A Vegetation Inventory of Disturbed Areas on the Kenai National Wildlife Refuge

Report: An inventory of vegetation on disturbed areas of Kenai National Wildlife Refuge

David T. Barnett and Sara E. Simonson

Natural Resource Ecology Lab, Colorado State University, Fort Collins, CO 80523 ph: 970.491.2302, email: barnett@nrel.colostate

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INTRODUCTION

The global redistribution and impact of plant species has been documented and studied for many years (Elton 1958). Consensus that species richness declined with increasing latitude and associated environmental factors (Huston 1979, 1994, and Rosenzweig 1992,1995) lead to the assumption that non-native plant species followed similar patterns. Consequently areas with lower plant species richness, productivity, and non-native propagule pressure were thought to be at less risk of invasion (Conn et al. 2004). Despite these assumptions, casual observation, inventory, and rigorous research provided evidence that Alaska is not immune to plant invasion, which generated concern and action.

The Alaska Committee for Noxious and Invasive Plant Management crafted *The Strategic Plan for Noxious and Invasive Plant Management in Alaska* in 2001, and a multitude of agencies and organizations have undertaken efforts to increase awareness and coordination of invasive plant management and research. The Alaska Natural Heritage Program has created a ranking system to help managers prioritize the fast-growing list of invasive plant species in the state. An interagency group created a system to manage regional invasive plant species information that can be an invaluable tool for early detection of at multiple spatial scales (AKEPIC). The compilation of existing information indicates that the plant invasion is escalating yet seems to be generally limited to areas associated with anthropogenic disturbance (Fig. 1).

The distribution of invasive plant records in the AKEPIC database is indicative of the invasive plant species awareness and inventory on the Kenai Peninsula and the Kenai National Wildlife Refuge (Fig. 1). Under the Forest Inventory and Analysis Program

(FIA), the National Forest Service maintains a series of systematically placed monitoring plots across all forested areas of the United States (Frayer and Furnival 1999). In 2002, the FIA completed sampling at 175 locations on a 4.8-km grid across forested parts of the Refuge. The Refuge extended the grid sampling to non-forested sites, adding 152 points for a total of 327 sampled locations (Fig. 2). Collectively these plots create a mechanism to monitor multiple biological resources of the Refuge (Long Term Ecological Monitoring Protocal, LTEMP). Analysis of this information suggests that the Refuge is generally uninvaded: just under 4% of these plots contained any non-native plant species.

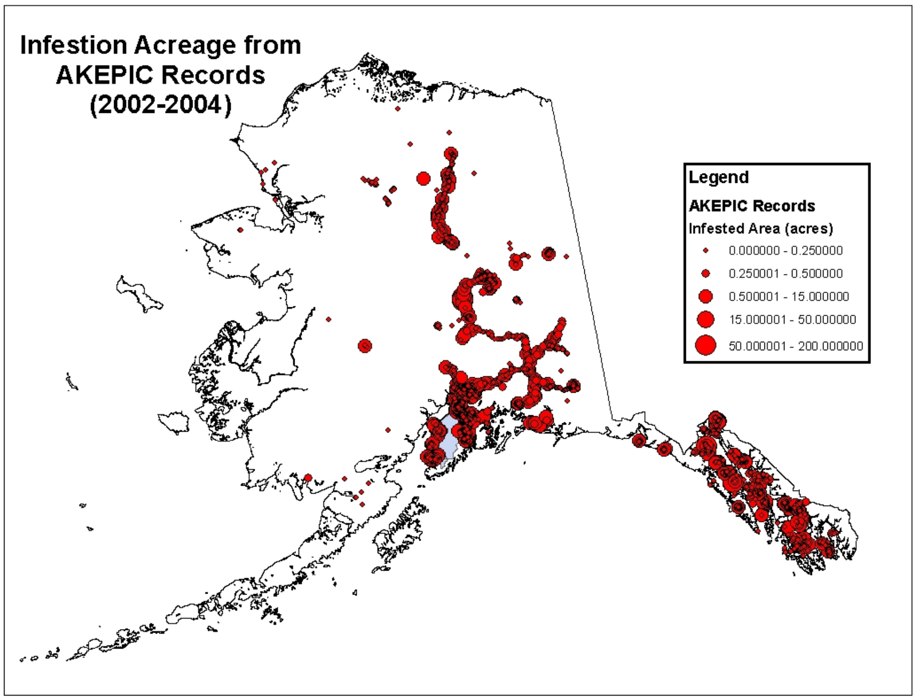


Figure 1. Records of invasive plant species invasion in the AKEPIC database (from C. R. Slemmons. 2005. Survey of Exotic, Invasive and Noxioius Flora: Kenai National Wildlife Refuge. Kenai National Wildlife Refuge Report.).

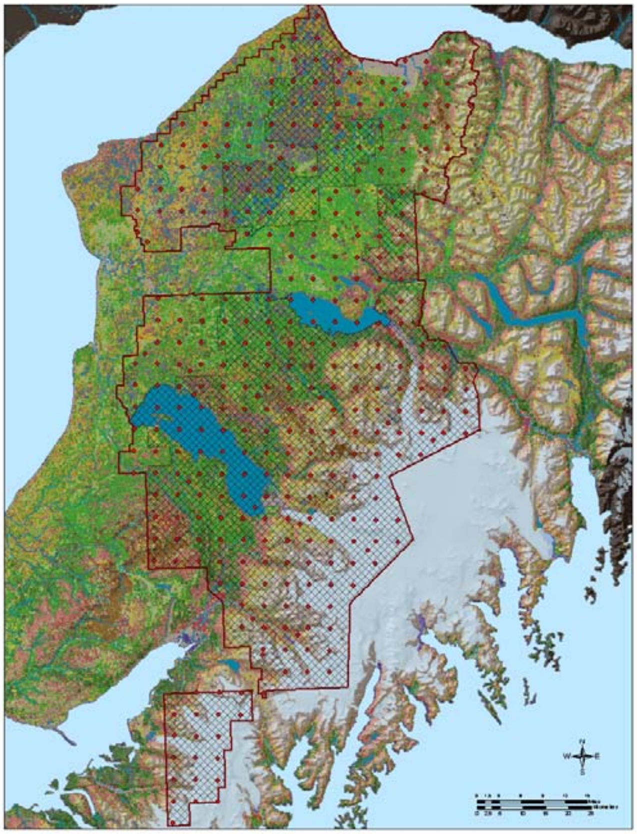


Figure 2. Distribution of the LTEMP grid on the Kenai National Wildlife Refuge (from Morton, J. 2004. Long Term Ecological Monitoring Program, Vegetation Sampling Protocaols. Kenai National Wildlife Refuge.).

An understanding that a systematic inventory undersamples rare landscape features (Legendre and Fortin 1989) and evidence of invasion of disturbed areas surrounding the Refuge (Fig. 1) prompted an inventory of anthropogenically disturbed Refuge areas in 2005 with help from the Volunteer Invasive Weed Mapping Project administered by The National Wildlife Refuge System Invasive Species Program. The goal was to compile species lists and establish a baseline distribution of non-native plant species on the Refuge. Covering a great deal of the disturbed landscape (belt transects perpendicular to linear features and timed searches of campgrounds and oil wells) the inventory detected 41 non-native plant species and provided some idea of where the plant invasion is most severe (Fig. 3, Table 1). While the distribution information is valuable, the methods did not provide data that are truly comparable across disturbance types

(Table 1), or the undisturbed landscape (Fig. 2). Neither are they useful for monitoring change in species composition and cover over time (Stohlgren et al. 1998; Barnett et al. 2007). Like many investigations of natural landscapes, the 2005 inventory and the information from the LTEMP grid-based plots provided information but also generated new questions.

Table 1. Anthropogenic footprint types and non-native plant species invasion from 2005 inventory.

