



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

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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.

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Karen Kathleen Allen

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; Oriens, 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

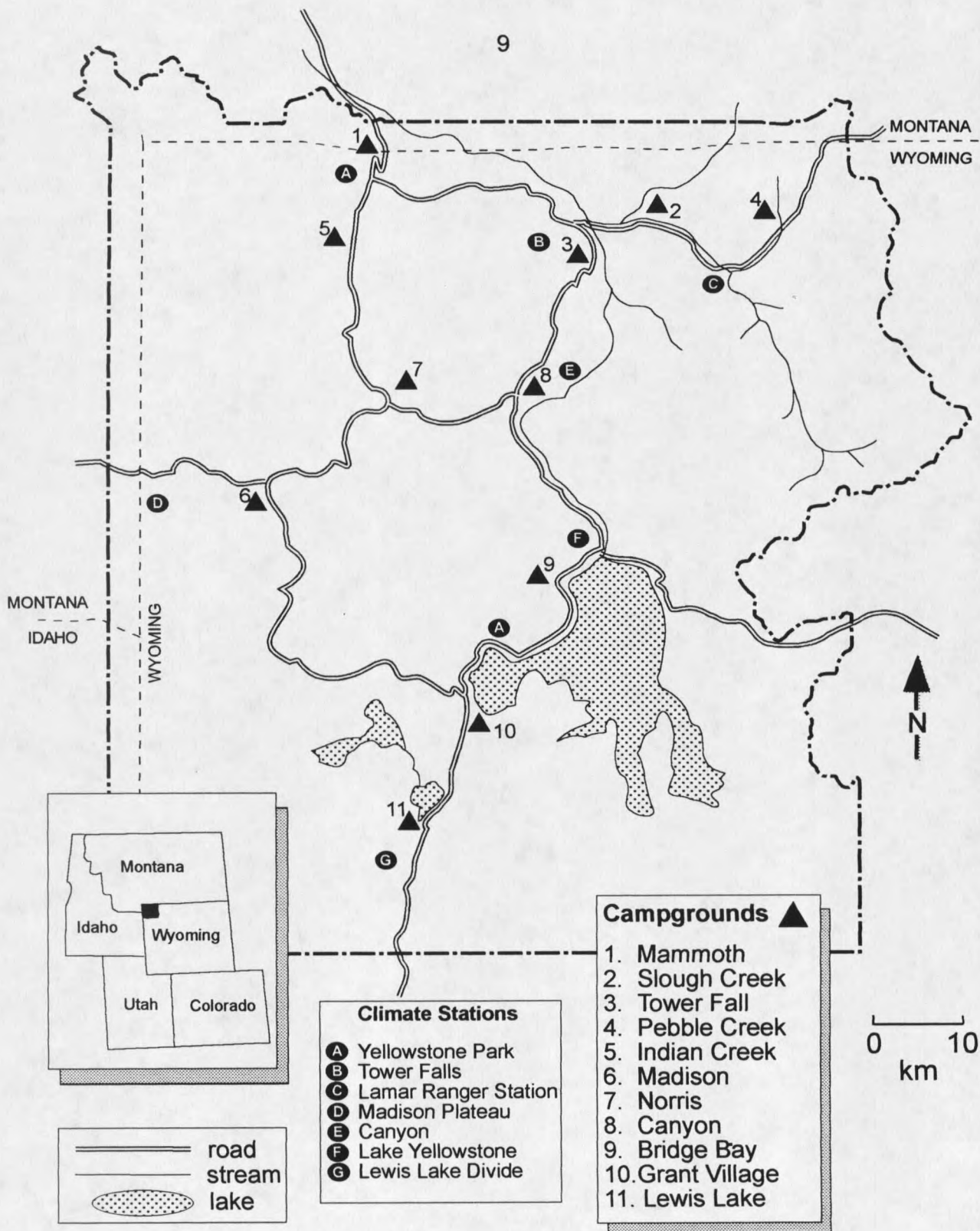


Figure 1. The study area, consisting of the 11 vehicle-accessible campgrounds within Yellowstone National Park, and climate stations.

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)	<i>Artemisia tridentata</i> / <i>Agropyron spicatum</i>
Slough Creek	1895 (6250)	<i>Artemisia tridentata</i> / <i>Festuca idahoensis</i> <i>Pseudotsuga menziesii</i> / <i>Symphoricarpos albus</i> <i>Picea engelmannii</i> / <i>Galium trifidum</i> <i>Picea engelmannii</i> / <i>Equisetum arvense</i>
Tower Fall	2000 (6600)	<i>Pseudotsuga menziesii</i> / <i>Symphoricarpos albus</i> <i>Abies lasiocarpa</i> / <i>Linnaea borealis</i>
Madison	2060 (6800)	<i>Abies lasiocarpa</i> / <i>Calamagrostis rubescens</i>
Pebble Creek	2090 (6900)	<i>Picea engelmannii</i> / <i>Galium trifidum</i> <i>Artemisia tridentata</i> / <i>Festuca idahoensis</i>
Indian Creek	2205 (7280)	<i>Abies lasiocarpa</i> / <i>Calamagrostis rubescens</i>
Norris	2275 (7500)	<i>Abies lasiocarpa</i> / <i>Vaccinium scoparium</i> <i>Abies lasiocarpa</i> / <i>Calamagrostis rubescens</i>
Bridge Bay	2365 (7800)	<i>Abies lasiocarpa</i> / <i>Vaccinium scoparium</i>
Grant Village	2365 (7800)	<i>Abies lasiocarpa</i> / <i>Vaccinium scoparium</i>
Lewis Lake	2365 (7800)	<i>Abies lasiocarpa</i> / <i>Vaccinium scoparium</i>
Canyon	2425 (8000)	<i>Abies lasiocarpa</i> / <i>Vaccinium scoparium</i>

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°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 to 15 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

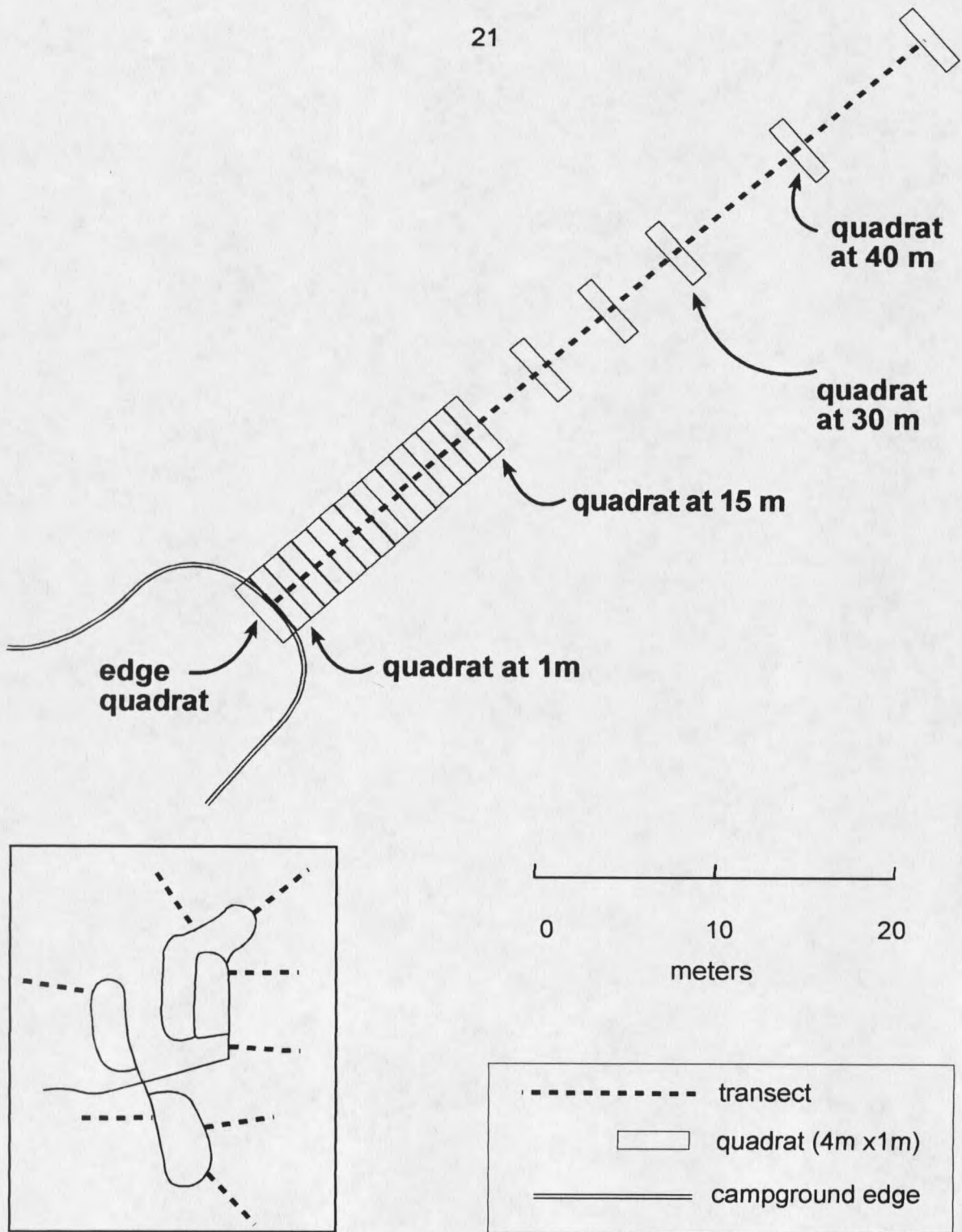


Figure 2. Location and orientation of quadrats along a transect.

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

mm), gravel (2 mm - 75 mm), and rock fragments including cobbles, stones and boulders (>75 mm)(Brady, 1990).

Percent canopy cover of overstory trees and shrubs, an indirect measurement of light availability, was measured using a spherical densiometer (Lemmon, 1957). The densiometer consisted of a circular spirit level which allowed leveling of the instrument and a concave mirror etched with a grid which reflected overstory canopy and allowed estimation of percent canopy cover above elbow height. The percent cover of ground that was disturbed ('disturbance cover') within a quadrat was visually estimated and recorded, as well as the type of disturbance such as a social trail, road and road edge, animal or human footprints, animal scat, and trampled grass. The density and percent cover of human-generated garbage (including pieces of paper and plastic, gum wrappers, cigarette butts, etc.) was noted as another indication of disturbance within a quadrat. The distance from a quadrat to a secondary disturbance such as a road, trail, river or campsite was measured if within 50 meters of the quadrat. Aspect and slope were also measured. The habitat type within which each transect was located was determined using a key to habitat types developed by the Park's plant ecologist Don Despain (1990) and GIS maps produced by the Branch of Advanced Resource Technology in Yellowstone National Park (1994).

Data Analysis

Exotic Plants and Distance from Campground Edge

The distributions of exotic plant cover and density in relation to distances from campground edges were analyzed with side-by-side boxplots for the campgrounds in which exotic plants were found. The Cox-Stuart test for trend was used to determine whether the mean, median, and third quartile observations of exotic cover and density exhibited an overall general trend with distance (Daniel, 1990).

Exotic Plants and Canopy Cover

A chi-square test was used to determine if an association existed between canopy cover and the presence of exotic plants. Three different canopy cover designations, 20%, 30% and 40%, were used for the analysis. Values above these thresholds were considered closed canopy for the analysis. Side-by-side boxplots of canopy cover versus the presence and absence of exotics were studied to determine if canopy cover conditions differed when exotics were found or were not found. A scatterplot was generated to display the relationship between Canada thistle cover and canopy cover for just those quadrats where the plant was found. Side-by-side boxplots were used to display the distributions of canopy cover when Canada thistle was present and absent for all

campgrounds, in order to understand similarities and differences in the canopy cover under which the plant was found and was not found.

Exotic Plants and Disturbance Cover

The relationships between disturbance within a quadrat and exotic plants were interpreted from scatterplots of disturbance cover versus exotic cover, and of trash density versus exotic cover. A chi-square test was used to determine if a significant association existed between disturbance and the presence of exotic plants. Side-by-side boxplots of disturbance cover when exotics were present and absent were studied to determine if differences in disturbance conditions existed when exotics were found or were not found. A graph of the cumulative presence of Canada thistle versus disturbance cover, relative to the total amount of disturbance found in all campgrounds, was used to discern the plant's relative abundance in disturbed soil. The relationship between disturbance indicators and the distributions of Canada thistle presence and absence for all campgrounds was interpreted from side-by-side boxplots.

Exotic Plants and Vegetation Variables

The relationships between vegetation variables measured in each plot and exotic plant cover was investigated using scatterplots. Side-by-side boxplots of exotic presence and absence versus the vegetation variables were interpreted for similarities or differences in the distributions. The relationship between vegetation

cover and the presence and absence distributions of Canada thistle was interpreted from side-by-side boxplots. By studying both presence and absence situations, it was hoped that potentially unique vegetative conditions where the plant was found would be realized.

Exotic Plants and Habitat Types

The habitat types in which exotic species were found were summarized in tabular form. Associations between habitat type, elevation ranges and canopy cover were described.

RESULTS

Six of the 11 campgrounds (Mammoth, Slough Creek, Madison, Norris, Grant Village, and Bridge Bay) contained 1 or more exotic species. Six species were found at Mammoth, including spotted knapweed, hound's-tongue, Canada thistle, dalmation toadflax, yellow sweetclover and common mullein. In all the other campgrounds, only 2 species were found (oxeye-daisy in 1 quadrat at Norris, and Canada thistle in 5 campgrounds). A total of 18 out of the 88 transects contained exotic plants: 8 at Mammoth, 4 at Slough Creek, 2 at both Norris and Bridge Bay, and 1 at both Madison and Grant Village. Due to the paucity of exotics found at campgrounds other than Mammoth, statistical analysis was restricted to 1) the exotics found at Mammoth, 2) the quadrats that contained Canada thistle, and 3) Canada thistle in relation to conditions at all campgrounds. The subheadings in this chapter ("Mammoth", "Canada Thistle Quadrats", and "All Campgrounds") refer to these 3 subsets of data. All data and results are on computer disks held in the Department of Earth Sciences at Montana State University.

Exotic Plants and Distance from Campground Edge

The relationships between exotic plant cover and distance from the campground edge and between exotic density and distance are displayed for the campgrounds that contained exotics (Figures 3 and 4). Within each boxplot: the circle with a horizontal line through it represents the median; the bottom and top

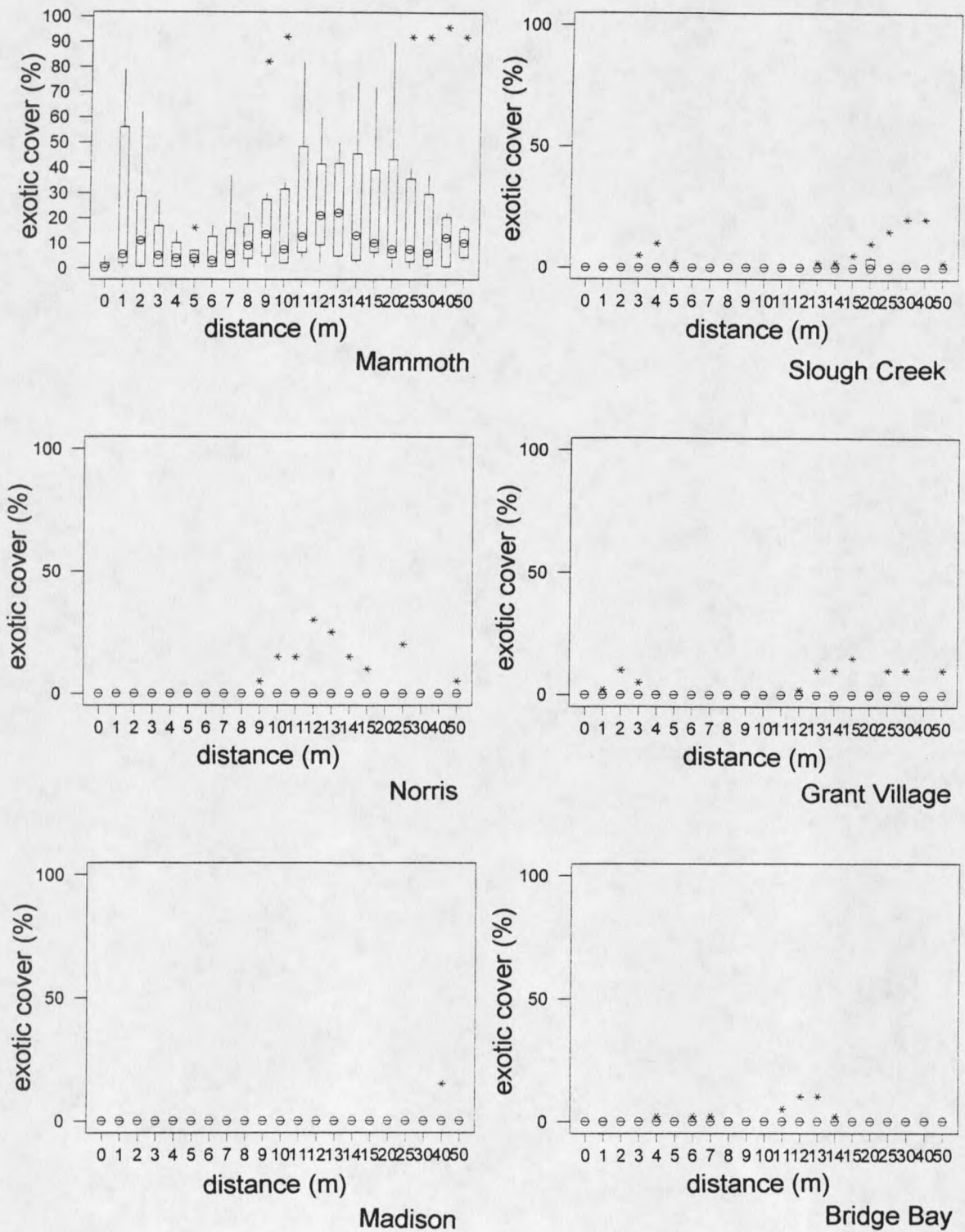


Figure 3. The distance from the campground edges versus exotic plant cover (%) for the 6 campgrounds where exotics were found

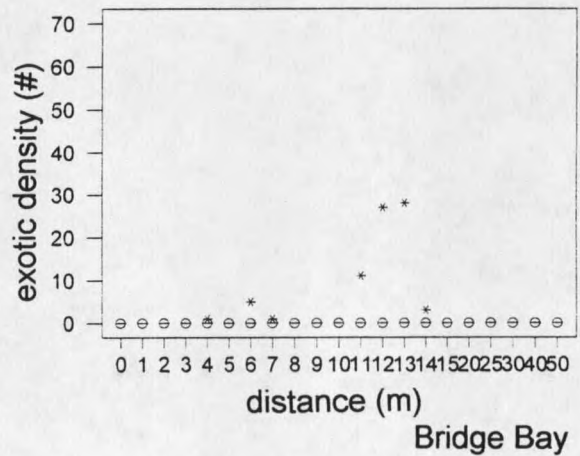
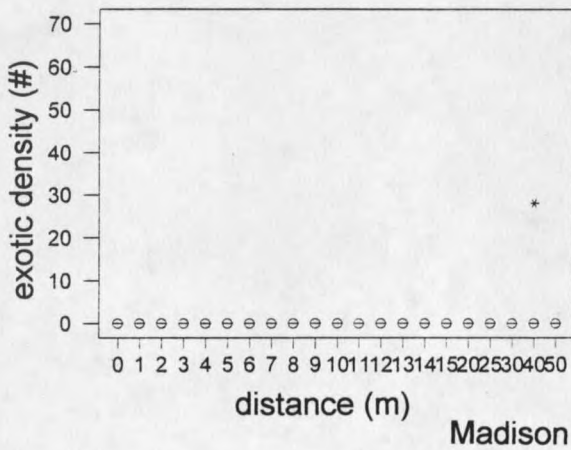
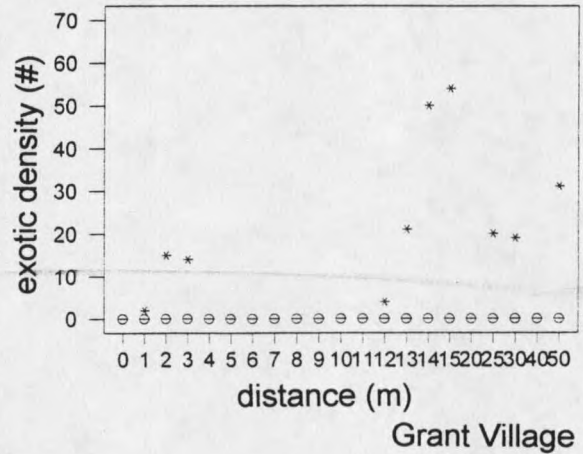
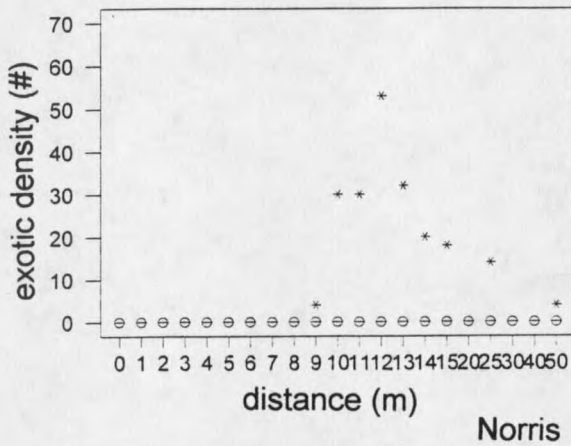
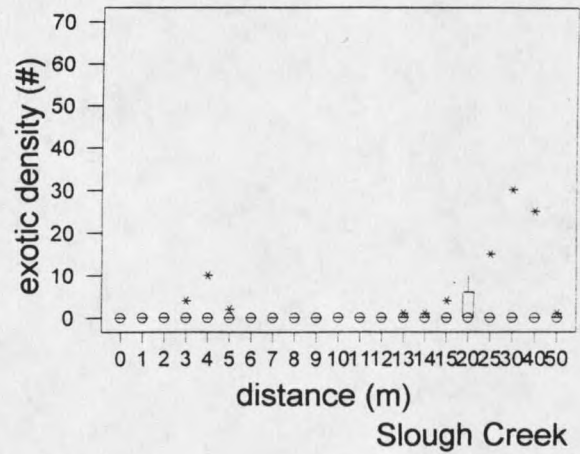
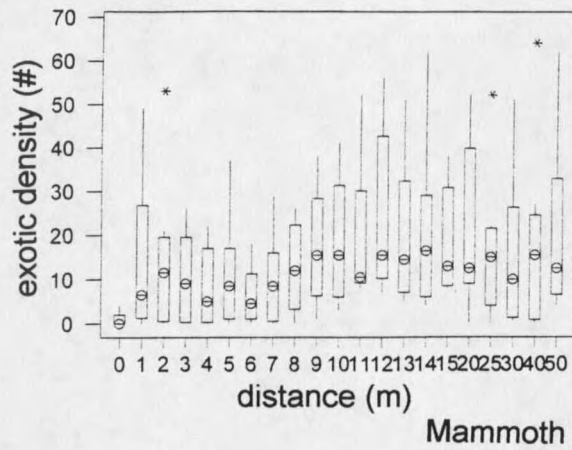


Figure 4. The distance from the campground edges versus exotic plant density (#) for the 6 campgrounds where exotics were found

of the box indicate the first (Q1) and third (Q3) quartiles, values at which 25% and 75%, respectively, of the observations fall at or below; the vertical size of the box represents the interquartile range (IQR), a simple measure of spread that gives the range covered by the middle half of the data (Moore and McCabe, 1993); whiskers extending beyond the bottom and top of the box indicate the smallest value that is greater than or equal to $Q1 - 1.5IQR$ and the largest value that is less than or equal to $Q3 + 1.5IQR$, respectively; and the asterisks (*) signify outliers beyond the values of the whiskers. Where an asterisk occurs alone, and the median, first quartile, and third quartile all occurred at zero, exotic plants were recorded in only 1 out of the possible 8 quadrats at a given distance.

