ARE BOREAL ECOSYSTEMS SUSCEPTIBLE TO INVASION BY ALIEN PLANTS? A CASE STUDY OF GROS MORNE NATIONAL PARK

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Are Boreal Ecosystems Susceptible to Invasion by Alien Plants?

A Case Study of Gros Morne National Park

by

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Abstract

Invasion by alien species is one of the major contributors to the local and global loss of indigenous biological diversity, and a concern to managers of protected areas. The objectives of this study were to document and evaluate the distribution and abundance of alien plant species in boreal ecosystems of Gros Morne National Park of Canada (GMNP). In areas susceptible to invasion by alien plants the physical parameters contributing to their presence or absence were determined. The importance of disturbance to alien plant invasion in boreal ecosystems was examined by evaluating how environmental conditions and diversity of alien species change as a function of disturbance regime. Functional characteristics contributing to successful invasion in GMNP were also examined.

Alien plants were found in areas of anthropogenic and natural disturbance throughout GMNP with the greatest abundance and diversity of species occurring in disturbances close to high anthropogenic activity. Although alien plants were absent from undisturbed areas, their unexpected occurrence in disturbed areas remote from human activity is of great concern because they may alter ecosystem properties and displace native species in these areas.

Vegetation types vulnerable to alien plant invasion in GMNP include forests, riparian areas, fens, and alpine meadows. Disturbance occurring in these vegetation types caused increases in bare ground and/or light availability which allowed alien plants to invade these areas. Although high soil pH was associated with alien plants in these areas,

disturbance was not found to cause changes in soil pH. This implies that areas susceptible to invasion by alien plants may be pre-determined by bedrock geology or other factors influencing soil pH.

The abundance of alien plants changed from high to undisturbed disturbance regimes. The greatest percentage of alien species occurred at high disturbance regimes, while the total number of alien species was greatest at intermediate disturbance regimes.

Moose (*Alces alces*), a non-native herbivore, acted as the primary conduit for alien plant invasion in GMNP by dispersal of propagules and creating or prolonging disturbance by trampling and browsing vegetation. Hiking trails were also found to be conduits for alien plant dispersal into natural areas.

Areas no longer experiencing disturbance by anthropogenic activity required long periods of time to recover. These areas acted as foci in which alien species could persist and spread to other areas of GMNP.

Species of concern in GMNP include *Ranunculus repens*, *Tussilago farfara*, *Lythrum salicaria*, *Digitalis purpurea*, *Hieracium* spp., *Taraxacum officinale*, *Cirsium arvense*, and *Myosotis scorpioides*.

Alien species able to successfully invade areas remote from human activity differed from alien species unable to invade these areas by exhibiting both vegetative reproduction and dispersal of asexually produced propagules.

Boreal ecosystems can be invaded by alien plants. Management plans must monitor the presence and potential spread of alien plants in GMNP.

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Chapter 1 - Introduction

1.1 - Why Be Concerned With Alien Plants?

After land use change and habitat loss, biological invasion by non-native species is one of the major contributors to the local and global loss of indigenous biological diversity (D'Antonio 1997; Kolar and Lodge 2001). Plant communities worldwide are becoming progressively homogenized by the spread of alien plants (Wiser et al. 1998). Human population growth and technology have favoured the spread and dispersal of alien species through increased transportation and expansion of disturbed habitats (Cooper 1981; Mooney and Drake 1986). Invasion by alien species is a conservation concern for protected areas, and is cited as a serious threat to National Parks in many countries such as Canada, South Africa, Australia, and the United States (MacDonald et al. 1986; Cowie and Werner 1993; Fensham et al. 1994; Westbrook, 1998, Canadian Heritage 1998; Parks Canada Agency 2000).

An alien species may be defined as a species that enters an ecosystem beyond its historic range, including any organism transferred from one country or province to another (Mosquin 1997). More specifically, an alien species in this thesis is considered any species which has been introduced to the Island of Newfoundland through human activity in the last 500 years. Many of the alien plant species present in Newfoundland became established due to a long history of vigorous trade with Europe (Cooper 1981). Meades et al. (2000) was the authority used to classify species as alien to the Island of Newfoundland.

Alien plants species contribute directly to the loss of native plant bio-diversity through competition and introduction of diseases, parasites, and fungi to an ecosystem (Mooney and Drake 1986; Drake et al. 1989; Groves and Burdon 1986; Hughes and Vitousek 1993; Kourtev et al. 1998). For example, the alien shrub *Lonicera maackii* has decreased the abundance of native tree seedlings and herbaceous plants in hardwood forests of Ohio by competitively excluding them from light (Hutchinson and Vankat 1997). Besides competitive exclusion of native species for space or resources alien plants can change the environment invade. Alien species have been found to alter ecosystem properties by changing resource availability, trophic structure, and disturbance regimes (Vitousek 1990; D'Antonio and Vitousek 1992; Mack and D'Antonio 1998). The alien nitrogen-fixing shrub *Myrica faya* alters resource supply and succession by quadrupling inputs of soil nutrients in Hawaii Volcanoes National Park (Vitousek 1990). Increased fire frequency due to the presence of alien grass species has altered disturbance regimes leading to a suppression of native trees in some areas of western North America and Hawaii (Ramakrishnan and Vitousek 1989; D'Antonio and Vitousek 1992).

National Parks and other protected areas are benchmarks against which society can evaluate change caused by human activity (Stohlgren et al. 1998; Parks Canada Agency 2000). Alien plants are threatening ecosystem processes and native biodiversity that contribute to these areas as benchmarks to sustainable human activity. Alien plants are listed as the fourth most common stressor occurring in Canadian National Parks (Canadian Heritage 1998). In US National Parks (excluding Alaska) it is estimated that invasive alien plants occur in 31 % of National Park Service area for a total of 28328 km^2 (7 million acres) of National Park Service land (Westbrook 1998). The alien plant Melaleuca (*Melaleuca quinquenervia*) is estimated to infest 2023.4 km^2 (500000 acres) of native wetlands in South Florida and is a problem in Everglades National Park where it displaces native vegetation and degrades wildlife habitat (Westbrook 1998). The alien plant Garlic Mustard (*Alliaria petiolata*) forms dense mono-cultures and is displacing rare Carolinian forest plant species in Point Pelee National Park of Canada (Haber 1997; Parks Canada Agency 2000). In Riding Mountain National Park of Canada high numbers of alien plants are invading native rough fescue communities and displacing native species (Parks Canada Agency 2000). The South American shrub Lantana (*Lantana camara*) is invading Australia's Forty Mile Scrub National Park where it decreases species richness and increases fuel loads (Fensham et al. 1994). Lantana also occurs in South Africa's Kruger National Park where heavy infestations of the species are threatening riparian habitats (Macdonald 1988).

Research presented in this thesis focuses on alien plant invasion in protected areas of boreal ecosystems. How disturbance and site characteristics contribute to alien plant invasion in natural areas of boreal ecosystems must be determined so that methods can be established to manage alien plants in these areas.

1.2 - Stages of Alien Plant Invasion

Although there is an abundance of literature on the negative implications of alien plant species, a very low proportion of introduced species eventually spread into natural plant communities (Andersen 1995). Fewer than 20% of plants colonizing a new area are thought to have a measureable population or system-level impact (D'Antonio 1997). Alien plants of greatest concern in this thesis are invasive species. Species are considered invasive when they are able to persist and expand in natural plant communities (Burke and Grime 1996).

Models of plant invasion generally refer to three primary elements; dispersal, establishment, and persistence and expansion (Figure 1) (Kruger et al. 1986; Hobbs 1989; Kolar and Lodge 2001). These basic elements can be applied to invasion over intercontinental or regional scales (Kruger et al. 1986). Dispersal refers to an alien species overcoming geographic barriers between its place of origin and the area in which it is invading (Kruger et al. 1986). Establishment refers to an alien plant being able to withstand the rigours of its new habitat by having the ability to successfully grow and reproduce at a site (Kruger et al. 1986). Characteristics of species which become established and their interaction with the invaded community determine how well a species will persist and expand in an area (Kolar and Lodge 2001).

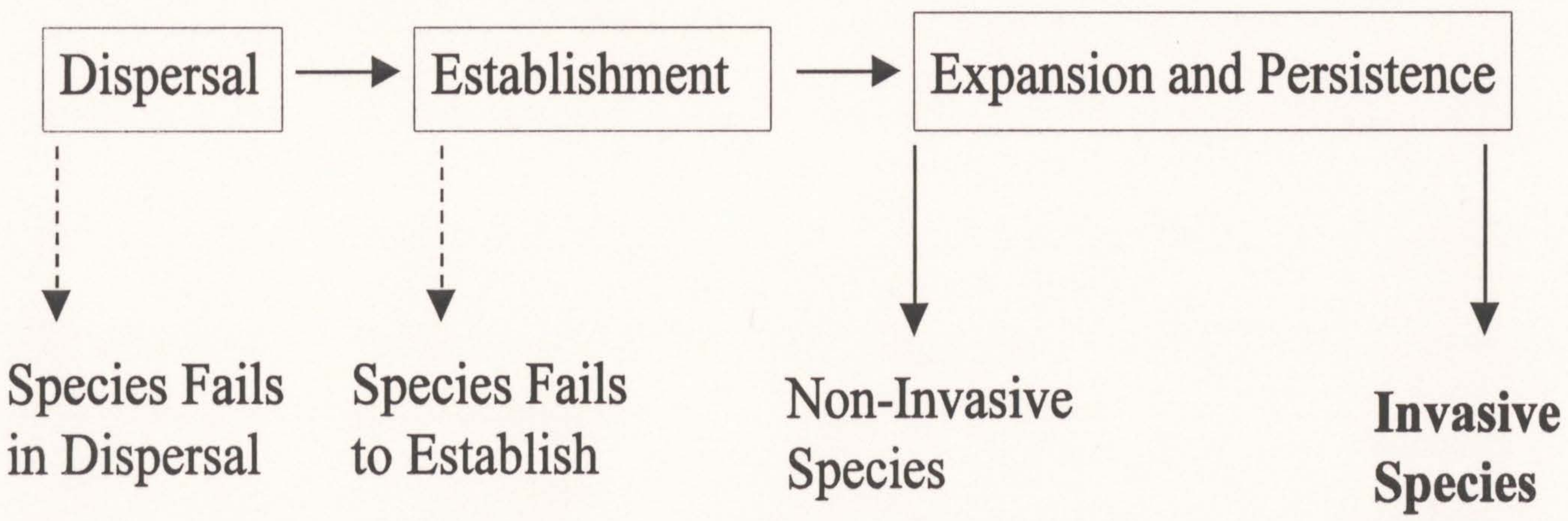

Figure 1: Conceptual Model of Alien Plant Invasion (Kolar and Lodge 2001)

The basic model of invasion becomes more complex when factors influencing each element are taken into account (Figure 2). Chance and timing influence all stages and aspects of invasion and include such things as synchrony of invasion with resource supply, weather conditions, habitat openings, competitor phenology, and dispersal vectors (Crawley 1989).

Factors influencing the dispersal stage include the supply and availability of plant propagules and the obstacles of distance and landscape which propagules must pass in order to be dispersed to a new site (Cooper 1981; Kruger et al. 1986; Tyser and Worley 1992; Brothers and Spingarn 1992; Andersen 1995). The dispersal vectors present in an area and the functional adaptations of alien plant species to utilize dispersal vectors determine how successful an alien species is at overcoming obstacles to dispersal (Dean et al. 1986; Kruger et al. 1986; Andersen 1995; McIntyre et al. 1995) (Figure 2).

Establishment of an alien species at a site is most limited by the site conditions of the area and how well individual species are adapted to growth and reproduction in these conditions (Wiser et al. 1998; Larson et al. 2001) (Figure 2). Site conditions such as light availability, temperature, nutrients, and soil pH are primarily influenced by environmental conditions such as geology, climate, and vegetation. Openings in areas suitable for alien plant growth are usually provided by disturbance, which decreases competition and increases resource availability for alien species (Fox and Fox 1986; Hobbs 1989; Stohlgren et al. 1999a). The response of alien plants to disturbance and site conditions vary within and between species, and sweeping generalizations about the

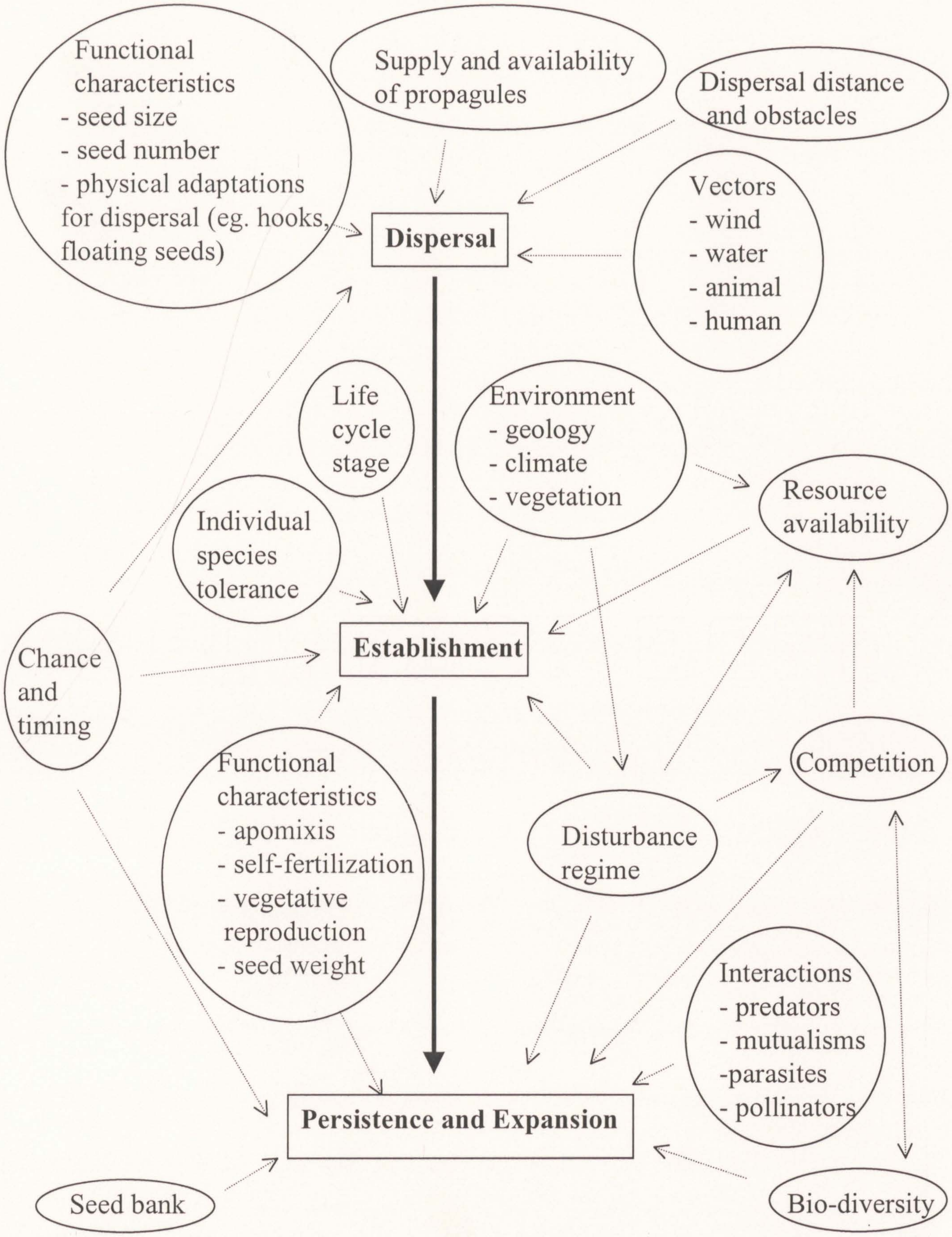

Figure 2: Factors Influencing Stages of Alien Plant Invasion

ability of alien plants to grow and reproduce in an area are difficult (Stohlgren et al. 1999b; Larson et al. 2001). Although it is difficult to predict whether or not a species will become invasive, some plant characteristics such as vegetative reproduction, self fertilization, and seed weight appear to influence the ability of an alien plant to establish, persist, and expand in an area (McIntyre et al. 1995; Lavorel et al. 1997; Kolar and Lodge 2001).

Alien plants with the ability to grow and reproduce in an area may not become invasive. Competition with other plants and the presence or absence of interactions with other organisms such as predators, parasites, and pollinators may increase or decrease the ability of an introduced species to become invasive (Crawley 1989) (Figure 2). Factors influencing the disturbance regime of an area such as frequency and severity of disturbance, and recovery after disturbance also influence persistence and expansion by determining the availability, duration, and frequency of habitat openings for alien plants (Bazzaz 1983). The longevity and abundance of alien plant seeds in the seed bank may also contribute to the persistence of alien plants in an area. Presently, the importance of bio-diversity on plant community invasibility is a major debate in plant ecology with research demonstrating both species rich and species poor communities being more susceptible to invasion (Stohlgren 1998; Wiser et al. 1998; Levine and D'Antonio 1999; Smith and Knapp 1999; Tilman 1999; Dukes 2001). Bio-diversity is influenced by the same conditions which influence invasibility, and it is difficult to isolate the impact of bio-diversity on invasibility when it is considered independently from factors such as competition, resource supply, disturbance, and propagule supply (Levine and D'Antonio 1999).

This study focuses primarily on factors influencing the establishment stage of invasion by examining the site conditions and disturbance regimes with which alien plant species are associated in GMNP. Important inferences about the dispersal stage and persistence and expansion stage are made using survey results, but in order to more accurately evaluate these stages of invasion, longer term monitoring is required.

1.3 -Disturbance and Alien Plants

Alien plants colonize habitat openings that are usually generated by both anthropogenic and natural disturbance, and for this reason alien species are generally found in disturbed areas (Fox and Fox 1986; Carson and Pickett 1990; Burke and Grime 1996; Schwartz 1997; Stohlgren et al. 1999a). Disturbance can be defined as any discrete event in time that disrupts ecosystem, community, or population structure and changes resources, substrate availability, or the physical environment (White and Pickett 1985). Hobbs (1989) suggested only those areas where disturbance has increased resource availability are suitable for colonization by alien plants. Disturbance has many parameters which interact to determine the disturbance regime of a particular area (Bazzaz 1983; White and Harrod 1997), and for this reason the availability of resources for alien plants in a particular area will vary with these parameters. Disturbance regime parameters include spatial (size, distribution, landscape context), temporal (frequency, seasonality, predictability, rotation period), specificity (species, age class or size class, land forms, community state), magnitude (intensity, severity), ecosystem effects (heterogeneity, ecosystem legacies), and synergisms (interactions) (White and Harrod 1997).

In almost all systems studied, disturbance is associated with change in important ecosystem parameters and enhance invasibility by alien plants (White and Pickett 1985). In forest environments change in light availability due to disturbance is one of the most important factors contributing to alien plant invasion (Bazzaz 1983; Brothers and Spingarn 1992; Hutchinson and Vankat 1997). Increased light availability may directly influence alien plants, or it may indirectly influence them by causing changes in other resources such as soil temperature, moisture, pH, and nutrient availability (Vitousek 1985; Shugart et al. 1992). The susceptibility of an area to alien plant invasion has been related to the availability of bare ground created by disturbance (Reader and Buck 1986; Burke and Grime 1996). Removal of a closed cover of native species by disturbance contributes to invasion by creating space in which alien plants can colonize and by decreasing competition for resources in the area (Burke and Grime 1996). Changes in the amount of bare ground in an area also has the potential to alter soil drainage patterns, temperature, moisture, and soil pH.

The majority of alien plants are adapted to capitalize on increased resources and decreased competition in disturbed areas by having life forms, life histories, and reproductive strategies which can withstand the effects of disturbance and / or competitively exclude native species for resources (Baker 1965; Grime 1979; Bazzaz 1983). For example, *Taraxacum* species have higher reproductive allocation in highly disturbed environments than stable environments; this allows them to spread rapidly and colonize disturbed areas before native species become established (Bazzaz 1983). Other examples are ruderal species such as *Plantago juncoides, Senecio viscosus*, and *Matricaria matricarioides* that are adapted to grow in highly disturbed environments by having rapid growth and reproduction, abundant seed production, small size, and life forms resistant to disturbance (Baker 1974; Grime 1979). These adaptations allow these species to avoid or minimize the detrimental impacts of disturbance while at the same time rapidly colonizing and growing in the open habitats provided by disturbance.

1.4 - Alien Plant Invasion in Boreal Ecosystems

In boreal forest ecosystems disturbance is a fundamental process that ensures the structure and function of the ecosystem (Elliot-Fisk 2000; Shugart et al. 1992). Natural disturbances such as fire, insect outbreaks, windfalls, and herbivory ensure patchiness and diversity in boreal forests (Shugart et al. 1992). Other areas of boreal ecosystems such as bogs, barrens, or alpine areas are disturbed at intervals less frequently than forested areas and may be sensitive to increased frequency of disturbance due to human activity. As disturbance is important in both alien plant invasion and boreal ecosystems, some alien plant species may be able to capitalize on natural disturbance or alter disturbance regimes in boreal ecosystems. Studying alien plant invasion in boreal ecosystems allows potential or unknown problems caused by alien plants in these areas to be determined for the present or future management of large scale development such as forestry and mining, and for managing natural areas.

Although boreal forests make up one third of the world's forested land (Shugart et al. 1992), few studies have examined alien plant invasion in boreal ecosystems. The presence of alien plants in disturbed areas near anthropogenic activity in boreal ecosystems is well documented (Cooper 1981; Wein et al. 1992; Canadian Heritage 1998; Rose 1998; Stapleton et al. 1998; Parks Canada Agency 2000), but little is known about alien plant invasion and persistence in undisturbed areas or areas of natural disturbance remote from human activity. Rose (1998) found disturbances remote from anthropogenic activity in boreal forests of Terra Nova National Park (Canada) did not contain alien plants. Wein et al. (1992) found river flood plains disturbed by agricultural practices, damming, timber harvesting, and natural disturbance in Wood Buffalo National Park contained alien plants and indicated a potential for alien plants to spread downstream from these areas along naturally disturbed river banks.

Boreal ecosystems are characterized by cool temperatures and a short growing season (Elliot-Fisk 2000). Soils in boreal regions are generally high in organic matter and moisture, are acidic, have low nutrient availability, and are often covered by a thick layer of moss (Bonan and Shugart 1989; Bonan 1992; Pastor and Mladenoff 1992). Boreal forests have dense evergreen tree canopies, which limit sunlight to under-storey vegetation (Elliot-Fisk 2000). Natural disturbance in boreal ecosystems has been shown to increase soil pH, light availability, and bare ground (Pastor and Mladenoff 1992), but it is uncertain if these increases in resource availability are sufficient enough to fuel the lifestyles of rapid growth and reproduction characteristic of many alien plants (Grime

1979; Bazzaz 1983), only those species which are pre-adapted to the harsh climatic and edaphic conditions of the region will have the potential to invade these areas.

1.5 - Gros Morne National Park

Gros Morne National Park of Canada, a UNESCO World Heritage Site, is the most diverse region on the island of Newfoundland, containing parts of four provincial eco-regions within its boundaries that result from the physiographic, geologic, and climatic diversity of the area (Bouchard et al. 1991). Gros Morne National Park has the highest native plant diversity in all of Newfoundland and contains 36 % of the Newfoundland's rare plant species within its boundaries (Brouillet et al. 1996). It is important to evaluate the distribution and abundance of alien plants in Gros Morne National Park to ensure that they are not altering the ecological processes that maintain the diversity in this area.

1.6 - Objectives

The objectives of this study are to: 1) use survey methods to document and evaluate the distribution and abundance of alien plant species in Gros Morne National Park (GMNP) and determine which areas appear most susceptible to invasion by alien plants; 2) determine how the abundance and diversity of alien plants change as a function of disturbance regime and environmental conditions; 3) for vegetation types susceptible to invasion by alien plants, determine which physical parameters contribute to the presence or absence of alien or native species; 4) evaluate alien plant attributes that contribute to successful invasion in GMNP.

Chapter 2 of this thesis describes the study area and outlines the environmental and human conditions which may influence alien plant invasion in GMNP. The use of surveys to evaluate the impacts of alien plant species in GMNP is presented in Chapter 3. The use of study sites to determine how disturbance regimes and environmental parameters are related to alien plant invasion in GMNP is given in Chapter 4. This chapter also examines species functional characteristics which contribute to successful invasion in GMNP. Chapter 5 discusses the implications of alien plants in GMNP and provides recommendations for future research and management.

Chapter 2 - Study Area

Gros Morne National Park of Canada is located on the west coast of the island of Newfoundland (Figure 3). GMNP was established in 1973 and is eastern Canada's largest national park at 1805 km^2 (Burzynski 1999). GMNP was designated a UNESCO World Heritage Site in 1987 for its unique geology and scenery. The topography, physiography, and geology of the area contributes to much local variation in climate and vegetation, making GMNP one of the most biologically diverse areas of Newfoundland.

2.1 - Topography, Physiography, Geology, and Recent Glacial History

GMNP is made up of three physiographic regions, which include the serpentine Tablelands, flat coastal lowland, and alpine plateau (Figure 4). Numerous authors have described the physiography and geology of GMNP (Damman 1983; Williams 1985; Bouchard et al. 1991; Berger et al. 1992; Burzynski 1999). Topography is an important determinant of climate, vegetation, and human activity in the park. The rapid change in elevation between the coastal lowlands and alpine plateau is one of the most conspicuous features of GMNP (Figure 5).

The coastal lowlands (50 - 150 m elevation - Figure 5) are composed primarily of sedimentary limestone and sandstone which lie in alternating bands parallel to the coast (Figure 6) (Williams 1985; Berger et al. 1992). Some limestone and dolomite exposures form high stratified cliffs in Bonne Bay (Bouchard et al. 1991). The coastal lowlands rise abruptly to the alpine plateau reaching elevations of 800 m (Figure 5). The alpine plateau forms part of the Long Range Appalachian Mountains of Newfoundland's Northern

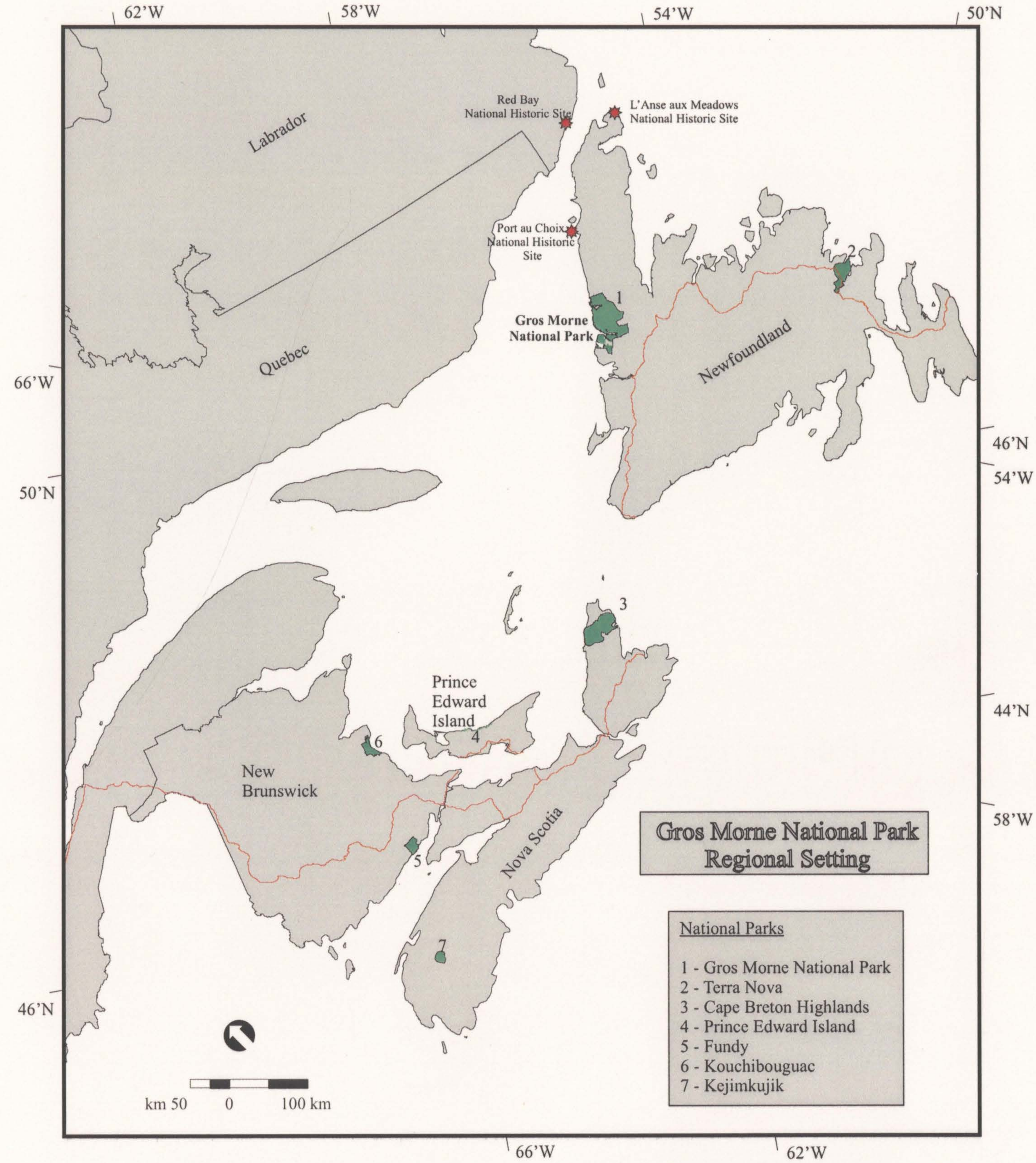

Figure 3: Regional Setting of GMNP (Taylor 2000)

Figure 4: Physiography of GMNP (Burzynski 1995)

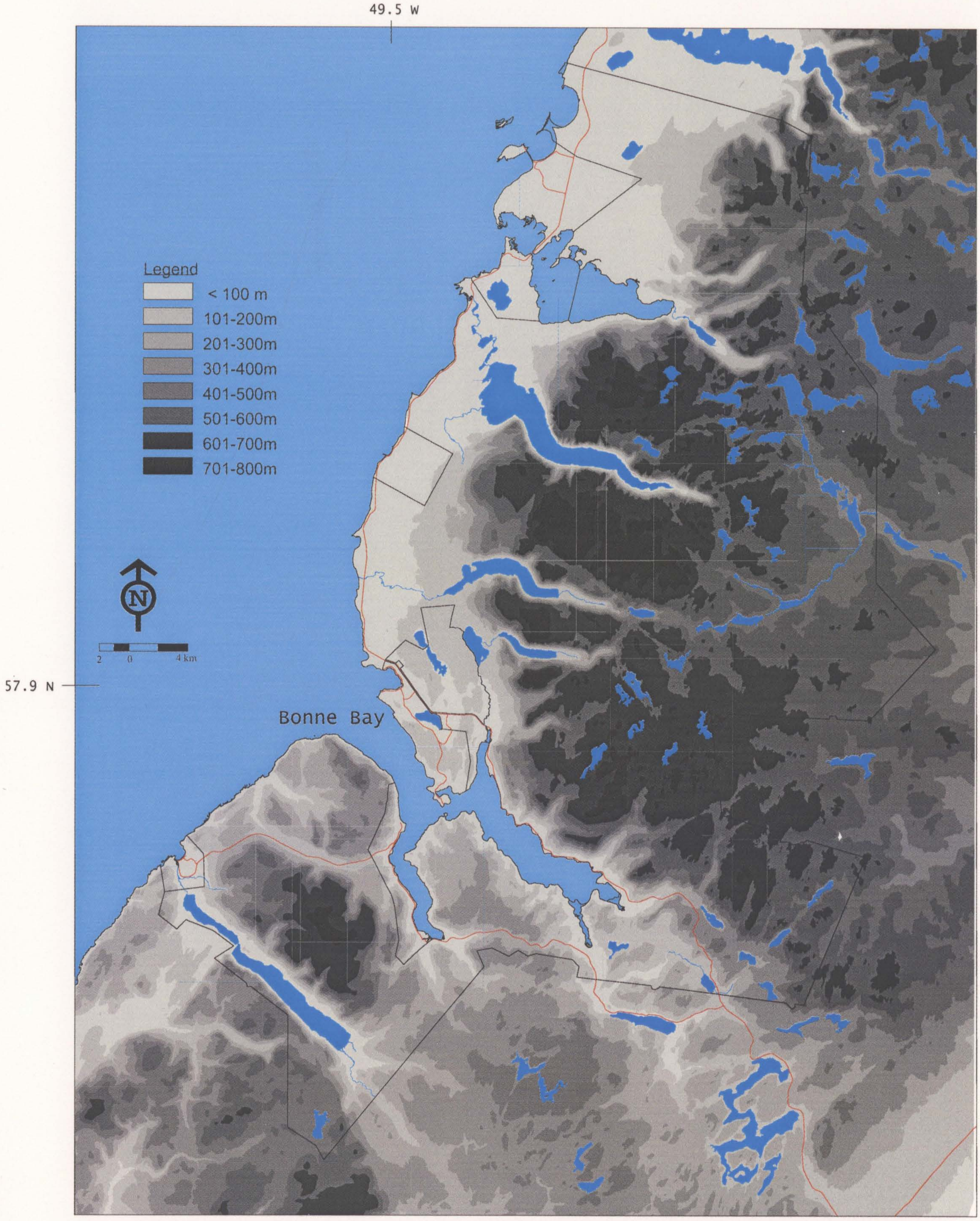

Figure 5: Topography of GMNP (Taylor 2000)

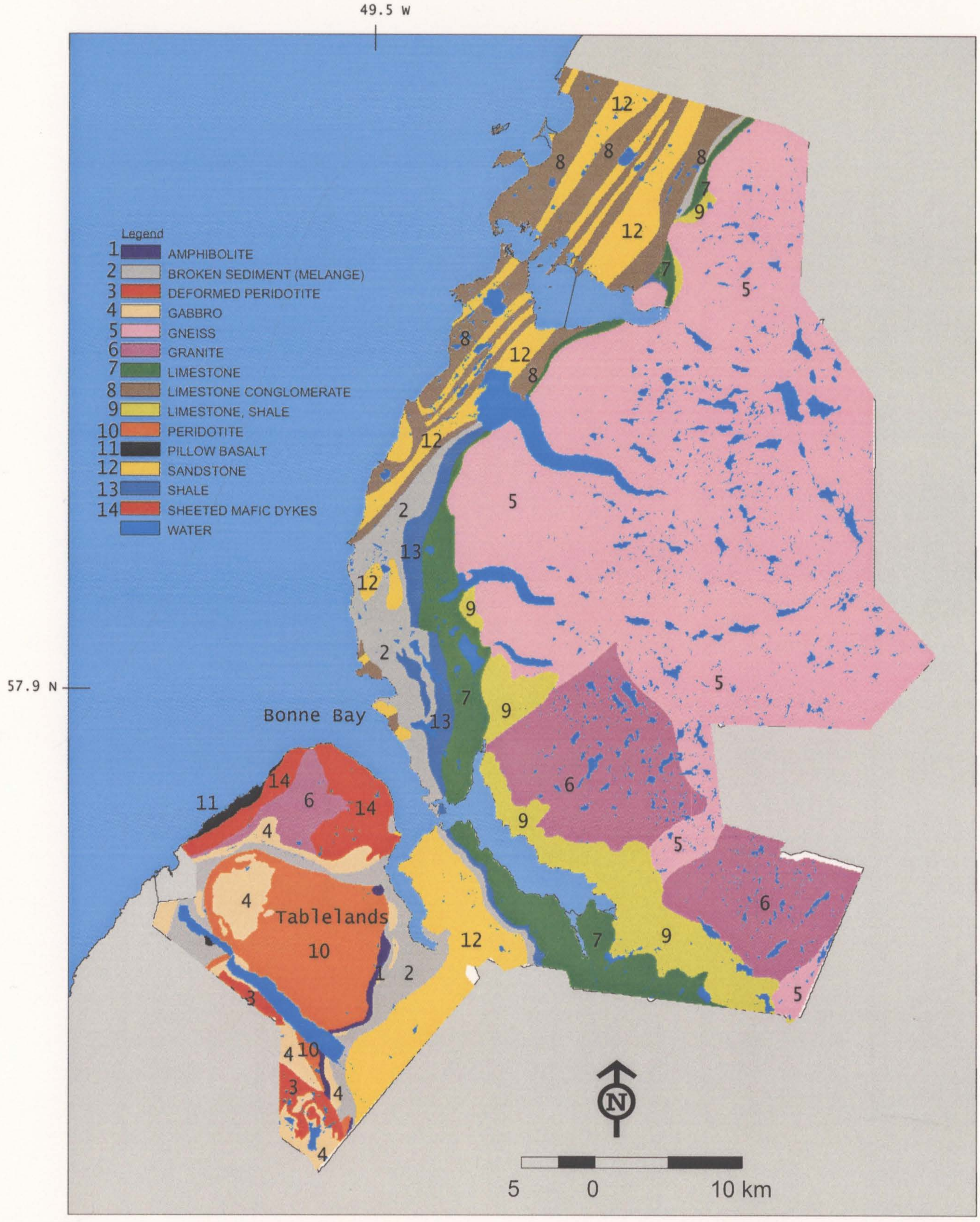

Figure 6: Geology of GMNP (Taylor 2000)

Peninsula and consists principally of meta-morphic and igneous granite or granite-gneiss (Williams 1985) (Figures 4 and 6). Exposures of sedimentary limestone and quartzites flank the abrupt escarpment between the coastal lowlands and alpine plateau (Bouchard et al. 1991).

