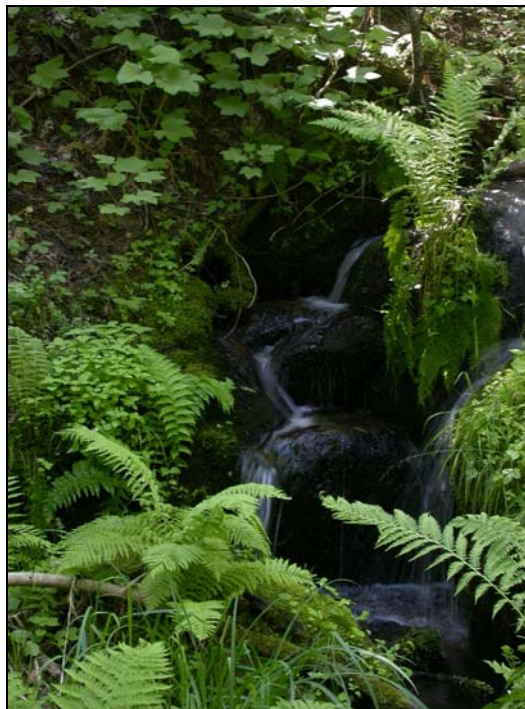




Non-Native Vascular Plant Inventory of Riparian Areas in Yosemite National Park, California

*Final Report submitted to Yosemite National Park and
Sierra Nevada Inventory and Monitoring Network*



Jeffrey M. Kane*, Sacha K. Heath* and Bill Kuhn†
January 2006

*PRBO Conservation Science
3820 Cypress Drive #11
Petaluma, CA 94954
707-781-2555
www.prbo.org

†Yosemite National Park, CA 95389
PRBO Contribution # 1335

TABLE OF CONTENTS

EXECUTIVE SUMMARY	1
INTRODUCTION AND BACKGROUND	2
METHODS AND STUDY AREA	7
RESULTS	14
DISCUSSION	25
RECOMMENDATIONS	30
ACKNOWLEDGEMENTS	31
LITERATURE CITED	32

LIST OF TABLES

Table 1. Goals proposed for 2005 riparian non-native plant inventory in Yosemite National Park, 2005.	6
Table 2. Number and distribution of riparian non-native plant inventory plots, by predictive surface zone, Yosemite National Park, 2005.	10
Table 3. Variables investigated in non-native plant species regression models.	12
Table 4. List of non-native species detected on riparian survey plots, Yosemite National Park, 2005.	14
Table 5. Non-native plant species richness and abundance values by plant community alliance type with standard error (SE) and sample size (n) for riparian vegetation surveys in Yosemite National Park, 2005.	21
Table 6. The effects of environmental and physiographic factors on non-native plant species richness in Yosemite National Park, 2005. Results from 10-variable linear regression.	22
Table 7. The effects of environmental and physiographic factors on non-native plant species abundance (where abundance > 0) in Yosemite National Park, 2005. Results from 10-variable linear regression.	23
Table 8. Factors that best predict the presence of <i>Bromus tectorum</i> in Yosemite National Park, 2005. Results from 10-variable logistic regression.	23
Table 9. Factors that best predict the presence of <i>Cirsium vulgare</i> in Yosemite National Park, 2005. Results from 10-variable logistic regression.	24
Table 10. Factors that best predict the presence of <i>Rumex acetosella</i> in Yosemite National Park, 2005. Results from 10-variable logistic regression.	24

LIST OF FIGURES

Figure 1. Plot locations for riparian non-native plant surveys in Yosemite National Park.	9
Figure 2. Elevational distribution of actual non-native monitoring plot locations in riparian	10
Figure 3. Non-native species richness for riparian vegetation surveys by plot in Yosemite National Park.	16
Figure 4. Non-native abundances for riparian vegetation by plot in Yosemite National Park.	17
Figure 5. Percent composition of duration (perennial, annual, other) and habit (forb, graminoid, or woody) for non-native plant species encountered in the riparian vegetation surveys of Yosemite National Park.	18
Figure 6. Descriptive representation of non-native species richness values over (a) elevation, (b) canopy cover (%) and (c) stream slope (degrees). Values not representative of final multi-variable regression models.	19
Figure 7. Descriptive representation of non-native species plant abundance values over (a) elevation, (b) canopy cover (%) and (c) stream slope (degrees). Values not representative of final multi-variable regression models.	20

LIST OF APPENDICES

Appendix A. Yosemite National Park riparian non-native plant survey plot locations (UTM NAD 27).	39
Appendix B. Descriptions of environmental and physiographic variables.	42
Appendix C. Field datasheets for non-native vegetation inventory in riparian areas of Yosemite National Park.	45
Appendix D. Reduced groupings for plant community association and soil texture categories. Groupings used for linear regression analysis to avoid over-fitting of models.	48

EXECUTIVE SUMMARY

The distribution and abundance of non-native plant species in natural areas is of serious concern to ecologists and land managers. The influence of natural disturbances, such as flooding, in riparian areas is also of significant interest. Management of non-native plant species in riparian areas requires sufficient information to make effective control and management decisions. In 2005, Yosemite National Park (YNP) and the National Park Service Sierra Nevada Inventory and Monitoring Network contracted PRBO Conservation Science to conduct a non-native vascular plant inventory in riparian areas of YNP.

Overall, 151 riparian plots in total were surveyed with 69 of the plots (46%) containing at least one non-native plant species. We also detected and identified a total of 59 non-native plant species throughout all the survey plots. The mean number of non-native plant species per plot was 1.8 with a mean abundance of 1,137 per plot. *Rumex acetosella*, *Bromus tectorum*, *Cirsium vulgare* and *Vulpia myuros* had the highest frequency over all survey plots. Non-native plant abundances ranged from 1 – 40,000 plants per plot. Non-native species found in highest plant abundances were *R. acetosella*, *B. tectorum*, *V. myuros*, *Bromus diandrus*, *Trifolium hirtum* and *Torilis arvensis*.

Of the plant community alliances encountered, the highest mean numbers of non-native species were located in the *Populus balsamifera* ssp. *trichocarpa* temporary flooded forest, *Quercus chrysolepis* forest, *Alnus rhombifolia* temporarily flooded forest and *Pinus ponderosa* woodland. *Pinus ponderosa* woodland had the highest mean abundance value, followed by *Ceanothus integerrimus* shrubland, *Quercus chrysolepis* forest and *Populus balsamifera* ssp. *trichocarpa* temporary flooded forest.

Based on multiple linear regression model results; elevation, stream slope, canopy cover and alliance groupings were significantly related to non-native species richness ($P < 0.0001$); while elevation, stream slope, canopy cover and soil texture groupings were significantly related to non-native plant abundance ($P < 0.0001$). Specifically, sites at lower elevations with less canopy cover and lower stream gradients harbored more non-native plant species after controlling for alliance grouping and more individuals after controlling for soil texture grouping. Models explained 65% and 61% percent of the variation in non-native plant species richness and plant abundances, respectively.

Of the three most frequently encountered non-natives, *B. tectorum* was more likely to occur at lower elevation sites with less canopy cover. *C. vulgare* occurrences were best predicted by Cowardin class, elevation and stream order, while *R. acetosella* was more

likely to occur at sites lower in elevation with a lower stream gradient. Logistic regression models containing these environmental, biological and physiographic variables explained 54% ($P < 0.0001$), 24% ($P = 0.0001$) and 36% ($P < 0.0001$) of the variation in the occurrence of these three species, respectively.

INTRODUCTION

The presence and establishment of non-native, invasive plant species in natural areas has long been recognized (Darwin 1859; Elton 1958) and over the past few decades has become a global phenomenon (Drake et. al. 1989, D'Antonio 2000). As human travel and trade has accelerated, plants and their seeds have been deliberately or inadvertently spread around the globe. In new environments, alien species can have unanticipated and devastating effects on local ecosystems. The negative impacts of invasive, alien plants on native ecosystems are an imperative issue worldwide. The threat of these invasives to native species is thought to be one of the primary causes of species loss, second only to habitat loss and fragmentation (Pimm and Gilpin 1989, Scott and Wilcove 1998, Randall 2000, Levine et al. 2003). Alien invasive species have contributed to approximately 57 percent of the imperilment of native species in the United States (Wilcove et al., 1998). The effects of these invasions and their recent acceleration are of increasing concern to ecologists and land managers and have serious implications for restoration and conservation initiatives (Simberloff et. al. 1997, Mack et. al. 2000, Mooney and Hobbs 2000).

While the influence and impact of non-native invasive plants species is an extremely pertinent issue, plant features attributed to species invasions are not well understood (Mack et al. 2000, United States National Research Council 2002). For example, some non-native species are present within areas for many years and are not invasive. But due to some triggered release (e.g. creation of favorable habitat) they might become invasive. Further hampering our knowledge of invasion biology is that some community types are more susceptible to invasion by non-native plants than others (Rejmánek 1989, Alpert 2000). The invasibility of certain areas is often a difficult quality to assess and it has proven onerous to make broad-based generalities (Moulton and Primm 1986, Rejmánek 1996). However, it is worth mentioning that not all non-native (or alien) species are invasive, in fact, it is estimated that only 0.1% of plant species introduced by humans outside their native range have become invasive (Williamson and Fitter 1996).

Many studies have investigated the mechanisms and factors facilitating the colonization and spread of non-native plants (Stohlgren et al. 1999, Rejmanek et al. 2004). One of the

primary factors associated with the establishment and spread of non-native species is disturbance. Disturbance typically falls into two broad categories, human-induced (exogenous) and natural (endogenous) disturbances (Gordon 2000). Exogenous disturbances have been associated with non-native species establishment for a longer period time (Elton 1958) while endogenous disturbances have been considered more recently (Rejmanek 1989, Mack and D'Antonio 1998). Recent focus on endogenous disturbance has largely been relegated to studies on the effects of fire on non-native plant introduction (D'Antonio 2000, Brooks and Pyke 2001, Keeley 2001), however, relatively few studies have addressed non-native plant invasions in riparian areas (Planty-Tabacchi et al. 1996, Stohlgren et al. 1998, Klinger and Underwood 2002).

Whether alien plant species occur within areas subject to endogenous or exogenous disturbances, they can have profound impacts at multiple scales. Non-native plants can alter native plant populations, plant communities, and ecosystem functions. Plant populations and communities are disrupted by non-native plants in several ways including direct modifications of native plant structure, alteration of reproduction and recruitment and through competition for resources. Recent research has documented reduced flowering capacity of the rare *Cordylanthus maritimus* subsp. *maritimus* as a result of non-native grass species introduction (Fellows and Zedler 2005), alteration of species compositions by non-native plant species in a coastal grassland community of California (Kolb et al. 2002), and reduced levels of biodiversity as the result of non-native plant invasions in the Central Grasslands and Colorado Rocky Mountains (Stohlgren et al. 1999).

Non-native plants also disrupt ecosystem processes through alteration of disturbance regimes, biogeochemical cycling, hydrologic flow and geomorphic processes (Macdonald et al. 1988). In addition, ecosystem processes such as fire return intervals have been altered in grassland and desert ecosystems of the United States (D'Antonio and Vitousek 1992, Brooks et al 2004). One alien plant genus in particular, *Tamarix* spp., has dramatically altered fluvial, geomorphic and nutrient cycling in riparian areas throughout the west (D'Antonio and Vitousek 1992).

The impacts of non-natives are of particular concern within protected natural areas, such as National Park Service (NPS) lands. Over 20 years ago, the presence of many non-native plants species was documented on most NPS lands (Goigel and Bratton 1983). Today, the incidence of non-natives poses one of the biggest obstacles for park management. As of 2003, an estimated 2.8 million hectares (7 million acres) of land in National Parks are thought to be infested with exotic plant species, with an additional 1,900 hectares (4,600 acres) of federal land succumbing to plant invasions annually (NPS 1996).

Some of the more invasive species have had a profound influence on NPS lands. In Hawaii Volcanoes National Park, for example, research has demonstrated that the introduction and spread of *Myrica faya* (fire tree) elevates the availability of nitrogen and subsequently encourages other non-native species to colonize early-successional volcanic sites (Vitousek and Walker 1989). In riparian corridors along the Green River, *Tamarix ramosissima* (salt cedar) has dramatically changed stream geomorphology at Canyonlands National Park (Graf 1978).

As a part of The National Park Service Organic Act of 1916, the NPS is mandated by Congress to "...conserve the scenery and the natural and historic objects and the wildlife there in and to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations". In addition, The National Environmental Policy Act of 1969 requires that knowledge of certain resource conditions enable and direct management objectives of federal lands.

In response to the growing set of problems facing natural resources within public lands due to introduction and spread of alien plant species, a "Strategic Plan for Managing Non-Native Plants on National Park Service Lands" was developed (NPS 1996). In this plan, the NPS outlines the necessary strategies to help reduce and prevent the invasions of alien species into NPS lands. The specific actions mentioned in the report included prevention, inventory and monitoring, control measures, research, management, and public awareness. Furthermore, Executive Order 13112 issued in 1999 established the National Invasive Species Council and defined the term invasive species for federal agencies as a species that is related to economic or environmental harm, or harm to public health. This Executive Order also stated that the introduction of invasive species is to be prevented and their economic, ecologic, and human health impacts minimized. This year the General Accounting Office (GAO, 2005) identified alien species as an important issue facing private and federal lands and it emphasizes the need to confront the problem in many ways.

