The distribution of exotic plants adjacent to campgrounds in Yellowstone National Park, USA
by Karen Kathleen Allen

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Earth Sciences
Montana State University

Abstract:
Eleven campgrounds in Yellowstone National Park were studied to determine if 10 specific exotic plant species decreased with distance from the campground edge disturbance and were more abundant under an open canopy. Measurements of exotic plant percent cover and density, canopy cover, and the cover of moss/lichen, grass, sedge, forb, shrub, tree, litter, bare ground, disturbance and human-generated garbage were collected along 8 transects located perpendicular to each campground edge. Along each transect, 4-by-1 meter quadrats were located every meter from the campground edge out to 15 meters to identify where exotic cover and density decreased, and at 20, 25, 30, 40 and 50 meters from the edge to estimate the distance out to which exotics spread from the campgrounds.

Six of the 11 campgrounds contained 1 or more exotic species. Six species were found at Mammoth. In all the other campgrounds, only 2 species were found. Exotic plants at Mammoth decreased with increasing distance from the campground edge, as hypothesized, out to 4 to 6 meters. The mean and variability in exotic cover decreased with distance from 1 meter out to 5 meters and the median cover decreased from 2 to 6 meters. The mean density decreased from 1 to 4 meters, the median density decreased from 2 to 4 meters, and the variability in exotic density decreased from 1 to 6 meters. Canada thistle (Cirsium arvense) was found most often between 11 and 15 meters and between 30 and 50 meters in the 6 campgrounds in which the plant was measured.

A significant association was found between open canopy and the presence of yellow sweetclover (Melilotus officinalis) and spotted knapweed (Centaurea maculosa), and between closed canopy and hound's-tongue (Cynoglossum officinale). Canada thistle primarily colonized beneath 20% or less canopy cover. A significant association was found between exotic presence and low covers of disturbed ground (<20%) at Mammoth. Low levels of disturbance (5%-40%) had a positive effect on Canada thistle presence, whereas high levels (>60%) had no effect. The cover of exotic plants at Mammoth decreased with increasing covers of grasses, forbs, shrubs, and all other vegetation combined. Over 75% of the time Canada thistle was found, it grew with at least 45% cover of other plants. Results suggest that 5 exotic species are most likely to be found in big sagebrush habitat types. Canada thistle was present from 1820 meters to 2365 meters in elevation, in big sagebrush/bluebunch wheatgrass (Artemisia tridentata/ Agropyron spicatum) habitat type up to subalpine fir/ grouse whortleberry (Abies Iasiocarpa/ Vaccinium scoparium) habitat type.

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This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency, and is ready for submission to the College of Graduate Studies.

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> Something will have gone out of us as a people if we ever let the remaining wilderness be destroyed; if we permit the last virgin forests to be turned into comic books and plastic cigarette cases; if we drive the few remaining members of the wild species into zoos or to extinction; if we pollute the last clean air and dirty the last clean streams and push our paved roads through the last of the silence, so that never again will Americans be free in their own country from the noise, the exhausts, the stinks of human and automotive waste. And so that never again can we have the chance to see ourselves single, separate, vertical and individual in the world, part of the environment of trees and rocks and soil, brother to the other animals, part of the natural world and competent to belong to it.

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ABSTRACT

Eleven campgrounds in Yellowstone National Park were studied to determine if 10 specific exotic plant species decreased with distance from the campground edge disturbance and were more abundant under an open canopy. Measurements of exotic plant percent cover and density, canopy cover, and the cover of moss/lichen, grass, sedge, forb, shrub, tree, litter, bare ground, disturbance and human-generated garbage were collected along 8 transects located perpendicular to each campground edge. Along each transect, 4-by-1 meter quadrats were located every meter from the campground edge out to 15 meters to identify where exotic cover and density decreased, and at 20, 25, 30, 40 and 50 meters from the edge to estimate the distance out to which exotics spread from the campgrounds.

Six of the 11 campgrounds contained 1 or more exotic species. Six species were found at Mammoth. In all the other campgrounds, only 2 species were found. Exotic plants at Mammoth decreased with increasing distance from the campground edge, as hypothesized, out to 4 to 6 meters. The mean and variability in exotic cover decreased with distance from 1 meter out to 5 meters and the median cover decreased from 2 to 6 meters. The mean density decreased from 1 to 4 meters, the median density decreased from 2 to 4 meters, and the variability in exotic density decreased from 1 to 6 meters. Canada thistle (*Cirsium arvense*) was found most often between 11 and 15 meters and between 30 and 50 meters in the 6 campgrounds in which the plant was measured.

