# Factors Controlling Patterns of Canada Thistle (*Cirsium arvense*) and Yellow Starthistle (*Centaurea solstitialis*) Across the Cascade-Siskiyou National Monument

Paul E. Hosten

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## Abstract

Landscape patterns of broadleaved noxious weeds across the Cascade-Siskiyou National Monument are examined in the context of environmental and management factors to improve our understanding of weed dynamics. Environmental factors include a range of topographic edaphic variables, while management factors provide insight about historic vegetation manipulation, road construction and forage utilization by wildlife and livestock. Distribution patterns of Canada thistle (*Cirsium arvense*) and yellow starthistle (*Centaurea solstitialis*) across the Monument are best described by a combination of topographic, edaphic, biotic, and management factors. Variables incorporated within models describing landscape patterns of weeds varied with response variable (actual weed locations versus weed density at random locations throughout the landscape) and the incorporation of private lands, characterized by less intense or localized lack of weed surveys, with public lands. Optimization of data quality by restriction of analysis to public lands in a landscape context identified elevation, maximum forage utilization by livestock and native ungulates, and past management treatments as predictors common to both Canada thistle and yellow starthistle distribution. Additional variables associated with the pattern of Canada thistle included heat-load and soil depth. The optimal model describing yellow starthistle distribution also included soil classification as vertisol, NRCS ecological type, woody vegetation cover, and average utilization by livestock and native ungulates. Analysis of individual variables indicated that roads and distance from water influenced the distribution of weeds. The association between roads, water, and forage utilization

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implies a synergy between road construction, proximity to water, livestock and wildlife dispersion, with weed establishment.

## Introduction

Canada thistle (*Cirsium arvense*) and yellow starthistle (*Centaurea solstitialis*) are aggressive invaders of wildlands, forming extensive monocultures in parts of Oregon and other western states (DiTomaso 2005). While the two thistles are both in the Asteraceae, they differ in life-history characteristics and habitat preferences. Yellow starthistle favors drier habitats at lower elevations and more southerly slopes while Canada thistle frequents open meadows and disturbed areas at higher elevation. Both species spread through seed, and Canada thistle has the ability to spread vegetatively on a localized basis.

Over the past 30 years, these weeds have become widely established in the Cascade-Siskiyou National Monument (CSNM) in southwestern Oregon and constitute a major management concern. Photo-retakes and collations of historic documents (Hosten et al. 2007b) identify recent management activities that may have influenced the current weed invasion process: herbicide application; aerial fertilization; seeding of native and non-native herbaceous species; removal of vegetation cover by logging in conifer communities and scarification in shrublands and woodlands; road construction; stock pond construction; and grazing by livestock and native ungulates.

The presence and abundance of weed species across the landscape is commonly associated with disturbances such as fire, agriculture, roads, and grazing (Masters and Sheley 2001; Keeley et al. 2003; Gelbard and Harrison 2005; Harrison 1999; Fuhlendorf et al. 2001). Aspect, slope, elevation, plant community, and edaphic factors also influence the distribution of weeds (Roche et al. 1994; Gelbard and Harrison 2005). Some interactions between management and environmental factors may further facilitate weed invasion. These include the interaction of grazing and roads (Safford and Harrison 2001) and the interaction of grazing and fire (Noy-Meir 1995). Roads serve as corridors for dispersal, provide suitable habitat for weed growth, and thus maintain a reservoir of plants and propagules for future invasions (.Parendes and Jones 2000, Gelbard and Belnap 2003).

The literature offers an abundance of information on the association of weeds with particular disturbances, on control of noxious weeds, and on the best management approaches for alleviating particular weed issues. The CSNM provides a rare opportunity to examine the pattern of weeds across the landscape in association with environmental variables, biotic descriptors, and management activities.

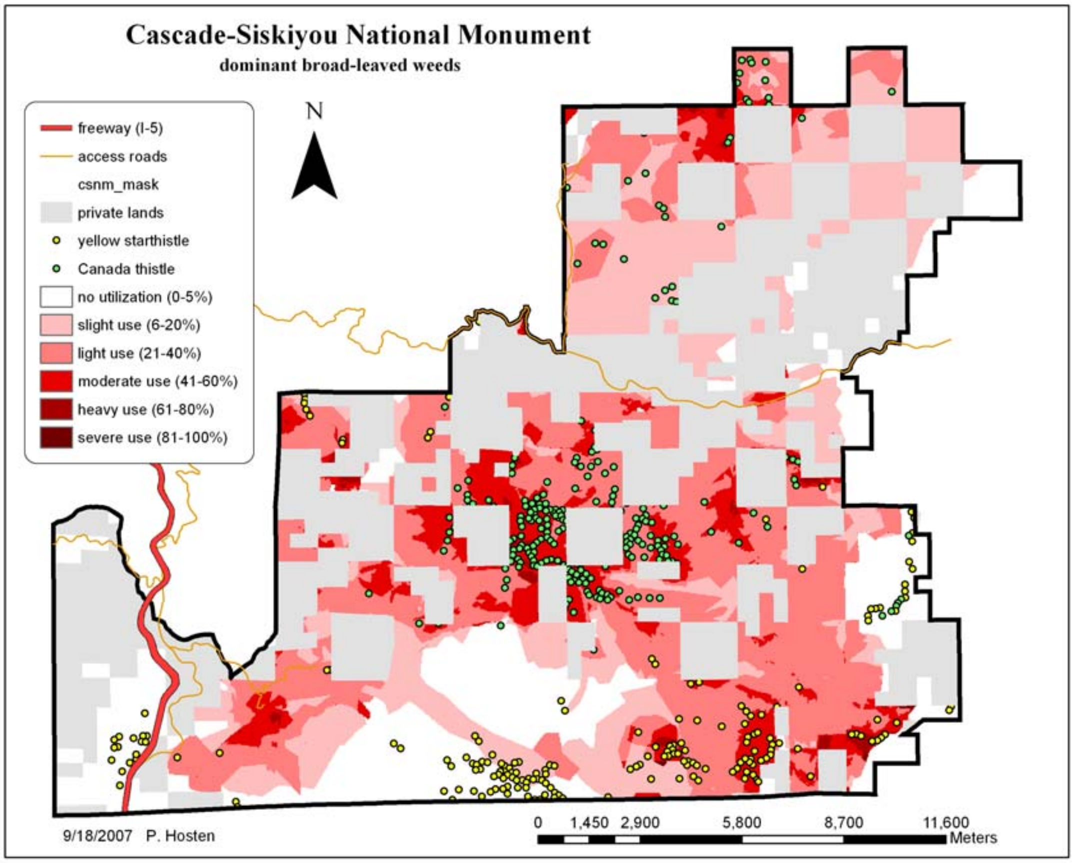
The CSNM is located in Jackson county southwest Oregon, its southern border conforming with the Oregon-California stateline. The monument covers 34 400 hectares with a checkerboard interface of public (21430 hectares) and privately owned lands (12950 hectares). The topography is highly variable with the south end being nearly level, to slopes in excess of 70 percent in the north. Elevation ranges from 724 meters to 1857 meters and average annual precipitation for this area ranges from 50 to 100 centimeters with most coming as rain below 1067 meters and snow above that level. Soils vary in the CSNM with land form and source material. Most soils were formed in alluvium or colluvium from hard volcanic rocks and, as a result, are often shallow or have a high rock content that decreases their water holding capacity. Plant communities range from grasslands, shrublands and woodlands to mixed conifer forests supporting Douglas-fir, white fir, ponderosa pine, sugar pine, incense cedar and Pacific yew.