In accordance with these governmental mandates, to provide for better information on NPS resources and to address issues such as non-native species invasions, the National Park Service Inventory and Monitoring Program (NPSIMP) was created. The program has five distinct goals to (NPS 2005):

- Inventory the natural resources and park ecosystems under National Park Service stewardship to determine their nature and status.
- Monitor park ecosystems to better understand their dynamic nature and condition and to provide reference points for comparisons with other, altered environments.

- Establish natural resource inventory and monitoring as a standard practice throughout the National Park system that transcends traditional program, activity, and funding boundaries.
- Integrate natural resource inventory and monitoring information into National Park Service planning, management, and decision making.
- Share National Park Service accomplishments and information with other natural resource organizations and form partnerships for attaining common goals and objectives.

The NPSIMP system contains 270 park units, nationwide, and is divided into 32 different networks, including the Sierra Nevada Inventory and Monitoring Network. Yosemite National Park (YNP) is one of three park units within this network. As one of the most visited parks in the nation, the concern for protecting its resources is paramount, although often at odds with the park's other goal of providing for visitor enjoyment. This conflict is perhaps most evident with issues surrounding non-native plant species management. The establishment of non-native plant species within National Parks has been directly related to human activities and their associated disturbances (Gerlach et al. 2001). While many efforts have been employed to prevent unwanted establishment of alien species via restrictions, policy initiatives and direct control measures, non-native plants continue to expand in distribution and abundance, often posing many challenges to their eradication.

In addition to the governmental mandates and creation of a NPSIMP, many parks and units within the National Park system spend a significant amount of money to aid in the direct control and eradication of non-native plant species. In 2003, the National Park Service Exotic Plant Management Teams (EPMT) and other partners leveraged \$2.8 million to help control exotic plant species on NPS lands. In YNP alone, approximately \$286,000 from varied sources is earmarked for 2006 non-native plant species management (Lisa Acree, pers. comm.). In order to most efficiently allocate limited funds for non-native plant management, it is advisable to conduct plant surveys to both detect incipient invasions and to aid in the prioritization and concentration of future management activities.

In an effort to address the need for non-native plant surveys to help guide management decisions, surveys within Yosemite, Sequoia and Kings Canyon National Parks were conducted in 1998 and 1999 focusing on exogenously disturbed areas, including campgrounds, picnic areas, developments, corrals, roads and trails (Gerlach et. al. 2001). However, natural disturbance regimes, such as fire and flooding also contribute to the introduction of non-native plants to NPS lands. With the intention of gaining more information related to the role of natural disturbances on invasive plant species,

NPSIMP funded a study to design sampling protocols for non-native plant species associated with burned and riparian areas in YNP (Klinger and Underwood 2002). Based on the recommendations of Klinger and Underwood (2002), YNP and NPSIMP contracted PRBO Conservation Science (PRBO) to conduct an inventory of non-native plant species within riparian areas in 2005.

This document summarizes the results of the non-native plant inventory conducted at YNP, California in 2005. The goals of this inventory are presented in Table 1.

Table 1. Goals proposed for 2005 riparian non-native plant inventory in Yosemite National Park, 2005.

Goals	Completed?
Collect information on the distribution and abundance of alien plant species in riparian areas of the park.	YES
Relate environmental and physiographic variables with species richness and abundance of non-native plant species within riparian areas of the park.	YES
Provide park officials and managers with information and recommendations regarding the prioritization of management and control for non-native plant species in riparian areas.	YES

METHODS

Study area

Yosemite National Park encompasses 302,768 hectares (ha) within the Sierra Nevada Mountains of California. The park ranges in elevation from 524 m to 3,998 m and is composed of two watersheds, the Merced River to the south and Tuolumne River to the north (Gerlach et al. 2001). Water courses in YNP are common with approximately 2,380,200 meters of streams and rivers present at a density of 935 meters/kilometer². Low to mid-elevations within YNP are characterized by a Mediterranean type climate, with cool, wet winters and hot, dry summers. Higher elevations are dominated by a microthermal (or boreal) climate, which is characterized by having average temperatures of the coldest month below -3°C . Within Yosemite Valley at approximately 1200 meters (where the vast majority of visitors travel), mean daily temperatures range from 8°C to 32°C . Mean daily temperatures for Tuolumne Meadows (2600m) ranges from -4°C to 32°C . Precipitation largely occurs from November through April and ranges from 900 mm at lower elevations to 1200 mm at higher elevations. The climatic and elevational gradients of YNP support an abundance of plant community types and contribute to the diversity in vascular plant flora of this area (Moore 1993). Over 1400 vascular plant species are known to occur within YNP (Botti 2001). Prior to 2005 surveys, 130 non-native plant species have been documented in the park (Gerlach et al. 2001).

European settlement of the Yosemite Valley region began in earnest around the 1850's, during the height of the gold rush in the foothills of the Sierra Nevada Mountains. Over the course of the next few decades, livestock became prevalent in the region and intensive grazing practices resulted. During this period, much of the lower elevation oak woodland and foothill grassland communities were invaded by non-native, annual grasses (Rejmanek et al. 1991). Upon the creation of YNP in 1890, the intensity of grazing began to decline and currently is relegated to mostly high elevation regions (predominantly meadows) where grazing is allowed for recreational and administrative stock use (Gerlach et al. 2001).

Today, YNP is recognized as one of the world's most scenic locations, partly due to its stark geologic formations and ecological character. As the fourth most visited national park in the United States, YNP exceeded 3.2 million recreational visits in 2004 (NPS 2004) with most visitation concentrated in Yosemite Valley.

Plot Selection

In preparing a sampling protocol for surveying and inventorying alien species within riparian zones, we consulted Klinger and Underwood (2002) who designed a sampling protocol for an inventory of alien plants within YNP. The Klinger and Underwood (2002) study design was the basis for the 2005 inventory, but several of its project goals and methods required augmentations.

The goal of this survey was to sample riparian vegetation within the park where alien species are likely to be found in order to inventory the presence of alien species. Klinger and Underwood (2002) developed a continuous probability surface of the likelihood of encountering alien species throughout the park based on plot data collected within the park. The authors generated this predictive model based on the results of logistic multiple regression analysis and ordination with biological and physical predictive variables. The authors then used the genetic algorithm for rule-set prediction (GARP) model to develop the predicted distributions of alien species throughout the park. This spatial model predicted the likelihood of the presence of alien plant species everywhere in the landscape at a resolution of 30 meters. The mean value for the likelihood of encountering an alien species was nine percent, with a range from zero to 100 percent. Their predictive surface (with a scale of zero to 100 percent) was then stratified by dividing it into six equal classes (each covering 16.67% probability) in order to sample evenly across all possible probabilities. These are labeled Zone 1 (0 - 16.67%), Zone 2 (16.68% – 33.33%), Zone 3 (33.34% - 50.00%), Zone 4 (50.01 – 66.67%), Zone 5 (66.68% - 83.34%), and Zone 6 (83.35% - 100%).

Using the expected probability surface developed by Klinger and Underwood (2002), we developed a series of masks to limit the area within which sample plots could be located. According to their analysis of vegetation plot data collected previously in the park, no exotic species were expected to be found above an elevation of 2772 meters (Klinger and Underwood 2002), and therefore only the park area below 2772 meters in elevation was selected for sampling. For accessibility, all areas further than three kilometers from all roads were excluded from the analysis. In addition, for accessibility and safety, all areas with slope greater than 40 degrees were excluded from the analysis. This mask was developed using ArcGIS 9.0 (Environmental Systems Research Institute 2004). The final result was an area within the park where sampling plots could be placed along water courses.

The goal of the survey effort was to sample across the entire range of locations where exotic species could possibly be found, from high to low probability. Using the stratified design described above, a total of 198 plots, 33 in each probability zone, were

randomly located along streams within the area covered by the intersection of the probability surface and the mask developed. Riparian areas were determined utilizing the stream layer provided from the National Hydrologic Data Set.

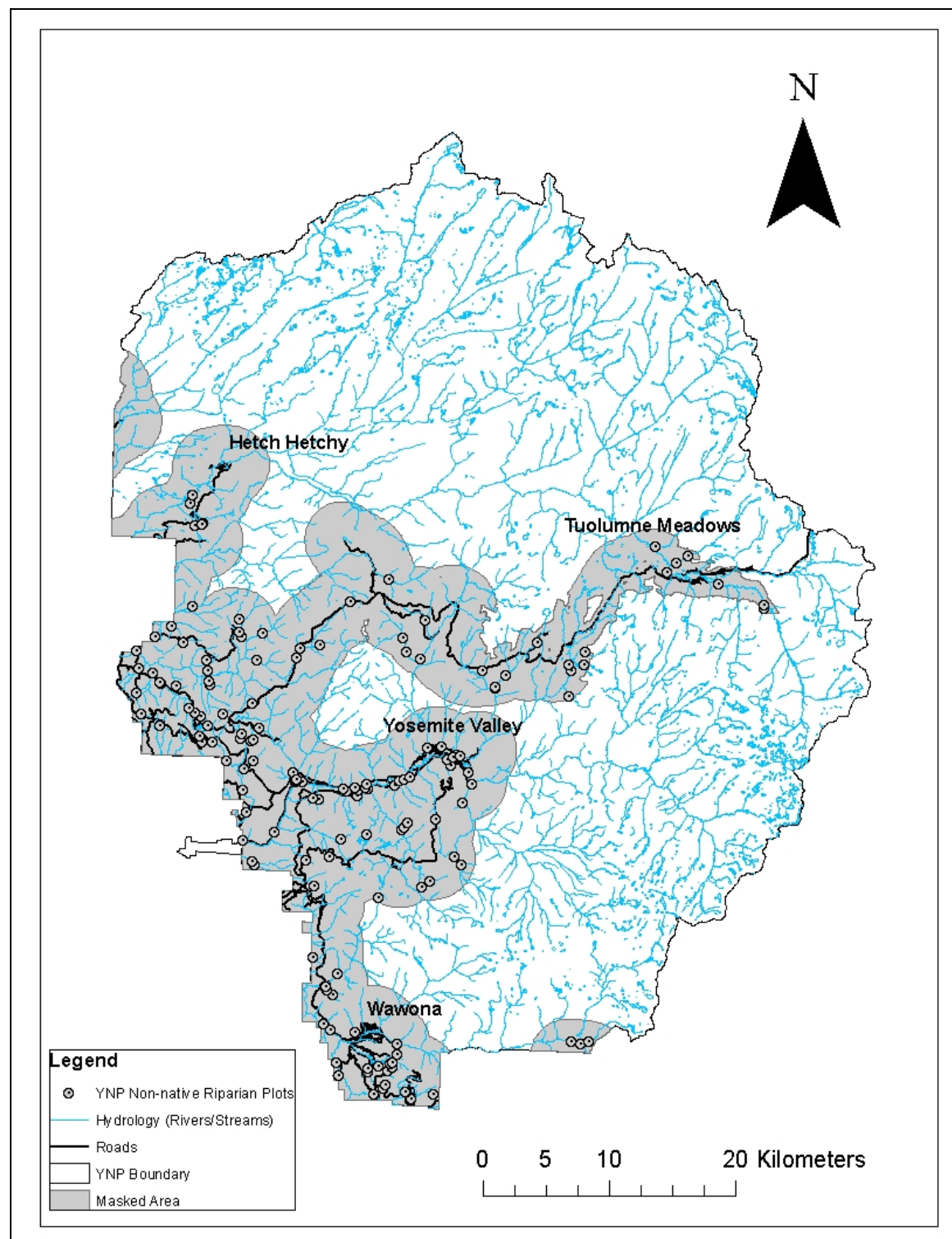


Figure 1. Plot locations for riparian non-native plant inventory in Yosemite National Park, 2005.

When field work began, it was discovered that some of the sampling plot locations chosen by these methods were inaccessible, or only accessible with considerable effort. At the conclusion of the field season, we were able to visit a total of 151 of the original 198 locations (Figure 1). Although not all 33 plots in each zone were sampled, the distribution of plots was relatively even, with the possible exception of Zone 2 which was slightly deficient (Table 2). Overall, elevational distribution of selected plots ranged from 652 – 2720 meters with a mean of 1721 meters (Figure 2, Table 3).

Table 2. Number and distribution of riparian non-native plant inventory plots, by predictive surface zone, Yosemite National Park, 2005.