The serpentine Tablelands are mainly composed of ultramafic peridotite, altered gabbroic rocks, and quartz diorite that originated from the suboceanic crust; the Tablelands are the primary reason GMNP is designated a UNESCO World Heritage Site (Brookes 1993; Burzynski 1999).

The island of Newfoundland was most recently de-glaciated approximately 11000 to 12000 B.P. with highland areas on the Long Range Mountains not being de-glaciated until approximately 9000 B.P. (Grant 1989). The dominant geomorphological features of the park reflect Pleistocene glaciation; these land forms include ice-scoured uplands, glacier-carved valleys, moraine-mantled lowlands, and coastal rock terraces (Bouchard et al. 1991). Highland areas were scoured by ice, and little soil development has occurred in these areas since the last glaciation so that barren rock knobs and rubble fields crown the hills (Grant 1989). Increased sea level in the time period immediately after glaciation means that much of the coastal lowlands are covered with marine deposits, which have differences in mineralogy and chemistry from the underlying bedrock depicted in Figure 6 (Berger et al. 1992).

2.2 - Climate

The location and physiography of GMNP contributes to much spatial and temporal variability in climate. GMNP can be divided into two main climatic zones: the coastal lowlands and alpine plateau (Banfield and Jacobs 1996). A third zone with a longer growing season and higher summer temperatures has been proposed for the southern portion of the park (Bouchard et al. 1991). The principal factors influencing the climate are cool temperatures, a short growing season, moderating oceanic influence, a continual moisture excess, and strong prevailing southwesterly and westerly winds (Bouchard et al. 1991).

The coastal lowland has its lowest mean monthly temperature in February at -7.5 °C, and highest mean monthly temperature in July at 17 °C (Banfield 1990). The coastal lowland receives 1200 - 1450 mm of precipitation per year (Banfield and Jacobs 1996). Estimates of annual snowfall in the area range from 435 to 540 cm depending on the locality (Banfield and Jacobs 1996). The growing season ranges from 150 days in southern areas to 140 days in northern areas (Bouchard et al. 1991).

Long-term climate data for the alpine plateau is lacking. Recent data vary, but seem to indicate that alpine areas have daily maximum and minimum temperatures that are 5.1 °C and 3.6 °C lower respectively than lowland regions (Banfield and Jacobs 1996). The alpine plateau has its coldest mean monthly temperature in January at -10.5 °C, and warmest mean monthly temperature in July at 13 °C (Banfield 1990). Current estimates of highland precipitation are in the range of 1600 - 1800 mm/yr (Banfield and Jacobs 1996). Lack of long term data and high winds make estimates of snowfall difficult in the alpine region, but snow cover is thought to be at least two months longer in duration than on the coastal lowland (Bouchard et al. 1991). The growing season in the alpine region can be as short as 130 days and even shorter in snow bed areas (Bouchard et al. 1991).

2.3 - Vegetation

Gros Morne National Park has the highest diversity of vegetation types in the province. These areas contain 36 % of all the rare plant species on the Island of Newfoundland (Brouillet et al. 1996). The vegetation of the park can be separated into four main regions: the coastal lowlands, Long Range Mountains, serpentine Tablelands, and undulating lowland forest. Vegetation types with the largest area in the park are balsam fir forest (36%), heath-lichen tundra (21.6%), tuckamore (krummholz) (12.9%), bog and fen (9.5%), black spruce forest and scrub (6%), and serpentine barrens (4.8%) (Taylor 1995) (Figure 7).

The coastal lowlands extend north from Bonne Bay to the park's northern boundary. The coastal lowlands comprise many habitats such as tidal flats, sand dunes, seashore cliffs, coastal tuckamore, sedge meadows, and salt marshes but consist mainly of ombrotrophic bog intermixed with black spruce (*Picea mariana*) and balsam fir (*Abies balsamea*) forest in upland areas (Bouchard et al. 1991; Figure 7). The coastal lowlands rise abruptly to the Long Range Mountains, where alpine tundra barrens are dominated by shrub heaths, shallow peatlands, alpine tuckamore, and some forest in sheltered valleys (Bouchard et al. 1991; Figure 7).

The southern portion of GMNP consists of two vegetation zones: the Tablelands

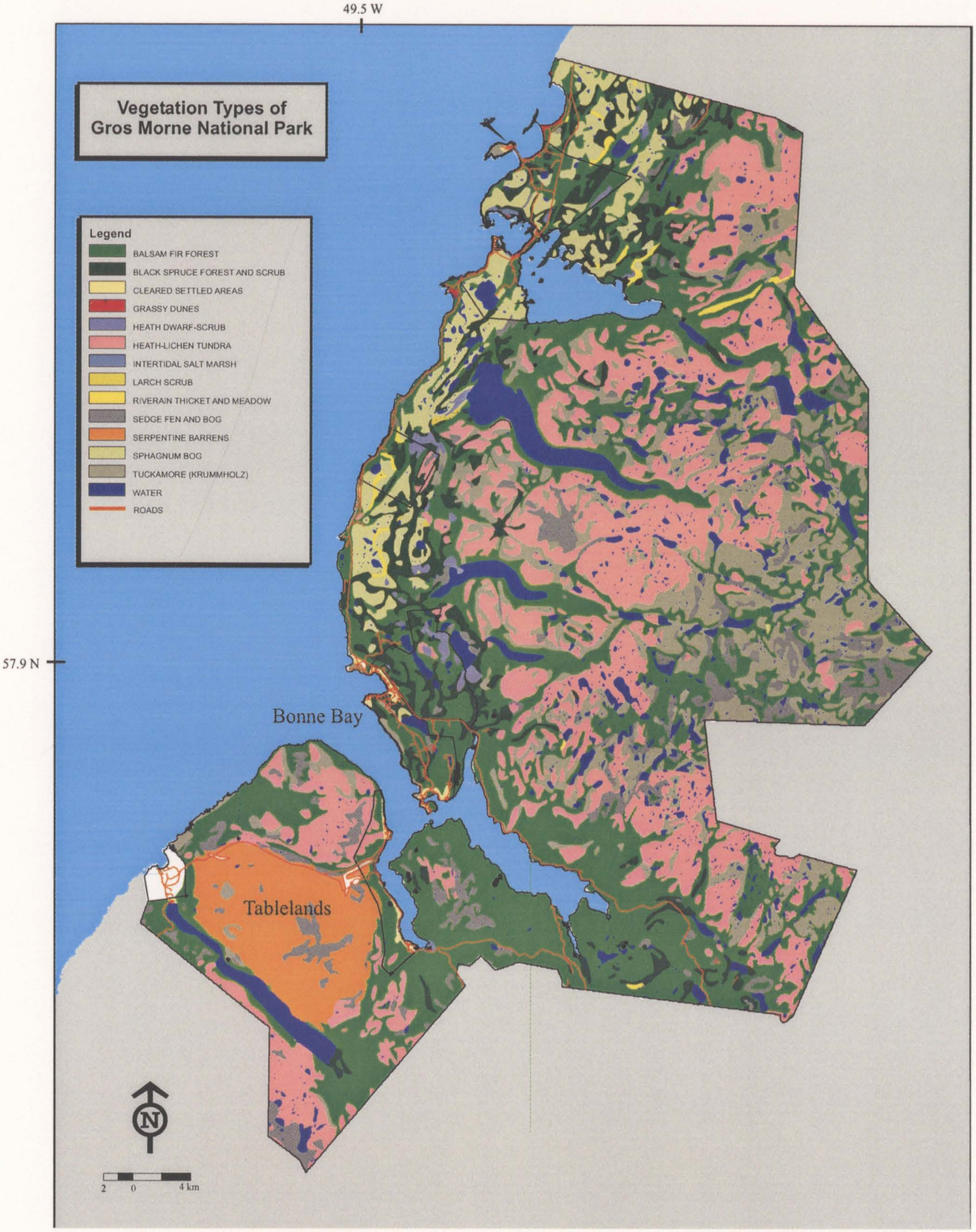

Figure 7: Vegetation of GMNP (Taylor 2000)

and the lowland forests (Figure 7). The Tablelands has substrates which are unfavorable to most plants because they are derived from serpentine and other ultramafic rocks which have low levels of essential elements such as nitrogen, potassium, phosphorus, and calcium, and high concentrations of nickel, magnesium, cobalt, iron, and chromium (Burzynski 1999). This area lacks forest cover, and with the exception of some fens and specialized or stress-tolerating plants, vegetation is sparse. The lowland forest extends from Bonne Bay south to the park's southern limit. This area differs from other regions of the park in that it has a longer growing season and generally contains nutrient-rich, productive soils (Bouchard et al. 1991). It contains predominantly balsam fir intermixed with black spruce, white birch (*Betula papyrifera*), white spruce (*Picea glauca*), larch (*Larix laricina*), and bogs (Figure 7).

2.4 - Human History

The earliest known human activity in GMNP occurred at least 5000 BP when the Maritime Archaic Indians inhabited the area (Burzynski 1999). Although several native cultures occupied the area since then, the landscape of GMNP was not heavily modified until the arrival of European settlers in the 1700s (Burzynski 1999). Human settlement in the area was due to a rich fishery along the coast and forest stands in the southern end of the park. Commercial logging started at the beginning of the 1900s and ended in the 1960s (Burzynski 1999). All forested areas in the Bonne Bay area and coastal lowlands have been cut at least once. Although commercial logging has ceased, and commercial fishing much reduced, almost all coastal areas show impacts of past resource use. The remains of abandoned communities, fields, gardens, saw mills, and fishing huts are still very obvious throughout all coastal areas.

Today GMNP contains ten enclave communities with a total population of 4500 (GMNP EIS Statement 2000). GMNP is the most visited tourism destination on Newfoundland's west coast (Burzynski 1999), receiving approximately 120 000 visitors per year (Parks Canada 2001). Present day anthropogenic activity and infrastructure such as roads, quarries, picnic areas, and campgrounds are concentrated predominantly in forest vegetation of coastal areas (Figure 8). Human activity is restricted primarily to coastal areas because abrupt changes in topography make access to the alpine plateau difficult and because resource extraction such as fishing and forestry occur near the coast. An exception to this are trails (designated or non-designated) used by hikers, skiers, and snowmobile users who travel to areas throughout the park. Although GMNP operates like other national parks, the park's establishment agreement allows certain "traditional" activities such as timber harvesting, small game hunting, and snowmobiling in some areas of the park; these activities are considered significant management issues by park officials (GMNP EIS Statement 2000).

2.5 - Disturbances Occurring within GMNP

Historical and current disturbances found in GMNP include anthropogenic disturbances such as roads, hiking trails, snowmobile trails, borrow pits, and clear cuts, and natural disturbances caused by rivers, wind, insects, caribou, and moose. Many areas experience concurrent multiple disturbances. For example, disturbance by moose is

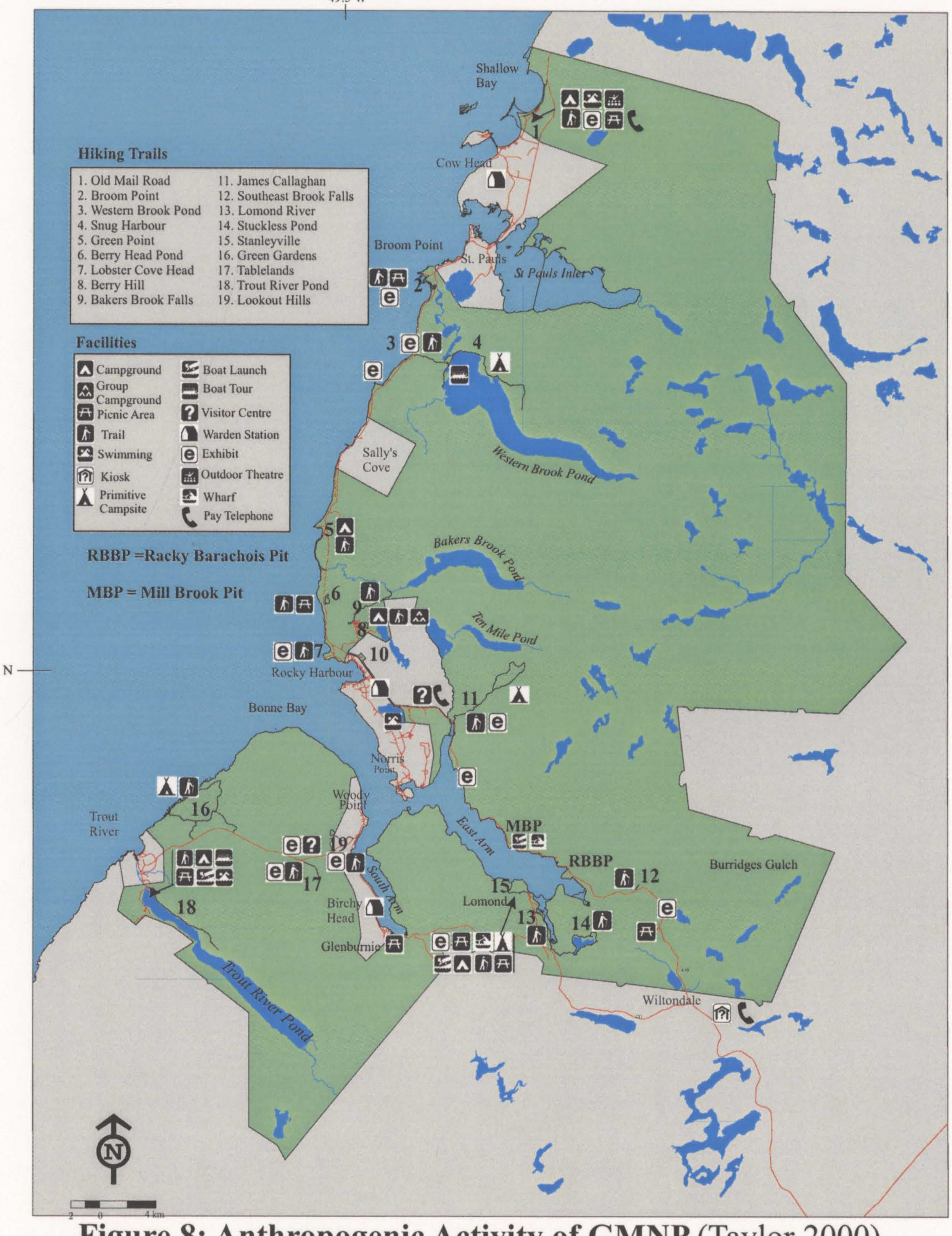

Figure 8: Anthropogenic Activity of GMNP (Taylor 2000)

widespread throughout the park and occurs along hiking trails and in clear cut areas.

2.5.1 - Anthropogenic Disturbances

(A) Roads

Roads are the most widespread anthropogenic disturbance occurring in GMNP. The majority of roads follow the coastline with the exception of some inland roads in the southern portion of the park (between Trout River and Woody Point, Glenburnie to Wiltondale, and just north of Wiltondale) (Figure 8). The majority of present day roads were constructed between 1979 and 1984 (Hendrickson 2000). Disturbance associated with roads includes construction, use and maintenance. Disturbance associated with road construction includes removal of trees in and around the area where the road is built. Construction also alters drainage patterns in the area around the road because of ditching and the introduction of rock and soil for the road bed. Where roads cross bogs, it may be necessary to remove large amounts of peat or drain moisture from these areas. The majority of borrow pits found in the park were created to supply gravel for road construction.

Present day disturbances along roads include vehicle compaction on road shoulders, unknown levels of disturbance caused by carbon monoxide production from motor vehicles, thinning of vegetation from roadside areas to ensure visibility of moose, and snow clearing operations which involve road plowing and salting.

(B) Hiking Trails

There are 19 designated hiking trails in GMNP (Figure 8). The majority of trails occur in forested areas of the coastal lowlands, but trails are present to some degree in all of the vegetation types found in GMNP. Several of these trails, including Trout River Pond, Snug Harbour, James Callahan, Lookout Hills, Stuckless Pond, Green Gardens, and Baker's Brook Pond, extend away from roadsides into areas of relatively low human activity. During trail construction the tree canopy is removed from areas near the trail, while removal of stumps and construction of drains along the trail alters drainage patterns. The introduction of non-indigenous gravel and boardwalks in areas along trails also modifies the area. Hikers using a trail disturb the area by trampling soil and vegetation on or near the trail.

In remote areas of the park, the Long Range Traverse and North Rim Traverse are backpacking trips which do not follow a designated trail. Although trampling of vegetation by hikers occurs as a result of this activity, the majority of disturbance resulting from hikers along these routes occurs at campsites. There are designated camping areas along the traverses so that the impact of hikers is limited to specific areas, but evidence of frequent camping in non-designated areas was found.

(C) Clear cuts

At present, harvesting of wood for domestic use occurs in designated cut blocks within GMNP. Domestic cut blocks are located throughout the park in almost all sections of balsam fir forest west of the Long Range Mountains. Disturbance by cutting opens various size portions of the tree canopy. The increased light in these areas can lead to changes in vegetation and soil moisture. Trees on the edge of clear cuts are more susceptible to wind disturbance because other trees which sheltered them from the impacts of wind are removed.

Forest disturbance due to past commercial forest operations within GMNP is not obvious in most areas, but this activity most likely caused increased abundance of balsam fir (*Abies balsamea*) and decreased abundance of black spruce (*Picea mariana*) and white pine (*Pinus strobus*) (Meades and Moores 1989). Past forest operations may have also influenced forest floor development such as accumulation of organic matter and composition of under-storey vegetation.

At present large-scale commercial forest harvesting outside GMNP is allowing access to the park's remote eastern boundary via road construction. The impacts of this activity on GMNP are currently being investigated.

(D) Snowmobile Trails

Snowmobile use occurs in almost all of the elevations and vegetation types found in GMNP. In forested areas cutting trees to make trails for snowmobiles is one form of disturbance associated with this activity. The use of snowmobile trails to access cut blocks and haul trees from these areas using snowmobiles causes further damage to these trails (Caissie 1999). Snowmobiles may also alter the moisture regime and vegetation in areas where trails occur (Caissie 1999).

2.5.2 - Natural Disturbances

(A) Fire

Fire is one of the most important natural disturbances occurring in boreal forests

(Shugart et al. 1992), but in GMNP this disturbance is not as significant as in other areas. The park has a very long fire cycle, greater than 500 years (Day et al. 1990). The presence of large areas of bog and heath and a maritime climate, which favors balsam fir as the dominant tree in forested areas, contribute to this long fire cycle.

(B) Rivers

Disturbance by rivers occurs in all areas of GMNP. Disturbed areas along river channels include active river bars and banks which are being disturbed on a regular basis by water eroding or passing over these geomorphological features. Riparian areas further away from the river channel can also experience disturbance during flooding which may erode soil, damage vegetation, and/or deposit sediment. Flooding may result from the formation of ice dams along the river channel, spring runoff, or excess amounts of rainfall. Large pieces of ice flowing in streams during spring runoff may physically disturb areas in and around the river channel.

(C) Insect Outbreaks

Insect outbreaks caused by hemlock looper (*Lambdina fiscellaria*) and spruce budworm (*Choristoneura fumiferana*) occur primarily in balsam fir forests throughout GMNP. The effects of the hemlock looper outbreaks which occurred from 1985 - 1987 near Baker's Brook Pond and Stuckless Pond (C. Wensal pers. comm., 1998) are still very obvious at the present time (Figure 9). The most recent insect outbreak in GMNP was a hemlock looper outbreak near Western Brook Pond (Snug Harbour) in 1996 (C. Wensal pers. comm. 1998, Figure 9). An outbreak of hemlock looper or spruce budworm

Figure 9: Large Scale Disturbances in GMNP (Taylor 2000)

can injure or kill large numbers of trees. Over a period of a few years these dead or damaged trees fall opening the forest canopy. The size of the canopy opening depends on the severity of the insect outbreak and the areas exposure to wind. Once the tree canopy is removed, the area has increased light availability, which may result in changes in vegetation, soil moisture and temperature on the forest floor (Bazzaz 1983; Vitousek 1985). Insect outbreaks differ from clear cuts in that the canopy in a disturbed area is generally removed at a much slower rate and trees which die remain intact until decay or windthrow.

(D) Wind

Disturbance by wind occurs throughout GMNP in varying degrees. Most wind disturbance causes small blow-downs which may open up small areas of the tree canopy and expose small patches of mineral soil ground by uprooting trees. In some areas wind disturbance can create large openings in the tree canopy. Large areas of wind disturbance occur near the park's northern boundary (Figure 9). As mentioned earlier, wind accentuates the impacts of other forest disturbances such as insect outbreaks and clear cuts.

Wind is also important in coastal areas where frequent disturbance by wind is responsible for sand dune and tuckamore vegetation types.

(E) Moose/Caribou

Disturbance by moose (*Alces alces*) and woodland caribou (*Rangifer tarandus caribou*) is the most widespread disturbance occurring in GMNP. Both species are distributed throughout the park, with moose primarily in forested areas and caribou primarily in heath-tundra environments. Both species occur in high numbers (Burzynski 1999). At present it is estimated that approximately 7700 moose inhabit the park (GMNP 2001). The high density areas of GMNP (which make up 51% of the park) have an average of 6.8 moose / km^2 (GMNP 2001). Moose and caribou disturb the environment by trampling, browsing, and defecating. Trampling the ground by moose and caribou creates trails and exposes bare ground in many areas. Moose browsing of balsam fir and deciduous growth can slow the re-growth of disturbed areas such as clear cuts and insect outbreaks, allowing light availability to remain high in these areas and contributing to changes in soil moisture and temperature. Moose and caribou feces may also add nutrients to the soil in some areas (Molvar et al. 1993).

Moose are an introduced species to Newfoundland; therefore, disturbance caused by moose can be indirectly attributed to anthropogenic activity.

Chapter 3 - How Prevalent are Alien Plants in Gros Morne National Park?

3.1 -Introduction

In order to monitor and manage alien plant invasion baseline information on the diversity and distribution of alien plant species in an area must first be determined. A scarcity of studies on alien plants in natural areas of boreal ecosystems indicates that land managers do not have this basic information. Very little work has been done on alien plants in Gros Morne National Park (GMNP). Detailed botanical inventories (Bouchard et al. 1991; Brouillet et al. 1996) record the presence of alien plants in GMNP, but information on alien plant invasion in natural areas was not investigated. These inventories occurred primarily during the park's inception, and changes to GMNP since that time may have facilitated alien plant invasion. Brouillet et al. (1996) noted the presence of the alien plant *Ranunculus repens* in remote areas of GMNP and suggested that it may be of concern. Hendrickson (2000) studied the distribution of the alien plant *Tussilago farfara* in GMNP, focusing primarily on factors contributing to its invasion in areas of high human activity such as roadsides. The priority of Canada's National Parks is to protect the ecological integrity of the areas in which they were established (NPA 2000). An absence of studies on alien plants in natural areas of GMNP and other boreal ecosystems prevents park managers from evaluating how alien plants are impacting the ecological integrity of GMNP.

The primary objective of surveys was to determine the distribution and abundance of alien plant species in GMNP. Although the distribution of alien plants in all areas of

GMNP is examined in this study, natural areas remote from anthropogenic activity are of greatest concern. This is because the presence of alien species in these areas may be a larger threat to native bio-diversity or ecosystem function than in areas already heavily impacted by high human activity. The distribution of alien plant species in GMNP is predicted to coincide primarily with disturbed areas near high anthropogenic activity because disturbed areas provide habitat openings in the form of space or increased resource availability to which many alien species are adapted (Baker 1965; Carson and Pickett 1990; Burke and Grime 1996; Stohlgren et al, 1999a). The introduction of alien plant reproductive propagules is primarily due to intentional or unintentional human activities (Cooper 1981; Thompson et al. 1987; Haber 1997; Hutchinson and Vankat 1997), indicating that disturbed areas of high human activity have the greatest chance of colonization by alien plants. Road sides, garbage dumps, communities, pits, campgrounds, and picnic areas are predicted to have the greatest abundance and diversity of alien plants because high amounts of disturbance and human activity occur in these areas.

Undisturbed areas and disturbed areas remote from human activity are not predicted to be colonized by alien plants. Although natural disturbances such as river channels, insect outbreaks, windfalls, and moose trails occur in all areas of GMNP, resource availability created by disturbance may be less in natural areas compared to modified landscapes of high human activity because boreal soils have low soil pH and nutrient availability (Shugart et al. 1992). For this reason natural disturbances may create habitat openings which do not provide a significant amount of available resources for the establishment of many alien plants. Dispersal limitation will also prevent alien plants from colonizing disturbed areas remote from human activity. Much of the vegetation in GMNP is made up of dense stands of evergreen forests which act as a barrier to wind dispersal (Brothers and Spingarn 1992). Rose (1998) found that naturally disturbed areas in remote forest areas of Terra Nova National Park (Canada) did not contain alien plant species.

3.2 - Methods

GMNP was surveyed extensively at the beginning of the 1998 field season in order to visually assess the geographic extent of alien plant distribution and to find suitable areas in which to establish permanent study sites. Representative areas from all disturbance and vegetation types in the park and park enclave communities were determined by observations (Table 1), and by examining maps which classified these areas (Berger et al. 1992; Taylor 1995) (Figures 7 and 9). Maps were only useful for large geographic areas, and for this reason were used to plan generalized survey routes. Detailed walking and driving surveys of disturbance and vegetation types were carried out (Table 2).

Surveys involved walking slowly along a trail or other area of interest such as a particular vegetation or disturbance type while at the same time examining the ground for alien plants. During most surveys two individuals participated, ensuring the majority of alien species were observed. All alien plant species observed in a survey area were recorded. In most situations it was not feasible to record the abundance of each alien plant species during surveys because they were usually found in high numbers and / or had widespread distributions. In order to quantify change in alien species between different areas of GMNP alien plant species richness (total number of species (R)) and abundance (total number of plants) in areas surveyed were mapped.

The origin of all plant species (alien or native) observed during surveys was

Table 1: Vegetation and Disturbance Types Surveyed and Survey Effort in GMNP

		Disturbance Types Observed Within Each Vegetation Type										
		Anthropogenic						Natural				
Vegetation Types*	% Area of GMNP (km^2)**	Roads	Pits	Hiking Trails	Snowmobile Trails	Clearcuts	Pastures	Windfalls	Beavers	Moose / Caribou	River Channels	# of Areas Surveyed in a Vegetation Type
Balsam fir forest	36% (708.17)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	> 50
Heath-Lichen Tundra	23% (414.91)	No	No	Yes	Yes	N/A	No	N/A	No	Yes	Yes	11
Tuckamore	13% (249.13)	Yes	No	Yes	Yes	N/A	Yes	Yes	No	Yes	Yes	14
Black spruce forest and scrub	6% (119.08)	Yes	No	Yes	Yes	No	No	Yes	Yes	Yes	Yes	9
Sedge Fen and Bog	5% (97.9)	No	No	Yes	?	N/A	No	N/A	No	Yes	Yes	4
Serpentine Barrens	5% (93.05)	Yes	No	Yes	Yes	N/A	No	N/A	No	No	Yes	3
Sphagnum Bog	4% (84.59)	Yes	No	Yes	Yes	N/A	No	N/A	No	Yes	Yes	5
Heath Dwarf-Scrub	Less than 1% (9.99)	No	No	Yes	?	N/A	No	N/A	?	?	?	0
Riverain Thicket and Meadow	Less than 1% (7.32)	Yes	No	Yes	Yes	N/A	No	N/A	Yes	Yes	Yes	11
Intertidal Salt Marsh	Less than 1% (1.63)	Yes	No	No	No	N/A	Yes	N/A	No	No	Yes	2
Larch Scrub	Less than 1% (.95)	No	No	No	No	N/A	No	N/A	No	?	?	0
Grassy Dunes	Less than 1% (.91)	Yes	No	Yes	No	N/A	No	N/A	No	No	Yes	2
Alpine Meadow		No	No	No	No	N/A	No	N/A	N/A	Yes	No	2

Notes: *Description of Vegetation Types in Appendix 1. ** % Area of Vegetation Types from Taylor (1995). ? = unknown. N/A = Not Applicable

Table 2: Survey Effort

Survey	Distance Surveyed	Total Distance Surveyed (accounts for multiple surveys of the same area)
Walking - Designated hiking trails	136 km	352 km*[1]
Walking - Un-designated trails	177 km	261 km*[1]
Walking - Roadsides	14.5 km	Unknown*[2]
Driving - Roadsides	205 km	Unknown*[3]

*[1] - survey distance is underestimated because only full trail surveys are included. On numerous occasions, sections of trails/routes were surveyed but the distance travelled is unknown.
[2] - Road shoulders were surveyed on several occasions, but the survey distance was not known (ie. walking back to vehicle, etc...).[3] - Road shoulders were surveyed from a vehicle on many occasions.

classified based on information from Fernald (1950) and Britton and Brown (1970), and later verified using Meades et al. (2000). The origin of bryophytes in GMNP was not evaluated in this study.

At least one specimen of every species of alien plant observed was collected, pressed, and verified. Unknown plant species were also collected, identified, and pressed. Specimens were deposited at the Newfoundland Museum and verified by the Curator of Natural History. Revision of species nomenclature was according to Meades et al. (2000). Authorities for Latin binomials are given in Appendix 2.

Many areas were re-surveyed throughout the summer in order to locate late growing or flowering species. Additional surveying was done in the summer of 1999 to re-assess areas surveyed in the previous summer and to find new locations of alien species in areas not previously surveyed.