Disturbance	Number of searches	Cumulative non-native plant species richness	Average Cover of non-native plant species/search
Access point	2	3	21
Building	7	8	19
Campground	28	28	30
Oil/Gas well	49	31	36
Road	139	26	17
Seismic lines	9	11	10
Trail	27	22	8
Transfer station	2	2	15

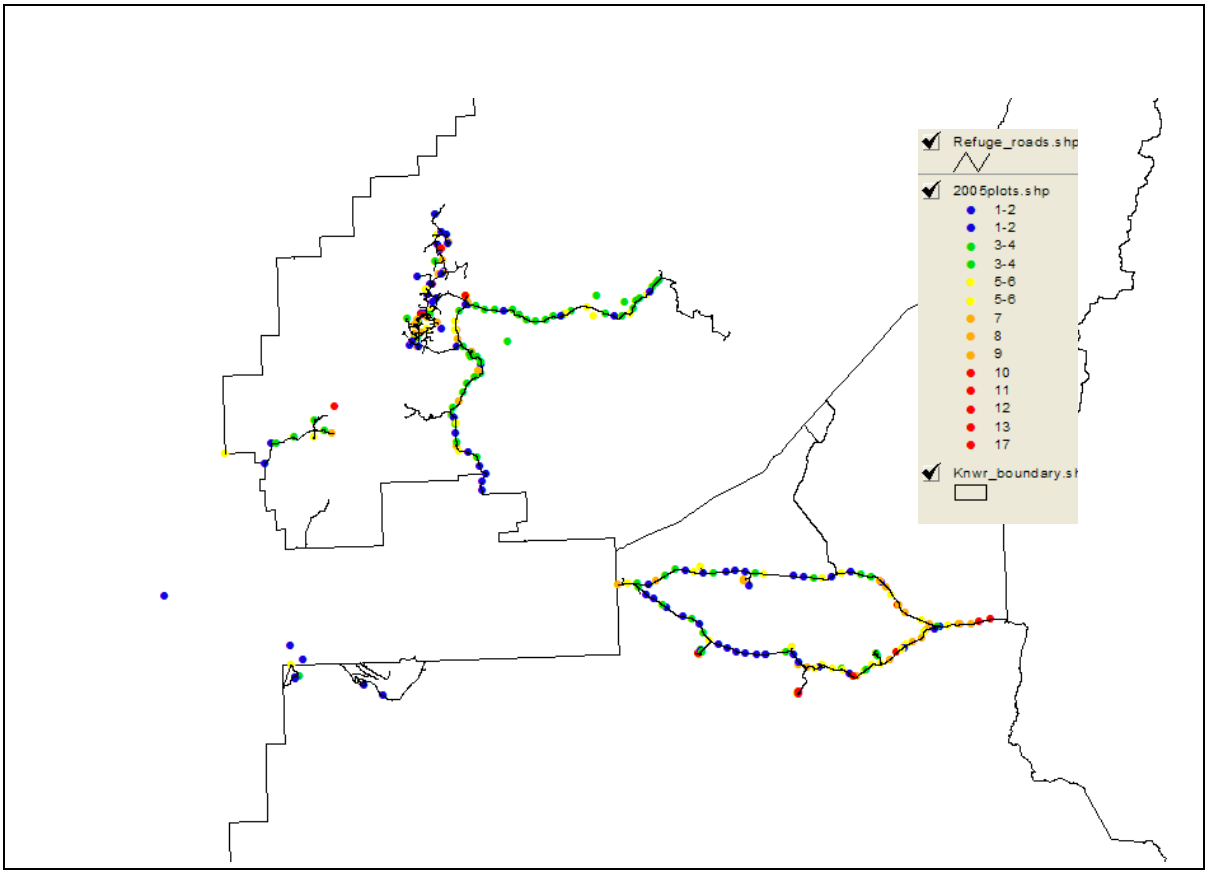
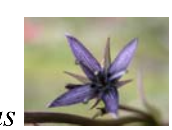


Figure 3. Non-native plant species distribution as sampled in 2005.

The summer of 2006 provided a chance address some of these questions and provided the following goals:

- Provide an unbiased description of invasion across different anthropogenic disturbance types.
- Establish a set of vegetation plots comparable to plots across the undisturbed landscape (LTEMP), and that could be used to monitor vegetation on the disturbed landscape over time.
- Evaluate non-native plant species establishment across temporal variability of seismic lines used for oil and gas exploration.
- Evaluate spread of invasion from disturbed landscape into the adjacent undisturbed landscape.

For the purposes of this report we refer to non-native and invasive species interchangeably as species that are of concern for the Refuge

METHODS

Sample Design and Field Methods

We sampled according to a stratified-random design. The anthropogenic disturbances were separated into six main categories (e.g. road, campground) and some of those were further separated into fine disturbance classes (e.g. dirt road, paved road; Tables 3 and 4). Based on time and resource limitations, our goal was to get at least ten plots in each main disturbance type (seismic lines, campgrounds, right of ways, roads, and oil and gas wells), with even distribution across the fine-scale disturbance types (e.g. five plots each in developed and undeveloped campgrounds; five on pipelines and five on powerlines). Random sample locations were selected within each strata with alternate locations should the primary location be inaccessible due to logistical constraints or hazardous conditions.

At each location we sampled with a 168-m^2 circular, multi-scale vegetation plot modified from the National Forest Service Inventory and Analysis Program (Fig. 4, Barnett et al. 2007). Species composition, cover, the average height of each species, and cover of abiotic variables (lichen, litter, moss, poop, rock, soil, standing duff, water, and wood) were recorded to the nearest 1% in each of three 1-m^2 subplots. We also collected species composition in the 5.64 m radius circular subplot, and the entire 7.32 m radius circular plot (168-m^2). The 5.64 m radius subplot is directly comparable to the size plot used in the LTEMP monitoring work. The 7.32 m radius plot is more comparable to the plot size used by most of the FIA program across the United States.

Photo: Ben Chemel

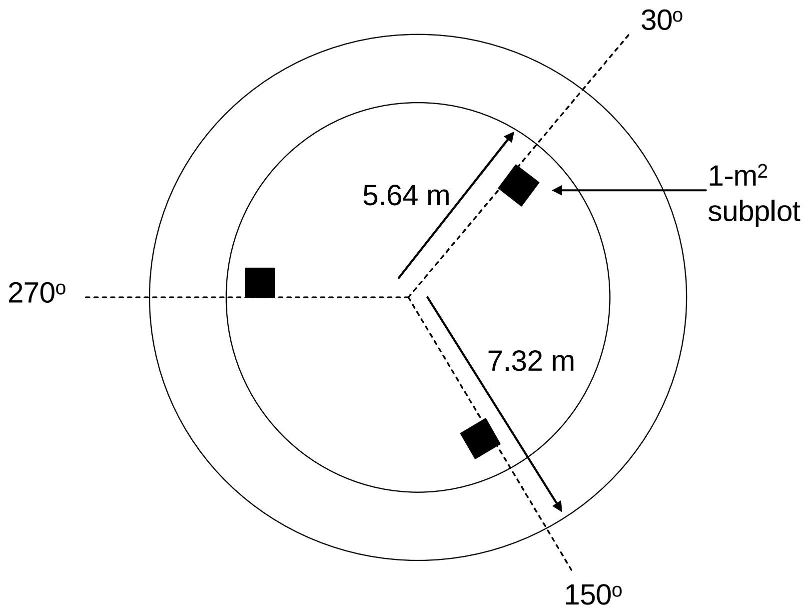


Figure 4. Multi-scale plot used to sample native and non-native plant species.

Near each randomly selected sample location we also evaluated invasion in the adjacent undisturbed landscape. A random and perpendicular (where appropriate) direction from the disturbance was selected. An area approximately 15 m wide by exactly 25 m long was searched for the presence of non-native plant species. If species were found in that area, a subjectively placed 7.32 m radius circular plot (no subplots) was established and all of the non-native plant species in the 168-m^2 area were recorded, and the process was repeated (another 25 m into the undisturbed landscape) until no non-native plant species were found on that trajectory. If no species were found an absence value was recorded.

Analysis

Plant species were identified according to the US Department of Agriculture PLANTS database (http://plants.usda.gov/index.html) and unknown plants were collected and identified by botanists at the Refuge. Summary statistics included plot frequency, average cover per plot, and dominance (frequency x cover). To facilitate comparison across disturbance types we calculated cumulative species richness by disturbance, mean

cumulative richness per plot, the mean species richness captured in each plot, and the mean cover for each disturbance type.