Zone	Number of Plots
1	25
2	19
3	25
4	24
5	29
6	29
Total	151

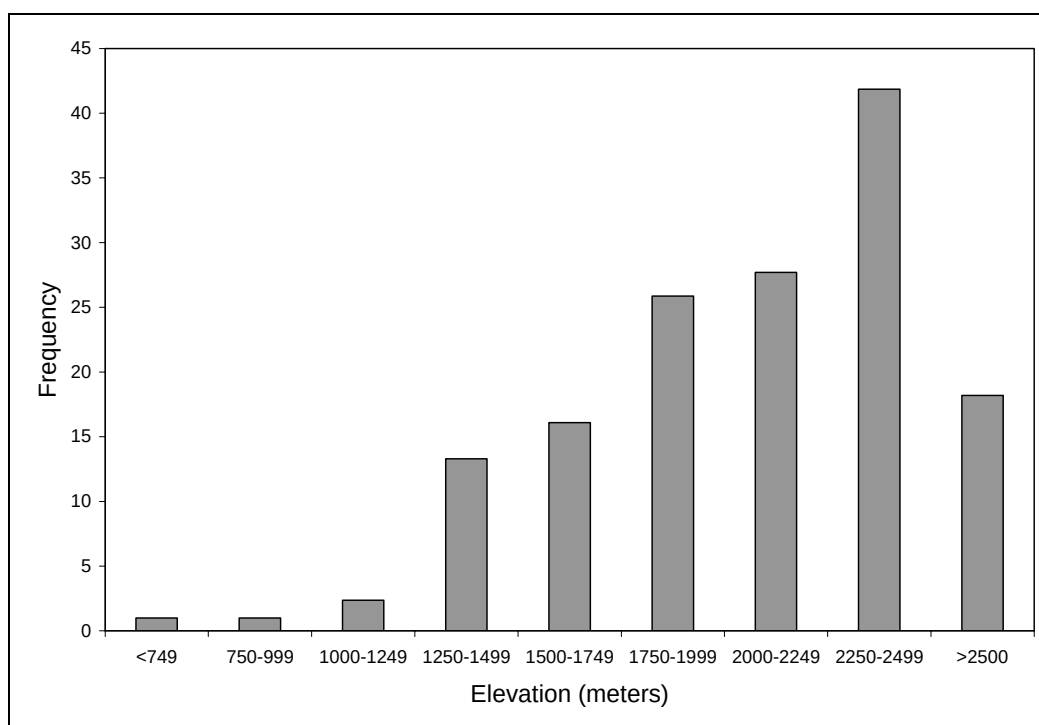


Figure 2. Elevational distribution of actual non-native monitoring plot locations in riparian areas of Yosemite National Park, 2005.

Survey Methods

We completed all field work June 15 – September 2, 2005. We navigated to randomly generated plot points with a Garmin GPS V Global Positioning System (GPS) device. At each plot point, we established a 100 m x 10 m, 0.1 ha survey plot, upstream unless otherwise noted, along the edge of the river or stream corridor. The side of riparian edge selected was determined by which ever side was closer to the GPS point navigated to, unless stream/river crossing was prohibitive. In the event that no flowing water was present, drainage center was used as plot edge to capture plant species growing in the dry stream channel. Areas incapable of supporting plant life (e.g. bridges, roads) were excluded from the plot survey and adjacent areas were added to the upstream side to account for the denuded area. Overall, we established 151 plots throughout YNP (Figure 1). Plot coordinates for all 2005 survey locations are provided in Appendix A.

Within each plot, we identified all vascular plants to the finest taxonomic level possible given phenological stage. Identification was primarily conducted to the species level, however, 13% of the time we identified only to the genus level. All taxonomic determinations and nomenclature follow, *The Jepson Manual: Higher Plants of California* (Hickman 1993). All non-native species were documented and the number of individuals was recorded if less than ten individuals were present, otherwise a visual estimation was made to approximate the total number of individuals.

We also recorded environmental, biological and physiographical variables associated with each riparian plot; including elevation, slope, aspect, canopy cover, stream order, soil texture, Cowardin class, flooding regime, plant community types, and distance to nearest road. Elevation was determined from a 10 meter digital elevation model (DEM) using actual plot coordinates. Both plot and stream slope were measured within each of the survey plots. Stream slope was measured as the representative slope (degrees) along the 100 meter transect following the river or stream course, while plot slope was measured as the representative slope perpendicular to the stream. For stream order classification, we referred to the National Hydrological dataset and applied the Strahler stream order system (Strahler 1952). We classified stream type as upland, riverine, lacustrine, or palustrine (Cowardin et al. 1979) and we assigned flooding regime (estimating the frequency of flooding) as annual, semi-annual, occasional, or rare. We determined plant community type at the alliance and association level using the *Classification of the Vegetation of Yosemite National Park and Surrounding Environs in Tuolumne, Mariposa, Madera and Mono Counties, California* (NatureServe 2002). We determined soil texture in the field using a simplified key to soil texture (Brewer and McCann 1982). Distance to road measures were made by calculating the distance of plots to nearest dirt or paved road using ArcGIS 9.0. (Environmental

Systems Research Institute 2004). Descriptions of environmental, biological and physiographical variables are provided in Appendix B. Field datasheets are provided in Appendix C.

Table 3. Variables investigated in non-native plant species regression models. ¹ = continuous variable. We reduced soil texture and plant community association categories from 12 to 5 and 23 to 8 respectively to avoid over-fitting regression models (see Appendix D).

Variable	Summary Statistics / Categories
Elevation ¹	mean=1721 m; min=652 m; max=2720 m
Stream Order ¹	1, 2, 3, 4 or 5 (Stahler 1952)
Stream Slope ¹	mean=6°; min=1°; max=30°
Distance to Road ¹	log-transformed(distance in km + 0.01) mean=0.74 km; min=0.01 km; max=3.41 km
Canopy Cover ¹	mean=55%; min=0%; max=90%
Stream Aspect Quadrant	4 categories: NE, SE, SW, NW
Flooding Regime	4 categories: annual, semi-annual, occasional, rare
Cowardin Class	4 categories: upland, riverine, lacustrine, palustrine
Soil Texture Grouping	5 classes: coarse, medium or fine grain; muck, rock
Plant Community Association Groupings	8 alliance groupings: herbaceous/meadow/sparse, pine, fir, oak, cedar, shrub, deciduous tree, sequoia

Statistical Analysis

We investigated the relationships of five continuous and five categorical environmental, biological and physiographical variables (Table 3) to 1. log-transformed non-native plant species richness, 2. log-transformed non-native plant species abundance (where abundance > 0), and 3. presence/absence (occurrence) of the three most frequently detected non-native species (*Rumex acetosella*, *Bromus tectorum* and *Cirsium vulgare*).

Since values were not normally distributed and variances were not homoscedastic, we log-transformed non-native abundance, non-native species richness, and distance to road. To avoid our inability to log-transform zeros, we added 0.01 km to all distance to road measurements and 1 to all non-native species richness. We reduced soil texture and plant community association categories from 12 to 5 and 23 to 8 respectively to avoid over-fitting regression models (Appendix D).

Using non-native species richness and abundance as the response variable, we determined the most parsimonious subset of independent explanatory variables using a three step process; 1. beginning with all variables, a 10-variable multiple linear regression model was constructed, 2. we then reduced variables using the stepwise

backward multiple linear regression procedure, and 3. finally, we re-added each of the dropped variables independently to our model and retained only significant variables. Residuals from non-native plant abundance models passed Skewness/Kurtosis tests for normality and Cook-Weisenberg tests for heteroscedasticity ($P > 0.05$), however, residuals from non-native species richness models did not pass tests for heteroscedasticity, so P -values for individual terms are possibly slightly inaccurate.

We also investigated the relationship of our predictor variables to species-specific occurrence for the three most frequently encountered non-native plant species, using the same three step process, but instead with logistic regression. All logistic regression models passed goodness of fit χ^2 tests ($P > 0.26$).

Statistical calculations were performed using Stata 8.0 (Stata Corps. 2003). Significance was assumed at $P < 0.05$.

RESULTS

Non-native Plant Species Distribution, Composition, Richness and Abundance

Sixty-nine of 151 survey plots (46%) contained at least one non-native plant species; 82 plots had none. We identified 59 different non-native plant species (Table 4). Five of these (*Ficus carica*, *Vicia sativa*, *Torilis arvensis*, *Trifolium hirtum* and *Vicia benghalensis*) were not listed on the 2005 Non-Native Flora of Yosemite National Park list, though the latter 3 were identified by Gerlach et al. (2001). The most frequently encountered alien species were *Rumex acetosella*, *Bromus tectorum*, *Cirsium vulgare* and *Vulpia myuros* (Table 4).

Table 4. List of non-native species detected on riparian survey plots, Yosemite National Park, 2005. Frequency (% of survey plots where present, n = 151), mean abundance per plot, and elevation range of occurrence, by species.

*= unavailable abundance data

Scientific Name	Frequency (%)	Mean Abundance per plot	Elevation Range (m)
<i>Rumex acetosella</i>	25	1749	869-2021
<i>Bromus tectorum</i>	15	2089	652-1571
<i>Cirsium vulgare</i>	11	19	1195-1746
<i>Vulpia myuros</i>	11	1661	652-1571
<i>Bromus diandrus</i>	6	1035	652-1356
<i>Cynosurus echinatus</i>	6	42	869-1560
<i>Holcus lanatus</i>	6	81	1184-1551
<i>Stellaria media</i>	6	46	869-1364
<i>Vulpia bromoides</i>	6	95	1021-1882
<i>Aira caryophylla</i>	5	174	652-1215
<i>Bromus hordeaceus</i>	5	33	1021-1517
<i>Torilis arvensis</i>	5	1444	652-1465
<i>Lactuca serriola</i>	4	7	652-1514
<i>Rumex crispus</i>	4	6	1184-1855
<i>Taraxacum officinale</i>	4	11	1205-1948
<i>Cerastium glomeratum</i>	3	29	1746-1874
<i>Hypochaeris glabra</i>	3	178	652-1044
<i>Hypochaeris radicata</i>	3	6	1021-1373
<i>Poa bulbosa</i>	3	17	1044-1205
<i>Poa pratensis</i> ssp. <i>pratensis</i>	3	38	1184-2115
<i>Rubus discolor</i>	3	71	652-1211

table continued on next page

Scientific Name	Frequency (%)	Mean Abundance per plot	Elevation Range (m)
<i>Cerastium fontanum</i> ssp. <i>vulgare</i>	2	7	1746-1848
<i>Erodium cicutarium</i>	2	120	652-1044
<i>Galium parisiense</i>	2	38	652-1044
<i>Hordeum marinum</i> ssp. <i>gussoneanum</i>	2	37	2115-2619
<i>Hypericum perforatum</i>	2	19	1021-1303
<i>Plantago lanceolata</i>	2	74	1021-1195
<i>Poa annua</i>	2	72	869-2686
<i>Agrostis stolonifera</i>	1	12	1046-1311
<i>Anthriscus caucalis</i>	1	265	869-1044
<i>Bromus arenarius</i>	1	9	652-1303
<i>Bromus madritensis</i> ssp. <i>rubens</i>	1	40	652-1044
<i>Hordeum murinum</i>	1	16	869-1044
<i>Medicago polymorpha</i>	1	53	1040-1044
<i>Melilotus indica</i>	1	16	1044-1195
<i>Plantago major</i>	1	13	1207-1211
<i>Spergularia rubra</i>	1	13	1040-1044
<i>Tragopogon dubius</i>	1	9	1207-1517
<i>Trifolium dubium</i>	1	402	652-1044
<i>Trifolium repens</i>	1	3	1303-1373
<i>Avena barbata</i>	1	15	1044
<i>Avena fatua</i>	1	30	869
<i>Chamomilla suaveolens</i>	1	200	1044
<i>Dactylis glomerata</i>	1	5	1311
<i>Festuca pratensis</i>	1	2	1040
<i>Ficus carica</i>	1	1	869
<i>Lepidium virginicum</i> var. <i>virginicum</i>	1	20	1195
<i>Leucanthemum vulgare</i>	1	15	1303
<i>Lotus scoparius</i>	1	*	1044
<i>Lychnis coronaria</i>	1	75	1195
<i>Mentha spicata</i> var. <i>spicata</i>	1	20	1195
<i>Phleum pratense</i>	1	5	1855
<i>Rubus laciniatus</i>	1	10	1195
<i>Silene gallica</i>	1	*	869
<i>Sisymbrium altissimum</i>	1	10	1211
<i>Trifolium hirtum</i>	1	1500	1044
<i>Vicia benghalensis</i>	1	200	1044
<i>Vicia sativa</i> ssp. <i>sativa</i>	1	30	1044
<i>Vinca major</i>	1	150	869

The mean number of non-native plant species per plot was 1.8 (95% confidence intervals 1.17- 2.45), while the maximum number of non-native plant species within a survey plot was 30 (Figure 3).