In order to locate and record as many alien plant species as possible, areas of high anthropogenic disturbance were surveyed extensively. All campgrounds, garbage dumps, pits, and day use areas in GMNP were surveyed. Due to time constraints and the large area covered by roads it was not feasible to survey all roadsides by foot. In order to locate the majority of alien species along roadsides, 500 m sections on both sides of the road were surveyed in 5 km intervals along all highways in GMNP. Other areas of roadsides were also surveyed on several occasions when other fieldwork required or resulted in field researchers walking along the road shoulder. Although large areas of roads were surveyed on foot, one of the most effective ways to find new species in GMNP was to observe them while driving (Table 2). Researchers frequently pulled over to the roadside to examine plants which appeared unusual or new to them, and this resulted in locating alien plants of limited distribution in GMNP on several occasions.

Due to their potential as foci, all enclave communities were throughly surveyed. Areas of particular interest in enclave communities were wharves, graveyards, abandoned gardens, agricultural fields, and roadsides.

Hiking trails were considered potential corridors in which alien plants could invade areas remote from high anthropogenic activity in GMNP (Tyser and Worley 1992). All designated hiking trails were surveyed at least once. Clear cuts, river channels, insect outbreaks, and caribou / moose trails were also considered disturbances in which alien species could invade remote areas away from high human activity, and therefore each of these disturbance types were surveyed in several areas throughout GMNP.

3.3 - Results

3.3.1 - General Trends

The survey detected a total of 95 alien species associated with both natural and anthropogenic disturbance in Gros Morne National Park (Table 3, Figure 10, 2). This compared with 100 introduced species listed by Brouillet et al. (1996).

The majority of alien plant species found in GMNP were associated with anthropogenic disturbances in areas of high human activity such as roads and pits (Tables 3 and 4, Figure 10). Alien plants were also found to be abundant and diverse in areas of past human activity such as abandoned fields or communities, which are not experiencing disturbance at the present time, but still show signs of past disturbance (Tables 3 and 4, Figure 10). Disturbances which were remote from high human activity such as hiking trails, moose trails, clear cuts, insect outbreaks, beaver dams, snowmobile trails, and rivers also contained alien species. However, the abundance and species richness of alien species was lower in these areas compared with disturbances of high anthropogenic activity such as roads and pits (Table 4, Figures 10, 11, and 12).

Species found in disturbed areas remote from human activity include *Ranunculus repens*, *R. acris*, *Trifolium* spp., *Taraxacum officinale*, *Tussilago farfara*, *Cirsium arvense*, *Digitalis purpurea*, *Hieracium* spp. (mainly *H. aurantiacum*, *H. pratense*, and *H.floribundum*) and *Myosotis scorpioides.* With the exception of *Digitalis purpurea*, all alien species found in remote areas were also abundant in areas of anthropogenic disturbance near high human activity throughout GMNP (Table 3).

Table 3: Disturbance Types in which Alien Plant Species* were found within GMNP

*Species are listed in decreasing order by number of disturbance types in which they are found.

	Disturbance Types																
	Anthropogenic												Natural				
Species	Road	Trail	Pit	Dayuse	Field	Garden	Dump	Graveyard	Pole Line	Snowmobile	Clear cut	Beach	Insect	River	Wind	Moose	Beaver
Ranunculus repens	x	x	x	x	x		x		x	x	x		x	x	x	x	x
Myosotis scorpioides	x	x	x	x	x		x	x	x	x	x			x		x	x
Hieracium floribundum	x	x	x	x	x		x	x	x		x		x	x		x	
Tussilago farfara	x	x	x	x	x		x		x		x		x	x		x	x
Taraxacum officinale	x	x	x	x	x	x	x	x	x		x			x		x	
Cirsium arvense	x	x	x	x	x		x		x		x			x	x	x	
Hieracium pratense	x	x	x	x	x		x	x	x		x			x		x	
Hieracium aurantiacum	x	x	x	x	x		x	x	x		x					x	
Chrysanthemum leucanthemum	x	x	x	x	x	x	x	x	x					x			
Ranunculus acris	x	x	x	x	x		x		x				x			x	
Plantago major	x	x	x	x	x	x	x	x									
Plantago lanceolata	x	x		x	x	x	x	x									
Rumex acetosella	x	x	x	x	x	x	x	x			x						
Achillea millefolium	x	x	x	x	x		x	x						x			
Centaurea nigra	x	x	x	x	x		x	x						x			
Trifolium repens	x	x	x	x	x		x				x			x			
Hieracium pilosella	x	x	x	x	x		x									x	
Hieracium florentinum	x	x	x	x	x		x	x									
Vicia cracca	x	x	x	x	x		x							x			
Lotus corniculatus	x	x	x	x	x		x							x			
Leontodon autumnalis	x	x	x	x	x		x		x								
Phleum pratense	x	x	x	x	x		x										
Rumex acetosa	x		x	x	x	x	x										
Rumex crispus	x		x	x	x	x	x										
Rumex domesticus	x		x	x	x	x	x										
Rumex obtusifolius	x		x	x	x	x	x										
Trifolium hybridum	x	x	x	x	x		x										
Linaria vulgaris	x		x	x	x		x										
Agropyron repens	x	x		x	x		x										
Chenopodium album	x		x	x			x					x					
Digitalis purpurea	x		x	x					x				x				
Lupinus perennis	x		x		x	x		x									
Senecio viscosus	x		x	x	x		x										
Stellaria graminea	x	x	x	x	x												
Stellaria media	x	x	x	x	x												
Trifolium pratense	x	x	x	x	x												
Capsella bursa-pastoris	x		x	x	x												
Lythrum salicaria			x	x	x									x			
Matricaria matricarioides	x	x	x				x										
Anthoxanthum odoratum	x	x			x												
Arctium minus	x						x		x								
Barbarea vulgaris	x	x	x														
Cerastium vulgatum	x	x									x						

Table 3: Disturbance Types in which Alien Plant Species* were found within GMNP

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	Disturbance Types																
	Anthropogenic											Natural					
Species	Road	Trail	Pit	Dayuse	Field	Garden	Dump	Graveyard	Pole Line	Snowmobile	Clear cut	Beach	Insect	River	Wind	Moose	Beaver
Cirsium vulgare	x		x				x										
Festuca elatior	x	x			x												
Festuca ovina	x	x			x												
Lysimachia punctata				x	x	x											
Malva moschata				x	x	x											
Medicago lupulina	x		x	x													
Mimulus moschatus				x	x	x											
Polygonum cuspidatum	x			x	x												
Plantago juncoides	x	x	x									x					
Aegopodium podagraria					x	x											
Aquilegia vulgaris					x	x											
Carum carvi	x				x												
Filipendula ulmaria					x	x											
Geranium pratense				x	x												
Hypericum perforatum			x	x													
Persicaria persicaria	x		x														
Poa compressa	x	x															
Senecio vulgaris	x		x														
Sonchus arvensis	x		x														
Trifolium agarium	x			x													
Veronica serpyllifolia	x	x															
Aconitum x bicolor						x											
Bellis perennis				x													
Brassica rapa	x																
Campanula rapunculoides	x																
Cichorium intybus	x																
Crepis tectorum	x																
Dactylis glomerata	x																
Dianthus armeria			x														
Echium vulgare	x																
Erysimum hieraciifolium	x																
Euphorbia cyparissias								x									
Galeopsis tetrahit											x						
Glechoma hederacea					x												
Hieracium caespitosum											x						
Hordeum jubatum	x																
Linum catharticum	x																
Matricaria maritima	x																
Medicago sativa	x																
Melilotus alba	x																
Melilotus officinalis	x																
Myosotis sylvatica	x																
Pastinaca sativa	x																

Table 3: Disturbance Types in which Alien Plant Species* were found within GMNP

*Species are listed in decreasing order by number of disturbance types in which they are found.

	Disturbance Types																	
	Anthropogenic												Natural					
Species	Road	Trail	Pit	Dayuse	Field	Garden	Dump	Graveyard	Pole Line	Snowmobile	Clear cut	Beach	Insect	River	Wind	Moose	Beaver
Phalaris canariensis							x										
Senecio jacobaea	x																
Silene cucubalus	x																
Solanum dulcamara							x										
Tragopogon pratensis			x														
Urtica dioca					x												
Verbascum thapsus	x																

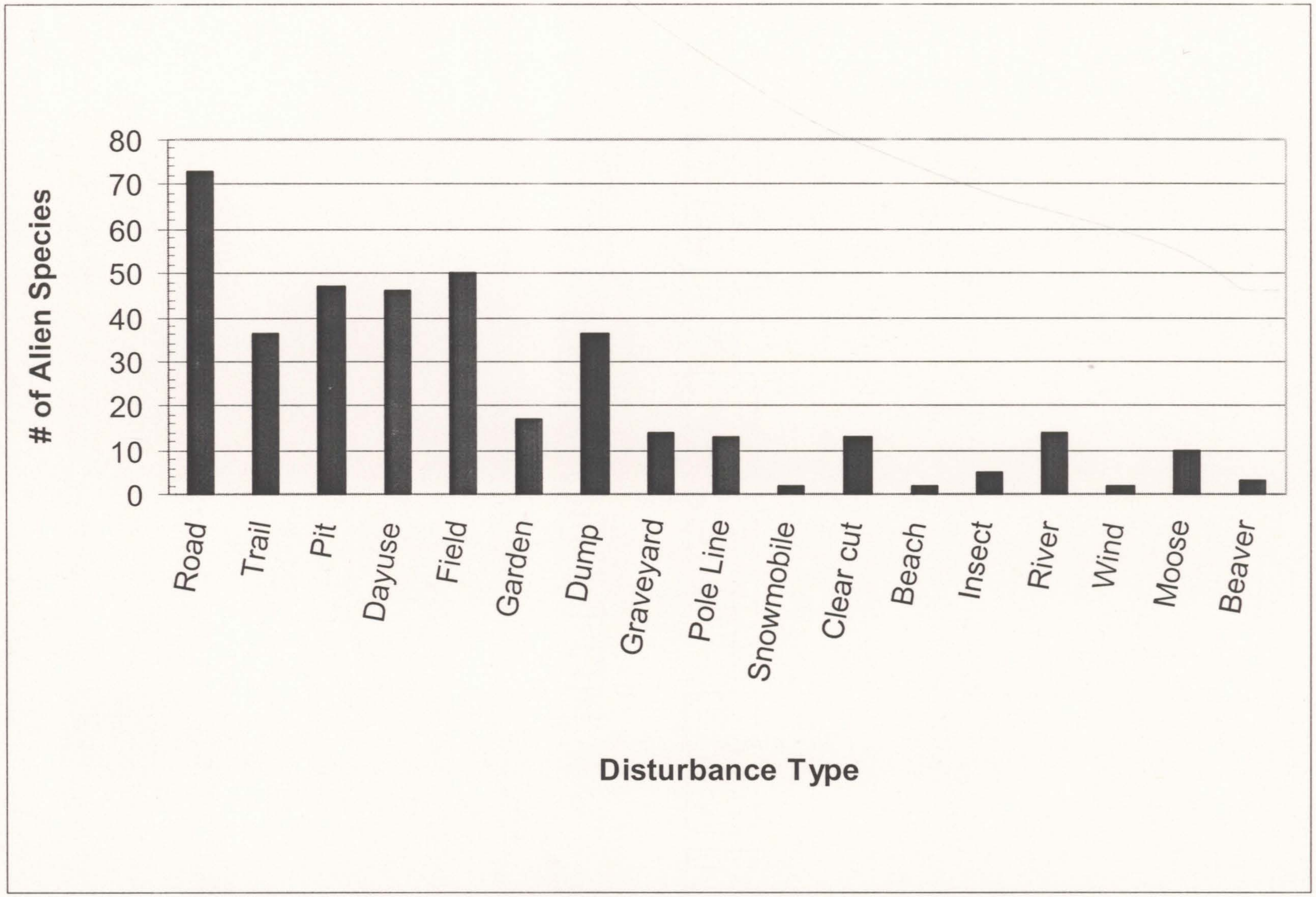


Figure 10: Alien Species Richness in Relation to Disturbance Type

Table 4: Mean Number of Alien Plant Species Associated with Disturbance Types of GMNP

Disturbance Type	Mean # of Species	Standard Error	Range	Number of Sites Surveyed
Hiking Trails	7.3	4.3	3 - 19	17
Roads	15.3	7.3	8 - 29	6
Pits	16.5	10.5	6 - 31	4
Various (campgrounds, dumps, etc...)	9.9	3.9	5 - 17	9
Abandoned Communities	15.4	9.5	6 - 31	5
Clear Cuts	6.5	4.3	0 - 11	5
Rivers	4.4	3.8	0 -13	10
Insect Outbreaks	3	2.9	0 - 9	7

Alien species commonly found in disturbances created by high human activity throughout GMNP include *Chrysanthemum leucanthemum*, *Trifolium* spp., *Centaurea nigra*, *Vicia cracca*, *Leontodon autumnalis*, *Barbarea vulgaris*, *Rumex acetosella*, *Achillea millefolium*, *Phleum pratense, Agropyron repens, Festuca* spp., *Poa* spp., *Anthoxanthum odoratum, Lotus corniculatus*, and *Plantago major* (Table 3).

Alien species of limited distribution in GMNP such as *Phalaris canariensis* and *Glechoma hederacea* were always found in disturbances close to high anthropogenic activity (Tables 3 and 5).

The majority of alien plants were found in disturbed areas on the western side of

Figure 11: Number of Alien Plants in Survey Areas

Figure 12: Alien Species Richness in Survey Areas

Table 5: Alien Plants* with Limited Distribution in GMNP

Uncommon Alien Species	Location / Details
Pastinaca sativa	Several plants found on the east side of the road shoulder between the community of Cow Head and the northern park boundary.
Phalaris canariensis	Specimen found at Norris Point dump.
Solanum dulcamara	Specimen found at Norris Point dump.
Silene cucubalus	Several plants found near a road cut on the north side of the road between the Discovery center and Tablelands parking lot / exhibit.
Verbascum thapsus	Located on the road connecting Woody Point and Trout River. Specimen was found in Woody Point just uphill from the turnoff to Trout River on the northern side of the road. Only one specimen was found, this specimen was removed from the area.
Matricaria maritima	Specimen found near the fish plant in Rocky Harbour.
Echium vulgare	Several plants found in the softball field and parking lot in Norris Point.
Campanula rapunculoides	Specimen found in parking lot of convenience store in Rocky Harbour. This store was on the same road as the fish plant.
Tragopogon pratensis	Specimen found at Rocky Barachois Pit.
Dianthus armeria	Several plants found at Rocky Barachois Pit.
Lythrum salicaria	Found in several locations, see Appendix 3.
Bellis perennis	Several plants found at Lomond campground.
Medicago sativa	3 specimens found along the Lomond Campground access road.
Hordeum jubatum	High numbers of this plant were found along the road shoulder of the South East Hills. Plants found scattered along a fair distance of the highway, but exact distance is unknown.
Glechoma hederacea	Specimens found scattered through fields near Lobster Cove Head and Green Point.
Senecio jacobea	High numbers of this plant were found in the area around the Discovery Center.
Erysimum hieraciifolium	Specimen found along the road shoulder near St. Paul's. Location and number of plants unknown
Brassica rapa	Specimen found along the road shoulder between Western Brook Pond parking lot and Sally's Cove. Location details and population size unknown.

* Species which were observed in graveyards and private gardens are not listed.

the Long Range Mountains (Figures 11 and 12). No alien species were found within GMNP on the eastern side of the Long Range Mountains even though this area experienced moose / caribou, river, and wind disturbance (Figures 11 and 12). The only areas in which alien plants (eg. *Taraxacum officinale*, *Hieracium* spp., *Ranunculus repens*) were found on top of the Long Range Mountains were alpine meadow vegetation on south facing slopes. As mentioned in Chapter 2 the eastern side and top of the Long Range Mountains are regularly accessed by humans, but not to the same degree as the western side of the Long Range Mountains where the majority of human activity is concentrated.

Vegetation types which were found to contain alien plants included forested areas, fens, riparian areas, sand dunes, and south-facing slopes in alpine areas. Vegetation types which did not contain alien plant species regardless of proximity to human activity included salt marshes, the serpentine tablelands, bogs, and alpine heath. The only activity which allowed alien plants to invade these vegetation types was the addition of "foreign"gravel or soil to a site, such as for trails or roadbeds (e.g. bogs along the Western Brook Pond Trail).

The presence of alien species in areas of low anthropogenic activity was associated with limestone bedrock and limestone conglomerate (Figure 6). The Lomond area is underlain primarily by limestone bedrock, and this is the area most heavily invaded by alien plants in GMNP (Figures 11 and 12). Rivers and moose trails examined in areas without limestone bedrock, such as the eastern side of the Long Range

Mountains and Burridges Gulch, were not found to contain alien plants (Figures 11 and 12). Other high soil pH rock types, such as pillow basalts in the Green Gardens area (Figure 6), also coincided with alien species (Figures 11 and 12).

Several different disturbance types were colonized by alien plants. A brief description of the survey results for the various types of disturbance occurring in GMNP follows. More detailed descriptions and locations of alien species are described in Appendix 3.

3.3.2 - Anthropogenic Disturbances

(A) Trails

All designated hiking trails in GMNP contained alien species (Figure 11). Although remote areas had sporadic occurrences of alien species, the number of alien species generally decreased with distance from human activity. For example, walking surveys along the Western Brook Pond and Snug Harbour trails found a high diversity of alien plants near the highway, but this number decreased to 1 or 2 species of alien plants at the end of the Snug Harbour trail (Figure 12). In most cases alien species were restricted to the trail, or side of the trail. Alien species were found in other disturbances along the trail such as beaver dams, rivers, moose trails, and insect outbreaks.

The trail which appeared to be the most heavily influenced by alien species in GMNP was the Lomond River Trail. This trail had a high species richness of alien plants along it (R = 11); the most common species found were *Ranunculus repens* and *Tussilago farfara*. Along this trail, fens and semi-open black spruce which appeared undisturbed, contained high abundances of these species. The rare native plants, *Allium schoenoprasum* var. *sibiricum* and *Cypripedium calceolus* are growing along this trail in close proximity to alien plants.

The Long Range and North Rim Traverses are un-designated hiking routes crossing rivers and heavily disturbed moose and caribou trails in remote areas of GMNP. No alien species were found to occur along them.

(B) Roadsides

Roadsides were the disturbance type with the highest diversity and abundance of alien plant species (Tables 3 and 4; Figures 10, 11 and 12). Several of the alien species present in GMNP were found only along roadsides, including *Verbascum thapsus*, *Medicago sativa*, *Silene cucubalus*, and *Pastinaca sativa* (Tables 3 and 5).

The use of various hydro-seed mixtures to stabilize sections of road shoulders after construction is very obvious as past and present day seed mixtures contain alien plants. Past hydro-seed mixtures contained alien species from the families Poaceae and Fabaceae, and these species persist in high numbers along all roadsides. The most obvious species seen are *Trifolium hybridum* and *Lotus corniculatus*, both of which form dense mats along some roadsides. One of the more recent seed mixtures (fall 1997) used by Parks Canada in both GMNP and Terra Nova National Park is 40% *Festuca rubra*, 20% *Poa compressa*, 15% *Festuca ovina*, and 10% *Agrostis stolonifera* (R. Power, pers. comm., November 1997). Hydro-seed mixtures were also used for the re-vegetation of picnic areas and pits in GMNP.

In addition to hydro-seed species another dominant species along road shoulders is *Tussilago farfara*. Survey results support Hendrickson (2000), which found *Tussilago farfara* to be associated with limestone gravel along road shoulders.

(C) Pits (borrow /quarry sites)

There are at least 29 pits in or near GMNP (Meaney 1990). Most of these sites are found within enclave communities of the park; only five pits occur within GMNP. All pits contained a high richness and abundance of alien species (Table 4, Figures 10, 11, and 12). The pit near Rocky Barachois Brook had the highest alien species richness (S = 31 species) anywhere in GMNP. Some of these species such as *Dianthus armeria* and *Crepis tectorum* were not found in any other locations in GMNP.

(D) Domestic cut blocks

Clear cuts within GMNP were often found to contain several species of alien plants (Table 3). In some clear cuts *Ranunculus repens*, *Myosotis scorpiodes*, *Cirsium arvense*, and *Tussilago farfara* were found to form dense, almost mono-specific stands, which contained low numbers of native species. Other alien species found in clear cuts included *Taraxacum officinale*, several *Hieracium* spp., and *Trifolium repens*.

The age of a clear cut appeared to be correlated to the abundance of alien plants. Very young (1 year old) or very old (> 30 years) clear cuts had an intact moss layer and contained no alien species. Clear cuts which were 2 - 30 years old often had the canopy layer removed and bare soil exposed and were found to contain alien species. For example a 1 year old clear cut near Lomond contained an intact moss layer and no alien plant species. A 6 year old clear cut in this same area had more bare ground and 6 different alien plant species present.

Recent logging operations on the eastern boundary of GMNP are a large scale disturbance adjacent to the park. Logging roads run over 40 kilometres from the Hampden Highway to GMNP's eastern boundary near Matty's Pond. Older sections of the road were found to contain *Hieracium* spp. for approximately the first 16 km, but as the logging roads became younger and at the same time got closer to the park boundary, no alien species were seen. The only other area in which alien species were seen on any other section of the logging road was at the end of the road, very close to the park boundary. At this site three *Trifolium repens* and one *Achillea millefolium* were found growing. The presence of alien species on these recently constructed roads indicates that these areas could act as foci from which alien plants have the potential to spread to natural areas of GMNP.

(E) Snowmobile trails

Few snowmobile trails were examined within the park as these had been characterized by Caissie (1999), but those examined in forested areas were found to contain alien plant species. Snowmobiles trails were very wet and muddy in some areas and found to contain high numbers of *Ranunculus repens*.

(F) Other anthropogenic disturbances

Although all past and present day human settlements contain a high diversity of alien plants, the abandoned community of Lomond appeared to be particularly diverse (S

= 31). Species present in this area but absent or rare in other areas of GMNP include *Medicago sativa*, *Medicago lupulina*, *Lythrum salicaria*, *Polygonum cuspidata*, *Cichorium intybus*, *Bellis perennis*, *Aegopodium podagaria*, *Malva moschata*, *Lysimachia punctata,* and *Arctium minus*.

Disturbed sites such as campgrounds, garbage dumps, hydro-line corridors, picnic areas, and interpretive sites contained alien plant assemblages similar to that of roadsides. Garbage dumps are found both in the park and in enclave areas. Norris Point dump is especially noteworthy because it contained alien plants such as *Solanum dulcamara*, *Capsella bursa-pastoris*, and *Phalaris canariensis* that were rarely or not found anywhere else in GMNP (Table 5).

3.3.3 - Natural Disturbances

(A) Rivers

Rivers cause disturbance in all areas of GMNP. Alien species were found along rivers in remote areas of the park, but generally the number of alien species found along rivers decreased with distance from past or present human activity.

Different areas of the river were colonized by different alien plants. Gravel longitudinal bars and river banks frequently contained *Tussilago farfara*. Slope failures on the banks of some rivers (in particular Baker's Brook) were found to contain *T. farfara* and *Taraxacum officinale*. *Ranunculus repens* and *T. officinale* were found on muddy and/or grassy areas on many stream banks. Alder thickets along some streams were found to contain *Cirsium arvense* and *R. repens*. Other alien species found less frequently in riparian areas included *Lythrum salicaria*, *Trifolium repens*, *Lotus corniculatus*, *Hieracium* spp., *Achillea millefolium*, and *Chrysanthemum leucanthemum* (Table 3).

The rare plant *Allium schoenoprasum* var. *sibiricum* was found growing close to alien plants in the estuaries of Lomond River and Deer Arm Brook. The Lomond River also had the rare plant *Cypripedium calceolus* growing near alien species along its banks.

(B) Insect outbreaks

Insect outbreaks were a disturbance found throughout balsam fir forests of GMNP. Several insect outbreaks in areas remote from human activity were found to contain alien plants (Tables 3 and 4, Figure 10). Alien plants commonly found colonizing insect outbreaks were *Ranunculus repens*, *Hieracium* spp., and *Cirsium arvense*. *Tussilago farfara*, *R. acris*, and *Myosotis scorpiodes* were found to a lesser degree.

(C) Beavers

Alien plants were found to be associated with beaver dams in several areas of GMNP. Beaver dams created several types of disturbance which were suitable for the growth of alien plants. Areas upstream from beaver dams experienced disturbance by flooding and these areas were colonized by alien plants after the flooding receded. Beaver dams are a mixture of sticks and mud which were found to be suitable substrates for the growth of alien plants. Sections of streams below beaver dams were found to have lower water levels, and the exposed substrates in these areas were found to support alien plants.

Alien species found to be colonizing habitats disturbed by beavers were predominantly *Tussilago farfara*, and *Ranunculus repens*. Other species found colonizing beaver disturbances in lesser numbers were *Myosotis scorpioides*, *Ranunculus acris*, *Lythrum salicaria, Hieracium* spp., and *Taraxacum officinale.*

(D) Moose / caribou

Moose activity in the form of feces, trails, and browsing is obvious in all areas of GMNP except the serpentine tablelands. Moose trampling coupled with other disturbances such as insect outbreaks, clear cuts, hiking trails, pole lines and snowmobile trails increased the size, severity, and frequency of disturbance in these areas.

Alien plants were found on moose trails in fens, forests, riparian areas, and alpine meadows. *Ranunculus repens* was the most commonly found alien plant on moose trails throughout GMNP. *Ranunculus repens* was most often found in wet and muddy trails, where it would sometimes grow in dense numbers. In many cases *Ranunculus repens* was found in areas with low light conditions. Other species commonly found along moose trails in GMNP were *Tussilago farfara*, *Hieracium* spp., and *Taraxacum officinale.*

Trampling by caribou also created trails and exposed soil in some areas. Many well developed caribou trails are obvious in alpine heath vegetation but none of these trails were found to contain alien plant species. *Ranunculus repens*, *Hieracium aurantiacum*, *H. pratense*, and *H. pilosella* were found growing on caribou / moose trails in alpine meadows on the south-facing slopes of Big Hill and Kildevil Mountain.

(E) Wind

Disturbance by wind influenced sand dunes and some forested areas. Sand dunes are continuously disturbed by wind. Exposed areas of the dunes lacked alien vegetation, but areas sheltered from the wind harboured small numbers of *Taraxacum officinale*. These areas were often valleys in the sand dunes where organic matter accumulates.

Blow-downs in forested areas near the Snug Harbour area of Western Brook Pond were colonized by alien species. Species found in the area included *Ranunculus repens* and *Cirsium arvense*. Wind disturbance was also important to alien plants in GMNP because it increased the impacts of insect outbreaks in forest areas by blowing down standing dead or damaged trees, further opening the tree canopy of the area.

3.3.4 - Native Species of Disturbed Areas

Native species which colonized anthropogenic and natural disturbances included *Fragaria virginiana*, *Solidago rugosa*, *Anaphalis margaritacea*, *Epilobium angustifolium*, several *Aster* spp., *Equisetum* spp., *Sanguisorba canadensis*, *Alnus rugosa*, *Euphrasia* spp., *Heracleum maximum*, *Typha latifolia*, *Rubus idaeus*, and *Dryopteris spinulosa* var. *americana*. *Heracleum maximum* is a large plant that forms dense stands in some roadside areas, shading out other plant species. Areas of low human activity away from road sides were not found to have dense stands of *Heracleum maximum*. Another species to note is *Typha latifolia*, which is found in several locations along wet roadsides in GMNP. The origin of *T. latifolia* is questionable in Newfoundland, and this species has been found to be invasive to wetland areas in other native regions of North America (Thompson et al. 1987).

3.4 - Discussion

3.4.1 - Anthropogenic Disturbances as Sources for Invasion of Natural Areas

Consistent with other studies, the present surveys found highly disturbed areas close to anthropogenic activity contained a high diversity and abundance of alien plants (Fox and Fox 1986; Mooney and Drake 1986; Drake et al. 1989; Schwartz 1996; Stohlgren et al.1999a). However, areas of greatest concern in GMNP are "natural areas" which are remote from high human activity. Surveys confirmed that disturbances remote from high anthropogenic activity such as rivers, insect outbreaks, moose trails, beaver dams, and clear cuts in GMNP have been invaded by some alien plant species. Alien species found in remote areas of GMNP were also abundant in disturbed areas of high anthropogenic activity, suggesting that disturbances such as roadsides and settlements are acting as sources of reproductive propagules from which alien species can be dispersed to natural areas of GMNP.

The persistence of alien plants in areas no longer experiencing disturbance such as abandoned pits, communities, and road beds is evidence that alien species can remain in an area long after a disturbance has passed (Brandt and Rickard 1994), and continue to act as foci for alien plant dispersal for long periods of time. Long residence times of alien plants in GMNP are also a concern because even if they are not invading natural areas at present, conditions may change which will allow them to become invasive in the future. Alien plants present in vegetation are usually present in the seed bank (Tsuyuzaki and Kanda 1996), and the extent to which alien plants persist in the seed bank in GMNP should be examined further.

Roads are the most serious anthropogenic disturbance occurring in GMNP because they were associated with a high diversity and abundance of alien species, and because they act as sources for alien seed production over large areas (Tyser and Worley 1992). Roadsides in many national parks have been found to be sources for alien plant species (Tyser and Worley 1992; Parks Canada Agency 2000). Continuous disturbance along roads ensures persistence of alien species (Tyser and Worley 1992), unless replaced by native species with appropriate life history characteristics (Baker 1965).

The use of soil or gravel in road construction and maintenance from pits colonized by alien plants facilitates their spread (Hendrickson 2000). The high abundance of *Tussilago farfara* along many roadsides in GMNP is thought to have resulted from using gravel for road construction containing propagules of the species (Hendrickson 2000). Active pits in GMNP were found to contain alien species not found anywhere else in the park, and gravel distributed throughout the park could facilitate their spread.

The use of hydro-seed mixtures containing alien species to stabilize roadsides and other disturbances further increases the spread of alien species in GMNP. *Lotus corniculatus*, *Vicia cracca*, *Trifolium repens*, *T. agarium*, *T. hybridum*, *T. pratense*, and *Medicago lupulina* are particularly noticeable species that have been spread by hydro-seeding. These species are members of the family Fabaceae and are nitrogen fixing plants. Nitrogen-fixing plants may alter trophic structure, inhibit colonization of native species, facilitate the invasion of other alien species, and alter litter quality (Maron and

Connors 1996; Vitousek 1990).

Alien species found to have low abundances and limited distributions in GMNP should be monitored or removed to ensure that they do not become more widespread. If uncommon alien species of GMNP become better established in areas of anthropogenic activity, the potential for these species to spread to remote disturbances in the park increases.

3.4.2 - Conduits to Invasion of Natural Areas (Dispersal Vectors)

Moose and hiking trails appeared to act as the primary conduits dispersing alien plants into natural areas of GMNP. Moose and hiking trails are corridors into natural areas that continually remain disturbed due to trampling (Cole 1981; Hall and Kuss 1989; Benninger-Traux et al. 1992). Once alien plants colonize these trails, they can gradually spread to other areas on or near this corridor of disturbance (Benninger-Traux et al. 1992). It is suspected that moose are dispersing alien plant propagules to remote disturbances away from trails in their hair and hooves, and in feces. Dispersal of alien species along trails by horses occurs in several areas (Benninger-Traux et al. 1992, Tyser and Worley 1992; Larson et al. 2001) and a similar means of dispersal by moose may occur in GMNP. Accidental dispersal of seeds along trails on clothing and footwear of hikers may also be spreading alien plants (Cole 1981). The introduction of 'foreign' soil or boardwalks along some hiking trails is also a means of dispersal (Hendrickson 2000).

Moose also contribute to alien plant invasion by trampling other disturbed areas such as insect outbreaks, snowmobile trails, clear cuts, and rivers, increasing the degree of disturbance in these areas. Over-browsing of balsam fir and deciduous trees by moose within insect outbreaks and clear cuts delays recovery of these areas from disturbance, prolonging the time period in which alien plants can colonize and remain in these areas.

Rivers also act as corridors to alien plant invasion in some areas of GMNP. These areas are favorable for alien species because they are generally productive sites which are high in nutrients and light, and because they experience various degrees of hydrological disturbance from water level fluctuations (Pysek and Prach 1993; Planty-Tabacchi et al. 1996; Stohlgren et al. 1998).

Although many alien species had effective wind dispersal mechanisms, varied topography and dense forests are likely barriers to long distance wind dispersal of alien species in GMNP (Brothers and Spingarn 1992; Wiser et al. 1998).

3.4.3 - Vegetation Types Associated with Alien Plant Establishment

Once an alien species is dispersed to an area, site characteristics are most limiting to invasion success (Wiser et al. 1998). Vegetation type strongly influenced species establishment. Disturbances in forest, riparian, alpine meadow, and fen vegetation types in GMNP were colonized by alien plants. In all of these vegetation types alien species were found in areas with bare ground and available light. Areas with bare ground are beneficial to alien plants because these areas have open space and decreased competition for resources (Burke and Grime 1996). Light is considered one of the resources most limiting to invasion of forested areas (Vitousek 1985; Brothers and Spingarn 1992; Hutchinson and Vankat 1997), and alien species in forested areas of GMNP were only found in areas where disturbance opened the tree canopy. An exception to this was the alien species *Ranunculus repens*, which was observed in areas of relatively low light on several occasions. Alpine meadows, fens, and river banks have open canopies and do not require disturbance to increase light availability. Increases in bare ground and light can also cause changes in less easily observable environmental conditions such as soil pH, nutrient availability, moisture, and temperature (Vitousek 1985). Although areas of bog and alpine heath vegetation were found to contain bare ground and open canopies, these areas were not invaded by alien plants. Other environmental factors such as low nutrient availability and acidic soil conditions which are generally associated with bog and heath environments (Jonasson 1999; Elliot-Fisk 2000) may constrain alien plant invasion in these areas.

