Cataloging and Predicting the Spatial Distributions of Exotic Invasive Plants Along the Grande Ronde River

By: Derek DeLong and Maggie Evans

Cataloging and Predicting the Spatial Distributions of Exotic Invasive Plants Along the Grande Ronde River

Abstract:

Over the past two centuries, anthropogenic activity has rapidly degraded stream and riparian ecosystems such as the Grande Ronde River. Anthropogenic pressures, such as agriculture and recreational activities, are sources for invasive species introduction into these environments. Invasive vegetation threatens native species, because they change ecosystem functions by altering hydrological cycles, nutrient cycles, fire regimes, and they displace native plants, pollinators, and herbivores. We surveyed and inventoried invasive plant distributions along the Grande Ronde River, and recorded environmental variables relevant to invasive plant spread and establishment. We developed alternative habitat suitability models (HSMs) from environmental data, and evaluated relative HSM performance using information theoretic methods. Our best HSMs can be applied to predict locations of additional invasive plant populations along the Grande Ronde River, and to forecast future distributions as invasive species spread. These results can inform invasive plant management programs and help managers improve effectiveness within limited resources.

Introduction

Over the past two centuries, anthropogenic activity has rapidly depleted the health of stream and riparian ecosystems (Wissmar et al. 1994). The land surrounding the Grande Ronde River is vulnerable, as it has been greatly disturbed by livestock grazing, mining, timber harvests, roads, dams, irrigation, fisheries, and fire management. Agencies often address the symptoms of ecosystem degradation rather than the root cause, resulting in mitigation efforts that are often unsuccessful (Wissmar et al. 1994). A variety of microbiomes surround the upper Grande Ronde watershed, each biome associated with a particular vegetative composition (Stewart 2007). The short dry summers and long cold winters bring high variability of precipitation across the changing elevations and this is reflected by the vegetation patterns; approximately 86% forest, 11% grassland, and 3% riparian habitat (Ayre et al. 2012). The last 95 river miles of the Grande Ronde is dominated by steep bank gradients of basalt that is often unsuitable for riparian vegetation and is instead home to xeric adapted species (Stewart 2007).

Land use changes surrounding the Grande Ronde basin have significantly altered the terrestrial and aquatic ecosystems (Lawson 2007). Agricultural practices serve as a source for invasive introduction that alter the environment away from its historical conditions (Stewart 2007). Cattle grazing has anthropogenically disturbed some riparian zones of the Grande Ronde River such that some areas are completely devoid of riparian vegetation and thus primed for

Cataloging and Predicting the Spatial Distributions of Exotic Invasive Plants Along the Grande Ronde River

invasion (Stewart 2007). Invasive vegetation poses a threat to the survival of native species, as they alter the ecosystem's hydrological cycle, nutrient cycle, and decrease overall biodiversity (Harrod 2001). Once invasive populations have become established, successional transition of native species diminishes as the non-native populations can persist for decades (Cai et al. 2020). Eradication efforts prior to the establishment of invasive species are costly and often unsuccessful due to narrow approaches that fail to recognize the non-static nature of invasion.

Therefore, well-informed strategies focused on preventive or proactive measures are critical in successfully mitigating the establishment or spread of invasive populations and subsequently conserve the equilibrium of the system (Davies et al. 2017). Stakeholders should pursue efforts to catalog the current regional invasive vegetation, as well as create predictive models that monitor the potential spread of invasives. Such efforts could be useful in developing efficient management strategies that predict and limit the spread of invasive vegetation that threatens the biodiversity of the Grande Ronde River watershed.

Information Theoretic Approach coupled with Habitat Suitability Modeling

Invasive species distributions are determined by a dynamic amalgamation of spatial, biological, environmental, and anthropogenic factors (Wilson et al. 2007). Spatial patterns of invasive species are known to be strongly influenced by limitations of potentially invasivable habitat, temporal factors such as residence time, and anthropogenic pressures (Higgins et al. 1996; Thuiller et al. 2006; Wilson et al. 2007). Identifying environments that are vulnerable to invasion while also identifying characteristics of invasive species that are well-adapted to those environments is key to preventing, detecting and/or eliminating invaders while they are still in the initial early stages of colonization (Peterson et al. 2001; Zalba et al. 2000). Environmental factors that influence vegetation composition are necessary to predict the distribution of both native and invasive vegetation. The use of an Information Theoretical Approach can be used to build robust predictive models that determine which environmental variables best explain the response variable(Rushton et al. 2004).

Habitat Suitability Modeling utilizes environmental variables to predict the likelihood of occurrence within potential habitat ranges of invasive species. Additional correlation of climate projections with known favorable environmental conditions of each species can be used for spatial temporal predictions (Chai et al. 2016). The distribution of invasive vegetation to potential and/or future habitats can be modeled by combining methods that incorporate known invasive species population locations and favorable environmental conditions in conjunction with topographical, climate and/or other environmental variables with GIS layering (Jorgensen et al. 2021; Hirzel et al. 2008).

Cataloging and Predicting the Spatial Distributions of Exotic Invasive Plants Along the Grande Ronde River

Coupling the best fit Information Theoretical Approach model with the Habitat Suitability Model would allow for rigorous testing of the validity of species distribution predictions as well as quantitatively evaluate the risk of invasion/spread of species of interest (Rushton et al. 2004; Zalba et al. 2000). Results from combined Habitat Suitability Model and Information Theoretical can be used to develop efficient and effective mitigation and/or elimination management strategies if there is a current inventory of known invasive populations. A current species inventory is necessary to create an accurate Habitat Suitability Model prediction on spatial distributions of invasives. Thus, to maximize the conservation of biodiversity, creating an inventory is fundamental to the entire process (Peterson et al. 2001; Zalba et al. 2000).

Our Project

Our project built the first preliminary catalog of the exotic invasive vegetation populations along the Grande Ronde River. For the purpose of our project, we focused on only inventorying the non-native, invasive vegetation, including noxious and non-noxious species, and only inventoried the species that were 100% identifiable at the time of our study. We used an Information Theoretic Approach to determine what environmental variables were synergizing to form the favorable conditions for the exotic invasives. Finally we used Habitat Suitability Modeling to build predictive models that can be applied to GIS layering for finding the potential distribution patterns of the invasive species of interest. The results of our project will help to inform conservation and restoration efforts as to what invasive species are present in the region, as well as potential habitats that should be monitored proactively in order to maximize the conservation of biodiversity along the Grande Ronde River.

Methods

Field Data Collection

Prior to this study, there was no existing inventory of the invasive vegetation along the Grande Ronde River. Additionally, environmental conditions that provide favorable habitat for invasive vegetation was unknown. Our study was conducted along the last 92 river miles of the Grande Ronde River. Our survey was carried out within the coniferous dominated forests of the upper river, as well as grassland dominated fields, as the environmental conditions dramatically shifted as elevation decreased. At approximately river miles; 72, 58, 39, 24, and 12 data was collected along random systematic transects, starting from the edge of the river and moving inland, away from the river. Each sampling site had multiple transects. Each plot in the transect was $1m^2$ and spaced 10m apart. At each plot, we took pictures, samples, and codified any suspect plant. We then counted all suspect species in the plot. Environmental variables: aspect, slope, canopy coverage, percent ground coverage, and sediment type were measured and recorded onto our data sheets.

- Forbs within the plot were individually counted.
- Sparse grasses within the plot were individually counted
- In plots that were densely packed with invasive grasses, we divided the grind into 10 cells, each 10 x 10 cm. Grasses of the same species were counted within the 10 x 10 cm cell, and then multiplied to obtain a good estimate of the total number of grasses within the plot.
- ground coverage was measured by using the same protocol as our grass density. We used 10-(cells with bare soil) to estimate ground coverage.
- Aspect was assigned to each transect with a compass and assigned with the corresponding cardinal or intercardinal point: N, NE, E, SE, S, SW, W, NW
- The slope was measured using a rangefinder and averaging two measurements.
- Canopy coverage was measured using a convex spherical densiometer.
- Sediment type was distinguished into four main categories; fine, sand, gravel, and/or cobble. Sediment within plots was determined by the dominant type being greater than 80%, however, some plots contained a combination of two different dominant sediment types and were designated as such.
- Each plot was assigned a land classification according to dominant terrain features: Grassland, Forest, Riparian, Burn.
- GPS coordinates of each plot were taken using the US Topo Maps application.

Cataloging Exotic Invasive Vegetation

For the purpose of our study, we strictly focused on inventorying exotic invasive vegetation. The invasive vegetation was identified using the book *"Northwest Weeds: The Ugly and Beautiful Villains of Fields, Gardens, and Roadsides"* by Ronald J. Taylor. Invasive species that we observed outside of our plots were also identified and inventoried. Any suspect invasive that was too young to accurately identify was collected, pressed in our herbarium press, and assigned a unique codified letter from the alphabet for later identification. Pressed specimens were compared against invasive species encountered at lower elevations that were further along in their development. Any specimen that could not be confidently identified was discarded.

Data Entry

Data collected in the field was entered into a generated Google Sheet that had the appropriate formatting for exporting to RStudio specifically for using the Information Theoretic Approach. Data entered fell into two categories: Field Data and Site Data. Field Data included all independent variables in addition to sum total columns representing all grass, all forbs, and all invasives per plot. Site Data included columns for Site, plot number, elevation, and river mile. Elevation and river mile were obtained using GPS data checked against topographic maps and Google Earth. A second Google Sheet was generated for Habitat Suitability Modeling which was identical except that the response variables were changed to binomial, present versus absent as opposed to density counts. Site data was saved as a CSV file and incorporated into an attribute table in ArcGIS pro, allowing explanatory variables to be geospatially itemized per gps coordinate.