A significant association was found between open canopy and the presence of yellow sweetclover (*Melilotus officinalis*) and spotted knapweed (*Centaurea maculosa*), and between closed canopy and hound's-tongue (*Cynoglossum officinale*). Canada thistle primarily colonized beneath 20% or less canopy cover. A significant association was found between exotic presence and low covers of disturbed ground (<20%) at Mammoth. Low levels of disturbance (5%-40%) had a positive effect on Canada thistle presence, whereas high levels (>60%) had no effect. The cover of exotic plants at Mammoth decreased with increasing covers of grasses, forbs, shrubs, and all other vegetation combined. Over 75% of the time Canada thistle was found, it grew with at least 45% cover of other plants. Results suggest that 5 exotic species are most likely to be found in big sagebrush habitat types. Canada thistle was present from 1820 meters to 2365 meters in elevation, in big sagebrush/bluebunch wheatgrass (*Artemisia tridentata/ Agropyron spicatum*) habitat type up to subalpine fir/ grouse whortleberry (*Abies lasiocarpa/ Vaccinium scoparium*) habitat type.

INTRODUCTION

Exotic plants have dramatically transformed the vegetation of the western United States over the past 100 years and can be found today in most disturbed wildlands (Marion et al., 1985; Mack, 1986; Cheater, 1992). The term "exotic" refers to introduced plant species that are not indigenous to an area (Marion et al., 1985). Most exotics are weeds, those undesirable, uncultivated plants whose populations grow predominantly in disturbed environments (Baker, 1986; Bedunah, 1992). Until recently, most studies of exotic plants in the western United States have been concerned with the degradation of agricultural land and the economic losses due to reduced crop production and livestock yields (Bedunah, 1992). Comparatively little is known about the effects of exotic species on native plant diversity, aesthetics and wildlife in natural areas (Bedunah, 1992; Cheater, 1992).

The introduction and dispersal of exotic vegetation in a national park invokes concern for several reasons. Exotic plants can aggressively invade and displace the native plant communities that the National Park Service is mandated to preserve (Marion et al., 1985; Weaver et al., 1989; Westman, 1990). In some cases, exotic plants are the single greatest threat to natural communities (Cheater, 1992). Nature preserves such as national parks provide rare and important information on naturally functioning ecosystems that can be used as baseline data for the evaluation of human-induced changes in developed areas.

The presence of exotic vegetation near trails, campgrounds and other human development in national parks can give a false impression of natural vegetative conditions (Marion et al., 1985). No previous research has been conducted on the distribution of exotic plants adjacent to established campgrounds in Yellowstone National Park.

A strong relationship between exotic plant establishment and disturbance has led many researchers to study the distribution of exotic plants adjacent to the disturbance of roads or trails in national parks (Dale and Weaver, 1974; Weaver and Woods, 1986; Weaver et al., 1989; Benninger-Truax et al., 1992; Tyser and Worley, 1992). Disturbance can be defined as any disruption to an ecosystem, community or population structure that changes resources, substrate availability or the physical environment (Hobbs, 1989). In these studies, the occurrence of exotic plants decreased with distance from the disturbance of roads and trails. A greater abundance of exotics closer to roads or trails has also been associated with higher light intensities (Dale and Weaver, 1974; Benninger-Truax et al., 1992). Open canopy cover has been suggested to favor exotic establishment (Forcella and Harvey, 1983; Baker, 1986).

Objectives of Study

This study aimed to determine the distribution of exotic plants adjacent to campgrounds in Yellowstone National Park with respect to both disturbance and canopy cover. Because campgrounds in Yellowstone National Park receive high levels of disturbance, especially during summer months, it was expected that the occurrence of exotics would decrease with distance from campground disturbance. The first objective was to determine the distribution of several aggressively invading exotic plant species adjacent to campground disturbance in Yellowstone National Park. The second objective was to relate exotic plant species distribution around campgrounds to canopy cover. Two hypotheses were formulated in order to address these objectives: 1. The density and percent cover of exotics will decrease with increasing distance from the campground edge, out to a certain distance; and 2. The density and percent cover of exotics will be greater under a more open canopy than under a more closed canopy.

Previous Studies

The ability of exotic plants to displace native vegetation is well documented and is one of the primary concerns regarding their presence in national parks (Marion et al., 1985; Mack, 1986; Weaver and Woods, 1986; Bedunah, 1992; Kummerow, 1992; Tyser and Worley, 1992; Lesica and Ahlenslager, 1993). Studies conducted in natural areas have primarily measured the abundance of exotics or species composition changes outward from roads (Forcella and Harvey, 1983; Weaver and Woods, 1986; Weaver et al., 1989; Tyser and Worley, 1992) and trails (Dale and Weaver, 1974; Cole, 1978; Cole, 1981; Hall and Kuss, 1989; Benninger-Truax et al., 1992; Tyser and Worley, 1992). These studies found exotic species cover and richness decreased with distance from roads and trails. Weaver et al. (1989) found that the reduced cover of every invading exotic with increased distance from the road was associated with decreased disturbance. Dale and Weaver (1974) suggested the greater abundance of exotics found closer to trails in the northern Rocky Mountains was a result of greater disturbance, light and proximity to a seed source.