The objectives of this study were to examine the abundance and distribution of Canada thistle and yellow starthistle, common broad-leaved noxious weeds, relative to environmental factors (topography, soils, biotic descriptors), management activities (livestock dispersion, relative forage utilization, distance from water), distance from roads, and past vegetation manipulation.

## Materials and Methods

### Weed Surveys

Weed population locations were recorded using a global positioning system (GPS) receiver and mapped with Geographic Information System (GIS) software (ARCMAP 9.2) for compilation of weed observations over a period of five years (2000-2004). The collation of weed observations was filtered to remove weed populations of datapoints closer than 100 meters to each other. This process also eliminated duplicate inventories of weed populations, since 100 meters exceeds the minimum accuracy of the GPS unit, and the spatial accuracy of existing data (roads, water sources, etc.) within the GIS system. Together with weed surveys, noxious weed encounters consequent to other management and monitoring activities have resulted in a synoptic map of weed observations across the CSNM (Map 1).




**Map1. Yellow starthistle and Canada thistle population locations across the CSNM.**

**Compilation of Weed Abundance, Environmental Data, and Past Management Activities**

This project examined patterns of Canada thistle and yellow starthistle relative to GIS-based grids representing environmental and management variables (Table 1). Weed surveys can be considered synoptic across the public lands of the monument, but not the intermingled public and private lands. Weed presence was sampled on private industrially owned lands only where field crews had permission to record weed presence. Some of the predictive variables were extant datasets collated for public lands only (Table 1). Interspersed public and private lands therefore differed in survey data quality.

**Table 1. Extent, quality, and origin of response and predictor variables.**

| Variable | Extent | Source |
|---|---|---|
| **Response variables** | | |
| Weed actual location | Variable quality across public and private | Survey |
| Weed density | Variable quality across public and private | Density map created from surveyed points |
| **Predictor Variables** | | |
| Elevation | Public and private | Digital terrain Model |
| Heat-load | Public and private | Incorporation of slope, aspect, and latitude in heat-load equation |
| % sand | Public and private | NRCS survey |
| % silt | Public and private | NRCS survey |
| % clay | Public and private | NRCS survey |
| Soil depth | Public and private | NRCS survey |
| Vertisol soil | Public and private | NRCS survey |
| NRCS ecological type* | Public and private | NRCS survey |
| Coarse plant community* | Public and private | NRCS survey |
| Woody vegetation cover | Public and private | TM imagery |
| Conifer cover change | Public and private | TM imagery |
| Vegetation structure | Public only | Survey for spotted owl habitat |
| Distance from roads | Public and private | Proximity mapping, GIS |
| Distance from water-source | Public and private | Proximity mapping, GIS |
| Average utilization | Public and private | Collation of range utilization maps |
| Maximum utilization | Public and private | Collation of range utilization maps |
| Years of rest | Public and private | Collation of range utilization maps |
| Non-conifer treatments | Public only | Aerial photo interpretation, collation of various databases |
| Forest structure* | Public only | Aerial photo and field-validation of spotted owl habitat |

* non-binary categorical variables examined as individual variables only

Response variables (Table 1) are the actual sightings of Canada thistle and yellow starthistle. Because the location of weed populations was found to be spatially auto-correlated so that data analysis using individual weed locations might constitute ‘pseudo-replication’ (Hurlbert 1984), density maps were resampled at random locations to create response variables at independent sites. Density was calculated using a kernel approach with search radius set at 500 meters in ARCMAP 9.2 (ESRI 2006).

Environmental variables (Table 1) independent of management were derived from digital elevation data and soil surveys (USDA 1988). Aspect and slope were utilized to create a single continuous grid of heat loading representing the topography (McCune and Keon 2002). Woody vegetation cover derived from satellite imagery and validated by regressing woody cover derived from LIDAR (Light Detection And Ranging) over a smaller portion of the study area was used as a measure of light availability for herbaceous vegetation. Plant community groups examined across the CSNM include both naturally open areas such as meadows and grasslands, and areas influenced by canopy-disturbing management activities such as timber harvest, non-conifer scarification, and fire.

The estimation of effects from past management activities on interspersed private lands was complicated by an incomplete inventory of management activities and the resulting changes in vegetation structures. The following strategies were adopted to overcome these difficulties: 1) use of landscape-wide, GIS-derived variables as surrogates to livestock use and road influence; 2) analyses at different spatial scales to accommodate the differential availability of data across intermingled land ownership versus data available only on public lands; and 3) analyses of patterns of weed distribution relative to individual variables of interest. GIS derived variables representative of management activities across all land ownerships included distance from existing roads (in increments of 100 m), distance from perennial water (in increments of 100 m) as a surrogate for livestock utilization around water availability, and change detection in satellite imagery-derived canopy closure (1972-2000) within conifer ecological sites as identified by Natural Resources Conservation Service (NRCS) soil surveys (USDA 1988) (Table 1). The canopy cover difference grid was acquired from Conservation Biology Institute and World Wildlife Fund.

Other variables defining management activities, but of more limited spatial extent included: 1) a compilation of annual livestock utilization mapping (1981 to 2004) to create a synoptic map of average and maximum utilization (see Hosten et al. 2007b for full description), and a map indicating number of years since last grazed; 2) vegetation structure; and 3) a compilation of non-conifer management activities identified from aerial photos, oblique photos of past management activities, archived documents, and the extant Range Improvements Database administered by the Bureau of Land Management. A GIS library of grids representing all data variables (response and predictors) was created at a 30m x 30m resolution to form the basis for all analyses.

## Data Analysis

Predictive variables of interest were analyzed individually and collectively to assess their association with response variables representing weed abundance. Graphic portrayal and statistical analysis of individual variables is useful for understanding differences in weed species biology, whereas multivariate techniques provide inference about the association of weed abundances with environmental and management factors in the context the larger landscape. The variable quality of weed surveys across public and private lands necessitated separate analyses with and without private lands.

### Analysis using Individual Variables

Individual variables were analyzed by counting the number of weed populations by class for key categorical variables for comparison to expected weed counts. Expected weed counts were calculated by class and based on total weed count multiplied by the proportion of class area to total area. Actual and expected weed counts were compared graphically and subjected to chi-square analysis for statistical significance. Significance was determined at a probability level of 0.1, using a Bon-Feroni adjustment for the number of variables examined.

### Multivariate Analysis

HYPERNICHE (McCune 2006) was used to explore the response of yellow starthistle and Canada thistle to the range of predictor environmental factors, vegetative descriptors, and management activities prevalent across the CSNM. Nonparametric Multiplicative Regression

(NPMR) was used to derive best-fit models describing the pattern of the above defined response variables relative to predictor variables. The Local Mean form of the NPMR regression enables the incorporation of binary or quantitative data. The modeling process includes an initial screening for variables of interest followed by an exhaustive modeling approach. As the number of predictor variables increases, a stepwise search is initiated. All predictor variables are assessed in one-variable models to determine the best one-variable model. Additional variables are added stepwise, assessing improvement at each step. This approach evaluates all possible combinations of predictors and tolerances.

In addition to identifying important variables, the modeling process provides several measures for assessing importance of individual variables and overall model quality. When a response variable is declared as quantitative, model quality is evaluated in terms of the size of the cross-validated residual sum of squares in relation to the total sum of squares. The HYPERNICHE manual calls this the "cross $r^2$" ($xr^2$) because the calculation incorporates a cross validation procedure. The $xr^2$ value is a measure of variability captured by the best fit model.