Forests are important because they are the largest vegetation type occurring within GMNP. Forests are particularly susceptible to alien plant establishment because they are generally close to high human activity, and several types of disturbance in these areas are colonized by alien species. Riparian zones are valuable regions of all ecosystems because they are productive sites with high species diversity (Stohlgren et al. 1998). The presence of high number of alien plants in these rich areas of continuous disturbance may be threatening native bio-diversity in some riparian zones of GMNP. Fen and alpine meadows are vegetation types present in only a few areas of GMNP. The rarity of these habitats in GMNP means that threats to these vegetation types by alien plants is of particular concern.

Alien plants growing in close proximity to rare plants in alpine meadow, fen, and riparian vegetation types in GMNP are a concern because they may threaten these rare species. For this reason alien plants in these areas should be monitored.

The distribution of alien plants in many areas of GMNP corresponded with limestone or limestone conglomerate. Areas of limestone bedrock in western Newfoundland have higher soil pH than the more acid soils found on the remainder of the Island allowing more favorable growing conditions for many alien plants (Roberts 1983, Brouillet (pers. comm.1999). Limestone bedrock has been found to contribute to alien invasion in other areas of eastern Canada where the presence of limestone bedrock is allowing invasion of *Alliaria petiolata* (Haber 1996; Parks Canada Agency 2000).

3.4.4 - Relationship of Boreal Ecosystems and Alien Plants in GMNP

Disturbance is an integral and natural process in boreal ecosystems (Elliot-Fisk 2000), indicating that habitat openings for alien plants will continue to occur in suitable vegetation types in GMNP. Anthropogenic disturbances occurring in remote areas of GMNP serve to increase the number of habitat openings in GMNP.

Although disturbed areas may recover to pre-disturbance conditions over long time periods thereby eliminating alien plants from a particular area (Rose 1998), new disturbances such as insect outbreaks and windfalls are continually being created in GMNP. The persistence of alien plants in areas of high anthropogenic activity for long periods of time and the ability of conduits to successfully disperse alien plant reproductive propagules to remote areas of GMNP mean that disturbed areas suitable for the establishment of alien plants will continue to be invaded in the future. Some natural habitats such as river channels and moose trails are continually being naturally disturbed. Once alien plants become established in these areas they may be able to persist indefinitely.

Alien plant invasion into remote areas of GMNP is likely to increase in the future. At present, propagules of alien plants colonizing remote areas of GMNP appear to be dispersed primarily from disturbed areas of high anthropogenic activity. As alien plants become more established in remote disturbances of GMNP, they may act as foci from which alien plants can spread to other disturbed areas, decreasing the dispersal distance for invasion of disturbances in remote areas of GMNP (Stohlgren et al. 1998; Wiser et al. 1998). Some rivers, clear cuts, and moose trails in GMNP were found to contain high numbers of alien plant species, and these areas may already be acting as foci.

Changes induced by alien species which are likely occurring in GMNP at present include alteration of disturbance regimes, changes in resource availability, and reduction of native species. In forested areas disturbance regimes may be altered by the presence of mono-specific stands of *Cirsium arvense*, *Tussilago farfara*, and *Ranunculus repens*. These species may be delaying recovery after disturbance by slowing the establishment of balsam fir or deciduous species in disturbed areas such as clear cuts and insect outbreaks. Species which form mono-specific stands after natural or anthropogenic disturbances may influence resource availability because the litter produced from these species have chemical ratios, decomposition rates, and nutrient immobilization which are different from native plant litter. For example, native evergreen tree species of boreal regions have chemical ratios which contribute to acidic soils with slow decomposition rates and low nutrient availability (Pastor and Mladenoff 1992). In areas where native evergreen species such as balsam fir are replaced by non-coniferous alien species, soil properties may be altered.

Alien species present in natural disturbances of riparian, forest, fen, and alpine meadow vegetation types may be replacing native species which normally colonize these disturbances. As no previous baseline data has been collected for these areas, little is known about the consequences of altering the succession of species after disturbance in these vegetation types. In other areas alien species have been found to alter ecosystems by increasing or decreasing erosion, decreasing pollination of native plants, altering forage quality, displacing fauna, and altering abundances of soil invertebrates (Thompson et al. 1987; D'Antonio and Vitousek 1992; Mosquin 1997; Kourtev et al. 1998).

No published research has examined the distribution and abundance of alien plants in remote areas of boreal ecosystems until this study. The use of surveys to obtain baseline information on boreal ecosystems found that alien species can successfully colonize and grow in disturbed areas remote from human activity. Further study on the influence of alien plants on ecosystem properties and native species is required to determine if alien plants are having measurable impacts on boreal ecosystems. Alien plants should be monitored in GMNP so that changes in the distribution of alien plants can be evaluated in the future.

Chapter 4 - Factors influencing Alien Plant Invasion in GMNP

4.1 - Introduction

It is well documented that disturbance increases resource availability and habitat openings, allowing alien plant invasion to occur (Fox and Fox 1986; Carson and Pickett 1990; Burke and Grime 1996; Stohlgren et al.1999a). In boreal ecosystems no published research has examined the influence of disturbance on alien plant invasion. In order to assess the importance of disturbance in boreal ecosystems, this chapter determines how environmental conditions and the community structure of alien plants change as a function of disturbance regime. This study predicts that resources available for alien plants will increase with the degree of disturbance in GMNP. Areas with high levels of disturbance will contain the greatest percentage of alien plants because many alien plants have adaptations that allow them to withstand the effects of disturbance and out-compete native species for space or other resources (Baker 1965; Grime 1979; Bazzaz 1983). The greatest diversity of alien and native species will occur in areas of intermediate disturbance regime because these areas have a diversity of environmental conditions that allow early and late successional species to co-exist (Connell 1978). The majority of alien species will not be associated with any particular disturbance regime because most alien species are adapted to capitalize on a variety of disturbance types by being plastic and widely distributed (Baker 1974; Bazzaz 1983). It is predicted that undisturbed areas of GMNP will not be invaded by alien plants because habitat openings and resource availability in boreal ecosystems are limited due to sub-optimal growing conditions such as dense evergreen forest canopies which limit light availability, and forest soils that have low soil pH and nutrient availability (Shugart et al. 1992; Elliot-Fisk 2000).

Many environmental conditions change with disturbance (White and Harrod 1997), but not all of these changes may be important for alien plant invasion. Therefore, environmental parameters that limit the establishment of alien plant species in GMNP will be determined. Environmental parameters found important to alien plants in other studies include light availability, bare ground, soil pH, and nutrients (Burke and Grime 1996; Maron and Connors 1996; Hutchinson and Vankat 1997; Stohlgren et al. 1998; 1999a; 1999b). These parameters are also predicted to limit the distribution of alien plants in GMNP.

Alien species present in GMNP that are restricted to disturbances near human activity are of less concern than species that are able to colonize natural disturbances remote from anthropogenic activity because the latter species may alter ecosystem function and displace native species in otherwise pristine habitats (Vitousek 1990). Individual species life history characteristics which influence establishment and persistence may contribute to alien plant invasion of remote areas in GMNP. Functional characteristics that differ between alien species successful and unsuccessful at colonizing remote disturbances in GMNP were examined to determine alien plant attributes important to invasion success of natural areas. Plant functional characteristics predicted to contribute to invasion success of remote areas include animal and water dispersal mechanisms, vegetative reproduction, large seed size, and tall perennial life forms. Dispersal by animals or water has been found to contribute to alien plant invasion in other areas (Pysek and Preach 1993; Rejamanek 1996) and may be the best means of dispersal into remote areas of GMNP. Forests act as a barrier to alien plant wind dispersal (Brothers and

Spingarn 1992) indicating that this means of dispersal may not contribute to invasive ability in GMNP. Vegetative reproduction, perennial life form, and large seed size are plant characteristics which increase competitive ability in boreal ecosystems because these traits are useful for establishment and persistence in dense vegetation (McIntyre et al. 1995; Pysek et al. 1995; Burke and Grime 1996; Rejmanek 1996). Life-forms that are tall or spread along the ground increase competitive ability because they out-compete other plants for space or resources.

4.2 - Material and Methods

4.2.1 - Study Site Selection

Study sites were chosen to represent the spectrum of disturbance types within each dominant vegetation type based on the distribution/location of alien plants identified during surveying (Chapter 3; Table 6, Figure 9). Definition of vegetation types, environmental characteristics, and location codes are give in Appendix 1. Study site descriptions and locations are given in Appendix 4.

Disturbance types examined included anthropogenic (e.g., roads, clear cuts, pits) and natural (rivers, insect outbreaks, windfalls, moose) disturbance (Table 6). Study sites often represented more than one type of disturbance, as some disturbances such as moose and past human activity often overlapped with other disturbances.

The highest number of study sites occurred in forests because they represent the greatest area of vegetation in GMNP and because they contained more disturbance types than any other vegetation type (Table 6). Although heath-lichen tundra also represents a high percentage of area in GMNP, few study sites were established in these areas because surveys did not detect the presence of alien plant species (Table 6).

All of the study sites chosen occurred on the western side of GMNP (Figure 13). This is due to the fact that all of the vegetation and disturbance types found to contain alien species occurred on the western side or on top of the Long Range Mountains.

4.2.2 - Sampling Design

Site characteristics such as vegetation, drainage, aspect, slope, and elevation were

Table 6: Vegetation Types of GMNP in which Representative Study Sites were Established

Some study sites occurred in more than one vegetation type. Description of vegetation types given in Appendix 1.
** % Area of Vegetation Types from Taylor (1995). N/A = Not Applicable

		Disturbance Types Observed Within Each Vegetation Type										
		Anthropogenic						Natural				
Vegetation Types*	% Area of GMNP**	Roads	Pits	Hiking Trails	Snowmobile Trails	Clearcuts	Pastures	Windfalls	Beavers	Moose and Caribou	River Channels	Number of Study Sites
Balsam fir forest, and Black Spruce forest and scrub	43%	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	28
Riverain Thicket and Meadow (also includes river banks not classified by Berger et al. 1992)	Less than 1%	No	No	Yes	Yes	N/A	No	N/A	No	Yes	Yes	6
Tuckamore	13%	Yes	No	Yes	Yes	N/A	Yes	Yes	No	Yes	Yes	3
Sphagnum Bog	4%	Yes	No	Yes	Yes	N/A	No	N/A	No	Yes	Yes	2
Alpine Meadow (south facing slopes on Big Hill and Kildevil Mt.)	Not classified as a vegetation type (< 1%)	No	No	No	No	N/A	No	N/A	No	Yes	No	2
Heath-Lichen Tundra	23%	No	No	Yes	Yes	N/A	No	N/A	No	Yes	Yes	2
Sedge Fen and Bog	5%	No	No	Yes	?	N/A	No	N/A	No	Yes	Yes	1

Figure 13: Distribution of Study Sites in GMNP

recorded at each study site location. Vegetation was sampled using 1 m wide transects of varying lengths extending from disturbed to undisturbed areas. The size of the disturbance determined transect length and number of replicates carried out at each study site. The spacing of 1 m^2 quadrats along each transect was dependent on transect length and vegetation heterogeneity. Quadrats were generally spaced 2 m to 5 m apart in disturbances large in size, and were abutting or spaced 1 m apart in small disturbances.

Within each quadrat, the vegetation cover of each plant species was estimated to the nearest percent, along with other quadrat characteristics such as percentage of bare ground, light availability, cover of woody debris or leaf litter, and animal disturbance. Vegetation cover values were given for plant species at the ground-level. This may mean that the significance of upright herbs, shrubs, or trees is under-represented compared to mosses and trailing or low lying vegetation. Light availability measurements and substrate samples were collected from all transects.

4.2.3 - Classification of Disturbance Regimes

In order to evaluate how the ecology of alien plants was influenced by disturbance, each quadrat within each study site was given a qualitative ranking for disturbance regime. High, medium, low, and undisturbed categories were used to classify the degree of disturbance (definitions of each category to follow). Disturbance is a fundamental and ongoing process in boreal ecosystems such that all disturbance rankings represent a temporal sequence of recovery from disturbance (White and Pickett 1985).

The many parameters of disturbance and its complex nature means that disturbance does not act uniformly on the environment (Bazzaz 1983; White and Harrod 1997). For this reason it is unlikely to find disturbed areas which are identical in appearance, and quadrats with the same disturbance regime ranking appeared to be similar, but were not exact duplicates of one another.

The simplest and most consistent way to evaluate the degree of disturbance in a quadrat was to examine severity of disturbance. Severity of disturbance refers to the impact of disturbance on a site after or during a disturbance (White and Harrod 1997). Severity of disturbance was evaluated by comparing the amount of bare ground, condition of vegetation, and damage to forest canopies between disturbed areas and their adjacent undisturbed areas.

The frequency (number of disturbance events per time period) and intensity (physical force of a disturbance event) of disturbance could also be observed or predicted at some sites (White and Harrod 1997), and these were also taken into account when determining disturbance regime. Roadsides and hiking trails are good examples of areas where frequency and intensity could be evaluated. By observing the number of vehicles on a road or hikers on a trail over certain time periods, it was possible to get an estimate of the relative frequency and intensity of disturbance in these areas.

Although other parameters such as the size or age of disturbance contribute to disturbance regime (Bazazz 1983; White and Harrod 1997), they are difficult to observe or compare across all vegetation or disturbance types. For this reason other disturbance regime parameters were not often used to determine the disturbance regime of an area.

Disturbance regimes were ranked as "high" when there was frequent and / or intense natural or anthropogenic disturbance occurring at the present time (Table 7). As a result of high disturbance regime these areas have high amounts of available light and / or bare ground. Examples of areas with high disturbance regime include road shoulders, that may be disturbed by a variety of activities including vehicle or foot compaction, snow clearing operations such as plowing or salting, saturation of the ground or ice buildup due to accumulation of snow on road shoulders after plowing, and high carbon monoxide levels produced by vehicles. River banks, that experience frequent erosion or flooding, are also designated as highly disturbed.

Medium disturbance regimes have present or recent disturbance that occurs less frequently and / or less intensely than highly disturbed areas (Table 7). Areas categorized as medium disturbance regime have denser vegetation, and disturbance to soil and vegetation may not be obvious. Medium disturbance regimes may have been highly disturbed at one time, but have recovered to some degree. While these areas are slowly reverting to undisturbed vegetation, they may still be experiencing low intensity disturbance. An example of an area of medium disturbance is along roadsides, approximately five meters off the road shoulder. These areas were highly disturbed when the road was constructed, but at the present time are being disturbed little by vehicle compaction or snow clearing operations that contribute to high disturbance regimes in areas closer to the road shoulder. Trails that are used on a regular annual or seasonal basis with a disturbance interval ranging from a daily to weekly basis are considered medium

Table 7: Summary of Disturbance Regime Classifications

Disturbance Regime	Timing of Disturbance	Frequency and Intensity of Disturbance	Severity of Disturbance	Examples
High	present	- high frequency and/ or intensity	- high bare ground - open canopy - mature trees and shrubs absent - high light levels	- road shoulders - river channels - middle of heavily used hiking trails
Medium	present	- less frequent and/or intense than high disturbance regimes	- bare ground varies - open canopy - mature trees and shrubs infrequent - high light levels	- some moose trails - some hiking trails - many roadside ditches
	recent	- varies		
	past	- high frequency and/ or intensity		
Low	present or recent	- very infrequent - low intensity	- no bare ground - canopy varies - maturity of vegetation varies	- many insect outbreaks - abandoned communities
	past	- may have been high frequency and/ or intensity		
Undisturbed	no apparent past or present disturbance	not applicable	- no bare ground - canopy is well developed in forests - mature vegetation	- mature balsam fir forest - bogs

disturbance areas.

Low disturbance regimes experience little or no obvious present day disturbance but still show impacts from past disturbance (Table 7). Disturbance in these areas may not be readily obvious, and no bare ground resulting from past disturbance remains exposed in these areas. Areas of low disturbance are areas which are experiencing very infrequent disturbance or are recovering from past disturbances. Examples of areas of low disturbance are abandoned communities and most insect outbreaks. Other examples of low disturbance areas are fields alongside trails that were highly disturbed in the past, but receive very infrequent (~ twice a year) or no trampling by hikers at the present time.

Undisturbed areas experience no apparent present day disturbance and show no signs of recent past disturbance (Table 7). Examples of undisturbed areas are mature stands of balsam fir forest and bogs. When the overall disturbance regime classification at a site was uncertain, it was assumed that an area was more disturbed than less. An example of this would be a site where no disturbance can be seen, but it is designated as experiencing low disturbance because moose or past human activity is known to have occurred in the area. This helped ensure that disturbed areas were not mistakenly given an undisturbed ranking.

4.2.4 - Measurement of Physical Parameters

(A) Light Availability

To compare light availability among disturbance types, available light measurements (μmol s^{-1} m^{-2})(PAR- Photosynthetically Active Radiation) were taken at knee height using a LiCor Model LI 250 light meter in all quadrats within each transect. Light availability was measured in 438 quadrats.

Light availability measurements from a single transect were taken at the same time and under similar cloud conditions so that light availability readings did not differ due to changes in the atmosphere. Light availability was also measured in an open canopy area near each transect. It was assumed that light availability measurements taken in open canopy areas represented 100 % light availability.

Light availability measurements were converted to percent light availability to allow comparison of light availability among transects, where

% Light availability = (light reading for quadrat) / (light reading for nearby open canopy area) x 100.

(B) Substrate Sampling and Analysis

To compare substrate properties among vegetation and disturbance types, substrate samples were collected from areas within transects which exhibited change in such variables as canopy cover, substrate type, substrate moisture, and disturbance. Substrate was sampled using a soil corer (20 mm diameter) to a depth of approximately 15 cm from a total of 229 quadrats. This depth was chosen because it is the approximate maximum depth at which roots or rhizomes of most herbaceous alien plant species occurred. To capture substrate variability in each quadrat, 3 substrate samples were randomly collected from different areas of the quadrat and pooled. In areas where the substrate was not deep enough to take samples at a depth of 15 cm, the number of substrate samples collected from the quadrat was increased so that the amount of substrate obtained from each quadrat was approximately equal. Replicate substrate samples were collected from each quadrat for nutrient analysis. The duff depth (cm) in each quadrat was estimated by measuring the organic matter obtained at the top of the soil core. Duff was defined as any dead material that was not mineral soil.

Substrate samples were analyzed for pH, soil moisture, organic content, nutrient content, gravel weight, and soil texture. The pH of substrate samples was obtained by mixing an equal volume of substrate and distilled water. The pH of the supernatant was measured after 30 minutes using a Fisher Accumet 925 pH meter.

The soil moisture of substrate samples was determined by weighing a known volume of substrate to obtain its wet weight. Substrate samples were dried in an oven at 30 °C for two days and left at room temperature for at least two weeks. Dried samples were then re-weighed and % moisture calculated as:

% Soil Moisture = ((wet weight of substrate - dry weight of substrate) / wet weight of substrate) x 100.

These methods followed Cornell Nutrient Analysis Labratories (1989), and were a measure of water available for plant growth.

The organic content of the substrate samples was estimated using loss on ignition following the methods outlined by Bengtsson and Enell (1986). These methods briefly follow: A porcelain crucible (~30 ml) was placed in a muffle furnace for 1 hour at 550 °C and then cooled to room temperature in a desiccator to obtain its weight (weight of crucible). A substrate sample was transferred to the porcelain crucible and weighted (weight of sample and crucible). The crucible and sample are placed in an air-circulation oven at 105 °C for 12 hours and then cooled to room temperature in a desiccator and weighted (weight of dry sample and crucible). The crucible and dry sample was placed in a muffle furnace at 550 °C for 2 hrs, and then dried to room temperature in a desiccator and weighed (weight of ash and crucible). Loss on ignition of the substrate sample was then calculated as:

$$\text{Loss on Ignition} = \frac{(\text{weight of dry sample and crucible}) - (\text{weight of ash and crucible})}{(\text{weight of sample and crucible}) - (\text{weight of crucible})}$$

In order to obtain an estimate of the particle size of a substrate sample, the soil texture was estimated using USDA finger assessment (Rowsell 1993). The approximate particle size distribution for each sample was then determined using the USDA textural class and particle distribution diagram (Rowsell 1993). Particle size classes were sand, silt, and clay.

The % gravel weight in a substrate sample was determined by weighing an air dried sample to obtain the total dry weight. Substrate samples were then shaken through a 2 mm sieve until only stone particles greater than 2 mm in size remained. The remaining stone particles were then weighed and % gravel in a sample calculated using:

$$\text{\% Gravel weight} = ((\text{weight of stones} > 2\text{ mm in size}) / (\text{total substrate sample dry weight})) \times 100.$$

It should be noted that this measurement can be misleading because a volume of stone will weigh much more than the same volume of organic material. In substrate samples with a high organic content this leads to an over-estimate of the abundance of stone in a sample and an underestimate of organic material.

The nutrient content in the substrate samples was determined for nitrogen, phosphorus, calcium, magnesium, and potassium at the agriculture soil lab of the Newfoundland Department of Forest Resources and Agrifoods. Percent nitrogen content was determined using combustion with a LECO CHN Analyzer (detection limit 0.1%). Parts per million of calcium (detection limit 5 ppm), magnesium (detection limit 2 ppm), and potassium (detection limit 1 ppm) were determined using a Mehlich No. 3 Soil Extraction with a Varian Atomic Absorption Spectrometer. Parts per million of phosphorus was determined using a Mehlich No. 3 Soil Extraction with a Technicon Auto Analyzer (detection limit 5 ppm). Devices used for nutrient content analysis were tested using known standards before analysis, and every eighth sample was replicated to ensure reproducibility of results.

4.2.5 - Plant Collection and Identification

All plant species found in transects were identified. The main source used to identify plant species was Fernald (1950). Other sources included Britton and Brown (1970), Crum and Andrews (1981), Harrington (1977), Robertson (1984), and Ryan (1978). Un-identified species in the field were collected and later identified. Unknown species were most commonly members of the Poaceae, Cyperaceae, or Juncaceae.

4.2.6 - Data Analysis

So that differences in environmental and biological characteristics could be investigated for different vegetation and disturbance types, quadrat data were organized into subsets according to disturbance type, vegetation type, substrate type, and disturbance regime. Other data groupings included all study sites combined, and remote forest disturbances. Remote forest disturbance differed from other groupings because it included only those disturbances that occurred away from high anthropogenic activity such as roads and pits. This grouping was considered important because it may be a good indicator of conditions most likely to allow alien plant invasion into remote areas of GMNP.

(A) Correlation of Environmental Parameters

Correlations between each of the environmental parameters were calculated using Spearman's Rank Correlation on SPSS version 8.0 for Windows 95. Spearman's Rank Correlation is a non-parametric test, which was used because the data were not normally distributed (Sokal and Rohlf 1995).

(B) Species-Environmental Relationships

Canonical correspondence analysis (CCA) by the program Canoco for Windows 95 (ter Braak and Smilauer 1998), was used to determine which environmental variables contributed to differences in species distribution between disturbed and undisturbed vegetation types. Species which occurred fewer than four times in the species data set were excluded from the CCA. Forward selection methods using unrestricted Monte Carlo permutation tests were used to ensure that only those environmental variables which contributed significantly to the model were used in the analysis (ter Braak and Smilauer 1998). Unrestricted Monte Carlo permutation tests were also used to evaluate the statistical significance of the relation between the species data and the environmental axes (ter Braak and Smilauer 1998). More detail on the setup of CCA models is given in Table 8.

Table 8: Project Setup for Canonical Correspondence Analysis Models

Note: CCA's were completed using Canoco (ter Braak and Smilauer 1998)

Step 1: Data Available for Analysis
- Species and environment data available.

Step 2: Type of Analysis
- CCA analysis
- unimodal response methods chosen.
- direct gradient analysis method chosen.

Step 3: Scaling
- Focus scaling on: inter-species distances.
- Scaling type: Hill's scaling (L^a) / (1 - L).

Step 4: Transformation of Species data
- Log transformation chosen
Y = log (A*Y + B), A = 10, B = 1

Step 5: Data Editing Choices
- Samples and species were not altered
- Interactions and co-variables were not selected.

Step 6: Forward Selection of Environmental variables
- Forward selection was used to eliminate environmental variables that did not contribute significantly to the model ($\propto$= 0.05).
- Automatic selection was used, with the best environmental variables selected sequentially on the basis of maximum extra fit.
- The statistical significance of each variable was evaluated using Monte Carlo permutation tests (reduced model) (number of permutations = 199).

Step 7: Global Permutation Test
- Evaluation of the model using Monte Carlo Permutation test ($\propto$= 0.05). Significance of the first and axis and significance of all canonical axes together were tested.
- Permutation under reduced model (number of permutations 199, power of test increases only slightly after 199 permutations (ter Braak and Smilauer 1998)).
- Permutation type: unrestricted permutations.

C) Relationship of Disturbance Regime to Physical and Biological Parameters

The descriptive statistics (mean, standard error) of physical and biological parameters within each disturbance regime category (high, mean, low, undisturbed) were calculated for different disturbance and vegetation types using Excel and graphed as histograms using Jandel Scientific Sigma Plot Version 3.0 for Windows 95.

In order to test whether there was a significant difference in physical parameters with change in disturbance ranking, the difference between the mean parameters of high and undisturbed disturbance regimes were tested using Randomization tests (Sokal and Rohlf 1995; Schneider and Hendry 1996). Randomization tests were used instead of Analysis of Variance (ANOVA) because assumptions of data normality, homogeneity of residuals, and independence of residuals required for this test were not satisfied. (Schneider and Hendry 1996). Randomization methods are non-parametric tests that allow estimation of a p-value without needing to rely on the above assumptions (Schneider and Hendry 1996).

Randomization tests involve computing an observed test statistic (in this case the difference between mean high and mean undisturbed disturbance regime parameters) from the data. The data is then randomized to make the null hypothesis true, and a test statistic from the randomized data is computed. Randomization of the data and calculation of a test statistic is then repeated many times ($n = 500$) in order to construct a frequency distribution of outcomes when the null hypothesis is true. The observed test statistic is then compared to the distribution of outcomes in order to calculate a probability level.

In cases where there were insufficient data to compare the difference between high and undisturbed disturbance regimes, high was pooled with medium disturbance regime data, and undisturbed was pooled with low disturbance regime data. Because Randomization methods were used to test a number of characteristics at each site, a more conservative p-value must be used to determine significance between disturbance regimes (Sokal and Rohlf 1995). A more conservative p-value was determined using the Bonferroni method (Sokal and Rohlf 1995).

(D) Functional Characteristics Related to Invasion Success

Canonical correspondence analysis was also used to determine which alien plant characteristics favored successful invasion into areas remote from high anthropogenic activity. These methods are the same as described in Table 8 (exception is that scaling was focused on inter-sample distances, and species success ratings were used as environmental variables).

Alien species within GMNP were given a designation of successful invader of remote areas, unsuccessful invader of remote areas, or occasional/questionable invader. Definitions of invader success ratings are given in Appendix 5. The invasion success of alien species was designated based on extensive survey results throughout GMNP, and only alien species that commonly occurred in areas of high anthropogenic activity were included in the analysis to ensure that the results would not be influenced by alien species that are rare in GMNP.

Functional characteristics used in the analysis included: dispersal of asexually produced propagules, seed weight, vegetative reproduction, seed dispersal unit, life form, maximum flowering height, ability to self-pollinate, and flowering phenology. Dispersal of asexually produced propagules refers to asexual reproduction, which has the potential to disperse alien species such as through apomixis, self-fertilization, or vegetative fragmentation. Vegetative reproduction refers to asexual reproduction which does not have the potential to disperse alien species long distances, but instead maintains or increases species abundance in an area already colonized, examples include the ability to reproduce by runners or rhizomes. Further definitions of functional characteristics are given in Appendix 5. Functional characteristics of each alien species were obtained from Grime et al. (1988), and Thompson et al. (1987).

4.3 - Results

4.3.1 Relationship of Physical and Biological Parameters to Disturbance Regime

Compared to undisturbed areas, high disturbance regimes across all sites were characterized by higher % gravel weight, soil pH, light availability, calcium (ppm), bare ground, and % alien species, and lower % organic matter, soil moisture, and % non-vascular species (Table 9- all sites).

The percentage of gravel was significantly greater in areas of high disturbance compared with undisturbed areas at all site types tested, with the exception of remote forest disturbance sites such as clear cuts, insect outbreaks, and moose trails (Table 9; Figure 14). Areas of high disturbance had much higher amounts of gravel than other disturbance regimes, which generally did not differ greatly (Figure 14).

Soil moisture was found to be significantly lower in high disturbances than in undisturbed areas at all sites tested except remote forest disturbances (Figure 15). Generally areas of low, medium, and undisturbed disturbance regimes had similar levels of soil moisture (Figure 15).

Organic content of soil samples was significantly different between high and undisturbed disturbance regimes at all site types tested, but there was variation in % organic content between vegetation and disturbance types (Figure 16).

Soil pH was found to be significantly different between high and undisturbed disturbance regimes in forest and riparian vegetation types, and all sites combined (Figure 17). There was little difference in soil pH between disturbance regimes in remote forest

Table. 9: Comparison of parameters between quadrats of high (H) and undisturbed (U) disturbance regime using Randomization Methods at study sites in GMNP (Legend located at bottom of table)

Site Type	Parameter	Sample Size		Approximate p-value	Significant at 0.05 (0.008)*	Comment
		H	U			
All Sites	% Gravel Weight	42	47	0.000	yes	
	% Soil Moisture	40	47	0.000	yes	
	% Loss on Ignition	40	49	0.000	yes	
	Soil pH	42	51	0.000	yes	
	% Nitrogen	41	51	0.000	yes	
	Phosphorus (ppm)	41	51	0.120	no	
	Potassium (ppm)	41	51	0.600	no	
	Calcium (ppm)	41	51	0.012	no	
	Magnesium (ppm)	41	51	0.776	no	
	% Light Availability	62	80	0.000	yes	
	% Bareground	65	89	0.000	yes	
	% Non-vascular spp.	65	89	0.000	yes	
	% Alien Species	65	89	0.000	yes	
Roads	% Bareground	7	8	0.000	yes	
	% Non-vascular spp.	7	8	0.002	yes	
	% Alien Species	7	8	0.000	yes	
Trails	% Gravel Weight	8	7	0.000	yes	
	% Soil Moisture	8	12	0.002	yes	
	% Loss on Ignition	7	12	0.002	yes	
	Soil pH	6	11	0.024	no	
	% Nitrogen	6	11	0.132	no	
	Phosphorus (ppm)	6	11	0.200	no	
	Potassium (ppm)	6	11	0.568	no	
	Calcium (ppm)	6	11	0.104	no	
	Magnesium (ppm)	6	11	0.840	no	
	% Light Availability	17	18	0.000	yes	
	% Bareground	17	20	0.000	yes	
	% Non-vascular spp.	17	20	0.010	no	
	% Alien Species	17	20	0.000	yes	
Within Forest Disturbance	% Gravel Weight	13	25	0.332	no	
	% Soil Moisture	13	24	0.060	no	
	% Loss on Ignition	39	24	0.000	yes	H = H and M
	Soil pH	15	23	0.516	no	
	% Nitrogen	14	23	0.168	no	
	Phosphorus (ppm)	14	23	0.360	no	
	Potassium (ppm)	14	23	0.240	no	
	Calcium (ppm)	14	23	0.144	no	
	Magnesium (ppm)	14	23	0.168	no	
	% Light Availability	20	38	0.000	yes	
	% Bareground	20	43	0.000	yes	
	% Non-vascular spp.	20	43	0.000	yes	

Table. 9: Comparison of parameters between quadrats of high (H) and undisturbed (U) disturbance regime using Randomization Methods at study sites in GMNP (Legend located at bottom of table)

Site Type	Parameter	Sample Size		Approximate p-value	Significant at 0.05 (0.008)*	Comment
		H	U			
	% Alien Species	20	43	0.000	yes	
Forest	% Gravel Weight	53	39	0.002	yes	H = H and M
	% Soil Moisture	19	40	0.000	yes	
	% Loss on Ignition	52	41	0.006	yes	H = H and M
	Soil pH	54	42	0.000	yes	H = H and M
	% Nitrogen	53	42	0.036	no	H = H and M
	Phosphorus (ppm)	53	42	0.150	no	H = H and M
	Potassium (ppm)	20	13	0.210	no	
	Calcium (ppm)	53	42	0.014	no	H = H and M
	Magnesium (ppm)	16	42	0.420	no	
	% Light Availability	32	66	0.000	yes	
	% Bareground	35	75	0.000	yes	
	% Non-vascular spp.	35	75	0.000	yes	
	% Alien Species	35	75	0.000	yes	
Rivers	% Gravel Weight	20	27	0.000	yes	U = L and U
	% Soil Moisture	18	25	0.004	yes	U = L and U
	% Loss on Ignition	20	25	0.004	yes	U = L and U
	Soil pH	20	26	0.000	yes	U = L and U
	% Nitrogen	20	26	0.020	no	U = L and U
	Phosphorus (ppm)	20	13	0.296	no	
	Potassium (ppm)	20	13	0.600	no	
	Calcium (ppm)	20	13	0.010	no	
	Magnesium (ppm)	20	13	0.276	no	
	% Light Availability	21	14	0.000	yes	
	% Bareground	21	14	0.000	yes	
	% Non-vascular spp.	21	14	0.000	yes	
	% Alien Species	21	14	0.002	yes	

Legend

Approximate p-value generated using Randomization methods.