Information Theoretic Approach

An Information Theoretic Approach, following the script template provided by John Mclaughlin, was used to model the data in RStudio with the associated CSV file. All modeling used poisson regression as our response variables were non-linear. Three separate models, one for each response variable was generated; all invasives, all invasive grass and all forbs. Each model had unique parameters assigned according to our hypotheses which produced bivariate and multivariate models. A table was generated for each response variable that showed the scores for all variable combinations. Included were individual variables that were necessary for providing statistical support for model interpretation. Plots of each statistically significant variable were generated against the response variable. These plots fell into two categories: Numerical and Categorical. Numerical independent variables were represented with Scatterplots where categorical independent variables used Box and Whisker Plots.

Habitat Suitability Modeling

Habitat Suitability Modeling, following the script template provided by John Mclaughlin, was used to model the data in RStudio with the associated CSV file. All modeling used binomial regression as our response variables were either present versus absent. Three separate models, one for each response variable was generated; all invasives, all invasive grass, and all forbs. Each model had unique parameters assigned according to our hypotheses which produced bivariate and multivariate models. A table was generated for each response variable that showed the scores for all variable combinations. Included were individual variables that were necessary for providing statistical support for model interpretation. Plots of each statistically significant variable were generated against the response variable. These plots fell into two categories: Numerical and Categorical. Numerical independent variables were represented with Scatterplots where categorical independent variables used Box and Whisker Plots.

Field Collection

As we decreased in elevation, invasive species richness and density increased as the habitat type shifted from coniferous forests to grasslands. We collected data from 10 plots at river mile 72, which has an elevation range between 670m - 650m. No invasive forbs were detected within our plots, but a total of 56 *Poa bulbosa* were counted. A total of 45 plots were surveyed at river mile 57.75, which has an elevation of 580m - 565m. Within the 45 plots, a total of 829 invasives were detected within our plots, 811 of which were *Poa bulbosa*, and the remaining 18 were *Bromus tectorum*. A total of 30 plots were surveyed at river mile 38.7, which has an elevation of 455m - 370m. Within the 30 plots, 18,767 invasives were detected, 5,556 of which were *Poa bulbosa,* 12,989 were *Bromus tectorum,* 119 were *Onopordum acanthium,* and 103 were *Euphorbia esula.* A total of 15 plots were surveyed at river mile 23.7, which has an elevation range of 395m - 370m. A total of 6,830 invasives were detected within our plots, 4,188 of which were *Poa bulbosa,* 2,635 were *Bromus tectorum,* 6 were *Taraxacum officinale,* and 1 was *Onopordum acanthium.* A total of 24 plots were surveyed at river mile 12, which has an elevation range of 340m - 320m. Within the 24 plots, 27,798 invasives were detected, 1,952 of which were *Poa pratensis,* 2,623 were *Poa bulbosa,* 23,063 were *Bromus tectorum,* 3 were *Onopordum acanthium,* 76 were *Euphorbia esula,* and 78 were *Sisymbrium altissimum.*

Exotic Invasive Vegetation Catalog

We created a table for the 14 exotic invasive plant species that we obtained a positive identification on (Table 1). Additionally, we noted their common names, native origins, noxious statues to Washington, Oregon, and/or Idaho State, as well as their associated noxious classification. Species cataloged are as follows: *Verbascum thapsus, Rumex acetosella, Rumex obtusifolius, Euphorbia esula, Linaria dalmatica, Potentilla erecta, Poa pratensis, Poa Bulbosa, Taraxacum officinale, Bromus tectorum, Cynoglossum officinale, Onopordum acanthium, Carduus nutans, Sisymbrium altissimum*.

Cataloging and Predicting the Spatial Distributions of Exotic Invasive Plants Along the Grande Ronde River

Information Theoretic Approach

All Exotic Invasive Vegetation

A single multivariate model had overwhelming statistical support for the response variable, all exotic invasives. This model used the variables: elevation, fine sediment and cobble. The model had a K score of 4, a Log(ℓ) score of -24,147.369, a Deviance score of 47,698.577 compared to the null Deviance score of 117,193.606, an $AIC_ι$ score of 48,302.738, a $Δ_ι$ score of 0, and a $ω_ι$ of 1. The general linear multivariate model for the all exotic invasives has an intercept estimate of 9.76, an intercept standard error of $5.06*10^{-2}$, an intercept z-value of 193.0, and a statistically significant intercept p-value of < 0.05. Elevation has an estimate of $-1.29*10^{-2}$, a standard error of $6.85*10^{-5}$, a z-value of -187.0, and a statistically significant p-value of < 0.05. Fine sediment has an estimate of 1.89, a standard error of $4.40*10^{-2}$, a z-value of 42.9, and a statistically significant p-value of < 0.05. Cobble has an estimate of $-9.98*10^{-1}$, a standard error of $1.13*10^{-2}$, a z-value of -88.7, and a statistically significant p-value of $<$ 0.05. The general linear model for all exotic invasives and elevation has an intercept estimate of 9.76, an intercept standard error of $2.60*10^{-2}$, an intercept z-value of 426.0, and a statistically significant intercept p-value of < 0.05. Elevation has an estimate of $-1.22*10^{-2}$, a standard error of $6.97*10^{-5}$, a z-value of -175.0, and a statistically significant p-value of < 0.05. The general linear model for all exotic invasives and fine sediment has an intercept estimate of 3.6946, an intercept standard error of 0.0437, an intercept z-value of 84.5, and a statistically significant intercept p-value of < 0.05. Fine sediment has an estimate of 2.4881, a standard error of 0.0439, a z-value of 56.6, and a statistically significant p-value of < 0.05. The general linear model for all exotic invasives and cobble has an intercept estimate of 6.20550, an intercept standard error of 0.00474, an intercept z-value of 1310.4, and a statistically significant intercept p-value of < 0.05 Cobble has an estimate of -0.55322, a standard error of 0.01121, a z-value of -49.4, and a statistically significant p-value of < 0.05.

Exotic Invasive Graminoids

A single multivariate model had overwhelming statistical support for the response variable, exotic invasive graminoids. This model used the variables: elevation, fine sediment and cobble. The model had a K score of 4, a Log(ℓ) score of -24083.722, a Deviance score of 47,575.015 compared to the null Deviance score of 116762.289, an $AIC_ι$ score of 48175.443, a $Δ_ι$ score of 0, and a $ω_ι$ of 1. The general linear multivariate model for all exotic invasive graminoids has an intercept estimate of 9.77, an intercept standard error of $5.06*10^{-2}$, an intercept z-value of 193.0, and a statistically significant intercept p-value of < 0.05. Elevation has an estimate of $-1.29*10^{-2}$, a standard error of $6.89*10^{-5}$, a z-value of -187.2, and a statistically significant p-value of < 0.05. Fine sediment has an estimate of 1.88, a standard error of $4.40*10^{-2}$, a z-value of 42.7, and a statistically significant p-value of < 0.05. Cobble has an estimate of $-1.01*10^{-1}$, a standard error of $1.13*10^{-2}$, a z-value of -88.8, and a statistically significant p-value of $<$ 0.05. The general linear model for exotic invasive graminoids and elevation has an intercept estimate of

11.1, an intercept standard error of $2.61*10^{-2}$, an intercept z-value of 424.0, and a statistically significant intercept p-value of < 0.05. Elevation has an estimate of $-1.22*10^{-2}$, a standard error of $7.01*10^{-5}$, a z-value of -174.0, and a statistically significant p-value of <0.05. The general linear model for exotic invasive graminoids and fine sediment has an intercept estimate of 3.6946, an intercept standard error of 0.0437, an intercept z-value of 84.5, and an intercept statistically significant intercept p-value of < 0.05. Fine sediment has an estimate of 2.4881, a standard error of 0.0439, a z-value of 56.6, and a statistically significant p-value of < 0.05. The general linear model for exotic invasive graminoids and cobble has an intercept estimate of 6.19949, an intercept standard error of 0.00475, an intercept z-value of 1305.2, and a statistically significant intercept p-value of < 0.05. Cobble has an estimate of -0.55988, a standard error of 0.01127, a z-value of -49.7, and a statistically significant p-value of < 0.05.

Exotic Invasive Forbs

A single multivariate model had the greatest empirical support for the response variable, exotic invasive forbs. This model used the variables: shade, fine sediment and percent ground coverage. The model had a K score of 4, a Log(ℓ) score of -538.325, a Deviance score of 949.433 compared to the null Deviance score of 1,404.37, a AIC_{ι} score of 1,084.651, a Δ_{ι} score of 0 and a ω_{ι} of 0.9831. The general linear multivariate model for exotic invasive forbs has an intercept estimate of -15.95594, an intercept standard error of 420.78958, an intercept z-value of -0.04, and an intercept p-value of 0.97. Shade has an estimate of -0.06683, a standard error of 0.00729, a z-value of -9.16, and a statistically significant p-value of < 0.05. Fine sediment has an estimate of 16.37136, a standard error of 420.7894, a z-value of 0.04, and a p-value of < 0.97. ground coverage has an estimate of 0.01565, a standard error of 0.00370, a z-value of 4.23, and a statistically significant p-value of < 0.05. The general linear model for exotic forbs and shade has an intercept estimate of 1.7868, an intercept standard error of 0.05360, an intercept z-value of 33.34, and a statistically significant intercept p-value of < 0.05. Shade has an estimate of -0.09084, a standard error of 0.00911, a z-value of -9.97, and a statistically significant p-value of < 0.05. The general linear model for exotic forbs and fine sediment has an intercept estimate of -15.3, an intercept standard error of 353.8, an intercept z-value of -0.04, and an intercept p-value of 0.97. Fine sediment have an estimate of 16.6, a standard error of 353.8, a z-value of 0.05, and a p-value of 0.96. The general linear model for exotic forbs and ground coverage has an intercept estimate of -1.02684, a standard error of 0.30357, a z-value of -3.38, and a statistically significant p-value of < 0.05. ground coverage has an estimate of 0.02502, a standard error of 0.00325, a z-value of 7.69, and a statistically significant p-value of < 0.05.

