases in herbaceous species richness were observed throughout the fen, however, there were areas that experienced losses of herbaceous species richness as a result of woody species removal. Herbaceous species richness losses were mostly located in areas that had dense woody vegetation cover pre-treatment which supported a shade dependent herbaceous understory that was not able to survive the exposed conditions created by the removal of the woody vegetation.

The response of special status species to the treatment is central in determining the success of the treatment. While special status species cover decreased slightly (-0.32%), occurrences increased dramatically (43%) which could signal the beginning of recovery of early successional habitat within Big Lagoon Bog and the conservation of special status species at this location. New occurrences could represent the establishment of new sub-populations which will increase the population viability of special status species within Big Lagoon Bog. The slight decrease in special status species cover was likely driven by woody vegetation removal activity and stringed trimmer use within herbaceous dominated portions of the fen. The 43% increase in occurrences was driven by special status species seedlings and starts which initially have very low cover values but represents the establishment of special status species into portions of the fen where they were not observed pre-treatment. The substantial increase in special status species occurrences may indicate that woody vegetation removal treatment was effective at improving habitat for special status species within Big Lagoon Bog. *Sphagnum* moss

exhibited the highest number of increases with a 55% increase in occurrences post treatment over pre-treatment occurrences. Sphagnum is arguably a cornerstone species within peatlands and its occurrences influence the unique floristic assemblages found in peatlands such as Big Lagoon Bog by impacting organic matter accumulation and pH (Leppig 2002, Cronk and Fennessy 2001). Additional years of study are needed to determine if this increase in special status seedlings and starts leads to greater cover and dominance of special status species within Big Lagoon Bog or if the increases represent short term increases that will be lost as woody vegetation regrows or non-native species become established.

Manual removal of woody vegetation may have been effective at improving habitat for special status species; however, results from a GLM for predicting the response of special status cover to the treatment suggests that burning may be even more effective at improving habitat for special status species. Changes in thatch cover, litter cover, and herbaceous species richness were found to be significant predictors of a change in cover by special status species. Change in thatch and litter cover are directly related to disturbance which often results in a decrease in cover of thatch and litter. While the woody vegetation removal treatment conducted in Big Lagoon Bog did include removal of cut debris, the majority of the thatch and litter on the ground remained in place following the treatment potentially limiting the effectiveness of the treatment. Treatment such as burning or other disturbance that removes additional thatch or litter may be more effective in promoting dominance and cover by special status species. This finding is supported by research in European fens that are maintained through annual

mowing and debris removal which reduces woody vegetation establishment and the accumulation of litter and thatch and promotes herbaceous species diversity (Matthias 2001; Güsewell 2004, Mälson 2010; Ross 2019).

Herbaceous species richness and special status species cover are closely related, as special status species occurrences contribute to herbaceous species richness. This relationship indicates that special status species cover is positively influenced by woody vegetation removal as herbaceous species richness was positively affected by woody vegetation removal. The relationship between the increase in special status species occurrences and herbaceous species richness is driven by seedlings and *Sphagnum* starts with low cover.

Woody vegetation removal and other disturbance based restoration methods contain risks that can jeopardize the success of the treatment (Clark 2001; Joyce 2014) of these, non-native species introduction is the most likely to threaten the success of the treatment at Big Lagoon Bog. Non-native species cover increased by 2.36% following treatment; however, plots with non-native species occurrences increased by 71%. The dramatic increase in non-native species occurrences indicates that the treatment may have aided in non-native species incursion and increase in Big Lagoon Bog. Furthermore, the dramatic increase in non-native species suggests that the future vegetation composition within Big Lagoon Bog may contain more non-native species potentially jeopardizing the occurrence of special status species and the unique habitat they require to survive. Non-native occurrence increase of 71% (89 plots pre-treatment to 152 plots post treatment) surpassed the special status occurrence increase of 43% (119 plots pre-treatment to 170

plots post treatment). Furthermore, the increase in cover by non-native species by 2.36% indicates that non-native seedlings were more aggressive than the special status species that decreased in cover by 0.32%. This further indicates that non-native species, which are often aggressive weedy species, may be more likely to exhibit greater cover within Big Lagoon Bog which could potentially lead to a new non-native dominated steady state. Again, additional years of study are needed to determine the trajectory of non-native species occurrences and dominance within Big Lagoon Bog. It is likely that some of the non-native species observed, such as *Senecio minimus* Poir. (coastal burnweed, Asteraceae) are transitory species that will not persist on-site, while others such as *Rubus armeniacus* are persistent, aggressive species that could highly alter the habitat within Big Lagoon Bog.

