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Predictors of Exotic Plant Species in United States National Parks

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ABSTRACT

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Invasive species are recognized as a major threat to biodiversity. Understanding what factors facilitate invasion is of great conservation value, as this will allow for more specific and targeted conservation efforts related to non-native species. Knowledge of factors that contribute to invasion play an important role in conservation of particularly unique habitats, such as the iconic United States National Parks. Though National Parks have some legal protections against some forms of habitat degradation, they are still vulnerable to the introduction of non-natives. The purpose of this study is to characterize species invasion in National Parks and identify what environmental conditions may contribute to invasion on a national and regional level. We used plot-level and park-level data from 165 National Parks and National Historic Monuments throughout the United States to make correlations between the degree of invasion and predictor variables using a statistical regression analysis. We were unable to obtain a nationwide predictor of invasion, however were more successful on a regional basis. We concluded that the degree of human impact was the most important factor in predicting invasion. In addition, area of the park and precipitation were important factors correlated with invasion. Native species richness was correlated as well, however weakly. These results will be used to better assist in conservation efforts of National Parks in the future.

INTRODUCTION

Non-native species remain a major threat to biodiversity, as establishment can have serious impacts on the ecosystem. Non-natives can alter the makeup of a community by shifting the dominant species and altering nutrient cycling and plant productivity (Mack et al. 2009). Extirpation of the native species can be achieved by disease, competitive exclusion, or predation, all potential results of invasive species introduction and establishment (White and Houlahan 2007). This is significant as changes in the community or ecosystem threaten conservation efforts, biodiversity, and agricultural production (Mack et al. 2000).

Considering the detrimental impact of invasive species on the ecosystem, it is beneficial to note what makes one community more vulnerable to invasion than another. There are several factors that contribute to invasion success, including both biological and abiotic factors.

A number of studies investigate the relationship between native and non-native species richness, with two very distinct and contrasting theories. The first theory put forth by Charles Elton in 1958 (Pauchard and Shea 2006) has been called the vacant niche hypothesis (Mack et al. 2000). This states that habitats with fewer native species are unable to resist invasion, and more likely to be colonized by non-native species (Mack et al. 2000) The basis of this concept is that diverse communities have fewer open niches that potential invasive species can exploit (Pauchard and Shea 2006).

However, larger scale studies have found that native and non-native species richness are positively correlated (McKinney 2006, Richardson et al. 2005) meaning “the rich get richer” and that invasive species are more likely to invade diverse communities.

Areas that are conducive to native species will also be for non-native invaders (Pauchard and Shea 2006, Stohlgren et al. 2003).

This paradox may be explained by differences in spatial scales: at smaller scales, the vacant niche hypothesis may apply. Within such small scales, soil and climate conditions are less likely to vary and so interactions between individual plants are paramount (Pauchard and Shea 2006, Shea and Chesson 2002). But at larger scales, there is a greater chance that abiotic factors will vary, which promotes diversity. In this scenario, what is good for native diversity may also be good for non-native diversity (Pauchard and Shea 2006).

Besides native species richness, several studies also found human impact to be a documented predictor of non-native invasive species (Chiron et al. 2009, McKinney 2006, Richardson et al. 2005). Human disturbance allows a means for introduction for non-natives, by opening up potential space for colonization (Chiron et al. 2009). Disturbance can be defined as processes that either release nutrients or get rid of competitors. Disturbances can be done on a smaller or larger scale, modifying niches and affecting what species can colonize (Pauchard and Shea 2006).

Human activity also affects dispersal of non-native species. Dispersal is the process of movement from one location to another (Pauchard and Shea 2006), and is influenced by many factors. Long distance and short distance dispersal is often accomplished by natural mechanisms, such as transportation by animals, wind, tides, and birds. It can, however, be enhanced by humans through modification of biotic and abiotic factors (Pauchard and She 2006). It is made possible by increased visitation to areas, whether accidental or purposeful. Visitation is more accessible by the addition of roadways, leading to further disturbance, as well as another means for propagule introduction (Allen et al. 2009).