Exotic plants in campgrounds other than Mammoth tended to occur between approximately 12 and 50 meters from the campground edges (Figures 3 and 4). No apparent decreasing trend in exotic cover and density with increasing distance from the campground edges was found, due to the lack of exotics located in these campgrounds. Canada thistle was the only species found at Slough Creek (4 transects), Bridge Bay (2 transects), Grant Village (1 transect), and Madison (1 transect). Norris contained both Canada thistle (2 transects) and oxeye-daisy (1 transect).

Mammoth

Exotic Cover and Density versus Distance. At Mammoth campground, exotics occurred at all measured distances from the campground edge (Figures 3

and 4). The variability in exotic cover, expressed as the IQR, decreased beyond 1 meter away from the campground edge out to 5 meters, and the median cover decreased beyond 2 meters out to 6 meters (Figure 3). This trend suggests that the probability of observing greater exotic cover is higher closer to the campground edge than further away, out to 5 or 6 meters, based on the sample taken in this study. Beyond 6 meters, the median and variability in exotic cover generally increased and then decreased with increasing distance from the campground edge. Mean exotic cover showed a similar trend (Figure 5). The mean cover decreased from 1 meter to 5 meters from the campground edge, increased out to 11 meters, and showed a decreasing trend beyond 11 meters. This data supports the first hypothesis, since the distribution of exotics decreased with distance from the campground edge, out to 5 and 6 meters. Beyond this point, factors other than distance from campground edge disturbance, such as canopy cover or other disturbances, may have contributed to the increase and eventual decrease in exotic cover.

The variability in exotic density decreased overall with distance from the Mammoth campground edge, from 1 meter to 6 meters (Figure 4). The median density decreased from 2 meters to 4 meters, beyond which it fluctuated up and down at less than 20 plants per quadrat. Mean density also decreased initially from the campground edge (from 1 meter to 4 meters), increased from 6 meters to 12 meters, and showed a decreasing trend beyond 12 meters (Figure 5). This

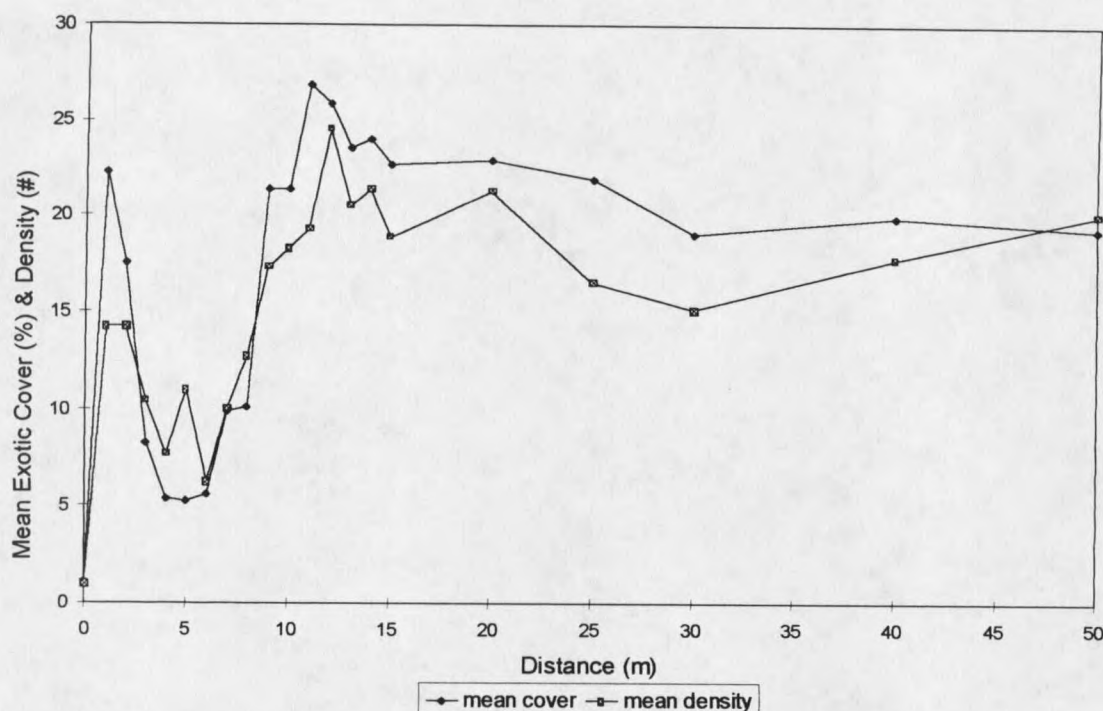


Figure 5. Mean percent cover and density of exotic plants at Mammoth.

data suggests that the density of plants decreased with distance from the campground edge out to about 4 meters.

Trend in Exotic Cover and Density with Distance. The null and alternative hypotheses for the Cox-Stuart test for trend were: H_0 = there is no upward trend in the mean, median or third quartile observation of exotic plant cover and density, and H_A = there is an upward trend in the mean, median or third quartile observation. The data was first divided into two equal-sized groups based on distance (observations within 10 meters of the campground edge and those further than 10 meters). Observations from each group were systematically paired (e.g. the observation from 0 meters was paired with that from 11 meters, 1 meter

was paired with 12 meters, 2 meters with 13 meters, etc.). Each pair was classified as to whether the observation closer to the edge was greater than or less than the more distant observation. The total number of greater than and less than cases was calculated and then tested for statistical significance. The data would support the conjecture of an upward trend if the magnitudes of the more distant observations tended to exceed those of the closer observations. If the values of the closer observations tended to be greater than those of the more distant observations, then there would be evidence of a downward trend.

Results of the Cox-Stuart test for trend provide evidence for an overall upward trend with distance in the mean, median, and third quartile percent cover and density of all exotics found at Mammoth (Table 5). All p-values consistently indicated a general trend of higher exotic cover and density at greater distances (11 meters to 50 meters) from the campground edge. This increase in exotics with distance is likely a result of a combination of factors. Viable seed availability,

Exotic Measurement		P-value
Percent Cover	Mean	0.0108**
	Median	0.0108**
	Third quartile	0.0547*
Density	Mean	0.0010***
	Median	0.0108**
	Third quartile	0.0010***

Table 5. Results of the Cox-Stuart test for an upward trend in the mean, median and third quartile observation of exotic plant percent cover and density at Mammoth campground.

* = significant at 0.10 level

** = significant at 0.05 level

*** = significant at 0.01 level

canopy cover, disturbance within a quadrat, and proximity to roads and trails may all play a role in the high number of exotics colonizing far from the edge of campground disturbance.

Canada Thistle Quadrats

Canada thistle was the only exotic species found outside of Mammoth, with the exception of one quadrat at Norris that contained oxeye-daisy. All 39 quadrats that contained Canada thistle were combined and analyzed to determine potential factors influencing the plant's distribution. The greatest presence of Canada thistle was found between 11 and 15 meters and between 30 and 50 meters from the campground edges, indicated by the steepest slope of the cumulative relative frequency between these distances (Figure 6). The gentler slope at distances less than 11 meters indicates a slightly lower abundance of the plant close to the campground edges.

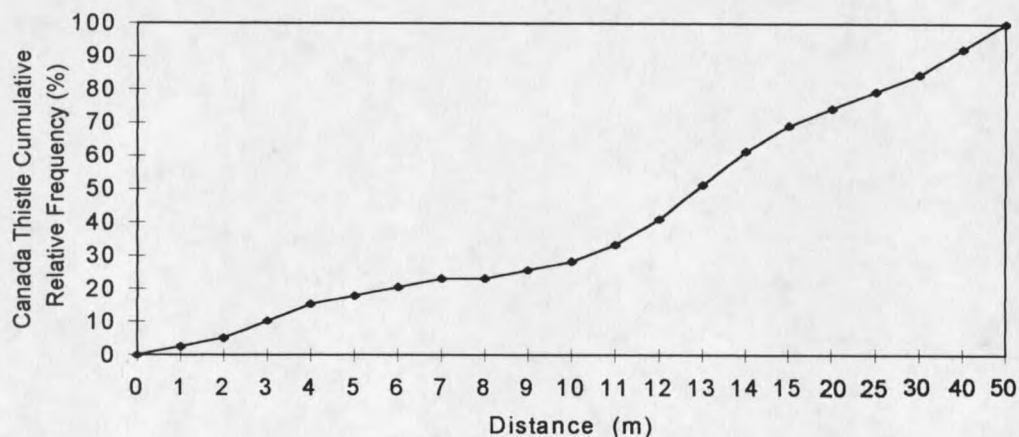


Figure 6. Distance from campground edges versus the cumulative relative frequency (%) of Canada thistle for only those quadrats that contained the plant.

Exotic Plants and Canopy Cover

Mammoth

Exotic Presence and Canopy Cover. The results of chi-square tests were used to determine if an association existed between canopy cover and the presence of exotic plants at Mammoth (Table 6). The null and alternative hypotheses were stated as H_0 : canopy has no effect on the presence of exotics, and H_A : canopy has an effect on the presence of exotics. Three different canopy cover threshold values (Table 6) were used as potential dividing points between open and closed canopy designation. Canopy covers above the thresholds were classified as closed canopy for the chi-square analysis. Expected frequencies in all cells of the 2-by-2 contingency tables used for the tests were at least 5.

The chi-square analyses indicate a significant association existed between canopy cover and the presence of hound's-tongue, spotted knapweed and yellow sweetclover (Table 6). In the case of hound's-tongue, under all three open/closed canopy threshold designations, more plants were observed than expected (assuming H_0 is true) under closed canopies and less were observed than expected under open canopies, suggesting that hound's-tongue prefers or tolerates more closed canopies, and consequent shade. Hound's tongue tended to be found under higher canopy covers than any other exotic species at Mammoth (Figure 7). The presence of spotted knapweed and yellow sweetclover was directly related to open canopy conditions (Table 6). In all three open/closed

Canopy cover (%)	Exotic plant(s)	Chi-square	P-value
20	all	0.940	0.3323
30	"	1.334	0.2481
40	"	2.047	0.1525
20	hound's-tongue	18.476	0.0000***
30	"	5.483	0.0192**
40	"	2.853	0.0912*
20	spotted knapweed	7.920	0.0049***
30	"	3.859	0.0495**
40	"	3.047	0.0809*
20	dalmation toadflax	0.036	0.8495
30	"	0.025	0.8744
40	"	0.017	0.8963
20	yellow sweetclover	19.313	0.0000***
30	"	5.797	0.0161**
40	"	3.053	0.0806*
20	mullein	2.098	0.1475
30	"	2.208	0.1373
40	"	1.743	0.1868
20	Canada thistle	0.355	0.5513
30	"	0.173	0.6775
40	"	0.137	0.7113

Table 6. Results of chi-square tests used to determine the association between canopy cover and exotic plant presence at Mammoth campground.

* = significant at 0.10 level

** = significant at 0.05 level

*** = significant at 0.01 level

canopy delineations, there were more spotted knapweed and yellow sweetclover plants than expected (assuming H_0 is true) under open canopy conditions, and less of both species than expected under closed canopies. Spotted knapweed was never found in an area with more than 20% canopy (Figure 7). In only 8% of the quadrats in which yellow sweetclover was present was the canopy cover greater than 40% (Figure 7). The statistical significance of the relationship

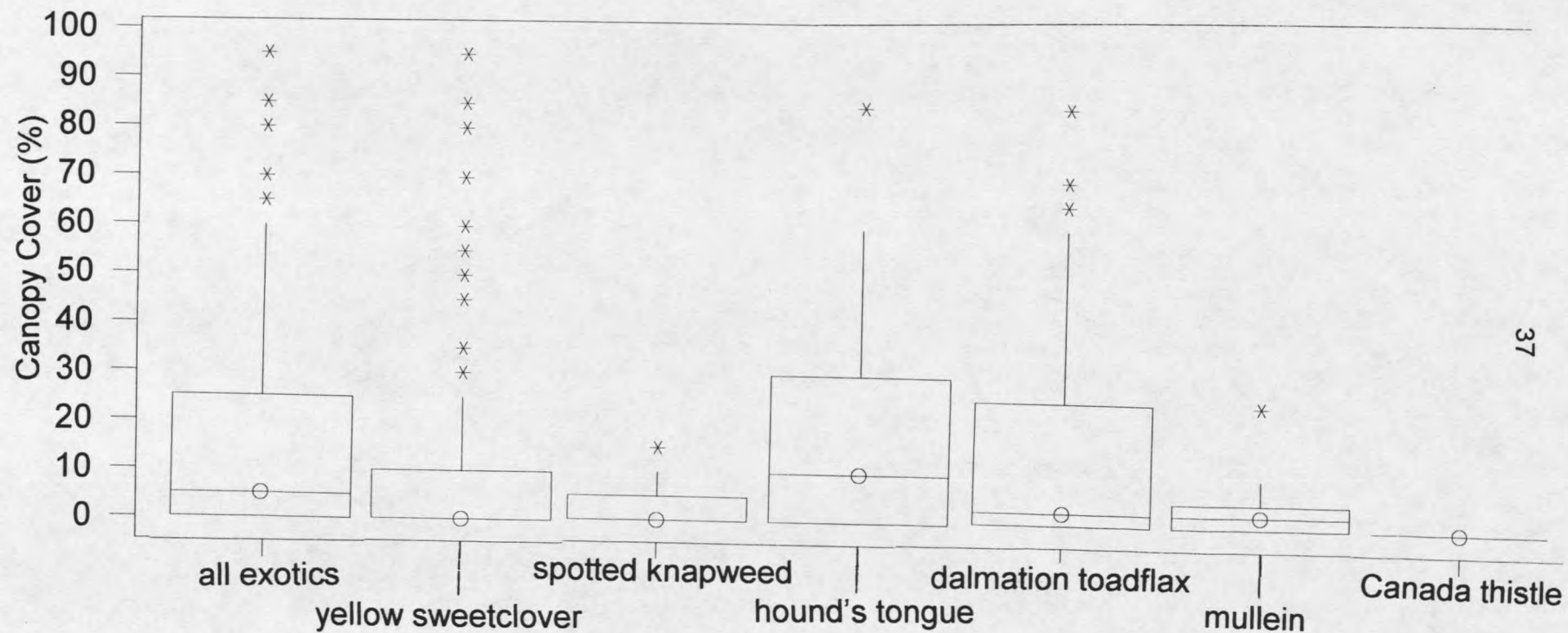


Figure 7. Side-by-side boxplots showing the distribution of canopy cover where yellow sweetclover, spotted knapweed, hound's tongue, dalmation toadflax, Canada thistle, mullein and all exotics combined were found at Mammoth.

between canopy and each of the three species is stronger the lower the closed canopy designation (20% vs. 30% vs. 40%) (Table 6). The statistically significant results of the chi-square test support the second hypothesis, that the presence of exotics will be greater under a more open canopy than a more closed canopy, for both spotted knapweed and yellow sweetclover. The opposite is true for hound's-tongue.

No significant relationships were found to exist between canopy cover and the presence of dalmation toadflax, mullein, or Canada thistle (Table 6). However, in those cases when mullein was found, only 8% of the time was it growing beneath a canopy cover greater than 20%. Mullein was never found in 30% canopy cover or greater (Figure 7). Canada thistle was only found in one quadrat at Mammoth, under less than 20% canopy. The presence of Canada thistle in other campgrounds may provide more information on its ability to grow under variable light conditions. Dalmation toadflax was found growing under a wide range of canopies, from 0 to 85% (Figure 7).

No significant association was found between canopy cover and the presence of all the exotics combined at Mammoth (Table 6). This reflects the differences, as described above, in the types of associations between individual species and canopy cover (canopy-tolerant versus canopy-intolerant), and the lack of a significant association for some species. Eighty-four percent of the time that exotics were present, the plants grew under a canopy cover of 30% or less (Figure 8). Exotics were also present in higher percent covers and densities at

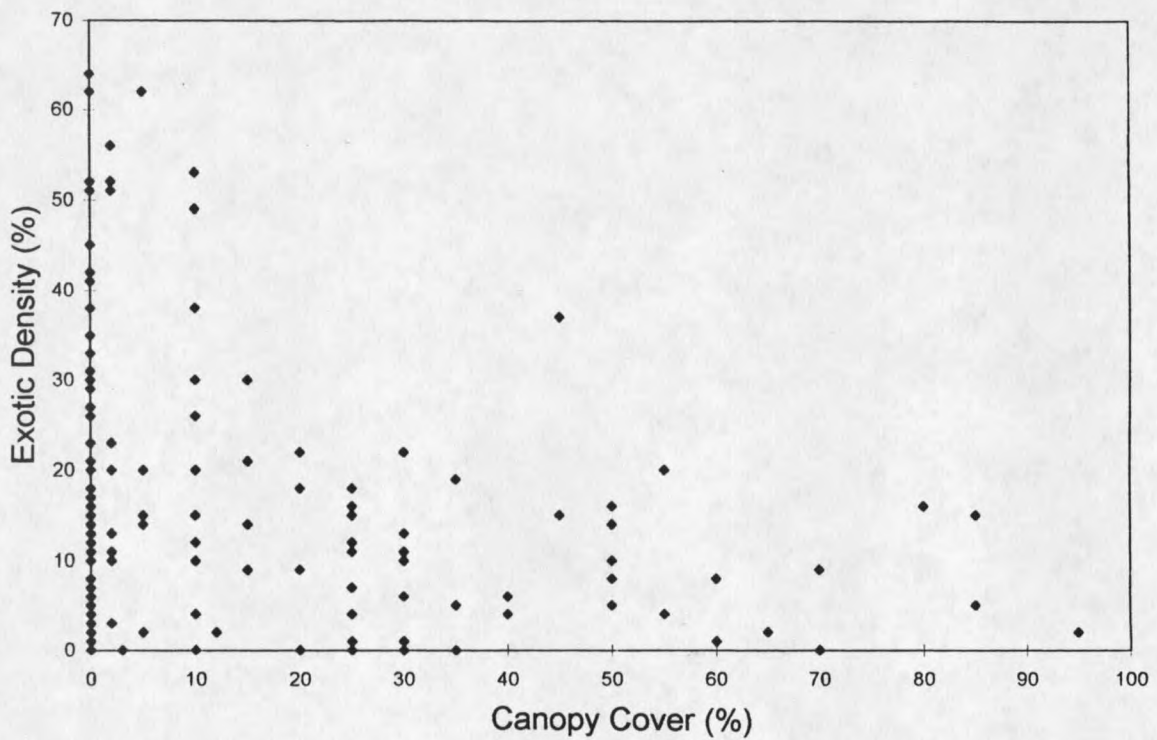
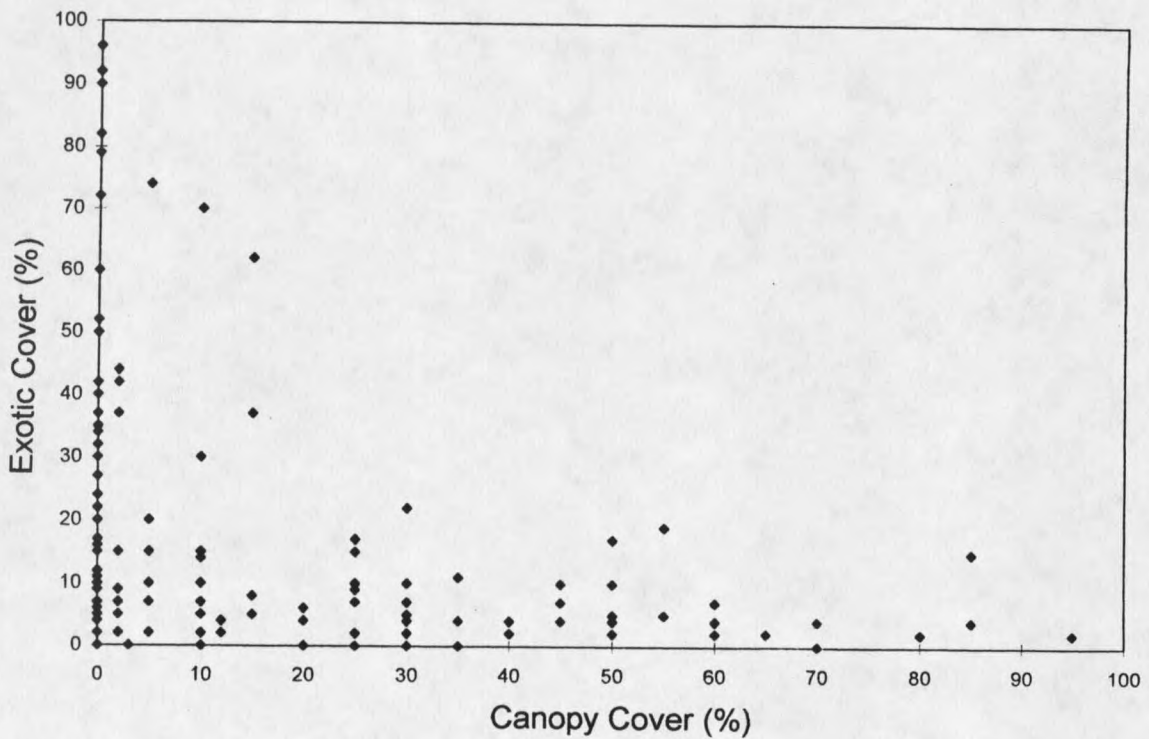


Figure 8. Canopy cover versus exotic plant cover and density for all exotics found at Mammoth

lower canopy covers. Although these results suggest an apparent pattern of increased exotic presence under a more open canopy (0 to 30%), results of the chi-square analysis indicate that the second hypothesis is not supported when all exotics are combined at the Mammoth campground.

Exotic Presence and Absence versus Canopy Cover. Where exotics were present at Mammoth (144 cases), a greater interquartile range and therefore more variable canopy covers existed than where the plants were absent (24 cases) (Figure 9). The median and third quartile canopy measurements were slightly greater where exotics were found than where exotics were absent. The side-by-side boxplots suggest that canopy covers under which no exotics occurred fell within the spread of canopy covers found under which exotics did occur.