A GLM developed to predict the response of non-native species to the treatment suggests a more complicated response by non-native species to woody vegetation removal than simple increases in occurrences would suggest. Non-native species cover decreased with increased woody vegetation removal and increased with increased distance from the edge of the fen (Fig. 4, panels e and f). Non-native species cover was lower in areas with the highest amounts of woody vegetation removal reflecting smaller seedlings and limits to establishment in the first year. The model output reflects the high cover of some of the open, early successional habitat by two non-native species, specifically *Danthonia decumbens* L. (mountain heathgrass, Poaceae) and *Eleocharis pachycarpa* (E.) Desv. (broadfruit spikerush, Cyperaceae) which in many plots displayed over 30% cover. These two species pose the greatest risk to special status species within

the un-encroached portions of the fen and present a large amount of uncertainty in unintended consequences associated with the treatment. The increase in non-native species cover was driven primarily by these two species; however, the increase in occurrences was driven by new introductions of other non-native species, many of which are transitory (Table 5). Increases in non-native species are known to occur as a result of disturbance as disturbance is frequently a space creating process that provides ample opportunity for external or internal propagules to become established in plant communities (Stohlgren 2008). While the model indicates that increases in non-native species cover were driven by existing populations of non-native species, the model output is more a result of the short timeframe of the study rather than a reflection of how non-native species respond to woody vegetation removal in the long-term. It is unknown how the vegetation composition within Big Lagoon Bog will shift as a result of the treatment and how increased occurrences of non-native species will impact special status species and native species diversity within the fen. One study suggests that exotic species with niche requirements poorly represented in the regional flora of native species may establish with relatively little resistance or consequence for native species richness (Gilbert 2005).

The results from this study highlight the benefits and uncertainties associated with restoration treatment methods in natural systems. While disturbance is necessary to maintain open, early successional habitat, years of anthropogenic manipulation, introduction of non-native species, and changes in disturbance regimes have made it difficult if not impossible to return to a completely natural state. This does not suggest

however, that restoration ecologists are fighting a losing battle, rather that restoration cannot be seen as a one-time event that will fix all problems within a system. The increase in special status species occurrences within Big Lagoon Bog indicates that the treatment was successful in re-establishing habitat for these species; however, the increase in non-native species highlights the risks involved in conducting treatment. Without woody vegetation removal, open, early successional habitat was sure to be lost in the coming years; therefore, treatment and continued monitoring are needed to determine the best ways to maintain the early successional habitat required by special status species at this location.

Of critical importance in this study is the need for additional years of data collection and additional treatment efforts to target regrowth of woody species, and equally important, the growth of non-native species. The results from this study provides direction for future restoration treatment within Big Lagoon Bog. Currently two additional treatments are planned in Big Lagoon Bog: the first will occur three years (year 2021) after the initial treatment and the second will occur five years (year 2023) after the initial treatment. These treatments should consist of removal of woody vegetation regrowth but should also target aggressive non-native species such as those found to be increasing in cover and occurrence. This may require hand pulling of aggressive non-native herbaceous species that are exhibiting increased dominance throughout the fen rather than simple woody vegetation removal techniques. Additional attention should be given to the removal of litter and thatch to promote the growth and establishment of special status species. Targeted vegetation removal treatment may be

more effective in locations with established or new populations of special status plant species. Lastly, continued annual monitoring and monitoring of any additional treatments is needed to determine vegetation composition trajectories and to document non-native species introductions and woody vegetation regrowth. This will improve the effectiveness of the future treatments as treatments can be tailored to the non-native species and woody vegetation regrowth observed during monitoring. Results from continued monitoring and additional treatments could be used in developing methods for addressing the loss of special status species habitat to woody vegetation encroachment in other fens within the Pacific Northwest.