Species accumulation curves describe the rate at which sampling adds new species to the entire species list as more plots are placed on the landscape. We calculated species accumulation curves for all native and non-native plant species detected and for each main disturbance strata (Colwell 2005). For the by-strata curves, we randomly selected seven plots to normalize for the smallest number of plots sampled in a particular disturbance type (Table 4).

We used regression and regression tree techniques to understand the biotic and abiotic factors (ancillary data collected at each plot) associated with patterns of non-native plant species richness and cover across the Refuge. After eliminating cross-correlated independent variables and transforming variables to approximate normality, we used a stepwise multiple regression analysis (Reich and Davis 1998) to describe coarse-scale variability. We then modeled error (i.e., residuals) from the regression model using a binary regression tree (De'ath and Fabricius 2000), and avoided over-fitting the model by using a 10-fold cross-validation procedure to minimize the total deviance associated with the tree size. The two methods can be combined to create a model that describes variability in the data (R^2; Reich and Davis 1998).

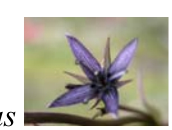
RESULTS

Plot Sampling

In the plot-based survey, we identified a total of 184 species in the 74 168-m^2 plots. The AKEPIC database and Refuge list 28 (Table 2) of these as non-native plant species. The common dandelion (*Taraxacum officinale*) occurred with the highest frequency (26 plots). Other species occurring with high frequency include, alsike clover (*Trifolium hybridum*, 24 plots), and Kentucky bluegrass (*Poa pratensis,* 21 plots). Eleven non-native species occurred on only one plot (Table 2). A total of 26 listed non-native plant species were found in all of the plots at the 5.64 m radius that is comparable to the LTEMP monitoring work (Appendix 1).

Table 2. Non-native plant species detected on disturbed areas of Kenai National Wildlife Refuge in the 7.32m plot, 2006.

NRCS Name	NRCS Code	Plot Frequency	Mean Cover per plot	Dominance
Alopecurus pratensis, meadow foxtail	alpr3	9	2.6	23
Capsella bursa-pastoris, shepherd`s purse	cabu2	1		
Cerastium fontanum, common chickweed	cefo2	2	0.2	0.3
Crepis tectorum, narrowleaf hawksbeard	crte3	6	0.5	2.8
Elymus repens	elre4	9	1.2	11
Erysimum cheiranthoides, wormseed wallflower	erch9	1		
Hieracium caespitosum	hica10	1	0.7	0.7
Hieracium umbellatum	hium	1		
Hieracium x flagellare	hifl2	1		
Hordeum jubatum, foxtail barley	hoju	9	0.8	7.5
Leucanthemum vulgare, oxeyedaisy	levu	1		
Lupinus polyphyllus, bigleaf lupine	lupo2	10	3.3	32.8
Matricaria discoidea, disc mayweed	madi6	10	0.2	2.2
Phleum pratense, timothy	phpr3	7	0.75	5.25
Plantago major, common plantain	plma2	12	1.9	23
Poa annua, annual bluegrass	poan	3	1.9	5. 7
Poa compressa, canada bluegrass	poco	11	0.6	6.9
Poa pratensis, kentucky bluegrass	popr	21	2.9	59.9
Polygonum aviculare, prostrate knotweed	poav	4	0.3	1.1
Rumex crispus, curly dock	rucr	1		
Senecio vulgaris, common groundsel	sevu	11	0.3	3.7
Spergularia rubra, red sandspurry	spru	1	0.2	0.2
Stellaria media, common chickweed	stme2	1	0.2	0.2
Taraxacum officinale, common dandelion	taof	26	1.3	34.7
Trifolium hybridum, alsike clover	trhy	24	8.4	201.4
Trifolium pratense, red clover	trpr2	1		
Trifolium repens, white clover	trre3	12	13.3	159
Viburnum opulus	viop	1		



Eight non-native species only occurred in the largest plot (Fig. 1) and do not have cover values (Table 2). Of the 20 non-native species occurring in subplots, white clover (*Trifolium repens*) had the highest average cover, followed by alsike clover (Table 2). Cover values for a single sub-plot for these species reached the values of 80-90 %, especially near roads, oil wells, and campgrounds. On the other end of the spectrum, a majority of the non-native species had cover values less than five percent.

While the sampling effort was not equitable across the main disturbance types (Table 3), we found the highest cumulative non-native species in the oil and gas well type, and the highest number of non-native species per plot in the oil and gas well and campground main disturbance types (Table 3). While the numbers are not identical the same patterns occur when these results are considered for the 5.64 m subplot (Appendix 2).

In the fine-scale disturbance stratification the undeveloped campground cumulated the most non-native plant species (aside from oil and gas well which was not broken into a fine strata) and the most non-native plant species per plot while the paved road had the highest mean cover of non-native plant species per plot (Table 4). And again, the same patterns hold for the 5.64 m radius subplot (Appendix 3).

In undisturbed areas adjacent to the plots we found 17 instances of non-native plant species in the first 15 x 25 m area searched. The subjectively placed paired-plots in these areas detected a total of seven species. The incidence of detection was greatest in the undeveloped campground (Table 5).

Table 5. Incidence of non-native plant species in undisturbed area paired-plots

Disturbance Type	Number of paired-plots	Mean number of species per plot
Campground, undeveloped	3	3
Right of way, powerline	1	1
Road, unpaved	2	3
Trail, foot	1	2
well	1	1

Species Accumulation Curves and Statistical Analysis

Species-accumulation curves for total native and non-native species demonstrated a continued steep increase while the non-native species curve seemed to flatten (Fig. 5a). However, when the y-axis was rescaled and only the non-native plant species accumulation curve was plotted, the curve did not demonstrate a decreased slope (Fig. 5b). Most of the non-native plant species accumulation curves by disturbance type did not demonstrate a flattening of the curve, but the curve of the seismic line accumulation was nearly flat (Fig. 6).

Independent variables available to the stepwise multiple linear regression for non-native species richness included native species richness, aspect (absolute value of 180-plot aspect in degrees), slope, elevation, percent cover of litter, rock, soil, standing duff, moss, wood, and the estimated total plot canopy cover. Significant variables in the

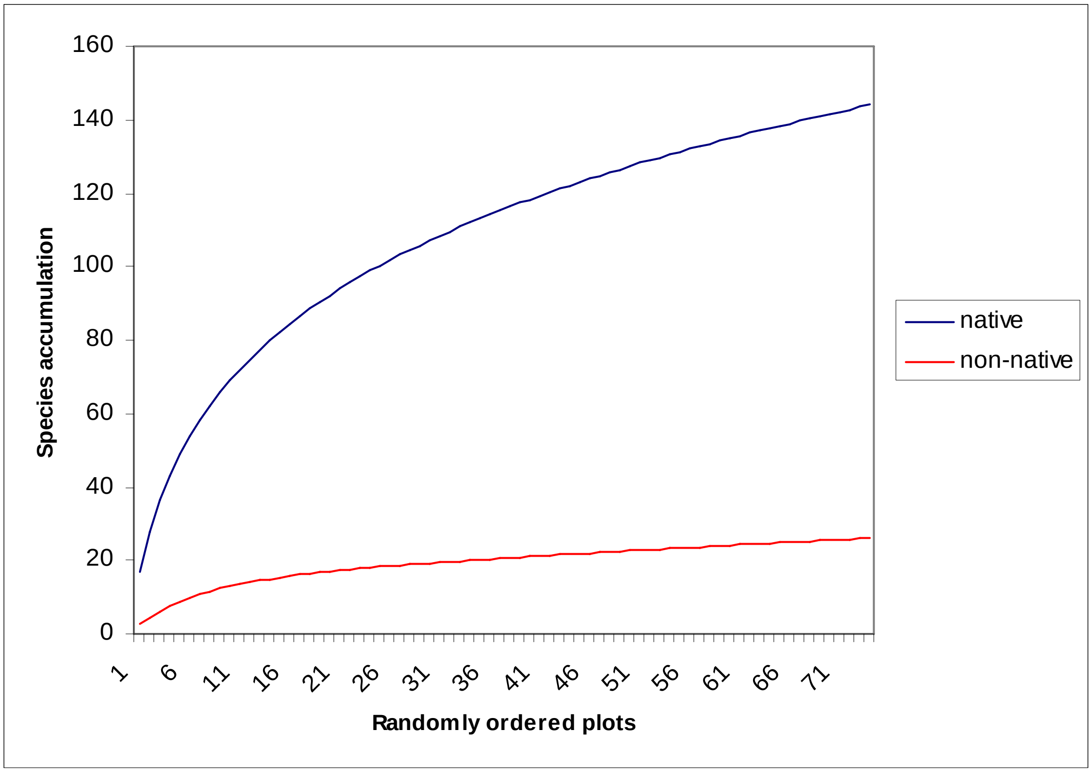
Moose near powerline, photo: Ben Chemel.