Canada Thistle Quadrats

An analysis of the data from only those quadrats where Canada thistle was found showed that the occurrence and cover of Canada thistle decreased with increasing canopy cover (Figure 10). Eighty-seven percent of the time Canada thistle was found, it grew under a canopy cover of 20% or less. Since Canada thistle's cover ranges from less than 5% to 30% at low canopy covers (less than 20%), the linear relationship between the two variables is negligible ($r^2 = 1.2\%$).

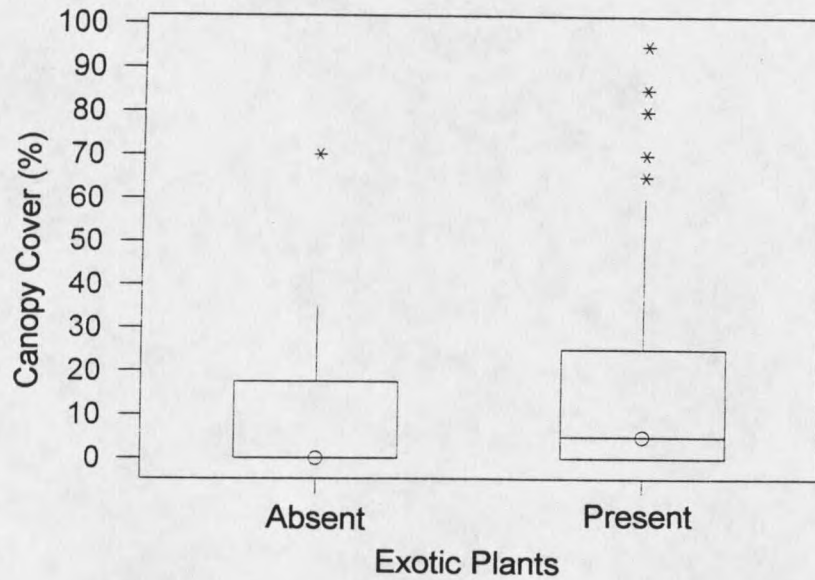


Figure 9. Side-by-side boxplots showing the distribution of canopy cover at Mammoth where exotics were present and absent.

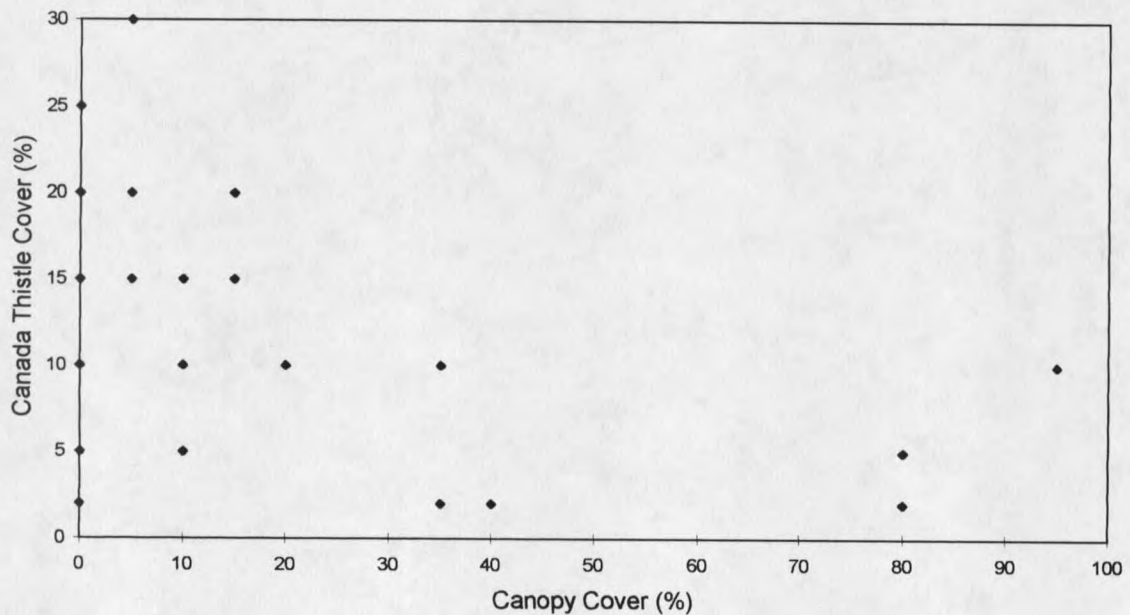


Figure 10. The relationship between canopy cover and Canada thistle cover for only those quadrats where the plant was found.

All Campgrounds

The median, first quartile, and third quartile canopy measurements were smaller when Canada thistle was present (39 quadrats) than when it was not present (1809 quadrats), suggesting that the plant tended to colonize under more open canopies than the canopies corresponding to the cases when it was absent (Figure 11). The interquartile range was also smaller when Canada thistle was present, suggesting the plant colonized beneath less variable canopy covers than occurred where it was absent. Where the plant was absent, 75% of canopy cover measurements were 50% or less, whereas when present, 75% of canopy cover observations were only 15% or less. Canada thistle appears to prefer more open canopies (Figures 10 and 11), however its occasional presence under more closed canopy covers (up to 95%) suggests it can grow in shade.

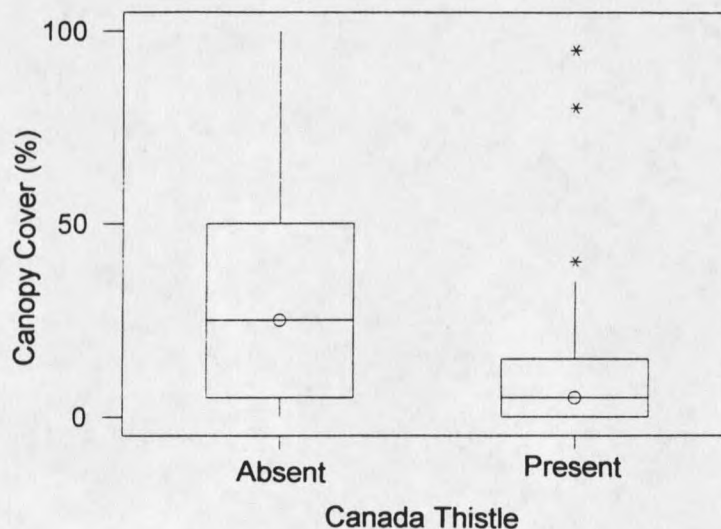


Figure 11. Side-by-side boxplots of the distributions of canopy cover when Canada thistle was absent and present at all campgrounds.

Exotic Plants and Disturbance Cover

Mammoth

A general trend of decreasing exotic plant cover with increasing disturbance was found at the Mammoth campground (Figure 12). Almost 40% of the quadrats at Mammoth contained no visible disturbance, as indicated by the points at 0% disturbance on Figure 12. When disturbance was noted, it was found to cover 20% or less within a quadrat in almost three-quarters of the quadrats. Sixty-six percent of the time that exotics were found growing in or near disturbed soil, the quadrat contained 20% or less disturbed soil.

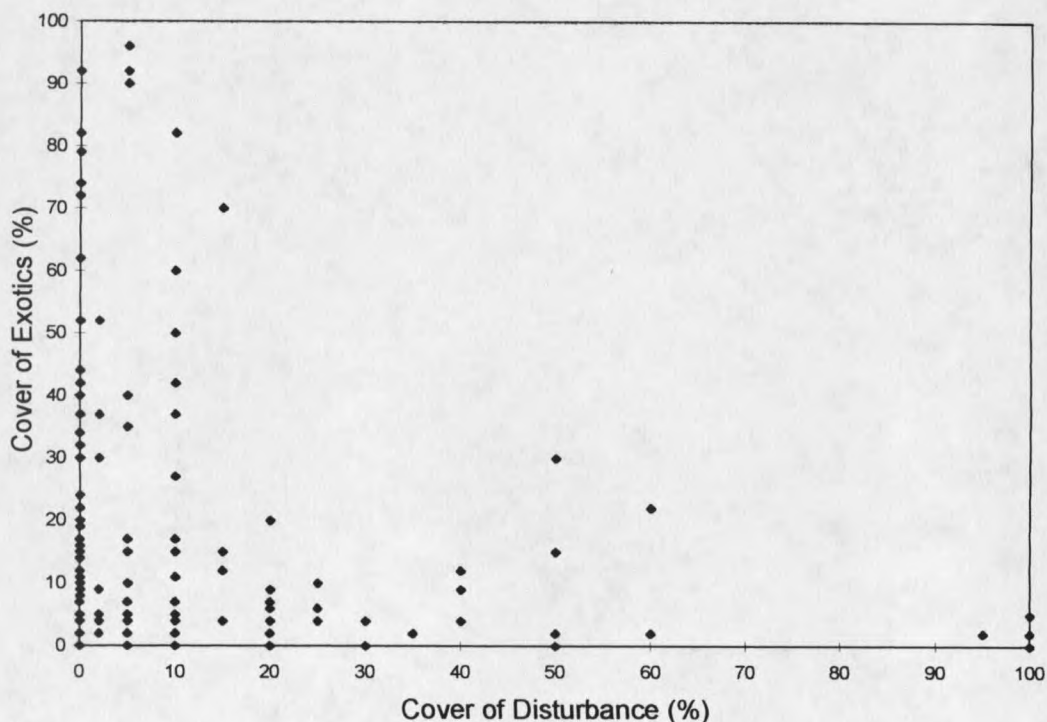


Figure 12. The cover of disturbance versus exotic cover at Mammoth campground.

Trend in Disturbance Cover with Distance. A Cox-Stuart test for trend was used to determine if a significant trend was present in the percent cover of disturbance within a quadrat as distance from the campground edge increased. The null and alternative hypotheses were stated as H_0 : there is no trend present in the data; and H_A : there is either an upward trend or a downward trend. No significant trend was found in the mean, median, and third quartile disturbance covers (level of significance = 0.05) (Table 7). Exotic cover also showed no relationship to the amount of human-generated garbage in the campground. A National Park Service employee was observed picking up trash in the Mammoth campground, providing a partial explanation for the minute amount found.

Disturbance Measurement		P-value
Percent Cover	Mean	0.3770
	Median	0.3770
	Third quartile	0.1719

Table 7. Results of Cox-Stuart test for trend in percent cover of disturbance within a quadrat as distance from the Mammoth campground edge increased.

Exotic Presence and Disturbance Cover. A disturbance threshold of less than or equal to 20%, based on Figure 12, was used for a chi-square test of association between disturbance and the presence of exotic plants at Mammoth (Table 8). The results (significant at the 0.01 level) suggest that colonization by exotics is favored by low levels of disturbance (20% or less) at Mammoth.

Variable	Chi-square	P-value
Disturbance	13.599	0.0002

Table 8. Results of a chi-square test used to determine the association between disturbance within a quadrat and exotic plant presence at Mammoth campground.

Exotic Presence and Absence versus Disturbance Cover. Seventy-five percent of the time exotics were found at Mammoth, they occurred in 10% or less disturbance (Figure 13). The striking difference between the third quartile disturbance cover when exotics were present (10%) and when exotics were absent (100%) is partly due to the fact, mentioned above, that almost three-quarters of the time that disturbance was noted, it covered 20% or less of a quadrat. Exotics occurred most frequently at low covers partially because those are the conditions most commonly encountered at Mammoth. Only 15 quadrats contained between 30% and 90% disturbance, 7 of which contained exotics. The third quartile value when exotics were absent (100%) is due to 9 (out of 24) quadrats that contained 100% disturbance. When disturbance covers were 100%, the disturbance was consistently a road or gravel road edge. The low number of exotics in 100% disturbed ground is probably a result of too much or too frequent disturbance for the plants to become established and survive.

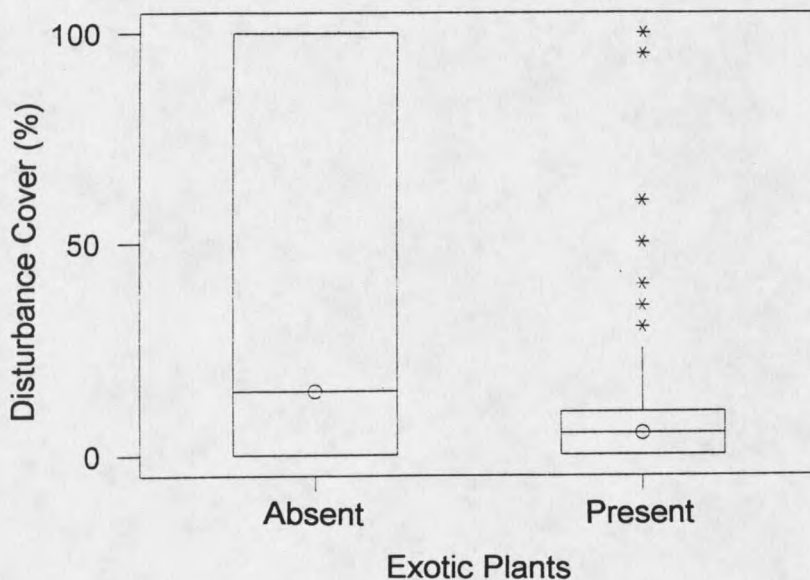


Figure 13. Side-by-side boxplots showing the distribution of disturbance cover when exotics were present and absent at Mammoth.

Canada Thistle Quadrats

Canada thistle was found growing within quadrats that contained from 0 to 100% disturbed ground. When disturbance and Canada thistle were both present, the plant was consistently rooted within the disturbance. Sixty-five percent of the time that Canada thistle was found growing in disturbed soil, it colonized a disturbed area that occupied between 5% and 30% of the quadrat (Figure 14). When Canada thistle was established in disturbed soil, 52% of the time it grew in disturbed bare ground, 23% in trampled grass, 16% in human footprints, and 13% in social trails. Canada thistle occurred in undisturbed soil in 21% of the quadrats in which it was present. Another scatterplot showed no relationship between

Canada thistle and the amount of human-generated garbage. These data suggest that Canada thistle prefers low levels of disturbance, but is able to colonize a wide variety of disturbance conditions, from undisturbed to 100% disturbed ground.

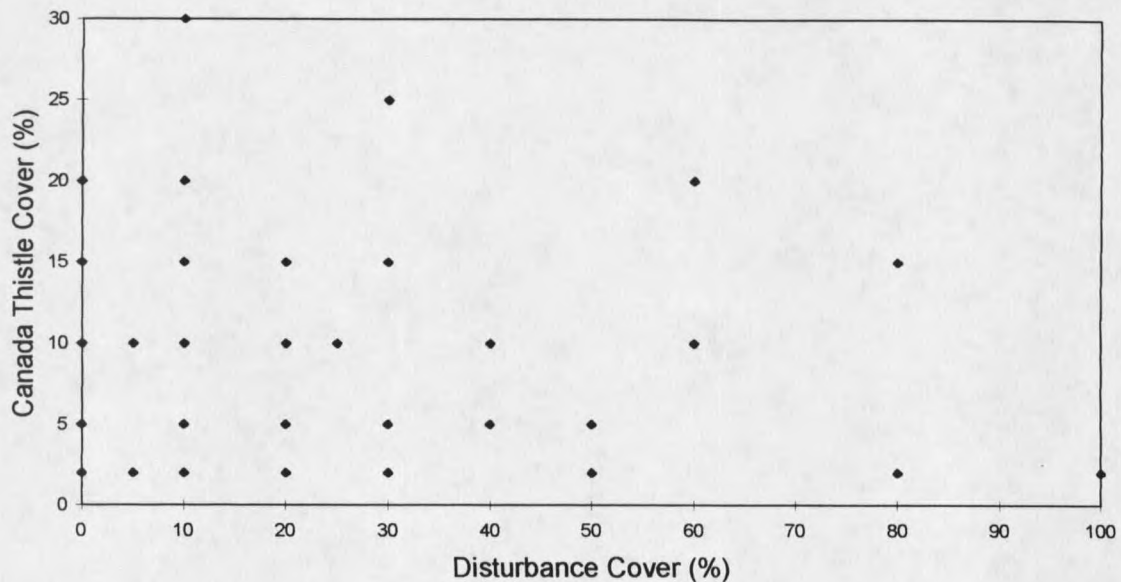


Figure 14. The relationship between the cover of disturbance within a quadrat and Canada thistle cover for cases where the plant was found.

All Campgrounds

Canada Thistle Cumulative Presence Relative to Disturbance Cover. The cumulative presence of Canada thistle plotted against disturbance cover provided an indication of the abundance of Canada thistle relative to the cumulative amount of disturbance cover found in all campgrounds (Figure 15). For example, Canada thistle was present in undisturbed ground (0% disturbance cover) 1.1%

of the time that undisturbed ground was recorded. The positive slope between 5% and 40% disturbance cover indicates that Canada thistle presence was increasing, or there was an increasing chance of finding Canada thistle from 5% to 40% disturbance cover. The flat slope above 60% disturbance cover suggests that there was no difference in the abundance of Canada thistle at disturbance covers above 60% relative to the total number of times disturbance was found in these higher covers. That is, there was no effect of disturbance when covers exceeded 60%.

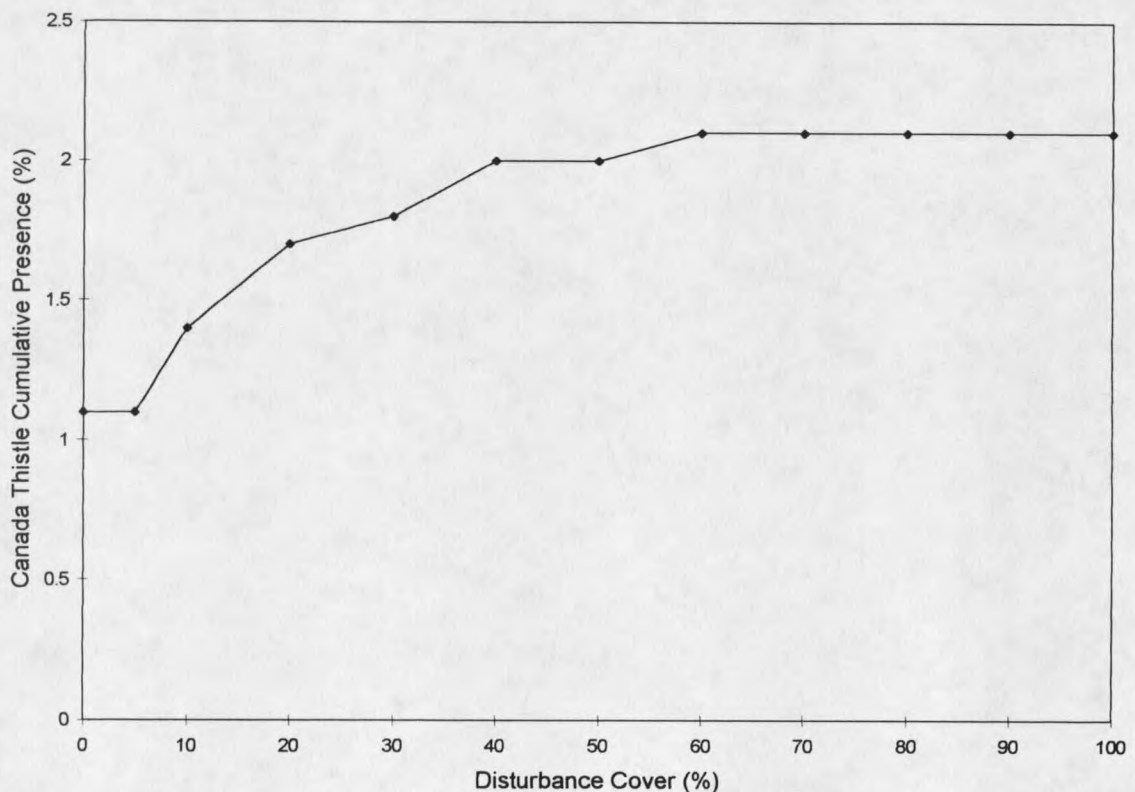


Figure 15. Disturbance cover versus the cumulative percentage of time Canada thistle was present. All campground data was used.

Canada Thistle Presence and Absence versus Disturbance Cover. A slightly higher median disturbance cover value (20%) existed when Canada thistle was present than when it was absent (10%), suggesting the plant colonized slightly higher disturbances than were found when the plant was absent (Figure 16). The greater variability in disturbance covers where the plant was present suggests the plant's tolerance of a wide range of disturbance conditions. The median disturbance cover where Canada thistle was absent (10%) falls within the spread of values (5%-40%) recorded where Canada thistle was most commonly found. Both when Canada thistle colonized a site and when it did not, disturbance cover ranged from 0% to 100%.