Habitat Suitability Modeling

All Exotic Invasive Vegetation

A single multivariate model had the greatest empirical support for the response variable, all exotic invasives. This model used the variables: aspect, ground coverage, and fine sediment. The model had a K score of 4, a $\text{Log}(\ell)$ score of -39.18, a Deviance score of 78.361 compared to the null Deviance score of 157.389, an AIC score of 86.361, a Delta score of 0, and a weight of 0.5195. The general linear multivariate model for the all exotic invasives has an intercept estimate of 4.62194, an intercept standard error of 1.31496, an intercept z-value of 3.51, and a statistically significant intercept p-value of < 0.05. Cover has an estimate of 0.03288, a standard error of 0.01076, a z-value of 3.06, and a statistically significant p-value of < 0.05. Aspect has an estimate of -0.03556, a standard error of 0.00669, a z-value of -5.31, and a statistically significant p-value of < 0.05. Fine sediment has an estimate of -2.34307, a standard error of 1.09396, a z-value of -2.14, and a p-value of 0.03221. The general linear model for all exotic invasives and aspect has an intercept estimate of 4.61639, an intercept standard error of 0.81210, an intercept z-value of 5.68, and a statistically significant intercept p-value of < 0.05. Aspect has an estimate of -0.03382, a standard error of 0.00586, a z-value of -5.77, and a statistically significant p-value of < 0.05. The general linear model for all exotic invasives and fine sediment has an intercept estimate of 0.470, an intercept standard error of 0.570, an intercept z-value of 0.82, and an intercept p-value of 0.41. Fine sediment has an estimate of 0.264, a standard error of 0.605, a z-value of 0.44, and a p-value of 0.66.

Exotic Invasive Graminoids

A single multivariate model had the greatest empirical support for the response variable, all exotic graminoids. This model used the variables: ground coverage, aspect and fine sediment. The model had a K score of 4, a $\text{Log}(\ell)$ score of -41.423, a Deviance score of 82.845 compared to the null Deviance score of 158.764, an AIC score of 90.845, a Delta score of 0, and a weight of 0.3304.The general linear multivariate model for the all exotic invasives has an intercept estimate of 4.34040, an intercept standard error of 1.24374, an intercept z-value of 3.49, and a statistically significant intercept p-value of < 0.05. ground coverage has an estimate of 0.03039, a standard error of 0.01037, a z-value of 2.93, and a statistically significant p-value of < 0.05. Aspect has an estimate of -0.03340, a standard error of 0.00614, a z-value of -5.44, and a statistically significant p-value of < 0.05. Fine sediment has an estimate of -2.24735, a standard error of 1.06126, a z-value of -2.12, and a p-value 0.03421. The general linear model for all exotic invasives and ground coverage has an intercept estimate of -1.29377, an intercept standard error of 0.54416, an intercept z-value of -2.38, and an intercept p-value of 0.017. ground coverage has an estimate of 0.02569, a standard error of 0.00654, a z-value of 3.93, and a statistically significant p-value of < 0.05. The general linear model for all exotic invasives and fine sediment has an intercept estimate of 0.470, an intercept standard error of 0.570, an intercept z-value of 0.82, and an intercept p-value of 0.41. Fine sediment has an estimate of 0.223, a standard error of 0.605, a z-value of 0.37, and a p-value of 0.71.

Exotic Invasive Forbs

A single multivariate model had statistical support for the response variable, exotic forbs. This model used the variables: canopy coverage, elevation, and fine sediment. The model had a K score of 4, a $\text{Log}(\ell)$ score of -51.215, a Deviance score of 102.429 compared to the null Deviance score of 145.672, an AIC score of 10.429, a Delta score of 0, and a weight of 0.2111. The general linear multivariate model for the all exotic invasive forbs has an intercept estimate of -14.0844, an intercept standard error of 1563.3410, an intercept z-value of -0.01, and an intercept p-value of 0.993. Canopy cover has an estimate of -0.0285, a standard error of 0.0194, a z-value of -1.47, and a p-value of 0.142. Fine sediment has an estimate of 17.4525, a standard error of 1563.3403, a z-value of 0.01, and a p-value of 0.991. Elevation has an estimate -0.0088, a standard error of 0.0039, a z-value of -2.26, and a statistically significant p-value of < 0.05. The general linear model for exotic invasive forbs and canopy cover has an intercept estimate of -1.02684, an intercept standard error of 0.30357, an intercept z-value of -3.38, and a statistically significant intercept p-value of < 0.05. Canopy cover has an estimate of 0.02502, a standard error of 0.00325, a z-value of 7.69, and a statistically significant p-value of < 0.05. The general linear model for exotic invasive forbs and fine sediment has an intercept estimate of -15.3, an intercept standard error of 353.8, an intercept z-value of -0.04, and an intercept p-value of 0.97. Fine sediment has an estimate of 16.6, a standard error of 353.8, a z-value of 0.05, and a p-value of 0.96. The general linear model for exotic invasive forbs and elevation has an intercept estimate of 4.57109, an intercept standard error of 1.13294, an intercept z-value of 4.03, and a statistically significant intercept p-value of < 0.05. Elevation has an estimate of -0.01275, a standard error of 0.00275, a z-value of - 4.63, and a statistically significant p-value of < 0.05.

Tables and Figures

Exotic Invasive Vegetation Catalog

Table 1
Inventory of all exotic invasive vegetation encountered along the last 92 river miles of the Grande Ronde River. The inventory is made up of all exotic invasive species that we encountered that were mature enough to positively ID. This inventory is likely incomplete, as the season was early during the time of our study. The table below lists the species scientific name, common name(s), noxious status and classification to Washington, Oregon, and Idaho, and the native region in which they originated.

Scientific Name	Common Name	Noxious (Y/N)	Classification	Native Region
Verbascum thapsus	Great Mullein, Greater Mullein, Common Mullein	N	NA	Eurasia and Africa
Rumex acetosella	Sheep's Sorrel, Red Sorrel, Field sorrel, sour Weed	N	NA	Eurasia and the British Isles
Rumex obtusifolius	Bitter Dock, Broad-Leaved Dock, Bluntleaf Dock, Dock Leaf, Butter Dock	N	NA	Europe
Euphorbia esula	Green Spurge, Leafy Spurge	Y	B	Eurasia
Linaria dalmatica	Balkan Toadflax, Broadleaf Toadflax, Dalmatian Toadflax	Y	B	Western Asia and southeastern Europe
Potentilla erecta	Erect Cinquefoil	N	NA	Europe
Poa pratensis	Kentucky Bluegrass	N	NA	Europe, North Asia, mountains of Algeria and Morocco
Poa Bulbosa	Bulbous Bluegrass, Bulbous Meadow-Grass	N	NA	Eurasia and North Africa

Taraxacum officinale	Dandelion or Common Dandelion	N	NA	Eurasia
Bromus tectorum	Downy Brome, Drooping Brome, Cheatgrass	N	NA	Europe, southwestern Asia, and northern Africa
Cynoglossum officinale	Hounds tongue, Gypsy Flower, Rats and Mice, Dog Bur	Y	B	Eurasia
Onopordum acanthium	Cotton Thistle, Scotch (or Scottish) Thistle	Y	B	Europe and Western Asia
Carduus nutans	Nodding Thistle, Musk Thistle	Y	B	Eurasia
Sisymbrium altissimum	Tumble mustard, Jim Hill mustard	N	NA	Mediterranean Basin in Europe and Northern Africa

Cataloging and Predicting the Spatial Distributions of Exotic Invasive Plants Along the Grande Ronde River

All Exotic Invasive Vegetation Models

Table 2.1 Information Theoretic Approach - All Exotic Invasive Vegetation
A single multivariate model consisting of Elevation, Fine Sediments, and Cobble had the greatest empirical support for exotic invasive vegetation.