Knowledge of predictors of invasion plays an important role in conservation of particularly unique habitats, such as the iconic United States National Parks. National Parks are protected areas for preservation of wildlife, which can be greatly impacted by non-native invaders. Protection is accomplished with the aim of managing biological diversity in unique habitats (Stohlgren et al. 2002). The uniqueness of these landscapes is made vulnerable by the introduction of invasive species, which can threaten the existence of native species and alter the existing ecosystem.

The purpose of this study is to identify predictors of invasive species in these vulnerable National Parks. We used plot-level data from 165 National Parks and National Historic Monuments in the United States to test for biotic and abiotic conditions that contribute to species invasions. While previous studies have relates species invasion to such environmental variables, none has made such large-scale correlations using plot level data. Our aim was to determine nationwide and regional predictors of invasion using this method. We hypothesized that factors that show a greater degree of human influence will be positively correlated with invasion. We also tested contrasting hypotheses about the relationship between native and non-native species richness, which could be either positive or negative. From this information, we can identify what makes one community more vulnerable to invasion than another using a very elaborate dataset to make more generalized predictions.

METHODOLOGY

The United States National Park Service (NPS) began an Inventory and Monitoring Program (I&M) across the nation in order to classify the vegetation in these iconic parks, monuments, and national historic sites "NPS Inventory and Monitoring Program"). This program was mandated in 1998, where today more than 270 parks have participated. The goal of this program was to classify the plant community in order to provide information as to the overall health of the site. This information could be utilized to determine policy and to modify conservation efforts.

Monitoring was done in 32 I&M networks, each conducting similar research techniques to classify the landscape. Broadly, these techniques included classifying the vegetation within a 400 m^2 plots throughout the landscape. These locations were selected randomly, and each species was recorded as well as percent cover. The native and invasive species were classified within these plots ("NPS Inventory and Monitoring Program").

Every species was classified as "native" or "exotic" by comparing it to the USDA PLANTS database ("PLANTS Database"). Each plot's plant species composition was summarized to yield the total number of species, number of native and exotic species, and the proportion of total species that were exotic.

We also compiled a set of environmental variables based on geospatial locations of each plot as well as each plot's park. Average visitation at each park was determined for the year 2006, as recorded on the NPS Visitor Use Statistics (*Annual Visitation by Park (1979-Last Calendar Year)*). Additional datasets provided area, region, and state on a park level. Using Geographic Information Systems, elevation, distance to roads, and precipitation on the plot level was determined for each point. Elevation was extracted using a Digital Elevation Model (DEM) ("30 Arc-second DEM of North America"), the latter were extracted from shapefiles ("United States Average Annual Precipitation, 1990-2009 – Direct Download").

Because both response and predictor variables were highly non-normal, we log-transformed the data prior to statistical analysis. We conducted separate stepwise linear regressions for the number of exotic species and the proportion of the total number of species that were exotic using R (Version 3.3.1). The program determined which variables to use from among our environmental variables plus number of native species. We also ran separate stepwise regressions in each geographic region: Alaska, Northeast, Pacific West, Intermountain, Midwest, Nations Capital, and Southeast.

After collection, the data was summarized to tell for each plot the predictor and response variables detailed above. The data was log transformed when necessary and a stepwise linear regression was run using the program R (Version 3.2). The program determined which variables to use, whether a positive or negative correlation was achieved, along with a p-value and R^2. The linear regression was run for all predictor variables and number of native species. This was completed using two different response variables: number of invasive species and ratio of native to exotic.

RESULTS

Nationwide Analysis

Stepwise regression of the 6,025 plots within United States National Parks that we analyzed reported that distance to road, area, average annual precipitation, and visitation were all negatively correlated with the number of exotic species. Number of native species was positively correlated in this model. The p-value for each was less than 0.0001 (Table 1). The R^2 for this model, 0.11, was relatively low.

Table 1: Results of a stepwise regression analysis comparing number of invasive species to the predictor variables in row 1.

Predictor Variables	Estimate	Std. Error	T-value	P-value
logDist_Road	$-1.458e^{-01}$	$6.667e^{-03}$	-21.867	< 0.0001
Area	$-1.884e^{-05}$	$1.397e^{-06}$	-13.482	< 0.0001
Precipitation	$-9.500e^{-03}$	$7.115e^{-04}$	-13.352	< 0.0001
logNspp	$1.564e^{-01}$	$1.525e^{-02}$	10.257	< 0.0001
Visitation	$-4.533e^{-03}$	$6.282e^{-04}$	-7.216	< 0.0001

Regression of proportion of exotic species, meaning number of exotic species over total number of species, to the same predictor variables reported similar results, except that the number of native species was absent from the final model (Table 2). As was the case for the number of native species, the R^2 value for this regression – 0.11 – was relatively low.