Table 3. The disturbance type, number of plots, and native and non-native plant species as detected in the 7.32m plot at Kenai National Wildlife Refuge, 2006.

Main Disturbance	Number of plots	Native species accumulation	Non-native species accumulation	Mean native species accumulation per plot	Mean non-native species accumulation per plot	Mean native species per plot	Mean non-native species per plot	Mean native species cover per plot	Mean non-native species cover per plot
Campground	10	70	18	7	2	19	7	39.9	12.0
Right of way	10	92	9	9	1	25	3	71.9	5.7
Road	12	59	14	5	1	20	4	47.8	21.6
Seismic	25	103	2	4	0.1	19	1	71.8	3.0
Trail	7	58	3	8	0.4	19	3	74.7	
Well	10	45	21	5	2	13	7	25.6	16.2

Table 4. The fine-scale disturbance type, number of plots, and native and non-native plant species as detected in the 7.32m plot at Kenai National Wildlife Refuge, 2006

Disturbance	Number of plots	Native species accumulation	Non-native species accumulation	Mean native species acc./plot	Mean non-native species acc./plot	Mean native species per plot	Mean non-native species per plot	Mean native species cover per plot	Mean non-native species cover per plot
Campground, developed	5	48	12	10	2	18	6	45.9	17.8
Campground, undeveloped	5	56	16	11	3	20	8	33.9	7.5
Right of way, pipeline	5	61	6	12	1	23	3	68.8	3.7
Right of way, powerline	5	72	8	14	2	26	3	75.1	7.1
Road, dirt	7	44	6	6	1	19	2	45.2	3.8
Road, paved	5	48	13	10	3	22	5	51.4	28.7
Seismic, 1950	5	54		11		20		61.2	
Seismic, 1960	5	44	1	9	0.2	16	1	74.2	5.0
Seismic, 1970	5	53	1	11	0.2	20	1	70.0	1.0
Seismic, 1980	5	47		9		19		72.4	
Seismic, 1990	5	48		10		19		84.2	
Trail, foot	6	55	3	9	1	20	3	79.0	
Trail, horse	1	19		19		19		48.5	
well	10	45	21	5	2	13	7	25.6	16.2



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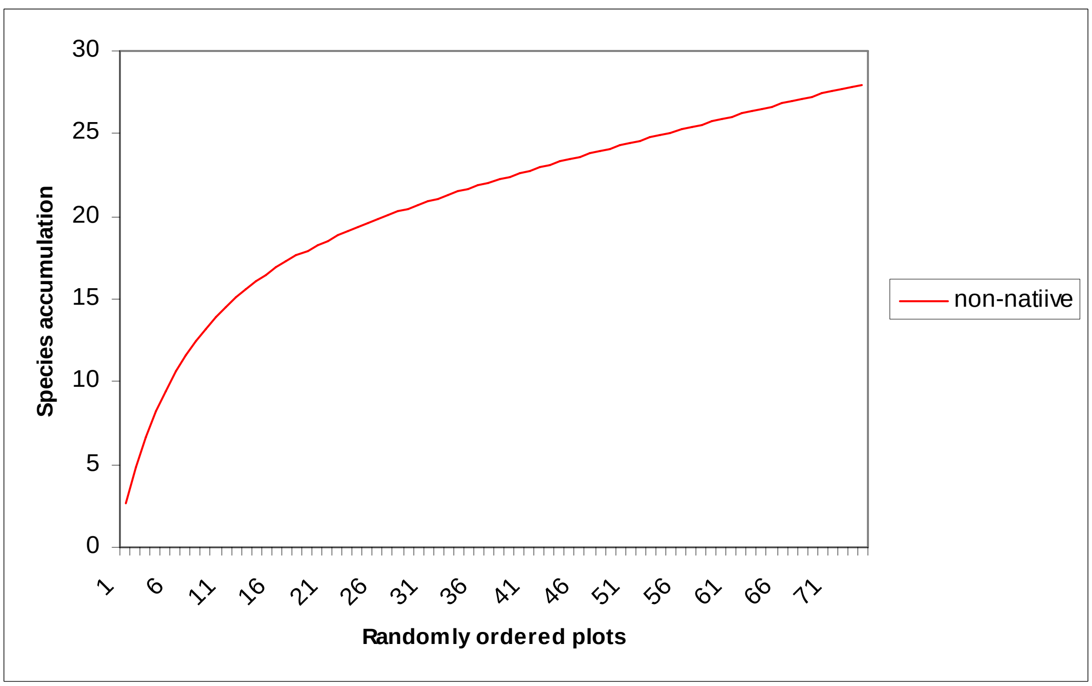
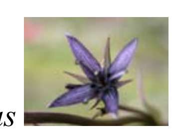


b.

Figure 5. Native and non-native species accumulation (a) and non-native species accumulation with a re-scaled y-axis.

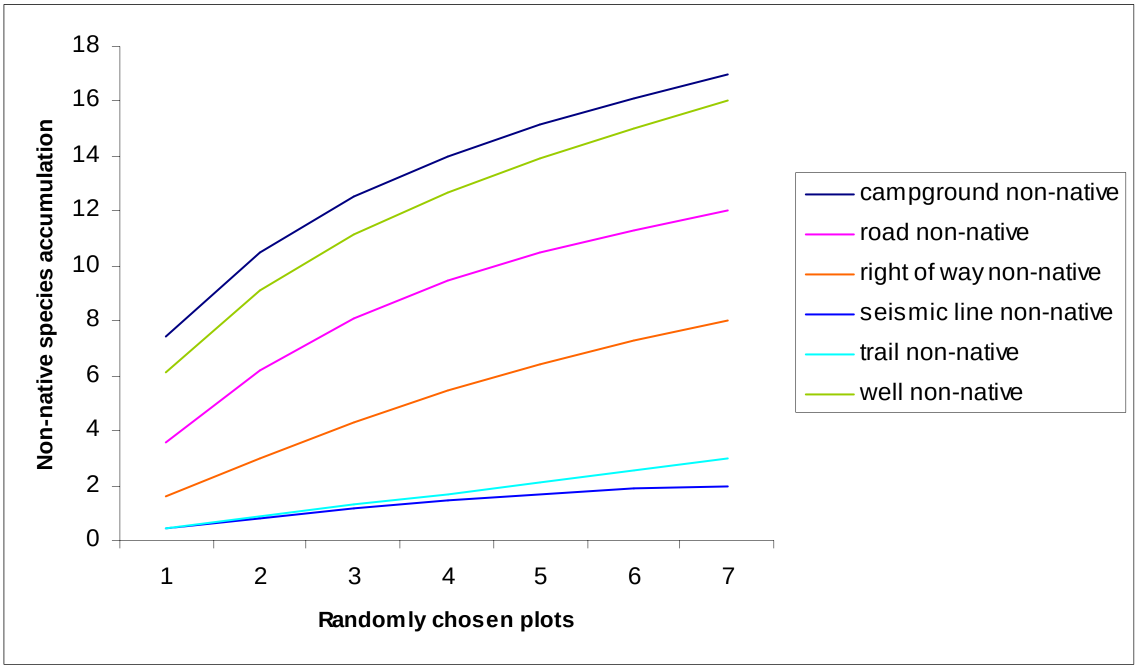


Figure 6. Non-native species-accumulation curves by disturbance type.

multiple regression model (Eq. 1) alone describe 58% of the variability in the data (R^2=0.58).

Eq. 1 richness = 0.23*rock+0.22*soil-0.23*standduff-0.14*moss-0.04*plot canopy cover

The same independent variables were used to describe the residuals or fine scale variability of the data with the regression tree in addition to the categorical variables of the fine-scale disturbance and Level I of the Viereck plot vegetation description (forest, shrub, or herbaceous). The cross-validation cut the tree down from ten terminal nodes using seven variables to three nodes using just the fine-scale disturbance variable. The combination of the two techniques described 74% of the variability in the data (R^2=0.74).