Information Theoretic Approach Models or All Invasives

Independent Variables	K	log(ℓ)	Deviance	AIC_i	Δ_i	ω_i
GLMNULL	1	-58894.883	117193.606	117791.767	69489.029	0
Elevation	2	-31505.634	62415.108	63015.269	14712.531	0
Aspect	2	-35461.616	70327.072	70927.233	22624.495	0
Slope	2	-58876.951	117157.742	117757.903	69455.165	0
Cover	2	-48689.372	96782.584	97382.745	49080.007	0
Shade	2	-36475.441	72354.722	72954.883	24652.145	0
Fine	2	-54710.094	108824.027	109424.188	61121.45	0
Cobble	2	-57530.76	114465.36	115065.521	66762.783	0
Elevation + Fine	3	-28903.038	57209.915	57812.075	9509.337	0
Aspect + Fine	3	-32874.462	65152.763	65754.924	17452.186	0
Slope + Fine	3	-54691.916	108787.67	109389.831	61087.093	0
Cover + Fine	3	-47405.344	94214.527	94816.688	46513.95	0
Shade + Fine	3	-33163.505	65730.849	66333.01	18030.272	0
Fine + Cobble	3	-53989.179	107382.196	107984.357	59681.619	0
Shade + Elevation + Fine	4	-27391.96	54187.759	54791.92	6489.182	0
Shade + Elevation + Cobble	4	-24464.128	48332.096	48936.257	633.519	2.71E-138
Shade + Elevation + Cover	4	-26945.699	53295.237	53899.397	5596.659	0
Shade + Elevation + Aspect	4	-29752.73	58909.3	59513.461	11210.723	0
Shade + Fine + Cobble	4	-29880.276	59164.391	59768.551	11465.813	0
Shade + Fine + Cover	4	-28675.357	56754.553	57358.714	9055.976	0
Shade + Fine + Aspect	4	-29643.934	58691.706	59295.867	10993.129	0
Elevation + Fine + Cobble	**4**	**-24147.369**	**47698.577**	**48302.738**	**0**	**1**
Elevation + Fine + Cover	4	-27166.604	53737.047	54341.208	6038.47	0
Elevation + Fine + Aspect	4	-28708.699	56821.238	57425.399	9122.661	0
Cover + Fine + Cobble	4	-46220.321	91844.481	92448.642	44145.904	0
Cover + Fine + Aspect	4	-30147.291	59698.422	60302.583	11999.845	0
Aspect + Cover + Shade	4	-28550.018	56503.875	57108.036	8805.298	0
Aspect + Cover + Elevation	4	-28495.892	56395.624	56999.785	8697.047	0

Table 2.2 Habitat Suitability Model - All Exotic Invasive Vegetation
A single multivariate model consisting of ground coverage, Fine sediments and Land Aspect performed better than the others, but the model has relatively weak empirical support for predicting the presence of exotic invasive vegetation

Habitat Suitability Models s for All Invasives

Independent Variables	K	log(ℓ)	Deviance	AIC_i	Δ_i	ω_i
GLMNULL	1	-78.695	157.389	159.389	73.028	7.21E-17
Elevation	2	-45.114	90.228	94.228	7.867	0.01017
Aspect	2	-46.429	92.858	96.858	10.497	0.00273
Slope	2	-78.688	157.376	161.376	75.015	2.67E-17
Cover	2	-69.057	138.115	142.115	55.754	4.06E-13
Shade	2	-69.501	139.002	143.002	56.641	2.61E-13
Fine	2	-78.601	157.202	161.202	74.841	2.91E-17
Cobble	2	-74.769	149.537	153.537	67.176	1.34E-15
Elevation + Fine	3	-43.785	87.571	93.571	7.21	0.01413
Aspect + Fine	3	-46.021	92.043	98.043	11.682	0.00151
Slope + Fine	3	-78.594	157.189	163.189	76.828	1.08E-17
Cover + Fine	3	-67.757	135.514	141.514	55.153	5.49E-13
Shade + Fine	3	-69.106	138.212	144.212	57.851	1.42E-13
Fine + Cobble	3	-74.192	148.384	154.384	68.023	8.80E-16
Shade + Elevation + Fine	4	-40.551	81.102	89.102	2.741	0.132
Shade + Elevation + Cobble	4	-42.353	84.706	92.706	6.345	0.02177
Shade + Elevation + Cover	4	-43.133	86.266	94.266	7.905	0.009979
Shade + Elevation + Aspect	4	-42.655	85.31	93.31	6.949	0.01609
Shade + Fine + Cobble	4	-66.129	132.257	140.257	53.896	1.03E-12
Shade + Fine + Cover	4	-57.806	115.612	123.612	37.251	4.23E-09
Shade + Fine + Aspect	4	-42.631	85.262	93.262	6.901	0.01648
Elevation + Fine + Cobble	4	-43.419	86.839	94.839	8.478	0.007493
Elevation + Fine + Cover	4	-40.825	81.65	89.65	3.289	0.1003
Elevation + Fine + Aspect	4	-43.703	87.406	95.406	9.045	0.005643
Cover + Fine + Cobble	4	-64.875	129.75	137.75	51.389	3.60E-12
Cover + Fine + Aspect	**4**	**-39.18**	**78.361**	**86.361**	**0**	**0.5195**
Aspect + Cover + Shade	4	-40.805	81.61	89.61	3.249	0.1024
Aspect + Cover + Elevation	4	-41.749	83.498	91.498	5.137	0.03982

Cataloging and Predicting the Spatial Distributions of Exotic Invasive Plants Along the Grande Ronde River

Exotic Invasive Graminoids Models

Table 3.1 Information Theoretic Approach - All Exotic Invasive Graminoids
A single multivariate model consisting of Elevation, Fine Sediments, and Cobble had the greatest empirical support for all ecotic invasive graminoids.

Information Theoretic Approach Models for All Graminoids						
Independent Variables	**K**	**log(ℓ)**	**Deviance**	AIC_i	Δ_i	ω_i
GLMNULL	1	-58677.359	116762.289	117356.717	69181.274	0
Elevation	2	-31437.49	62282.551	62878.979	14703.536	0
Aspect	2	-35383.265	70174.102	70770.53	22595.087	0
Slope	2	-58660.525	116728.622	117325.05	69149.607	0
Cover	2	-48519.248	96446.068	97042.496	48867.053	0
Shade	2	-36438.598	72284.768	72881.195	24705.752	0
Fine	2	-54531.872	108471.316	109067.744	60892.301	0
Cobble	2	-57293.754	113995.079	114591.507	66416.064	0
Elevation + Fine	3	-28861.478	57130.527	57728.955	9553.512	0
Aspect + Fine	3	-32823.154	65053.88	65652.308	17476.865	0
Slope + Fine	3	-54514.792	108437.156	109035.584	60860.141	0
Cover + Fine	3	-47253.02	93913.613	94512.041	46336.598	0
Shade + Fine	3	-33156.992	65721.557	66319.985	18144.542	0
Fine + Cobble	3	-53794.016	106995.604	107594.031	59418.588	0
Shade + Elevation + Fine	4	-27379.219	54166.01	54766.438	6590.995	0
Shade + Elevation + Cobble	4	-24407.31	48222.193	48822.62	647.177	2.93E-141
Shade + Elevation + Cover	4	-26916.373	53240.318	53840.746	5665.303	0
Shade + Elevation + Aspect	4	-29713.349	58834.27	59434.698	11259.255	0
Shade + Fine + Cobble	4	-29852.984	59113.541	59713.969	11538.526	0
Shade + Fine + Cover	4	-28674.141	56755.853	57356.281	9180.838	0
Shade + Fine + Aspect	4	-29635.951	58679.474	59279.901	11104.458	0
Elevation + Fine + Cobble	**4**	**-24083.722**	**47575.015**	**48175.443**	**0**	**1**
Elevation + Fine + Cover	4	-27125.062	53657.697	54258.124	6082.681	0
Elevation + Fine + Aspect	4	-28665.797	56739.166	57339.594	9164.151	0
Cover + Fine + Cobble	4	-46047.46	91502.492	92102.919	43927.476	0
Cover + Fine + Aspect	4	-30100.593	59608.758	60209.186	12033.743	0
Aspect + Cover + Shade	4	-28525.985	56459.542	57059.97	8884.527	0
Aspect + Cover + Elevation	4	-28432.988	56273.547	56873.975	8698.532	0

Table 3.2 Habitat Suitability Model - All Exotic Invasive Graminoids
A single multivariate model consisting of ground coverage, Fine sediments and Land Aspect performed better than the others, but the model has relatively weak empirical support for predicting the presence of exotic invasive graminoids.

Habitat Suitability Models for All Graminoids						
Independent Variables	**K**	**log(ℓ)**	**Deviance**	AIC_i	Δ_i	ω_i
GLMNULL	1	-79.382	158.764	160.764	69.919	2.17E-16
Elevation	2	-46.79	93.579	97.579	6.734	0.0114
Aspect	2	-47.941	95.881	99.881	9.036	0.003605
Slope	2	-79.379	158.757	162.757	71.912	8.01E-17
Cover	2	-70.365	140.73	144.73	53.885	6.58E-13
Shade	2	-70.902	141.804	145.804	54.959	3.85E-13
Fine	2	-79.315	158.629	162.629	71.784	8.54E-17
Cobble	2	-75.151	150.302	154.302	63.457	5.49E-15
Elevation + Fine	3	-45.425	90.85	96.85	6.005	0.01641
Aspect + Fine	3	-47.476	94.951	100.951	10.106	0.002111
Slope + Fine	3	-79.311	158.623	164.623	73.778	3.15E-17
Cover + Fine	3	-69.063	138.125	144.125	53.28	8.90E-13
Shade + Fine	3	-70.589	141.177	147.177	56.332	1.94E-13
Fine + Cobble	3	-74.623	149.246	155.246	64.401	3.42E-15
Shade + Elevation + Fine	4	-41.594	83.189	91.189	0.344	0.2782
Shade + Elevation + Cobble	4	-43.447	86.893	94.893	4.048	0.04365
Shade + Elevation + Cover	4	-44.692	89.384	97.384	6.539	0.01256
Shade + Elevation + Aspect	4	-43.907	87.814	95.814	4.969	0.02754
Shade + Fine + Cobble	4	-67.33	134.66	142.66	51.815	1.85E-12
Shade + Fine + Cover	4	-60.066	120.132	128.132	37.287	2.64E-09
Shade + Fine + Aspect	4	-43.469	86.938	94.938	4.093	0.04268
Elevation + Fine + Cobble	4	-44.938	89.877	97.877	7.032	0.009819
Elevation + Fine + Cover	4	-42.808	85.617	93.617	2.772	0.08263
Elevation + Fine + Aspect	4	-45.35	90.7	98.7	7.855	0.006507
Cover + Fine + Cobble	4	-65.905	131.809	139.809	48.964	7.70E-12
Cover + Fine + Aspect	**4**	**-41.423**	**82.845**	**90.845**	**0**	**0.3304**
Aspect + Cover + Shade	4	-42.568	85.136	93.136	2.291	0.1051
Aspect + Cover + Elevation	4	-43.912	87.825	95.825	4.98	0.02739

Cataloging and Predicting the Spatial Distributions of Exotic Invasive Plants Along the Grande Ronde River

Exotic Invasive Forbs Models

Table 4.1 Information Theoretic Approach - Exotic Invasive Forbs
A single multivariate model consisting of Canopy Coverage, Fine Sediments, and ground coverage had the greatest empirical support for exotic invasive forbs.