Sensitivity analysis provides a measure of the relative importance of individual quantitative predictors in NPMR models. The sensitivity measure used here refers to the mean absolute difference resulting from nudging the predictors, expressed as a proportion of the range of the response variable. The greater the sensitivity, the more influence that variable has in the model. With this sensitivity measure, a value of 1.0 implies a change in response variable equal to that of change in a predictor. A sensitivity of 0.5 implies that the change of response variable magnitude is half that of the predictor variable. A sensitivity of 0.0 implies that nudging the value of a predictor has no detectable effect on the response variable.

NPMR models can be applied in the same way that traditional regression models are used (McCune 2006). A major difference is that estimates from the model require reference to the original data. Three-dimensional plots of select predictor and response variables provide a visual assessment of how the relationship of predictor variables to response variables. The modeling approach as utilized by HYPERNICHE works well with variables defined in GIS as ASCII grids, allowing the formulation of probability estimate maps for response variables.

Since HYPERNICHE does not accommodate for spatial autocorrelation (MJM Software 2004), it remains for the user to ensure that results are not constrained by the pattern of observations. Since weed locations were found to be spatially auto-correlated (ARCGIS 9), data was further examined in the context of the range of occurrence of all observations, as well as across the monument landscape by resampling. Random resampling of weed density and environmental allowed the creation of a dataset with independent points, thus overcoming problems with autocorrelation.

## Results

### Description of Weed Abundance by Individual Variables at actual weed locations

Topographic Variables. A scattergram of heat load (Figure 1) (encompassing slope and aspect) by elevation indicates that yellow starthistle and Canada thistle occupy the same range of values for heat load, but favor different elevations. Canada thistle is generally restricted to elevations higher than 1300 meters, while yellow starthistle is found below this delineation.

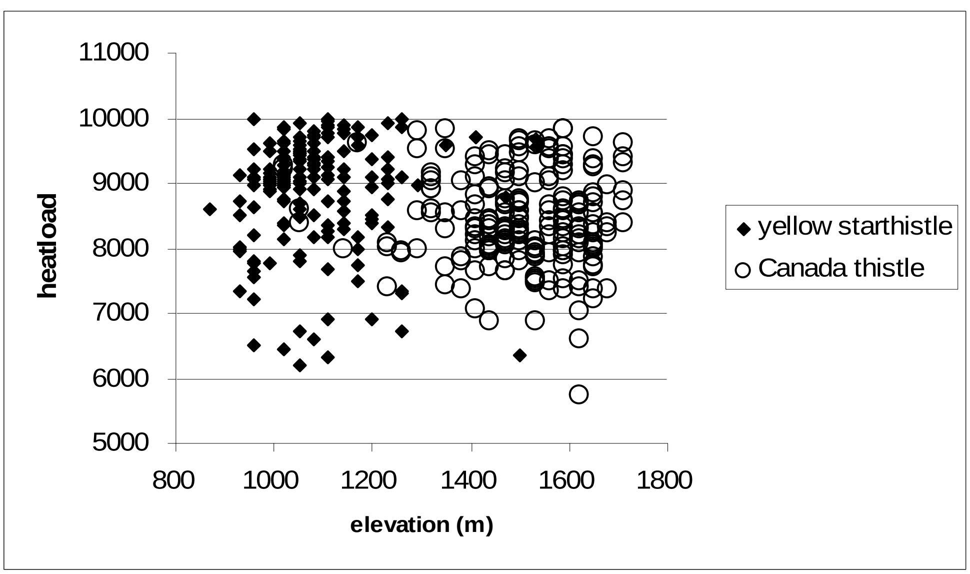



**Figure 1. Heat load by elevation for actual Canada thistle and yellow starthistle locations.**

## Edaphic Factors

All edaphic factors were significant at probability level of 0.1 using chi-square analysis. Yellow starthistle was found across a wide range of soil textures, while Canada thistle occurred in locations with lower clay composition (Figure 2a and b). Yellow starthistle was found to be more abundant on vertisols(Figure 3a and b).

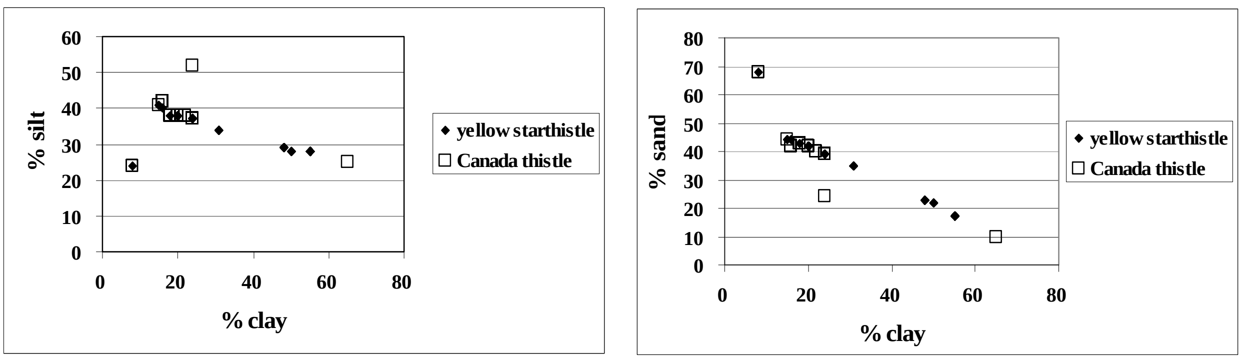



**Figure 2. Percent silt by percent clay (a), and percent sand by percent clay (b).**

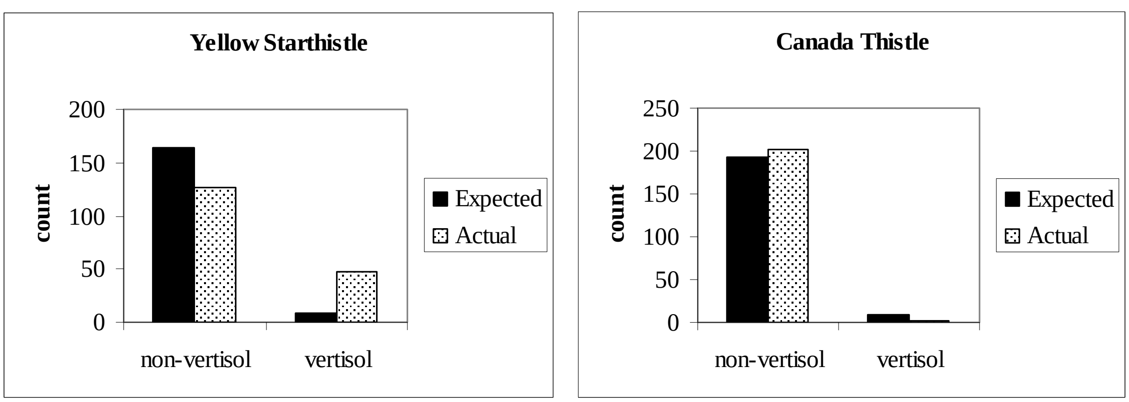



**Figure 3. Actual and expected counts of Yellow starthistle (a) and Canada thistle (b) within vertisol and non-vertisol classified soils.**

Biotic Factors

All biotic factors were significant at the probability level of 0.1 using chi-square analysis. An examination of rangeland versus forest ecological sites as defined by the NRCS surveys (Figure 4) shows Canada thistle occupying conifer sites, and yellow starthistle favoring non-conifer communities.