The same independent variables were used in the model of non-native plant species cover, but in this case the significant variables only described 30% of the variability in the data (Eq. 2; R^2=0.30).

Eq. 2 cover = 3.9*rock+4.9*soil-0.42* plot canopy cover

Like the model of non-native plant species richness, the same set of independent variables, the fine-scale disturbance, and Level I of the Vierect plot vegetation description were used to model the residuals of the model. Cross-validation of the model cut the tree from ten terminal nodes and six variables to three terminal nodes using two variables: the fine-scale disturbance strata and elevation. The combination of the regression model and the regression tree to describe the fine-scale variability described 47% of the variability (R^2=0.47).

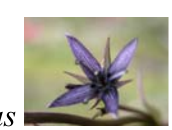
We also ran regression trees on the raw non-native plant species richness and cover data to further describe how they might be related to independent variables collected at each plot (Fig. 7).

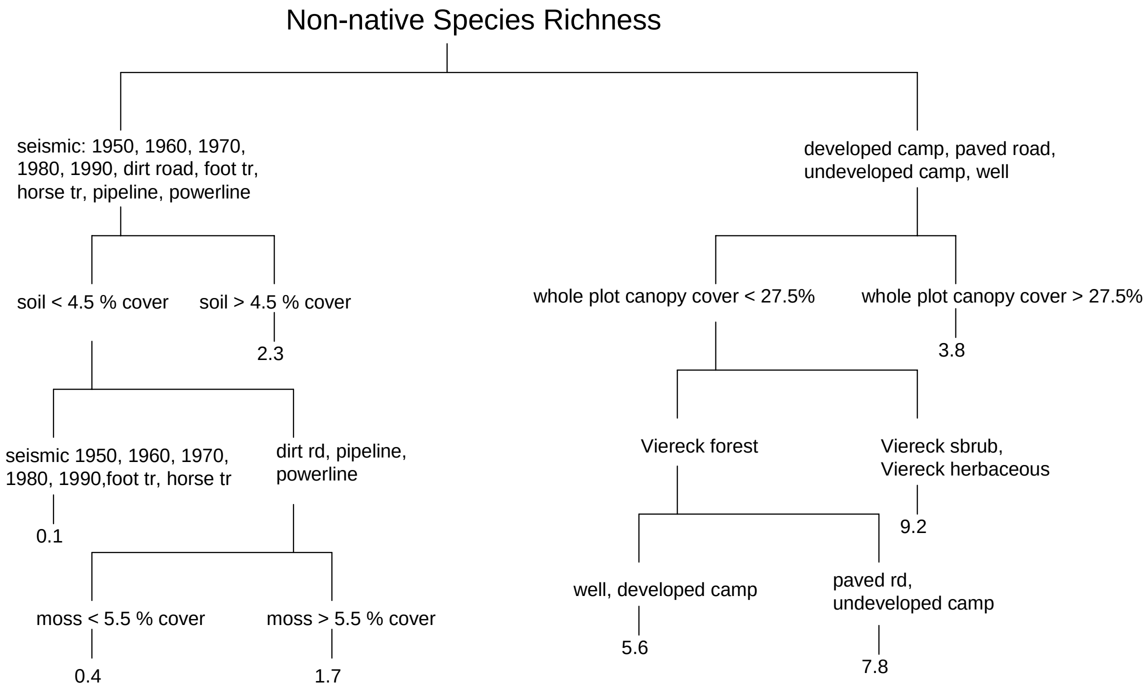
DISCUSSION

There are numerous ways this inventory can contribute to the understanding of invasive species at the Kenai National Wildlife Refuge. Simple risk analysis can be used to prioritize the current invaders according to threat and evaluate the vulnerability of habitats to invasion. Statistical investigation can describe how environmental variables contribute to these distributions, and can also be useful for directing control, further inventory and monitoring, and assessing impact to natural resource assets and management objectives.

The Species

Species identity matters in invasion biology. Some species wreak havoc on natural systems while others seem to be additive, existing at low levels that do not disrupt native species or processes. Most of the detrimental invasive plant species undergo a lag phase, existing at low, background numbers and densities for some time before spreading across the landscape (Hobbs and Humphries 1995). While further inventory and monitoring should maintain a landscape-scale focus that accounts for all non-native plant species, limited resources and widespread distribution of some species will force control efforts to focus on a subset of species. The difficulty of differentiating between relatively harmless invasive species and the next big invader is one of the difficulties of management.





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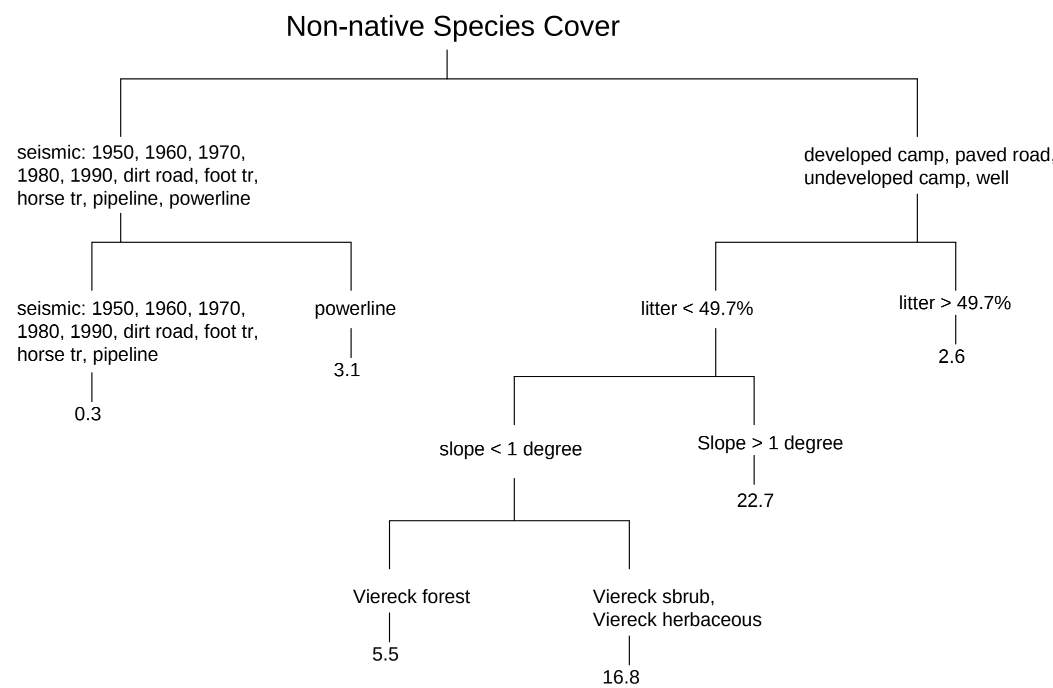


b.

Figure 7. Regression tree analysis of non-native plant species richness (a) and cover (b). Terminal node values represent mean number of species (a) and mean percent cover in a 1-m^2 subplot (b).

A species-specific approach that examines frequency of occurrence and cover of species can provide an estimate of how prevalent detected non-native plant species are on the landscape, and perhaps help identify which species might be targeted for control (Table 2). Dominance (cover x frequency) combines these two metrics to provide another way to assess the relative importance of species in the disturbed areas that were sampled (Huston 2004, Crall 2006). The high dominance scores of alsike clover and the white clover (*Trifolium repens*) reflect pervasiveness (Table 2). Depending on the threat to valued natural resources and processes (spatial and biological), a dominant species may not be one worth attempting to control. Some species had low dominance scores despite moderately high frequencies (e.g. disc mayweed (*Matricaria discoidea*) and common groundsel (*Senecio vulgaris*)). These species may currently be a lower priority as they are not taking up a lot of space or resources. Conversely, species with relatively low frequency and high dominance (e.g. meadow foxtail (*Alopecurus pratensis*)) might be worth prioritizing for control. These species seem to have limited distribution across the landscape but locally high cover. They should be continuously evaluated and monitored as they may have the ability to spread and have a significant impact on native plant species.

Plot sampling on well and foot trail.