Table 2: Results of a stepwise regression analysis comparing proportion of invasive species to the predictor variables in row 1.

Predictor Variables	Estimate	Std. Error	T-value	P-value
logDist_Road	$-9.988e^{-02}$	$4.529e^{-03}$	-22.053	< 0.0001
Precip	$-8.396e^{-03}$	$4.627e^{-04}$	-18.145	< 0.0001
Area	$-1.136e^{-05}$	$9.516e^{-07}$	-11.936	< 0.0001
Visitation	$-2.059e^{-03}$	$4.249e^{-04}$	-4.846	< 0.0001

Comparison of Exotic Species Richness vs. Native Species Richness

Table 3: Comparison of log(exotic species) vs. log (native species) using a stepwise regression analysis.

Predictor Variable	Estimate	Std. Errror	T-value	P-Value
logNspp	0.10156	0.01501	6.766	< 0.0001

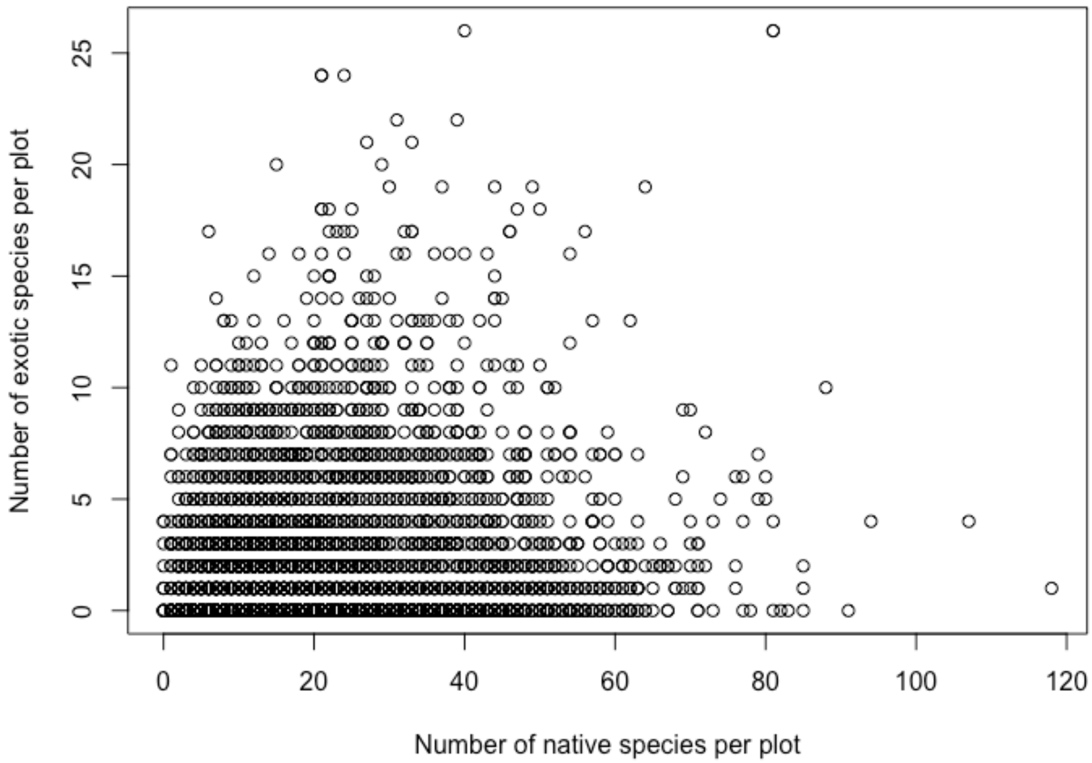

Figure 1: Correlation between native species richness and exotic species richness per plot.

A regression analysis of exotic and native species richness reported a positive correlation, with a significant p-value of less than 0.0001 (Table 3) However, the R^2 value was 0.007, meaning it was a very weak correlation.