An examination of actual versus expected counts for Canada thistle and yellow starthistle for coarse plant communities derived from NRCS potential vegetation indicates that yellow starthistle is found in higher than expected levels in grasslands, shrublands and woodlands (Figure 5). Canada thistle is found in higher than expected counts in mixed conifer and semi-wetlands, but not grasslands, shrublands, woodlands, or white fir communities (Figure 5).

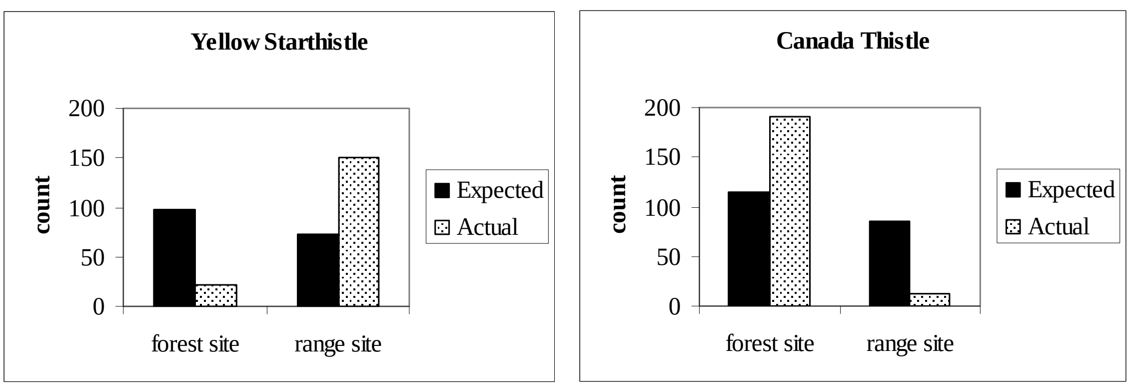



**Figure 4. Actual and expected counts of yellow starthistle (a) and Canada thistle (b) within forest versus range sites.**

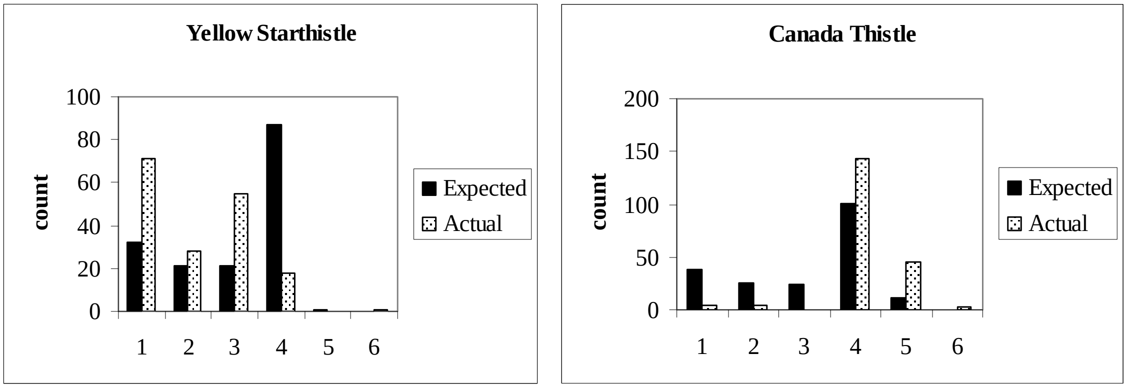



**Figure 5. Actual and expected counts of Yellow starthistle (a) and Canada thistle (b) within coarse plant communities derived from NRCS potential vegetation** (1=grasslands, 2=shrublands, and 3=woodlands, 4=mixed conifer, 5=semi wetlands, 6=white fir).

Management Factors

All management factors, except change in forest cover, showed significant difference between actual and expected values at the probability level of 0.1 using chi-square analysis. Actual counts of Canada thistle (Figure 6b) are higher than expected in moderate to high areas of maximum livestock utilization, but lower than expected in areas of low to moderate use. Yellow starthistle shows higher actual than expected population counts for both severe livestock use and no use (Figure 6a), indicating that several factors may be responsible for its distribution and abundance. This pattern of weed population abundance by livestock utilization is similar for the average utilization classes (Figure 7a and b).

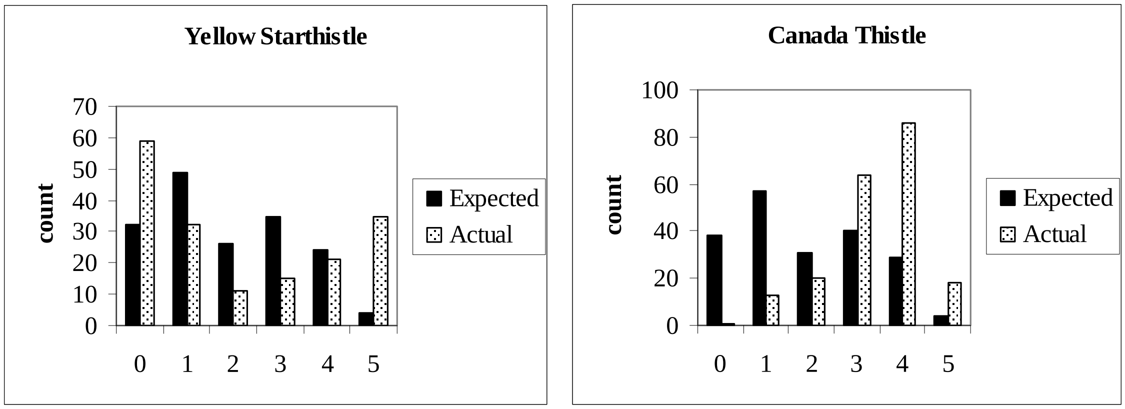



**Figure 6. Actual and expected counts of Yellow starthistle (a) and Canada thistle (b) within maximum utilization classes** (0 = no use, 1 = slight use, 2 = light, 3 = moderate use, 4 = heavy use, 5 = severe use).

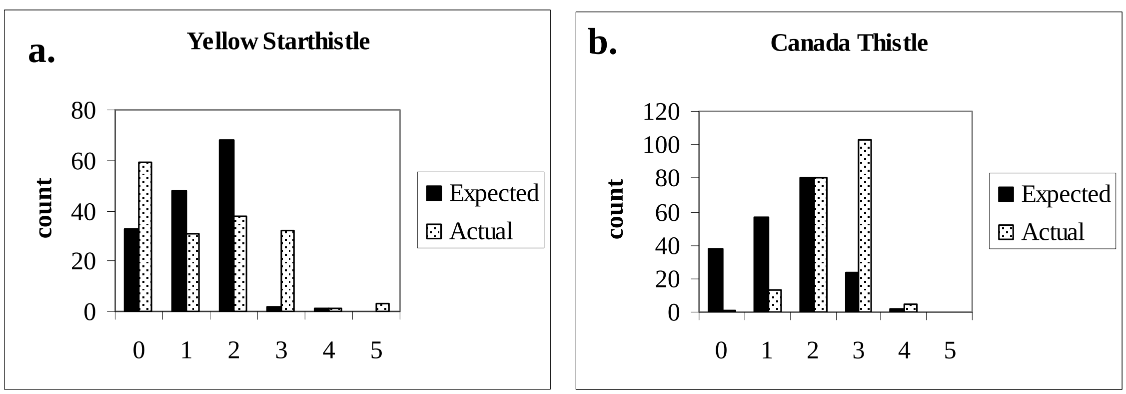



**Figure 7. Actual and expected counts of Yellow starthistle (a) and Canada thistle (b) within average utilization classes** (0 = no use, 1 = slight use, 2 = light, 3 = moderate use, 4 = heavy use, 5 = severe use).