Most previous studies support the theory that colonization of a site by exotic vegetation is facilitated by disturbance (Marion et al., 1985; Baker, 1986; Mack, 1986; Hobbs, 1989; Weaver et al., 1989; Bedunah, 1992; Benninger-Truax et al., 1992). Natural or anthropogenic disturbance is almost always necessary for plant invaders to be successful (Baker, 1986; Westman, 1990). Some researchers have suggested that disturbance is important to the spread of exotic plants because it reduces competition for nutrients by disrupting strong species' interactions and provides a seedbed for rapidly colonizing species (Fox and Fox, 1986; Orians, 1986; Hobbs, 1989; Bedunah,1992). Disturbance can also create patches of open ground which increase the availability of light (Hobbs, 1989).

Many studies have shown that once exotic species have become established in disturbed ground, they are able to invade and alter healthy stands of native vegetation (Mack, 1986; Hobbs, 1989; Bedunah, 1992; Benninger-Truax et al., 1992; Tyser and Worley, 1992). Tyser and Key (1988) found that as spotted knapweed (*Centaurea maculosa*) density increased, the number and occurrence of native species declined in undisturbed grassland communities in Glacier National Park, USA. Tyser and Worley (1992) found high levels of exotics

100 meters away from trails in undisturbed grassland in Glacier National Park, USA. Benninger-Truax et al. (1992) suggest that trails facilitated the invasion of exotic species into the undisturbed forests of Rocky Mountain National Park, USA. These studies cause concern over the potential for exotic spread into native plant communities in Yellowstone National Park once the plants have established a foothold in the disturbance of a campground.

Disturbance to an ecosystem caused by human trampling is well documented (Burden and Randerson, 1972; Liddle, 1975; Cole, 1982; Kuss and Graefe, 1985; Cole and Knight, 1990). Human trampling in campgrounds has caused the loss of vegetation, soil disturbance and the introduction of a potential seed source, all of which are conducive to the colonization of exotics (Kuss and Graefe, 1985; Cole and Knight, 1990; Tyser and Worley, 1992). Cole (1981) found exotics became established in trampled forested campsites in the backcountry of the Eagle Cap Wilderness Area, Oregon. The distribution of exotics outward from campgrounds is expected to decrease with increasing distance from the campground disturbance (Dale and Weaver,1974; Benninger-Truax et al., 1992).

High light intensity and frequent openings in canopy cover are thought to facilitate invasion by exotic plants (Forcella and Harvey, 1983; Baker, 1986; Tyser and Worley, 1992). Dale and Weaver (1974) and Benninger-Truax et al. (1992) suggest that disturbed trail edges in northern Rocky Mountain forests and in Rocky Mountain National Park, Colorado, respectively, provided habitat for exotic species due partly to increased light intensity relative to the adjacent forest. Canopy openings in Great Smoky Mountains National Park, USA, due to either park maintenance practices or visitor trampling, has encouraged exotic plant establishment (Marion et al., 1985). Forcella and Harvey (1983) found the degree of canopy cover and available light was an important limit to exotic invasion in western Montana and suggested that light availability may allow exotic plants to invade relatively undisturbed vegetation. Information regarding shade tolerance of exotic species is largely observational; there is little quantification of the actual canopy cover limitations to growth for individual species.

A common approach taken in exotic plant distribution research has been to find correlations between existing distributions and the habitat types in which they are found (Forcella and Harvey, 1983; Weaver et al., 1989; Forcella, 1992). Some habitats seem more susceptible to exotic establishment than others, due partially to canopy cover and light availability (Forcella and Harvey, 1983; Baker, 1986; Weaver et al., 1989; Forcella, 1992). Forcella and Harvey (1983) found that in low montane Ponderosa pine (*Pinus ponderosa*) and grassland (*Festuca idahoensis, F. scabrella* and *Agropyron spicatum*) habitat types in western Montana, sufficient light intensity allowed weed colonization regardless of the degree of disturbance, whereas the dense canopy of the subalpine (*Abies lasiocarpa*) zone seemed to preclude exotic establishment. In mid-montane Douglas fir (*Pseudotsuga menziesii*) habitats, exotics were present only in very disturbed areas (Forcella and Harvey, 1983; Forcella, 1992). Baker (1986) notes grasslands, especially when overgrazed, roadsides and trails are among ecosystems most susceptible to invasion because of the frequent breaks in plant cover. He suggests dense forest habitats are more resistant to invasion due to the closed canopy.

Current distributions of exotics have been mapped and analyzed in an effort to predict their future spread (Forcella and Harvey, 1981; Chicoine et al., 1985; Baker, 1986; Mack, 1986; Chicoine et al., 1988; Weaver et al., 1989). Forcella and Harvey (1981) used herbarium specimens as an indicator of weed distributions in Montana, available from 1881 to 1980, in an effort to provide insight into future spread. Others recommend the use of climate parameters associated with a species' native distribution to predict the geographic limits in an invaded continent (Lindsay, 1953; Chicoine et al., 1985; Forcella, 1992), since exotics are likely to spread into areas where the environmental conditions are similar to their native distribution (Forcella and Harvey,1981; Forcella and Harvey, 1983; Forcella and Wood, 1984). Chicoine et al. (1985, 1988) predicted the spread of spotted knapweed using soil characteristics, elevation, annual precipitation, length of frost free season, mean maximum July temperature and evapotranspiration for currently invaded sites as a tool to predict the future distribution in areas with a similar combination of environmental variables. They found that no single variable was an effective predictor of sites vulnerable to spotted knapweed invasion. Species with relatively wide native distributions tend to colonize and spread more successfully than those with narrow distributions (Forcella and Wood, 1984; Forcella, 1992).