CHAPTER 3: BIG LAGOON MONITORING PROTOCOL

For continued post-treatment monitoring within Big Lagoon Bog to be conducted by California Native Plant Society (CNPS) members

INTRODUCTION

Big Lagoon Bog is a peatland fen along the north coast of California (Fig. 1) and represents an uncommon habitat that supports numerous special status plant species (Leppig 2002; Leppig 2004; Smith 2014). A total of 103 plant species have been recorded from Big Lagoon Bog (Appendix A) following the collection of pre-treatment data and year one post-treatment data and including previous studies (Leppig 2002; Smith 2014). Of the 103 species recorded, 11 are considered rare in California, representing approximately 11% of the species diversity present within the fen (Appendix A). Of the 11 special status species reported from Big Lagoon Bog, three (*Carex leptalea* (bristle-stalked sedge), *Juncus nevadensis* var. *inventus* (dune rush), and *Vaccinium uliginosum* subsp. *occidentale* (western blueberry) are presumed to be extirpated from the site and another, *Lycopodiella inundata* (inundated bog club-moss), is in immediate risk of extirpation. *Viola pulustris* (alpine marsh violet), *Drosera rotundifolia* (round-leaved sundew), and *Carex buxbaumii* (Buxbaum's sedge) are wetland dependent species restricted to coastal or montane wetlands in California (Baldwin 2012). *Sphagnum* moss is known from only a few disparate locations along the coast of California (CNDDB 2019). All of the rare botanical species reported from Big Lagoon Bog require early successional open habitat (Baldwin 2012).

A marked and progressive decline in open habitat within Big Lagoon Bog has been documented due to encroachment by woody vegetation for at least the last four decades (Christy 1979; Leppig 2004; Bencie 2007). It is estimated that 60% of the open

early successional habitat in Big Lagoon Bog has been lost as a result of woody vegetation encroachment. Many similar fens along the coast have been completely eliminated in the last 10-20 years due to woody vegetation encroachment and progression to forested habitat (Christy 1979; Leppig 2002). In response to the threat that it posed to the remaining open, early successional habitat within Big Lagoon Bog, woody vegetation removal was proposed and conducted in Fall 2018, and is described below.

Woody vegetation removal within Big Lagoon Bog was conducted from September 12, 2018 to October 17, 2018. All woody vegetation within the fen with a diameter at breast height (DBH) under 30 cm was slated for removal. Vegetation removal was conducted by the California Conservation Corps (CCC) and began in the southeast portion of the fen. Removal of woody vegetation required four weeks of work by crews of 9 to 17 individuals. Chain saws, polesaws, weedwackers, lopers and polaskis were used for vegetation removal. Areas with lower growing woody vegetation were weedwacked which included larger herbaceous species primarily *Calamagrostis nutkaensis*, although special status herbaceous species were specifically avoided which often required the use of selective removal of woody vegetation using loppers. All debris was carried (not dragged) and dispersed within the *Picea sitchensis* forest east of the fen. All large cut material was removed; however, there were portions of the fen that had significant amounts of woody detritus that was not removed as a result of the tremendous amount of material that was initially present within the fen. Areas with substantial populations of special status species were flagged and avoided as were individual occurrences of special status species. In addition, areas with mucky or saturated soils

were protected using temporary placement of plywood for the duration of work and debris removal. Lastly, species recorded as being invasive by the California Invasive Plant Council (Cal-IPC) were targeted for removal. These included *Rubus armeniacus* Focke (Himalayan blackberry, Rosaceae) and *Cortaderia jubata* (Lemoine) Stapf (jubata grass, Poaceae), which was cut and covered by weedmat to prevent re-growth. Smaller herbaceous invasive species such as *Hypochaeris radicata* L. (hairy cat's-ear, Asteraceae) were treated with the stringed trimmer.

The primary objective of this monitoring plan is to document yearly changes within Big Lagoon Bog resulting from the woody vegetation removal treatment, ultimately to assess the effectiveness of the treatment. Specifically, monitoring of this site will aid in determining whether or not woody vegetation removal is a suitable treatment method within other fens and wetlands experiencing woody vegetation encroachment. Yearly monitoring will document woody vegetation regrowth, change in non-native species cover, and change in herbaceous vegetation cover, species richness, and rare plant populations. In addition, yearly monitoring will work to maintain a current botanical species list for Big Lagoon Bog including new species introductions with specific attention to non-native and invasive species.