Canada thistle is very strongly associated with distance from water (Figure 8b), while yellow starthistle is generally located further from water (Figure 8a). The higher actual than predicted abundance at mid-ranges and furthest distance from water increments indicates that factors other than proximity to water play a role in the distribution of yellow starthistle.

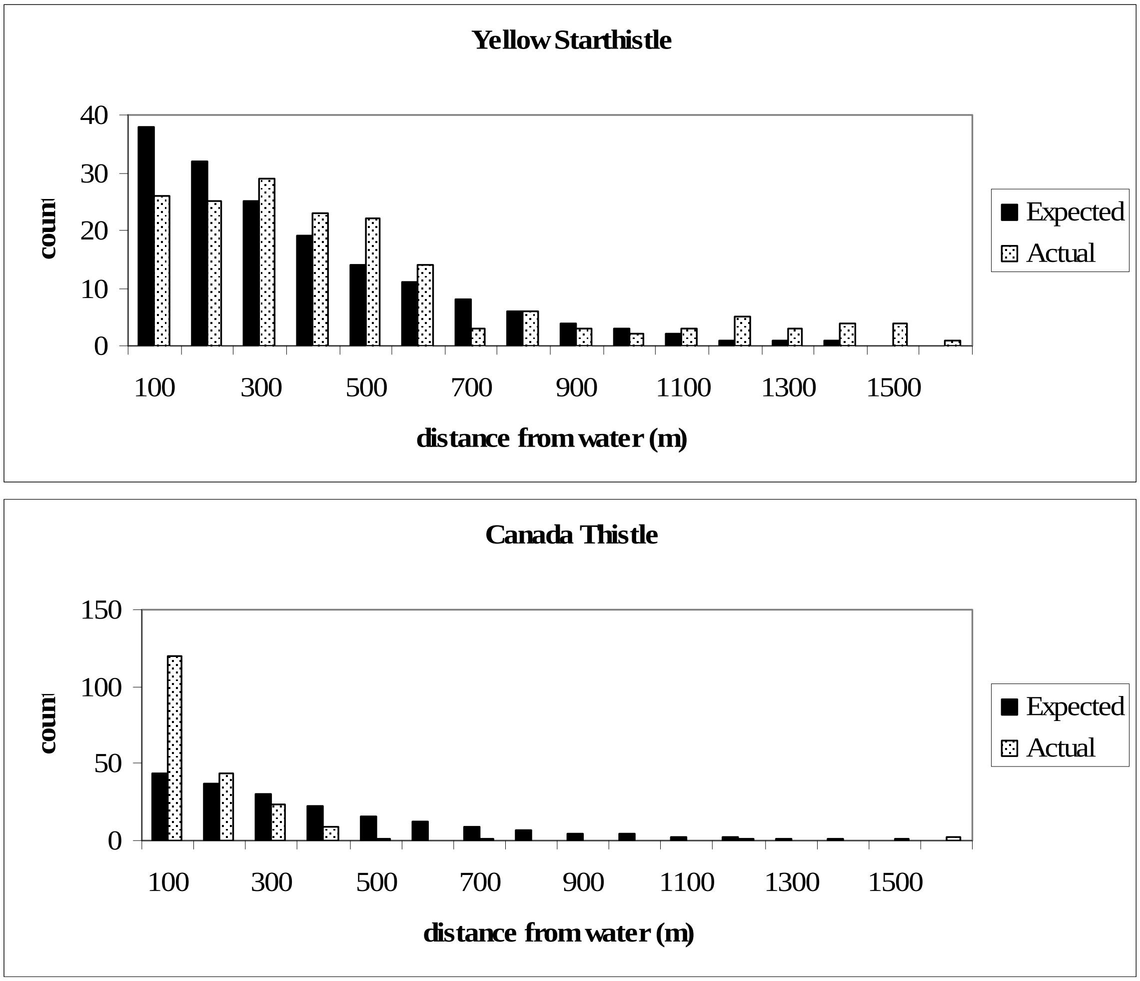
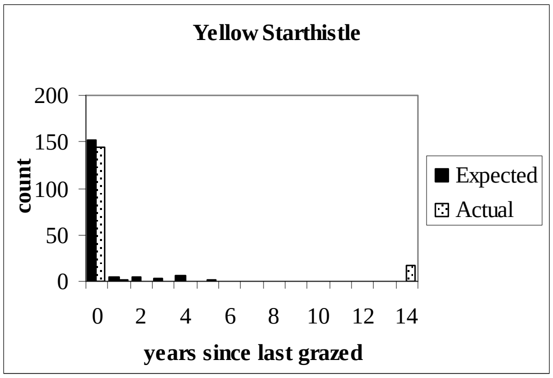



**Figure 8. Actual and expected counts of Yellow starthistle (a) and Canada thistle (b) within distance increments from water sources.**

Results are less clear [though still statistically significant] when relating weed abundance to time elapsed since last grazing disturbance (Figure 9). While Canada thistle population counts appeared higher then expected in currently grazed areas, yellow starthistle showed higher than expected counts for areas that were ungrazed for 14 years. Yellow starthistle and Canada thistle show much higher actual than expected population counts in distance increments closest to roads (Figure 10a and b). The varied weed abundance with distance from roads in the histogram for yellow starthistle (Figure 10a) indicate that other factors may play a role in its distribution.



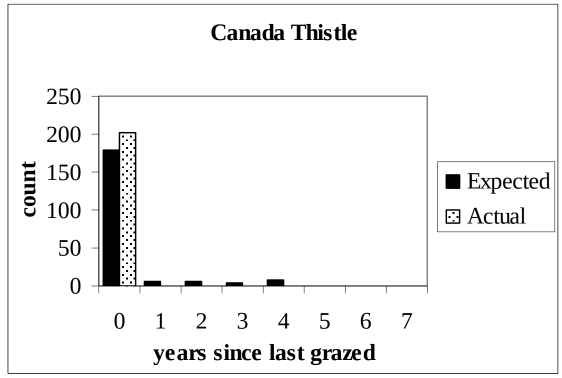
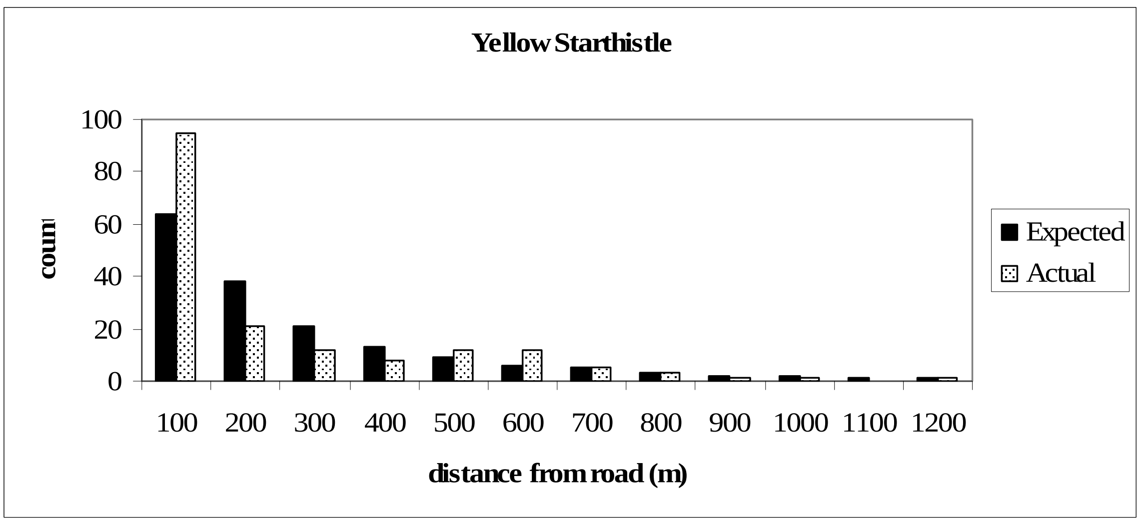