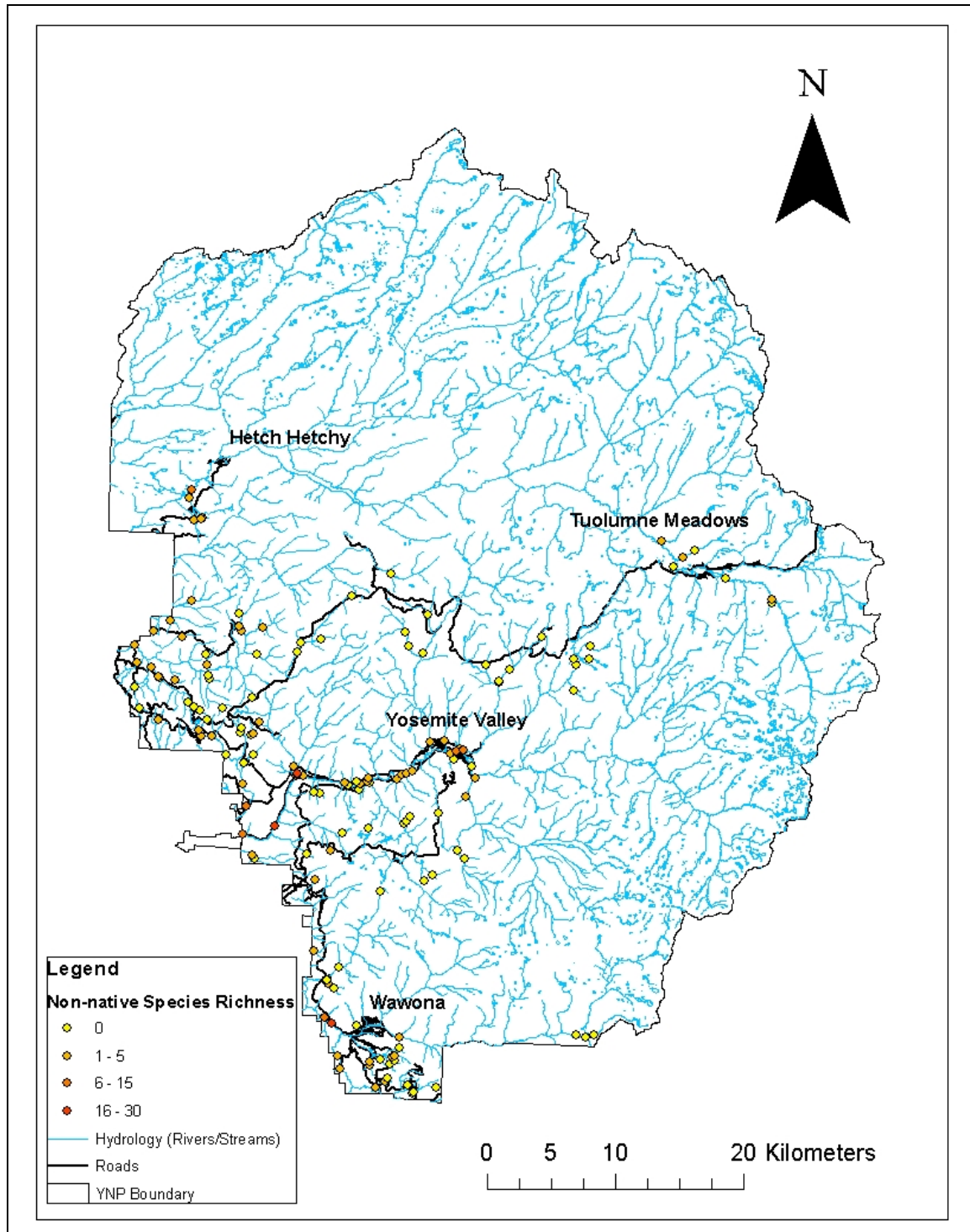


Figure 3. Non-native species richness for riparian vegetation surveys by plot in Yosemite National Park, 2005.

Total estimated abundance of non-native individuals over all plots was 171,657 plants, averaging 1,137 plants per survey plot (95% confidence intervals 361.1- 1912.5) with a range of values from 1 to 40,000 per plot (Figure 4).

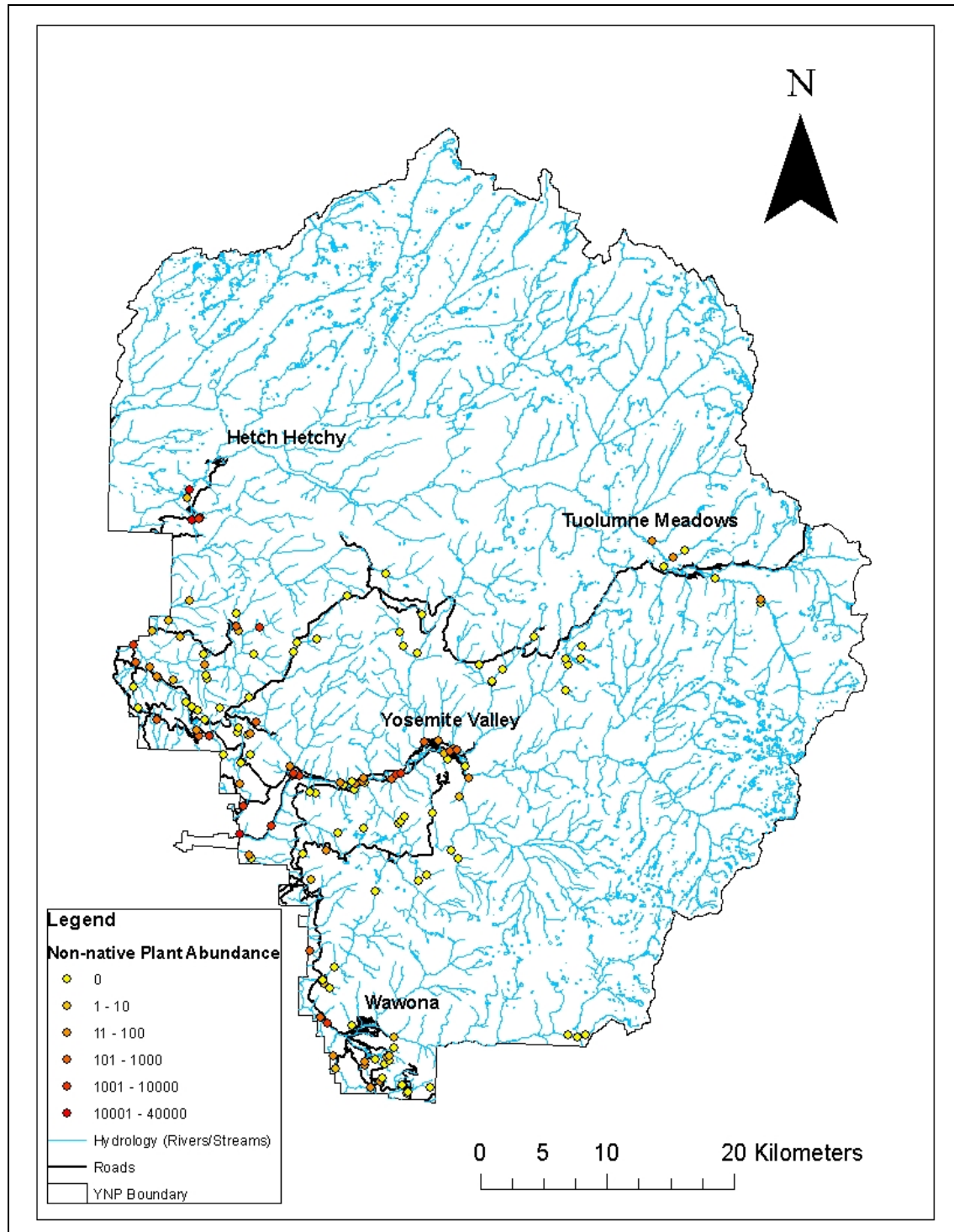


Figure 4. Non-native plant abundances for riparian vegetation by plot in Yosemite National Park, 2005.

Numbers of non-native species per plot and plant abundances were generally higher in some areas of high and concentrated visitor use (e.g. Yosemite Valley and Wawona). Conversely, another high visitor use area Tuolumne Meadows did not follow this trend and had lower values of non-native species richness and plant abundances (Figure 3, Figure 4).

Just over half (52.5%) of non-native plant species identified were annuals while 40.7% were perennial species (Figure 5). Annual plant species were composed of forbs and graminoids, while perennial species were predominantly composed of forbs, and fewer graminoids. Biennial/mixed duration species composed of 6.8% of all non-native species identified. In addition, only three species (5.1%) of non-native woody plants were encountered over all survey plots (Figure 5).

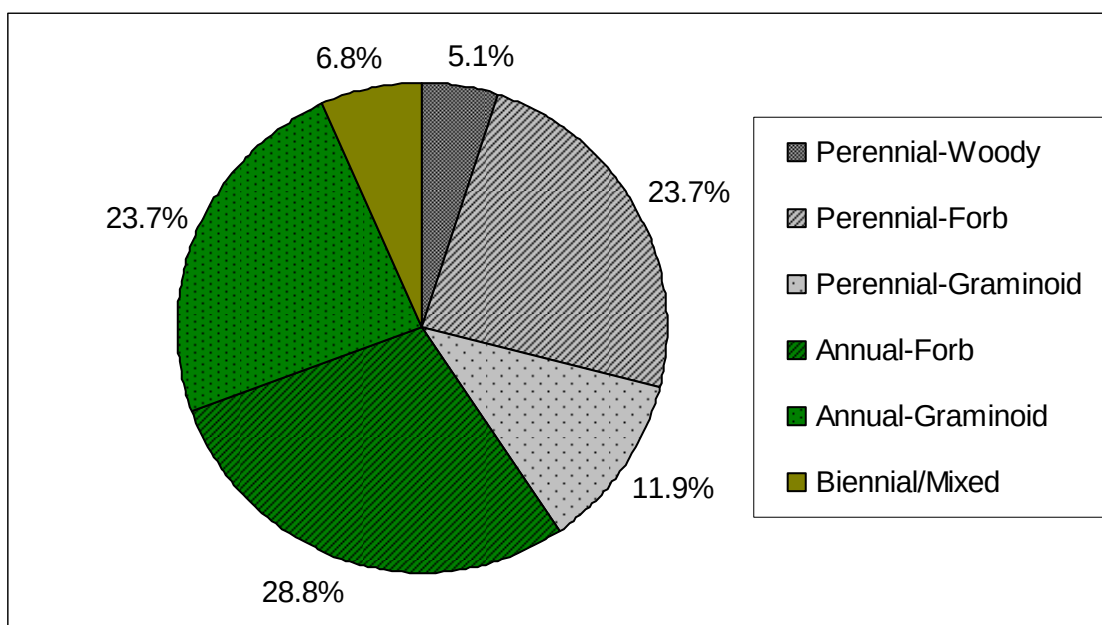


Figure 5. Percent composition of duration (perennial, annual, biennial-mixed) and habit (forb, graminoid, or woody) for non-native plant species encountered in the riparian vegetation surveys of YNP.

Individual factors displayed a visual trend in three of the continuous variables measured; elevation, canopy cover and stream slope for both non-native species richness and plant abundance. In both instances, non-native plant species richness (Figure 6) and non-native plant abundance (Figure 7) demonstrated increases in values with decreases in elevation, canopy cover and stream slope. These values are not lone predictors but provide a descriptive representation of some of the variables considered in the full multiple linear regression analysis.

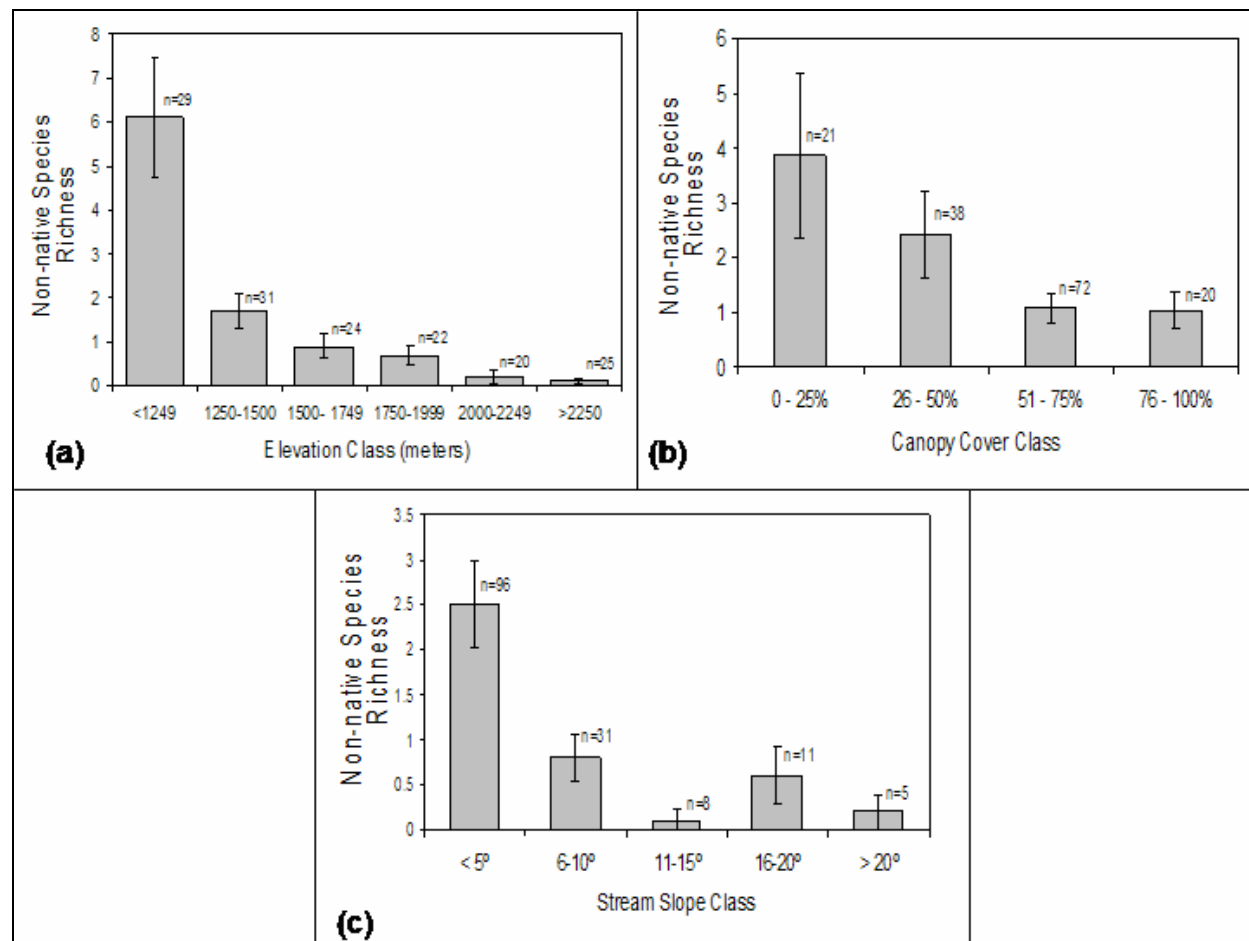


Figure 6. Descriptive representation of non-native species richness values over (a) elevation, (b) canopy cover (%) and (c) stream slope (degrees). Values not representative of final multi-variable regression models.