The previous discussion describes the state of invasion across the disturbed areas sampled, but prioritization also depends on a determination of threat to Refuge resources and processes. There are several systems to assist with this determination. The Alien Plant Ranking System is a tool that accounts for species traits and site-specific information (Hiebert 1997, APRS Implementation Team 2000). The Alaska Natural Heritage Program and AKEPIC have also created the Weed Ranking Project (http://akweeds.uaa.alaska.edu/akweeds_ranking_page.htm) that gives species a relative score based on a risk assessment report. Relative to other non-native plant species found in our study foxtail barley's (*Hordeum jubatum*) moderate dominance score and high AKEPIC ranking might qualify it as a species of concern (Table 2, Appendix 1). Several of the highest ranking species in the Weed Ranking Project list that occur on the Refuge were not detected in this study (Appendix 4).

What Did We Miss?

Adherence to a stratified-random design does not maximize species detection, especially of non-native species that are rare on the landscape (Barnett et al. 2007). In an effort to describe the disturbed landscape and supplement previous invasive species inventory, this study missed non-native plant species (Appendix 4) documented on the Refuge. We attempted to evaluate how many native and non-native plant species we missed with the species-accumulation curves for both native and non-native plant species (Fig. 5). A flattening of the curve on the right side of these graphs might indicate that further sampling would detect few if any new species (Barnett and Stohlgren 2003). It should come as no surprise that we did not capture all of the species (Appendix 4) as the plots cover a very small portion of the disturbed area and the anthropogenic disturbance (especially linear disturbances like pipelines and seismic lines) cover a considerable range of vegetation types.

The by-type species-accumulation curves attempted to evaluate the disturbance type species pool, or beta diversity for each disturbance type (Fig. 6). The flattened curve for the seismic line disturbance suggests that with any seven plots we captured most of the non-native species capable of invading those areas; there may not be that many species that have invaded this disturbance type. Seismic lines aside, it seems that we missed non-native species in other disturbance types, or that at least these areas are prone to further invasion. A selection of seven random plots allows direct comparison across disturbance types, and these curves suggest that

especially campgrounds and oil and gas wells seem to be the most invaded disturbance types (Fig. 6).

Invasion and Vulnerability by Disturbance Type

The general pattern established by the species-accumulation curve analysis is corroborated by comparison of invasion across disturbance types: the campgrounds, wells, and roads had higher rates of non-native plant species than other disturbance types (Table 4). At the finer disturbance scale, the paved roads were considerably more invaded than dirt roads, and the undeveloped campgrounds had a higher presence of non-native plant species than the developed campgrounds (Table 4). It could be argued that not only are these disturbance types more invaded, but the species-accumulation curves described above suggest that these same areas are more vulnerable to further invasion. They should be the focus of control efforts, and they should be more rigorously monitored in the future.

The Drivers of Invasion

We did not quantify disturbance at each plot location, our subjective opinion is that the disturbed strata that were more invaded also seemed to be more disturbed. The oil and gas wells were often freshly graded with machinery likely to spread seeds. The paved roads were subjected to greater use than dirt roads and have a significantly greater right of way maintained. And, while developed campgrounds may have higher user numbers, use is confined to established paths and camping platforms that don’t exist at undeveloped campgrounds which seem to be more impacted.

Regression models were run in an effort to further understand the factors associated with both non-native plant species richness and cover. Models suggest that higher incidence of invasion is related to disturbance and access to resources or openings for growth. Greater numbers of non-native plant species occurred in areas with more rock cover – places not occupied by plants, more bare soil – likely due to disturbance, less standing duff – standing desiccated material either knocked down by disturbance or never existed leaving more open space, less moss – either because it was removed or not there to dominate space, and less canopy cover – more access to light (Eq. 1). Non-native plant species cover was related to similar factors (Eq. 2). Additionally, we regressed soil variables not collected at every plot (N = 49)

against non-native plant species cover and found a significant positive relationship with soil nitrogen and percent sand ($R^2 = 0.45$, $p < 0.001$) providing further evidence that non-native plant species congregate in areas conducive to growth (Stohlgren et al. 2001).

Regression trees provide a more visual way of looking at relationships between dependent and independent variables, and in this case they demonstrate patterns similar to the multiple regression. Both trees begin by separating paved roads, wells, and campgrounds from the other fine disturbance classes. In subsequent splits invasion seems to favor areas with more open space (less canopy cover or less litter), and open vegetation types as compared to forest (Fig. 7).

In short, models, subjective observation, and evaluation across strata suggest that incidence of invasion, both richness and cover, seem to be in areas that are more disturbed, have more openings for establishment, and more resources available for growth.

Undisturbed Landscape

It is worth noting that the disturbance type with the most non-native plant species per plot in the surrounding undistured landscape is one of the most invaded disturbance types. It makes sense that disturbed areas will act as source populations for invasion into undisturbed areas, and it may follow that the process will be most pronounced near the greater disturbance and incidence of invasion. It may also be that these areas will be invaded first by more invasive species. Of the seven species detected in undisturbed areas, three species had some of the higher AKEPIC rankings (Appendix 4).

RECCOMENDATIONS

Future Sampling

The inventory described was resource limited. We established as many permanent sampling plots as possible and distributed them evenly across disturbance types. In the absence of an a priori power calculation to establish sample size, the monitoring question becomes one of sensitivity – how much would the resource need to change (i.e. increase in non-native plant species cover) to be detected with statistical significance? Traditionally such an analysis evaluated pilot study data to calculate power and required sample size as demonstrated in Krebs

(1989). With a fixed sample size we are left to evaluate the change (*d*) our existing sample size can detect:

Eq. 3 $$d = |\mu_A - \mu_B|$$

where d = smallest change detected

μ_A = mean of population A

μ_B = mean of population B

The difference *d* must be expressed in units of the standard deviation of the variable measured:

Eq. 4 $$D = d/s$$

where D = standardized smallest difference detected

d = smallest difference detected

s = standard deviation of variable measured (assumed to be same for both populations)

The following example reflects application of evaluating cover of non-native plant species across all plots sampled. By convention we set $\alpha = 0.01$ and $\beta = 0.05$ and with a sample size of 74, table calculation for sample size designates (Krebs 1989):

$$D = d/s = 0.45$$

$$\mu_A = 4.3\%$$

$$s = 8.4$$

and $$d = 3.8\%$$

If all 74 plots were resampled and measured accurately a 3.8% change in non-native plant species cover could be detected. We completed similar calculations to evaluate the possibility of detecting change in cover of non-native plant species by disturbance type (Table 6).

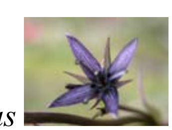


Table 6. Existing sample size ability to detect change in non-native plant species cover by disturbance type, $\alpha = 0.01$ and $\beta = 0.05$.

Disturbance type	Mean cover non-native plant species	Standard deviation	Sample size	*D*	*d*
Campground, developed	11.5	9.2	5	3	27.5
Campground, undeveloped	6.8	7.9	5	3	23.9
Right of way, pipeline	0.9	1.5	5	3	4.4
Right of way, powerline	3.1	4.3	5	3	12.8
Road, dirt	0.7	1.6	7	2	3.2
Road, paved	12.7	11.4	5	3	34.2
Seismic, 1950	0	0	5	3	0
Seismic, 1960	0.3	0.7	5	3	2.2
Seismic, 1970	0.1	0.1	5	3	0.4
Seismic, 1980	0	0	5	3	0
Seismic, 1990	0	0	5	3	0
Trail, foot	0	0	6	2	0
Trail, horse	0	0	1	2	0
Well	14.0	13.5	10	2	27

An alternative to the sensitivity approach is sequential sampling (Krebs 1989). Sample size is fixed in advance. Measurements are made one at a time, and after each observation or series of observations, the accumulated data indicates if a conclusion can be reached. The technique minimizes sample size and is well suited to resource constrained inventory. Instead of simply rejecting or accepting a null hypothesis, the analysis can direct that another sample be taken (Fig. 8). See Krebs (1989) for more information. It may be that a large sample size is needed to detect changes on a scale that is useful to management decisions.