**Figure 9. Actual and expected counts of Yellow starthistle (a) and Canada thistle (b) within areas of differential rest from livestock use.**



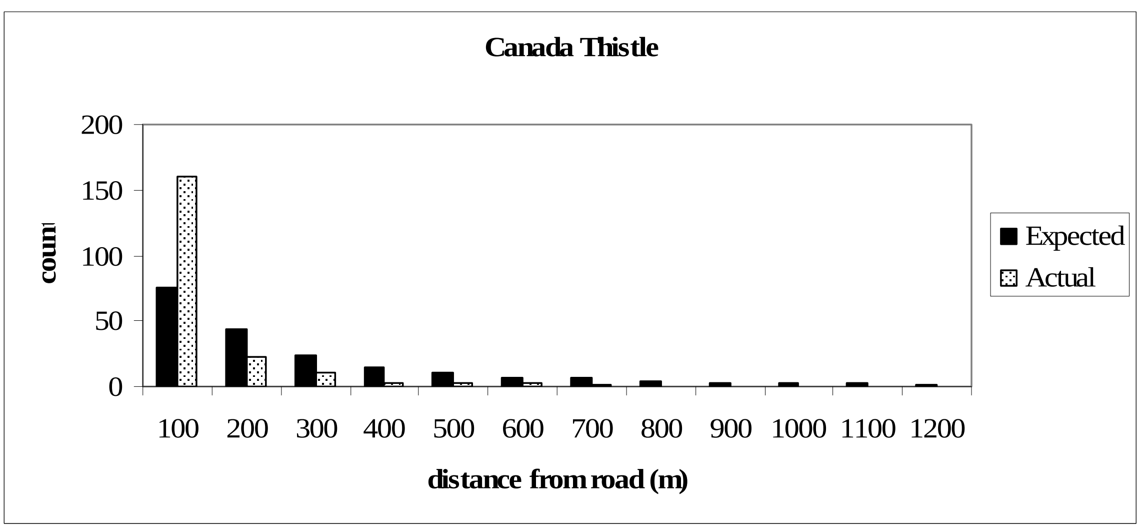



**Figure 10. Actual and expected counts of Yellow starthistle (a) and Canada thistle (b) within 100 meter increments from roads.**

Higher actual than expected counts of yellow starthistle in areas disturbed by non-conifer vegetation manipulation (Figure 11 a and b) including seeding, tilling, scarification, and restoration following fire.

Areas logged in the last 30 years harbor more Canada thistle than less disturbed habitats. Both Canada thistle and yellow starthistle show increased abundance of actual population counts over expected counts in areas where change in canopy cover indicates disturbance (Figure 12 a and b).

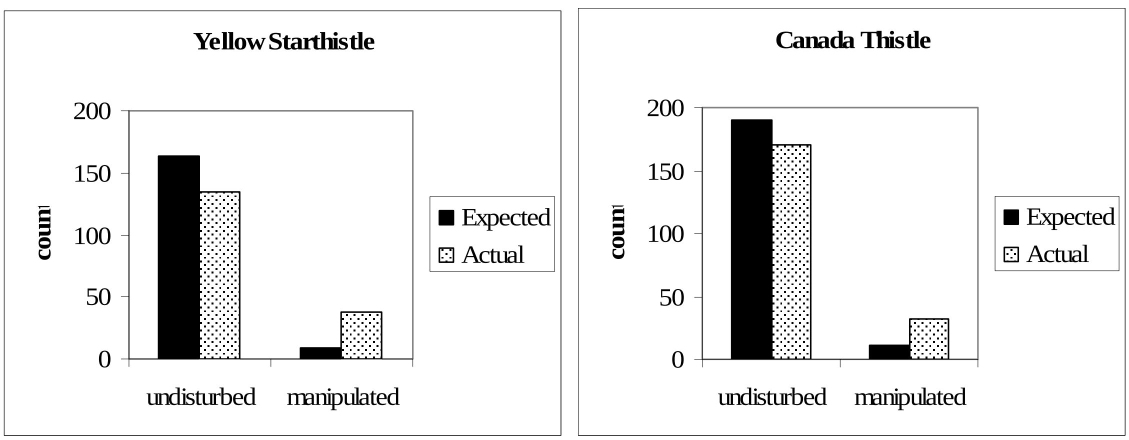



**Figure 11. Actual and expected counts of Yellow starthistle (a) and Canada thistle (b) within areas of non-conifer vegetation manipulation and undisturbed areas.**

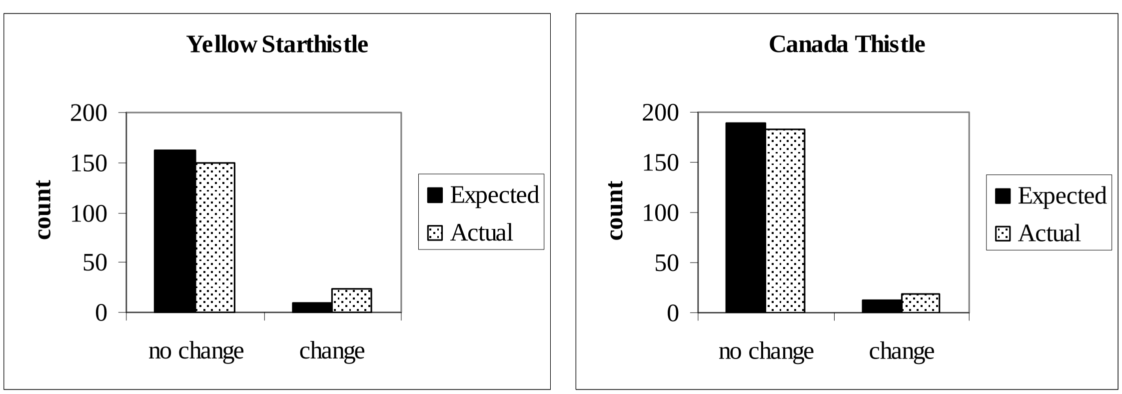



**Figure 12. Actual and expected counts of Yellow starthistle (a) and Canada thistle (b) within satellite derived areas of no-change and change in canopy cover.**

In surveys determining forest structure, yellow starthistle was associated with non-conifer communities (Figure 13a). Of the range of structural classes within conifer communities, Canada thistle was found at counts greater than expected in pole stands associated with ecological sites with a history of disturbance, and less than expected in old growth and late-seral conditions.