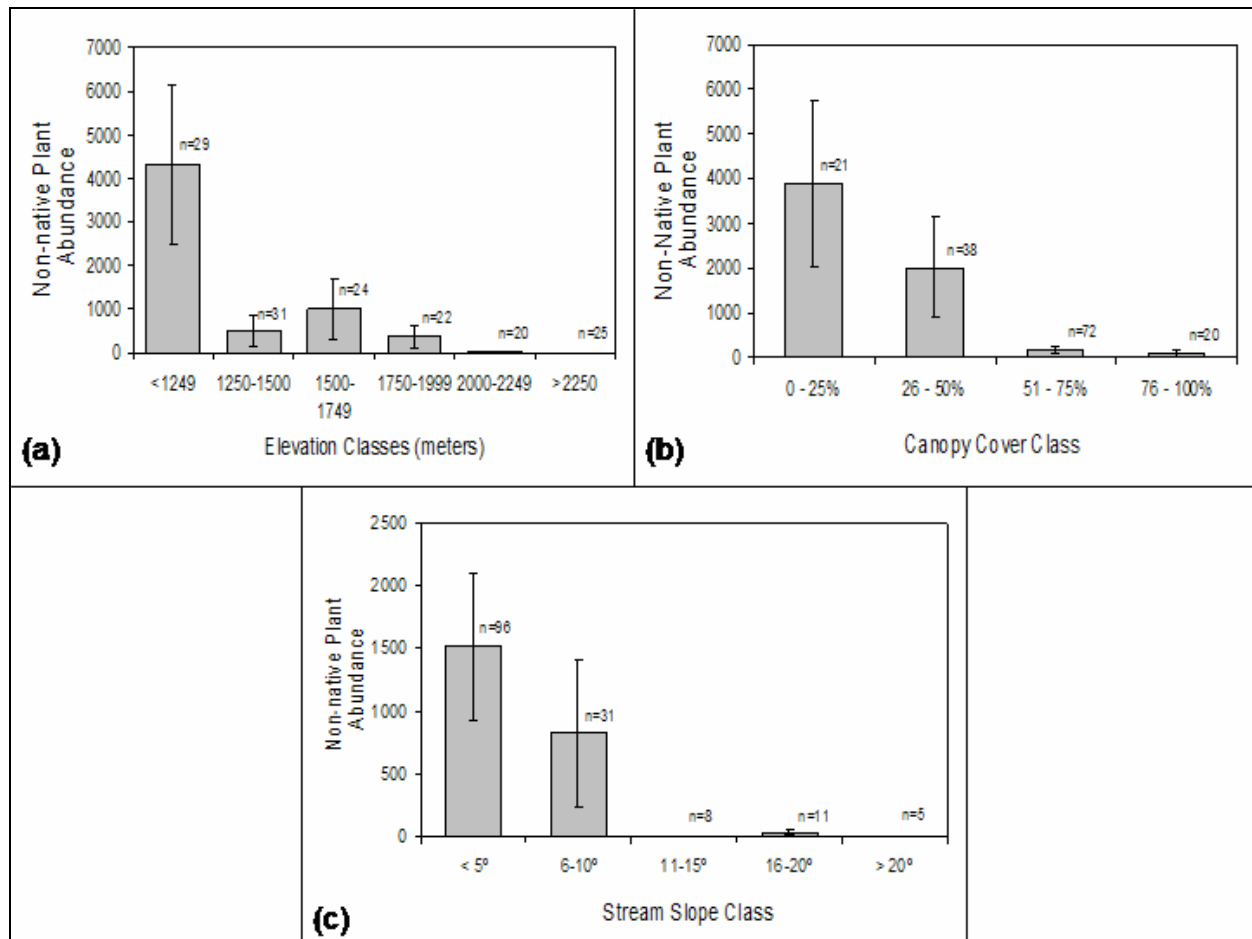


Figure 7. Descriptive representation of non-native species plant abundance values over (a) elevation, (b) canopy cover (%) and (c) stream slope (degrees). Values not representative of final multi-variable regression models.

Plant Community Alliances

Within the plant community alliances that were recorded, the highest mean number of non-native species per plot were found in *Populus balsamifera ssp. trichocarpa* temporary flooded forest (11.5 species), *Quercus chrysolepis* forest (10.2 species), *Alnus rhombifolia* temporarily flooded forest (8.0 species) and *Pinus ponderosa* woodland (7.5 species, Table 5). Certain alliance types had low numbers of non-native plant species

Table 5. Non-native plant species richness and abundance values by plant community alliance type with standard error (SE) and sample size (n) for riparian vegetation surveys in Yosemite National Park, 2005.

Plant Community Alliance Type	n	Richness		Abundance	
		Mean	SE	Mean	SE
<i>Populus balsamifera</i> ssp. <i>trichocarpa</i> temporary flooded forest	2	11.5	1.8	4271	2414
<i>Quercus chrysolepis</i> forest	5	10.2	2.5	4315	1139
<i>Alnus rhombifolia</i> temporarily flooded forest	5	8.0	1.8	1704	589
<i>Pinus ponderosa</i> woodland	2	7.5	4.6	17815	12596
<i>Ceanothus integerrimus</i> shrubland	2	4.5	0.4	12776	1807
<i>Carex nebrascensis</i> seasonally flooded herbaceous	1	4.0	-	135	-
<i>Pinus ponderosa</i> - <i>Calocedrus decurrens</i> forest	18	3.2	0.9	2827	521
<i>Populus tremuloides</i> forest	1	3.0	-	80	-
<i>Calocedrus decurrens</i> forest	12	2.1	0.1	125	25
<i>Quercus kelloggii</i> forest	4	2.0	0.4	77	24
Unknown	11	1.0	0.1	861	260
<i>Glyceria elata</i> temporarily flooded	1	1.0	-	100	-
<i>Abies concolor</i> forest	3	1.0	0.3	51	28
<i>Pseudotsuga menziesii</i> forest	7	1.0	0.2	39	7
<i>Pseudotsuga menziesii</i> - <i>Pinus ponderosa</i> forest	2	1.0	0.0	26	17
<i>Pinus jeffreyi</i> woodland	1	1.0	-	6	-
<i>Pinus contorta</i> forest	14	0.3	0.0	369	96
<i>Abies concolor</i> - <i>Pinus lambertiana</i> forest	30	0.2	0.0	7	1
<i>Abies magnifica</i> - <i>Abies concolor</i> forest	6	0.2	0.1	500	204
<i>Abies magnifica</i> forest	19	0.1	0.0	26	6
Sparsely vegetated to non-vegetated	1	0.0	-	0	-
<i>Sequoiadendron giganteum</i> forest	2	0.0	0.0	0	0

consistently over many sampled plots: *Pinus contorta* forest (0.3 species), *Abies concolor*-*Pinus lambertiana* forest (0.2 species), and *Abies magnifica* forest (0.1 species). *Pinus ponderosa* woodland had the highest mean non-native plant abundance value (17,815/plot) followed by *Ceanothus integerrimus* shrubland (12,776/plot), *Quercus chrysolepis* forest (4,315/plot) and *Populus balsamifera* ssp. *trichocarpa* temporary flooded forest (4,271/plot, Table 5).

Environmental, Biological and Physiographic Factors as Predictors of Patterns in Non-native Plant Species Richness, Abundance, and Occurrence

The four factors selected by the predictive model that significantly explained variation in non-native plant species richness were elevation, stream slope, canopy cover and alliance group (Table 6). We found that after controlling for alliance grouping, sites at lower elevations with less canopy cover and lower stream gradients harbored more non-native plant species. When controlling for elevation, stream slope and canopy cover, the riparian deciduous tree, oak and cedar alliance groupings had more non-native plants. These four factors together explained 65% of the variation in non-native plant species richness.

Table 6. The effects of environmental, biological and physiographical factors on non-native plant species richness in Yosemite National Park, 2005. Results from 10-variable linear regression.

<u>Dependent Variable:</u> log-transformed (non-native species richness +1)			
<u>Model Statistics:</u> n = 151, $P < 0.0001$, $R^2 = 65\%$, df = 10			
Variable	Coefficient	df	P
Elevation	-0.0008	1	< 0.0001
Stream Slope	-0.0294	1	< 0.0001
Canopy Cover	-0.0118	1	< 0.0001
Alliance Grouping	-	7	< 0.0001

We found that four factors contributed significantly to the predictive model in explaining variation in non-native plant species abundance (Table 7). After controlling for differences in soil texture groupings, sites at lower elevations, with less canopy cover and lower stream gradients supported greater numbers of non-native plants. When controlling for elevation, stream slope and canopy cover, the medium and coarse soil texture groupings had more non-native plants than finer soils, muck or rock. These four factors explained 61% of the variation in non-native plant species abundance.

Table 7. The effects of environmental biological and physiographical factors on non-native plant abundance (where abundance > 0) in Yosemite National Park, 2005. Results from 10-variable linear regression.

Dependent Variable: log-transformed non-native abundance (where abundance > 0)

Model Statistics: n = 69, $P < 0.0001$, $R^2 = 61\%$, df = 7

Variable	Coefficient	df	P
Elevation	-0.0029	1	0.0002
Stream Slope	-0.1951	1	0.0001
Canopy Cover	-0.0595	1	< 0.0001
Soil Texture Grouping	-	4	0.0001

We also investigated which variables best predicted the presence of the most common alien species. Elevation and canopy cover were the best predictors in the presence of *Bromus tectorum*, indicating that *B. tectorum* is more likely to occur at sites at lower elevations and with less canopy cover (Table 8). These factors explained 54% of the variation in the occurrence of *B. tectorum*.

Table 8. Factors that best predict the presence of *Bromus tectorum* in Yosemite National Park, 2005. Results from 10-variable logistic regression.

Dependent Variable: Occurrence of *Bromus tectorum*

Model Statistics: n = 151, $P < 0.0001$, Pseudo $R^2 = 54\%$

Variable	Coefficient	P
Elevation	-0.0088	< 0.0001
Canopy Cover	-0.0578	< 0.0001

After controlling for Cowardin classification, *Cirsium vulgare* was more likely to occur at sites at lower elevations and with lower order streams (Table 9). These three factors explained 24% of the variation in the occurrence of this species.

Table 9. Factors that best predict the presence of *Cirsium vulgare* in Yosemite National Park, 2005. Results from 10-variable logistic regression.

<u>Dependent Variable: Occurrence of <i>Cirsium vulgare</i></u>		
<u>Model Statistics: n = 151, $P = 0.0001$, Pseudo $R^2 = 24\%$</u>		
Variable	Coefficient	P
Elevation	-0.0047	< 0.0001
Stream Order	-0.9535	0.0008
Cowardin Classification	--	0.0037

The presence of *Rumex acetosella* was best predicted by elevation, stream slope and Cowardin classification, in which this species was more likely to occur at sites in lower elevations with a lower stream gradient (Table 10). These three factors explained 36% of the variation in the occurrence of *R. acetosella*.

Table 10. Factors that best predict the presence of *Rumex acetosella* in Yosemite National Park, 2005. Results from 10-variable logistic regression.

<u>Dependent Variable: Occurrence of <i>Rumex acetosella</i></u>		
<u>Model Statistics: n = 151, $P < 0.0001$, Pseudo $R^2 = 36\%$</u>		
Variable	Coefficient	P
Elevation	-0.0023	< 0.0001
Stream Slope	-0.4820	< 0.0001

DISCUSSION

Our study revealed a high amount of variation in non-native plant species richness and abundance in riparian areas of YNP. Overall, non-native plant species were present within almost half of the riparian areas surveyed within YNP. Occurrence was concentrated at low and mid elevations. Although we found that most of these species occurred in one to a few plots, there were several that occurred in greater than 10 plots. In addition, while most non-native species occurred in relatively low numbers some species were found in great abundance (greater than 1,000 individuals per plot).