Regional Analysis

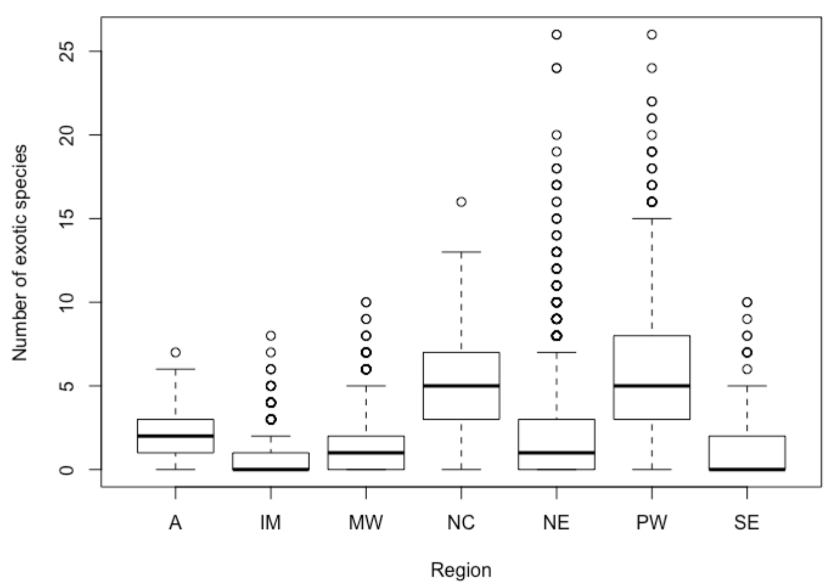

Figure 2: ANOVA of number of exotic species vs. region. (A-Alaska, IM-Intermountain, MW-Midwest, NC-Nations Capital, NE-Northeast, PW-Pacific West, SE-Southeast).

Table 4: Series of stepwise regression analyses of number of invasive species. Performed in different regions of the United States (A-Alaska, IM-Intermountain, MW-Midwest, NC-Nations Capital, NE-Northeast, PW-Pacific West, SE-Southeast). utilizing the predictor variables in the first column. NS indicates not significant, n indicates number of plots within each region.

	Visitation	logNspp	Precip	logDist_Road	Area	R^2	n
A	NS	NS	NS	NS	NS	0.1197	25
IM	NS	NS	-	-	-	0.0876	1641
MW	NS	NS	-	-	-	0.232	1145
NE	+	+	NS	-	-	0.0911	2307
PW	-	+	-	-	-	0.458	652
SE	+	+	NS	NS	-	0.468	255

The degree of invasion varied amongst regions and certain regions were more invaded than others (Figure 2) Alaska, Nations Capital, and the Pacific West had the highest reported level of invasion by more than 5. When comparing all significant correlations across regions, precipitation, distance to roads, and area were all consistently negatively correlated to number of exotic species. There was much variation between regions, and R^2 values were also much greater in the Midwest, Pacific West and Southeast.