Some researchers debate whether rates of spread of exotics follow a predictable pattern or can be predicted by a particular disturbance type (Mack, 1986; Hobbs, 1989). Hobbs (1989) emphasized that the characteristics of the ecosystem being invaded combine with disturbance to determine exotic distribution. Even though some authors debate the predictability of exotic spread (Mack, 1986; Hobbs, 1989), the use of climate and soils data are considered a useful best-guess at potential future distributions.

Study Area

Eleven vehicle-accessible campgrounds of Yellowstone National Park, located in northwestern Wyoming, were studied (Figure 1). This park was chosen as the study area because of a known presence of exotics and concern over their spread (Yellowstone National Park,1986; Whipple, 1993). In 1986, 85 exotic plant species were known to exist within the Park boundaries (Yellowstone National Park, 1986). In 1994, over 140 exotic species had been identified in the Park, and by 1996, 168 exotic species had been found within Yellowstone National Park, with the highest concentration found in the northern part of the park (Whipple, 1993, 1996). Formal research on exotic species in Yellowstone National Park has included a study of the effect of yellow sweetclover (*Melilotus officinalis*) on native

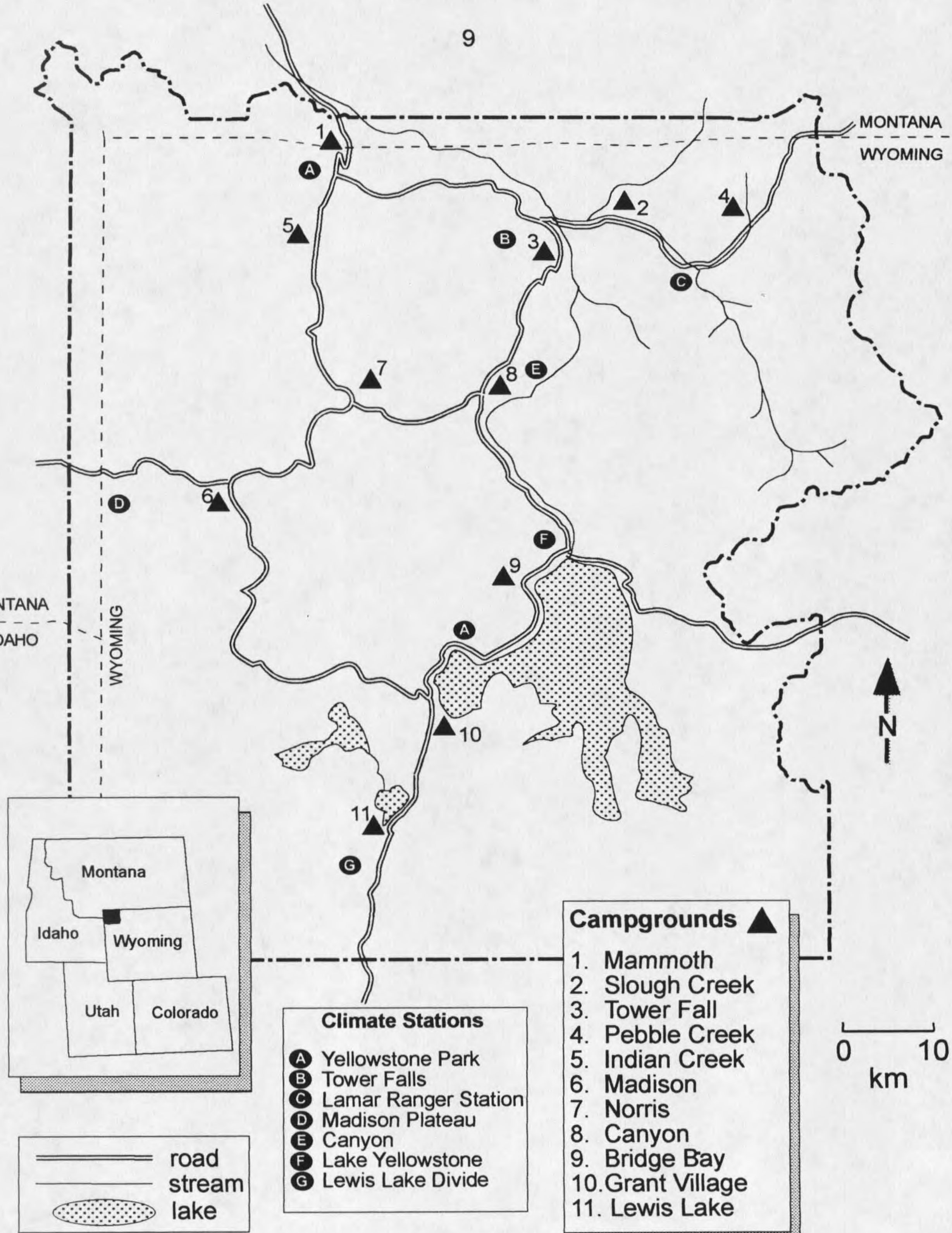

Figure 1. The study area, consisting of the 11 vehicle-accessible campgrounds within Yellowstone National Park, and climate stations.

plant community diversity near Mammoth, Wyoming (McMillan, 1995) and a study of the current and potential distributions of exotic plants adjacent to roadsides according to habitat type and degree of disturbance (Weaver et al., 1989).