Information Theoretic Approach Models for All Forbs						
Independent Variables	**K**	**log(ℓ)**	**Deviance**	AIC_i	Δ_i	ω_i
GLMNULL	1	-765.794	1404.37	1533.588	448.937	3.22E-98
Elevation	2	-611.881	1096.544	1227.762	143.111	8.25E-32
Aspect	2	-624.956	1122.695	1253.913	169.262	1.73E-37
Slope	2	-762.629	1398.041	1529.258	444.607	2.80E-97
Cover	2	-714.321	1301.426	1432.643	347.992	2.67E-76
Shade	2	-582.852	1038.486	1169.703	85.052	3.34E-19
Fine	2	-722.712	1318.206	1449.423	364.772	6.07E-80
Cobble	2	-764.316	1401.415	1532.632	447.981	5.19E-98
Elevation + Fine	3	-581.325	1035.433	1168.651	84	5.65E-19
Aspect + Fine	3	-594.006	1060.795	1194.012	109.361	1.76E-24
Slope + Fine	3	-719.589	1311.96	1445.177	360.526	5.07E-79
Cover + Fine	3	-692.008	1256.798	1390.015	305.364	4.83E-67
Shade + Fine	3	-549.415	971.613	1104.83	20.179	4.08E-05
Fine + Cobble	3	-717.771	1308.325	1441.542	356.891	3.12E-78
Shade + Elevation + Fine	4	-542.55	957.883	1093.101	8.45	0.01438
Shade + Elevation + Cobble	4	-568.812	1010.406	1145.623	60.972	5.66E-14
Shade + Elevation + Cover	4	-560.358	993.498	1128.715	44.064	2.66E-10
Shade + Elevation + Aspect	4	-572.679	1018.141	1153.358	68.707	1.18E-15
Shade + Fine + Cobble	4	-549.028	970.838	1106.056	21.405	2.21E-05
Shade + Fine + Cover	**4**	**-538.325**	**949.433**	**1084.651**	**0**	**0.9831**
Shade + Fine + Aspect	4	-544.318	961.419	1096.636	11.985	0.002455
Elevation + Fine + Cobble	4	-579.786	1032.355	1167.572	82.921	9.70E-19
Elevation + Fine + Cover	4	-577.475	1027.732	1162.949	78.298	9.78E-18
Elevation + Fine + Aspect	4	-581.325	1035.433	1170.65	85.999	2.08E-19
Cover + Fine + Cobble	4	-689.184	1251.152	1386.369	301.718	2.99E-66
Cover + Fine + Aspect	4	-585.687	1044.157	1179.374	94.723	2.65E-21
Aspect + Cover + Shade	4	-561.265	995.312	1130.53	45.879	1.07E-10
Aspect + Cover + Elevation	4	-601.301	1075.385	1210.603	125.952	4.39E-28

Table 4.2 Habitat Suitability Model - Exotic Invasive Forbs
A single multivariate model consisting of Canopy Coverage, Elevation and Fine sediments performed better than the others, but the model has relatively weak empirical support for predicting the presence of exotic invasive forbs.

Habitat Suitability Models s for All Forbs						
Independent Variables	**K**	**log(ℓ)**	**Deviance**	AIC_i	Δ_i	ω_i
GLMNULL	1	-72.836	145.672	147.672	37.243	1.73E-09
Elevation	2	-56.288	112.577	116.577	6.148	0.009762
Aspect	2	-57.427	114.853	118.853	8.424	0.003128
Slope	2	-72.465	144.931	148.931	38.502	9.20E-10
Cover	2	-68.765	137.531	141.531	31.102	3.72E-08
Shade	2	-58.381	116.762	120.762	10.333	0.001204
Fine	2	-68.389	136.777	140.777	30.348	5.43E-08
Cobble	2	-72.825	145.65	149.65	39.221	6.43E-10
Elevation + Fine	3	-52.674	105.348	111.348	0.919	0.1334
Aspect + Fine	3	-53.806	107.612	113.612	3.183	0.04299
Slope + Fine	3	-68.008	136.017	142.017	31.588	2.92E-08
Cover + Fine	3	-66.213	132.427	138.427	27.998	1.76E-07
Shade + Fine	3	-53.848	107.696	113.696	3.267	0.04122
Fine + Cobble	3	-68.328	136.656	142.656	32.227	2.12E-08
Shade + Elevation + Fine	**4**	**-51.215**	**102.429**	**110.429**	**0**	**0.2111**
Shade + Elevation + Cobble	4	-53.249	106.499	114.499	4.07	0.02759
Shade + Elevation + Cover	4	-54.187	108.375	116.375	5.946	0.0108
Shade + Elevation + Aspect	4	-54.886	109.772	117.772	7.343	0.005371
Shade + Fine + Cobble	4	-53.507	107.015	115.015	4.586	0.02132
Shade + Fine + Cover	4	-52.619	105.238	113.238	2.809	0.05183
Shade + Fine + Aspect	4	-51.829	103.657	111.657	1.228	0.1143
Elevation + Fine + Cobble	4	-51.291	102.583	110.583	0.154	0.1955
Elevation + Fine + Cover	4	-52.645	105.29	113.29	2.861	0.0505
Elevation + Fine + Aspect	4	-52.67	105.339	113.339	2.91	0.04928
Cover + Fine + Cobble	4	-66.208	132.415	140.415	29.986	6.50E-08
Cover + Fine + Aspect	4	-53.509	107.018	115.018	4.589	0.02129
Aspect + Cover + Shade	4	-54.573	109.145	117.145	6.716	0.007349
Aspect + Cover + Elevation	4	-55.829	111.657	119.657	9.228	0.002093

Cataloging and Predicting the Spatial Distributions of Exotic Invasive Plants Along the Grande Ronde River

Information Theoretic Approach

All Exotic Invasive Vegetation

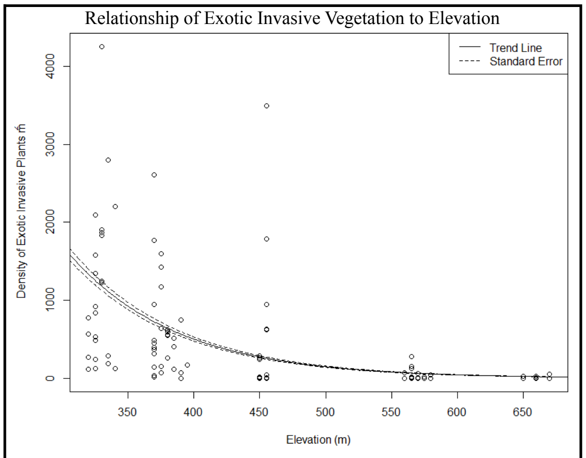

Figure 5.1 *Information Theoretic Approach - All Exotic Invasives*
There is a nonlinear relationship between density of exotic invasive vegetation and elevation. As elevation increases, the density of all exotic invasive vegetation decreases. The highest density of invasive vegetation encountered occurred at the end of the Grande Ronde River, at an elevation below 350m.

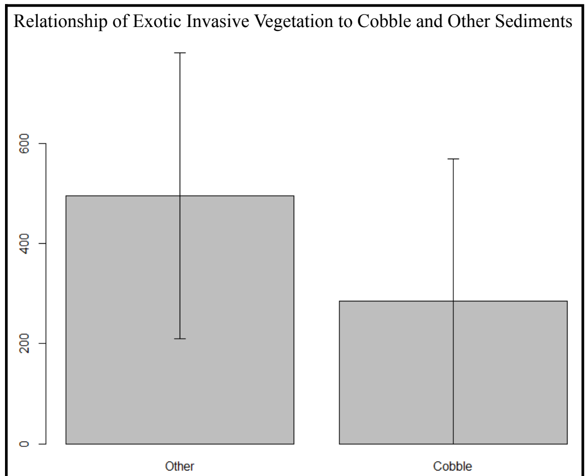

Figure 5.2 *Information Theoretic Approach - All Exotic Invasives*
The uncertainty of cobble within our model is lower than other sediments but still relatively large which leads to low confidence in the difference between coefficients for cobble vs. other substrates. Cobble was exerting a positive effect on all exotic invasive vegetation. However, there is so much variability within our results that a closer look on how substrate is facilitating vegetative growth is necessary.