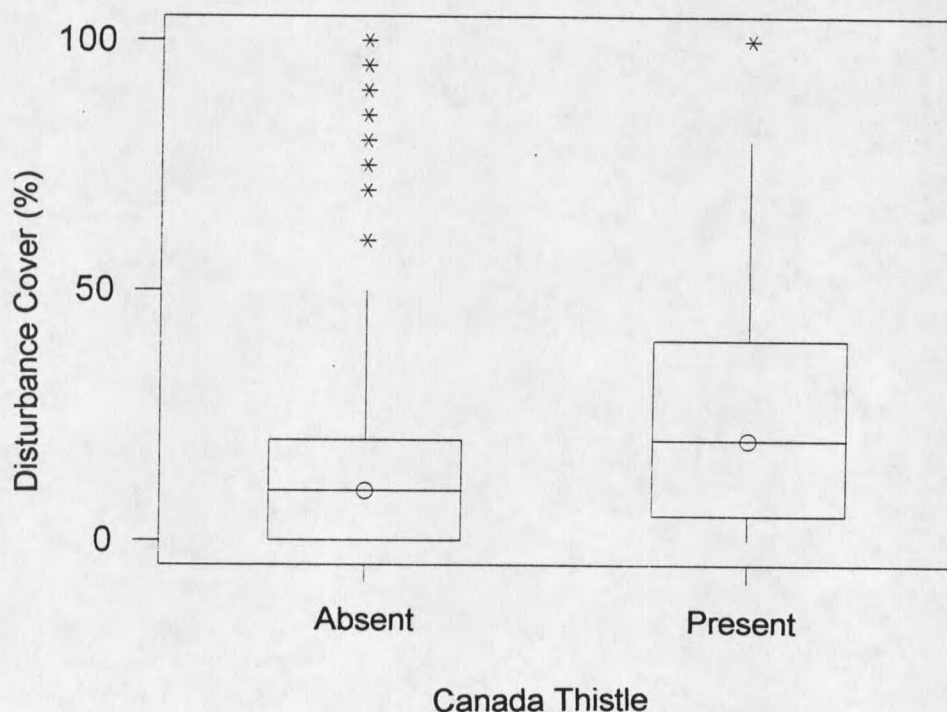
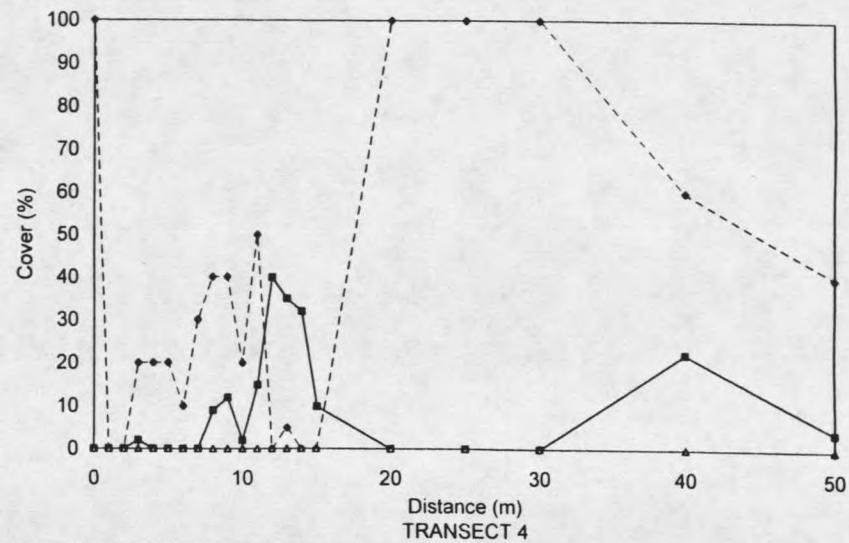
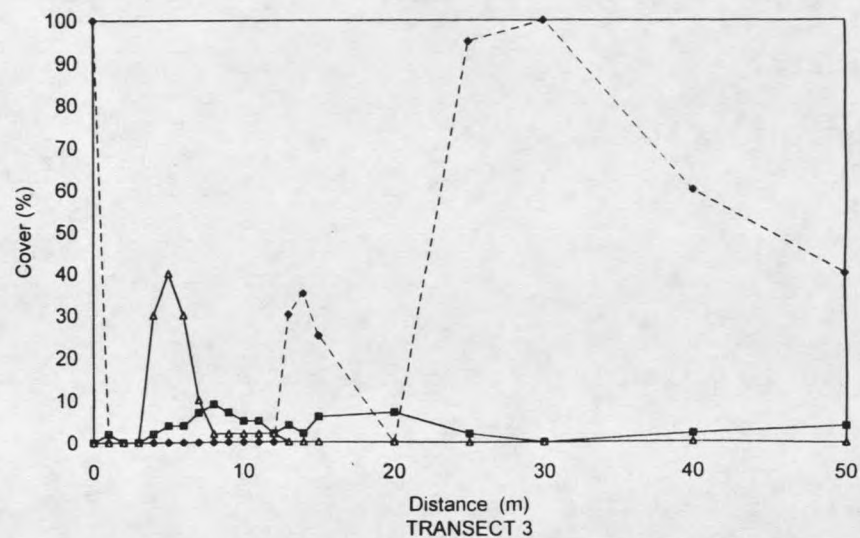
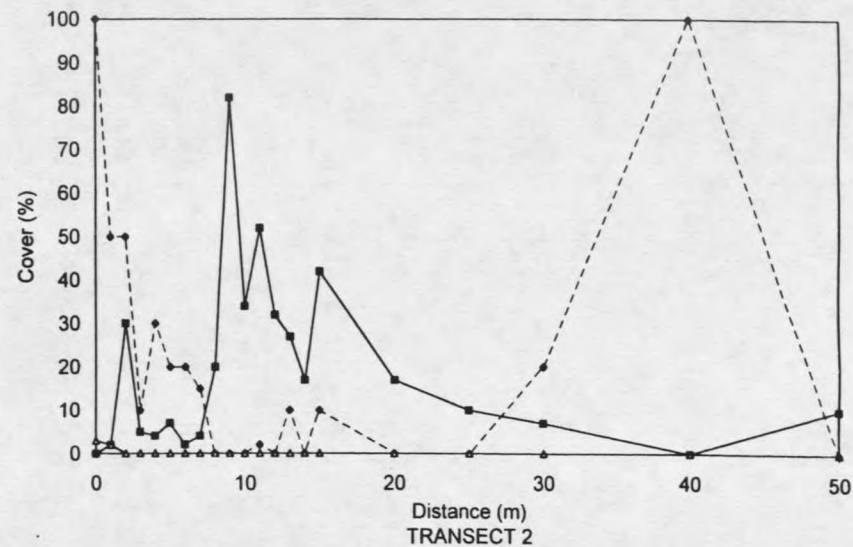
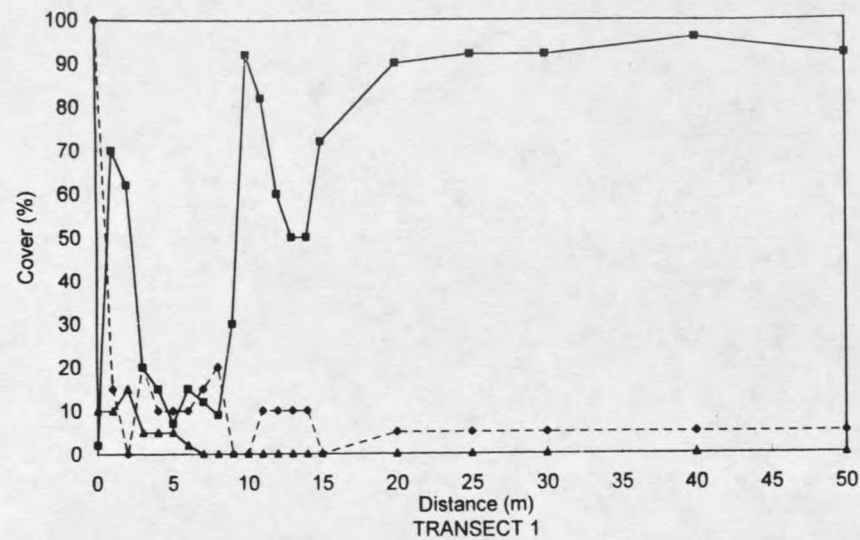


Figure 16. The relationship between disturbance cover within a quadrat and the presence and absence of Canada thistle for all campgrounds.

Exotic Plant, Canopy and Disturbance Covers at Mammoth

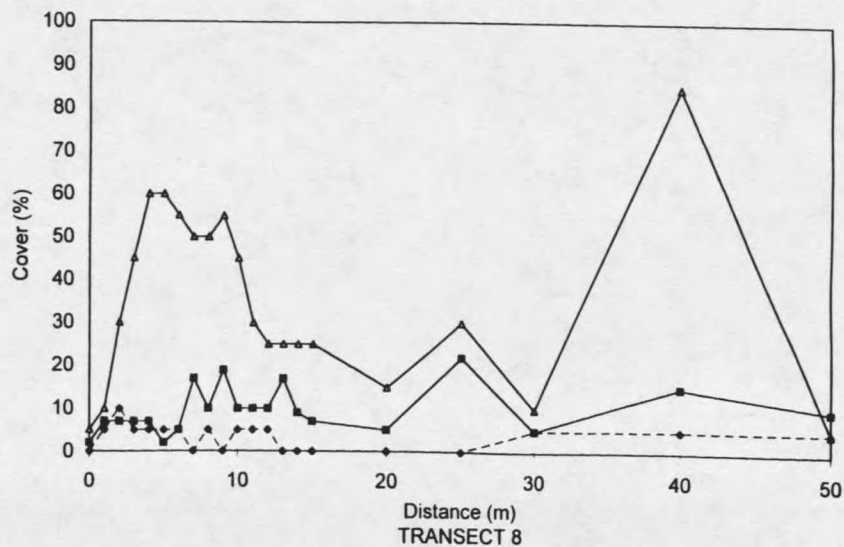
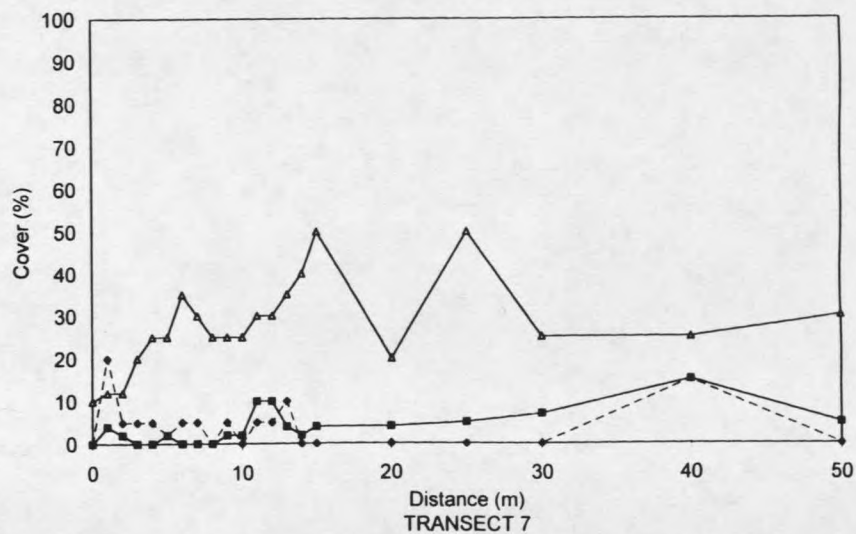
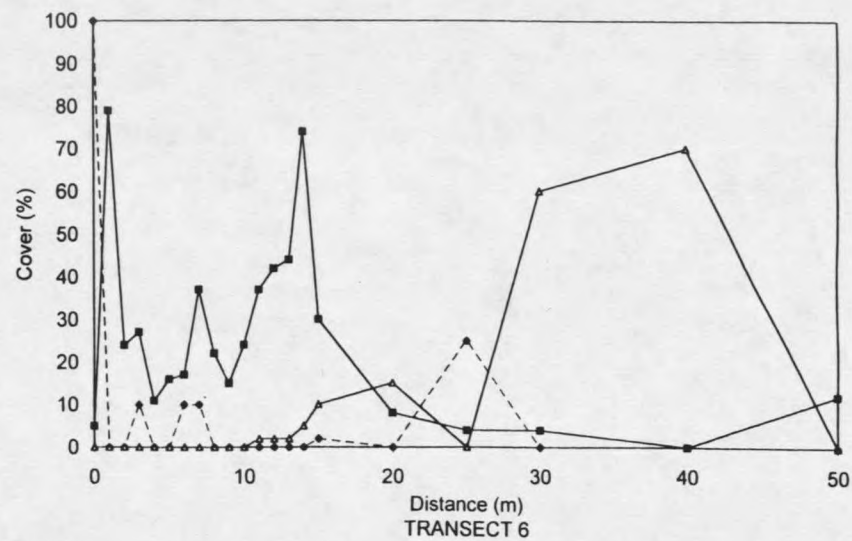
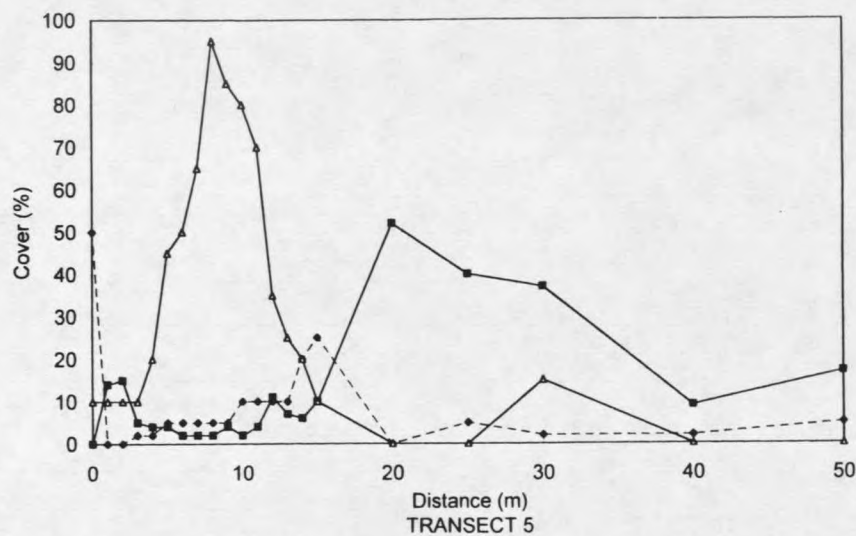
The covers of exotic plants, canopy and disturbance were plotted together against distance for the 8 individual transects at Mammoth to visually discern unique patterns in exotic covers that may be explained by the covers of canopy and disturbance (Figure 17). The pattern of high exotic covers at distances greater than 10 meters found in transect 1, largely a result of yellow sweetclover presence, dominates the pattern seen in Figures 3 and 5, and can be explained, in part, by low canopy and disturbance covers. The highest exotic covers in most of the transects occurred where canopy and disturbance covers were low, which is consistent with results previously discussed. In transects 2, 3 and 4, where the covers of disturbed ground increased markedly between 20 and 40 meters, the transects laid within or near the road and the covers of exotics and canopy are correspondingly low. The only exception to this is in transect 4, where the 20% exotic cover found in 60% disturbed ground at 40 meters from the campground edge is a patch of Canada thistle growing in a road edge berm. In transects 7 and 8, where the highest exotic covers were found under higher canopies (>25%) than in the other transects, hound's tongue was always the species found. This finding is consistent with the results of the chi-square analysis that showed hound's tongue to be associated with a more closed canopy.

The mean covers of individual species, all exotics, canopy and disturbance at Mammoth plotted against distance provides further indication of which species had the greatest effect on overall patterns (Figure 18). Yellow sweetclover was



—■— all exotics ◆..... disturbance —▲— canopy

Figure 17. Exotic plant, canopy and disturbance covers along the 8 transects at Mammoth.



—■— all exotics ◆..... disturbance —▲— canopy

Figure 17 continued

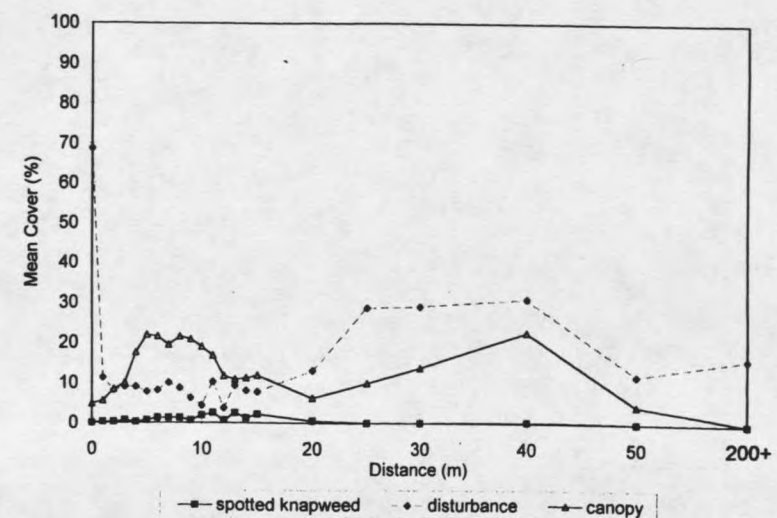
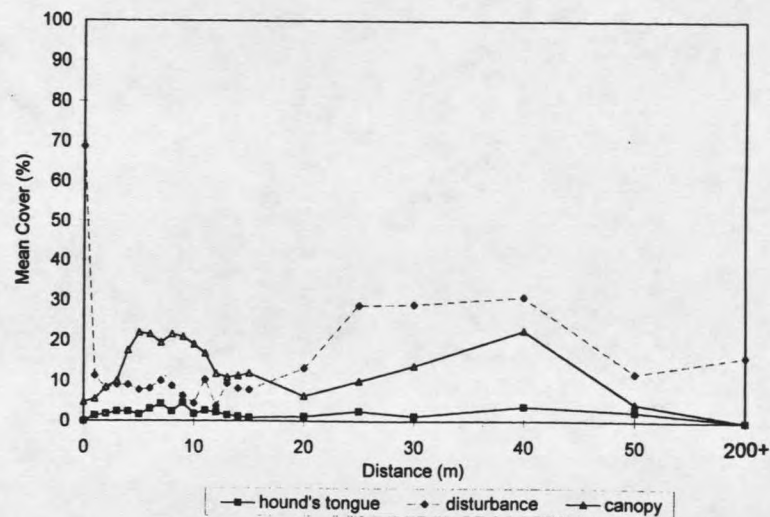
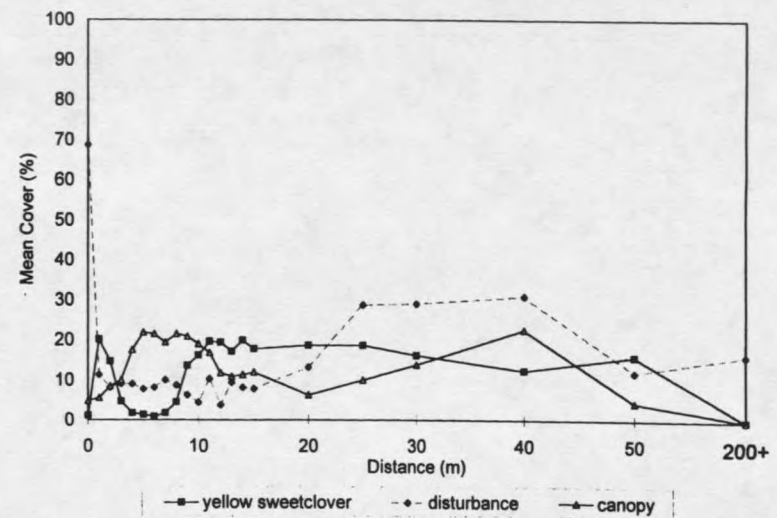
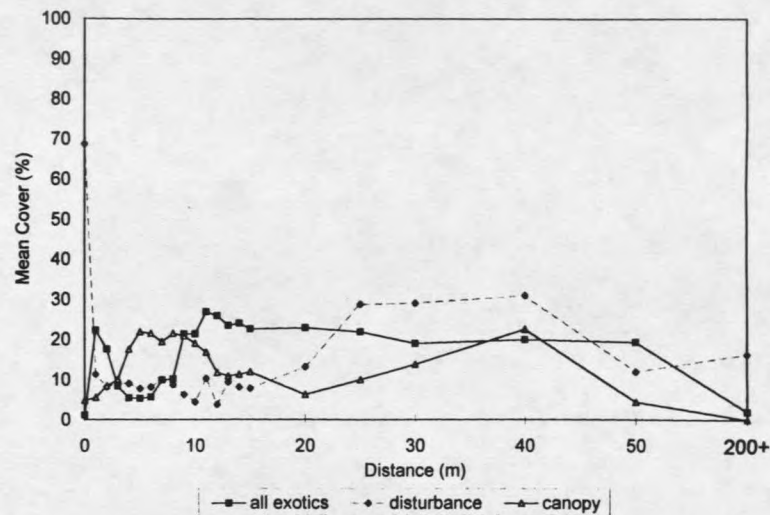


Figure 18. Mean exotic plant, canopy and disturbance covers by species at Mammoth. Includes measurements taken in the 8 Mammoth control quadrats, 200+ meters from human disturbance.

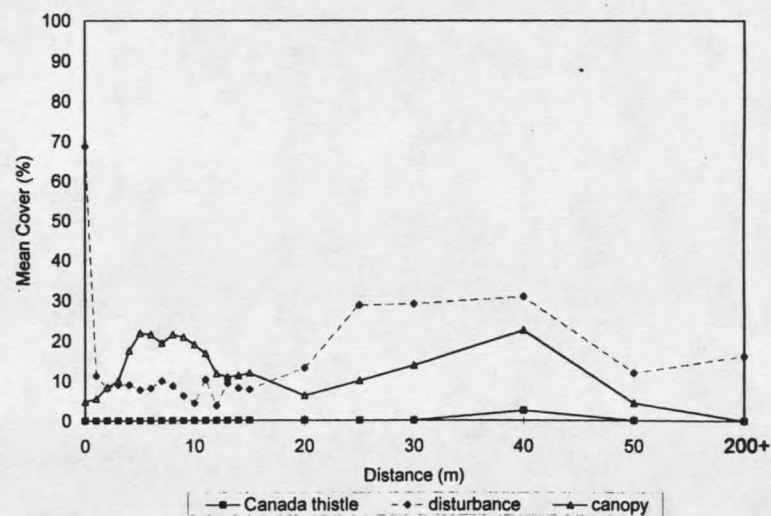
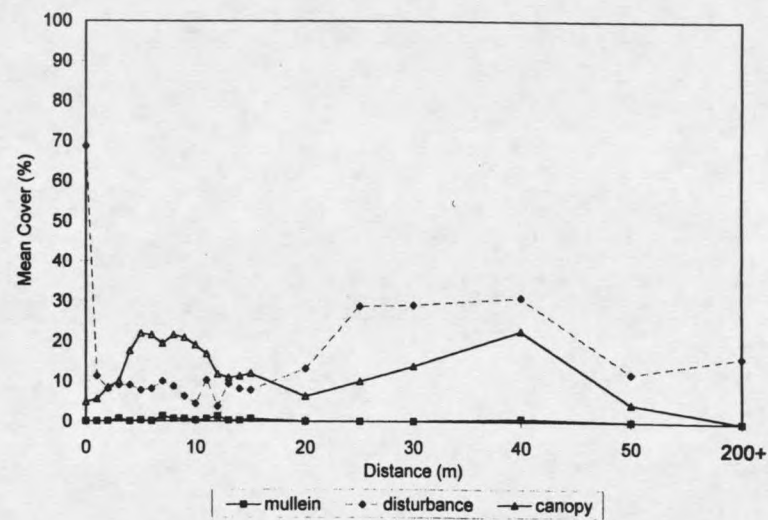
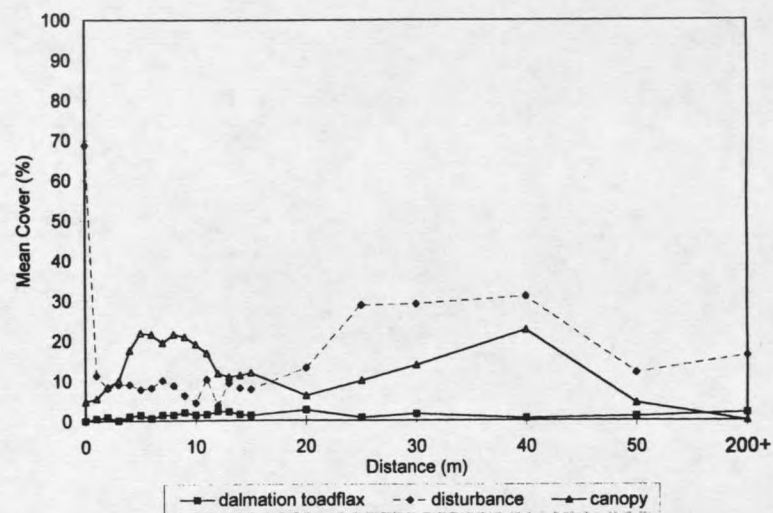


Figure 18 *continued*

the most abundant species at Mammoth, and consequently the pattern of yellow sweetclover covers with increasing distance largely shaped the pattern seen for all exotics combined. The mean covers of yellow sweetclover and all exotics combined tended to respond inversely to the cover of canopy. This pattern is consistent with results of the chi-square analysis that showed a significant association between yellow sweetclover and open canopy. As shown in Figure 17, the presence of roads between 20 and 40 meters caused the mean disturbance at these distances to increase, but besides Canada thistle growing in transect 4, exotic plants were rarely found in these higher covers of disturbed ground. The presence of exotic species drops off in the control quadrats (at least 200 meters from any human disturbance) near Mammoth to virtually zero. The covers of dalmation toadflax, the only species found in the Mammoth control quadrats, were low, as were the covers of canopy and disturbance.