Environmental Conditions at Campgrounds

The campgrounds range from 1820 meters to 2425 meters in elevation and differ in habitat type, geologic parent material, soil texture, relative plant nutrient levels and water-holding capacity (Tables 1 and 2). Habitat types in the campgrounds range from big sagebrush/bluebunch wheatgrass (*Artemisia tridentata/Agropyron spicatum*) at lower elevations to subalpine fir/grouse whortleberry (*Abies lasiocarpa/ Vaccinium scoparium*) at higher elevations (Table 1). More than one habitat type is often found within and surrounding a campground.

Glacial and fluvial processes have reshaped Yellowstone's surficial features since the Tertiary volcanic episode that formed the Absaroka mountains (andesite) and Quaternary events that created the Yellowstone volcanic plateau (ryolite), leaving evidence today of ice-contact fluvioglacial deposits, glacial till, lacustrine and alluvial deposits in and near the campgrounds (Lageson and Spearing, 1988; USGS, 1972). Andesitic and rhyolitic parent material partially controls soil texture and relative water-holding capacity and nutrient availability to plants (Table 2).

CAMPGROUND	APPROXIMATE ELEVATION M (FT)	HABITAT TYPE(S)
Mammoth	1820 (6000)	*Artemisia tridentata / Agropyron spicatum*
Slough Creek	1895 (6250)	*Artemisia tridentata / Festuca idahoensis* *Pseudotsuga menziesii / Symphoricarpos albus* *Picea engelmannii / Galium trifidum* *Picea engelmannii / Equisetum arvense*
Tower Fall	2000 (6600)	*Pseudotsuga menziesii / Symphoricarpos albus* *Abies lasiocarpa / Linnaea borealis*
Madison	2060 (6800)	*Abies lasiocarpa / Calamagrostis rubescens*
Pebble Creek	2090 (6900)	*Picea engelmannii / Galium trifidum* *Artemisia tridentata / Festuca idahoensis*
Indian Creek	2205 (7280)	*Abies lasiocarpa / Calamagrostis rubescens*
Norris	2275 (7500)	*Abies lasiocarpa/ Vaccinium scoparium* *Abies lasiocarpa / Calamagrostis rubescens*
Bridge Bay	2365 (7800)	*Abies lasiocarpa/ Vaccinium scoparium*
Grant Village	2365 (7800)	*Abies lasiocarpa/ Vaccinium scoparium*
Lewis Lake	2365 (7800)	*Abies lasiocarpa/ Vaccinium scoparium*
Canyon	2425 (8000)	*Abies lasiocarpa/ Vaccinium scoparium*

Table 1. The elevations of and habitat types within and surrounding the campgrounds in Yellowstone National Park (BART, 1994; Despain, 1990).

Climate

Latitude, continental location, and the orographic effect of mountains control most of the climatic patterns within Yellowstone National Park. During the winter, the area lies within the polar frontal zone where westerly winds carry

CAMPGROUND	GEOLOGIC PARENT MATERIAL	SOIL TEXTURE	RELATIVE PLANT NUTRIENT LEVELS & WATER-HOLDING CAPACITY
Mammoth	andesite, sedimentary	fine, clay and silt-rich	high
Slough Creek	andesite	fine, clay and silt-rich	high
Tower Fall	andesite	fine, clay and silt-rich	high
Madison	rhyolite	coarse, sandy	low
Pebble Creek	andesite	fine, clay and silt-rich	high
Indian Creek	rhyolite	coarse, sandy	low
Norris	rhyolite	coarse, sandy	low
Bridge Bay	rhyolite	coarse, sandy	low
Grant Village	rhyolite	coarse, sandy	low
Lewis Lake	rhyolite	coarse, sandy	low
Canyon	rhyolite	coarse, sandy	low

Table 2. Geologic parent material, soil texture and relative plant nutrient levels and water-holding capacity at the 11 campgrounds (Despain, 1990; USGS, 1972).

moisture inland and northerly winds advect low temperatures and low specific humidities into the Park. Winter daily maximum temperatures are frequently below $0^{o}C$ (Diaz, 1979). Most of the Park receives between 76 and 127 cm (30-50 in.) of precipitation, depending on elevation (Despain, 1990), with peak snowfall occurring in January (Diaz, 1979). The dominance of the subtropical high in summer (July and August), brings higher daily temperatures and milder nighttime temperatures which rarely drop below 0°C (Diaz, 1979). Daily development in summer months of thermally-induced lows results in convection, expansional cooling of local air masses, and thunderstorms. The highest temperature at the Yellowstone Park climate station (Mammoth) between 1887 and 1977 was 36°C (96°F) in July, 1901, while the lowest temperature at this site was -41°C (-41°F) in January, 1888 (Diaz, 1979).