Permanent plots along transects have been established and sampled within Big Lagoon Bog prior to treatment to be used every year of monitoring to allow for direct comparisons between years and between pre-treatment conditions (Fig. 5). In each plot all herbaceous species, cover for each herbaceous species, as well as cover measures of non-living components such as thatch, litter, and large woody debris will be recorded. In

addition, woody species richness, cover, and average height of regrowth will also be recorded within each plot. Species recorded as being invasive by Cal-IPC within each plot will be noted and observations of these invasive species outside of plots can be recorded.

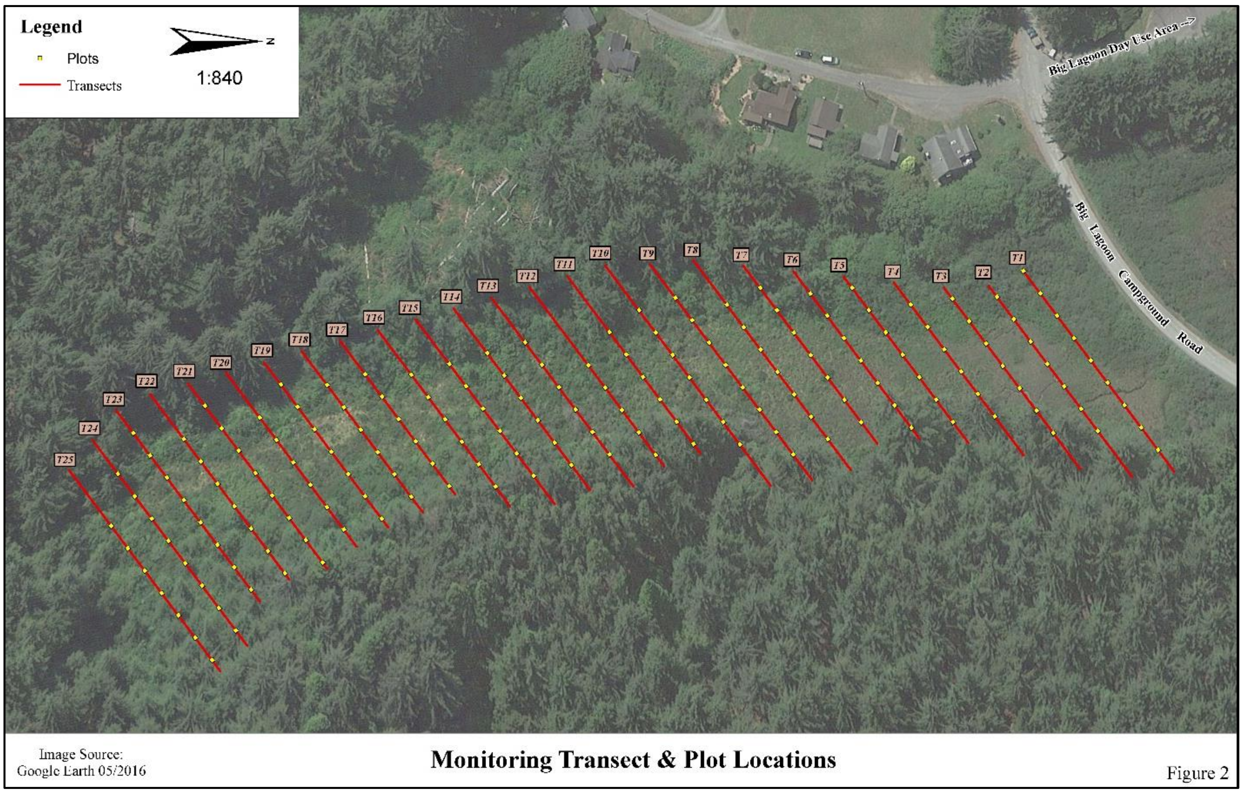

Figure 5. Monitoring Transects and Plot Locations.

MATERIALS AND METHODS

Yearly Monitoring

A total of 25 transects were established by evenly dividing the length of Big Lagoon Bog from north to south and developing transects running from the west side of the fen eastward across the fen to ensure that the entire fen is adequately sampled (Fig. 5). PVC pipe stakes with the corresponding transect number and side (east or west) inscribed have been installed in the forest soils at the edge of the fen at both ends of each transect to enable the transects to be relocated during the yearly monitoring effort. Each start and end point has also been recorded using a sub-meter Trimble 6T GPS unit should the PVC stakes become damaged or go missing. Transects are 12 m distant from the previous transect with start and end points placed just outside of the fen and recorded using the Trimble 6T GPS unit. Transects were numbered from 1 to 25 from north to south. Each transect had its origin on the western edge of the fen and its largest plot numbers on the east side of the fen. All transect start and end points were installed and recorded prior to tape measure and plot placement on any of the transects.