Exotic Plants and Vegetation Variables

Mammoth

Exotic plants at Mammoth were usually found growing with other plants. A pattern of decreasing exotic cover with increasing cover of grasses, forbs, shrubs and 'total vegetation cover' (cover of all vegetation below elbow height *excluding* exotics) within the quadrat was found (Figure 19). In some instances, the negative effect of other vegetation was quite strong, such as the total exotic cover never exceeding 5% when the cover of shrubs exceeded 30%. A range of

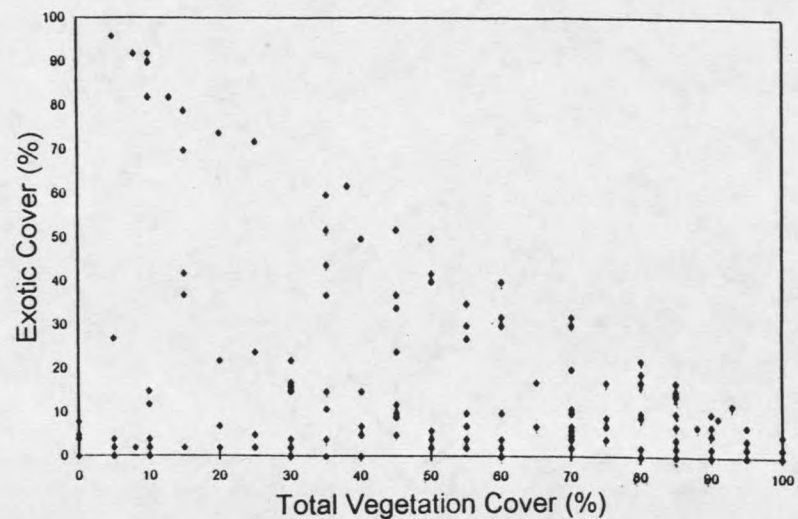
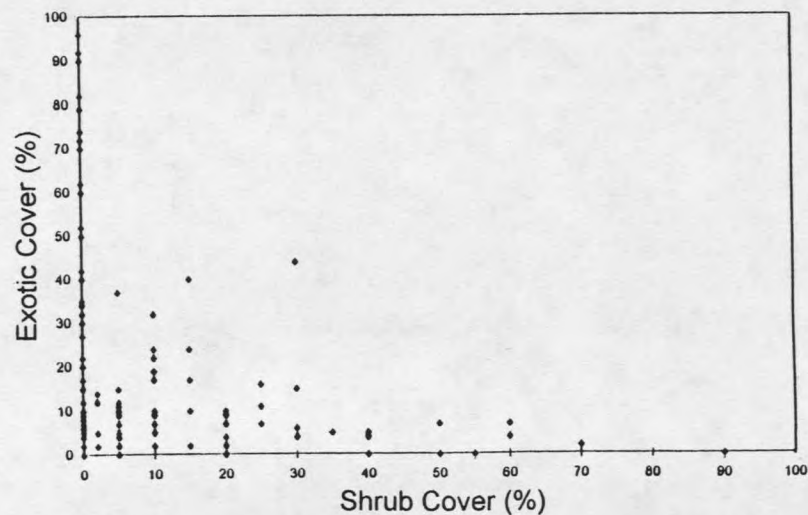
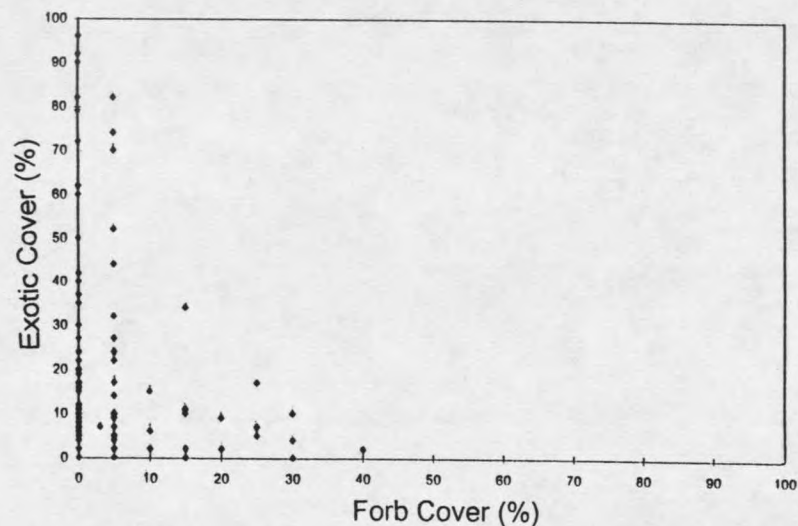
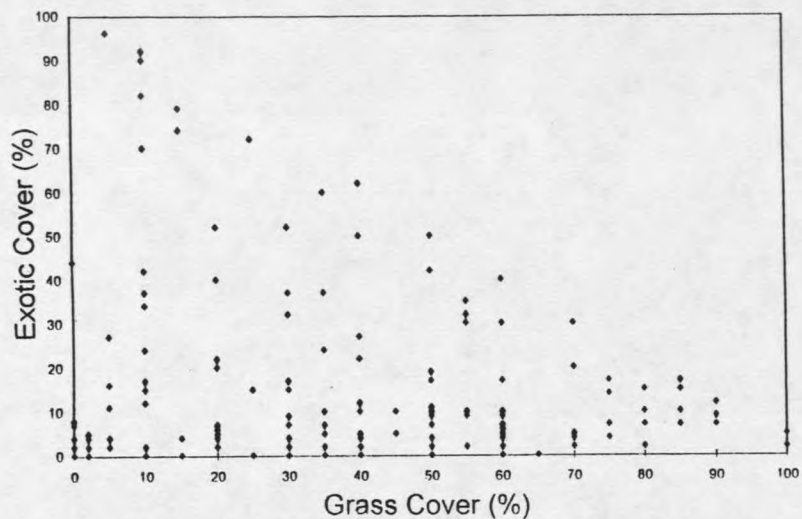
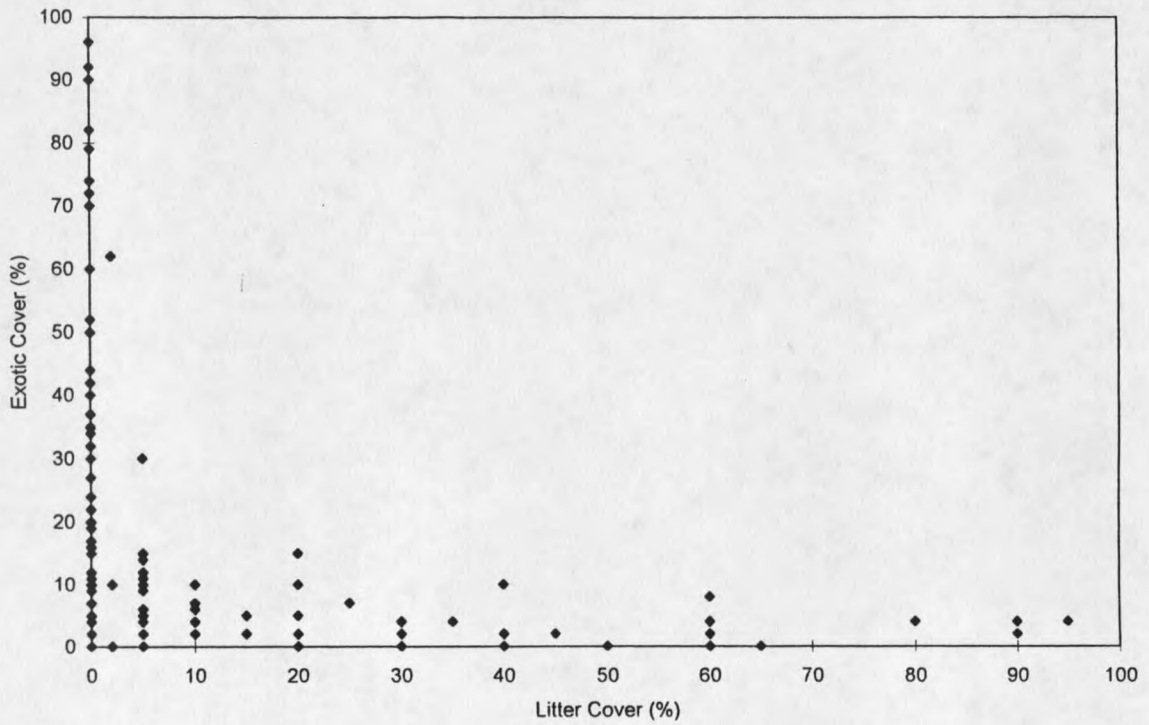
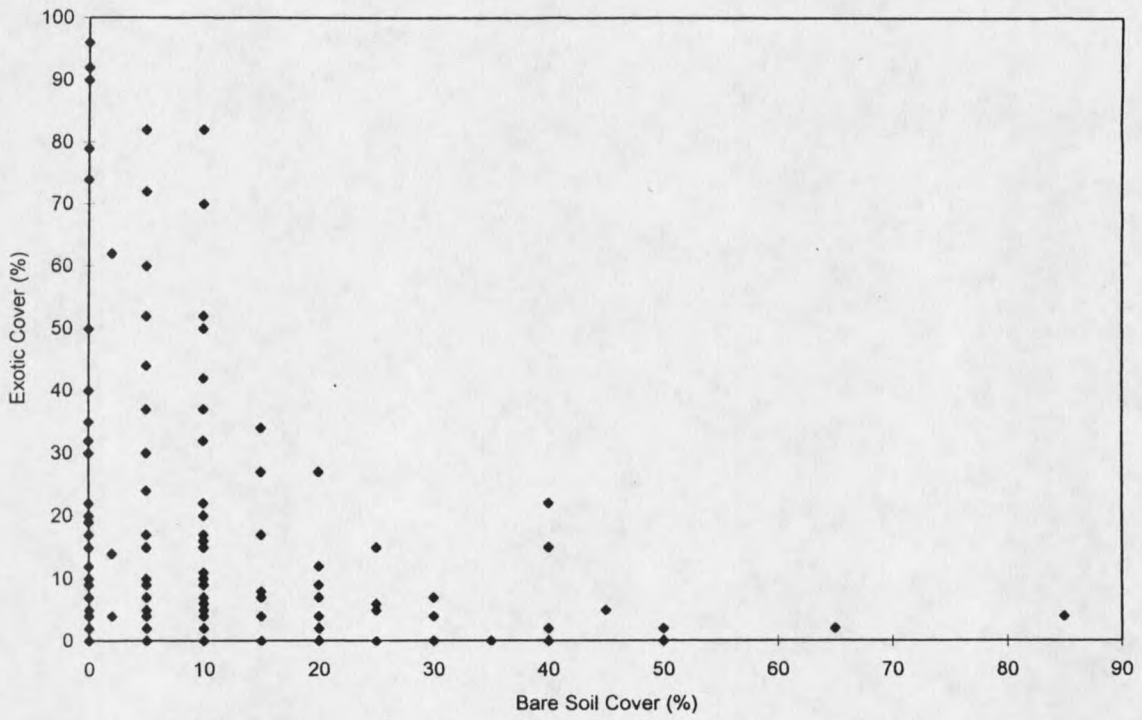


Figure 19. The relationship between exotic plant cover at Mammoth and the cover of grass, forbs, shrubs, total vegetation, bare soil, and litter.

Figure 19 *continued*

exotic covers (0-95%) was found when the total vegetation cover was below 30%, but exotic cover remained below 20% where total vegetation cover exceeded 80% (Figure 19).

Exotic plants occurred more frequently and in higher percent covers in low percent covers of bare soil at Mammoth (Figure 19). The highest exotic covers occurred in 10% or less of bare soil. Bare soil was occasionally recorded in amounts greater than 20%, and when it was, exotic plants occurred in low percent covers. This pattern is consistent with the relationship between exotics and disturbance previously discussed, because the disturbance was often found in bare soil. A slight decreasing trend in exotic cover with increased litter cover was found (Figure 19). The relationship is weak, however, partially because litter was so rarely observed at Mammoth. No relationship was found between exotic cover and that of moss/lichen, sedges, or trees.

Exotic Presence and Absence versus Other Vegetation Cover. A comparison of the vegetative conditions that existed where exotics were present and absent at Mammoth suggest that exotics tended to colonize areas with more grass cover and total vegetation cover than existed where exotics were absent (Figure 20). Seventy-five percent of the time exotics were found at Mammoth, they grew with at least 30% of other total vegetative cover. Exotics also tended to grow under lower and less variable shrub and litter covers than existed in their absence. Both higher shrub cover and litter cover contribute to a higher canopy cover, and it was previously determined that most of the time exotics were

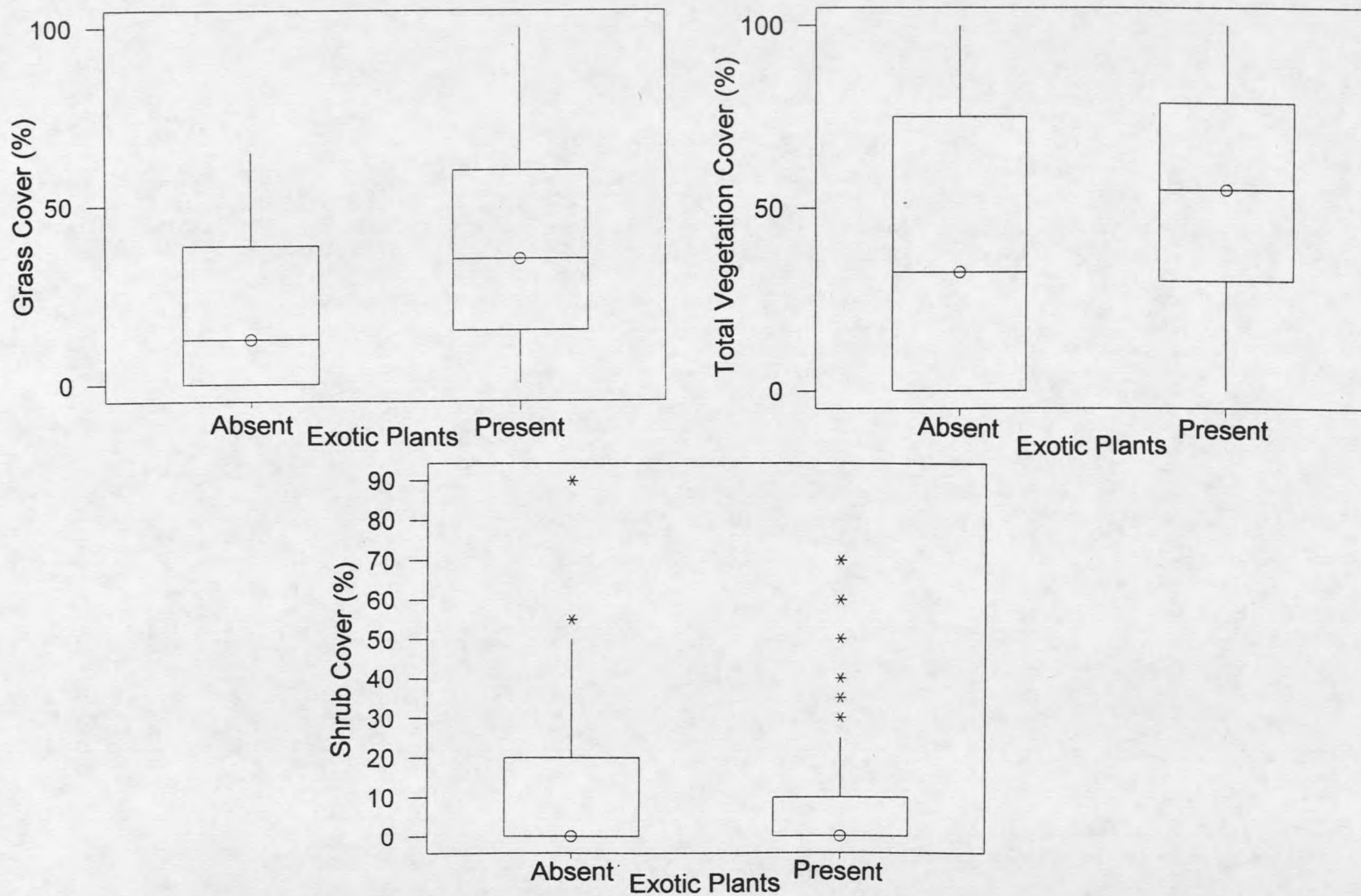


Figure 20. Side-by-side boxplots showing the distributions of grass, total vegetation, shrub, litter and bare soil covers when exotic plants were absent and present at Mammoth.

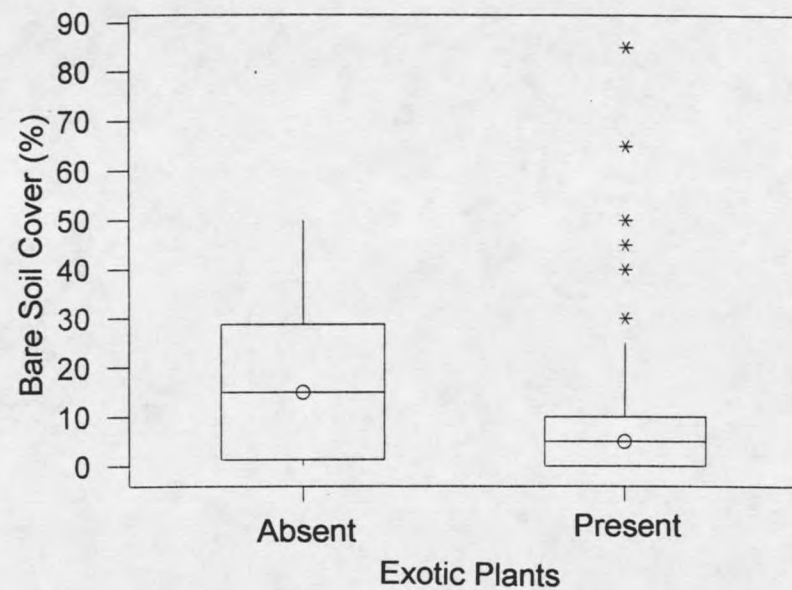
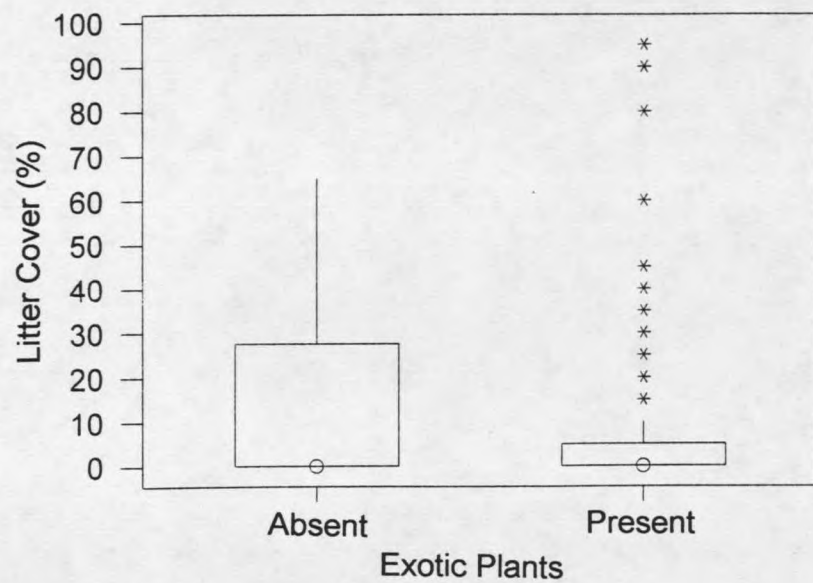


Figure 20 continued

present at Mammoth, they grew under 30% or less canopy cover (Figure 8). Bare soil covers were less when exotics were present than when they were absent. The presence/absence distributions of bare soil are very similar to those of disturbance (Figure 20), since often disturbance occurred in bare soil, except when disturbance was located in a gravel or paved road edge. The median values and interquartile ranges of the cover of forbs, sedges, trees, and moss/lichen in areas with and without exotics were very similar, suggesting that the presence or absence of exotics at Mammoth is independent of the cover of these variables.

Canada Thistle Quadrats

Canada thistle was found growing between the elevations of 1820 meters (at Mammoth) and 2365 meters (at Grant Village and Bridge Bay) in shrub/grassland, montane, and subalpine zones. Eighty-two percent of the time Canada thistle was found, it was growing on flat ground. It was never found on slopes greater than 10 degrees. When found colonizing a slope, the aspect was consistently southeast, or 130 degrees.