Climate data collected at seven weather stations near the eleven campgrounds (Figure 1), indicates the differences in frost free days, precipitation, and temperature (Table 3). The number of frost free days reflects the variability in elevation, topography, and length of the growing season between sites. Since plants are typically not damaged until their tissues reach -1°C to -2°C (Moran, 1986), dates of frosts and frost free days refer to temperatures at or below -2°C (NRCS, 1994). Yellowstone Park station, the lowest in elevation, experiences more than twice the number of frost free days as other climate stations. The low number of frost free days at the Lamar Ranger Station climate station, despite its relatively low elevation, may result from cold air drainage along the Lamar River.

Relatively high precipitation values at the Madison Plateau climate station reflect its western location and interception of westerly air masses. Lower precipitation values at the Lake Yellowstone, Canyon, Tower Falls, and Lamar Ranger Station climate stations suggest a rainshadow effect. The highest precipitation at Lewis Lake Divide climate station reflects moist air advecting

Climate Station	Elevation (m)	Frost Free Days	Date of Last Spring Frost[2]	Date of First Fall Frost	Avg. Annual Precipitation (1961-1990) (cm)	Average Monthly Temperature During Growing Season (°C)[3]				
						May	June	July	Aug	Sept
Yellowstone Park	1890	125	May 15	Sept 19	39.1	8	13	16	17	12
Tower Falls	1900	60	June 27	Aug 27	43.0	NA[4]	11	14	14	NA
Lamar Ranger Station	2030	21	July 19	Aug 10	37.0	NA	11	12	14	NA
Madison Plateau	2350	na[1]	na	na	105.6	NA	8	13	12	NA
Lake Yellowstone	2365	64	June 24	Aug 28	51.8	NA	9	10	12	NA
Lewis Lake Divide	2380	na	na	na	141.5	NA	14	15	14	NA
Canyon	2450	na	na	na	70.4	NA	8	11	11	NA

Table 3. Climate data collected at 7 weather stations near the 11 campgrounds (NRCS, 1994).

1. na = data not available
2. Frost dates are medians for ten year record and refer to temperatures of or below -2°C.
3. Length of avg. monthly temperature record: 1983-1992 at Yellowstone Park, Tower Falls, Lake Yellowstone, Lewis Lake Divide; 1967-1976 at Lamar station; 1989-1993 at Madison Plateau, Canyon.
4. NA = does not apply since not during growing season

north from the Snake River drainage. Values for the average monthly temperature during the growing season values indicate that maximum temperatures occur in July and August.

Campground History and Use

The campgrounds of Yellowstone National Park have a rich history of establishment, expansions and improvements. An accurate assessment of the establishment and expansion of the 11 campgrounds currently in use in the Park is difficult due to sporadic and inconsistent records and the huge task involved in compiling a truly thorough history (Whittlesey, 1996). The first campgrounds were established in 1919 and 1922 as "auto camps" soon after the automobile first entered the Park, and included parts of the current Mammoth, Madison and Tower Fall campgrounds (Table 4). At Mammoth, trees were planted and fire pits and tables were added in 1934 (Whittlesey, 1996). At Tower Fall, records of "tent cabins" for visitor use in 1925 suggest improvements, and Madison was possibly expanded in 1933 (Whittlesey, 1996). Although records of later changes to these campgrounds were not found, modifications certainly occurred in order to transform these campgrounds into the car and tent camping sites they are today.

Some campgrounds were planned and later built as a result of the "Mission 66" Program, a 10-year program of national park infrastructure improvements (Whittlesey, 1996). By 1962, plans existed for all campgrounds that exist today (YNP, 1962). Mission 66 "improvements", including construction of and changes

Camp-ground	Date Established (date "improved")	Number of Sites	Approximate Season of Camper Use	Approximate Weeks open Annually	Campers Annually (avg.) (1986-1988 & 1991-1993)
Mammoth	1919 (1934)	85	year-round	52	40,057
Slough Creek	planned 1962 (1975)	29	5/20-10/31	23	10,508
Tower Fall	1922 (1925)	32	5/27-9/12	15	10,400
Madison	1922 (1933) (1952)	292	5/1-10/31	26	111,415
Pebble Creek	planned 1962 (1975)	36	6/10-9/6	12	7575
Indian Creek	planned 1962 (1975)	75	6/10-9/12	13	108,671
Norris	1964	116	5/20-9/26	18	40,018
Bridge Bay	1962	420	5/27-9/26	17	114,307
Grant Village	1965	414	6/22-10/11	16	102,970
Lewis Lake	1934	85	6/10-10/31	20	21,942
Canyon	1956-57	280	6/10-9/6	12	62,637