Plant community composition and species dominance data will be collected using 1x1 m quadrats placed along the transects at points that were sampled during the pre-treatment data collection effort so as to sample the same locations from year to year. Plot locations have been randomly assigned with the first plot location listed on Table 9. Each successive plot is located eight meters from the previous plot for a uniform grid of 170

samples from across the fen (Table 9, Fig.5). Eight meters between plots is twice the distance between plots than was used in the pre-treatment data collection and post treatment data collection resulting in half of the plots for monitoring. This will enable volunteers to finish the data collection throughout the entire fen in a more timely manner and will continue to result in a substantial amount of vegetation data collection from the fen. Plot location along the transect will be determined in the field by placing a tape measure between the start and end point of the transect so that plot locations will be the same as previously collected data and can be recorded and revisited for the duration of the monitoring. Care will need to be taken to ensure that the tape measure is placed in the same location it was in during pre-treatment data collection and during previous monitoring efforts. Specifically, the tape measure will need to be placed in a straight line across the fen between the start and end point of each transect while attempting to minimize impacts to surrounding vegetation so as not to influence vegetation cover data. Plots should be offset to the south of the tape measure to collect undisturbed vegetation data.

Data should be collected from early/mid July to mid/late August during the time when herbaceous species are most easily identified. It is also imperative to conduct field work during the same window of time from year to year so that coverage by species is relatively similar. All vascular plant species and their percent cover for each species will be recorded within every plot. Data will be recorded using the Field Data Sheet (Table 10). Individual species and their corresponding percent cover will be recorded within either herb stratum or woody stratum. Species do not have to be rooted within a plot to

contribute to cover percentages. The herb stratum includes relative cover percentages for litter, thatch, large woody debris (LWD), bare ground, water and *sphagnum* in addition to relative cover percentages by non-woody plant species such that all plant and abiotic elements sum to 100%. The woody vegetation stratum includes all woody vegetation cover within and above the quadrat including trees and shrubs of any size. Cover includes the relative percentage cover by each woody species for a total less than or equal to 100%. Overlapping woody vegetation could lead to inflated cover estimates that would influence the analysis on the effect of total woody vegetation cover on herbaceous species cover and species richness. Areas of direct overlap will be excluded to prevent double counting and inflating woody vegetation cover. Incidental occurrence and population characteristics (location based on the nearest transect station with distance and compass direction from the transect; also, number of plants, aerial extent, phenology, evidence of browsing and disease, etc.) for special status species and invasive species should be recorded in relation to each plot to develop population record and a comprehensive, current plant list for Big Lagoon Bog.

Lastly, photos documenting conditions within the fen should be taken at photo stations established at the mid-point of each transect. Four photos should be taken from the center of each transect, one in each of the cardinal directions from the photo station to document visually the changes that occur from year to year. A representative photo of a plot should be taken on each transect to document conditions within a representative plot. The plot with the photo taken should be recorded in the notes. Any additional points of

interest recorded with photos should be GPS referenced or measured from a known plot location and notes should be written about the significance of each photo.

Should a limited number of volunteers be available for monitoring, then the number of plots can be reduced by only sampling every 12 meters rather than every 8 meters as detailed within this monitoring plan. It is estimated that it will take eight to ten volunteers two full days to complete the monitoring with plots placed every 8 meters.

Table 9. Monitoring Transects, plot locations, and photo station locations to be used in continued monitoring of Big Lagoon Bog following completion of this study.

Transect #	Plot Start Point (m)	Plots/ Transect	Photo Station (m)	Transect Length (m)
T1	0	9	33	66
T2	4	7	26	52
T3	4	7	29	58
T4	8	6	28	56
T5	4	7	27	57
T6	8	7	29	58
T7	8	7	38	61
T8	16	7	40	68
T9	12	8	42	72.1
T10	20	7	43	70
T11	20	6	41.5	62
T12	28	5	43	62.5
T13	16	6	37	62
T14	16	6	37.5	63.1
T15	16	6	34.5	63.6
T16	16	6	36	61
T17	12	6	33.5	55
T18	12	6	33	57.5
T19	8	7	33.5	59
T20	16	6	36	62.2
T21	8	8	37	66
T22	16	7	37	66
T23	8	8	37.5	68.2
T24	12	8	39.3	73.6
T25	20	7	46.4	71.8

Table 10. Field data sheet to be used at each monitoring plot during future monitoring efforts.