Cataloging and Predicting the Spatial Distributions of Exotic Invasive Plants Along the Grande Ronde River

Exotic Invasive Graminoids

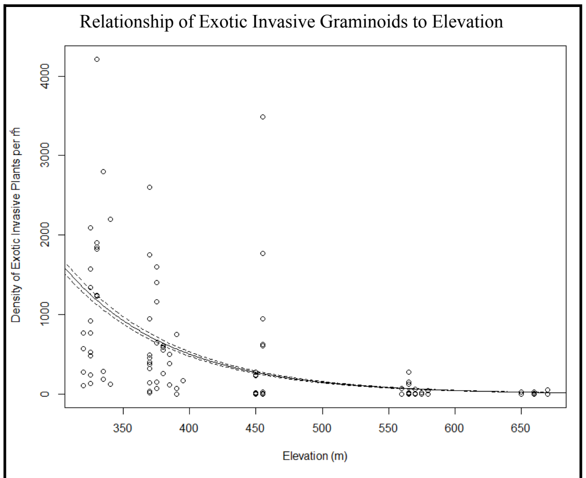

Figure 5.3 *Information Theoretic Approach - Graminoids*
There is a nonlinear relationship between density of exotic invasive graminoids and elevation. As elevation increases, the density of all exotic invasive graminoids decreases. The highest density of invasive graminoids encountered occurred at the end of the Grande Ronde River, at an elevation below 350m.

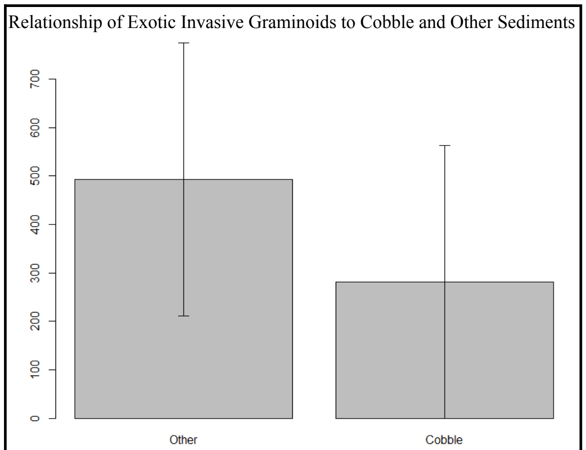

Figure 5.4 *Information Theoretic Approach - Graminoids*
The uncertainty of cobble within our model is lower than other sediments but still relatively large which leads to low confidence in the difference between coefficients for cobble vs. other substrates. Cobble was exerting a positive effect on all exotic invasive graminoids. However, there is so much variability within our results that a closer look on how substrate is facilitating vegetative growth is necessary.

Cataloging and Predicting the Spatial Distributions of Exotic Invasive Plants Along the Grande Ronde River

Exotic Invasive Forbs

The Relationship Between Exotic Invasive Forbs and Canopy Coverage

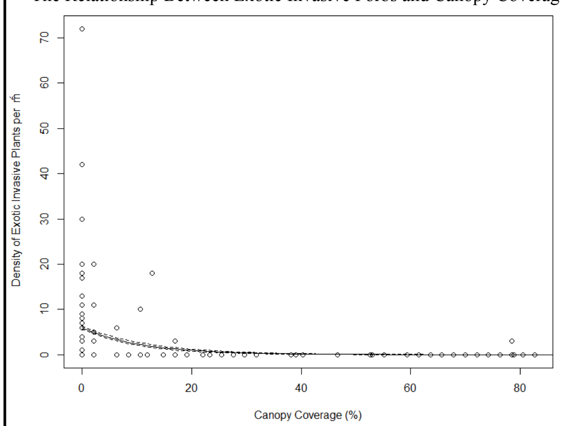

Figure 5.5 *Information Theoretic Approach - Forbs*
There is a nonlinear relationship between density of exotic invasive forbs and percent canopy coverage. As canopy coverage increases, the density of all exotic invasive forbs decreases. The highest density of exotic invasive forbs occurs at 0% canopy coverage.

The Relationship Between Invasive Forbs and ground coverage

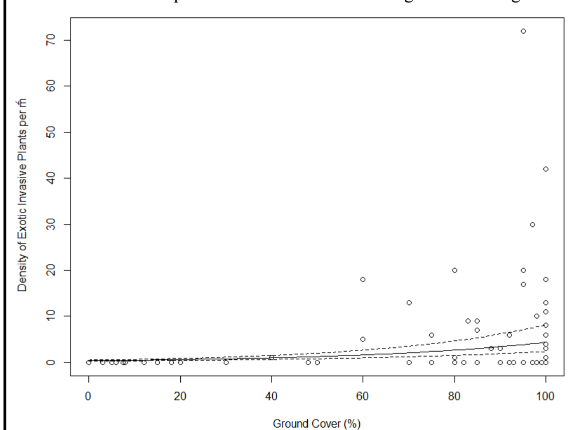

Figure 5.6 *Information Theoretic Approach - Forbs*
There is a nonlinear relationship between density of exotic invasive forbs and ground coverage. As ground coverage increased, the density of all exotic invasive forbs increased. The highest density of forbs were found in plots with near 100% ground coverage although it should be noted that ground coverage was typically made up of graminoids as opposed to cobbles and/or other debris that would physically block plant establishment.

Cataloging and Predicting the Spatial Distributions of Exotic Invasive Plants Along the Grande Ronde River

Habitat Suitability Models

All Exotic Invasive Vegetation

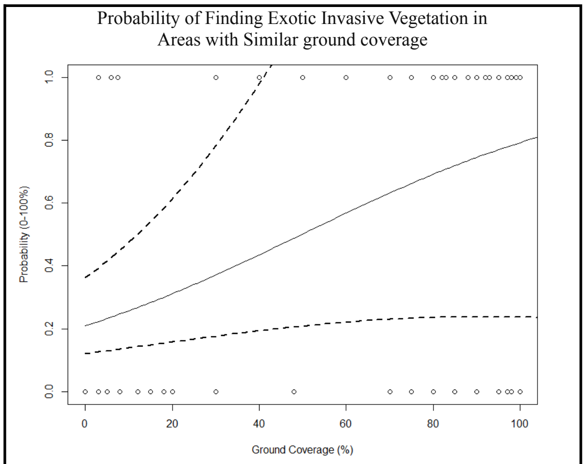

Figure 6.1 *Habitat Suitability Model - All Exotic Invasives*
The probability of finding any exotic invasive vegetation increased as ground coverage increased. It should be noted that ground coverage was typically made up of graminoids as opposed to cobbles and/or other debris that would physically block plant establishment.

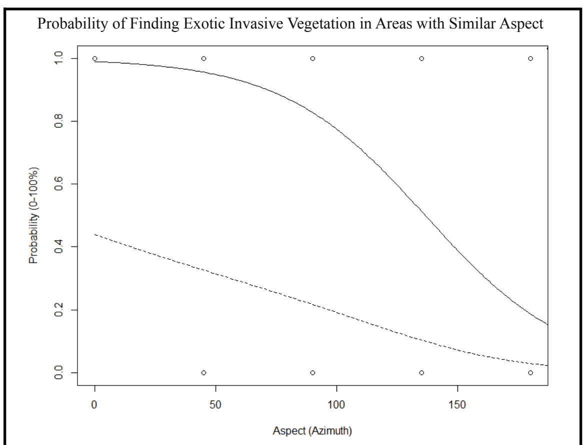

Figure 6.2 *Habitat Suitability Model - All Exotic Invasives*
The probability of finding exotic invasive graminoids increased as the aspect of the land approached North and quickly decreased as the aspect approached South East (+90°).

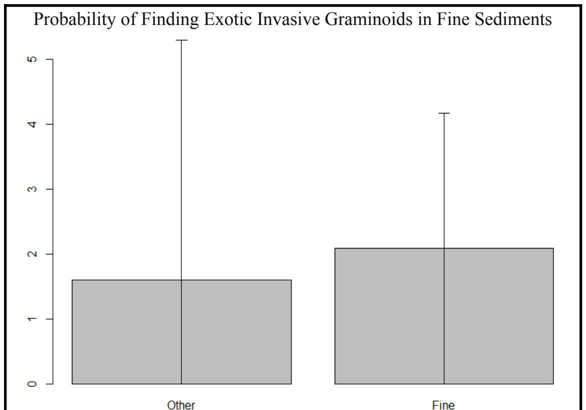

Figure 6.3. *Habitat Suitability Model - All Exotic Invasives*
The uncertainty of fine sediments within our model is lower than other sediments but still relatively large which leads to low confidence in the difference between coefficients for fine vs. other substrates. Fine sediment was exerting a positive effect on all exotic invasives.

Cataloging and Predicting the Spatial Distributions of Exotic Invasive Plants Along the Grande Ronde River

Exotic Invasive Graminoids

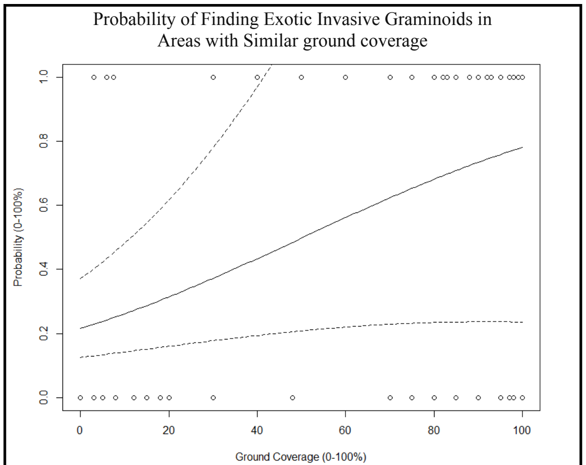

Figure 6.4 *Habitat Suitability Model - Exotic Invasive Graminoids*
The probability of finding any exotic invasive graminoids increased almost linearly as ground coverage increased. It should be noted that ground coverage was typically made up of graminoids as opposed to cobbles and/or other debris that physically block plant establishment. Thus, graminoids were influencing the results. This would also indicate that areas that are initially free of ground obstructions quickly become invaded and dominated by graminoids if other environmental conditions are favorable.