The significance value was corrected using the Bonferroni method (a = 0.05/k = 0.008, k = # of tests = 6).

Yes = Significant at 0.008.

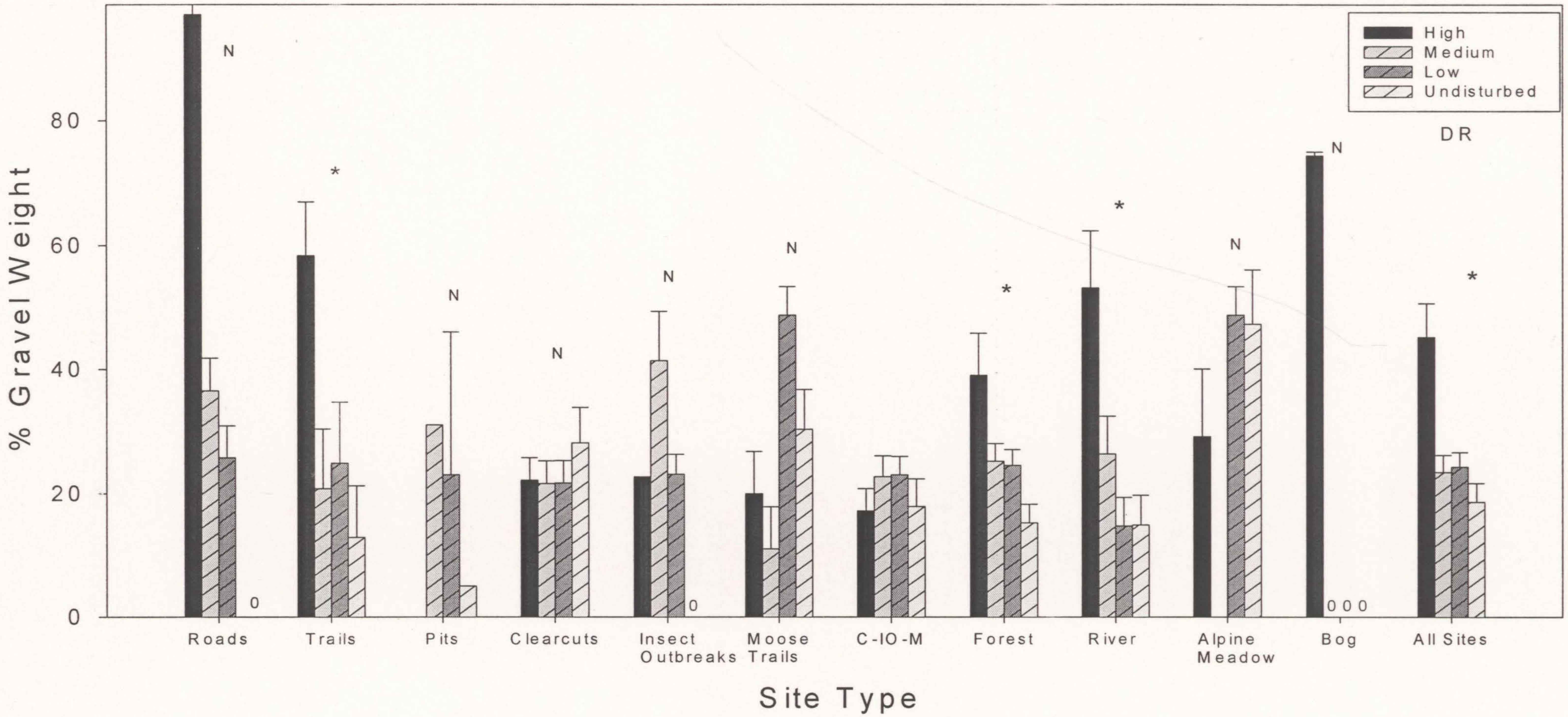


Figure 14: The Effect of Disturbance Regime (DR) on % Gravel Weight in Various Types of Disturbance and Vegetation Sampled in GMNP

0 = indicates that disturbance regime was sampled for gravel weight with a value of zero.

C-IO-M = Remote forest disturbances = Clearcuts, insect outbreaks, and moose trails combined.

Forest = All disturbance types sampled which occurred in forest vegetation (roads, pits, trails, clearcuts, moose, insect).

* = Significant difference (at 0.05) between high and undisturbed disturbance regimes.

N = Significant difference between high and undisturbed disturbance regimes was not tested due to insufficient sample size.

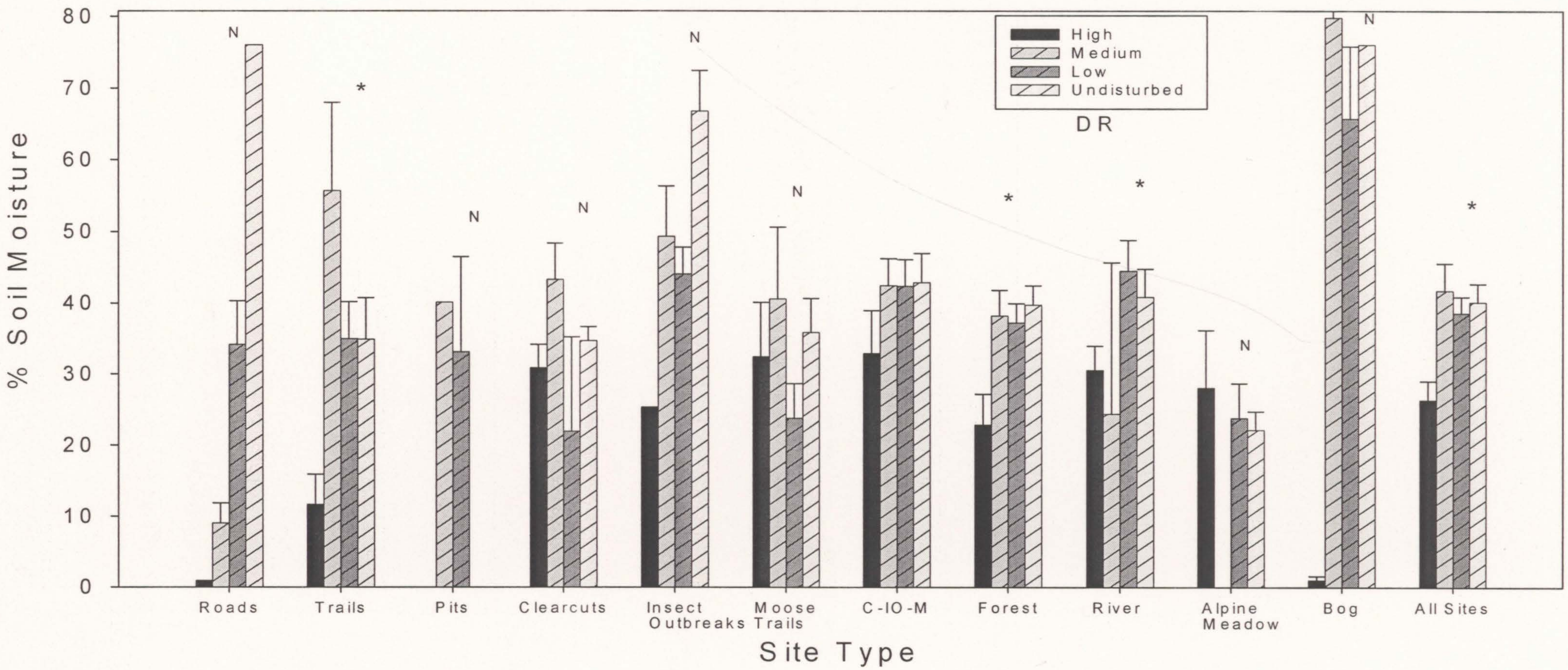


Figure 15: The Effect of Disturbance Regime (DR) on % Soil Moisture in Various Types of Disturbance and Vegetation Sampled in GMNP

0 = disturbance regime was sampled for % soil moisture with a value of zero.

C-IO-M = Remote forest disturbances = Clearcuts, insect outbreaks, and moose trails combined.

Forest = All disturbance types sampled which occurred in forest vegetation (roads, pits, trails, clearcuts, moose, insect).

* = Significant difference (at 0.05) between high and undisturbed disturbance regimes.

N = Significant difference between high and undisturbed disturbance regimes was not tested due to insufficient sample size.

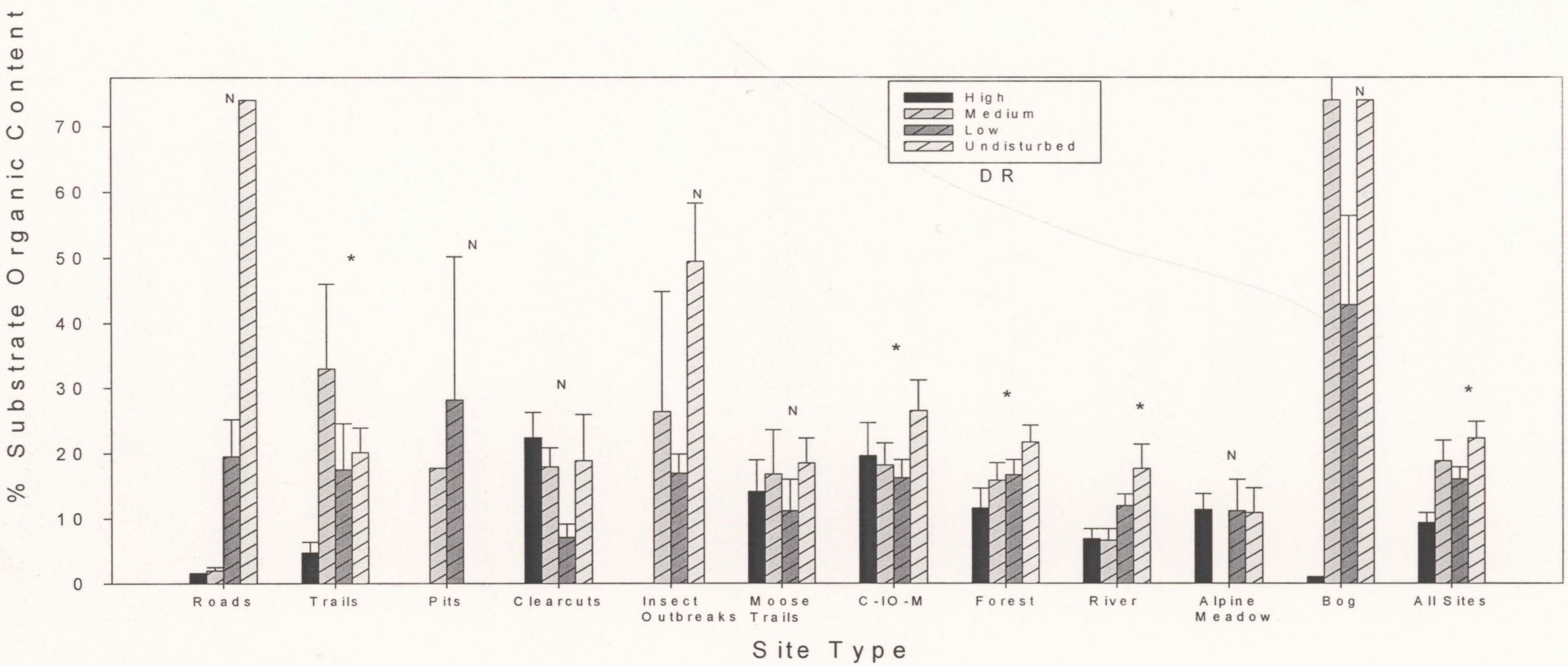


Figure 16: The Effect of Disturbance Regime (DR) on % Organic Content in Various Types of Disturbance and Vegetation Sampled in GMNP

0 = disturbance regime was sampled for organic content with a value of zero.

C-IO-M = Remote forest disturbances = Clearcuts, insect outbreaks, and moose trails combined.

Forest = All disturbance types sampled which occurred in forest vegetation (roads, pits, trails, clearcuts, moose, insect).

* = Significant difference (at 0.05) between high and undisturbed disturbance regimes.

N = Significant difference between high and undisturbed disturbance regimes was not tested due to insufficient sample size.

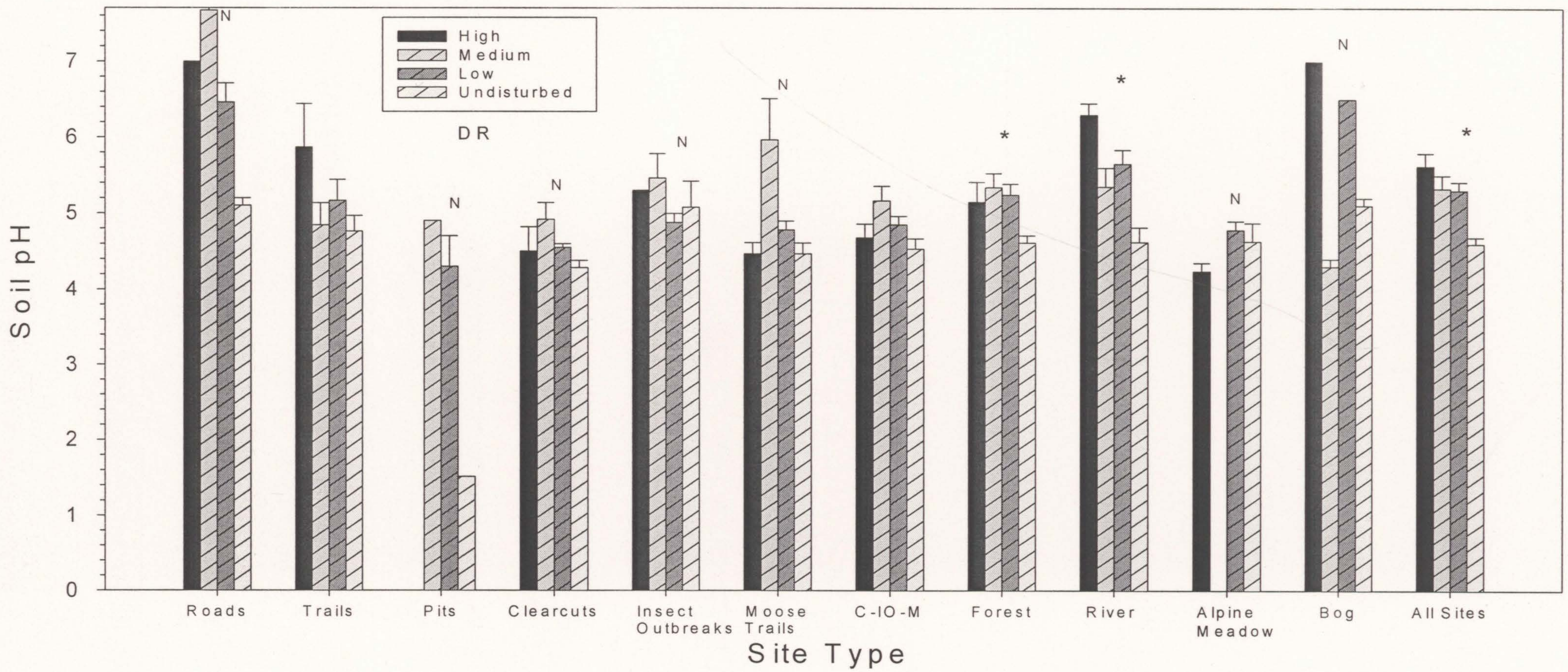


Figure 17: The Effect of Disturbance Regime (DR) on Soil pH in Various Types of Disturbance and Vegetation Sampled in GMNP

0 = indicates that disturbance regime was sampled for soil pH with a value of zero.

C-IO-M = Remote forest disturbances = Clearcuts, insect outbreaks, and moose trails combined.

Forest = All disturbance types sampled which occurred in forest vegetation (roads, pits, trails, clearcuts, moose, insect).

* = Significant difference (at 0.05) between high and undisturbed disturbance regimes.

N = Significant difference between high and undisturbed disturbance regimes was not tested due to insufficient sample size.

disturbances such as insect outbreaks, moose trails, and clear cuts. The highest soil pH values were associated with introduced gravel in high disturbance regimes of trail, road, and bog (areas of bog vegetation with trails and roads) site types.

Nutrient content differed little between disturbance regimes at all site types (Table 9). Nitrogen was generally greater in undisturbed areas compared to other disturbance regimes, but was only found to be significantly different between high and undisturbed areas at all sites combined (Table 9). Compared to other areas calcium levels were noticeably higher on highly disturbed gravel road shoulders and trail beds (Figure 18).

Light availability was found to be significantly higher in areas of high disturbance compared to undisturbed areas at all sites tested (Figure 19).

The percentage of bare ground was found to be significantly different between high and undisturbed disturbance regimes at all sites tested (Figure 20). Generally % bare ground decreased in a stepwise manner from high to undisturbed disturbance regimes (Figure 20).

The mean number of species (alien and native) was greatest in areas of medium and low disturbance regimes, although there was some variation between site types (Figure 21). The mean number of alien species was generally greatest in areas of medium disturbance regime (Figure 22). Alien species were also frequent in high and low disturbance regimes, while undisturbed areas had few or no alien species (Figure 22).

The percentage of non-vascular species was significantly lower in areas of high disturbance compared to undisturbed areas at all site types tested except trails (Table 9,

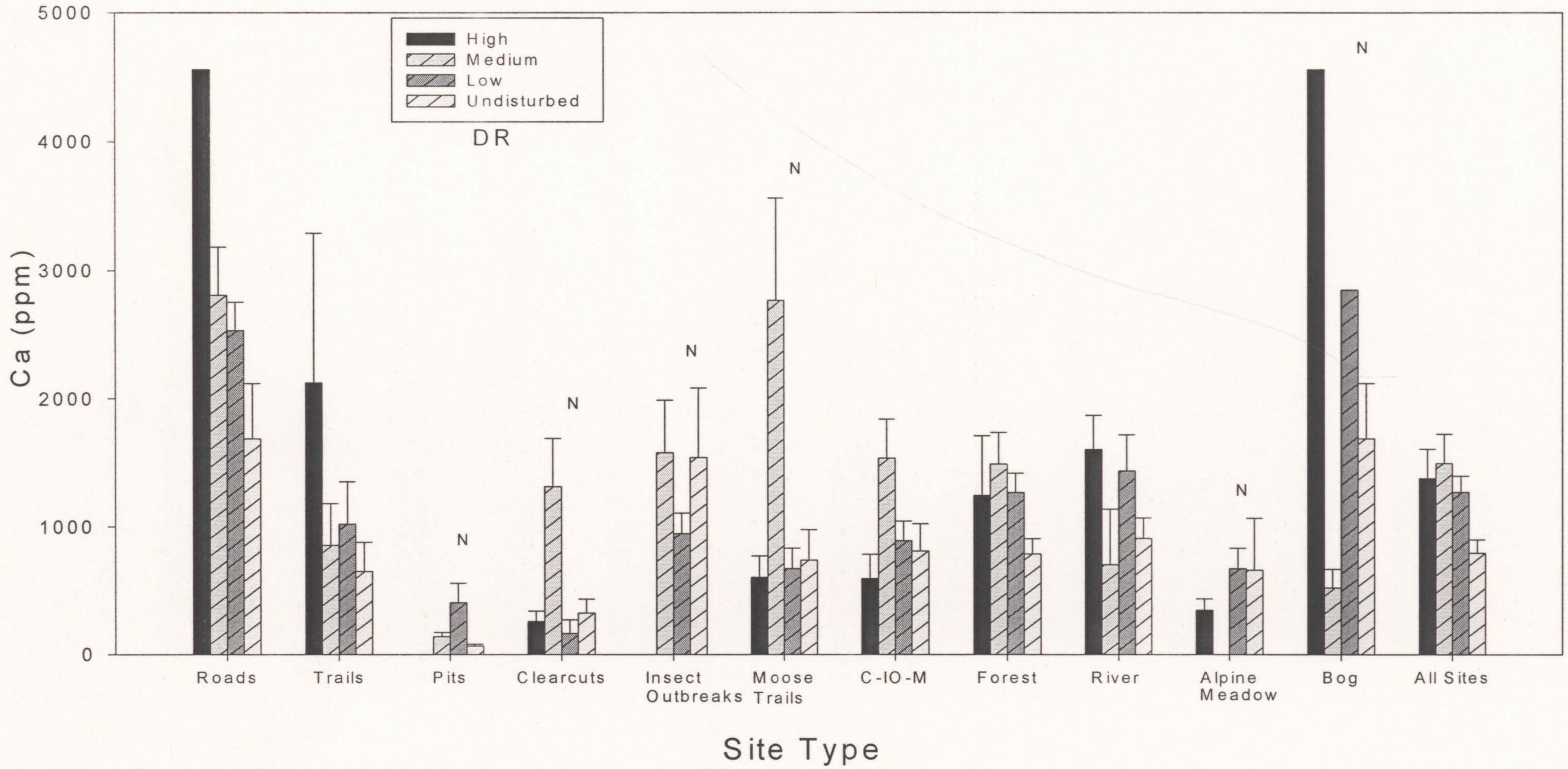


Figure 18: The Effect of Disturbance Regime (DR) on Calcium in Various Types of Disturbance and Vegetation Sampled in GMNP

C-IO-M = Remote forest disturbances = Clearcuts, insect outbreaks, and moose trails combined.

Forest = All disturbance types sampled which occurred in forest vegetation (roads, pits, trails, clearcuts, moose, insect).

* = Significant difference (at 0.05) between high and undisturbed disturbance regimes.

N = Significant difference between high and undisturbed disturbance regimes was not tested due to insufficient sample size.

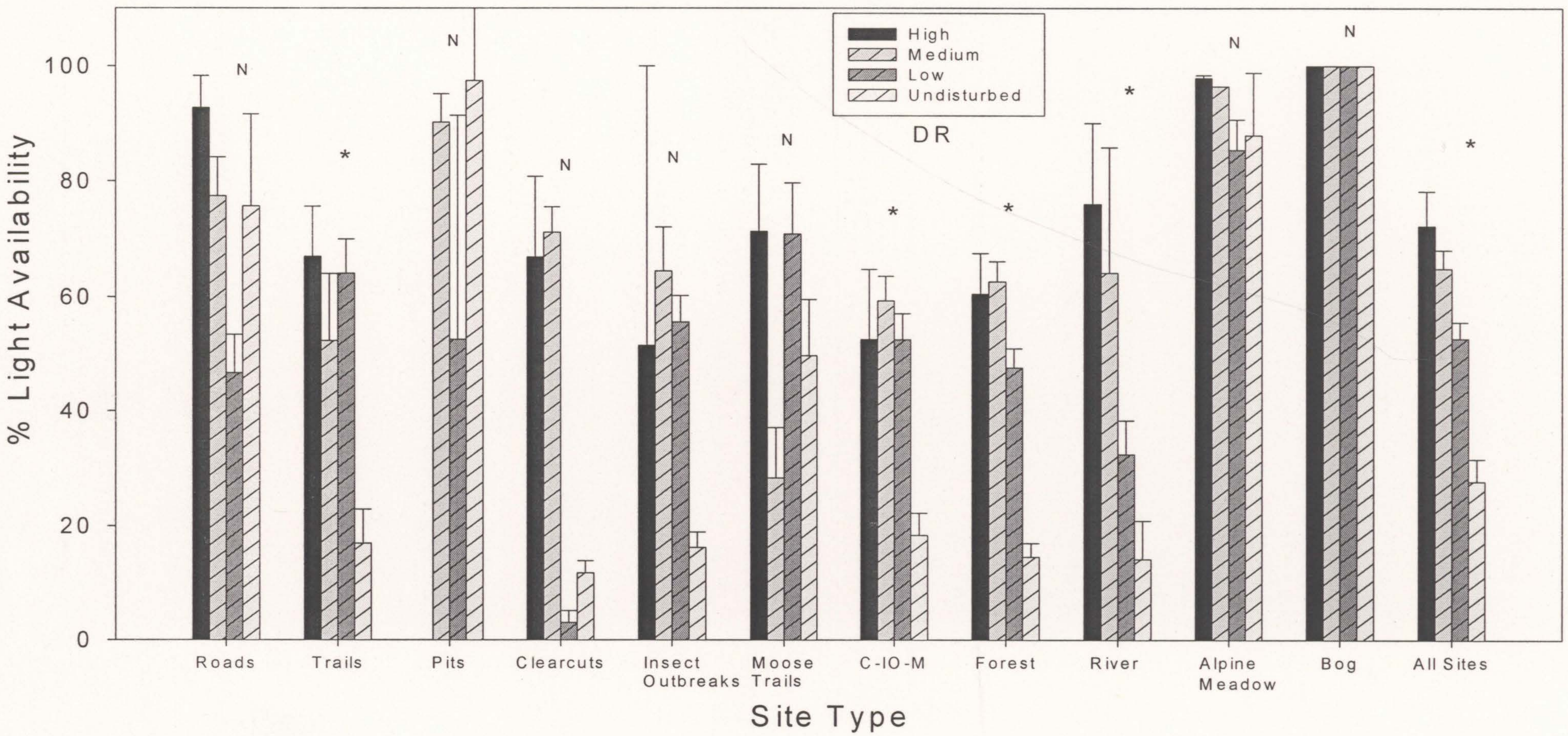


Figure 19: The Effect of Disturbance Regime (DR) on % Light Availability in Various Types of Disturbance and Vegetation Sampled in GMNP

C-IO-M = Remote forest disturbances = Clearcuts, insect outbreaks, and moose trails combined.

Forest = All disturbance types sampled which occurred in forest vegetation (roads, pits, trails, clearcuts, moose, insect).

* = Significant difference (at 0.05) between high and undisturbed disturbance regimes.

N = Significant difference between high and undisturbed disturbance regimes was not tested due to insufficient sample size.

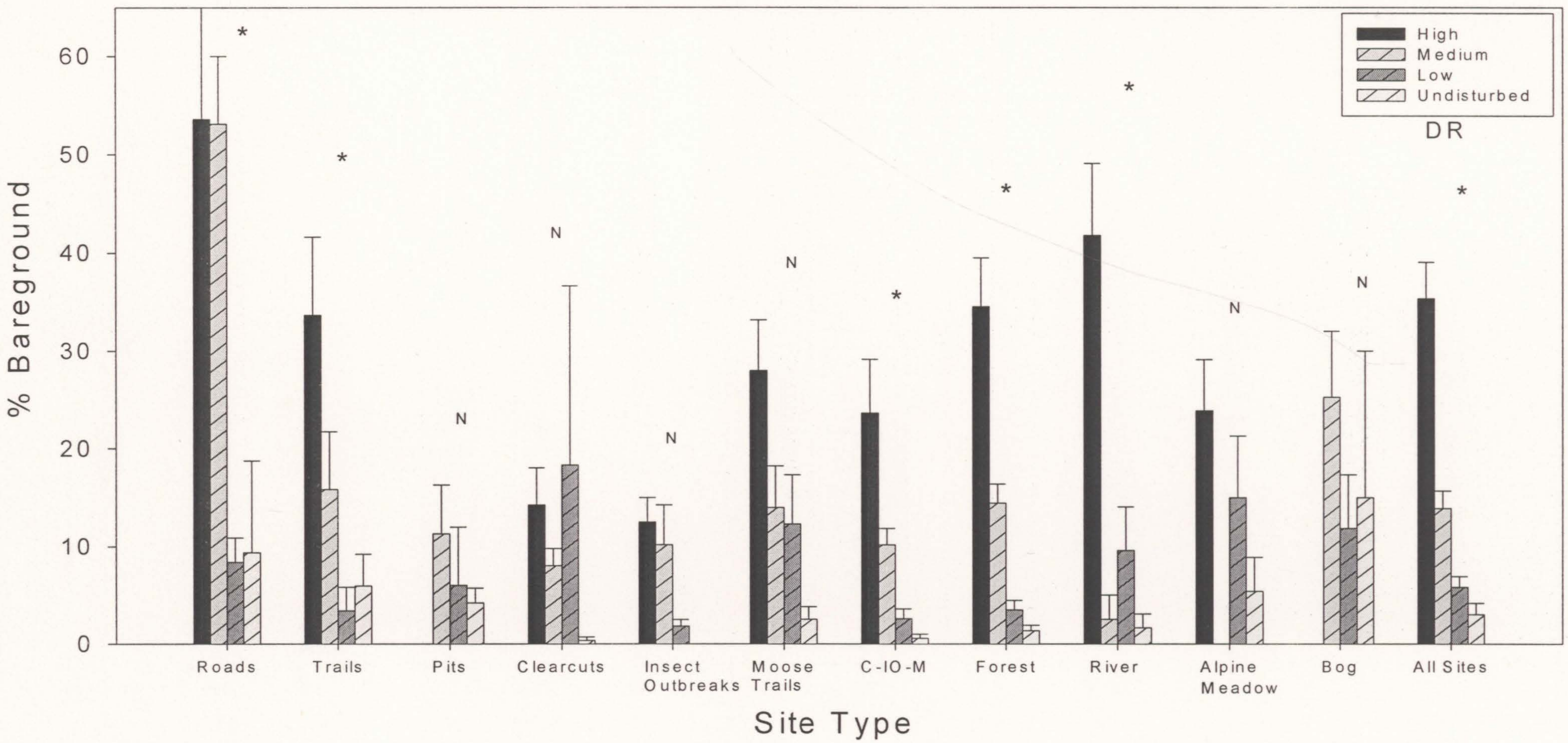


Figure 20: The Effect of Disturbance Regime (DR) on % Bare Ground in Various Types of Disturbance and Vegetation Sampled in GMNP

C-IO-M = Remote forest disturbances = Clearcuts, insect outbreaks, and moose trails combined.

Forest = All disturbance types sampled which occurred in forest vegetation (roads, pits, trails, clearcuts, moose, insect).

* = Significant difference (at 0.05) between high and undisturbed disturbance regimes.

N = Significant difference between high and undisturbed disturbance regimes was not tested due to insufficient sample size.

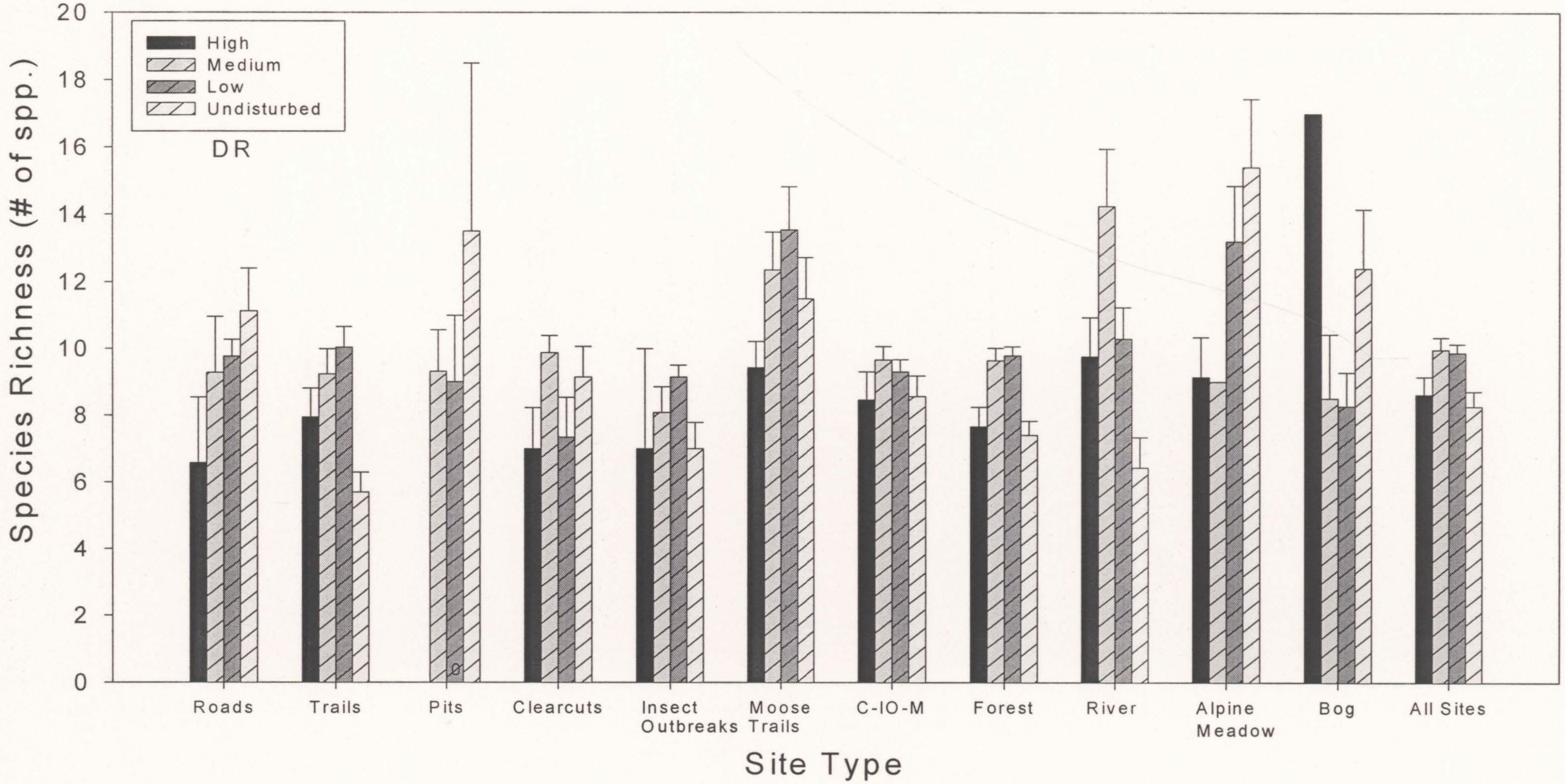


Figure 21: The Effect of Disturbance Regime (DR) on Number of Species (alien and native) in Various Types of Disturbance and Vegetation Sampled in GMNP

C-IO-M = Remote forest disturbances = Clearcuts, insect outbreaks, and moose trails combined.