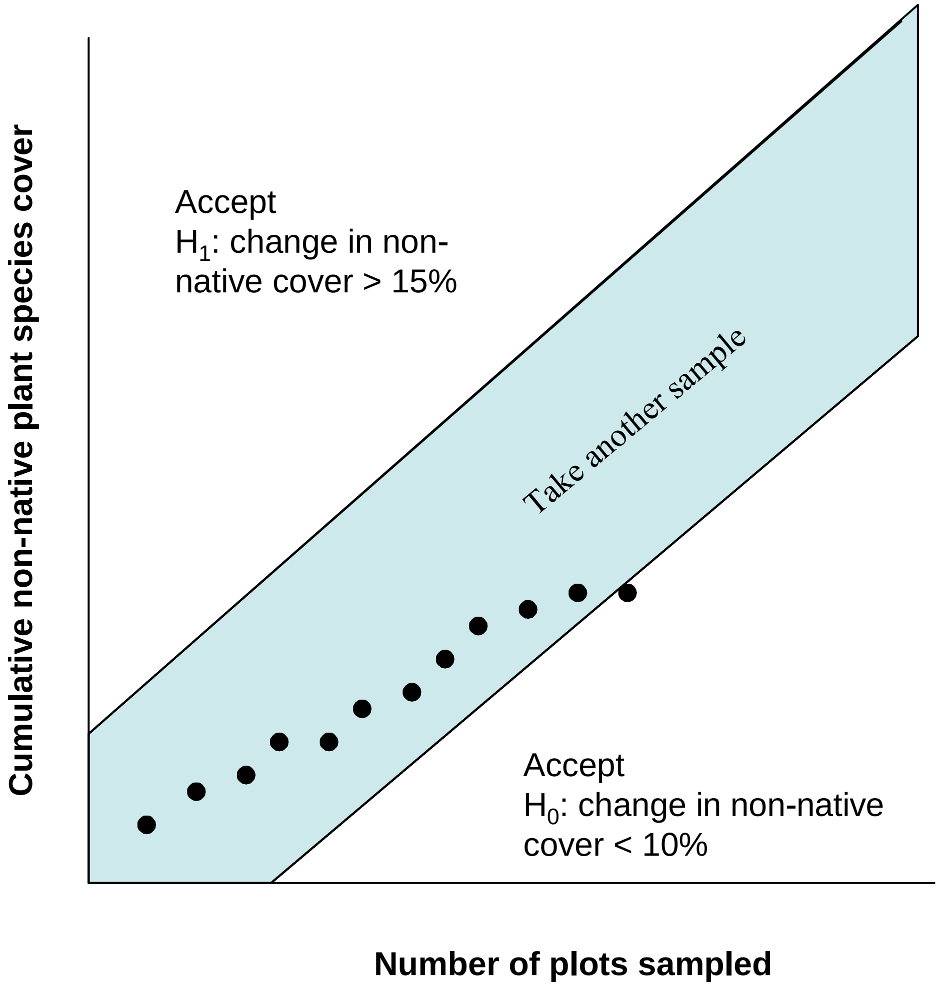
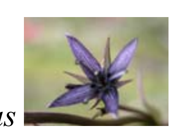


Figure 8. An example of sequential sampling to detect change in non-native plant species cover (adopted from Krebs 1989).

Existing Information and Continued Inventory and Monitoring

This study provided an unbiased description of native and non-native vegetation across the human-disturbed landscape. The plots are permanently marked so they can be sampled as part of future monitoring efforts. However, this set of plots is not sufficient for a proactive invasive plant species management program. The small fraction of the landscape covered by this set of plots caused them to miss non-native plant species on the landscape (28 of 60 known Refuge species were detected, Appendix 4), and chances are small that they would be invaded by new invaders and prove useful for early detection.



Previous work on National Wildlife Refuges has demonstrated that a combination of plot sampling and strategic mapping of non-native plant species may be the most useful tool for both early detection and monitoring of non-native plant species. Stratified-random plots force inventory to areas that may have been undersampled, provide an unbiased assessment of cover, generate comparable data across time and space, and document trends in both native and non-native plant species. Mapping allows the inventory to cover a greater portion of the landscape and sample areas likely to be invaded (Barnett et al. 2007).

The 2005 inventory approximated mapping needs. Many more species were captured, and the exact location of some of those was recorded (Fig. 3). However, exact locations were not recorded in many areas (e.g. campgrounds) so increases in distribution and cover will go undetected. Similarly, limiting inventory to systematically placed belt transects likely caused the inventory to miss species because a small area was sampled at each location and systematic surveys miss unique vegetation types and disturbances likely to be invaded (Legendre and Fortin 1989). We suggest that future inventory include mapping according to AKEPIC and North American Weed Mapping standards. It is also likely that more plots will be needed. New strata can be defined as understanding of patterns of plant invasions improve and evolve, and plots should be placed subjectively in areas that have been controlled to track both native and non-native plant species, and in areas that have a high occurrence and consequence of invasion. Subjective plot location incorporates the flexibility of mapping and the quantification of plot inventory.

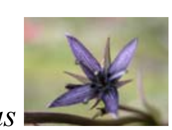
Early Detection

The importance and difficulty of detecting a species early in the invasion process is well documented (Hobbs and Humphries 1995, Kaiser 1999, FICMNEW 2003). This work showed that the non-native plants preferentially invaded disturbed areas with greater degrees of disturbance. Oil and gas wells, campgrounds, and paved roads were more invaded and should be the focus of continued inventory by mapping and periodic plot sampling. These areas demonstrated vulnerability and disturbance originates from uses (humans, cars, heavy machinery) that can work as vectors that frequently move across Refuge boundaries. By the same logic, trails, and especially the popular canoe routes, horse packing trails, and associated trail heads (not included as a stratum in this study) should be monitored for invasion. These

disturbance types were not particularly invaded in our inventory, but demonstrated significant numbers of non-native plants in the 2005 inventory (Table 1), the vectors exists and the threat of transporting seeds to remote parts of the Refuge where they could then spread to the undisturbed landscape is high.

Our paired-plot inventory confirmed that much of the undisturbed landscape has resisted invasion. While we found some non-native plant species and anecdotal evidence of invasion in undisturbed areas exists, it is likely limited in extent, important to future management, and difficult to detect. Permanent plots (LTEMP or new ones) and mapping should be frequently evaluated near hotspots of invasion on the disturbed landscape - near oil and gas wells and areas explored by campers and firewood collectors. Subjective, permanent plots should quantify known undisturbed invasions, and examples of invasion of undisturbed areas off of the Refuge should be evaluated. Emerging patterns can direct future inventory and control. The regional invasive plant species database (AKEPIC) will help direct early detection. It might describe specific species invading undisturbed areas, but also the biotic (vegetation type, native species richness) and abiotic (elevation, soil, slope angle) characteristics of the undisturbed locations. This information can establish bounds on priorities for inventory and make an intractable problem manageable.

Finally, the Volunteer Invasive Species Mapping Program administered by the NWR Invasive Species Program demonstrated that the public can be an effective early detection tool. Invasive species identification and awareness information at canoe and horse trailheads and campground pay stations could lead to prevention and early detection on associated disturbances. The oil and gas industry presents a challenge. The disturbance is great, the vectors numerous, and the resulting problems significant (Table 4). Supervisors of the Swanson field expressed concern about the problem and we discussed real possibilities for prevention like spray stations for all machinery and boots entering the field and control. Leveraging their support optimizes a valuable public relations opportunity and has the chance to make a real difference on a landscape that is more invaded than imagined just a few years ago and may be on the verge of experiencing a rapid expansion of invasive plant species.



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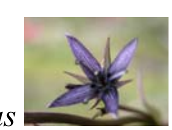


Appendix 1. Non-native plant species detected on disturbed areas of Kenai National Wildlife Refuge in the 5.64 m plot, 2006.