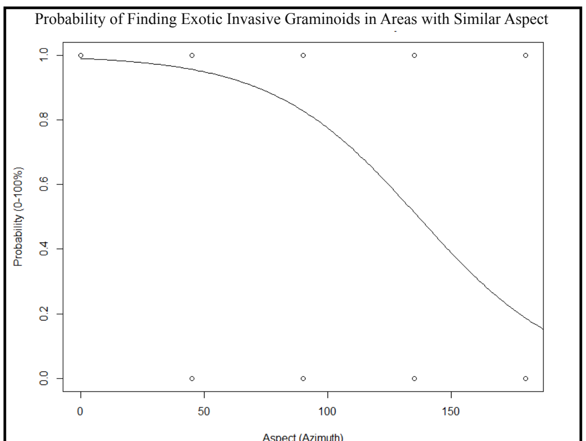

Figure 6.5 *Habitat Suitability Model - Graminoids*
The probability of finding exotic invasive graminoids increased as the aspect of the land approached North and quickly decreased as the aspect approached South East (+90°).

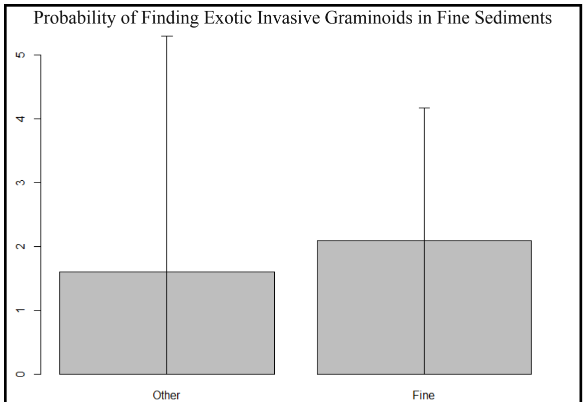

Figure 6.6 *Habitat Suitability Model - Graminoids*
The uncertainty of fine within our model is lower than other sediments but still relatively large which leads to low confidence in the difference between coefficients for fine vs. other substrates. Fine sediment was exerting a positive effect on invasive graminoids. However, there is so much variability within our results that a closer look on how substrate is facilitating vegetative growth is necessary.

Cataloging and Predicting the Spatial Distributions of Exotic Invasive Plants Along the Grande Ronde River

Exotic Invasive Forbs

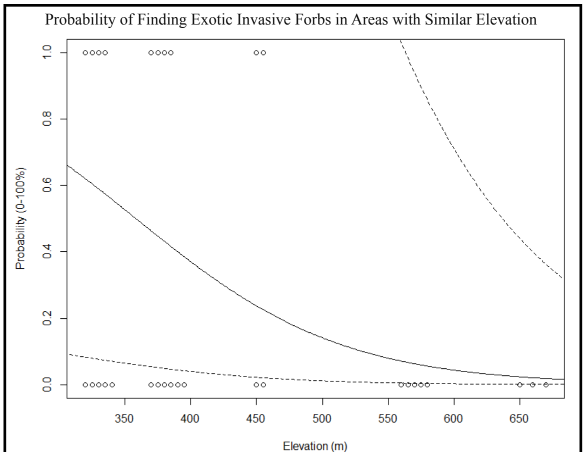

Figure 6.7 *Habitat Suitability Model - Forbs*
The probability of finding exotic invasive forbs nonlinearly decreases as elevation surpasses 500 (m). The probability increases to >50% as elevation goes below 375 (m), but the uncertainty is highly variable.

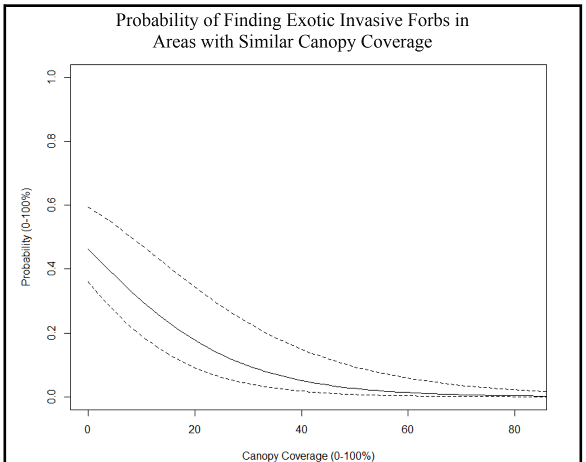

Figure 6.8 *Habitat Suitability Model - Forbs*
The probability of finding exotic invasive forbs was approximately 50% at 0% canopy coverage and decreased nonlinearly as canopy coverage approached 25%.

Cataloging and Predicting the Spatial Distributions of Exotic Invasive Plants Along the Grande Ronde River

Discussion

Data Interpretation of the Models

On the The Information Theoretic Approach and Habitat Suitability Modeling tables, each column represents a different parameter of the model. The Variables column is the number of predictor variable(s) in each model. The K column is the number of parameters required to fit each model; a measure of model complexity. The Log(ℓ) column is a measure of the probability of the data in the model being “true”; or the probability you would obtain these plant counts if the model was "true". The Deviance or “residual deviance” column is a measure of the amount of variability in response variables not explained by the model. The residual deviance of the model is compared against the residual deviance of the null model, which is equal to the total deviance. The AIC column is the AIC score, a measure of balance between fit and simplicity, for that model. The elta column is the transformed AIC score, obtained by subtracting the lowest AIC score from all other AIC scores. By definition, the model with greatest empirical support has Delta = 0. The weight column is the probability that the model would score best (Delta=0) if you conducted analysis with a replicate data set. Weight can also be interpreted as confidence in that model relative to other models in your candidate set.

Combining Graminoids With All Exotic Invasive Vegetations For The Discussion

The majority of exotic invasive plants we encountered were graminoids and this is reflected by the data analysis where we had overwhelming empirical support for the same single multivariate models for the ITA and HSM. Thus, forbs present the only outlier in this study. We will discuss forbs independently, but all discussion around exotic invasive vegetation and exotic invasive graminoids will be combined together, as there is little statistical difference in the models.

Exotic Invasive Vegetation

The combination of elevation, fine sediments and cobble were our best performing models for the ITA (Table 2.1, 3.1). As elevation decreases, the density of invasive exotic vegetation increases (Figures 5.1, 5.3). While there are many reasons why this may be, one in particular reason is that the land shifts from federally protected to lands that are private, and agriculture-adjacent. Thus, the invasion vector grows as the river decreases in elevation. The land at higher elevations is forested, and has greater canopy coverage which can shade out invasive vegetation as opposed to the arid, grassland dominated,open steppes at the lower elevations. These arid regions are where the majority of exotic invasives were encountered. The warmer climates at lower elevations allow vegetation to begin their life cycles earlier in the season relative to the colder regions at higher elevations. During the time of our study, many suspect invasives were unable to be counted due to their premature development that inhibited our ability to accurately identify them.

The substrate, fine sediments, consistently show up in the model selection for the ITA and HSM.

This means our models work better with fine sediments included than without (All Tables). From this, we can conclude that fine sediments are influencing exotic invasive vegetation composition, but we don't know what positive effect is occurring. This means we cannot interpret responses to that variable as there is low confidence in the difference between coefficients for fine vs. other substrates. The large extent of variability within our results requires more information to determine how substrate is facilitating vegetative growth, however our data is not sufficient to do so. We know fine sediment is the preferred substrate for all types of vegetation, as it retains moisture and is highly concentrated with nutrients relative to larger sediments. Therefore future studies should focus on fine sediments and their associated nutrients, moisture retention, porosity, and/or other abiotic and biotic factors that may be synergizing to positively affect exotic invasive plants.

The uncertainty of cobble within our models is lower than other sediments, but still relatively large which leads to low confidence in the difference between coefficients for cobble vs. other substrates (Figures 5.2, 5.4). Cobble was exerting a positive effect on all exotic invasive non-forbs. However, there is so much variability within our results, that a closer look on how substrate is facilitating vegetative growth is necessary. Vegetation cannot grow on cobble alone, as the cobbles physically obstruct the ground, hindering plants from establishing. However, vegetation will grow in the smaller sediments that accumulate in between cobbles. This is why our box plots (Figure 5.2, 5.4) shows that exotic invasive vegetation is found in plots that contain cobble, but has a higher relative density in plots dominated by other (smaller) sediment types.

Our HSM found that a single multivariate model consisting of ground coverage, fine sediments, and land aspect performed better than the others, but the model has relatively weak empirical support for predicting the presence of exotic invasive vegetation (Tables 3.2 - 4.2). As ground coverage increased, the probability of finding any exotic invasive vegetation also increased (Figure 6.1). Ground coverage, which was measured based upon the amount of exposed bare soil, was largely made up of graminoids in a majority of our plots. This is why our data shows that there is a positive relationship between invasive vegetation and ground coverage. This was an oversight in our project. Future studies may want to redefine ground coverage as physical obstruction of bare soil. For instance, large woody debris, large cobble, or massive single plants should define what constitutes ground coverage. We can infer that given the opportunity, such as after a large fire, graminoids will quickly dominate any bare soil and become the de facto “ground coverage” (Figures 6.3, 6.6.)