Forest = All disturbance types sampled which occurred in forest vegetation (roads, pits, trails, clearcuts, moose, insect).

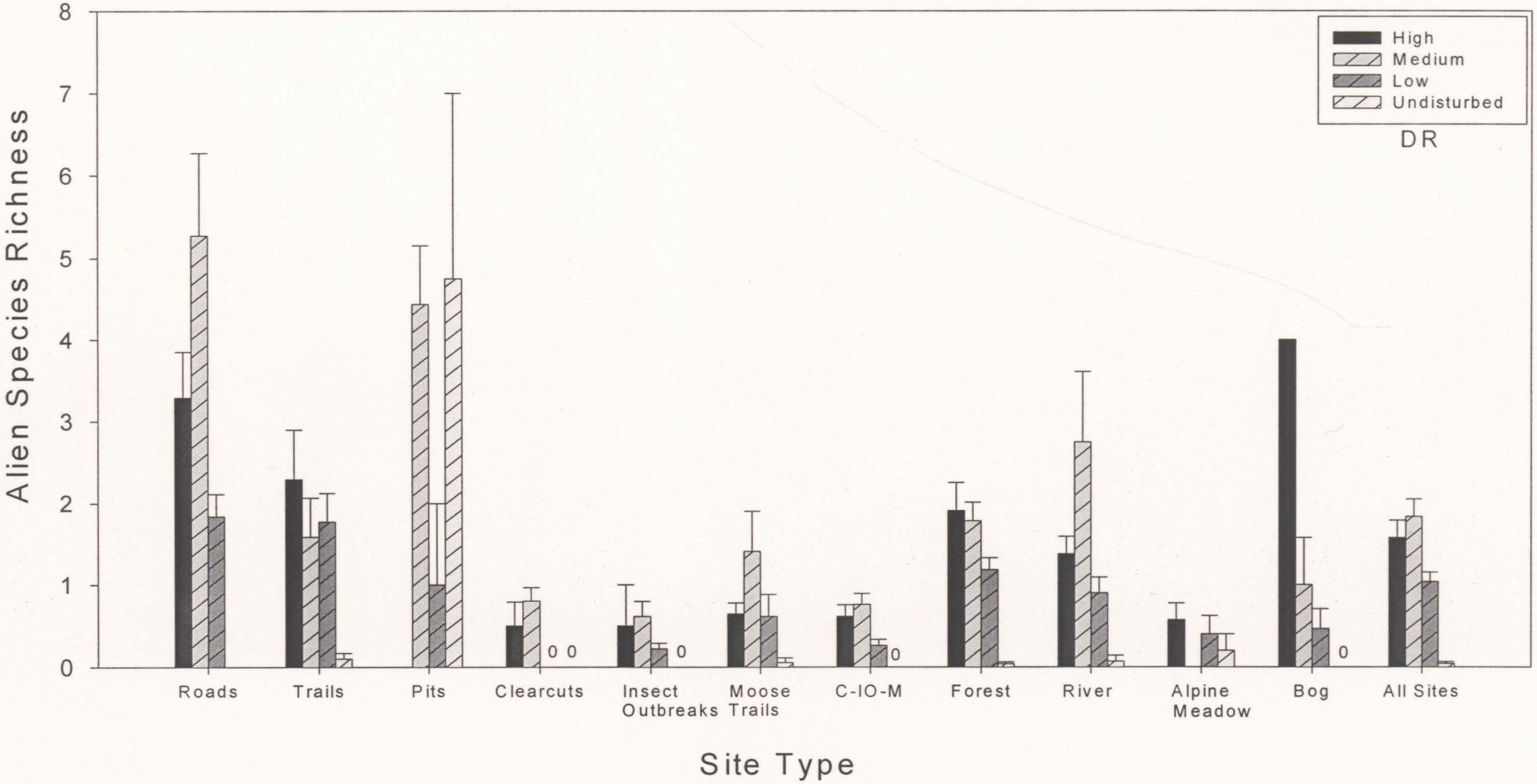


Figure 22: The Effect of Disturbance Regime (DR) on Number of Alien Species in Various Types of Disturbance and Vegetation Sampled in GMNP

C-IO-M = Remote forest disturbances = Clearcuts, insect outbreaks, and moose trails combined.

Forest = All disturbance types sampled which occurred in forest vegetation (roads, pits, trails, clearcuts, moose, insect).

Figure 23). Generally, areas of medium and low disturbance had % non-vascular species values between high and undisturbed disturbance regimes (Figure 23).

The percentage of alien species was significantly greater in high disturbance regimes compared to undisturbed disturbance regimes at all site types tested (Table 9, Figure 24). Areas of high and medium disturbance regimes often had similar % alien species values (Figure 24).

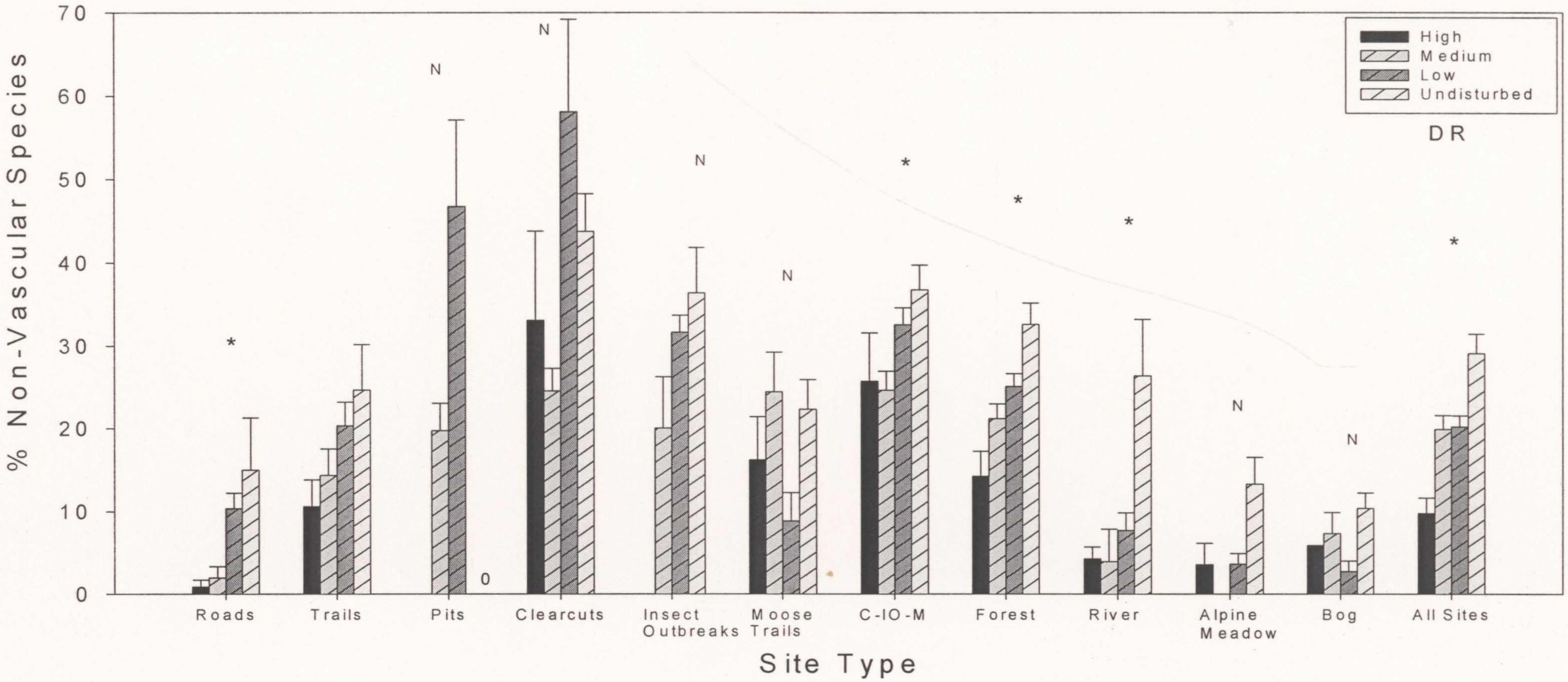


Figure 23: The Effect of Disturbance Regime (DR) on % Non-vascular species in Various Types of Disturbance and Vegetation Sampled in GMNP

C-IO-M = Remote forest disturbances = Clearcuts, insect outbreaks, and moose trails combined.

0 = indicates that disturbance regime was sampled for % non-vascular species with a value of zero.

Forest = All disturbance types sampled which occurred in forest vegetation (roads, pits, trails, clearcuts, moose, insect).

* = Significant difference (at 0.05) between high and undisturbed disturbance regimes.

N = Significant difference between high and undisturbed disturbance regimes was not tested due to insufficient sample size.

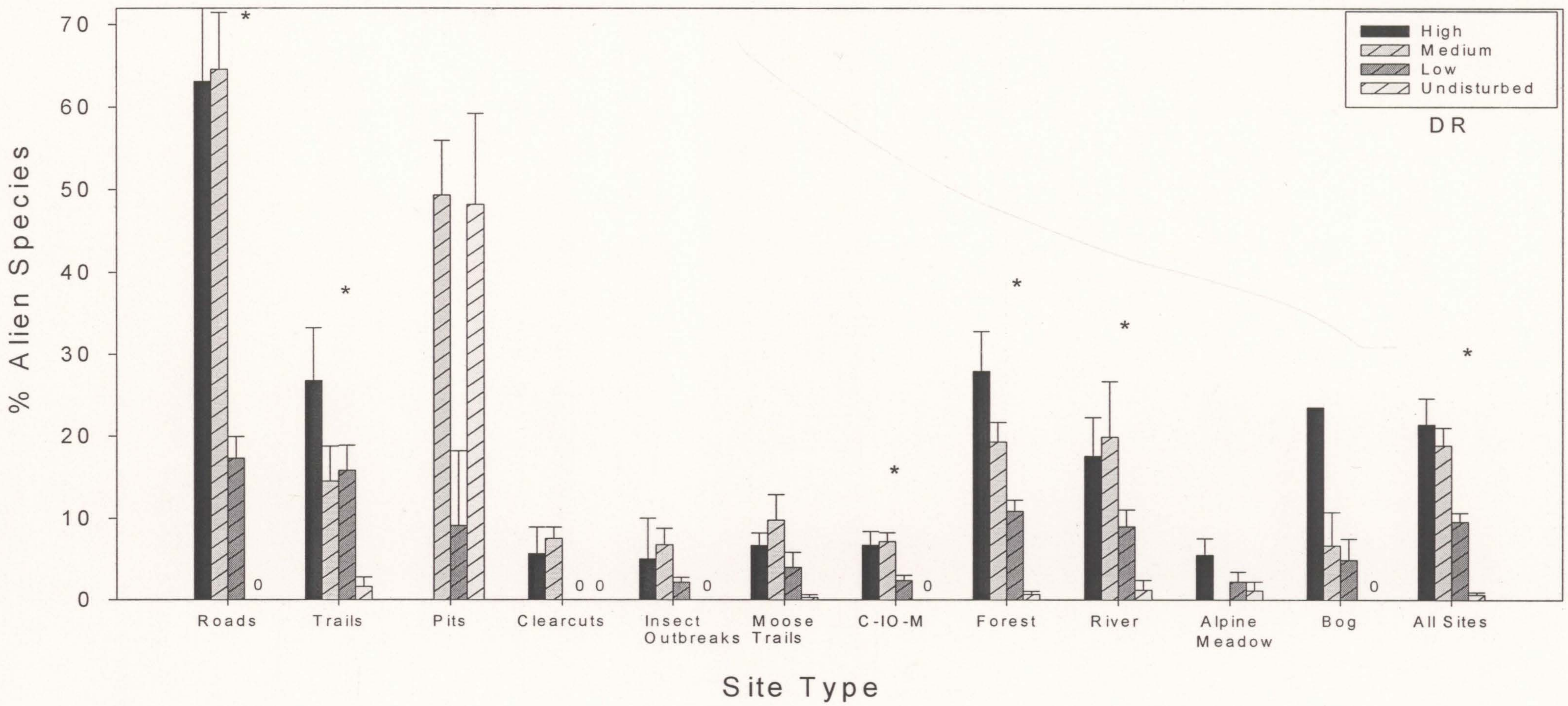


Figure 24: The Effect of Disturbance Regime (DR) on % Alien Species in Various Types of Disturbance and Vegetation Sampled in GMNP

0 = indicates that disturbance regime was sampled for alien species with a value of zero.

C-IO-M = Remote forest disturbances = Clearcuts, insect outbreaks, and moose trails combined.

Forest = All disturbance types sampled which occurred in forest vegetation (roads, pits, trails, clearcuts, moose, insect).

* = Significant difference (at 0.05) between high and undisturbed disturbance regimes.

N = Significant difference between high and undisturbed disturbance regimes was not tested due to insufficient sample size.

4.3.2 - Important Environmental Parameters

The importance of specific environmental parameters to alien plant distribution was examined using Canonical Correspondence Analysis (CCA) and Spearman's Correlations.

(A) CCA Ordination of Species - Environment Relationships

Data were examined using CCA to determine which environmental variables (light availability, bare ground, soil pH, soil nutrients (N, P, K, Ca, Mg), soil organic content, soil moisture, soil type, duff depth) contribute to alien plant invasion of different vegetation types. Sets of data analysed using CCA include: 1) All sites - The entire set of data collected across several disturbance and vegetation types was examined to determine general trends in alien plant invasion in GMNP; 2) Remote forest disturbances; 3) Riparian areas - As survey observations indicated remote forest disturbances and riparian areas were being invaded by alien plants, data from these areas were examined to determine which environmental changes allow alien plants to invade each of these vegetation types; 4) Samples with alien species - All quadrats containing alien species were grouped and analysed to determine native species which showed similar preferences to alien species in disturbed environments. Native species which have similar ecological preferences may be threatened by alien plants in these areas. These native species may also be used to replace alien species in hydro-seed mixtures used in vegetation restoration projects. Additional CCA Results are presented in Appendix 7.

1. CCA - All Sites (General Community Patterns)

Across all study site types numerous environmental variables contributed significantly to CCA model. The CCA model separated native and alien plant communities into the vegetation or disturbance types with which they were most frequently associated.

The most important factors contributing to plant community composition were soil pH, % bare ground, calcium (ppm), % gravel weight, and % light availability (Figure 25). Species axis 1 accounted for 29.1 % of the species-environment variation and was strongly correlated to soil pH (r= + 0.744), bare ground (r = + 0.524), and calcium (r = + 0.467). Species axis 2 was correlated to gravel weight (r = + 0.467) and light (r = + 0.397), and explained 16.9 % of the species-environment relations. Magnesium (ppm), potassium (ppm), log C:N, and soil moisture were correlated to all four of the axes at varying degrees. Species-environment relationships were statistically significant for the first axis (F = 5.67, P = 0.005) and all axes together (F = 2.387, P = 0.005).

All of the alien species occurred on the positive side of axis 1, and were associated with high soil pH, bare ground, and calcium (ppm), and low soil moisture and C:N ratio (Figure 25).

The majority of species occurring on the positive side of axis 1 were herbs. Field and roadside disturbance types could be distinguished by the clustering of species commonly found in these areas. Species common to fields such as *Poa pratensis* (PPS), *Trifolium repens* (TRS), and *Festuca ovina* (FO) were associated with higher light and

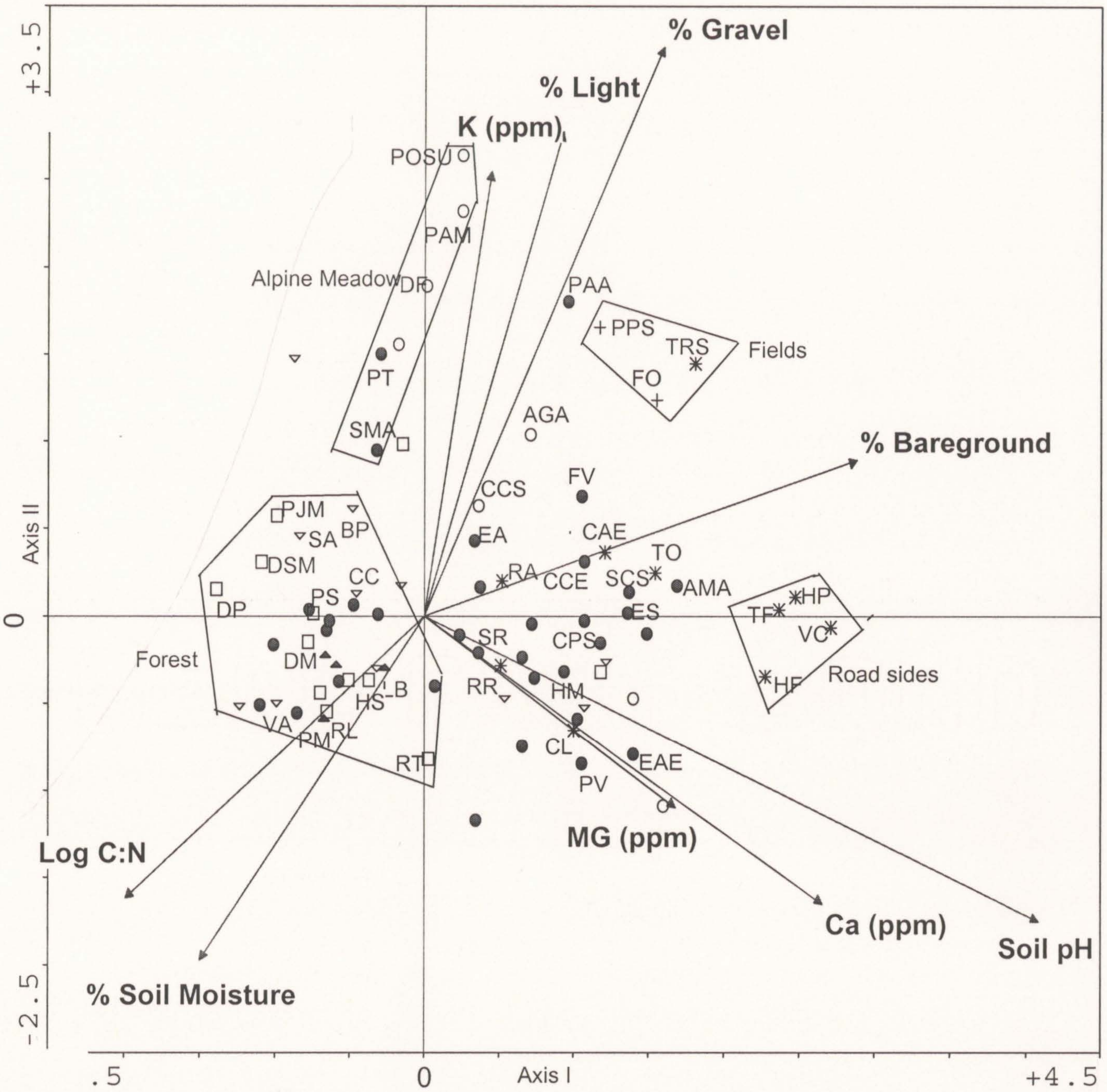


Figure 25: CCA Ordination Diagram of the Relationship of Species with Significant Environmental Variables in All Quadrats Sampled in GMNP
(Species acronyms are listed in Appendix 6)

Disturbance regime of samples: High = 8, Medium = 22, Low = 27, Undisturbed = 25

Legend: ✳ = Alien Forb + = Alien Grass ● = Native Forb ○ = Native Grass □ = Bryophytes
▲ = Evergreen Trees / Shrubs ∇ = Deciduous Trees / Shrubs

Note: Boxes surrounding species represent the disturbance or vegetation types in which the species were most frequently found.

gravel compared to other alien species. Alien species commonly found along roadsides such as *Tussilago farfara* (TF), *Hieracium pratense* (HP), *Vicia cracca* (VC), and *Hieracium floribundum* (HF) were associated with high soil pH and bare ground. Alien species commonly found in many types of disturbances such as *Ranunculus acris* (RA), *Cirsium arvense* (CAE), and *Taraxacum officinale* (TO) were associated with high % light availability, % gravel weight, % bare ground, soil pH, calcium, and magnesium on the positive side of axis 1, but did not show a strong association to any particular environmental parameter.

Native species occurring on the positive side of axis 1 which showed environmental preferences similar to alien species included *Agrostis geminata* (AGA), *Epilobium angustifolium* (EA), *Conioselinum chinese* (CCE), *Solidago rugosa* (SR), *Calamagrostis canadensis* (CCS), *Sanguisorba canadensis* (SCS), *Fragaria virginiana* (FV), *Potentilla anserina* (PAA), *Heracleum maximum* (HM), *Anaphalis margaritacea* (AMA), *Caltha palustris* (CPS), *Prunella vulgaris* (PV), *Equisetum sylvaticum* (ES), and *Equisetum arvense* (EAE).

The alien species *Ranunculus repens* (RR) was found in areas of high anthropogenic activity as well as more remote disturbances occurring in forests (clear cuts, trails, insect outbreaks), fens, alpine meadows, and riparian areas. This wide range of habitats is reflected on the ordination diagram, where the species occurs between forest vegetation and areas of anthropogenic activity (Figure 25). *Ranunculus repens* was associated with higher soil moisture than other alien species and did not appear to be correlated with light or gravel weight (Figure 25). Although *Ranunculus repens* was not as strongly associated with soil pH, bare ground, calcium, and magnesium as other alien species, these environmental variables separated *R. repens* from forest vegetation along axis 1 (Figure 25). Unexpectedly, the common roadside and field species *Chrysanthemum leucanthemum* (CL) also appeared near *R. repens* in the ordination (Figure 25). Its position on diagram was skewed by a single occurrence along a moose trail on a high pH fen. *Chrysanthemum leucanthemum* was not found to be invading natural areas within GMNP.

Forest species were associated with moderate to high soil moisture and C:N, and low measurements of soil pH, magnesium, calcium, bare ground, light availability, gravel weight, and potassium (Figure 25). The majority of moss species occurred in forest vegetation including *Pleurozium schreberi* (PS), *Hylocomium splendens* (HS), *Rhytidiadelphus triquestrus* (RT), *Rhytidiadelphus loreus* (RL), *Polytrichum juniperinum* (PJM), and *Dicranum* spp (DSM, DP, DM). This area also corresponded to all of the evergreen species, including *Abies balsamea* (AB), *Linnaea borealis* (LB), and *Picea mariana* (PM), and most of the woody deciduous species such as *Betula papyrifera* (BP), *Vaccinium angustifolium* (VA), *Cornus canadensis* (CC), and *Sorbus americana* (SA).

Alpine meadow vegetation corresponded to high light availability, % gravel, and potassium, and relatively low soil pH, magnesium, and calcium (Figure 25). The fact that some areas of alpine meadows were on well-drained, steep slopes with little soil development is reflected by the tendency for alpine meadow species to be associated with low soil moisture and C:N. Species commonly occurring in alpine meadow vegetation were typical arctic / alpine tolerant species such as *Poa subcaerulea* (POSU), *Deschampsia flexuosa* (DF), *Solidago macrophylla* (SMA), *Potentilla tridentata* (PT), and *Phleum alpinum* (PAM).

<u>*2. CCA - Remote Forest Disturbances (Clear cuts, Insect Outbreaks, and Moose Trails)*</u>

To determine important environmental parameters associated with alien species colonizing forest disturbances, data collected from forest vegetation were examined.

Species axis 1 accounted for 37.2% of the species-environment variation. Light availability was the most important factor determining the distribution of species in forest vegetation with a correlation of + 0.624 to axis 1 (Figure 26). Species axis 2 explained 25.6 % of the species-environment relationship, with calcium ($r = + 0.574$) and soil pH ($r = + 0.524$) most strongly correlated to axis 2 (Figure 26). Calcium also had a high correlation to axis 1 ($r = + 0.425$). Phosphorus was not strongly correlated to axis 1 or axis 2, and it was difficult to see any patterns in species relationships to phosphorus. A Monte Carlo permutation test confirmed that the relations were significant for the first axis ($F = 3.05$, $P= 0.005$) and all axes combined ($F = 2.196$, $P = 0.005$).

The alien plants *Ranunculus repens* (RR) and *Taraxacum officinale* (TO) were associated with high soil pH, calcium, and light availability on the positive sides of axes 1 and 2 (Figure 26). Native species which showed similar environmental preferences included *Anaphalis margaritacea* (AMA), *Epilobium glandulosum* (EG), *Impatiens capensis* (IC), *Viola* spp. (Vt), and *Solidago rugosa* (SR).

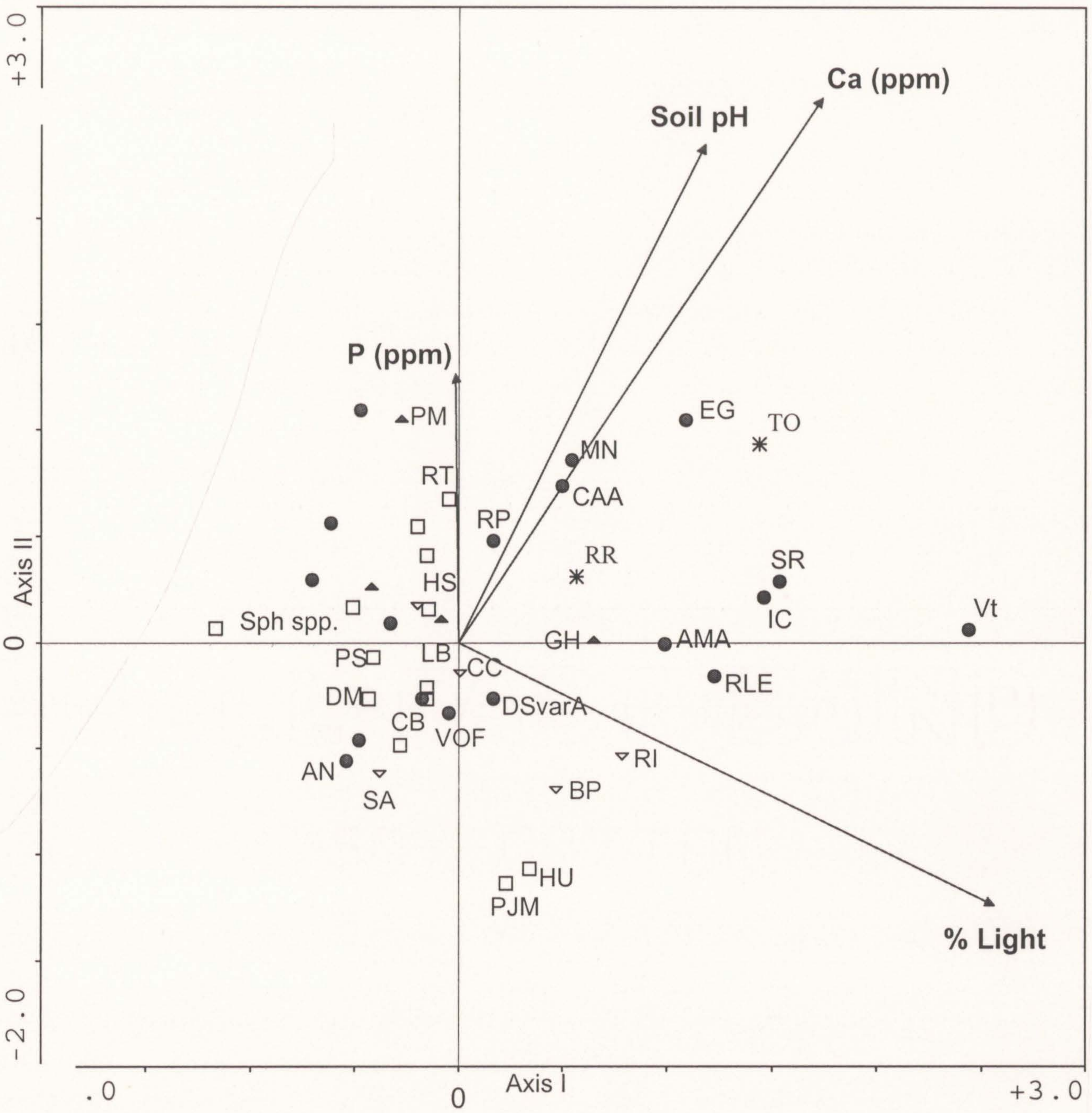


Figure 26: CCA Ordination Diagram of the Relationship of Species with Significant Environmental Variables in Remote Forest Disturbances of GMNP (Species acronyms are listed in Appendix 6)

Notes: Samples from balsam fir, and black spruce forest were analysed. Disturbance types present in the samples included clear cuts, insect outbreaks, and moose trails. These disturbances were considered to occur away from high human activity.

Disturbance regime of samples: High = 8, Medium = 22, Low = 27, Undisturbed = 25

Legend: ✳ = Alien Forb + = Alien Grass ● = Native Forb □ = Bryophytes

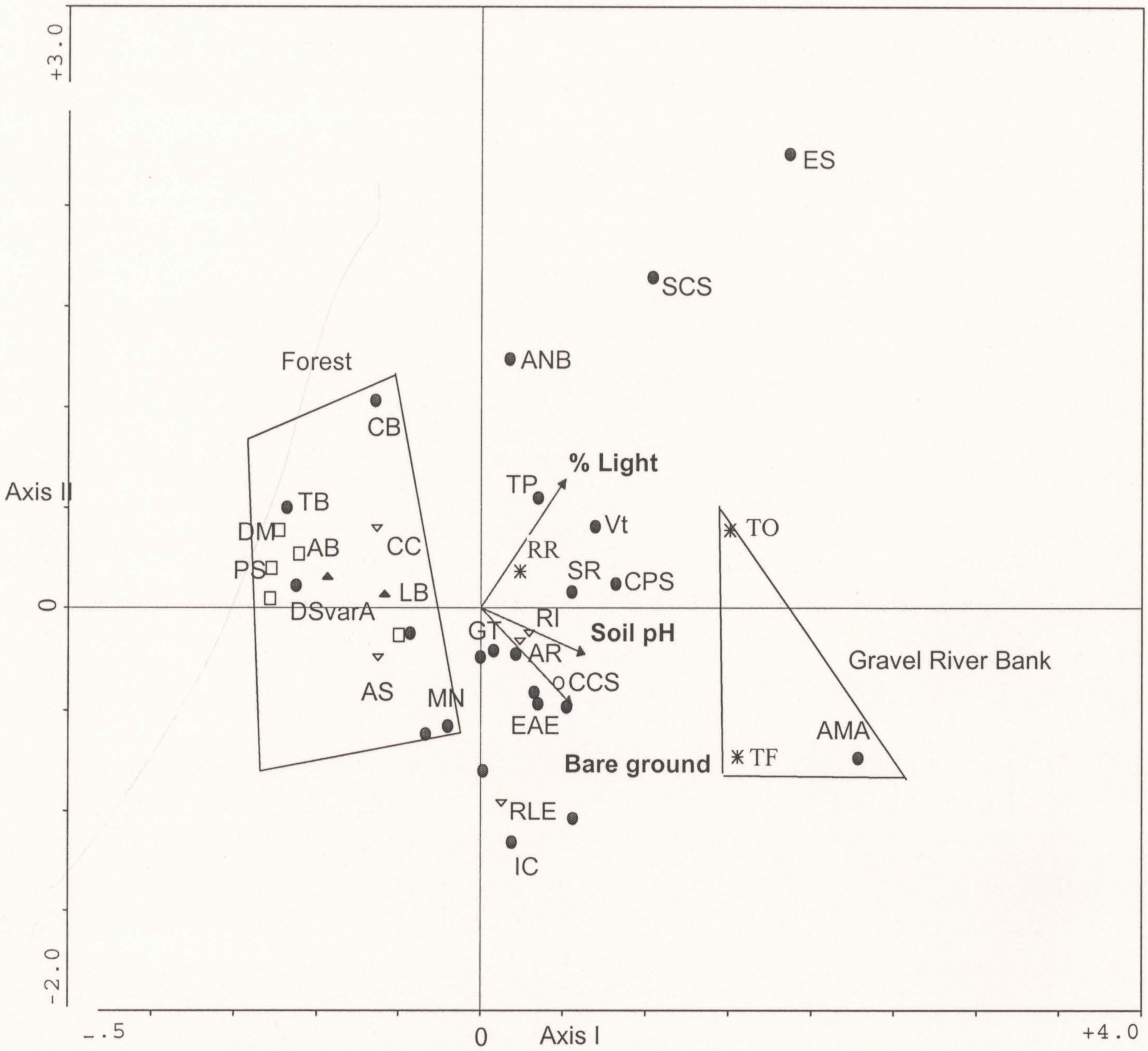
▲ = Evergreen Trees / Shrubs ∇ = Deciduous Trees / Shrubs

The negative side of axis 1 corresponded to low light availability and soil pH (Figure 26). Typical forest moss and evergreen species were associated with these environmental conditions (Figure 26). Species of open areas such as *Betula papyrifera* (BP), *Rubus idaeus* (RI), and *Polytrichum juniperinum* (PJM) were found on the positive side of axis 1, associated with high light availability, and low soil pH and low calcium. Forest species commonly found under both open and closed canopies such as *Rubus pubescens* (RP), *Mitella nuda* (MN), and *Circaea alpina* (CAA) occurred in the centre of the ordination diagram coinciding with moderate soil pH, calcium, and light availability.