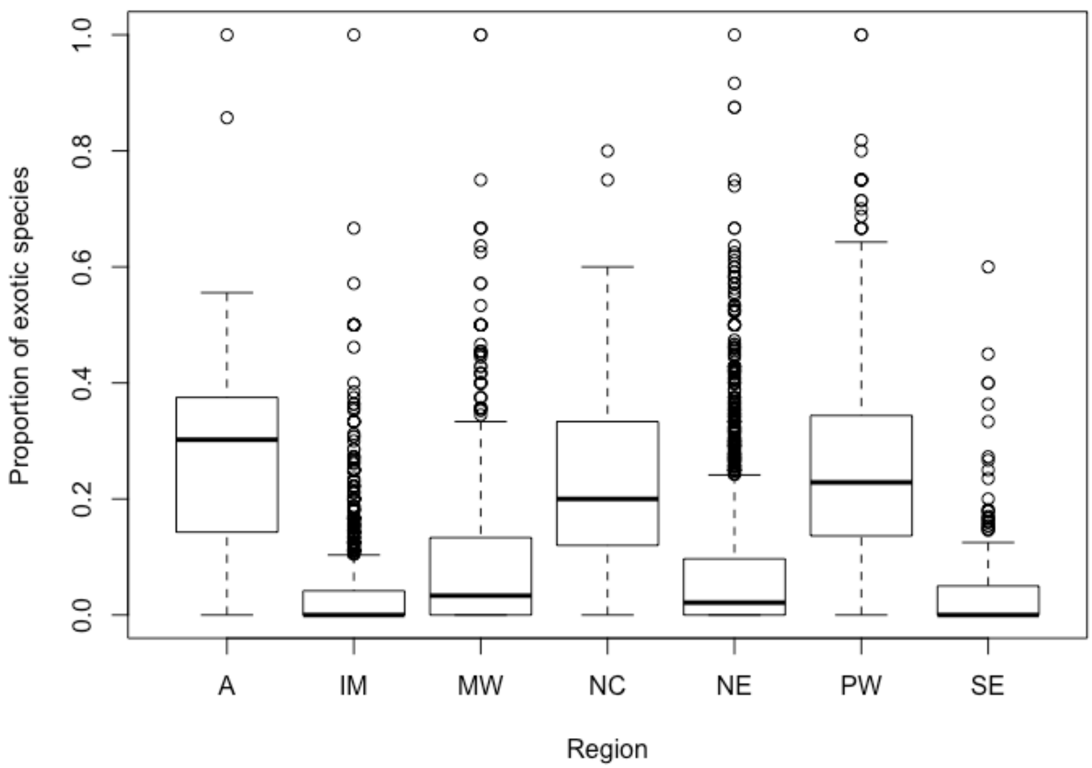

Figure 3: ANOVA of proportion of exotic species vs. region. (A-Alaska, IM-Intermountain, MW-Midwest, NC-Nations Capital, NE-Northeast, PW-Pacific West, SE-Southeast).

Table 5: Series of stepwise regression analyses of proportion of invasive species. Performed in different regions of the United States utilizing the predictor variables in the first column. NS indicates not significant, n indicates number of plots within each region.

	Visitation	logNspp	Precip	logDist_Road	Area	R^2	n
A	NS	NS	NS	NS	NS	NS	25
IM	NS	-	-	-	NS	0.1269	1641
MW	NS	-	-	-	-	0.307	1145
NE	+	-	NS	-	-	0.1274	2307
PW	-	-	-	-	NS	0.397	652
SE	+	-	-	NS	-	0.515	255

When analyzing proportion of invasive species, Alaska, Nations Capital, and Pacific West were also significantly more invaded, as with the previous model. A similar result was reported, and distance to roads, area, and precipitation were also consistently negatively correlated to proportion of exotic species. The R^2 values in the Midwest, Pacific West, and Southeast were also much greater than the other regions in this model as well.

DISCUSSION

One of the goals of this study was to determine a nationwide predictor of exotic plant species in United States National Parks. The R^2 values we obtained from our stepwise regression analysis for exotic species richness and proportion of exotic species on a nationwide basis were very low. In other words, this means that a nationwide predictor of exotic plant species in United States National Parks could not be obtained from our dataset. What these low R^2 value indicate is that we are not factoring in chance, or that there are other variables that better predict invasion when investigating on a nationwide level. These results can also be explained by the differences in landscape and vegetation across the United States. This indicates that a nationwide predictor may not be feasible with all of these differences.

However, when looking on a regional basis, our model can better explain invasion. The R^2 values were consistently higher in the Midwest, Pacific West, and Southeast regions when analyzing both invasive species richness and proportion of exotic species. The R^2 values range from 0.232 to 0.515, meaning the regional regression models can explain a greater degree of invasion.

There are regional trends regarding correlations between the predictor and response variables. I hypothesized that factors showing a greater degree of human influence would be correlated to a greater amount of invasion. This hypothesis was supported by the dataset. Distance to roads shows a nationwide and regional trend as it was negatively correlated to degree of invasion. This indicates that the closer a plot is to a road, the more invaded it is. This variable was also consistently the most important predictor in the regression models run. These results are supported by other studies done by Chiron et al. (2009), McKinney (2006), and Richardson et al. (2005). Each of these studies investigated the relationship between human influence and degree of invasion, also finding a positive correlation and corroborating our findings.