In all but one case, Canada thistle was growing with other plants (Figure 21). Seventy-seven percent of the time Canada thistle was present, the plant grew with at least 45% cover of other total vegetation within the quadrat, and over one third of the time it grew with at least 75% cover of other vegetation. The

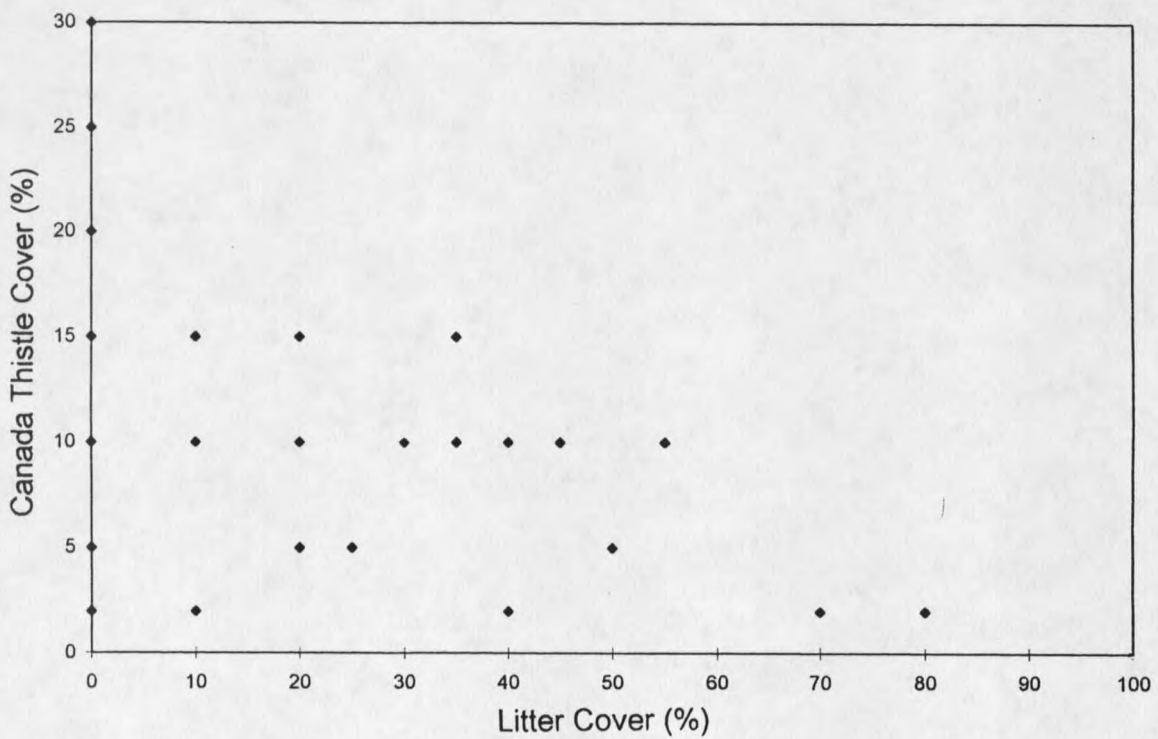
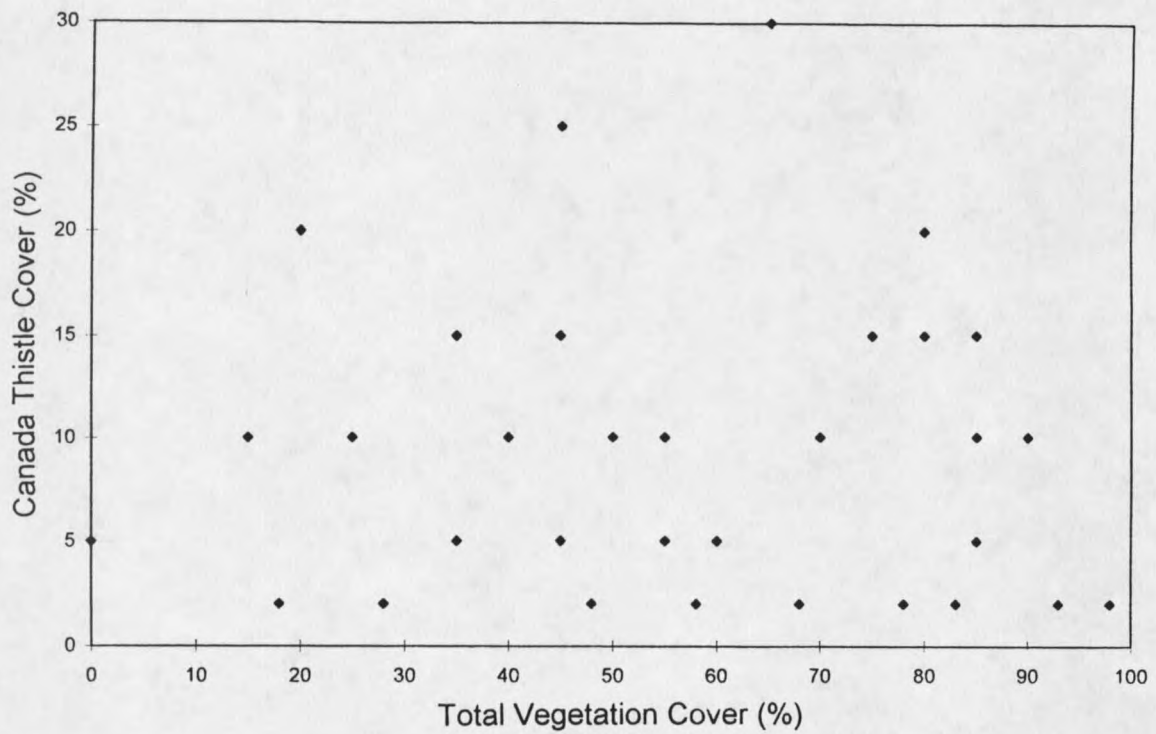


Figure 21. Total vegetation cover (besides exotics studied) and litter cover versus Canada thistle cover for quadrats that contained the plant.

highest cover of Canada thistle found (30%) occurred with 50% grass cover and 15% other forb cover.

Over 50% of the quadrats with Canada thistle contained no conifer litter (Figure 21). However, when litter was present, a slight trend toward decreasing Canada thistle cover with increasing conifer litter cover is suggested. Litter presence is a result of a coniferous canopy, and these results show a trend similar to that of canopy. Only 4.2% of Canada thistle cover could be explained by litter cover using linear regression analysis ($r^2 = 4.2\%$). No apparent relationship was found between Canada thistle cover and the cover of bare soil, moss/lichen, grass, sedge, forbs, shrubs, or trees. Bare soil was present in amounts between 5% and 40% when Canada thistle was found, while no bare soil was found in 38% of the quadrats.

All Campgrounds

An analysis of vegetation cover and Canada thistle presence and absence data indicates that when the plant was present, the median value of bare soil cover was slightly higher and the variability was slightly greater than when the plant was absent (Figure 22). When Canada thistle was present, bare soil was not found in covers exceeding 40%, whereas when the plant was absent bare soil was found up to 100% cover. This suggests that when bare soil exceeds 40% the likelihood of finding Canada thistle is negligible.

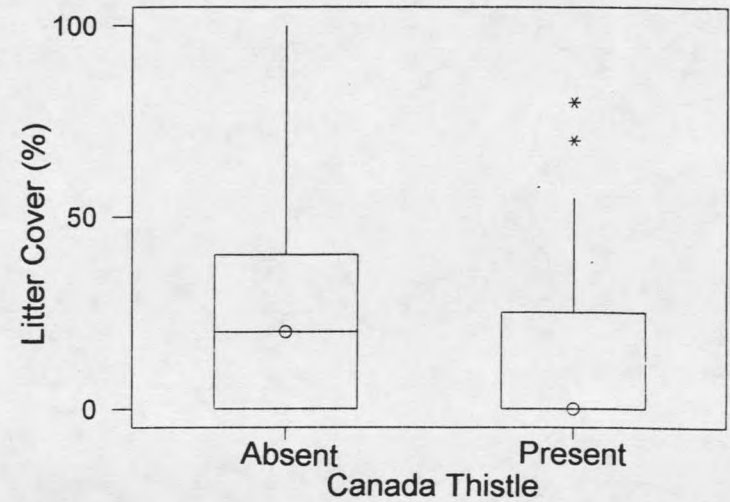
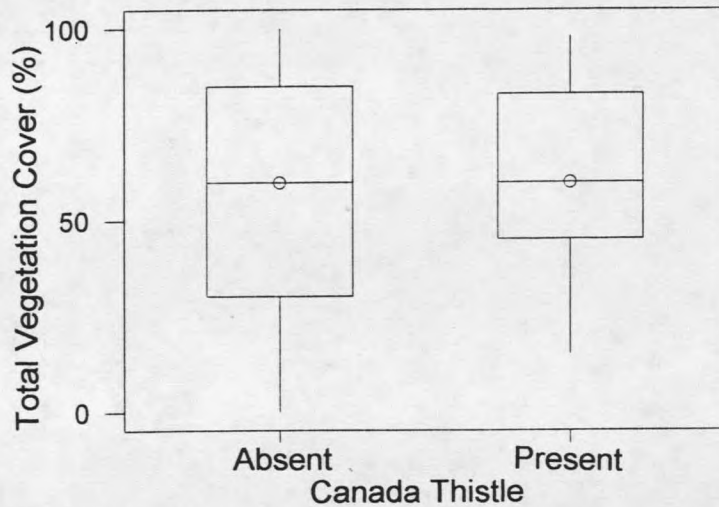
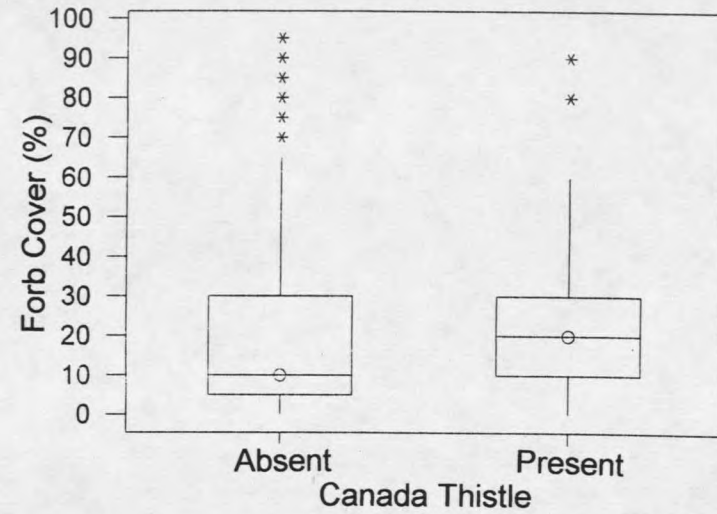
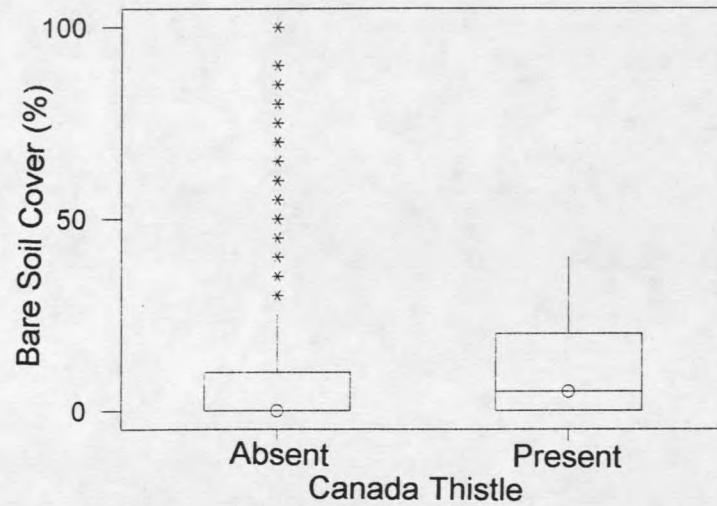


Figure 22. Side-by-side boxplots showing the distributions of bare soil, forb, total vegetation, and litter covers at all campgrounds when Canada thistle was absent and present.

Forb distributions differ little where Canada thistle was present or absent, except that the median where Canada thistle was present was slightly higher (Figure 22). Where Canada thistle was present, the variability in total cover of other vegetation was slightly less than when it was absent, but the median values were identical. Canada thistle apparently grows well with a moderate to high cover of other species, conditions can be found throughout all campgrounds. Median litter and variability in litter were less when Canada thistle was present. A number of variables showed very similar median values and variability in the side-by-side boxplots, including moss/lichen, grass, sedge, shrub, and tree. These distributions suggest that Canada thistle presence or absence is fairly independent of the cover of forbs, moss/lichen, grass, sedge, shrub, tree, and total vegetation.

Exotic Plants and Habitat Types

Six of the seven habitats that were sampled contained at least one exotic species (Table 9). Some campgrounds contained more than one habitat type, but all transects lay within a single habitat type. Six species were found in big sagebrush habitats between the elevations of 1820 and 1895 meters at Mammoth and Slough Creek campgrounds (Table 9).

Within the mid-elevation Douglas fir/common snowberry, Engelmann spruce/sweetscented bedstraw, Engelmann spruce/horsetail and subalpine fir/twinflower habitats, Canada thistle was the only exotic species found. It was

HABITAT TYPE	ELEVATION RANGE(M)	CAMPGROUND(S)	NUMBER OF TRANSECTS	NUMBER OF TRANSECTS WITH EXOTICS	TRANSECT FREQUENCY (%) ¹	EXOTIC SPECIES FOUND ²	MEAN CANOPY (%) ³
big sagebrush/ bluebunch wheatgrass	1820	Mammoth	8	8	100	SK, YSC, HT, MULL CT, DT	14
big sagebrush/ Idaho fescue	1895-2090	Slough Ck. Pebble Ck.	8	2	25	CT	0
Douglas fir/common snowberry	1895-2000	Slough Ck. Tower Fall	6	1	17	CT	0
Engelmann spruce/ sweetscented bedstraw or horsetail	1895-2090	Slough Ck. Pebble Ck.	7	1	14	CT	27
subalpine fir/ twinflower	2000	Tower Fall	3	0	0	none	n/a
subalpine fir/pinegrass	2060-2275	Norris Indian Ck. Madison	21	2 1	14	OD, CT CT	6
subalpine fir/grouse whortleberry	2275-2425	Canyon Grant Village Norris Bridge Bay Lewis Lake	35	1 2	9	CT CT	21

Table 9. Habitat types and related elevations and mean canopy covers in which exotic plants were found in the campgrounds of Yellowstone National Park.

1. Transect Frequency: percentage of transects in a given habitat type that contain exotics.
2. Key to Exotic Species Found: SK = spotted knapweed, HT = hound's-tongue, CT = Canada thistle, OD = oxeye-daisy, DT = dalmation toadflax, YSC = yellow sweetclover, MULL = common mullein.
3. Mean Canopy: refers to quadrats where exotics were found.

discovered in 2 transects at Slough Creek (1895 m), including 1 transect in a Douglas fir habitat under a completely open canopy, and 1 transect in a riparian spruce/bedstraw habitat under a canopy ranging from 5% to 80%. In the latter case, the density and percent cover of Canada thistle increased with decreasing canopy covers. Canada thistle was absent in quadrats from the subalpine fir/twinflower habitat.

Within the subalpine habitats, including subalpine fir/pinegrass and subalpine fir/grouse whortleberry habitats, oxeye-daisy and Canada thistle were found. Oxeye-daisy was found in 1 transect at Norris (2275 m) growing under a completely open canopy in a subalpine fir/pinegrass habitat. Canada thistle was found growing at elevations ranging from 2060 meters at Norris to 2365 meters at Grant Village and Bridge Bay campgrounds, and under canopies ranging from 0% to 95% cover. It was more commonly found under low canopy covers (0%-20%) in subalpine fir forests.

Random and Control Quadrats

Random Quadrats

All 8 quadrats sampled within the Mammoth campground contained hound's-tongue, spotted knapweed, dalmation toadflax, and yellow sweetclover. Since these species were among the 6 species found adjacent to the campground edge, seeds may have been introduced within the campground core and spread outward from the campground or visa-versa. Canada thistle was

found in 2 quadrats within the Slough Creek campground as well as in quadrats adjacent to the campground edge.

Control Quadrats

The control quadrats nearest Mammoth were the only control quadrats that contained exotic plants. Five of these 8 quadrats contained dalmation toadflax. This data suggests that dalmation toadflax is the only species spreading into the surrounding vegetation, from either the campground, nearby roads, or other disturbances in the Mammoth area. However, the small sample size may account for the lack of exotics in the controls.

DISCUSSION AND CONCLUSION

The objectives of this study were to determine if the percent cover and density of exotic plants decreased with distance from campground disturbance and if the presence and cover of exotics was greater under a more open canopy than beneath a more closed canopy. Most other researchers investigating exotic plant distributions in natural areas have studied species cover and richness at relatively short distances from roads and trails. This study focused on campground disturbance as a point of inoculation. It is unique in its focus on the association between canopy cover values and exotic presence, and on the distance from the campground disturbance that was sampled.

Exotic Plants and Distance from Campground Edge

Results of this study indicate that the Mammoth campground was the only campground where exotic presence was apparently sufficient enough to show a correlation with distance from the individual campground edges (Figures 3 and 4). The decreasing pattern of exotic cover and density between 1 meter from the Mammoth campground edge disturbance and 5 or 6 meters are consistent with other studies in terms of the distance from disturbances out to which exotics were found to decrease. Benninger-Truax et al. (1992) sampled only 5 meters from the trail disturbance and found species richness declined with distance from disturbance, but found no significant correlation with exotic cover and distance. Dale and Weaver (1974) sampled out to 4.6 meters from the trail edge, and found

the frequency of 3 exotic species decreased to zero from the trail edge out to 2.4 and 4.6 meters from the trail. Tyser and Worley (1992) found that the abundance of spotted knapweed decreased from road edges out to 100 meters, Canada thistle decreased out to 25 meters and yellow sweetclover was present in road edge disturbances only, in a grassland habitat. Yellow sweetclover, Canada thistle, and spotted knapweed have been found along roadsides in Grand Teton National Park in sagebrush habitat between 3 and 15 meters from the road edge (Weaver and Woods, 1986).

Viable seed availability, canopy cover, disturbance within a quadrat, and proximity to roads and trails may all play a role in the high number of exotics found colonizing between 11 and 50 meters from the Mammoth campground edge disturbance in this study. The presence of exotics 50 meters from the campground edge suggests that either the plants are spreading outward from the campground or from other nearby disturbances. The presence of roads and trails surrounding the campgrounds, through which transects were sometimes laid, provided a potential source of exotic seed and a disturbance which may have facilitated exotic presence at greater distances from the campground edge. At Mammoth, 3 transects actually crossed the road that encircles part of the campground, and one transect approached to within 15 meters of the road. Sometimes it was not possible to discern the source of exotic seed inoculation, be it the campground, roads or trails, especially at greater distances from the campground edge.

Exotic Plants and Canopy Cover

Results of this study provide new information about the canopy conditions under which some exotic plants may grow, yielding inferences about general light requirements. Little research has been conducted on the light requirements of most of the exotic species in this study. Spotted knapweed and yellow sweetclover were more abundant under a more open canopy (less than 40% canopy cover) than under a more closed canopy in this study (Table 6). In another study, seeds of spotted knapweed were found to germinate equally well under 0% to 100% canopy cover (Losensky, 1987). After germination, however, limited light restricted their growth. Spotted knapweed seems to prefer open habitat and is not commonly found in shaded areas (Watson and Renney, 1974; Milner, 1995).

The significant correlation of hound's-tongue's presence with a more closed canopy (Table 6) suggests the plant prefers or tolerates shady conditions. The plant has been documented to occur in thick litter accumulations, suggesting conditions similar to those found under a coniferous canopy (Lacey and Lacey, 1986). No significant association was found between dalmation toadflax and canopy cover as a result of its presence under a wide range of canopies (from 0% to 85%). The plant's ability to tolerate moderate shade, implied from its presence under high canopy covers, is perhaps new information since it is cited as establishing drier, open areas (Lajeunesse et al., 1993). No significant association was found between mullein and canopy cover. Canada thistle was

most often found under 20% or less canopy cover, suggesting it prefers greater exposure to light provided by open canopy conditions. Warm temperatures and long days are known to favor foliage growth and flowering in the plant (Haderlie et al., 1989), but apparently no research has been done on its light requirements (Dewey, 1996, pers. comm.).

Exotic Plants and Disturbance Cover

Disturbance at Mammoth may contribute to the increase in exotic cover beyond 5 or 6 meters. In other studies, it was often predetermined or assumed that disturbance decreased with distance from the road or trail, and that exotic presence responded to this gradient (Weaver et al. 1989; Benninger-Truax et al., 1992). However, at Mammoth disturbance did not decrease with distance from the campground edge (Table 7, Figures 17 and 18). In fact, the mean cover of disturbed ground increased between 25 and 40 meters from the Mammoth campground edge (Figure 18). Exotics at Mammoth showed a significant correlation with low covers of disturbed ground (Table 8). Higher disturbance covers (>60%) occurred infrequently (Figure 12), and were often found in the first quadrat of a transect. This "edge quadrat" was defined as containing 10% or less vegetative cover, and hence, was often located in the campground road edge disturbance. Exotics were apparently less able to become established where disturbance levels were high and occurred more frequently.

Canada thistle was found in greater relative frequencies in from 5% to 40% cover of disturbance (Figure 15). The plant was consistently found rooted in disturbance when the plant and disturbance were both present. This supports other studies which have suggested that colonization by exotic plants is facilitated by disturbance. The ability of Canada thistle to reproduce by lateral roots (Haderlie et al., 1989) may contribute to its presence in undisturbed and both low and high levels of disturbed ground. Results of this study suggest that disturbance conditions at all campgrounds were suitable for Canada thistle establishment. A lack of other environmental conditions necessary for Canada thistle establishment such as warm temperatures, soil fertility and moisture (Haderlie et al., 1989), and a lack of viable seeds may have contributed to the absence of the plant in some campgrounds.

Exotic Plants and Other Vegetation

Exotic plants at Mammoth were usually found growing with other plants, however exotic cover decreased with an increasing cover of other vegetation (Figure 19). This pattern may be due to increased competition for available nutrients, water and light. Most of the exotic species studied are known to release toxic chemicals into the soil that inhibit the growth of other plants, an ability known as allelopathy. This may partially explain why the cover of other vegetation is low where exotic cover is high. Exotics found growing with high covers of other plants in this study apparently had not displaced these other species. The high

covers and occurrence of exotics in low covers of bare soil is similar to the relationship found between exotics and disturbance at Mammoth because disturbance was often found in bare soil.

The high overall cover of other plants in the vicinity of Canada thistle indicates its ability to compete well for available resources and/or that it did not yet have a negative effect on other nearby plants. Canada thistle has been found to reduce crop yields to zero through competition and allelopathy (Haderlie et al., 1989). Longer studies would help clarify if some exotic species, including Canada thistle, are reducing the cover of other vegetation through allelopathy and competition in Yellowstone National Park.

Exotic Plants and Habitat Type

Results of this study suggest that 5 exotics (spotted knapweed, yellow sweetclover, hound's-tongue, mullein, and dalmation toadflax) are most likely to be found in the big sagebrush habitat types. A sixth species found in big sagebrush, Canada thistle, covers a wider range of habitat types. Big sagebrush habitat types were lower in elevation, often had lower canopy covers and tended to be more xeric than forested sites. Forcella and Harvey (1993) found that invasion by exotics was common in low, dry habitats but that in Douglas fir habitats, exotics were restricted to disturbed areas. Weaver et al. (1989) found hound's-tongue in Douglas fir/common snowberry habitat, and located Canada thistle, dalmation toadflax, and yellow sweetclover from lower elevation

sagebrush habitats up into cool, moist subalpine fir/grouse whortleberry habitats. The absence of Canada thistle in the subalpine fir/twinflower habitat in this study could be due to the small sample size (3 transects), since the plant was expected to be able to colonize this habitat given its presence at both lower and higher elevations.

Canada thistle's presence in a wide range of elevations (1820 meters to 2365 meters), from dry sagebrush habitat types up to subalpine habitat types, suggests the plant is adaptable to a wide range of environmental conditions. Weaver et al. (1989) found Canada thistle in a similar range of habitat types in disturbed soil, and Forcella and Harvey (1983) found the plant up as high as subalpine fir habitats. In general, however, there are fewer exotic species found at higher elevations, perhaps due to cool temperatures excluding exotics from higher elevations where native species retain more vigor and outcompete exotic species (Forcella and Harvey, 1983; Mooers, 1986; Weaver et al., 1989). Insufficient light due to dense canopies may also impede exotic establishment. The disturbance and reduction in canopy associated with campgrounds in subalpine fir habitats may allow for greater exotic establishment than what would occur under natural conditions.

The reasons so few exotics were found at most campgrounds in this study was probably related to elevation and related habitat types, canopy covers and climates. Spotted knapweed, for instance, has been found growing up to 3048 meters (10,000 feet) (Lacey et al., 1989), but is most common between 610 to

1829 meters (2,000 to 6,000 feet) (Chicoine et al., 1988; Milner, 1995). It has been shown to require 50-120 frost free days (Chicoine et al., 1988), conditions that exist at only a few of the campgrounds (Table 3). Cold was discovered to inhibit total germination and rate of germination in yellow sweetclover (McElgunn, 1973). Oxeye-daisy is adapted to a more northern climate (Lindsay, 1953) than that of Yellowstone National Park, which may explain its presence at a higher elevation (2275 meters).