<u>3. CCA - Riparian Areas</u>

Data collected from river study sites were examined to determine environmental conditions that contribute to alien invasion of riparian habitats in GMNP. There was an observable change in vegetation with distance from the river channel in riparian areas. Forest vegetation was associated with low light availability, bare ground, and soil pH on the negative side of axis 1, while open canopy gravel river banks corresponded to high light, bare ground, and soil pH on the positive side of axis 1 (Figure 27).

The first CCA axis explained 46.1 % of the variance in the species-environment relationship and had high correlations with soil pH ($r = +0.668$), % bare ground ($r = +0.586$), and % light availability ($r = + 0.543$) (Figure 27). The second axis explained 29.7 % of the species-environment variation and was correlated to light availability ($r = +0.592$), and bare ground ($r = - 0.4429$). Both the first axes ($F = 3.272$, $P = 0.005$) and all of the axes together ($F = 2.604$, $P = 0. 005$) were found to be significant using Monte



<u>Figure 27: CCA Ordination Diagram of the Relationship of Species with Significant Environmental Variables in Riparian Areas of GMNP (Species acronyms are listed in Appendix 6)</u>

<u>Notes</u>: Samples were taken from transects that ran from stream banks into undisturbed areas. Moose disturbance occurred in some areas along the transects.

<u>Disturbance regime of samples</u>: High = 21, Medium = 2, Low = 12, Undisturbed = 11

<u>Legend</u>: ✳ = Alien Forb + = Alien Grass ● = Native Forb □ = Bryophytes

▲ = Evergreen Trees / Shrubs ∇ = Deciduous Trees / Shrubs

Note: Boxes surrounding species represent the disturbance or vegetation types in which the species were most frequently found.

Carlo permutation tests. Highly disturbed gravel river banks commonly contained *Anaphalis margaritacea* (AMA), and the alien species *Taraxacum officinale* (TO) and *Tussilago farfara* (TF) (Figure 27). In some areas *Tussilago farfara* comprised over half of the vegetative cover on gravel river banks.

The origin of the ordination diagram coincided with moderate soil pH, light availability, and bare ground (Figure 27), and represents a transition between the habitats of highly disturbed river banks, and forest vegetation. The alien species *Ranunculus repens* (RR) was commonly found in these conditions. The size of transitional areas and composition of vegetation in transitional areas varied with riparian habitats in GMNP. Vegetation ranged among herbaceous meadows, alder thicket, or a mixture of rock and herbaceous substrates. Most of the species associated with transition areas were forbs such as *Galium triflorum* (GT), *Equisetum arvense* (EAE), *Sanguisorba canadensis* (SCS), and *Calamagrostis canadensis* (CCS), but deciduous species such as *Alnus rugosa* (AR)and *Rubus idaeus* (RI) were also common.

All of the moss and evergreen species present in riparian areas were associated with forest environments of low soil pH, light availability, and bare ground (Figure 27). Typical forest floor herbs such as *Cornus canadensis* (CC), *Trientalis borealis* (TB), and *Mitella nuda* (MN) were also found here.

4. CCA - Samples Containing Alien Species

Analysis of only those quadrats which contained alien species were used to examine environmental parameters most strongly associated with the distribution of different alien species and to determine native species which showed distributions similar to alien species.

Soil pH (r = + 0.573), bare ground (r = + 0.547), and soil moisture (r = -0.495) were highly correlated with species axis 1, which accounted for 35.8 % of the variation in species-environment relationships (Figure 28). The second axis explained 22.7 % of the species-environment variation and was correlated to % light availability (r = + 0.3297), % soil moisture (r = -0.3376), and soil pH (r = -0.4121). A Monte Carlo permutation test found both the first axis (F = 2.99, P = 0.005), and the second axis (F = 1.81, P = 0.005) to be statistically significant.

Native species of forest vegetation coincided with low light availability, soil pH, calcium, and bare ground, and high % soil moisture on the negative side of axis 1 (Figure 28). This is the only portion of the ordination diagram which contained moss and evergreen species.

Alien species occurred on the positive side of axis 1, where they showed a strong negative association with soil moisture and positive correlations to soil pH, light availability, calcium, and bare ground. These results were consistent with the results for the CCA of all sites (Figure 25).

The importance of environmental parameters to alien species varied. Species found in fields, such as *Festuca ovina* (FO) and *Trifolium repens* (TRS) showed the strongest associations with light availability, while the roadside species *Tussilago farfara* (TF) showed the strongest correlations to soil pH and calcium (Figure 28). Species

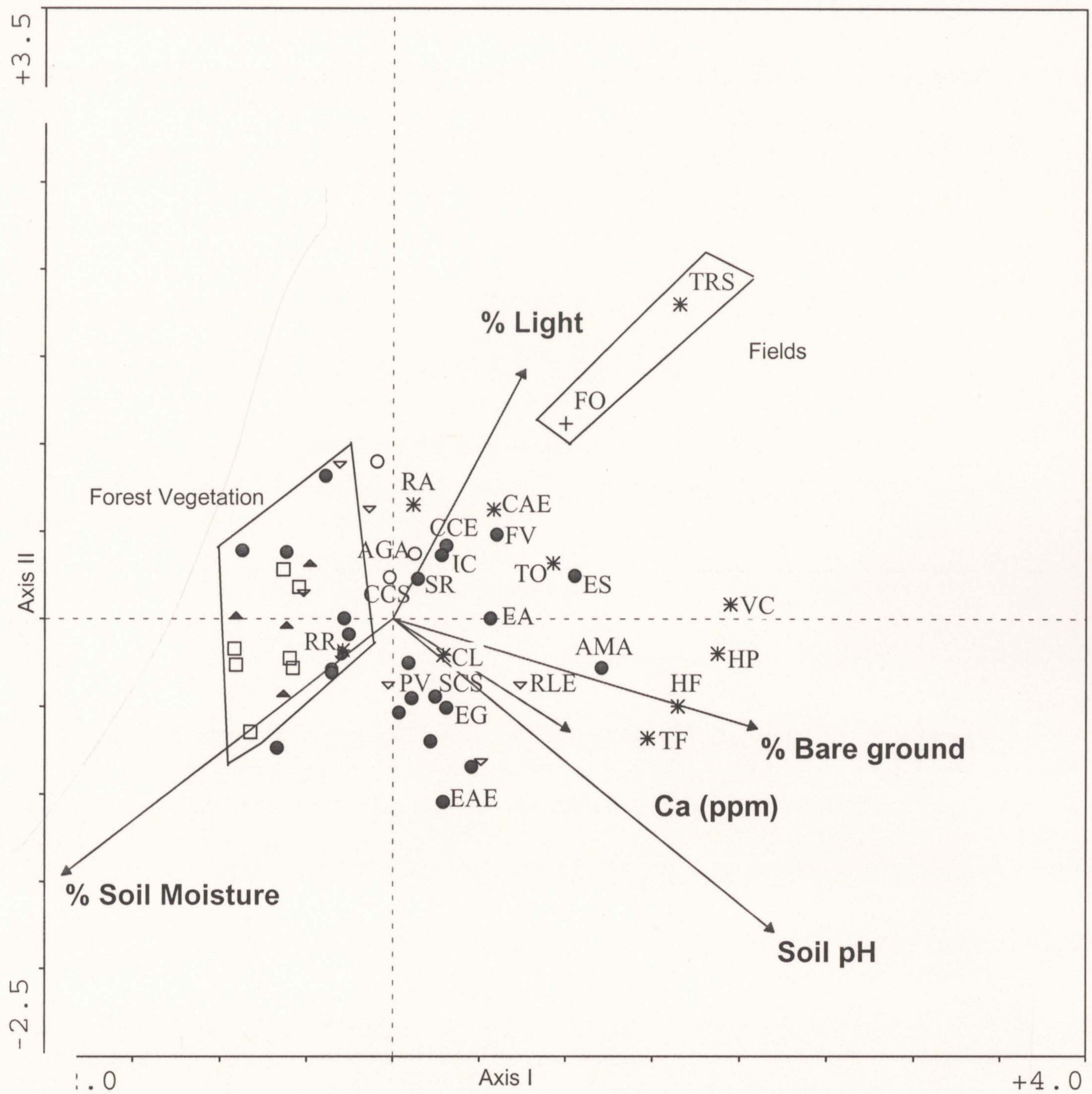


Fig. 28: CCA Ordination Diagram of the Relationship of Species with Significant Environmental Variables in Areas Containing Alien Species in GMNP (Species Acronyms are listed in Appendix 6)

Notes: Samples included in analysis were those which contained at least one alien species. Almost all samples are from disturbed areas.

Disturbance regime of samples: High = 24, Medium = 21, Low = 26, Undisturbed = 3

Legend: ✳ = Alien Forb + = Alien Grass ● = Native Forb ○ = Native Grass □ = Bryophytes ▲ = Evergreen Trees / Shrubs ∇ = Deciduous Trees / Shrubs common to all anthropogenic disturbances, such as *Cirsium arvense* (CAE), *Taraxacum officinale* (TO), *Vicia cracca* (VC), *Hieracium floribundum* (HF), *Hieracium pratense* (HP), and *Ranunculus acris* (RA), were associated with high light, bare ground, soil pH, and calcium, but did not strongly favour any particular one of these environmental parameters. *Ranunculus repens* (RR) differed from all other alien species because it was associated with high soil moisture and relatively low levels of light availability and bare ground (Figure 28). *Ranunculus repens* had associations with environmental parameters that were more similar to native forest species than other alien species.

Native species showing similar environmental preferences to alien species included *Anaphalis margaritacea* (AMA), *Solidago rugosa* (SR), *Fragaria virginiana* (FV), *Epilobium angustifolium* (EA), *Prunella vulgaris* (PV), *Sanguisorba canadensis* (SCS), *Impatiens capensis* (IC), *Equisetum sylvaticum* (ES), *E. arvense* (EAE), *Calamagrostis canadensis* (CCS), *Agrostis geminata* (AGA), and *Ribes lacustre* (RLE) (Figure 28).

(B) Correlation of Parameters

Only those environmental variables that explained statistically significant variation in species-environment relationships were included in CCA models. Some environmental variables were highly correlated with one another, and variables that did not explain any additional variance in the CCA models were excluded. Spearman's correlation coefficients are important because they indicate relationships between variables which may not be obvious in CCA models.

Bare ground, % alien species, light availability, gravel, and soil pH were positively correlated with one another, while duff depth, soil moisture, organic content, non-vascular species, and vegetative cover were positively correlated with each other (Table 10). The two suites of variables (exception light) were negatively correlated with each other. Light availability correlated negatively with duff depth, total vegetative cover, and non-vascular species, and positively with bare ground, and gravel (Table 10).

All of the nutrients (N, P, K, Ca, Mg) were positively correlated with the exception of P and Ca, which were not correlated. All nutrients except calcium were positively correlated to organic content (Table 10). Nitrogen was negatively correlated to gravel and alien species. Calcium was the only nutrient to show a positive correlation to alien species. Soil pH had high positive correlations with calcium and magnesium and was negatively correlated to nitrogen, and phosphorus (Table 10). Non-vascular species were negatively correlated to nitrogen, calcium, and magnesium. Soil moisture was positively correlated to magnesium and nitrogen.

In forest vegetation alien species showed fewer associations to physical and biological characteristics than across all sites (Table 11). Alien species were negatively correlated to duff depth and non-vascular species and positively correlated to soil pH, light and bare ground (Table 11). In forest study sites, nutrients (N, P, K, Ca, Mg) were positively correlated with each other and with soil moisture (Table 11). Organic content was positively correlated to nitrogen, phosphorus, and potassium, but not correlated to magnesium and calcium.

Table 10: Spearman's Correlation Matrix of Physical and Biological Parameters Sampled Over All Study Sites in GMNP

(Bold and Italic numbers indicate that correlation coeffecients are significant at $\alpha = 0.05$.)

Characteristic	Duff Depth (cm)	% Gravel Weight	% Soil Moisture	% Organic Content	Soil pH	% N	P (ppm)	K (ppm)	Ca (ppm)	Mg (ppm)	% Light	% BG	% TVC	%NVS
Duff Depth (cm)														
% Gravel Weight	***-0.331***													
% Soil Moisture	***0.357***	***-0.394***												
% Organic Content	***0.478***	***-0.475***	***0.675***											
Soil pH	***-0.379***	***0.176***	***-0.178***	***-0.392***										
% N	-0.021	***-0.166***	***0.389***	***0.367***	***-0.168***									
P (ppm)	-0.069	-0.081	0.12	***0.304***	***-0.19***	***0.232***								
K (ppm)	-0.111	0.052	0.14	***0.218***	-0.105	***0.46***	***0.328***							
Ca (ppm)	***-0.179***	-0.056	0.101	-0.018	***0.732***	***0.182***	0.033	***0.245***						
Mg (ppm)	-0.045	-0.081	***0.277***	***0.148***	***0.386***	***0.372***	***0.21***	***0.495***	***0.725***					
% Light	***-0.248***	***0.225***	-0.064	-0.091	0.095	0.014	0.097	-0.026	-0.003	-0.048				
% BG	***-0.479***	***0.334***	***-0.234***	***-0.297***	***0.216***	0.002	-0.045	-0.052	0.021	-0.113	***0.18***			
% TVC	***0.351***	***-0.288***	***0.212***	***0.278***	***-0.161***	0.013	-0.011	0.009	-0.049	0.034	***-0.156***	***-0.765***		
% NVS	***0.282***	***-0.243***	***0.194***	***0.224***	***-0.358***	***-0.166***	0.037	-0.051	***-0.263***	***-0.16***	***-0.321***	***-0.318***	***0.271***	
%AS	***-0.296***	***0.189***	***-0.207***	***-0.294***	***0.5***	***-0.156***	0.047	-0.007	***0.329***	0.11	***0.143***	***0.217***	***-0.117***	***-0.392***

Sample Size (N)

Characteristic	Duff Depth (cm)	% Gravel Weight	% Soil Moisture	% Organic Content	Soil pH	% N	P (ppm)	K (ppm)	Ca (ppm)	Mg (ppm)	% Light	% BG	% TVC	%NVS
Duff Depth (cm)	180													
% Gravel Weight	151	199												
% Soil Moisture	151	186	198											
% Organic Content	143	170	168	180										
Soil pH	161	182	179	182	206									
% N	161	180	177	181	204	204								
P (ppm)	161	181	178	182	205	204	205							
K (ppm)	161	181	178	182	205	204	205	205						
Ca (ppm)	161	181	178	182	205	204	205	205	205					
Mg (ppm)	161	181	178	182	205	204	205	205	205	205				
% Light	175	194	192	194	201	199	200	200	200	200	437			
% BG	180	199	198	200	206	204	205	205	205	205	437	475		
% TVC	180	199	198	200	206	204	205	205	205	205	437	475	475	
% NVS	180	199	198	200	206	204	205	205	205	205	437	475	475	475
%AS	180	199	198	200	206	204	205	205	205	205	437	475	475	475

List of Abbreviations				
N = Nitrogen	K = Potassium	Mg = Magnesium	% Light = % Light availability	% TVC = % Total vegetative cover
P = Phosphorus	Ca = Calcium	% BG = % Bareground	% AS = % Alien species	% NVS = % Non-vascular species

Table 11: Spearman's Correlation Matrix of Physical and Biological Parameters Sampled from Remote Forest Study Sites within GMNP
(Bold and Italic numbers indicate that correlation coeffecients are significant at α = 0.05.)

Characteristic	Duff Depth (cm)	% Gravel Weight	% Soil Moisture	% Organic Content	Soil pH	% N	P (ppm)	K (ppm)	Ca (ppm)	Mg (ppm)	% Light	% BG	% TVC	%NVS
Duff Depth (cm)														
% Gravel Weight	***0.054***													
% Soil Moisture	***0.271***	-0.139												
% Organic Content	***0.260***	-0.223	***0.644***											
Soil pH	-0.153	-0.177	0.129	***-0.238***										
% N	-0.055	-0.208	***0.314***	***0.381***	0.072									
P (ppm)	-0.072	***-0.233***	***0.470***	***0.502***	-0.132	***0.411***								
K (ppm)	***-0.250***	***-0.246***	***0.416***	***0.380***	-0.059	***0.565***	***0.615***							
Ca (ppm)	-0.016	-0.222	***0.522***	0.181	***0.655***	***0.378***	***0.388***	***0.420***						
Mg (ppm)	-0.021	-0.127	***0.498***	0.185	***0.414***	***0.416***	***0.580***	***0.632***	***0.804***					
% Light	0.014	0.054	0.148	0.064	0.030	0.086	0.040	-0.046	0.025	-0.054				
% BG	*-0.349*	0.019	-0.102	0.036	0.001	0.090	0.044	-0.049	-0.037	-0.066	-0.056			
% TVC	0.193	-0.112	0.056	-0.040	0.023	0.000	-0.056	0.141	0.015	0.032	-0.014	***-0.646***		
% NVS	-0.152	-0.103	0.050	0.028	-0.200	***-0.247***	-0.038	-0.084	-0.206	-0.119	***-0.252***	***-0.220***	***0.172***	
%AS	***-0.288***	0.092	-0.161	-0.175	***0.337***	0.133	-0.032	-0.048	0.183	0.063	***0.157***	***0.312***	-0.113	***-0.469***

Sample Size (N)

Duff Depth (cm)	77													
% Gravel Weight	67	79												
% Soil Moisture	66	74	78											
% Organic Content	69	74	75	80										
Soil pH	73	74	74	77	85									
% N	73	73	73	77	84	84								
P (ppm)	73	73	73	77	84	84	84							
K (ppm)	73	73	73	77	84	84	84	84						
Ca (ppm)	73	73	73	77	84	84	84	84	84					
Mg (ppm)	73	73	73	77	84	84	84	84	84	84				
% Light	74	75	74	76	81	80	80	80	80	80	184			
% BG	77	79	78	80	85	84	84	84	84	84	184	203		
% TVC	77	79	78	80	85	84	84	84	84	84	184	203	203	
% NVS	77	79	78	80	85	84	84	84	84	84	184	203	203	203
%AS	77	79	78	80	85	84	84	84	84	84	184	203	203	203

List of Abbreviations				
N = Nitrogen	K = Potassium	Mg = Magnesium	% Light = % Light availability	% TVC = % Total vegetative cover
P = Phosphorus	Ca = Calcium	% BG = % Bareground	% AS = % Alien species	% NVS = % Non-vascular species

In forests soil pH showed positive correlations to calcium, magnesium, and alien species, but did not show correlations with any other biotic or abiotic parameters (Table 11). Non-vascular species were positively correlated to total vegetative cover and negatively correlated to nitrogen, light, and bare ground. Organic content, soil moisture, and duff depth showed positive correlations with one another in forests.

4.3.3 - Relationship Between Functional Characteristics and Invasion Success

The association between alien plant functional characteristics and invasion success was examined using. Definition of functional attributes used in analysis are given in Appendix 5.

The first axis explained 58.2 % of the species (success ranking) - environment (functional characteristics) variation, while the second axis explained 42.8 % of the variation. Both the first axis ($F = 9.163$, $P = 0.005$) and all axes together ($F = 9.027$, $P = 0.005$) were found to be statistically significant with a Monte Carlo permutation test. The only functional characteristics that contributed significantly to species success were the interaction between vegetative reproduction and dispersal of asexually produced propagules (vegetative reproduction*dispersal of asexually produced propagules), and seed weight. Vegetative reproduction*dispersal of asexually produced propagules was correlated with species axis 1 ($r = 0.4817$), while seed weight was correlated with species axis 2 ($r = 0.4433$).

Alien species classified as successful invaders had vegetative reproduction*dispersal of asexually produced propagules and had a strong positive correlation with axis 1 (Figure 29 A), with the exception of *Taraxacum officinale* (TO) and *Digitalis purpurea* (DP) (Figure 29 B).

Successful invaders were separated along axis 2 by seed weight (Figure 29 B). Successful invaders with small seeds, such as *Lythrum salicaria* (LS), *Tussilago farfara*

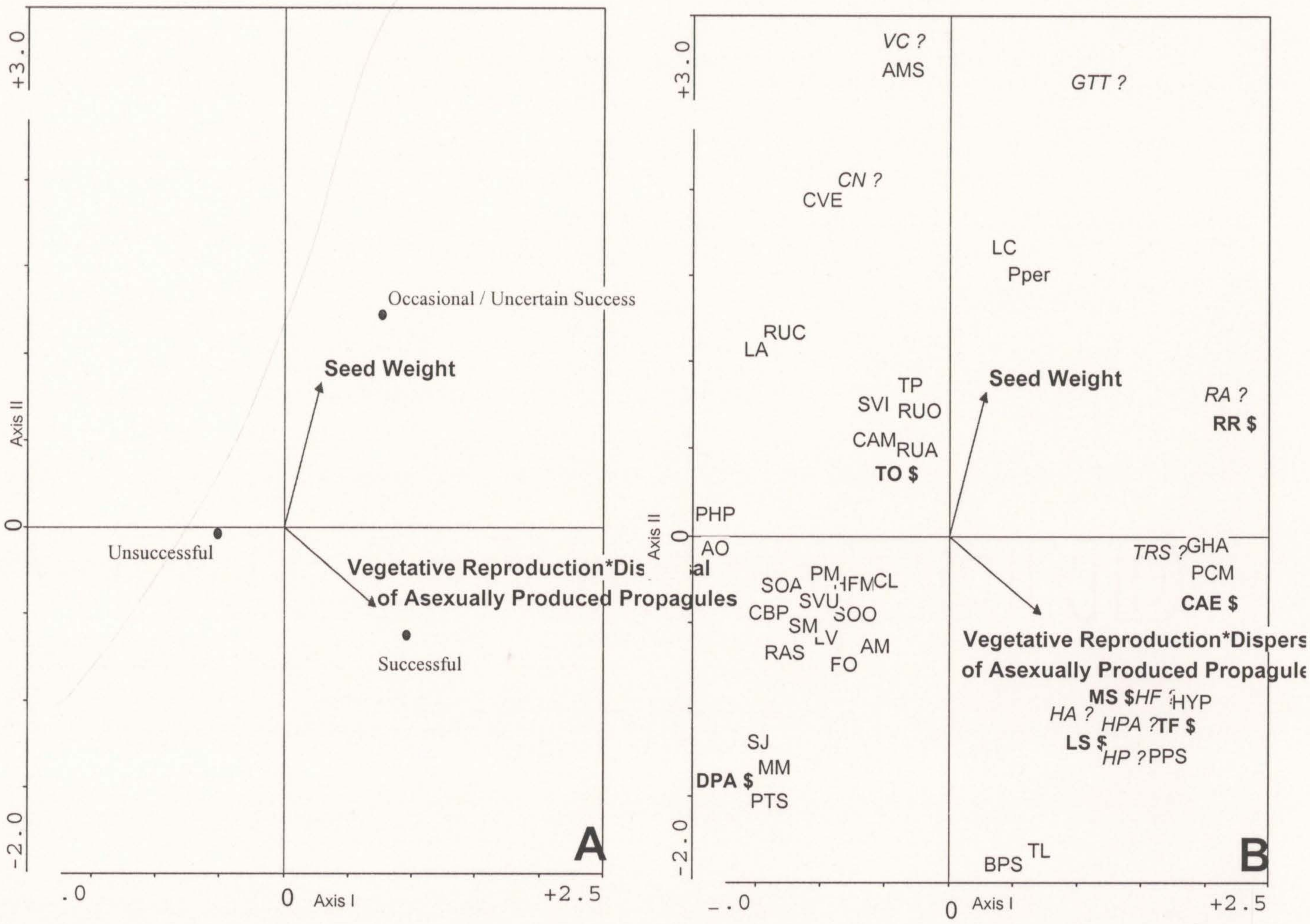


Figure 29: CCA Ordination Diagram of the Relationship Between Functional Characteristics of Alien Species to Invasion Success in GMNP (Species acronyms are listed in Appendix 6)

A - Functional characteristics in relation to invasion success.

B - Functional characteristics in relation to individual species.

Note: For an alien species to be included in the analysis it had to have occurred in disturbed areas of high anthropogenic activity throughout GMNP.

Legend: **Bold and $** = Successful Invader: Any alien species which was found to occur in disturbances remote from high anthropogenic activity such as clear cuts, insect outbreaks, riparian areas, and moose trails.
Italic and ? = Occasional Invader: Any alien species which was found to occur in a disturbance remote from high anthropogenic activity on 1 or two occasions. The potential of these species as invaders in GMNP is uncertain.
No symbol = Unsuccessful Invader: Any species which was found to occur only in disturbed areas of high anthropogenic activity.

(TF), *Hieracium* spp. (HPA, HA, HP, HF), and *Myosotis scorpiodes* (MS), occurred on the negative side of axis 2. Successful medium-size seed invaders, such as *Cirsium arvense* (CAE) and *Taraxacum officinale* (TO), occurred near the origin of axis 2 (Figure 29 B). *Ranunculus repens* (RR) was the only successful invader to have large seeds, while *Digitalis purpurea* was the only successful invader to have very small seeds (Figure 29 B).

Species classified as unsuccessful invaders of natural areas were negatively correlated to axes 1 and 2 (Figure 29 A). Generally, these species did not have vegetative reproduction*dispersal of asexually produced propagules (Figure 29 A). A large number of unsuccessful species were self-fertilizing, but did not have vegetative reproduction. The majority of unsuccessful species were also characterized by very small or small seeds (Figure 29 B).

Species classified as occasional / uncertain invaders occurred on both sides of axis 1, but showed positive correlations to axis 2 (Figure 29 B). *Galeopsis tetrahit* (GTT) and *Vicia cracca* (VC) had very large seeds. With the exception of *Hieracium* spp., other occasional / uncertain invaders had large or medium seed weights.

4.4 - Discussion

Although other studies have found alien plants in areas of high human activity, this is the first published research to examine factors which influence invasion into natural areas of boreal ecosystems. This study indicates that boreal ecosystems are susceptible to invasion by alien plant species provided disturbance and environmental conditions are suitable.

4.4.1 - Importance of Disturbance to Alien Plant Invasion in Boreal Ecosystems

The results of this study indicate that disturbance is a pre-requisite for alien plant establishment in boreal ecosystems, supporting studies from other ecosystems which have also found disturbance necessary for alien plants (Fox and Fox 1986; Carson and Pickett 1990; Burke and Grime 1996; Schwartz 1997; Stohlgren et al. 1999a). The relationship of disturbance regime to physical parameters (light, soil moisture, organic content, bare ground, soil pH) shows that disturbance is associated with changes in resource availability in boreal ecosystems. Alien species were correlated with changes in environmental parameters supporting studies from other ecosystems which found disturbance contributes to alien plant invasion by increasing resource availability (Bazazz 1983; Brothers and Spingarn 1992; Burke and Grime 1996; Hutchinson and Vankat 1997).

4.4.2 - Community Structure in Relation to Disturbance

Disturbance is a continuous and fundamental process in boreal ecosystems (Elliot-Fisk 2000), therefore it is not surprising that many native species were also found across a variety of disturbance regimes. Native species specialized to colonize ongoing natural disturbances in boreal ecosystems such as insect outbreaks and river channels evolved to fill niches caused by disturbance long before the introduction of alien plants. Although native species were commonly found in disturbed areas, the impact of alien species on native species adapted to fill a similar ecological role is unknown and requires further examination. As mentioned in the previous chapter, there is also a potential for alien plant species to disrupt disturbance regimes, change litter quality, alter resource availability, influence soil properties, displace fauna, and introduce diseases or parasites to the area (Thompson et al. 1987; Vitousek 1990; D'Antonio and Vitousek 1992; Kourtev et al. 1998; Mack and D'Antonio 1998).

Conversely, native species adapted to colonize disturbed areas may act to reduce alien plant invasion in natural disturbances. Native species, such as *Anaphalis margaritacea*, *Solidago rugosa*, *Potentilla anserina*, *Fragaria virginiana*, and *Epilobium angustifolium,* were associated with disturbed areas and showed correlations to environmental parameters that were similar to many alien plant species. These native species are most likely competing with alien species for space and resources in disturbed areas.

High disturbance areas of boreal ecosystems had the highest percentage of alien species relative to native species, supporting the idea that alien species are best adapted to colonizing disturbed areas by having high seed production, fast growth rates, and life forms resistant to disturbance (Baker 1965).

The high diversity of species in medium disturbance regimes supported the intermediate disturbance hypothesis (Connell 1978). In GMNP, areas of medium disturbance regime generally had conditions of light availability, bare ground, soil moisture, and soil pH which were between the conditions characteristic of high and undisturbed disturbance regimes, allowing a variety of species to co-exist in these areas.

Plant communities in undisturbed areas of boreal ecosystems of GMNP did not contain alien species. Many of the native species in undisturbed areas were mosses and evergreen species because organic rich soils with low soil pH and nutrient availability, and closed canopies which limit light availability in these areas require slow growing, conservative, and efficient life strategies (Rorison 1987; Shugart et al. 1992). Alien plant strategies of fast opportunistic growth are excluded from undisturbed areas of boreal ecosystems because these life strategies are ineffective in areas where resource availability is low (Grime 1979; Bazazz 1983).

4.4.3 - Relationship of Vegetation Type to Alien Plant Invasion

Although areas of high anthropogenic disturbance contained the majority of alien species, invasion of areas remote from human activity are of greatest concern to park managers because alien species may displace native species or alter ecosystem properties in these areas.

In other areas vegetation types are not equally susceptible to alien plant invasion (Harrison 1999; Stohlgren et al. 1999b; Larson et al. 2001), and this appears to be the case in boreal ecosystems. Riparian areas, forests, alpine meadows, and fens were the only vegetation types found in GMNP in which alien plants could become established. Resources necessary for alien plants were supplied by disturbance or were not limiting in these vegetation types.

This study agrees with a large body of research that has demonstrated alien plant invasion in riparian zones (Pysek and Prach 1993; Planty-Tabacchi et al. 1996; Stohlgren et al. 1998; Larson et al. 2001). Light availability, bare ground, and soil pH were important for alien plants in riparian zones. Ongoing natural disturbances due to river channels, ice scour, and flooding ensure that riparian areas have suitable light availability, soil pH, and bare ground for alien plants. Riparian zones are widespread throughout GMNP which allows these areas to act as corridors for the spread of alien plants (Pysek and Prach 1993; Planty-Tabacchi et al. 1996), and act as source populations for the spread of alien species to the other favourable sites (Stohlgren et al. 1998).

Low levels of light availability, bare ground, and soil pH limited alien plant invasion in forest vegetation types. Disturbance of the tree canopy by clear cuts, wind falls, insect outbreaks, and trails increased light availability for alien plant invasion supporting other studies on alien plant invasion in forests (Brothers and Spingarn 1992; Hutchinson and Vankat 1997). Although light was correlated with the presence of alien plants in forests, unexpectedly it was not correlated to any other physical parameters. Increased light availability was expected to increase bare ground and soil pH by increasing soil temperature on the forest floor (Vitousek 1985; Bonan 1992). Light availability was negatively correlated to non-vascular species in forests, indicating it may have contributed to invasion by decreasing competition from moss species.

Available bare ground differed significantly between disturbed and undisturbed areas in remote forest vegetation, and was correlated with the presence of alien species. Disturbance by moose trampling exposed bare ground in forests throughout GMNP and was the primary mechanism creating suitable patches of bare ground for alien species. Areas disturbed by clear cuts and insect outbreaks were re-vegetated with species palatable to moose such as birch and balsam fir seedlings, concentrating moose in these areas and further increasing disturbance by trampling. Browsing by moose in disturbed areas is also significant because it slowed regeneration of these areas after disturbance, allowing them to remain susceptible to alien plant invasion for longer time periods.

Although soil pH was associated with alien plants in remote forest vegetation, soil pH did not differ across disturbance regimes and was not correlated with other physical parameters that changed with disturbance. These results indicate disturbance in forest vegetation did not initiate changes in soil pH, implying that soil pH conditions needed for alien plant invasion are pre-determined by bedrock geology, soil organic content or other factors. Limestone (represented by calcium) was correlated to soil pH and was found to explain variance in species-environment relationships within remote forest disturbances, indicating that the presence of limestone bedrock determined suitable soil pH conditions in forest vegetation.

Fens and alpine meadows were vegetation types with small areas in GMNP, and a sufficient amount of study site data was not collected to statistically determine environmental parameters which allowed invasion in these areas. Alien plants are not limited by light availability in these vegetation types, but soil pH and bare ground appeared to limit invasion. In fen vegetation types alien plants were found in areas of high soil pH (soil samples collected at one site had pH = 7.0) and where the ground was disturbed by moose or a hiking trails. Alpine meadow vegetation was found in only two locations within GMNP, and these areas coincided with south- facing slopes and limestone bedrock. Warmer soil temperatures due to aspect, slopes with better drainage and less accumulation of organic matter, and calcium-carbonate rich bedrock geology are thought to contribute to soil pH favourable for alien plant invasion of alpine meadows. Bare ground also appeared important for invasion in alpine meadows; alien plants were found predominantly along moose trails and eroding gravel outcrops where open ground was exposed. These results support studies on alien plants in other open canopy vegetation types such as grasslands, which found soil nutrient characteristics and disturbance were important for alien plant invasion (Harrison 1999; Stohlgren et al. 1998; 1999b; Larson et al. 2001).

This study indicates that soil pH is the most significant parameter related to alien plants invasion in natural areas of GMNP. While bare ground and light are continually being made available by natural disturbance in boreal ecosystems, no evidence from natural areas suggested soil pH changed as a result of disturbance. Natural areas susceptible to alien invasion appear to be pre-determined by soil pH. These results are beneficial to park managers because they imply that alien plant monitoring efforts in natural areas should focus on disturbed areas which overlap with areas of favourable soil pH such as limestone bedrock.