Field Data Sheet	
Plot #: **Plot Location (m):**	**Date:** **Name:**
Estimated Shrub Height (m):	
Shrub Stratum Species:	**% Cover:**
	Total Cover:
Herb Stratum Species:	**% Cover:**
	Total Cover:
Notes: **Write additional notes on back**	

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APPENDICES

Appendix A. Vascular plants and Mosses observed in Big Lagoon Bog. Compiled from Smith (2014), Leppig (2002), CNDDB (2020), and from this study.

Scientific Name	**Common Name**	**Family**	**Status**	**Obs. 2018**	**Obs. 2019**
Trees					
Abies grandis	grand fir	Pinaceae	Native	Y (not in plots)	Y
Alnus rubra	red alder	Betulaceae	Native	Y	Y
Malus fusca	Oregon crab apple	Rosaceae	Native	Y	Y
Picea sitchensis	Sitka spruce	Pinaceae	Native	Y	Y
Pseudotsuga menziesii	Douglas fir	Pinaceae	Native	Y (New)	N
Salix hookeriana	coast willow	Salicaceae	Native	Y	Y
Salix lasiolepis	arroyo willow	Salicaceae	Native	Unknown	Unknown
Sequoia sempervirens	coast redwood	Cupressaceae	Native	Y	Not in plot
Thuja plicata	western redcedar	Cupressaceae	Native	Y	Y
Tsuga heterophylla	western hemlock	Pinaceae	Native	Y	Y
Shrubs					
Baccharis pilularis ssp. *consanguinea*	coyote brush	Asteraceae	Native	N	Y (New)
Frangula purshiana	cascara	Rhamnaceae	Native	Y	Y
Gaultheria shallon	salal	Ericaceae	Native	Y	Y
Ledum glandulosum	Labrador tea	Ericaceae	Native	Y	Y
Lonicera involucrata var. *ledebourii*	twinberry	Caprifoliaceae	Native	Y	Y
Morella californica	California wax-myrtle	Myrtaceae	Native	Y	Y

Scientific Name	Common Name	Family	Status	Obs. 2018	Obs. 2019
Rhododendron occidentale	western azalea	Ericaceae	Native	Y	Y
Rosa pisocarpa ssp. *pisocarpa*	wild rose	Rosaceae	Native	Y (New)	Y
Rubus armeniacus	Himalayan blackberry	Rosaceae	Invasive[1]	Y	Y
Rubus parviflorus	thimbleberry	Rosaceae	Native	Y	Y
Rubus spectabilis	salmonberry	Rosaceae	Native	Y	Y
Rubus ursinus	California blackberry	Rosaceae	Native	Y	Y
Sambucus racemosa var. *racemosa*	Red elderberry	Adoxaceae	Native	N	Y (New)
Spirea douglasii	Douglas spirea	Rosaceae	Native	Y	Y
Vaccinium ovatum	California huckleberry	Ericaceae	Native	Y	Y
Vaccinium uliginosum subsp. *occidentale*	western blueberry	Ericaceae	**Rare locally, common elsewhere (CNPS 2020)**	**N**	**N**
Ferns and Allies					
Athyrium filix-femina	lady fern	Woodsiaceae	Native	Y	Y
Equisetum laevigatum	smooth horsetail	Equisetaceae	Native	N	N
Lycopodiella inundata	bog club-moss	Lycopodiaceae	**Rare: 2B.2**	**Y (Not in plots)**	**Y (Not in plots)**
Polystichum munitum	sword fern	Dryopteridacedae	Native	Y (Not in plots)	Y (Not in plots)
Pteridium aquilinum var. *pubescens*	bracken fern	Dennstaedtiaceae	Native	Y (New)	Y
Sceptridium multifidum	grape fern	Ophioglossaceae	Native	Y (Not in plots)	Y (Not in plots)
Struthiopteris spicant	deer fern	Blechnaceae	Native	Y	Y