The abundance of exotics at Mammoth may relate to the climate of the campground. Mammoth lies at the lowest elevation of the campgrounds, it has the longest period of frost free days and, therefore, the longest growing season, and it has higher temperatures during the summer months (Table 3). The seven exotic species found in this study have all been introduced from Europe or Asia (Hitchcock and Cronquist, 1973; Whitson et al., 1992). These areas may possess microclimates that are more like those found near Mammoth and along the northern range of the Park than at higher elevations.

Previous Exotic Plant Management in Campgrounds

Control of exotics in the campgrounds of Yellowstone has been underway since the 1960's on some species, and not until recently for others (Sweaney, 1996, pers. comm.). Release of an insect to target and control dalmation toadflax in the 1960's proved unsuccessful. In the early 1980's aggressive control of spotted knapweed began, and continues today as methods of spraying that best

contain the plant continue to be refined. In 1995, the Park began spraying hound's-tongue patches in the Mammoth campground. Canada thistle, mullein, and yellow sweetclover are not currently actively targeted in the northern part of the Park, however yellow sweetclover is pulled in other parts of the Park where it occurs in small patches. The National Park Service does not financially support exotic plant control directly. Most funding for control comes from Federal Highways Program money geared toward exotic plant control along roadsides (Sweaney, 1996, pers. comm.).

The canopy cover in forested campgrounds has been and continues to be reduced by the removal of "hazard trees". In 1984, in response to a lawsuit against the Park in which a tree fell on a man in 1966, the National Park Service cut down a large portion of the trees at Bridge Bay campground, resulting in an opening of the canopy and increased sunlight reaching the surface (Whittlesey, 1995). Future cutting of hazard trees will continue to open the canopy, making conditions more conducive to sun-loving exotics. Canada thistle was the only species found colonizing forested campgrounds in this study, but other species are known to invade forested habitats, especially under open canopies or disturbed conditions.

Future Management Implications

This research provides baseline data on the abundance of some exotic species in campgrounds in Yellowstone National Park against which managers

can measure future changes. The results imply that the presence of exotic plants around campgrounds other than Mammoth is not great. However, only 10 species were chosen for study, out of 168 known to be present in the Park (Whipple, 1996, pers. comm.). Exotics were occasionally seen outside the transects, and the lack of exotics measured was at times a result of the transects not capturing those plants. The paucity of exotics found in this study could also have been a result of previous successful control efforts, especially in the northern part of the Park where the climate is more suited to exotic establishment.

Because of the high amount of trampling that occurs at campgrounds, they will continue to be disturbed environments. Managers can try to mitigate low levels of disturbance that were found to have the highest number of exotics.

Awareness of the increased potential for exotic establishment when canopy is opened by hazard tree removal or construction may help prevent exotic spread.

When hazardous trees are removed or exotics are controlled, leaving bare and often disturbed soil, revegetating a site with native seed mixes may help prevent exotics from reestablishing on the same site.

Future exotic control may benefit from efforts to prevent exotic seed from entering the Park. Yellowstone National Park now permits only weed-seed-free hay to pass through the Park or be used in the front-country, and no hay is allowed into the backcountry (Sweaney, 1996, pers. comm.). However, the weed-seed-free designation is determined by counties in order to protect agricultural crops and sometimes does not exclude seeds of exotic species that may concern

the Park. Since a large source of exotics is believed to come from sand and gravel, used on the roads in winter or for construction, the Park could also require weed-seed-free sand and gravel. This may create an economic incentive for weed-seed-free sand and gravel sources outside the Park (Sweaney, 1996, pers. comm.). Increased education of visitors about the Park's efforts to control exotics and about the methods that visitors may unintentionally introduce exotic seed to the Park (cars, snowmobiles, shoes) may help to maintain the natural plant communities that the National Park Service is mandated to preserve. Cooperative efforts to coordinate exotic plant management with land management agencies whose lands border Yellowstone National Park are currently underway (Free et al., 1990) and should be continued in order to reduce the spread of exotics into the Park from surrounding lands.

Further Studies

Duplication of this study in 5 and 10 years is recommended to assess changes in the abundance of the exotics studied over time. A study similar to this one, but with an adaptive sampling design that could capture more of the exotic plants in the campground, is also suggested. The design might include continued sampling around an exotic plant, when found, so that a better measurement of how much that exotic was spreading nearby could be collected. A sampling design that entailed sampling a larger area around the campgrounds might also capture more plants.

Studies on the source of exotic seed into the Park may be beneficial, such as a germination study of weed- seed-free hay or gravel. Studies of the effects of exotics on displacing native vegetation, that take place over many years, could be very useful in establishing the extent to which exotic plants in the Park are truly affecting native vegetation. Finally, it is recommended that studies on control efforts be conducted to document the effects of treatments over time on the populations of exotic species.