Allen et al. (2009) found degree of human influence to be the most important factor, specifically distance to roads and number of visitors. Distance to roads was the most important predictor of invasion according to both Allen et al. (2009) and our findings. While the number of visitors was one of the most important factors in predicting invasion in Allen et al. (2009) study, it was not significant in our model. Visitation was negatively correlated to invasion in both nationwide regression models, however was consistently the least important predictor. When analyzing on a regional level, visitation varies from positive to negative, but is only significant in half of the regions. According to our analysis, visitation is not well correlated to invasion in this particular dataset.

Previous research has found both positive and negative correlations between the number of native species and the number of exotic species (McKinney 2006, Pauchard and Shea 2006, Richardson et al. 2005, Shea and Chesson 2002, Stohlgren et al. 2003). Our nationwide analysis shows that native species is positively correlated to invasive species richness but not a significant predictor of proportion of invasive species. Regional analyses show a positive correlation to invasive species richness, and a negative correlation to proportion of invasive species. A separate regression looking at just the effect of native species on number of invasive species also does show a positive correlation, but with an R^2 value of 0.007. While this relationship ultimately seems to be positively correlated, it is a weak correlation, as noted by the R^2 value of <1%. These findings on the relationship between native and non-native species is corroborated by the studies of Stohlgren et al. 2003, McKinney 2006, and Richardson et al. 2005. These studies also found a positive correlation between native and non-native species richness. While it is a weak correlation, it does appear that areas with more native species, meaning more diverse communities, are able to host more invasive species.

Other important factors noted in our model are precipitation and area of the park. On a nationwide and regional level, precipitation and area are both negatively correlated to number and proportion of invasive species. Meaning, areas with less precipitation and smaller parks have less invasive species present according to our analysis.

The results of this analysis could prove vital to conservation of United States National Parks. Overall this dataset has highlighted some very important environmental variables that impact invasion. The United States National Parks are iconic, and in order to keep them pristine, this dataset could serve as a useful guide to predict invasion in order to ensure conservation efforts continue to be successful.

REFERENCES

Annual Visitation by Park (1979-Last Calendar Year). National Parks Service.

Allen J, Brown CS, Stohlgren TJ. 2009. Non-native plant invasions of United States National Parks. Biological Invasions. 11: 2195-2207.

Chiron F, Kark S, Shirley S. 2009. Human-related processes drive the richness of exotic birds in Europe. Proc. R. Soc. B. 276: 47-53.

Houlahan J, White PJT. 2007. The relationship between native and non-native species differs among taxa in Canadian national parks. 14 (2): 195-204.

Mack RN, Simberloff D, Lonsdale WM, Evans H, Clout M. 2000. Biotic Invasions: Causes, Epidemiology, Global Consequences, and Control. Ecological Applications. 10(3): 689-710.

McKinney ML. 2002. Influence of settlement time, human population, park shape and age, visitation and roads on the number of alien plant species in protected areas in the USA. Diversity and Distributions. 8: 311-318.

McKinney ML. 2006. Correlated non-native species richness of birds, mammals, herptiles and plants: scale effects of area, human population and native plants. Biological Invasions. 8: 415-425.

"NPS Inventory and Monitoring Program." *National Parks Service.* U.S. Department of the Interior.

Pauchard A, Alaback PB, Edlund EG. 2003. Plant invasions in protected areas at multiple scales: *Linaria vulgaris* (Scrophulariaceae) in the West Yellowstone area. Western North American Naturalist. 63 (4): Article 2.

Pauchard A, Shea K. 2006. Integrating the study of non-native plant invasions across spatial scales. Biological Invasions. 8: 399-413.

"PLANTS Database." *United States Department of Agriculture.* Natural Resources Conservation Service.

Richardson DM, Rouget M, Ralston SJ, Cowling RM, VanRensburg BJ, Thuiller W. 2005. Species richness of alien plants in South Africa: Environmental correlates and the relationship with indigenous plant species richness. 12 (3): 391-402.

Stohlgren TJ, Quinn JF, Ruggiero M, Waggoner GS. 1995. Status of Biotic Inventories in US National Parks. Biological Conservation. 74: 97-106.

"United States Average Annual Precipitation, 1990-2009 – Direct Download." *Data.gov.* Responsible Party National Atlas of the United States, 02 June 2015.

"30 Arc-second DEM of North America." Conservation Biology Institute, 29 July 2010.