Comparatively, our non-native species richness values were higher than those encountered by a different study conducted within YNP that examined two sets of data collected in 1988 to 1993 and in 1998 to 1999 (see Underwood et al. 2004). We found a mean number of 1.8 non-native species per plot and 59 non-native species overall, while Underwood et al. (2004) reported 0.69 species per plot and 41 non-native species encountered overall. The fact that Underwood et al. (2004) sampled more plots at higher elevations (where fewer non-native plants occurred) may partially explain some of these differences. Also, our study plots were located exclusively within riparian areas, while their plots were distributed throughout the landscape and thus covered a greater variety of habitats present in the park.

Conversely, we encountered less than half of the number of non-native species than Gerlach et al. (2001) reported from their 1998 – 1999 YNP plant survey. We expected this discrepancy, as Gerlach et al. (2001) found high incidences of non-native plant species as a result of directing their sampling efforts to areas of intense and frequent human disturbance.

Variation in the richness and abundance of non-native species was largely explained by a set of physiological and biological independent variables (accounting for 65% and 61% of the variation respectively). Specifically, elevation, stream slope and canopy cover best explained the variation in non-native species richness and abundance, after controlling for plant community alliance and soil texture groupings respectively. These results are largely consistent with the findings of Underwood et al. (2004), in which lower elevation, lower slope and more open areas significantly predicted higher non-native species occurrence. In addition, Gerlach et al. (2001) established a strong negative relationship between elevation and non-native species richness within human mediated disturbances.

The importance of elevation in the distribution and abundance of non-native plants species seems to hold true for both the Sierra Nevada (Gerlach et al. 2001, Underwood 2004) and elsewhere (Stohlgren et al. 2002). Although the mechanisms responsible for this elevational trend have not been fully examined, a possible explanation may be the harsher climates associated with higher elevational regions. In addition, the large majority of non-native plants found in natural areas of California are of Mediterranean origin. These plants are adapted to the climate typical of that region. Much of California is also considered to have a Mediterranean climate, with the exception of the higher elevations of the Sierra Nevada where there is a boreal climate. These high elevation zones are typically colder and have fewer growing days available which may preclude many potential invaders. In addition, higher elevation areas have likely experienced fewer human disturbances and are typically farther from major propagule sources that are both known to aid non-native species invasions.

The phenomenon of global climate change is recognized as a serious threat to native systems. Climate in North America is expected to continue to warm (CEC 2003; Hayhoe et al. 2004) causing ecosystems and species to move both poleward and up in elevation. Shifts in ecosystem distribution have been predicted through modeling (Lenihan et al. 2003), and species shifts have been documented through direct observation (Parmesan 1996; Parmesan et al. 1999; Walther et al. 2002). For the Sierra Nevada, the future will likely bring an expansion upward of the Mediterranean environment into the currently boreal environments, leading to an increase in the distribution and abundance of non-native plants within the park.

The influences of stream slope and canopy openness on non-native species richness and plant abundance were also relatively intuitive results. Riparian areas with low slope gradients are probably more likely to experience flooding events which may aid in creating openings for non-native plant invasions. With this said, the lack of a significant relationship of flooding regime as a strong predictor of non-native plant species abundance was a surprise. However, the rough, more subjective categorical measure of flooding regime may not have appropriately quantified the true influence or temporal aspects of flooding in YNP. Furthermore, areas with lower canopy cover values, suggest open growing conditions for understory plant species. Since most non-native plant species in YNP are low growing, the increased levels of sunlight would likely have a favorable influence on most of these species.

Unlike previous studies, our results demonstrated that plant community alliance played a large part in determining the number of non-native plant species. Deciduous tree, oak and cedar alliance groupings (specific alliances found in these groupings are presented in Appendix D) harbored the most non-native species. Possible factors that

may encourage establishment of non-native species in these plant communities are temporal aspects of nutrient availability (Robinson et al. 1995) or the presence of facilitative species (Callaway and Walker 1997). Whether these plant communities exhibit other characteristics that are influencing the presence of non-native species is uncertain and deserves further research. In addition, soil texture groupings were also significantly related to the abundance of non-native plant species with large to medium grained soil texture classes containing more individual plants. This finding was also somewhat unexpected and continued investigations addressing the mechanisms of this relationship are needed.

Non-native species richness and abundance appeared to be higher in areas of more intense human use within the park, with the possible exception of the high elevation Tuolumne Meadows (see Figures 2 and 3). However, our only proxy variable for human disturbance was the distance to nearest road, and we did not find a relationship between non-native plant abundance or richness and this measure. In order to more accurately measure the effects of human disturbances on alien species presence and abundance, other human disturbance variables (e.g. number of campgrounds, number of human visitors, pack stock presence etc.) should be further investigated.

The lack of a relationship with distance to road was counter to our expectations, since Gerlach et al. (2001) associated non-native species and abundances with human disturbances (e.g. roads, trails, campground, etc.) in YNP. In addition, road corridors are widely known to be vectors for alien species and roadside zones experience high disturbances and often are hosts to many alien species. However, our surveys were limited to within three kilometers of all roads, and so our sample was biased in its proximity to roads.

With the obvious exception of a few species (e.g. *Cirsium vulgare*, *Holcus lanatus*, *Poa pratensis* ssp. *pratensis*), many of the species that we encountered within our survey plots (Table 4) did not seem to be typical of riparian areas within the park, but rather were more often associated with upland areas (e.g. *Bromus tectorum*, *Vulpia myuros*, *Bromus diandrus*). Two possible explanations for this occurrence are likely: 1) the plants more typically associated with upland areas are also invading riparian areas; 2) our sampling methodology encompassed some upland areas contained within our riparian surveys. Both possibilities are likely scenarios; however, the later may provide a more reasonable explanation. Our plot area was the same at all study plots, regardless of stream size or width of riparian-related vegetation. Thus, chances of encountering vegetation more typified as upland increased if width of riparian vegetation was narrow. This coupled with the fact that riparian areas are not often fixed zones but

rather contain transitional or heterogeneous sections with adjacent upland areas makes for some added difficulty in restricting plot size and sampling locations.

R. acetosella was the most frequently detected, the third most abundant non-native species, and was more likely to occur in sites at lower elevations and a lower stream gradient. While *R. acetosella* was found in surveys outside of riparian areas within the park in other studies (Gerlach et al. 2001, Klinger and Underwood 2002), it did not occur as frequently in their surveys. This is possibly due to the fact that the distribution and abundance of this species has been expanding since the time of the previous research efforts. This species has been documented to tolerate a variety of soil types and is highly adapted to a broad range of environmental conditions (Wilson and Tilman 1991, Underwood et al. 2004). Compared to all other alien plant species we encountered, *R. acetosella* was found to have the most expansive elevational range, covering over 1,150 (869- 2021 m). According to the California Invasive Plant Council, *R. acetosella* is considered a species with a medium priority and concern for land managers (CAL-IPC 2005). Control decisions regarding this species should consider the impacts on riparian ecosystems and rare plant populations of YNP.

Other species that had relatively high frequencies included *Bromus tectorum* and *Cirsium vulgare*. *B. tectorum* had the highest mean abundance by plot value and was associated with lower elevations and a more open canopy in riparian areas. In contrast, although *Cirsium vulgare* was also located in areas that were lower in elevation, it tended to occur along smaller stream channels and there were relatively few individuals present. According to the California Invasive Plant Council, *C. vulgare* has a medium priority level for control and management, while *B. tectorum* is a high priority species (CAL-IPC 2005). Additionally, both *B. tectorum* (Keeley 2001) and *C. vulgare* (Randall 1991) distribution and abundance patterns have been associated with areas that have witnessed recent fires. Future investigations that look at couple disturbances (i.e. fire and flooding) may provide additional insight to the presence and abundance of certain non-native plant species.

The level of frequency and abundance of *B. tectorum* in riparian areas is of considerable concern. This invasive species has been documented to alter fire regimes throughout the Great Basin (Mack 1981, Whisenant 1989). Keeley (2001) postulates that non-native species, such as *B. tectorum*, may alter fire regimes in the Sierra Nevada by increasing fire frequency in chaparral communities.

The presence and relatively high densities of non-native Mediterranean grasses, such as *B. tectorum* and *Vulpia myuros* in riparian areas of YNP is also of considerable concern. High abundances may be best explained by potential increases in atmospheric nitrogen

deposition in national park watersheds (Lynch et al. 1995). Increases in the abundance of non-native, invasive species and subsequent reduction in native diversity has been attributed to increased deposition of atmospheric nitrogen (Vitrousek and Howarth 1991, Vitrousek 1997). Increased deposition of atmospheric nitrogen has also been attributed to enhanced individual plant growth and invasion of Mediterranean non-native grass species in Southern California coastal sage scrub communities (Allen et al. 1988).

Non-native plant species present in natural areas pose a risk to the success of native species and assemblages in these areas. Each year more land is invaded by non-native plant species in National Parks. In order to best serve the natural resource needs and to appropriately allocate the limited funding available, dialogues between researchers and managers must continue to address current and future needs.

This study provides an important baseline data set from which to monitor changes in non-native plant occurrence and abundance in riparian areas of YNP. Regular monitoring of the occurrence and abundance of non-native plants may further elucidate how important factors such as global climate change, nitrogen deposition and others may influence the propagation and spread of non-native plants species over the coming decades. Evidence within this study and abroad suggest that continued increase in non-native plant species invasions into natural areas is highly likely. Baseline studies, coupled with future monitoring and detection efforts can provide insight into changes in the distribution and abundance of non-native plant species in riparian areas of YNP.

RECOMMENDATIONS

We provide the following recommendations to aid in the management and control of non-native species in riparian areas of YNP. Recommendations are based on data presented in this report.

- 1) To maximize the number of non-native species and individuals targeted during control efforts, concentrate riparian-associated non-native plant management efforts in low to mid elevation areas, particularly below 2000 meters.
- 2) Prevent further spread of non-natives into areas where they are currently present in small numbers by concentrating removal efforts at high elevations and especially in and around Tuolumne Meadows.
- 3) Utilize the model results of this study to aid in the design of future monitoring protocols and to develop predictive maps of non-native plant species richness and abundances within the masked section of riparian areas of YNP to assist in the prioritization of control and management efforts.
- 4) Continue to monitor riparian-associated non-native plants throughout the park at regular intervals to determine the level of spread. Emphasize the monitoring of non-native species that were more common (e.g. *R. acetosella*, *B. tectorum*) or located in sensitive areas (i.e. near species of special concern populations).
- 5) Promote studies that directly incorporate and stratify environmental and physiographic variables (e.g. elevation, plant community type, stream order, distance to road, etc.) into the survey criteria to better understand the factors affecting non-native species richness and abundance values in riparian areas.
- 6) Promote studies that research mechanisms of dispersal and invasion of non-native plant species in riparian areas of YNP.
- 7) Promote research that investigates coupled disturbance factors (e.g. fire and flooding, compaction and flooding) on non-native plant species in riparian areas of YNP.

ACKNOWLEDGEMENTS

Funding for this study was provided by the National Park Service Inventory and Monitoring Program, Sierra Nevada Network. Yosemite National Park and Sierra Nevada Inventory and Monitoring Network staff (Barbara Moritsch, Peggy Moore, Meryl Rose, Lisa Acree, Linda Mutch, and Rose Cook) designed the study, determined protocols and supported field staff. Their expertise, assistance and generosity were greatly appreciated. In addition, Lisa Acree, Linda Mutch, Peggy Moore and Emily Orling provided insightful comments and critical review of previous drafts. Brent Johnson (NPS) was helpful in providing support in the determination of unknown specimens. Nadav Nur (PRBO) provided helpful analysis discussion and review. This project was greatly advanced through the field assistance and botanical savvy of PRBO field staff Keir Morse, Emily Orling, Matthew Danielczyk, Rebecca Green and Leah Culp. Keir Morse provided the cover photograph. This is PRBO Contribution # 1335.

LITERATURE CITED

- Allen, E.B., P. E. Padgett, A. Bytnerowicz, and R. Minnich 1988. Nitrogen deposition effects on coastal sage vegetation of southern California. International Symposium on Air Pollution and Climate Change Effects on Forest Ecosystems. B. A., A. M.J., and S. S.L., editors. General Technical Report PSW-GTR-166, Pacific Southwest Research Station, USDA Forest Service, Riverside, California.
- Alpert, P., E. Bone and C. Holzapfel 2000. Invasiveness, invasibility and the role of environmental stress in the spread of non-native plants. *Perspectives in Plant Ecology, Evolution and Systematics* 3:52-66.
- Botti, S.J. 2001. An illustrated flora of YNP. The Yosemite Association, El Portal, California, USA.
- Brewer, R. and M.T. McCann 1982. Laboratory and field manual of ecology. Saunders College Publishing, New York.
- Brock, J.H. 1994. *Tamarix* spp. (Salt Cedar), an invasive exotic woody plant in arid and semi-arid riparian habitats of Western, USA. In de Waal, L.C., L.E. Child, P.M. Wade, and others, eds., *Ecology and Management of Invasive Riverside Plants*, John Wiley & Sons, New York.
- Brooks, M.L., C.M. D'Antonio, D.M. Richardson, J.B. Grace, J.E. Keeley, J.M. DiTomaso, R.J. Hobbs, M. Pellant, and D. Pyke 2004. Effects of invasive alien plants on fire regimes. *BioScience* 54:677-688.
- Brooks, M.L. and D. Pyke 2001. Invasive plants and fire in the deserts of North America. Pages 1-14 *in* K.E.M. Galley and T.P. Wilson, editors. *Proceedings of the Invasive Species Workshop: the Role of Fire in the Control and Spread of Invasive Species. Fire Conference 2000: the First National Congress on Fire Ecology, Prevention, and Management*. Tall Timbers Research Station, Tallahassee, Florida.
- CAL-IPC 2005. Invasive Plant Inventory Revision 2005. California Invasive Plant Council, Berkely CA. Available from http://www.cal-ipc.org/pest_plant_list/ (accessed 15Dec2005)
- CEC 2003. Climate Change and California: Staff Report. Sacramento, California Energy Commision: 46.