Scientific Name	Common Name	Family	Status	Obs. 2018	Obs. 2019
Sedges and Rushes					
Carex aquatilis var. *dives*	water sedge	Cyperaceae	Native	Y	Y
Carex buxbaumii	Buxbaum's sedge	Cyperaceae	**Rare: 4.2**	**Y**	**Y**
Carex cusickii	Cusick's sedge	Cyperaceae	Native	Y	Y
Carex echinata ssp. *phyllomanica*	star sedge	Cyperaceae	Native	Y	Y
Carex leptalea	bristle-stalked sedge	Cyperaceae	**Rare: 2B.2**	**N**	**N**
Carex obnupta	slough sedge	Cyperaceae	Native	Y	Y
Carex viridula ssp. *viridula*	green sedge	Cyperaceae	**Rare: 2B.3**	**Y**	**Y**
Cyperus eragrostis	three cornered rush	Cyperaceae	Native	Y (New)	Y
Eleocharis pachycarpa	spike rush	Cyperaceae	Non-native	Y	Y
Equisetum arvense	horsetail	Equisetaceae	Native	Y (New)	Y
Isolepis cernua	low bulrush	Cyperaceae	Native	N	Y (New)
Juncus balticus ssp. *ater*	Baltic rush	Juncaceae	Native	Y (New)	Y
Juncus bolanderi	bolander's rush	Juncaceae	Native	Y	Y
Juncus bufonius var. *bufonius*	toad rush	Juncaceae	Native	N	N
Juncus effusus ssp. *pacificus*	soft rush	Juncaceae	Native	Y	Y
Juncus ensifolius	swordleaf rush	Juncaceae	Native	Y	Y
Juncus falcatus	falcate rush	Juncaceae	Native	Y	Y
Juncus lescurii	Dune rush	Juncaceae	Native	Y (New)	Y
Juncus nevadensis var. *inventus*	Sierra rush	Juncaceae	**Rare: 2B.2**	**N**	**N**
Schoenoplectus acutus	common tule	Cyperaceae	Native	Y	Y
Schoenoplectus pungens	three square	Cyperaceae	Native	Y (Not in plots)	Y (Not in plots)

Scientific Name	Common Name	Family	Status	Obs. 2018	Obs. 2019
Scirpus microcarpus	bulrush	Cyperaceae	Native	Y	Y
Grasses					
Agrostis pallens	seashore bentgrass	Poaceae	Native	Y	Y
Aira caryophyllea	silver hairgrass	Poaceae	Non-native	Y (New)	N
Aira praecox	yellow hairgrass	Poaceae	Non-native	N	Y (New)
Anthoxanthum odoratum	sweet vernal grass	Poaceae	Invasive	Y	Y
Calamagrostis nutkaensis	Pacific reedgrass	Poaceae	Native	Y	Y
Cortaderia jubata	jubata grass	Poaceae	Invasive[1]	Y	Y (Not in plots)
Danthonia californica	California oatgrass	Poaceae	Native	N	N
Danthonia decumbens	common heathgrass	Poaceae	Non-native	Y	Y
Deschampsia caespitosa ssp. *holciformis*	pacific hairgrass	Poaceae	Native	Y	Y
Festuca myuros	six weeks grass	Poaceae	Invasive[1]	N	Y (New)
Holcus lanatus	velvet grass	Poaceae	Invasive[1]	Y (New)	Y (Not in plots)
Herbs					
Bidens cernua	nodding beggertick	Asteraceae	Native	N	N
Boykinia occidentalis	coastal brookfoam	Saxifragaceae	Native	Y	Y
Cicuta douglasii	western water hemlock	Apiaceae	Native	Y	Y
Cirsium sp.	thistle	Asteraceae	Unknown	N	N
Comarum palustre	marsh cinquefoil	Rosaceae	Native	Y	Y
Drosera rotundifolia	round-leaved sundew	Droseraceae	**Rare (Leppig 2002)**	**Y**	**Y**