According to our models, as the aspect of the land approaches north, the probability of finding exotic invasive vegetation increases, and as the land's aspect approaches southeast, the probability of finding exotic invasive vegetation rapidly decreases (Figure 6.2). In the northern hemisphere, north facing slopes receive less direct sunlight than south facing slopes and are cooler in temperature. Such environmental factors are often less preferable to vegetation, therefore, we suspect that the local terrain along the Grande Ronde may have a greater influence on invasive vegetation composition. The Grande Ronde River is surrounded by rugged canyons and steep hillsides that block sunlight from reaching the ground for extended periods of time. Thus, regardless of the hillsides aspect, the hours of sunlight that one area with similar aspect may receive might drastically differ from another area with similar aspect. Additionally, our data points were skewed, as the majority of our samples were taken along or near a north facing slope. Our results on the relationship between invasive exotic vegetation and aspect is thus inconclusive, and future studies should instead focus on the relationship between topography and invasive vegetation composition.

Cataloging and Predicting the Spatial Distributions of Exotic Invasive Plants Along the Grande Ronde River

Exotic Invasive Forbs

The ITA produced for forbs differed from graminoids and all exotic invasive vegetation, with support for a single multivariate model of shade, fine, and ground coverage (Table 2.3). The HSM for exotic invasive forbs found that a single multivariate model consisting of canopy coverage, elevation, and fine sediments performed better than the others, but the model has weak empirical support for predicting the presence of exotic invasive forbs. The variables elevation, fine sediments and cobble were discussed above and we believe the reasoning holds true for forbs.

Canopy coverage or "shade" was selected for the ITA and HSM. The greater canopy coverage in the higher elevation, forested land should shade out invasives. The nonlinear relationship between density of exotic invasive forbs and canopy coverage showed that as canopy coverage increases, forb density decreases according to our models (Figure 5.5). The nonlinear relationship between forbs and ground coverage shows that as ground coverage increased, the density of all exotic invasive forbs increased (Figure 5.6). The probability of finding exotic invasive forbs at different elevations also had a nonlinear relationship, with a greater probability at lower elevations (Figure 6.7). We expected to find greater densities of forbs at high elevation but reality did not meet our expectations. This might be explained by the fact that in the areas where we expected to find the more shade-tolerant forbs, a recent fire had occurred. The fire happened in the late summer of the previous year. If there were populations of invasive vegetation there, they would have been wiped out. Additionally, the timing of the fire was late enough that most invasive species would have already completed their life cycles and therefore would not have had a chance to become established. The majority of our data was collected at lower elevation and we believe this is skewing the models.

Conclusions

In retrospect, there are a multitude of factors within this study that we should have changed. However, as there was no preliminary inventory of the invasive vegetation within the area, we did not know what to expect. We believe this impacted the design of our study. Our plots were systematic transects and we believe a different sampling method would have been more efficient. During our study, our transects would bypass or edge zones that contained different types of invasive vegetation. Thus, although we knew the species were present in an area, we did not always collect any data on them. Directly pursuing exotic invasive vegetation would have allowed us to obtain more relevant species-specific environmental data. The weather also greatly impacted our study. The Grande Ronde river's water level was above normal before we arrived, and strong storms were ongoing throughout. The rising water level submerged many of the plants growing in the riparian zone that we had observed on the first day. These appeared to be mostly forbs and as such, we gathered less data on forbs compared to graminoids. Creating models for all exotic invasive vegetation was somewhat redundant as the data was heavily skewed towards graminoids due to the reasons above. Future studies should break down the response variables by family as opposed to classification since there is now a preliminary catalog of invasive vegetation for the Grande Ronde river.

Cataloging and Predicting the Spatial Distributions of Exotic Invasive Plants Along the Grande Ronde River

Cataloging and Predicting the Spatial Distributions of Exotic Invasive Plants Along the Grande Ronde River

Literature Cited

Ayre, K. K., & Landis, W. G. (2012). A Bayesian Approach To Landscape Ecological Risk Assessment Applied To The Upper Grande Ronde Watershed, Oregon. Human And Ecological Risk Assessment: An International Journal. 18(5): 946-970., 18(5), 946–970. Https://Doi.Org/10.1080/10807039.2012.707925

Cai, W., Huang, H., Chen, P., Huang, X., Gaurav, S., Pan, Z., & Lin, P. (2020). Effects of biochar from invasive weed on soil erosion under varying compaction and slope conditions: Comprehensive study using flume experiments. Biomass Conversion and Biorefinery. https://doi.org/10.1007/s13399-020-00943-3

Chai, S.-L., Zhang, J., Nixon, A., & Nielsen, S. (2016). Using Risk Assessment and Habitat Suitability Models to Prioritize Invasive Species for Management in a Changing Climate. PLOS ONE, 11(10), e0165292. https://doi.org/10.1371/journal.pone.0165292

Harrod, J., Richy (2001). Riparian Vegetation Of The Grande Ronde River. 21. The Effect Of Invasive And Noxious Plants On Land Management In Eastern Oregon And Washington—Washington State University. (N.D.). Northwest Science., Vol.75, Pp.85-90; 2001; Retrieved April 27, 2022, From Https://Hdl.Handle.Net/2376/985

Higgins, S. I., Richardson, D. M., & Cowling, R. M. (1996). Modeling Invasive Plant Spread: The Role Of Plant-Environment Interactions And Model Structure. Ecology, 77(7), 2043–2054. Https://Doi.Org/10.2307/2265699

Hirzel, A. H., & Le Lay, G. (2008). Habitat suitability modeling and niche theory. Journal of Applied Ecology, 45(5), 1372–1381. https://doi.org/10.1111/j.1365-2664.2008.01524.x

Wilson, J., Richardson, D., Rouget, M., Procheş, S., Amis, M., Henderson, L., Thuiller, T. (2007) Residence Time And Potential Range: Crucial Considerations In Modeling Plant Invasions, Diversity And Distributions.
Wiley Online Library. (N.D.). Retrieved April 27, 2022, From Https://Doi.Org/10.1111/J.1366-9516.2006.00302.X

Jorgensen, N., & Renz, M. (2021). Assessing the performance and accuracy of invasive plant habitat suitability models in detecting new observations in Wisconsin. Invasive Plant Science and Management, 14(4), 214–222. https://doi.org/10.1017/inp.2021.27

Cataloging and Predicting the Spatial Distributions of Exotic Invasive Plants Along the Grande Ronde River

Davies, K., Johnson, D. (2017) Are We “Missing The Boat” On Preventing The Spread Of Invasive Plants In Rangelands? Invasive Plant Science And Management Cambridge Core. (N.D.). Invasive Plant Science And Management , Volume 4 , Issue 1, March 2011 , Pp. 166 - 171. Https://Doi.Org/10.1614/Ipsm-D-10-00030.1

Lawson, Abigail J. (2007) Historical Land And Resource Use In The Grande Ronde Basin. Https://Watershed.Ucdavis.Edu/, 10 June 2007, Https://Watershed.Ucdavis.Edu/Education/Classes/Files/Content/Page/Lawson.Pdf.

Peterson, A. T., & Vieglais, D. A. (2001). Predicting Species Invasions Using Ecological Niche Modeling: New Approaches From Bioinformatics Attack A Pressing Problem: A New Approach To Ecological Niche Modeling, Based On New Tools Drawn From Biodiversity Informatics, Is Applied To The Challenge Of Predicting Potential Species' Invasions. Bioscience, 51(5), 363–371. Https://Doi.Org/10.1641/0006-3568(2001)051[0363:Psiuen]2.0.Co;2

Peterson, A. T., Papes, M., & Kluza, D. A. (2003). Predicting the potential invasive distributions of four alien plant species in North America. Weed Science, 51(6), 863–868. https://doi.org/10.1614/P2002-081

Rushton, S. P., Ormerod, S. J., & Kerby, G. (2004). New Paradigms For Modeling Species Distributions? Journal Of Applied Ecology, 41(2), 193–200. Https://Doi.Org/10.1111/J.0021-8901.2004.00903.X

Stewart, Joseph (2007) Riparian Vegetation of the Grande Ronde River. https://www.researchgate.net/publication/265575450_Riparian_Vegetation_of_the_Grande_Ronde_River.

Thuiller, W., Richardson, D. M., Rouget, M., Procheş, Ş., & Wilson, J. R. U. (2006). Interactions Between Environment, Species Traits, And Human Uses Describe Patterns Of Plant Invasions. Ecology, 87(7), 1755–1769. Https://Doi.Org/10.1890/0012-9658(2006)87[1755:Ibesta]2.0.Co;2

Wissmar, R.C, J. E. Smith, B. A. Mcintosh, H. W. Li, G. H. Reeves, And J. R. Sedell. (1994) A History Of Resource Use And Disturbance In Riverine Basins Of Eastern Oregon

And Washington (Early 1800's-1990's), Rsis Range Science Article Citations—Montana State University Library. (N.D.). Retrieved April 27, 2022, From Https://Arc.Lib.Montana.Edu/Range-Science/Item/1361

Zalba, S. M., Sonaglioni, M. I., Compagnoni, C. A., & Belenguer, C. J. (2000). Using A Habitat Model To Assess The Risk Of Invasion By An Exotic Plant. Biological Conservation, 93(2), 203–208. Https://Doi.Org/10.1016/S0006-3207(99)00146-9