NRCS Name	NRCS Code	Plot Frequency	Mean Cover per Plot	Dominance
Alopecurus pratensis, meadow foxtail	alpr3	8	2.6	20.4
Capsella bursa-pastoris, shepherd`s purse	cabu2	1		
Cerastium fontanum, common chickweed	cefo2	2	0.2	0.3
Crepis tectorum, narrowleaf hawksbeard	crte3	6	0.5	2.8
Elymus repens	elre4	8	1.2	9.8
Hieracium caespitosum	hica10	1	0.7	0. 7
Hieracium umbellatum	hium	1		
Hieracium x flagellare	hifl2	1		
Hordeum jubatum, foxtail barley	hoju	9	0.8	7.5
Leucanthemum vulgare, oxeyedaisy	levu	1		
Lupinus polyphyllus, bigleaf lupine	lupo2	10	3.3	32.8
Matricaria discoidea, disc mayweed	madi6	8	0.2	1.8
Phleum pratense, timothy	phpr3	6	0.8	4.5
Plantago major, common plantain	plma2	10	1.9	19.2
Poa annua, annual bluegrass	poan	3	1.9	5.7
Poa compressa, canada bluegrass	poco	8	0.6	5
Poa pratensis, kentucky bluegrass	popr	18	2.9	51.3
Polygonum aviculare, prostrate knotweed	poav	3	0.3	0.83
Rumex crispus, curly dock	rucr	1		
Senecio vulgaris, common groundsel	sevu	8	0.3	2.7
Spergularia rubra, red sandspurry	spru	1	0.2	0.2
Stellaria media, common chickweed	stme2	1	0.2	0.2
Taraxacum officinale, common dandelion	taof	26	1.3	34.7
Trifolium hybridum, alsike clover	trhy	22	8.4	184.6
Trifolium repens, white clover	trre3	11	13.3	145.8
Viburnum opulus	viop	1		

Appendix 2. The disturbance type, number of plots, and native and non-native plant species as detected in the 5.64m plot at Kenai National Wildlife Refuge, 2006.

Main Disturbance	Number of plots	Native species accumulation	Non-native species accumulation	Mean native species accumulation per plot	Mean non-native species accumulation per plot	Mean native species per plot	Mean non-native species per plot	Mean native species cover per plot	Mean non-native species cover per plot
Campground	10	63	17	6	2	16	6	40.0	12.0
Right of way	10	86	10	9	1	22	3	72.0	5.7
Road	12	57	11	5	1	18	3	47.8	21.6
Seismic	25	102	2	4	0.1	17	1	71.8	3.0
Trail	7	53	3	8	0.4	18	3	74.7	
Well	10	39	19	4	2	12	6	25.6	16.2

Table 3. The fine-scale disturbance type, number of plots, and native and non-native plant species as detected in the 5.64m plot at Kenai National Wildlife Refuge, 2006

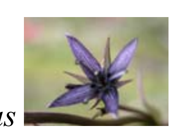
Disturbance	Number of plots	Native species accumulation	Non-native species accumulation	Mean native species acc./plot	Mean non-native species acc./plot	Mean native species per plot	Mean non-native species per plot	Mean native species cover per plot	Mean non-native species cover per plot
Campground, developed	5	42	11	8	2	15	4.8	45.9	17.8
Campground, undeveloped	5	46	15	9	3	16	7.4	33.9	7.5
Right of way, pipeline	5	59	6	12	1	21	2.5	68.8	3.7
Right of way, powerline	5	61	8	12	2	23	2.5	75.1	7.1
Road, dirt	7	40	5	6	1	16	1.5	45.2	3.8
Road, paved	5	47	10	9	2	21	3.8	51.4	28.7
Seismic, 1950	5	50		10		17		61.2	
Seismic, 1960	5	44	1	9	0.2	15	1	74.2	5.0
Seismic, 1970	5	53	1	11	0.2	18	1	70.0	1.0
Seismic, 1980	5	46		9		17		72.4	
Seismic, 1990	5	46		9		17		84.2	
Trail, foot	6	50	3	8	1	18	3	79.0	
Trail, horse	1	17		17		17		48.5	

Table 3. The fine-scale disturbance type, number of plots, and native and non-native plant species as detected in the 5.64m plot at Kenai National Wildlife Refuge, 2006

Well	10	39	19	4	2	12	6.3	25.6	16.2

Appendix 4. NRCS code, species name, species found on this study and AKEPIC ranking score.

NRCS Code	Scientific name	Common name	USGS study	AKEPIK ranking score
PHAR3	*Phalaris arundinacea*	reed canary grass		83
MEAL12	*Melilotus alba*	white sweet clover		80
BRTE	*Bromus tectorum*	cheatgrass		78
VICRC	*Vicia cracca*	bird vetch		73
LIVU2	*Linaria vulgaris*	common toadflax		69
CYSC4	*Cytisus scoparius*	Scotch broom		69
HOJU	*Hordeum jubatum*	foxtail barley	X	63
BRINI	*Bromus inermis ssp. inermis*	smooth brome		62
LEVU	*Leucanthemum vulgare*	oxeye daisy	X	61
ELRE4	*Elymus repens*	quackgrass	X	59
TRRE3	*Trifolium repens*	white clover	X_1	59
TAOFO	*Taraxacum officinale ssp. officinale*	common dandelion	X_1	58
TRHY	*Trifolium hybridum*	alsike clover	X_1	57
PHPR3	*Phleum pratense*	timothy	X	56
CRTE3	*Crepis tectorum*	narrowleaf hawksbeard	X	54
TRPR2	*Trifolium pratense*	red clover	X	53
DAGL	*Dactylis glomerata*	orchard grass		53
POPRI2	*Poa pratensis ssp. irrigata*	spreading bluegrass		52
POPRP2	*Poa pratensis ssp. pratensis*	Kentucky bluegrass	X_1	52
RUAC3	*Rumex acetosella*	sheep sorel		51
POCO10	*Polygonum convolvulus*	black bindweed		50
TRPE21	*Tripleurospermum perforata*	false mayweed		48
RUCR	*Rumex crispus*	curly dock	X	48
POAN	*Poa annua*	annual bluegrass	X	46
HIUM	*Hieracium umbellatum*	narrowleaf hawkweed	X	46
ACPT	*Achillea ptarmica*	sneezeweed		46
POAV	*Polygonum aviculare*	prostrate knotweed	X	45
PLMA2	*Plantago major*	common plantain	X_1	44
STME2	*Stellaria media*	common chickweed	X	42
LOPEP	*Lolium perenne ssp. perenne*	perennial rye grass		41
LOPEM2	*Lolium perenne ssp. multiflorum*	Italian rye grass		41
CABU2	*Capsella bursa-pastoris*	shepherd's purse	X	40
GABI3	*Galeopsis bifida*	splitlip hempnettle		40
POCO	*Poa compressa*	Canada bluegrass	X	39
CEFOV2	*Cerastium fontanum ssp. vulgare*	big chickweed	X	39



SEVU	*Senecio vulgaris*	common groundsel	X	35
CHAL7	*Chenopodium album*	lamb's quarters		35
SPAR	*Spergula arvensis*	corn sandspurry		32
MADI6	*Matricaria discoidea*	pineappleweed	X	32
LEDE	*Lepidium densiflorum*	common pepperweed		25
ALGE2	*Alopecurus geniculatus*	water foxtail		
ALPR3	*Alopecurus pratensis*	meadow foxtail	X[1]	
ASPR	*Asperugo procumbens*	German-madwort		
BEPE3	*Betula pendula*	European white birch		
BRRA	*Brassica rapa*	field mustard		
VIOP	*Viburnum opulus*	American cranberrybush	X	
TYLA	*Typha latifolia*	broadleaf cattail		
SOSO2	*Sorbaria sorbifolia*	false spirea		
CHBE4	*Chenopodium berlandieri*	pitseed goosefoot		
HICA10	*Hieracium caespitosum*	meadow hawkweed	X	
SPRU	*Spergularia rubra*	purple sandspurry	X	
LUPO2	*Lupinus polyphyllus*	bigleaf lupine	X[1]	
RAACA3	*Ranunculus acris var. acris*	showy buttercup		
RULO2	*Rumex longifolius*	dooryard dock		
ELSI	*Elymus sibiricus*	Siberian wild rye		
ERCH9	*Erysimum cheiranthoides*	wormseed wallflower	X	
FRAN	*Fragaria X ananassa*	domestic strawberry		
HIFL2	*Hieracium X flagellare*	whiplash hawkweed	X	
GATE2	*Galeopsis tetrahit*	brittlestem hempnettle		
POTR2	*Poa trivialis*	rough bluegrass		

[1]Species found in paired plots in undisturbed areas adjacent to disturbed areas.