Scientific Name	Common Name	Family	Status	Obs. 2018	Obs. 2019
Epilobium ciliatum	willow herb	Onagraceae	Native	N	Y (New)
Fragaria chiloensis	beach strawberry	Rosaceae	Native	Y (New)	Y
Galium parisiense	wall bedstraw	Rubiaceae	Non-native	N	Y (New)
Gentiana sceptrum	king's gentian	Gentianaceae	Native	Y	Y
Gnaphalium seedling	unknown	Asteraceae	Unknown	N	Y (New, not in plot)
Helenium bigelovii	Bigelow's sneeze weed	Asteraceae	Native	Y	Y
Hypericum anagalloides	creeping St. John's wort	Hypericaceae	Native	Y	Y
Hypochaeris radicata	hairy cat's ear	Asteraceae	Invasive[1]	Y	Y
Lathyrus palustris	hairy marsh pea	Fabaceae	**Rare: 2B.2**	**Y**	**Y**
Leucanthemum vulgare	ox-eye daisy	Asteraceae	Invasive[1]	N	N
Listera banksiana	northwest twayblade	Orchidaceae	Native	Y (New, out of plots)	N
Lotus corniculatus	birdsfoot trefoil	Fabaceae	Non-native	Y	Y
Lycopus uniflorus	water horehound	Lamiaceae	**Rare: 4.3**	**Y**	**Y**
Lysichiton americanum	western skunk cabbage	Araceae	Native	Y	Y
Lysimachia arvensis	scarlet pimpernel	Myrsinaceae	Non-native	N	Y (Not in plots)
Maianthemum dilatatum	false lily-of-the-valley	Liliaceae	Native	Y	Y
Mimulus guttatus	common monkeyflower	Phrymaceae	Native	N	N
Mimulus primuloides	primrose monkeyflower	Phrymaceae	Native	N	N
Nuphar polysepala	yellow pond lily	Nymphaceae	Native	N	N

Scientific Name	Common Name	Family	Status	Obs. 2018	Obs. 2019
Oenanthe sarmentosa	water parsley	Apiaceae	Native	Y	Y
Platanthera dilatata var. *leucostachys*	Sierra bog orchid	Orchidaceae	Native	Y	Y
Potentilla anserina ssp. *pacifica*	silverweed	Rosaceae	Native	Y	Y
Prunella vulgaris	selfheal	Lamicaeae	Native	Y (Not in plots)	Y (Not in plots)
Senecio hydrophilus	water ragwort	Asteraceae	Native	N	N
Senecio minimus	Australian fireweed	Asteraceae	Non-native	Y	Y
Senecio vulgaris	common groundsel	Asteraceae	Non-native	N	Y (New)
Sisyrinchium californicum	yellow-eyed grass	Iridaceae	Native	Y	Y
Solanum aviculare	New Zealand nightshade	Solanaceae	Invasive[1]	N	Y (New, Not in plot)
Sonchus oleraceus	sow thistle	Asteraceae	Non-native	N	Y (New)
Spiranthes romanzoffiana	hooded ladies tresses	Orchidaceae	Native	N	N
Stachys chamissonis	hedge nettle	Lamiaceae	Native	Y	Y
Symphyotrichum chilense	pacific aster	Asteraceae	Native	Y (New)	Y
Trifolium repens	white clover	Fabaceae	Non-native	N	N
Triglochin maritimum	seaside arrow-grass	Juncaginaceae	Native	Y	Y
Typha latifolia	broad-leaved cattail	Typhaceae	Native	Y (Not in plots)	Y (Not in plots)
Veronica americana	American brooklime	Plantaginaceae	Native	Y (New)	Y
Veronica anagallis-aquatica	speedwell	Plantaginaceae	Non-native	N	N
Viola macloskeyi	Macloskey's violet	Violaceae	Native	N	N

Scientific Name	Common Name	Family	Status	Obs. 2018	Obs. 2019
Viola palustris	marsh violet	Violaceae	**Rare: 2B.2**	**Y**	**Y**
Viola sempervirens	redwood violet	Violaceae	Native	N	Y (New)
Woody Vines					
Hedera helix	English ivy	Araliaceae	Invasive[1]	Y (New)	Y
Non-vascular					
Kindbergia praelonga	feather moss	Brachytheciaceae	Native	Y	Y
Marchantia sp.	liverwort	Marchantiaceae	Native	Y	Y
Meesia sp.	meesia	Meesiaceae	Native	Y (New)	Y
Sphagnum palustre	blunt-leaved sphagnum moss	Sphagnaceae	Sphagnum genus **Uncommon** (CNDDB 2020)	Y	Y
Sphagnum capillifolium	red sphagnum moss	Sphagnaceae		Y (New)	Y

1: Invasive according to Cal-IPC Rating (Cal-IPC 2020)

Appendix B. Big Lagoon Bog looking south from Transect 10. Pre-treatment (top) and post-treatment (bottom).