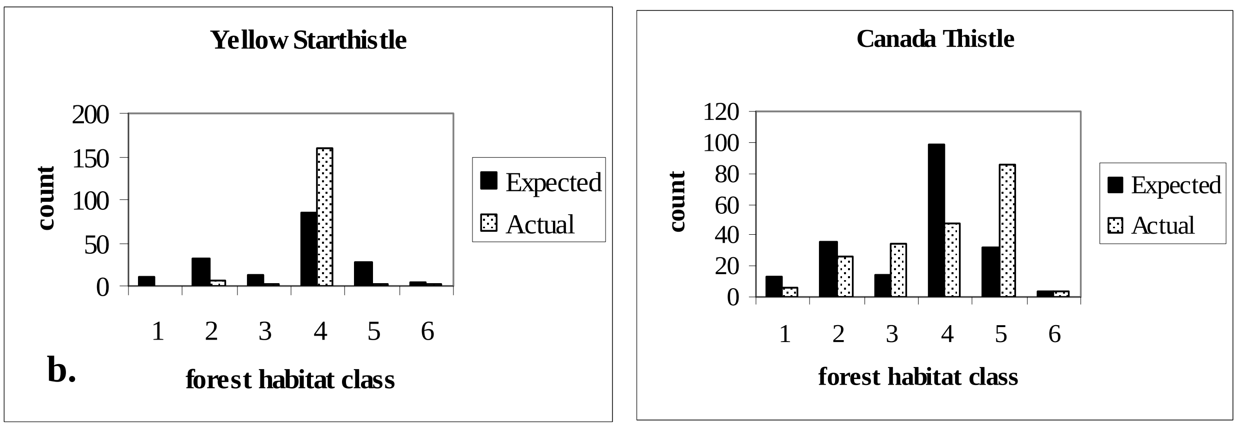



**Figure 13. Actual and expected counts of yellow starthistle (a) and Canada thistle (b) by forest habitat class** (1 = large trees, greater than 60% canopy cover, and multiple canopy layers; 2 = greater than 60% canopy cover, single layer structure; 3 = less than 40% canopy cover due to disturbance; 4 = non-conifer plant community; 5 = canopy cover greater than 40%, and a history of disturbance; 6 = canopy cover greater than 40% but with natural conditions preventing the development into habitat class 1 or 2).

## The Multivariate Approach

Non-parametric Multiplicative Regression considers one-variable models as an initial assessment of individual variables submitted to the modeling effort. The derived $xr^2$ values for the one variable models serve as a measure of relative importance for the datasets examined (Table 2). Regression coefficients can be compared between individual variables derived from the regression of data intercepted at the actual weed population locations versus randomly located points within public lands only, or the combination of public and private lands.

The magnitude of $xr^2$ values indicated that the relative importance of topographic and soil variables in comparison to management and other factors was identical for yellow starthistle and Canada thistle as derived from the interception of actual weed population locations with predictive data represented in GIS. The $xr^2$ values for individual variables derived at random locations followed the same pattern, with few exceptions: the $xr^2$ values were lower by an order of magnitude; yellow starthistle showed an elevated $xr^2$ value for vegetation cover and maximum utilization; and percent silt played a role in the distribution of Canada thistle.

**Table 2. $xR^2$ values for individual variable models derived from actual weed locations and random intercepts of weed population density maps (sorted by $xr^2$ value for yellow starthistle? actual locations).**

| **Predictor Variable** | **Cross $r^2$ values ($xr^2$)** | | | |
|---|---|---|---|---|
| | **Actual locations** | | **Random locations** | |
| | Yellow | Canada | Yellow | Canada |
| Elevation | 0.7 | 0.75 | 0.0605 | 0.1108 |
| Soil depth | 0.52 | 0.62 | 0.0382 | 0.326 |
| Maximum utilization | 0.32 | 0.32 | 0.0461 | 0.065 |
| Woody vegetation cover | 0.32 | 0.33 | 0.0734 | 0.0321 |
| % clay | 0.29 | 0.31 | 0.0337 | 0.0687 |
| % silt | 0.29 | 0.3 | 0.0339 | 0.2753 |
| Average utilization | 0.27 | 0.27 | 0.0032 | 0.0822 |
| Distance from water-source | 0.27 | 0.29 | -0.0034 | 0.0513 |
| % sand | 0.17 | 0.18 | 0.0322 | 0.0265 |
| Heatload | 0.14 | 0.16 | 0.0035 | 0.0192 |
| Distance from roads | 0.08 | 0.09 | -0.0032 | 0.0253 |
| Years of rest | 0.01 | 0.03 | -0.0017 | -0.0019 |

Models for Canada Thistle

The best-fit models across data extent, quality, and intercept type (weed locations versus random points) emphasized environmental variables followed by variables defining management impacts (Table 3). Elevation and soil depth were the most consistently included variables defining the environment whereas measures of maximum utilization and distance from water as a utilization surrogate were the most consistent variables defining past management. Soil texture was only incorporated in the model examining public and private lands at randomized locations. Models derived from data intercepted at the weed locations (and therefore spatially auto-correlated) included a measure of vegetation classification. Distance from roads was incorporated in the models defined for public lands and weed locations as well as public and private lands for random points. The optimal model for Canada Thistle with the most consistent weed surveys (across public lands) and with predictive variables defined from randomly located points included heat load and non-conifer treatments in addition to elevation, soil depth, and maximum utilization.

**Table 3. Variables retained for predicting Canada thistle presence/density for variable data extents and quality. Shading represents optimal data quality for random points located across the landscape.**

| | **Weed locations** | **Random points (Optimal Model)** |
|---|---|---|
| **Public** | Elevation<br>Soil depth<br>% silt<br>% sand<br>Woody cover change<br>Woody vegetation cover<br>Maximum utilization<br>Distance from water<br>[$R^2$ = 0.9085] | Heat load<br>Elevation<br>Soil depth<br>Maximum utilization<br>Non-conifer treatments<br>[$R^2$ = 0.5249] |
| **Public and Private** | Elevation<br>Soil depth<br>% clay<br>% silt<br>NRCS ecological type<br>Woody vegetation cover<br>Distance from water<br>Distance from roads<br>[$R^2$ = 0.8005] | Elevation<br>Soil depth<br>% clay<br>% silt<br>% sand<br>Distance from water<br>Distance from roads<br>[$R^2$ = 0.4544] |

While tolerance and sensitivity of the variables was provided for models derived from actual and randomly located intercepts, these values are only described for the latter (Table 4). Tolerance (a measure of whether or not a variable is of local or global significance) appeared inversely related to sensitivity for Canada thistle. While heat load showed the greatest tolerance, it was also the least sensitive in terms of the magnitude of increase in predictor with a small change in value. Maximum utilization showed a smaller tolerance, but the greatest sensitivity.

Elevation and soil depth were intermediate in tolerance and sensitivity. A comparison of expected and actual weed population counts provided a more detailed examination of categorical data.