- Callaway, R.M. and L.R. Walker 1997. Competition and facilitation: a synthetic approach to interactions in plant communities. *Ecology* 78: 1958-1965.
- Cowardin, L.M., V. Carter, F.C. Golet, E.T. LaRoe 1979. Classification of wetlands and deepwater habitats of the United States. U. S. Department of the Interior, Fish and Wildlife Service, Washington, D.C. Jamestown, ND: Northern Prairie Wildlife Research Center Online.
<http://www.npwrc.usgs.gov/resource/1998/classwet/classwet.htm> (Version 04DEC98).
- D'Antonio, C.M. 2000. Fire, plant invasions, and global changes. Pages 6-93 in H.A. Mooney and R.J. Hobbs, editors. *Invasive Species in a Changing World*. Island Press, Washington, D.C. USA.
- D'Antonio, C.M. and P.M. Vitousek 1992. Biological invasions by exotic grasses, the grass/fire cycle, and global change. *Annual Review of Ecology and Systematics* 23:63-87.
- Darwin, C. 1859. *On the Origin of Species*. Murray, London.
- Drake, J.A., H.A. Mooney, F. di Castri, R.H. Groves, F.J. Kruger, M. Rejmanek, and M. Williamson, editors 1989. *Biological invasions. A global perspective*. SCOPE 37. John Wiley & Sons, Chichester, UK.
- Elton, C.S. 1958. *The Ecology of Invasions by Animals and Plants*. Methuen and Co, London.
- Environmental Systems Research Institute 2004. ArcGIS; Release 9.0 [software]. Redlands, CA: Enviromental Systems Research Institute 1999-2004.
- Fellows, M.Q.N. and J.B. Zedler 2005. Effects of the non-native grass, *Parapholis incurvata* (Poaceae), on the rare and endangered hemiparasite, *Cordylanthus maritimus* subsp. *maritimus* (Scrophulariaceae). *Madroño* 52(2):91-98.
- GAO 2005. General Accounting Office report-GAO-05-185. *Invasive Species: Cooperation and Coordination Are Important for Effective Management of Invasive Weeds* (25-FEB-05).
- Gerlach, J.D., P. Moore, D.M. Lubin, B. Johnson, G. Roy, P. Whitmarsh, D.M. Graber, and J.E. Keeley 2001. *Exotic species threat assessment and management*

prioritizations for Sequoia-Kings and YNPs. USGS-BRD, Western Ecological Research Center.

Goigel, M. and S. Bratton 1983. Non-natives in the Parks. *National Parks* 57(1-2):25-29.

Graf, W.L. 1978. Fluvial adjustments to the spread of tamarisk in the Colorado Plateau region. *Geological Society of America Bulletin* 89:491-501.

Hayhoe, K., D. Cayan, C.B. Field, P.C. Frumhoff 2004. Emissions pathways, climate change, and impacts on California. *Proceedings of the National Academy of Sciences* 101(34): 12422-12427.

Hobbs RJ and L.F. Huenneke 1992. Disturbance, diversity, and invasion: implications for conservation. *Conservation Biology* 6: 324–337

Hickman, J.C., editor 1993. *The Jepson Manual: Higher Plants of California*. University of California Press, Berkeley. 1400 pp.

Keeley, J.E. 2001. Fire and invasive species in Mediterranean-climate ecosystems of California. Pages 81-94 *in* K.E.M. Galley and T.P. Wilson, editors. *Proceedings of the Invasive Species Workshop: the Role of Fire in the Control and Spread of Invasive Species*. Fire Conference 2000: the First National Congress on Fire Ecology, Prevention, and Management. Tall Timbers Research Station, Tallahassee, Florida.

Klinger, R. and E.C. Underwood 2002. The design and sampling protocols for an inventory of alien plant species in burned and riparian areas in YNP, California. University of California, Davis.

Kolb, A., P. Alpert, D. Enters, and C. Holzapfel 2002. Patterns of invasion within a grassland community. *Journal of Ecology* 90:871-881.

Lenihan, J.M., R. Drapek, D. Bachelet, and R.P. Neilson (2003). "Climate change effects on vegetation distribution, carbon, and fire in California." *Ecological Applications* 13(6): 1667-1681.

Levine, J.M., M. Vila, C.M. D'Antonio, J.S. Dukes, K. Grigulis and S. Lavorel 2003. Mechanisms underlying the impacts of exotic plant invasions. *Proceedings of the Royal Society of London Bulletin* 270: 775–781.

- Lynch, J. A., J. W. Grimm, and V. C. Bowersox 1995. Trends in precipitation chemistry in the United States: A national perspective. *Atmospheric Environment* 11:1231-1246.
- Macdonald, I.A.W., D.M. Graber, S. DeBenedetti, R.H. Groves, and E.R. Fuentes 1988. Introduced species in nature reserves in Mediterranean-type climatic regions of the world. *Biological Conservation* 44:37-66.
- Mack, R.N. 1981. Invasion of *Bromus tectorum* L. into western North America: an ecological chronicle. *Agro-Ecosystems* 7:145-165.
- Mack, R.N., D. Simberloff, W.M. Lonsdale, H. Evens, M. Clout, and F.A. Bazzaz 2000. Biotic Invasions: Causes, epidemiology, global consequences, and control. *Ecological Applications* 10:689-710.
- Mooney, H.A. and R.J. Hobbs 2000. *Invasive Species in a Changing World*. Island Press, Washington, D.C.
- Moore, P.E. 1993. Preliminary descriptions of terrestrial natural communities of YNP, California. Unpublished Manuscript, Yosemite Research Center Files, YNP, California. 42 pp.
- Moulton, M.P. and S.L. Pimm 1986. Species introductions to Hawaii. Pages 231-240 in H.A. Mooney and J.A. Drake (eds.) *Ecology of biological invasions of North America and Hawaii*, Springer-Verlag, New York.
- National Park Service 1996. A strategic plan for managing invasive non-native plants of National Park System lands. USDI National Park Service, Washington, D.C. Available from http://www.nature.nps.gov/biology/invasives/strat_pl.htm (accessed 17 October 2005).
- National Park Service 2004. NPS ten most visited units and national parks. Office of Public Affairs. USDI National Park Service, Washington, D.C. Available from http://www.nps.gov/pub_aff/refdesk/ (accessed 17 October 2005).
- NPS 2005. Inventory and monitoring goals. National Park Service Inventory and Monitoring Program. USDI National Park Service, Washington, D.C. Available from <http://science.nature.nps.gov/im/index.cfm> (accessed 17 October 2005).

- NatureServe 2002. Classification of the Vegetation of Yosemite National Park and Surrounding Environs in Tuolumne, Mariposa, Madera and Mono Counties, California. Final Draft Report submitted to the National Park Service. 498 pp.
- Parmesan, C. (1996). "Climate and species' range." *Nature* 382: 765-766.
- Parmesan, C., N. Ryrholm, C. Stefanescu, J.K. Hill, C.D. Thomas, H. Descimon, B. Huntley, L. Kaila, J. Kullberg, T. Tammari, W.J. Tennent, J.A. Thomas, and M. Warren (1999). "Poleward shifts in geographical ranges of butterfly species associated with regional warming." *Nature* 399: 579-583.
- Pimm, S.L. and M.E. Gilpin 1989. Theoretical issues in conservation biology. pp. 287-305 in J. Roughgarden, R.M. May, and S.A. Levin, eds. *Perspectives in Ecological Theory*. Princeton University Press, Princeton, NJ.
- Planty-Tabacchi, A., E. Tabacchi, R.J. Naiman, C. DeFerrari and H. Décamps 1996. Invasibility of Species-Rich Communities in Riparian Zones. *Cons. Biol.* 10: 598–607.
- Randall, J.M. 2000. Improving management for nonnative invasive plants in wilderness and other natural areas. pp. 64-73 in Cole, D.N., S.F. McCool, W.T. Borrie, J. O'Loughlin, comps. *Wilderness science in a time of change conference—Volume 5: Wilderness ecosystems, threats, and management; 1999 May 23–27; Missoula, MT. Proceedings RMRS-P-15-VOL-5*. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.
- Randall, J.M. 1991. Population dynamics and control of bull thistle, *Cirsium vulgare*, in Yosemite Valley. pp. 261-281 In R.F. Doren, R.L. Hofstetter, R.L. Meyers and L.D. Whiteaker (eds.) *Proceedings of the Symposium on Exotic Pest Plants*. University of Miami, Florida, 1988. United States Department of Interior / National Park Service.
- Rejmánek, M. 1989. Invasibility of plant communities. Pages 369-388 in J.A. Drake, F. DiCasti, R.H. Groves, F.J. Kruger, H.A. Mooney, M. Rejemanek and M. H. Williamson, editors. *Biological invasions: a global perspective*. Wiley, New York, New York, New York, USA.
- Rejmánek, M. 1996. Species richness and resistance to invasions. Pages 153-172 in H. Orians, R. Dirzo and J.H. Cushman (eds.) *Biodiversity and ecosystem processes in tropical forests*, Ecological Studies, Vol. 122, Springer-Verlag, Berlin.

- Robinson, G. R., J.F. Quinn, and M.L. Stanton 1995. Invasibility of experimental habitat in California winter annual grassland. *Ecology* 76: 786–794.
- Scott, J.M. and D.S. Wilcove 1998. Improving the future for endangered species. *BioScience* 48 (8): 579-580.
- Simberloff, D., D.C. Schmitz, and T.C. Brown, editors 1997. *Strangers in Paradise*. Island Press, Washington, D.C. USA.
- Stahler, A.N. 1952 Dynamic basis of geomorphology. *Geological Society of America Bulletin* 63: 923-938.
- StataCorp 2005. *Stata Statistical Software: Release 8.2*. College Station, TX: StataCorp LP.
- Stohlgren, T.J., M.B. Coughenour, G.W. Chong, D. Brinkley, M.A. Kalkhan, L.D. Schell, D.J. Buckley and J.K. Berry 1997. Landscape analysis of plant diversity. *Landscape Ecology* 12:155-170.
- Stohlgren, T. J., K. A. Bull, Y. Otsuki, C. Villa, and M. Lee. 1998. Riparian zones as havens for exotic plant species. *Plant Ecology* 138: 13–125.
- Stohlgren T.J., D. Binkley and G.W. Chong 1999. Exotic plant species invade hot spots of native plant diversity. *Ecological Monographs* 69: 25–46.
- Stohlgren, T.J., G.W. Chong, L.D. Schell, K.A. Rimar, Y. Otsuki, M. Lee, M.A. Kalkhan and C.A. Villa 2002. Assessing vulnerability to invasion by nonnative plant species at multiple spatial scales. *Environmental Management* 29:566-577.
- Underwood, E.C., R. Klinger and P.E. Moore 2004. Predicting patterns of non-native plant invasions in YNP, California, USA. *Diversity and Distributions* 10:447-459.
- United States National Research Council 2002. *Predicting Invasions of Nonindigenous Plants and Plant Pests*, National Academy Press, Washington, DC
- Vitousek, P. M. and R. W. Howarth 1991. Nitrogen limitation on land and in the sea: How can it occur? *Biogeochemistry* 13:87-115.
- Vitousek, P.M. and L.R. Walker 1989. Biological invasion by *Myrica faya* in Hawai'i: plant demography, nitrogen fixation, ecosystem effects. *Ecological Monographs* 59:247-265.

- Vitousek, P. M., J. Aber, R. W. Howarth, G. E. Likens, P. A. Matson, D. W. Schindler, W. H. Schlesinger, and G. D. Tilman 1997. Human alteration of the global nitrogen cycle: causes and consequences. *Issues in Ecology* 1:1-15.
- Walther, G., E. Post, P. Convey, A. Menzel, C. Parmesan, T.J.C. Beebee, J. Fromentin, O. Hoegh-Guldberg, and F. Bairlein (2002). "Ecological responses to recent climate change." *Nature* 416: 389-395.
- Wilcove, D. S., D. Rothstein, J. Dubow, A. Phillips, and E. Losos 1998. Quantifying threats to imperiled species in the United States. *BioScience* 48:607–615.
- Williamson, M. and A. Fritter 1996. The varying success of invaders. *Ecology* 77:1666-1670.
- Wilson, S.D. and D. Tilman 1991. Interactive effects of fertilization and disturbance on community structure and resource availability in an old-field plant community. *Oecologia* 88:61-71.
- Whisenant, S.G. 1989. Changing fire frequency on Idaho's Snake River Plains: ecological and management implications. Pages 4-10 in *Symposium on Cheatgrass Invasion, Shrub Die-Off and Other Aspects to Shrub Biology and Management*. USDA Forest Service, Las Vegas, NV.