Table 4. Number of sites, season of use, weeks open annually and average number of visitors per year at the 11 campgrounds in the Park. (Hill, 1934; YNP, 1962; Wert, 1985; Wert, 1994; Whittlesey,1996; McLaughlin, 1966).

made to campgrounds, were planned for Bridge Bay, Madison, Tower, Canyon, Norris, Indian Creek, and Pebble Creek. Norris, Canyon and Grant Village were completed by 1966 (McLaughlin, 1966). Reference to additions of pit toilets to Slough Creek, Pebble Creek, and Indian Creek campgrounds in 1975 suggest they had been established since the 1962 plans (Table 4). These 3 campgrounds are expected to be the most recently established of the 11, and are probably at least 30 years old. It is expected that campground expansions and changes occurred in addition to those mentioned in Table 4.

The type of overnight use at campgrounds today consists primarily of visitors in cars and recreational vehicles, and secondarily of hikers and bicyclists. While the type of use within the campgrounds is relatively homogeneous, the number of campers at a campground varies substantially depending on the number of sites and weeks that each campground is open annually (Wert, 1994) (Table 4). For example, in July, 1993 (the month of maximum use) there were 2,800 campers at Slough Creek and 36,000 at Bridge Bay (Wert, 1985).

METHODS

Exotic Species Studied

Ten invasive exotic plants were selected for this study due to their observed presence in campgrounds by Yellowstone National Park staff and their designation as a high priority for control in the Park (Yellowstone National Park, 1986). None of the species were known to exist in the Park when it was established as a national park in 1872 (Yellowstone National Park, 1986). Species studied include spotted knapweed (*Centaurea maculosa*), hound's-tongue (*Cynoglossum officinale*), Canada thistle (*Cirsium arvense*), oxeye-daisy (*Chrysanthemum leucanthemum*), dalmation toadflax (*Linaria dalmatica*), yellow sweetclover (*Melilotus officinalis*), Russian knapweed (*Centaurea repens*), musk thistle (*Carduus nutans*), tansy aster (*Tanacetum vulgare*) and common mullein (*Verbascum thapsis).* Species nomenclature and verification of exotic status follow Hitchcock and Cronquist (1973). All species researched have been found to invade disturbed sites (Lindsay, 1953; Weaver et al., 1989).

Spotted knapweed, hound's-tongue, Russian knapweed, musk thistle, tansy aster and oxeye-daisy are among the Park's "Priority 1" species for management because they are aggressive invaders found in relatively small areas and because control efforts have a high probability of eliminating or limiting their future spread (Yellowstone National Park, 1986). Mullein is designated a "Priority 2" species since it is less aggressive, and like Priority 1 species, it is found in localized areas and control efforts are likely to be successful. Canada thistle, dalmation toadflax, and yellow sweetclover are designated "Priority 3" species because they are aggressive exotics that are dispersed over large areas of Yellowstone National Park and control efforts are expected to be costly, ineffective, and to have negative effects on the ecosystem they invade. Monitoring and work to prevent the spread of Priority 3 species into the backcountry are carried out. All species, except yellow sweetclover, are considered noxious weeds, defined by federal law as plants of foreign origin that can directly or indirectly injure agriculture, navigation, fish or wildlife, or public health, by the states of Wyoming or Montana or both (Bedunah, 1992; Yellowstone National Park, 1986).

Study Design

Eight transects were established outward from and perpendicular to the edge of each campground. The campground edge was defined as the outer border of the campground road off of which campsites occur. The length of the edge was measured by pacing clockwise from the northernmost point along the edge. To establish the starting point along the edge for the first transect, the total distance of the edge was divided by eight and the first transect was randomly located within the first eighth of the edge distance, measured clockwise from north (Moore, 1993). The remaining seven transects were separated by equal intervals, a distance equivalent to the division remainder, around the campground edge.

The starting point of each transect at the campground edge was located where less than or equal to 10% vegetative cover existed. The first quadrat lay within the campground, its outer boundary positioned at the defined campground edge. The transect was established perpendicular to and outward from the edge to a distance of 50 meters (Appendix 1). Extensive field notes and photographs of transect locations were taken; no permanent markers were established.

Along each transect, the outer edge of a 4-by-1 meter quadrat (Barbour, 1980; Cain, 1959) was located every meter from 0 to15 meters, and at 20, 25, 30, 40, and 50 meters (Figure 2). The long axis of the quadrat was centered along the transect and lay parallel to the campground edge. The higher intensity of sampling within the first 15 meters was designed to identify the point at which exotic plant density and percent cover began to decrease with distance from campground disturbance. The less intense sampling between 20 and 50 meters was used to estimate the outer distance to which exotic species have spread from the campground.