**Table 4. Tolerance and sensitivity of variables incorporated within models of Canada thistle distribution across public lands of the CSNM. Tolerance and sensitivity were calculated for quantitative data (Q), but not for categorical data (C).**

| **Canada thistle actual locations** | | | | **Canada thistle random locations** | | | |
|---|---|---|---|---|---|---|---|
| **Name** | **Type** | **Tol,%** | **Sensitvity1** | **Name** | **Type** | **Tol,%** | **Sensivity1** |
| Elevation | Q | 15 | 0.2229 | Heatload | Q | 30 | 0.02 |
| Soil depth | Q | 35 | 0.0274 | Elevation | Q | 20 | 0.0724 |
| % silt | Q | 50 | 0.0046 | Soil depth | Q | 15 | 0.0948 |
| % sand | Q | 15 | 0.0293 | Maximum utilization | Q | 10 | 0.1068 |
| Woody vegetation change | C | 0 | | Non-conifer treatments | C | | |
| Woody vegetation cover | Q | 20 | 0.1114 | | | | |
| Maximum utilization | Q | 30 | 0.0471 | | | | |
| Distance from water | Q | 10 | 0.1628 | | | | |

<u>Models for Yellow Starthistle</u>

As with Canada thistle, derived models predicting weed presence/density of yellow starthistle (Table 3) favored the environmental variables of elevation over variables representing management. Elevation and current cover by woody vegetation were incorporated in all models. The environmental variables of soil depth and texture were represented in all models except the optimal model minimizing the variable weed survey quality and spatial autocorrelation (model for public lands) using data intercepted from randomly located points. All models incorporated a measure of livestock utilization (distance from water or average utilization, or maximum utilization) except for the model examining the pattern of weeds across public and private lands using the actual weed locations. Models examining data derived from random locations incorporated non-conifer treatments. In addition to elevation and cover by woody vegetation, the optimal model also incorporated NRCS ecological type, classification as vertisol soils, measures of utilization (by livestock and wildlife), and measures of disturbance (conifer and non-conifer treatments).

**Table 5.Variables retained for predicting yellow starthistle presence/density for variable data extents and weed survey quality. Shading represents optimal data quality for random points located across the landscape.**

| | **Weed locations** | **Random points (Optimal)** |
|---|---|---|
| **Public** | Elevation<br>Soil depth<br>% clay<br>% sand<br>Woody vegetation cover<br>Maximum utilization<br>Years of rest<br>Distance from water<br>[$R^2$ = 0.8491] | Elevation<br>Vertisol soil<br>NRCS ecological type<br>Woody vegetation cover<br>Maximum utilization<br>Average utilization<br>Non-conifer treatments<br>[$R^2$ = 0.5865] |
| **Public & Private** | Elevation<br>Soil depth<br>% clay<br>% sand<br>Woody vegetation cover<br>Distance from roads<br>[$R^2$ = 0.7068] | Elevation<br>Soil depth<br>% silt<br>% sand<br>Conifer cover change<br>Woody vegetation cover<br>Distance from water<br>Non-conifer treatments<br>[$R^2$ = 0.3492] |

For yellow starthistle, elevation showed the highest sensitivity while exhibiting moderate tolerance. Measures of utilization (maximum and minimum) showed a sensitivity lower by an order of magnitude. The tolerance for average utilization was greater than for maximum utilization.

**Table 6. Tolerance and sensitivity of variables incorporated within models of yellow starthistle patterning across public lands of the CSNM. Tolerance and sensitivity were calculated for quantitative data (Q), but not for categorical data (C).**

| **Yellow Starthistle Actual Locations** | | | | **Yellow Starthistle Random Locations** | | | |
|---|---|---|---|---|---|---|---|
| **Name** | **Type** | **Tol,%** | **Sensitivity1** | **Name** | **Type** | **Tol,%** | **Sensivity1** |
| Elevation | Q | 15 | 0.2392 | Elevation | Q | 25 | 0.0217 |
| Soil depth | Q | 15 | 0.083 | Vertisol soil | C | | |
| % clay | Q | 50 | 0.004 | NRCS ecological type | C | | |
| % sand | Q | 5 | 0.2649 | Woody vegetation cover | C | | |
| Woody vegetation cover | Q | 35 | 0.0501 | Maximum utilization | Q/C | 5 | 0.0047 |
| Maximum utilization | Q/C | 25 | 0.1034 | Average utilization | Q/C | 40 | 0.002 |
| Years of rest | Q | 40 | 0.0095 | Non-conifer treatments | C | | |
| Distance from water-source | Q/C | 10 | 0.217 | | | | |

## Discussion

### Analysis of Individual Variables

Comparison of actual and expected weed population counts (graphic analysis and chi-square tests) to the range of values for individual predictor variables indicated that actual weed population counts responded to topographic, edaphic, biotic and management factors. However, variation of actual weed counts were not always uniform with individual predictor variables, indicating possible interactions between predictor variables. The complexity of interacting variables confounds attempts to assign importance of individual variables in the expression of weed abundance, necessitating a multivariate approach.

### Multivariate Analysis

The models examining patterns of noxious weeds across public and private lands, disparate weed survey quality for models using actual versus randomized weed locations were consistent in identifying elevation as an important physical environmental factor describing yellow starthistle and Canada thistle distribution. Soil texture (identified by the incorporation of percent sand, silt, or clay) and the presence of montmorilinitic (shrink-swell) clays indicate that soil type and its inherent characteristics played an important role in their invasability by noxious weeds. The shrink-swell clays likely confer an endogenous disturbance favoring weed establishment and persistence. Cover was included directly as a variable of importance for yellow starthistle. Disturbance factors influenced the distribution of both Canada thistle and yellow starthistle across the CSNM. Both forest structure and woody vegetation cover changed as indicators of logging showed a facilitation of Canada thistle by past timber harvest practices. Non conifer vegetation manipulation (principally scarification, and tilling and seeding) favored both Canada thistle and yellow starthistle. Measures of forage utilization (utilization as well as distance from water) implicated livestock and wildlife in the facilitation of noxious weeds across the monument landscape.

While distance from roads was left out of the final model, this does not negate the biological significance of roads in the process of weed invasion. Indeed, isolated weed populations are found throughout the CSNM within 100 meters of the road. Associated studies suggest that roads link riparian areas and create movement corridors for livestock and wildlife resulting in an association of roads, riparian areas and forage utilization (Hosten et al. 2007 b).

The relative fit of the models to the data as measured by the $r^2$ values reflected the varying quality of weed surveys and spatial auto-correlation of the individual weed locations. The $r^2$ values for data derived from the actual weed locations were higher than those for randomized points, reflecting the spatial autocorrelation of the weed locations. Furthermore, the lower $r^2$ for models including private lands likely reflected the higher uncertainty of prediction due to poorer quality weed surveys and knowledge of past management activities on private lands, as well as greater variability associated with examining a larger landscape.

## CONCLUSIONS

Yellow starthistle and Canada thistle have different ecological requirements, as evident in the comparison of their responses to environmental and biotic variables such as coarse plant community, vertisol soil, NRCS ecotype, elevation, and forest type. However, variables reflecting management activities (maximum utilization, average utilization, distance from roads, and non conifer disturbance) reflect similar responses between the two species. This suggests that regardless of habitat requirements or ecological niche, both species of invasive weeds take advantage of anthropogenic disturbances.

Univariate and multivariate analyses implicate topography (elevation, slope and aspect as incorporated in a heat load term), soil (soil texture and depth, presence of shrink-swell clays), vegetation characteristics (cover, and plant community type), past management activities, road network, and ongoing grazing by livestock in the distribution pattern of Canada thistle and yellow starthistle across the CSNM. Weeds were generally found in moderate to severe use areas. Decrease in livestock utilization levels and recovery of woody vegetation within high forage utilization zones may reduce weed establishment and persistence.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