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APPENDIX

CAMPGROUND MAPS

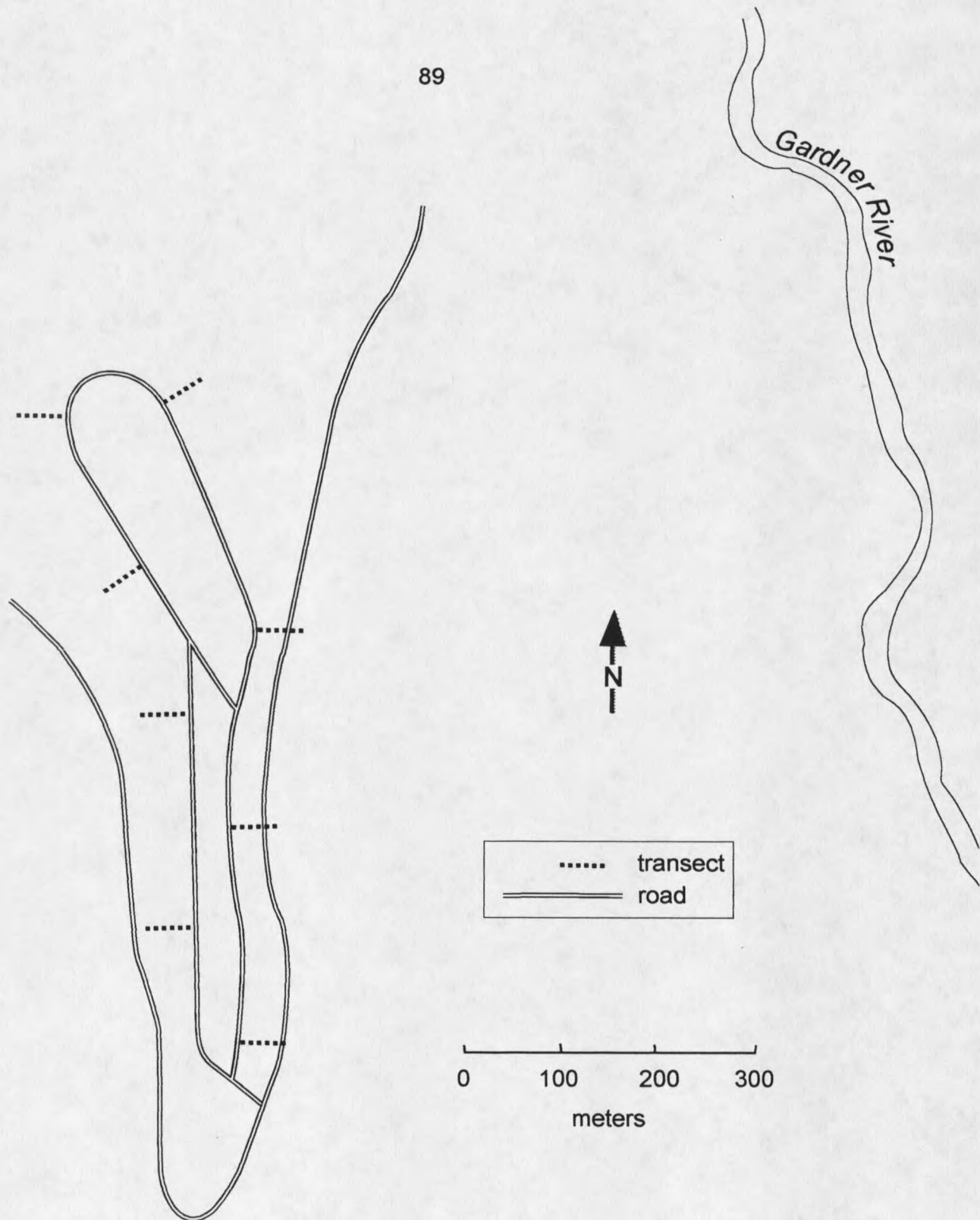


Figure 23. Mammoth Campground

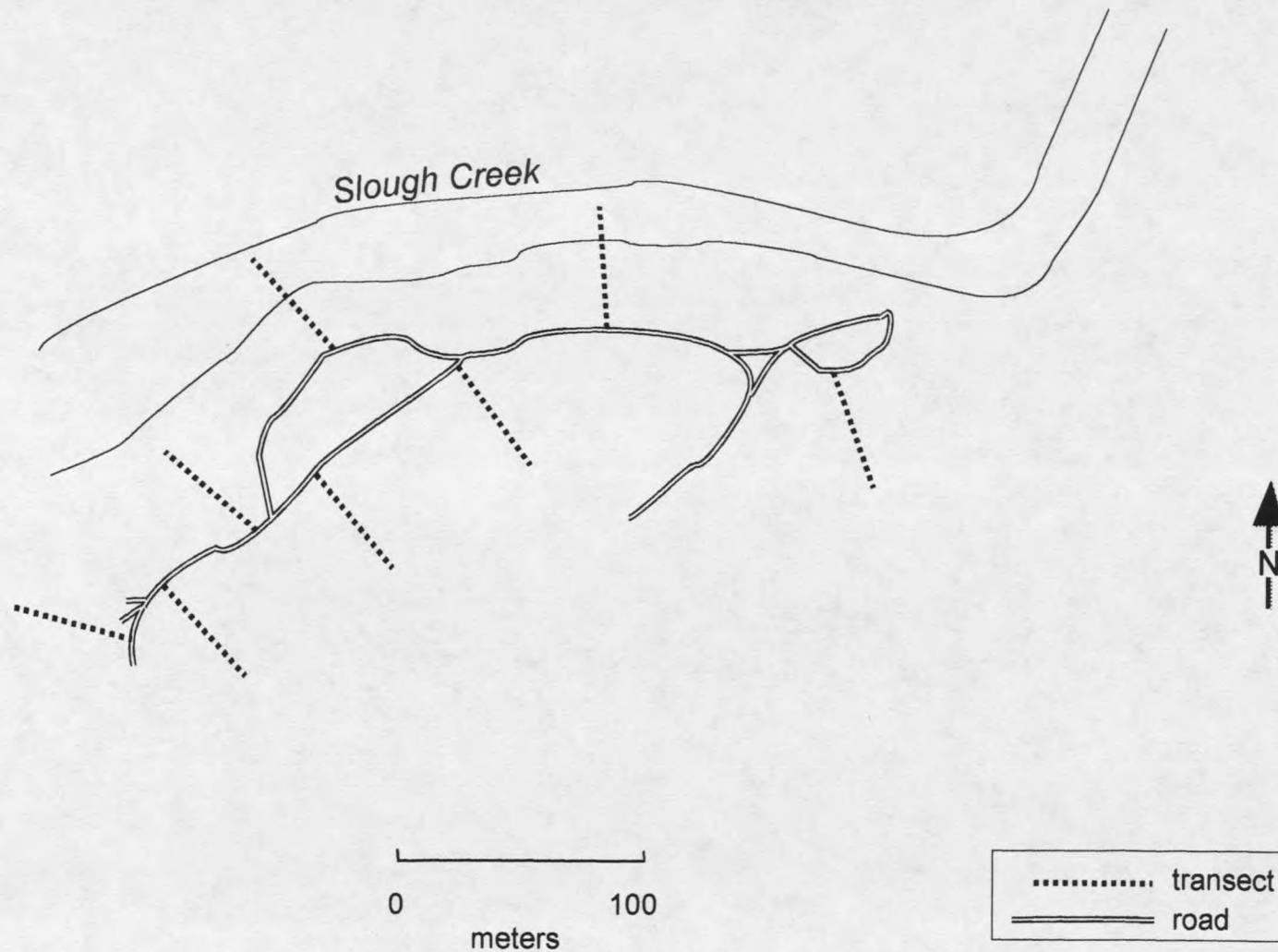


Figure 24. Slough Creek Campground

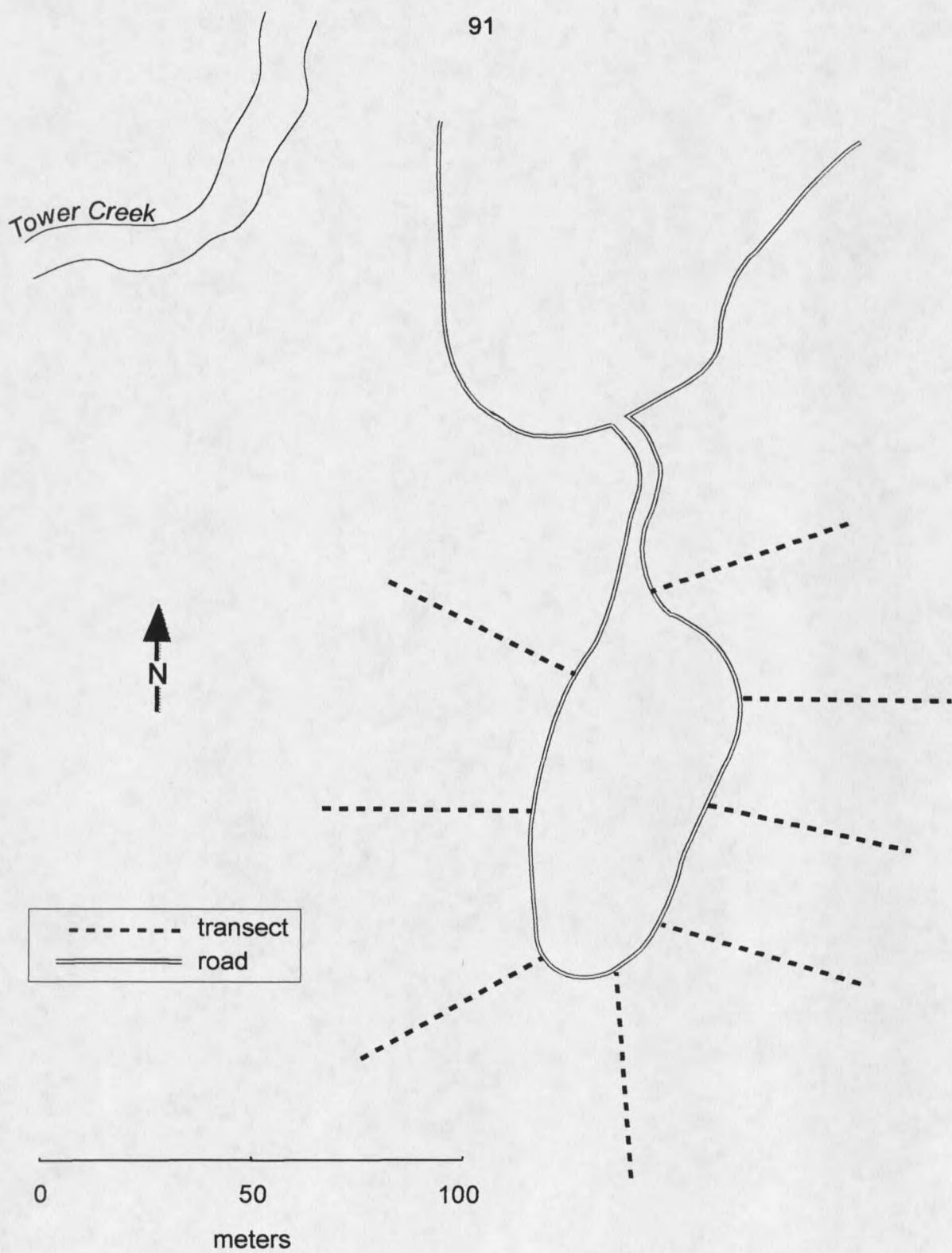


Figure 25. Tower Fall Campground

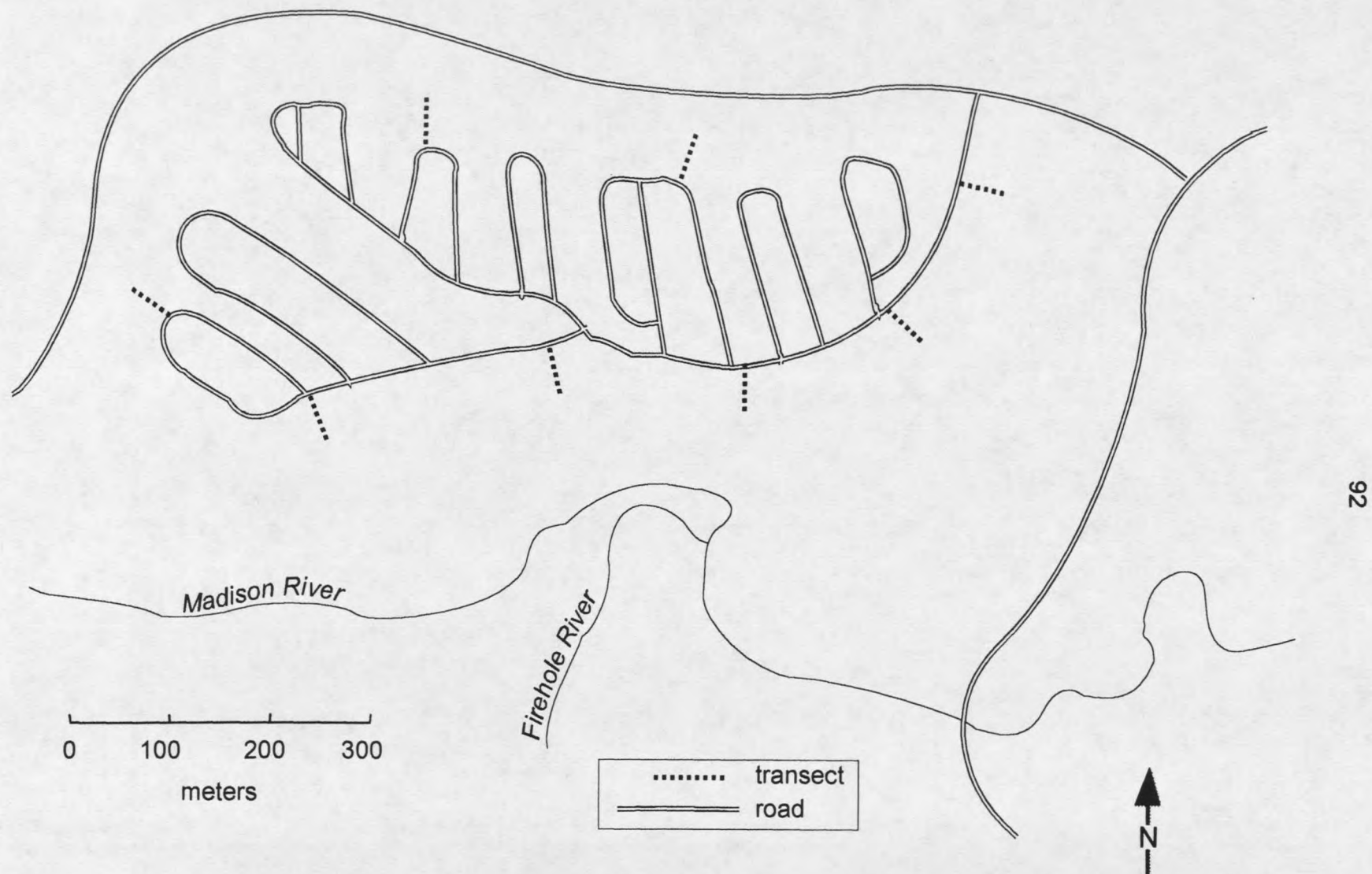


Figure 26. Madison Campground

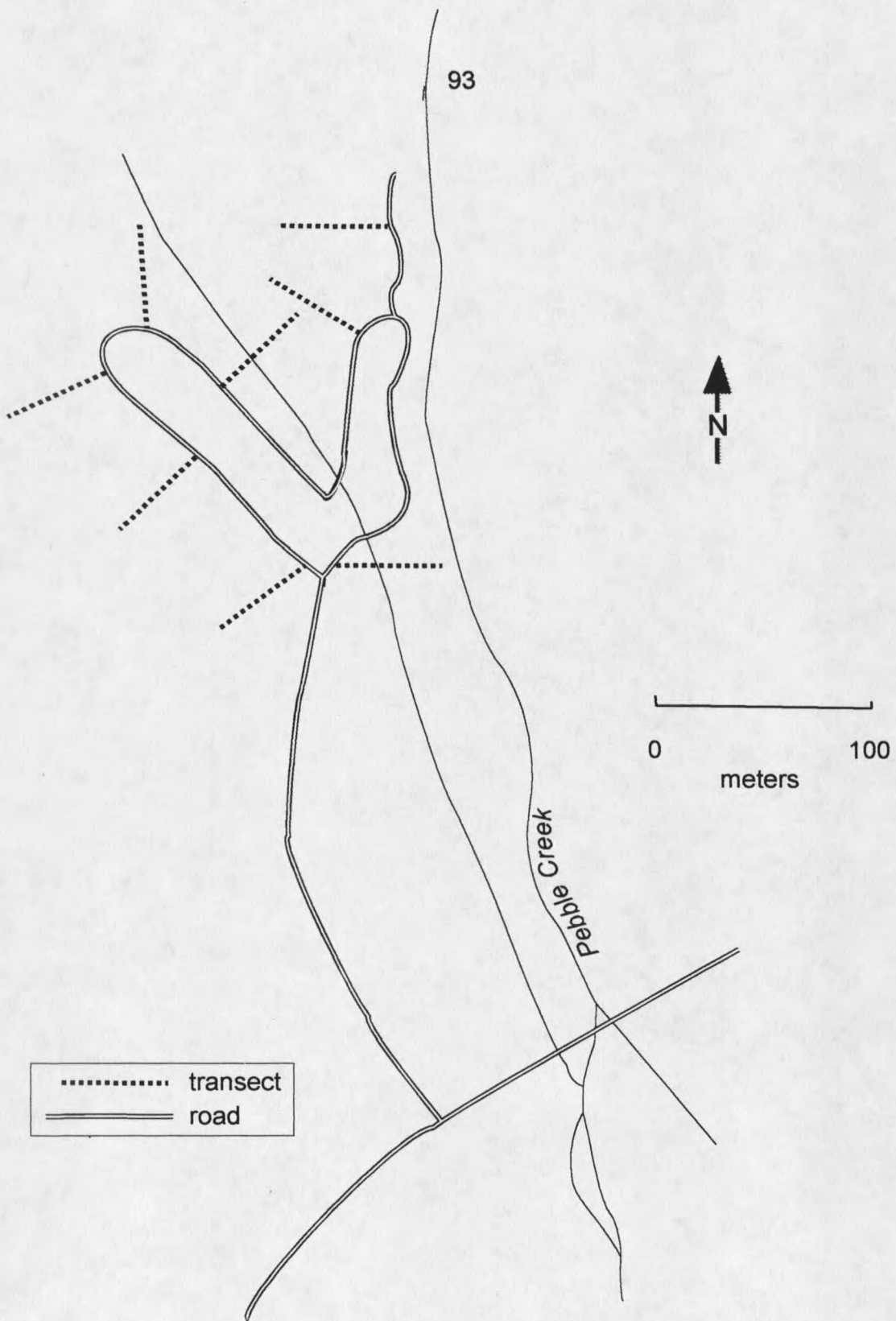


Figure 27. Pebble Creek Campground

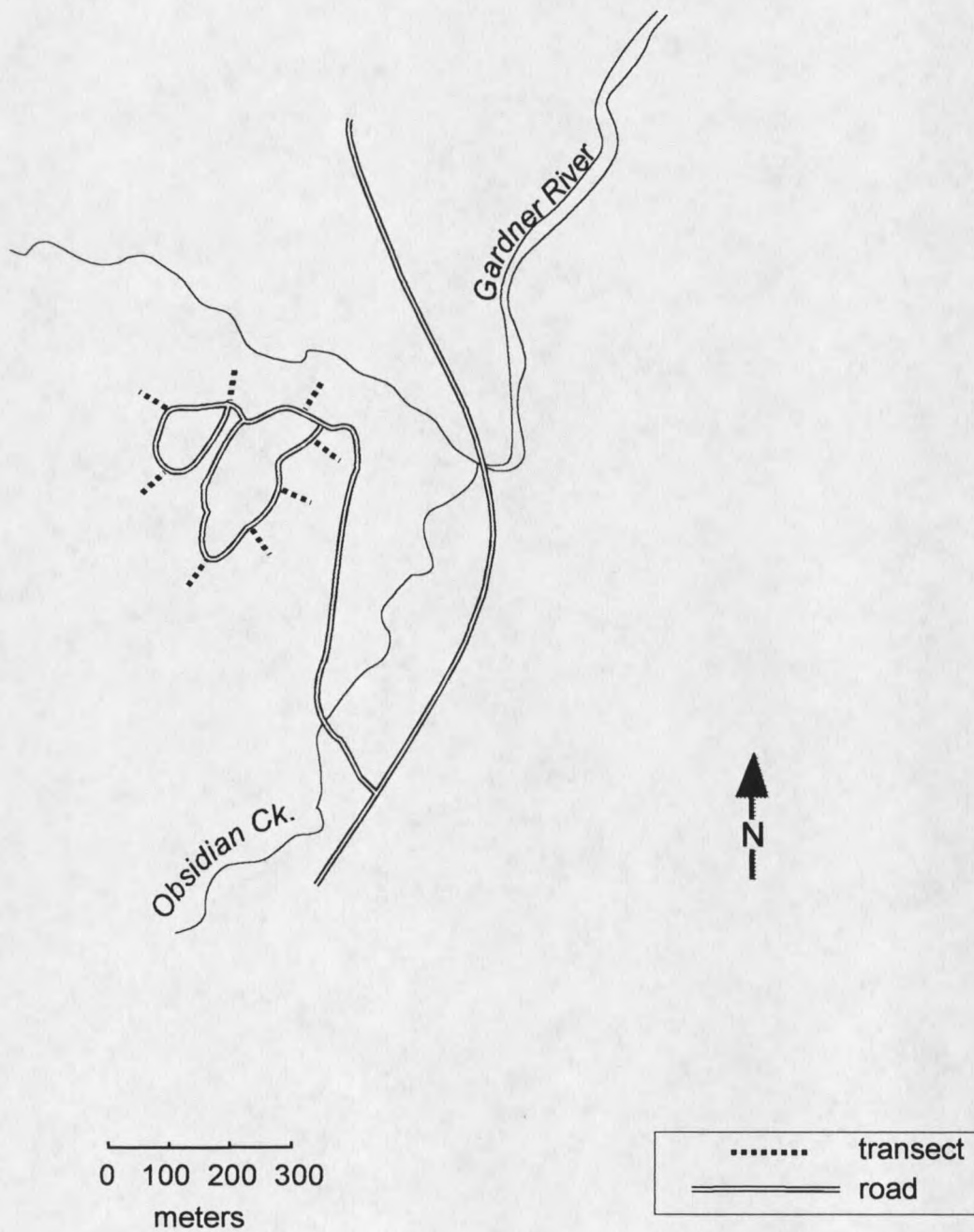


Figure 28. Indian Creek Campground

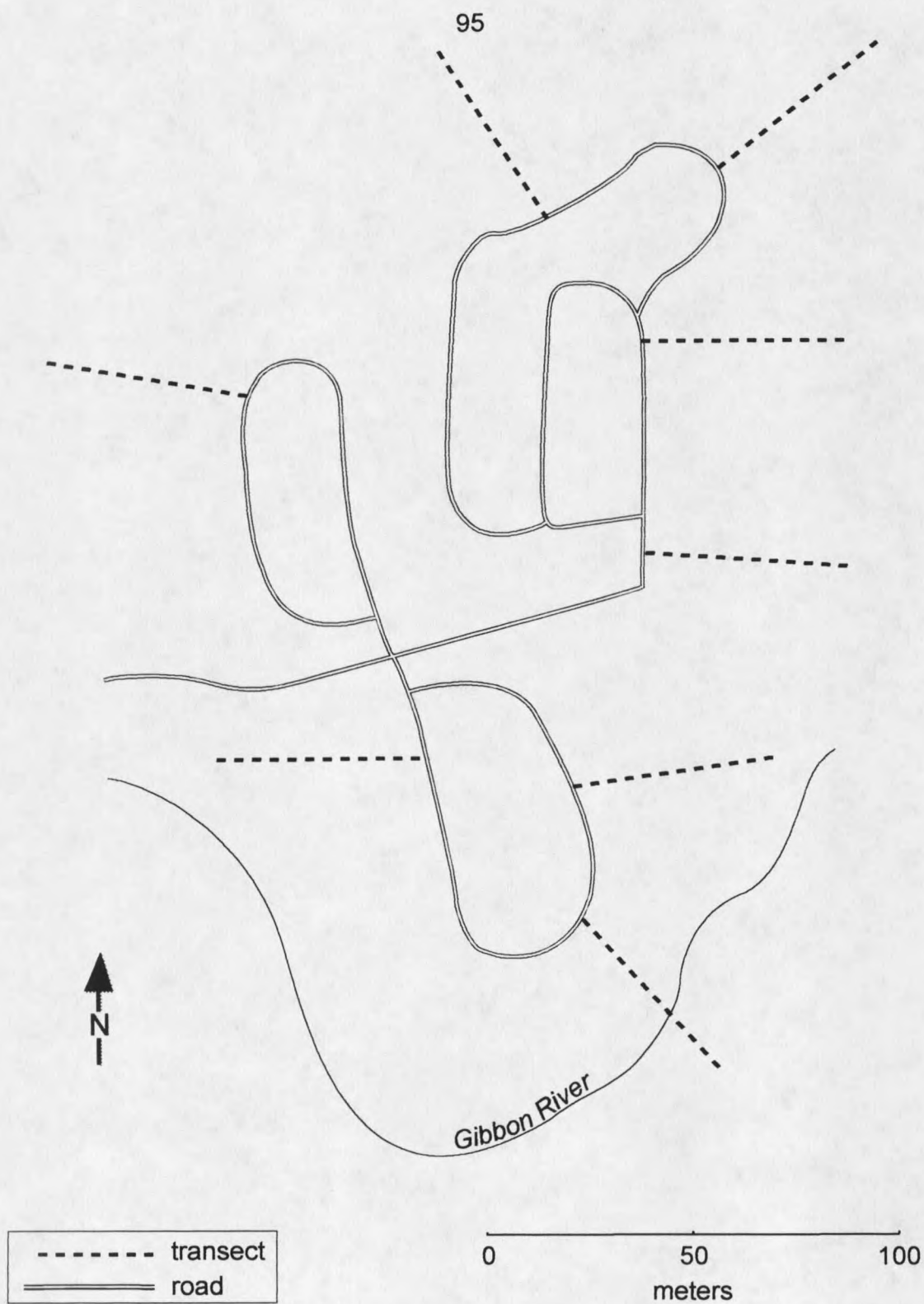


Figure 29. Norris Campground

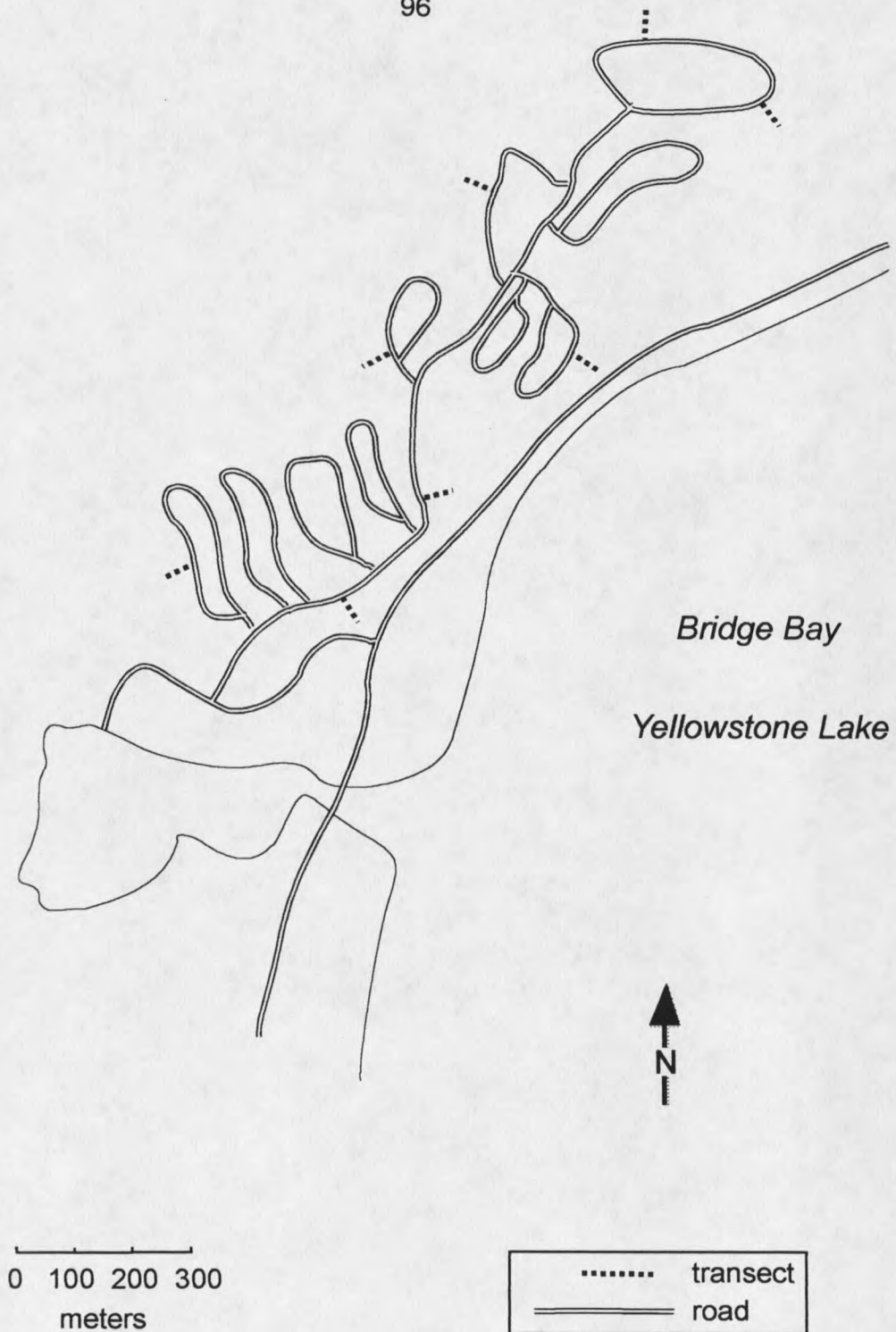


Figure 30. Bridge Bay Campground

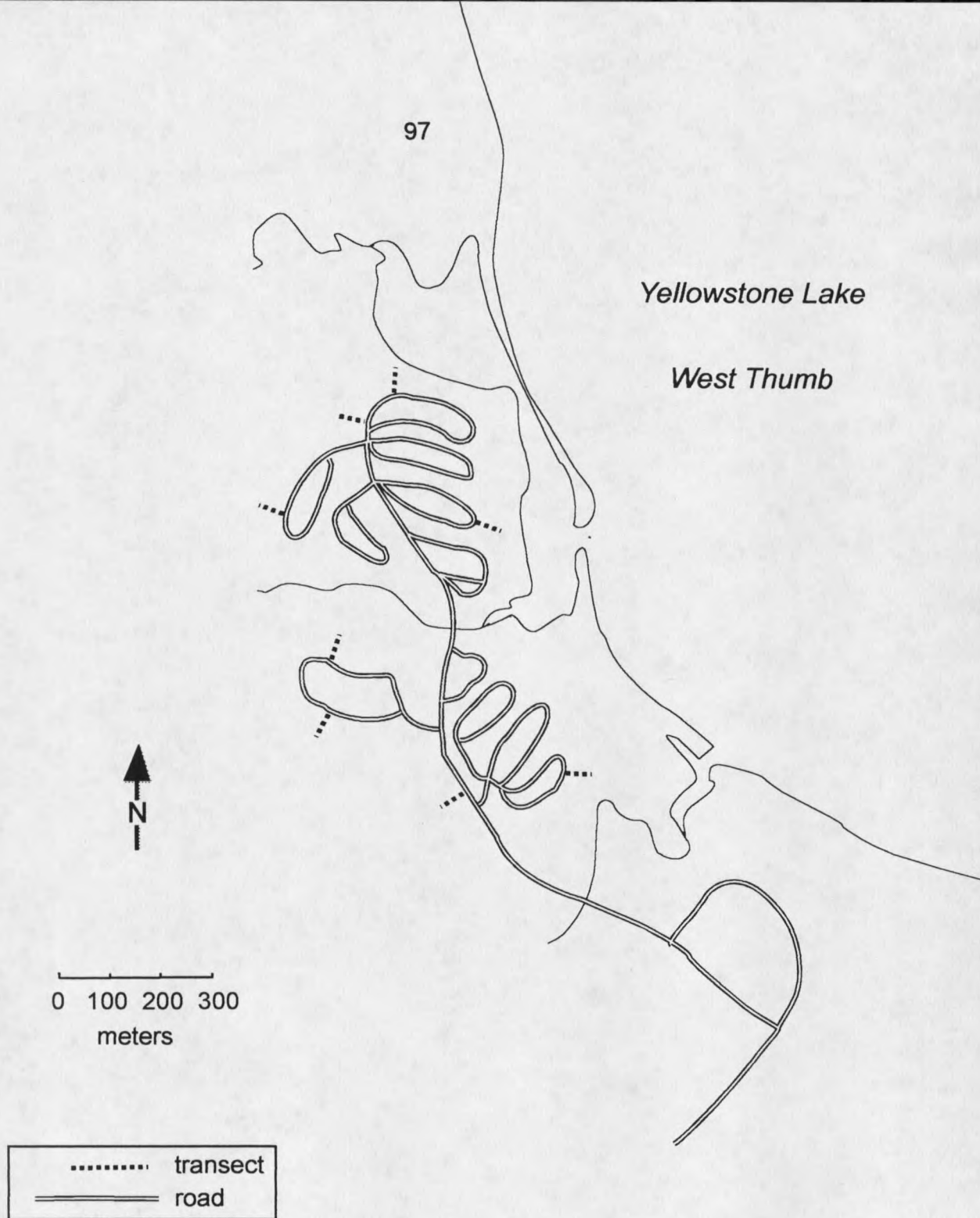


Figure 31. Grant Village Campground

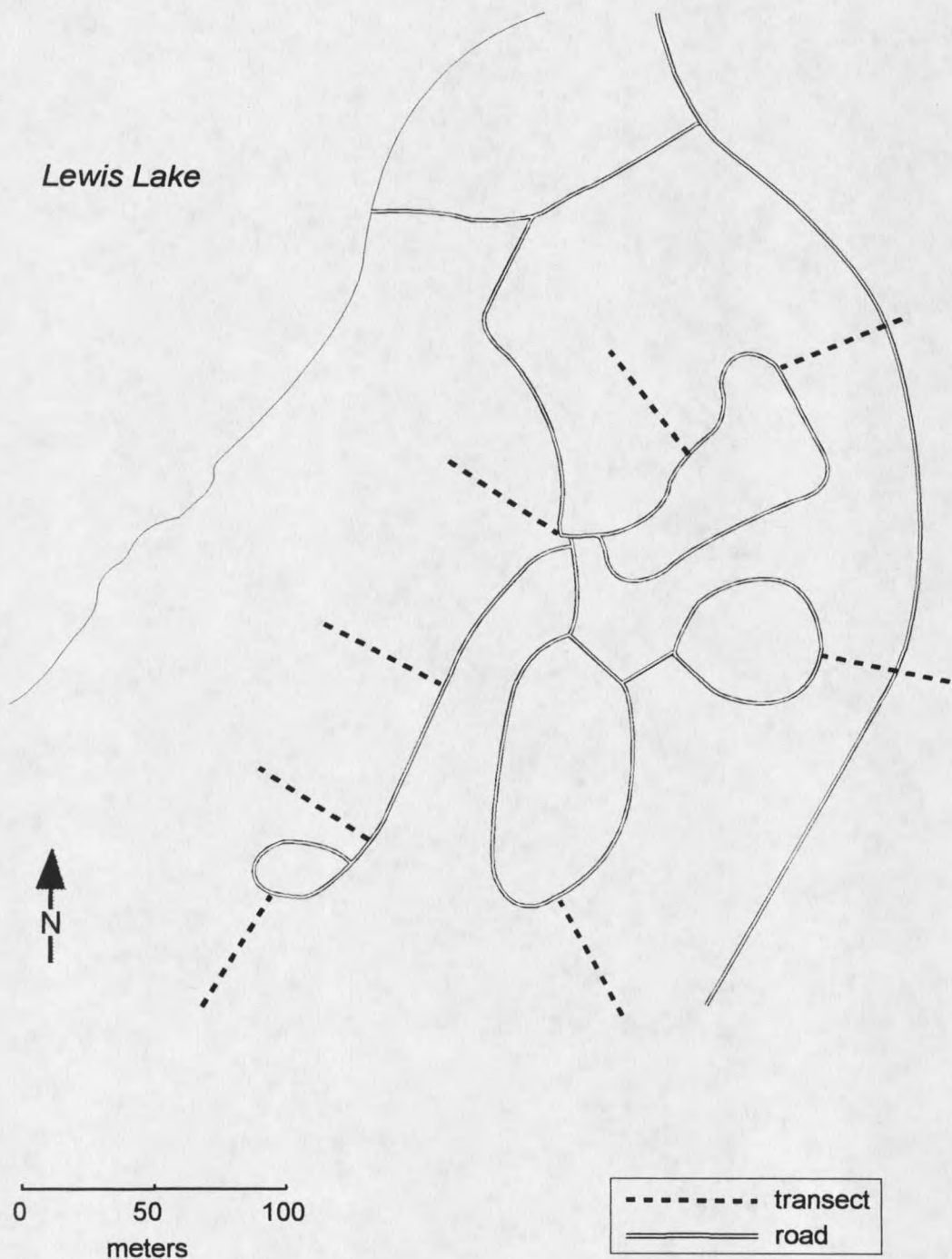


Figure 32. Lewis Lake Campground

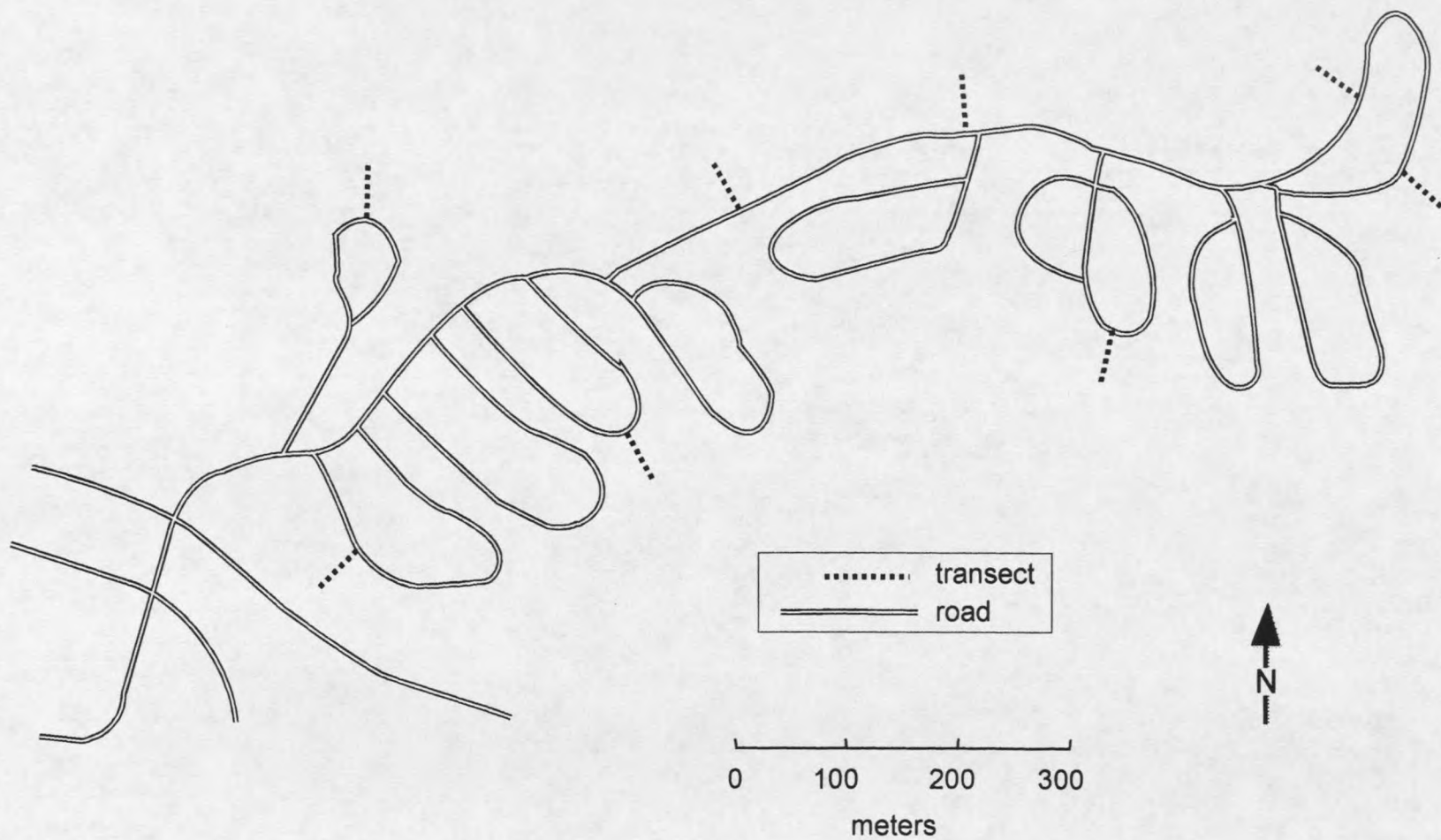


Figure 33. Canyon Campground

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