Appendix A. Yosemite National Park riparian non-native plant survey plot locations (UTM NAD 27).

Plot Number	X Coordinate (easting)	Y Coordinate (northing)	Plot Number	X Coordinate (easting)	Y Coordinate (northing)
1	283503	4157492	50	256593	4181625
2	282744	4157699	51	256744	4181974
3	284167	4157709	53	282605	4187500
4	267531	4169046	54	261031	4187996
5	274108	4171672	56	261358	4188707
6	256776	4173584	57	298021	4192125
7	264563	4173672	60	294360	4193826
9	274147	4176514	61	291989	4196057
12	282568	4184982	67	264205	4156023
14	276729	4185575	69	269001	4157565
15	276771	4185715	71	263954	4161402
17	277595	4186620	72	264269	4163039
18	282737	4186992	74	257725	4171675
19	283755	4187486	75	257563	4171946
20	270843	4187925	76	259280	4174275
21	283827	4188442	77	257090	4175826
22	269738	4188486	79	255532	4179888
23	262930	4189033	82	251559	4185791
24	269450	4189583	83	254175	4185869
27	297963	4191925	84	254087	4186207
28	265262	4192428	85	254027	4186955
29	268316	4194226	86	275757	4187038
30	268307	4194233	88	257901	4187787
31	290352	4194733	89	280063	4189166
32	291089	4195515	90	258402	4189937
33	289410	4196753	91	251154	4190546
34	271847	4153577	92	271193	4190930
37	270934	4169899	93	256532	4191049
38	271619	4170329	94	252796	4192055
40	273547	4172341	100	270003	4153108
41	266595	4174044	101	266663	4155308
42	269344	4174433	102	269002	4156680
43	269543	4174579	103	262330	4164367
44	269786	4174964	104	262459	4169958
46	257614	4179881	105	261749	4172024
48	257480	4181431	107	262830	4176860
49	257590	4181579	108	262366	4176889

continued next page

Appendix A- cont. Yosemite National Park riparian non-native plant survey
plot locations (UTM NAD 27).

Plot Number	X Coordinate (easting)	Y Coordinate (northing)	Plot Number	X Coordinate (easting)	Y Coordinate (northing)
109	274855	4178020	156	272947	4179982
110	273686	4180320	157	273436	4180149
111	271415	4180927	158	273940	4180295
112	272455	4180988	159	253352	4181850
113	253613	4181350	160	254061	4182684
114	254386	4181360	161	255255	4183598
115	258123	4182491	162	248444	4185215
116	253510	4183408	163	249716	4186835
117	257525	4184427	164	248596	4187134
118	253927	4187793	165	248436	4188568
119	249900	4189653	166	267133	4153586
120	256718	4189698	167	267897	4154064
121	256544	4190081	168	268108	4154298
123	253014	4198485	169	268282	4155397
125	253703	4198586	170	268622	4155731
126	253556	4198574	171	268416	4156001
128	252632	4200221	172	268653	4156069
129	252787	4200858	173	263459	4161785
133	270129	4153169	174	263302	4162030
134	269775	4153776	175	263402	4162058
135	269664	4153778	177	265867	4177094
136	264410	4155069	179	264981	4177514
137	266662	4155620	181	265969	4177578
138	267503	4155783	182	264704	4177656
139	265690	4158483	183	266642	4177684
140	263696	4158625	184	266493	4177782
141	263173	4159075	185	265683	4177776
142	263656	4172352	186	266557	4178075
145	271992	4175255	187	261511	4178178
146	256762	4177572	188	260985	4178240
147	268827	4177952	189	261091	4178328
148	269203	4178344	190	261015	4178378
149	269576	4178423	191	256902	4179198
150	270004	4178565	192	250252	4182697
152	274616	4178954	193	248724	4183533
153	260777	4178963	194	252973	4183674
155	273237	4179530	195	252595	4184072

continued next page

Appendix A – cont. Yosemite National Park riparian non-native plant survey
plot locations (UTM NAD 27).

Plot Number	X Coordinate (easting)	Y Coordinate (northing)	Plot Number	X Coordinate (easting)	Y Coordinate (northing)
196	250327	4185984	198	252102	4189209
197	250226	4186089			

Appendix B. Descriptions of environmental, biological and physiographic variables.

Surficial Geology

Note the geologic substrate influencing the plant community (bedrock or surficial materials). The list below provides an example of the values that might be included.

IGNEOUS ROCKS

Granitic (Granite, Schyolite, Syenite, Trachyte)
Ioritic (Diorite, Dacite, Andesite)
Gabbroic (Gabbro, Basalt, Pyroxenite, Peridotite)

SEDIMENTARY ROCKS

Conglomerates and Breccias
Sandstone
Siltstone
Shale
Limestone and Dolomite
Gypsum

METAMORPHIC ROCKS

Gneiss
Schist
Slate and Phyllite
Marble
Serpentine

GLACIAL DEPOSITS

Undifferentiated glacial deposit
Till
Moraine
Bedrock and till
GF
Glacio-fluvial deposits (outwash plains, ice-contacted GF deposits, eskers, kames, proglacial deltas, crevasse filling, etc.)
Deltaic deposits (alluvial cones, deltaic complexes)
Lacustrine and fluvial deposits (glacio-fluvial, fluvio-lacustrine, freshwater sandy beaches, stony/gravelly shoreline)

ORGANIC DEPOSITS

Peat (with clear fibric structure)
Muck
Marsh, regularly flooded by lake or river (high mineral content)

SLOPE AND MODIFIED DEPOSITS

talus and scree slopes
colluvial
solifluction, landslide

AEOLIAN DEPOSITS

dunes
aeolian sand flats
cover sands

Appendix B - continued. Descriptions of environmental, biological and physiographic variables.

Cowardin System

If the system is a wetland, check off the name of the United States Fish & Wildlife Services (USFWS) system that best describes its hydrology and landform. Indicate "upland" if the system is not a wetland.

Assess the hydrologic regime of the site using the descriptions below (adapted from Cowardin et al., 1979).

SEMIPERMANENTLY FLOODED - Surface water persists throughout growing season in most years except during periods of drought. Land surface is normally saturated when water level drops below soil surface. Includes Cowardin's Intermittently Exposed and Semipermanently Flooded modifiers.

SEASONALLY FLOODED - Surface water is present for extended periods during the growing season but is absent by the end of the growing season in most years. The water table after flooding ceases is variable, extending from saturated to a water table well below the ground surface. Includes Cowardin's Seasonal, Seasonal-Saturated, and Seasonal-Well Drained modifiers.

SATURATED - Surface water is seldom present, but substrate is saturated to surface for extended periods during the growing season. Equivalent to Cowardin's Saturated modifier.

TEMPORARILY FLOODED - Surface water present for brief periods during growing season, but water table usually lies well below soil surface. Often characterizes floodplain wetlands. Equivalent to Cowardin's Temporary modifier.

INTERMITTENTLY FLOODED - Substrate is usually exposed, but surface water can be present for variable periods without detectable seasonal periodicity. Inundation is not predictable to a given season and is dependent on highly localized rainstorms. This modifier was developed for use in the arid west for water regimes of playa lakes, intermittent streams, and dry washes but can be used in other parts of the U.S. where appropriate. This modifier can be applied to both wetland and nonwetland situations. Equivalent to Cowardin's Intermittently Flooded modifier.

PERMANENTLY FLOODED - Water covers the land surface at all times of the year in all years. Equivalent to Cowardin's Permanently Flooded.

UNKNOWN - The water regime of the area is not known. The unit is simply described as a nontidal wetland.

Appendix B - continued. Descriptions of environmental, biological and physiographic variables.

Soil Texture

Using the key below, assess average soil texture.

Simplified Key to Soil Texture (Brewer and McCann, 1982)

- A1 Soil does not remain in a ball when squeezed..... sand
- A2 Soil remains in a ball when squeezed B
- B1 Squeeze the ball between your thumb and forefinger, attempting to make a ribbon that you push up over your finger. Soil makes no ribbon loamy sand
- B2 Soil makes a ribbon; may be very short C
- C1 Ribbon extends less than 1 inch before breaking D
- C2 Ribbon extends 1 inch or more before breaking E
- D1 Add excess water to small amount of soil. Soil feels at least slightly gritty loam or sandy loam
- D2 Soil feels smooth silt loam
- E1 Soil makes a ribbon that breaks when 1–2 inches long; cracks if bent into a ring F
- E2 Soil makes a ribbon 2 or more inches long; does not crack when bent into a ring G
- F1 Add excess water to small amount of soil; soil feels at least slightly gritty sandy clay loam or clay loam
- F2 Soil feels smooth silty clay loam or silt
- G1 Add excess water to a small amount of soil; soil feels at least slightly gritty sandy clay or clay
- G2 Soil feels smooth silty clay

Appendix C. Field datasheets for non-native vegetation inventory in riparian areas of Yosemite National Park.

**NONNATIVE VASCULAR PLANT INVENTORY IN RIPARIAN AREAS
YOSEMITE NATIONAL PARK, CALIFORNIA
FIELD SURVEY FORM**

DATE (month/day/year): _____ REPORTER(S): _____
PLOT #: _____ Location Name: _____
Easting: _____ Northing: _____ Quad: _____

VEGETATION DESCRIPTION
Plant Community(ies): _____ _____
Did plot key easily? yes no if not, why not? _____
List 1-3 dominant species in each vegetation layer and % cover of each species:
Canopy: _____ Sub-canopy: _____ _____ _____
Shrub: _____ Herbaceous: _____ _____ _____
% Canopy Closure in Overstory: _____

PLOT INFORMATION
Plot Dimensions: ___10m x 100m ___5m x 200 m Other: _____
Stream Slope: _____ Stream Aspect: _____ Plot Slope: _____ Plot Aspect: _____
Soil Texture: ___sand ___loamy sand ___sandy loam ___loam ___silt loam ___silt ___clay loam ___silty clay ___clay ___peat ___muck ___silty clay loam
Surficial Geology: _____
Cowardin Classification: ___upland ___palustrine ___riverine ___lacustrine
Flooding Regime: ___annual ___semi-annual ___occassional ___rare

Appendix C-continued. Field datasheets for non-native vegetation inventory in riparian areas of Yosemite National Park.

PLOT INFORMATION (continued)

Nature of Riparian Corridor: _____

Human Disturbances (e.g., trails, roads, eroded banks): _____

ADDITIONAL COMMENTS:

Sketch Map of Plot (including roads, paved and unpaved trails, huge rocks, etc.)

Appendix C-continued. Field datasheets for non-native vegetation inventory in riparian areas of Yosemite National Park.

DATE (mo./day/year): _____ PLOT #: _____ Page__of__

VASCULAR PLANT SPECIES

[illegible]

Appendix D. Reduced groupings for plant community association and soil texture categories. Groupings used for linear regression analysis to avoid over-fitting of models.

Plant Community Alliance	Alliance Grouping
<i>Abies concolor</i> forest	Fir
<i>Abies concolor</i> - <i>Pinus lambertiana</i> forest	Fir
<i>Abies magnifica</i> forest	Fir
<i>Abies magnifica</i> - <i>Abies concolor</i> forest	Fir
<i>Alnus rhombifolia</i> temporarily flooded forest	Deciduous Tree
<i>Calocedrus decurrens</i> forest	Cedar
<i>Carex</i> spp. seasonally flooded herbaceous	Herbaceous/Meadow/Sparse
<i>Carex nebrascensis</i> seasonally flooded herbaceous	Herbaceous/Meadow/Sparse
<i>Ceanothus integerrimus</i> shrubland	Shrubland
<i>Glyceria elata</i> temporarily flooded	Herbaceous/Meadow/Sparse
<i>Pinus contorta</i> forest	Pine
<i>Pinus jeffreyi</i> woodland	Pine
<i>Pinus ponderosa</i> woodland	Pine
<i>Pinus ponderosa</i> - <i>Calocedrus decurrens</i> forest	Pine
<i>Populus balsamifera</i> ssp. <i>trichocarpa</i> temporary flooded forest	Deciduous Tree
<i>Populus tremuloides</i> forest	Deciduous Tree
<i>Pseudotsuga menziesii</i> forest	Fir
<i>Pseudotsuga menziesii</i> - <i>Pinus ponderosa</i> forest	Fir
<i>Philadelphia lewissii</i> shrub alliance	Shrubland
<i>Quercus chrysolepis</i> forest	Oak
<i>Quercus kelloggii</i> forest	Oak
<i>Sequoiadendron giganteum</i> forest	Sequoia
Sparsely vegetated to non-vegetated	Herbaceous/Meadow/Sparse
Soil Texture Classification	Soil Texture Grouping
sand, loamy sand, sandy loam	coarse
loam, silt loam, silt	medium
clay loam, silty clay, clay, silty clay loam	fine
muck	muck
rock	rock