In addition to measurements taken outward from the edge of a campground, eight quadrats were randomly located inside each campground edge to compare exotic plant distribution within a campground with that outside of a campground. Eight control quadrats per campground were also located outside of the campground edge, at least 200 meters away from roads, campgrounds or

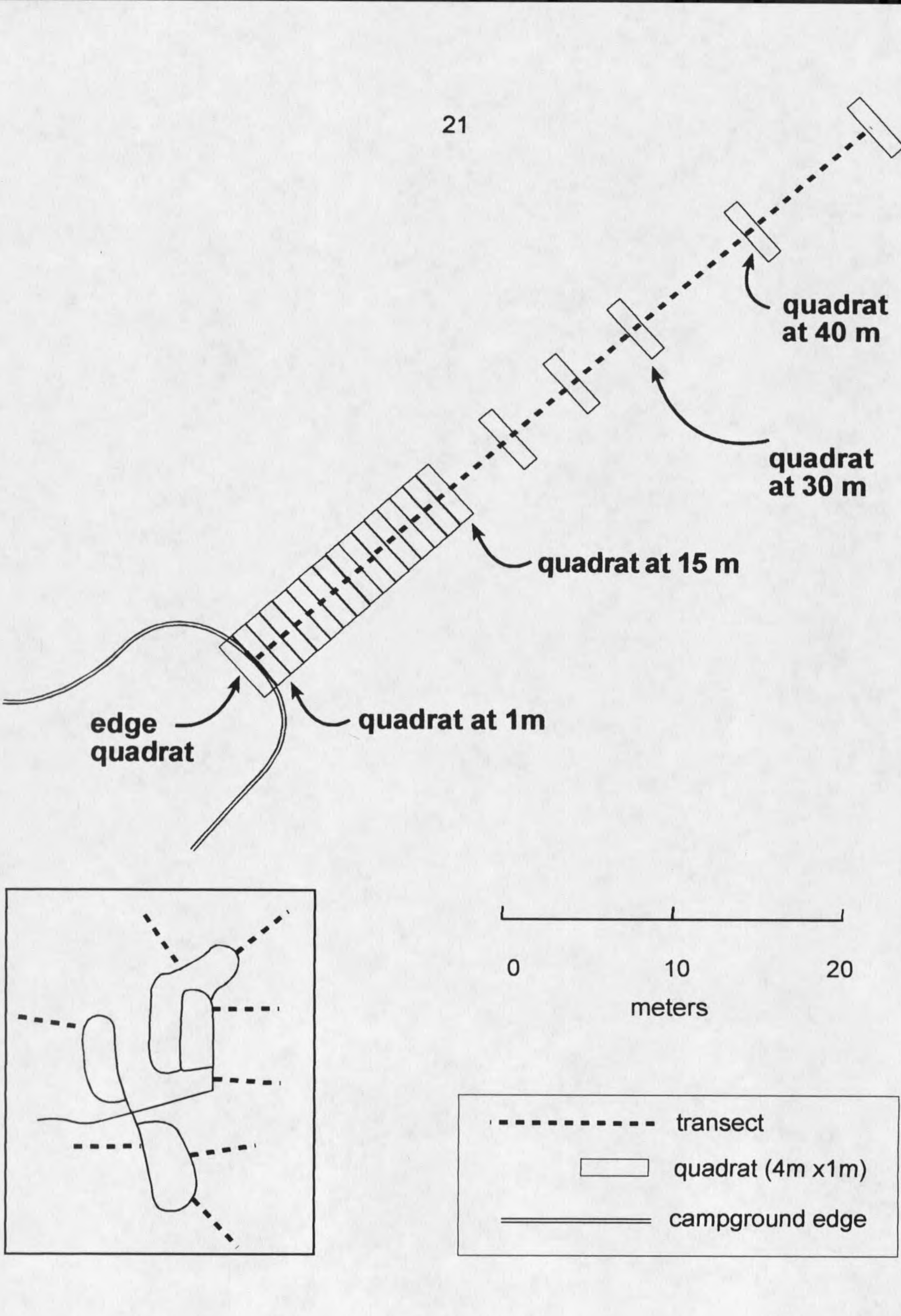

Figure 2. Location and orientation of quadrats along a transect.

established trail disturbances. This distance was visually estimated to be far enough away from human-caused disturbance for the distribution of exotic plants to be unrelated to anthropogenic impacts at the site. The control plots were first located on U.S.G.S. 1:24,000 topographic maps for their proximity to a campground and for their similarity of habitat type, slope and aspect to a campground. Data from the eight random and control plots was collected in a manner consistent with that from the other quadrats.

Field Data Collection

Field data was collected from June 21, 1994 to August 12, 1994, during the flowering stage of the exotics, which ensured accurate species identification and consistent estimates of vegetative cover between the 11 campgrounds. In an effort to capture the same phenological stage at all campgrounds, data was collected first from the lowest elevation campground and from consecutively higher elevation campgrounds thereafter.

Percent cover (the percentage of quadrat area beneath the canopy of a given species) and density (the number of plants rooted within each quadrat) were estimated for the 10 exotic species. The percent cover of all vegetative ground cover (vegetation variables) below elbow height was recorded according to life form: moss/lichen, grass, sedge, forb, shrub, tree, and conifer litter. Measurements of three substrate sizes included percent cover of bare soil (<2