The distribution of many rare plant species in GMNP coincide with limestone bedrock (Brouillet et al. 1996) indicating that areas favourable for rare plants may also be favourable for alien plants. The impact of alien plants on rare plant species, such as *Cypripedium calceolus*, *Coeloglossum viride*, *Arnica griscomiii*, *Arabis drummondii*, and *Valeriana dioica* ssp. *sylvatica,* in these areas is unknown and should be evaluated further.

Although soil pH did not change as a result of disturbance in natural areas, this study and other studies have found that soil pH in anthropogenic disturbances such as roads and trails increases due to the addition of limestone gravel during road and trail construction (Hendrickson 2000). Park managers should avoid addition of foreign soils to natural areas as the increased soil pH in some of these substrates will be favourable to alien plants. Foreign soils has also been found to facilitate the spread of alien plant reproductive propagules, and its introduction should also be avoided for this reason ((Tyser and Worley 1992; Hendrickson 2000).

4.4.4 - Creeping Buttercup (*Ranunculus repens*)

Ranunculus repens (Creeping Buttercup) was widespread in areas of high anthropogenic activity and was the most common alien species in natural areas. *Ranunculus repens* differed from other alien plants because it was not associated with light availability, but was associated with moderate amounts of soil moisture. Although

Ranunculus repens had moderate associations to bare ground and soil moisture, it could tolerate lower bare ground and higher soil moisture than other alien species. Soil pH appeared to be the most limiting parameter influencing the distribution of creeping buttercup. *Ranunculus repens* generally occurred in soils with pH values between 5 and 7 (average soil pH = 5.5, maximum soil pH = 7.4, minimum soil pH = 4), and consistent with Grime et al. (1988) was virtually absent from soils with pH lower than 4.5.

The wide ecological amplitude of *Ranunculus repens* explains its presence in a diversity of vegetation and disturbance types in GMNP. The present success of *Ranunculus repens* and its tolerance of boreal conditions means that this species may become more widespread within GMNP in the future.

4.4.5 - Functional Characteristics Related to Invasion Success

Although many of the alien species examined had functional characteristics of vegetative reproduction or dispersal of asexually produced propagules, the majority of species did not exhibit both characteristics. Many of the species that did exhibit both of these characteristics were successful invaders of natural areas.

Wiser et al. (1998) suggested that dispersal and establishment are the two important stages that limit invasion of natural areas. The most important factor influencing the initial stages of invasion of any area is dispersal limitation of propagules (Kruger et al. 1986; Hobbs 1989; Wiser et al. 1998; Kolar and Lodge 2001). Therefore, it is not surprising that dispersal of asexually produced propagules was found to be important in invasion success. Apomixis, self fertilization, and vegetative fragmentation provide several advantages to invading species. First, they increase the size of the effective breeding population by allowing one individual to give rise to a new population (Ehrendorfer 1965; Barrett and Richardson 1986). Second, asexual reproduction allows the fixation and multiplication of successful genotypes in an area (Barrett and Richardson 1986), allowing a large population to be built up in area while an open habitat exists (Baker 1965). Moose appear to be the primary mechanism that disperse asexual propagules in GMNP. Alien plants were regularly observed along moose trails, and it is suspected that moose are transporting propagules on hair and hooves, and in feces. Although no information was obtained in regards to wind and water dispersal in GMNP, this means of dispersal is most likely important in some areas.

Once an alien plant successfully colonizes an area, establishment of the species is limited by factors such as competition or site conditions (Wiser et al. 1998; Larson et al. 2001). Vegetative growth and a perennial lifestyle are important during establishment in boreal ecosystems because they allow alien species to spread and compete for limited space and resources in dense native vegetation (McIntyre et al. 1995; Pysek et al. 1995, Rejmanek 1996). A recent review of studies on functional characteristics important to invasion success by Kolar and Lodge (2001) found plant invasiveness increases if a plant reproduces vegetatively.

Digitalis purpurea and *Taraxacum officinale* were exceptions to the above functional strategies. *Taraxacum officinale* was different from other successful species because it did not have frequent vegetative reproduction, but this species does have the ability to compete for space in natural areas by being a perennial with a large tap root and a basal rosette of leaves (Grime et al. 1988). *Digitalis purpurea* exhibits frequent self fertilization, but differs from other successful invaders because it lacks frequent vegetative reproduction. The ability of *Digitalis purpurea* to grow in areas of acidic soil (Baker 1986; Grime et al. 1988) may explain its success in some areas of GMNP. The invasion success of *Digitalis purpurea* may also be attributed to the fact it can produce many (> 70 000) wind dispersed seeds which can persist in the seed bank for long periods of time (Grime et al. 1988).

Burke and Grime (1996) found large seeds show better persistence in dense vegetation and unfavourable conditions compared to small seeds. Although seed size does not guarantee establishment in dense vegetation (Burke and Grime 1996), it may explain why some large seeded species were occasionally found in natural areas. Large seeded species have large seed reserves and often have inherently slower growth rates which allow seedlings to tolerate periods of intense competition from established vegetation through more conservative use of resources (Burke and Grime 1996). The fact several occasional / questionable invaders had small or medium sized seeds indicates that seed size is not the only factor that may contribute to occasional invasion success in these species.

Numerous studies have examined which functional characteristics contribute to the distribution of alien plants (McIntyre et al.1995; Pysek et al. 1995; Burke and Grime 1996; Rejmanek and Richardson 1996; Goodwin et al. 1999), but these rarely focused on invasion success in natural areas. Anthropogenic disturbances such as roads, pastures, and pits are well known habitats of alien plants (Tyser and Worley 1992; Brandt and Rickard 1994; Tsuyuzaki and Kanda 1996), and studies on invasion success of these areas are of limited value to managers of nature reserves. The results of functional group analysis are useful to park managers because they indicate which kinds of species are most likely to invade natural areas of GMNP in the future. Species present in GMNP that are not invading natural areas at present but have functional characteristics that may allow them to invade natural areas in the future include *Hieracium* spp., *Ranunculus acris*, *Trifolium repens*, *Hypericum perforatum*, *Polygonum cuspidatum*, *Glechoma hederacea*, and *Bellis perennis*. Even if a species has functional characteristics that favour invasion of natural areas, successful species must also be adapted to tolerate the restrictive environmental parameters of boreal ecosystems.

4.4.6 - Conclusions

Disturbance created habitat openings and was associated with changes in physical parameters (light, soil pH, soil moisture, bare ground, calcium) that allowed alien plant invasion to occur in Gros Morne National Park. Areas of intermediate disturbance contained the greatest richness of alien species, while high disturbance regimes contained the greatest percentage of alien species relative to native species. Alien species were not associated with particular disturbance regimes because they have adaptations which allow them to colonize and persist in a wide range of disturbances and / or because disturbance regimes overlap in the conditions they produce.

Although undisturbed areas of GMNP were not invaded by alien species, the ability for alien species to successfully establish themselves in natural disturbances remote from anthropogenic activity in GMNP is a concern because they may disrupt ecosystem properties or replace native species in these areas. Alpine meadows, fens, forests, and riparian areas are susceptible to invasion in GMNP because disturbance of these vegetation types was associated with increased availability of resources which limit alien plants. Although disturbance was associated with change in soil pH in anthropogenic disturbances, disturbance was not found to increase soil pH in natural areas of GMNP indicating that other factors such as the distribution of limestone bedrock and organic content of the soil influence alien plant invasion of natural areas.

Functional characteristics associated with alien plants successful at colonizing disturbances remote from anthropogenic activity include dispersal of asexually produced propagules, which allow alien plants to colonize remote disturbances in GMNP, and vegetative reproduction, which allows plants to compete for resources in areas where resource availability and space is limited.

Although several alien species were found in natural areas of GMNP, *Ranunculus repens* is the alien species of most concern in GMNP because it can tolerate a wide range of environmental conditions and grow in a wide range of disturbance types.

Chapter 5 - Conclusions

5.1 - Summary: Relating the Stages of Alien Invasion to GMNP

Alien plants were not predicted to invade disturbed areas remote from anthropogenic activity in Gros Morne National Park because environmental conditions associated with these areas were considered unfavourable for the establishment and growth of alien plants. This study found that alien plants can colonize and grow in disturbed areas remote from human activity in GMNP.

5.1.1 - Dispersal

Highly disturbed areas close to human activity such as roads and settlements contained the highest diversity and number of alien plants, and these areas act as sources from which alien plants could be dispersed to areas remote from anthropogenic activity. Evidence of slow recovery of these areas after disturbance such as abandoned settlements, indicate these areas can act as sources of alien plant propagules for long time periods.

Moose and hiking trails, and river channels appeared to be the primary conduits allowing alien plants to be dispersed to natural areas of the park. These areas act as corridors of disturbance which alien plants could gradually spread along. In particular, moose dispersal of plant propagules on hair and hooves, and in feces is suspected to be the most common mechanism of dispersal to natural areas of GMNP.

5.1.2 - Establishment

Vegetation types in which alien plants could become established included forests, riparian areas, fens, and alpine meadows. Environmental conditions associated with establishment of alien plants in these areas were high levels of light, bare ground, calcium, and soil pH. The environmental conditions necessary for establishment of alien plants in these areas were dependent on disturbance regime and site characteristics. Disturbance was found to be associated with increased bare ground and light, with the exception of alpine meadows and fens where light was not limiting. However, site characteristics were also important because disturbances in areas remote from human activity were not associated with significant changes in soil pH, indicating that alien plant establishment also depends on site characteristics which favour high soil pH such as the presence of limestone bedrock or low soil organic content. The importance of soil pH to alien plants is supported by the fact that the distribution of alien plants in remote areas of GMNP coincided with that of limestone bedrock.

The majority of alien plants present in GMNP were not found to become established in areas remote from anthropogenic activity. Species able to successfully establish themselves in areas remote from human activity differed from species which were unsuccessful in these areas, by having both vegetative reproduction and dispersal of asexually produced propagules. When an individual is successfully dispersed into an area, these attributes permit a species to become established by allowing them to reproduce without a mate, spread quickly, and compete for space. The fact many species found in GMNP with these attributes could not become established in remote areas indicates that even if species have these attributes, they still must be able to tolerate the ecological conditions associated with boreal ecosystems.

5.1.3 - Persistence and Expansion

Alien plants will continue to persist in natural areas of GMNP because ongoing natural disturbances characteristic of boreal ecosystems will continue to provide resources and space for alien plants which are being dispersed from areas of high human activity.

Besides dispersing alien species, moose also contribute to the establishment, and persistence of alien species in GMNP by creating or prolonging disturbance in GMNP through browsing of *Abies balsamea* and deciduous growth, and by trampling the ground.

The persistence of large patches of alien plants in disturbed areas such as stream beds, moose trails, and clear cuts is evidence that alien plant species can spread and expand once they become established at a site. No published research exists on the impacts of alien plant species on native species, disturbance regimes, resource availability, and tropic levels in boreal ecosystems, and more explicit study is required.

5.2 - Species of Concern

Alien species in GMNP which are invading natural areas at present include *Ranunculus repens*, *Cirsium arvense*, *Tussilago farfara*, *Digitalis purpurea*, *Lythrum salicaria*, *Hieracium* spp., *Myosotis scorpioides*, and *Taraxacum officinale*. Alien species of natural areas which commonly form dense mono-specific patches such as *Ranunculus repens*, *Cirsium arvense*, *Tussilago farfara*, and *Lythrum salicaria* are of greatest concern because they can more readily displace native species and persist.

Ranunculus repens is the most problematic alien species occurring in GMNP.

Ranunculus repens was widespread throughout the park and found in all anthropogenic and natural disturbance types occurring in GMNP. All vegetation types which were susceptible to invasion contained *Ranunculus repens*. The widespread success of *R. repens* can be attributed to the fact that it can tolerate environmental conditions intermediate between forest vegetation and common anthropogenic vegetation. *Ranunculus repens* prefers wet or waterlogged soils (Lovett-Doust et al. 1990), and relative to other alien species can grow in a wide range of light conditions (Lovett-Doust 1987). *Ranunculus repens* is distributed in wide ranging levels of bare ground, but prefers higher amounts of exposed soil (Grime et al. 1988). Sexual (seeds) and asexual (vegetative fragments) propagules allow *R. repens* to be effectively dispersed throughout GMNP, and vegetative reproduction (clonal expansion) allows it to be an effective competitor once it colonizes a site (Grime et al. 1988, Lovett-Doust et al. 1990). Large seeds with long dormancy and viability (maximum recorded longevity of at least 45 years) allow *Ranunculus repens* to remain in the seed bank and germinate when conditions are favourable for growth to occur (Lovett-Doust et al. 1990; Thompson et al. 1997). As mentioned in Chapter 4 soil pH was most limiting to the distribution of *R. repens* in GMNP.

Tussilago farfara was the most common alien species along road shoulders, where it formed dense colonies. The natural areas most threatened by *Tussilago farfara* were fens and streams, where it was found in high numbers. *Tussilago farfara* was also found in open canopy areas of disturbed forests. In other areas, *T. farfara* has been found to have environmental preferences comparable to *Ranunculus repens* (Grime et al. 1988), but in GMNP was primarily restricted to areas of high soil pH, calcium, % bare ground, and light availability (Hendrickson 2000). *Tussilago farfara* can be dispersed to natural areas by seed or vegetative fragments, and once in an area can reach high abundances through extensive rhizomatous growth or by sexual or asexual production of large numbers of wind dispersed seeds (Grime et al. 1988; Hendrickson 2000).

Lythrum salicaria is thought to be a significant invasive plant of North American wetlands (Edwards et al. 1995; Thompson et al. 1987), but recently its negative impact in some areas has been questioned (Treberg and Husband 1999). Although there is uncertainty as to the invasiveness of this species in GMNP, its presence in several areas should be a concern to park managers. *Lythrum salicaria* has the ability to spread from vegetative fragments and abundantly produced seeds and, once established is a good competitor (Thompson et al. 1987). The presence of *L. salicaria* in close proximity to the rare plant *Cypripedium reginae* near Lomond may threaten the latter species.

Cirsium arvense is generally found to be a problematic species of agricultural areas, and due to high light requirements, is not generally considered a threat to forest areas (Haber 1997). This does not appear to be the case in GMNP where dense mono-specific stands of *C. arvense* were found in open canopy insect outbreaks and clear cuts. *Cirsium arvense* was also found along riparian areas and in all anthropogenic disturbances. This species can be dispersed in the form of seed or vegetative fragments, and once established at a site it can spread extensively by lateral roots (Grime et al.

1996). Low soil pH and light availability were the environmental parameters most limiting to the distribution of *Cirsium arvense* in GMNP. Although light availability limits *Cirsium arvense* in forested areas, it may be able to persist in disturbed forests of GMNP for long periods due to heavy moose browsing of balsam fir and deciduous trees, which normally shade out this species. The presence of dense stands of *Cirsium arvense* in forest disturbances may also be limiting re-colonization of these areas by native species.

Digitalis purpurea is an alien species which has become naturalized in forests of western North America (Baker 1986). In GMNP, *Digitalis purpurea* was associated with insect outbreaks and hydro-electric corridors, however it was not found to be widespread in anthropogenic disturbances throughout GMNP. Although high numbers of *Digitalis purpurea* were found in some areas, this species was not found in dense mono-specific stands, and this may be attributed to the fact that this species does not have significant vegetative reproduction. Characteristics which contribute to the success of *D. purpurea* in GMNP include the production of many small seeds (>70 000) which can persist in a seed bank, and its preference for acidic soils (Baker 1986; Grime et al. 1988). Availability of light and bare ground for germination of seed limit the distribution of *Digitalis purpurea* (Grime et al. 1988), and these conditions are likely important for its growth in GMNP.

Hieracium spp. (*H. pratense*, *H. aurantiacum*, *H. floribundum*, and *H. pilosella*) were widespread in areas of high anthropogenic activity and were found in clear cuts, areas of insect outbreaks, and alpine meadows. These species usually did not form dense patches in natural areas, but in alpine meadows on Kildevil Mountain high numbers of *Hieracium aurantiacum* were found. These species have the ability to quickly establish populations in habitat openings by producing seeds through apomixis, and once established are able to compete for space through vegetative reproduction. Environmental parameters which were most important in restricting the distribution of *Hieracium* spp. in GMNP were low light availability, soil pH, and bare ground.

Myosotis scorpioides was found to have limited dispersal ability in remote areas of GMNP, but in areas where it became established it often formed dense patches. This species prefers wet ground, and often formed dense patches in ditches. Very little information on the environmental preferences of *M. scorpioides* were determined in this study, but soil pH and light most likely restrict the distribution of this species in GMNP.

Taraxacum officinale was found in anthropogenic and natural disturbances throughout GMNP. Although this species was common, it did not occur in dense patches anywhere in GMNP. Asexual production of many seeds through apomixis allows *T. officinale* to be readily dispersed by wind or animals (Grime et al. 1988). *Taraxacum officinale* was associated with low soil moisture, and high light availability, soil pH, and bare ground. The presence of a species of *Taraxacum* on Kildevil Mountain is noteworthy because this was thought to be a native species during field research, but later examination of a specimen collected appeared to be the alien *Taraxacum officinale*. Further examination of *Taraxacum* on Kildevil Mountain is recommended.

5.3 - Recommendations for Future Research and Management

1. It is necessary to determine if alien plants already present in GMNP are spreading to natural disturbances remote from human activity and persisting. Alien plant monitoring programs of all representative disturbance and vegetation types in GMNP would be appropriate as alien species are able to invade areas remote from human activity.

2. It is important to determine whether aliens are directly or indirectly threatening rare native flora in GMNP. Areas of particular concern are Kildevil Mountain and some estuaries, where alien plants and rare plants are found near one another.

3. The impact of large numbers of alien plants on succession and native species diversity in natural areas must be evaluated. Large numbers of alien plants may also be impacting ecosystem properties such as resource availability, disturbance regimes, and trophic structure in these areas. Potential monitoring sites in GMNP where alien plants may be threatening native species or ecosystem properties are designated in Appendix 3.

4. New alien plant arrivals to GMNP should be located, removed, and traced. Finding and removing new species in GMNP may prevent these species from becoming established in high numbers in the future. Because new arrivals are most likely to occur in disturbed areas near human activity, a program monitoring these areas should be established. Continued monitoring of non-native species already present in these areas should also occur to ensure that further spread of non-native plants does not occur under circumstances of increased visitation and trail development.

5. The use of hydro-seed mixtures containing alien plant species should be stopped.

Re-vegetation experiments should be established in disturbed areas where hydro-seed mixtures are commonly used. Experimental plots should be seeded with native species which are commonly associated with disturbed areas of GMNP. These plots will allow park managers to get a better idea of which native species or combination of native species are able to be used in hydro-seed mixtures instead of alien species.

6. The addition of foreign soil or gravel for construction of hiking trails, roads, or other facilities should be avoided as it facilitates non-native plant invasion.

7. Removal of alien species should occur in areas where they appear to be threatening native species. Removal of aliens should occur only in those areas where it is feasible, and when alien plant removal does not have greater negative impacts than the presence of the alien species in the area. Areas on Kildevil Mountain and Big Hill, where alien species occur in relatively low numbers, may be areas where removal is feasible. Removal of *Lythrum salicaria* from Lomond campground may also be practical. This area is already highly disturbed and removal of *L. salicaria* should not alter the ecological integrity of this area. The large number of campers which use this site have the potential to disperse *L. salicaria* to other areas of the park or province.

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Appendix 1

Legend of Symbols Used in Thesis or Appendices

Definition of Vegetation Types used in Table 1 and Figure 7 (From Berger et al. 1992)

Balsam Fir Forest: Balsam fir dominant with white spruce and white birch as mature stands and successional scrub after logging.

Black Spruce Forest and Scrub: Black spruce and Balsam fir, mainly on boggy ground of sphagnum mosses, and a shrub layer of sheep laurel.

Grassy Dunes: Grassy sand dunes with Marram grass and lyme grass on active unstable surfaces, with scrub balsam fir on stable surfaces.

Heath Dwarf-Scrub: Dense, low shrubs, predominantly sheep laurel, low bush blueberry, Labrador tea, and rhododendron.

Heath-Lichen Tundra: Wind-exposed mat of black crowberry, alpine bear bearberry, tundra bilberry, and diapensia, interspersed with rock and rubble covered with lichen (rock tripe) and moss (*Rhacomitrium* spp.). Several arctic-alpine plants (alpine clubmoss, sibbaldia) occur in late-lying snow sites.

Intertidal Salt Marsh: Salt-tolerant herbaceous plants in the intertidal zone; samphire typifies the lower mud flats; salt marsh sedges (chaffy sedge, salt sedge) dominate the higher marshes.

Larch Scrub: Semi-open larch scrub with sweet gale, dwarf birch, and a herb layer of meadow-rue and bottle brush.

Riverain Thicket and Meadow: Thickets of speckled alder, sweet gale, and meadow-sweet; wet meadows of meadow-rue, bottlebrush, and reed grass.

Sedge Fen and Bog: Meadow-like fens and slope bogs, mainly of sedges (meagre sedge, wooly sedge, lead sedge) and sphagnum mosses.

Serpentine Barrens: Rock barrens with sparse dwarf-scrub (juniper, larch, dwarf birch), cushion mosses (*Rhacomitrium* spp.) and unusual arctic-alpine plants (sea thrift, alpine campion, Lapland rosebay).

Sphagnum Bog: Domed bog of sphagnum mosses, lichens (reindeer moss), and tussock rush with a dense dwarf-scrub border of black spruce, sheep laurel, leatherleaf, and bog rosemary.

Tuckamore: Dense wind-shaped thickets of balsam fir with white spruce on the coast and black spruce on exposed upland slopes.

Location Codes

BBIO#2 = Baker's Brook Insect Outbreak Transect #2
BBRT = Baker's Brook River Transect
BBT#1 = Bakers Brook Insect Outbreak Transect #1
BHT = Big Hill Transect
BPCCT = Big Pond Clear Cut Transect
BPMT = Big Pond Moose Trail Transect
DRT = Deer Arm Road Transect
GGTBT = Green Gardens Trail Birch Transect
GGTFT = Green Gardens Trail Fir Transect
GPRT = Green Point River Transect
JCMT = James Callahan Trail Moose Trail Transect
JCNMT = James Callahan Trail Non-Moose Trail Transect
KT = Kildevil Mountain Transect
LCHT = Lobster Cove Head Transect
LCMTT = Lomond Canopy Moose Trail Transect
LCNMTT = Lomond Canopy Non-Moose Trail Transect
LFMTT = Lomond Fen Moose Trail Transect
LGCCNT = Lomond-Glenburnie Clear Cut New Transect
LGCCOT = Lomond-Glenburnie Clear Cut Old Transect
LRT = Lomond River Transect
MBCCT = Mill Brook Clear Cut Transect
MBP = Mill Brook Pit Transect
MPI = Martin Point Insect Outbreak
MRFT = Mail Road Field Transect
RBBP = Rocky Barachois Brook Pit Transect
RDAT = Deer Arm River Transect
SHIO = Snug Harbour Insect Outbreak
SHRT = Snug Harbour River Transect
SPI = Stuckless Pond Insect Outbreak
WBPTBT = Western Brook Pond Trail Bog Transect
WBPTFFT = Western Brook Pond Trail Fir Forest Transect
WBRBT = Western Brook Road Bog Transect
WBT = Western Brook Transect
WRT = Wiltondale Road Transect

Environmental Parameter Codes
C:N = Carbon to Nitrogen Ratio
N = Nitrogen
P = Phosphorus
K = Potassium
Ca = Calcium
Mg = Magnesium
% Light = % Available Photosynthetically Active Radiation (PAR)
%BG = % Bare ground
TVC % = % Total Vegetative Cover
TS # = Total Number of Species
NVS # = Total # of Non-Vascular Species
VS # = Total # of Vascular Species
AS # = Total Number of Alien Species
% NVS = % Non-Vascular Species = # non-vascular species / total # species
% AS = % Alien Species = # alien species / total number of species
% AVS = % Alien Vascular Species = # alien vascular species / total number of vascular species

Soil Textural Class Codes
Codes for % Sand, % Clay, % Silt:
- 0 = texture not measured in soil sample
- 1 = 0 - 25 %
- 2 = 25 - 50 %
- 3 = 50 - 75 %
- 4 = 75 - 100 %

Codes for Organic soil:
- 1 = predominately mineral soil
- 2 = predominately organic soil

Vegetation Type Codes used in Excel Spreadsheets
Veg. Type = Pre-disturbance Vegetation Type
Heath-Lichen Tundra = 1
Alpine Meadow = 2
Forest (mainly fir, but large spruce component in some cases) = 3
Black Spruce = 4
Tuckamore (fir or spruce) = 5
Fen = 6
Bog = 7
Riparian = 8
Deciduous or mixed = 9

Disturbance Type Codes
Dominant Disturbance Type = DDT
Roadside = 1
Trail = 2
Pit = 3
Clearcut = 4
Insect Outbreak = 5
Moose Trail = 6
River = 7

Disturbance Age Codes
Dist. Age = Age of disturbance (only takes visually obvious moose disturbance into account)
0 = present - 2yrs
1 = 2 - 10 yrs
2= 11 - 20 yrs
3 = 21 - 30 yrs
4 = 31 yrs - none, minor amounts, or unknown

Disturbance Regime Codes
Overall DR = Overall Disturbance Regime
High = 0
Medium = 1
Low = 2
Undisturbed = 3

Anth. DR = Anthropogenic Disturbance Regime
High = 0
Medium = 1
Low = 2
Undisturbed = 3

Nat. DR = Natural Disturbance Regime (excluding moose activity)
severe, ongoing = 0
severe, recovering = 1
moderate, ongoing = 2
recovering, very low = 3
undisturbed = 4

Moose DR = Moose Disturbance Regime
Intense = 0 Low = 2
Moderate = 1 Undisturbed = 3

Appendix 2

List of Species collected or which occurred in transects in Gros Morne National Park

Appendix 2: List of species collected or which occurred in transects in Gros Morne National Park during 1998 and 1999

Genus and Species	Family	Authority	Alien	Comment
Sambucus racemosa L.ssp. pubens	Adoxaceae	(Michx.) House		Sambucus pubens L.
Viburnum edule	Adoxaceae	(Michx.) Raf.		
Viburnum nudum L. var. cassinoides	Adoxaceae	(L.) Torr. & Gray		Viburnum cassinoides L.
Viburnum opulus L. var. americanum	Adoxaceae	Aiton		Viburnum trilobum Marsh.
Atriplex glabriuscula	Amaranthaceae	Edmonston		specimen collected, not listed in Anions (1994)
Atriplex subspicata	Amaranthaceae	L. (Nutt.) Rydb.		specimen collected, not listed in Anions (1994)
Chenopodium album	Amaranthaceae	L.	A	specimen collected
Campylium polyganum	Amblystegiaceae	(B.S.G.) C.		
Nemopanthes mucronatus	Aquifoliaceae	(L.) Loesner ex Koehne		
Aralia nudicaulis	Araliaceae	L.		
Achillea millefolium	Asteraceae	L.	A	specimen collected
Achillea millefolium L. ssp. lanulosa	Asteraceae	(Nutt.) Piper		A. borealis Bong.
Anaphalis margaritacea	Asteraceae	(L.) C. B. Clarke		specimen collected
Arctium minus	Asteraceae	(Hill) Bernh.	A	specimen collected
Bellis perennis	Asteraceae	L.	A	specimen collected
Centaurea nigra	Asteraceae	L.	A	specimen collected
Cichorium intybus	Asteraceae	L.	A	specimen collected
Cirsium arvense	Asteraceae	(L.) Scop.	A	specimen collected
Cirsium muticum	Asteraceae	Michx.		
Cirsium vulgare	Asteraceae	(Savi) Tenore	A	specimen collected
Crepis tectorum	Asteraceae	L.	A	specimen collected, not listed in Anions (1994)
Doellingeria umbellata	Asteraceae	(P. Mill.) Nees		Aster umbellatus L.
Erigeron philadelphus	Asteraceae	L.		specimen collected
Eupatorium maculatum	Asteraceae	L.		
Hieracium aurantiacum	Asteraceae	L.	A	specimen collected
Hieracium caespitosum	Asteraceae	(Dumort) Sell and C. West.	A	not listed in Anions (1994)

Genus and Species	Family	Authority	Alien	Comment
Hieracium caespitosum L. ssp. caespitosum	Asteraceae	Dumort.	A	specimen collected, Hieracium pratense L.
Hieracium floribundum	Asteraceae	Wimm. & Grab.	A	specimen collected
Hieracium kalmii	Asteraceae	L.		Hieracium canadense Michx.
Hieracium paniculatum	Asteraceae	L.		specimen collected
Hieracium pilosella	Asteraceae	L.	A	specimen collected
Hieracium piloselloides	Asteraceae	Vill.	A	specimen collected, Hieracium florentinum All.
Lactuca biennis	Asteraceae	(Moench) Fern.		specimen collected
Leontodon autumnalis	Asteraceae	L.	A	specimen collected
Leucanthemum vulgare	Asteraceae	Lam.	A	Chrysanthemum leucanthemum L., specimen collected
Matricaria maritima	Asteraceae	L.	A	
Matricaria matricarioides	Asteraceae	(Less.) Porter	A	specimen collected
Oclemena nemoralis	Asteraceae	(Dryand. ex Ait.) E.L. Greene		Aster nemoralis Ait.
Packera aureua	Asteraceae	(L.) A. & D. Love		specimen collected, Senecio aureus L.
Prenanthes nana	Asteraceae	(Bigel.) Torr.		not listed in Anions (1994), Prenanthes alba L.
Prenanthes trifoliolata	Asteraceae	(Cass.) Fern.		
Senecio jacobaea	Asteraceae	L.	A	specimen collected
Senecio viscosus	Asteraceae	L.	A	specimen collected, not listed in Anions (1994)
Senecio vulgaris	Asteraceae	L.	A	specimen collected
Solidago hispida	Asteraceae	T. & G.		specimen collected
Solidago macrophylla	Asteraceae	Pursh		specimen collected
Solidago rugosa	Asteraceae	Ait.		
Solidago uliginosum	Asteraceae	T. & G.		
Sonchus arvensis	Asteraceae	L.	A	specimen collected
Symphyotrichum novae-angliae	Asteraceae	(L.) Nesom		not listed in Anions (1994), ?, Aster novae-angliae L.
Symphyotrichum novi-belgii	Asteraceae	(L.) Nesom		Aster novi-belgii L.
Symphyotrichum puniceus	Asteraceae	(L.) A. & D.		Aster puniceus L.
Taraxacun officinale	Asteraceae	Weber	A	specimen collected
Tragopogon pratensis	Asteraceae	L.	A	specimen collected, not listed in Anions (1994)
Tussilago farfara	Asteraceae	L.	A	
Impatiens capensis	Balsaminaceae	Meerb.		specimen collected

Genus and Species	Family	Authority	Alien	Comment
Philonotis fontona	Bartramiaceae	(Hedw.) Brid.		
Alnus incana L. ssp. rugosa	Betulaceae	(Du Roi) Clausen		
Betula glandulosa	Betulaceae	Michx.		
Betula papyrifera	Betulaceae	Marsh.		
Echium vulgare	Boraginaceae	L.	A	specimen collected
Myosotis scorpioides	Boraginaceae	L.	A	specimen collected
Myosotis sylvatica	Boraginaceae	Hoffm.	A	specimen collected, not listed in Anions (1994)
Campanula rapunculoides	Campanulaceae	L.	A	specimen collected
Campanula rotundifolia	Campanulaceae	L.		specimen collected
Linnaea borealis	Caprifoliaceae	L.		
Cerastium beeringianum	Caryophylaceae	Cham. & Schltdl.		specimen collected
Cerastium fontanum Baumg ssp. vulgare	Caryophyllaceae	(Hartman) Greuter & Burdet	A	specimen collected, Cerastium vulgatum L.
Dianthus armeria	Caryophyllaceae	L.	A	specimen collected, not listed in Anions (1994)
Lychnis alpina	Caryophyllaceae	L.		specimen collected
Minuartia marcescens	Caryophyllaceae	(Fern.) House		specimen collected, Arenaria marcesens Fern.
Sagina procumbens	Caryophyllaceae	L.		
Silene vulgaris	Caryophyllaceae	(Moench) Garcke	A	specimen collected, Silene cucubalus Wibel., not listed in Anions (1994)
Stellaria graminea	Caryophyllaceae	L.	A	specimen collected
Stellaria media	Caryophyllaceae	(L.) Cyrillo	A	
Cornus canadensis	Cornaceae	L.		
Cornus stolonifera	Cornaceae	Michx.		
Sedum rosea	Crassulaceae	(L.) Scop.		
Arabis drummondi	Cruciferae	Gray		specimen collected
Barbarea orthocerus	Cruciferae	Ledeb.		specimen collected
Barbarea vulgaris	Cruciferae	R. Br.	A	specimen collected
Brassica rapa	Cruciferae	L.	A	specimen collected
Cakile edentula	Cruciferae	(Bigel.) Hook.		specimen collected
Capsella bursa-pastoris	Cruciferae	(L.) Medic.	A	specimen collected
Cardamine flexousa	Cruciferae	With.		specimen collected
Erysimum hieraciifolium	Cruciferae	L.	A	specimen collected, not listed in Anions (1994)
Carex adusta	Cyperaceae	Boott.		identification uncertain, specimen collected, not listed in Anions (1994)

Genus and Species	Family	Authority	Alien	Comment
Carex aquatilis	Cyperaceae	Wahlenb.		specimen collected
Carex aurea	Cyperaceae	Nutt.		specimen collected
Carex brunnescens	Cyperaceae	(Pers.) Poir		specimen collected
Carex capillaris	Cyperaceae	L.		specimen collected
Carex castanea	Cyperaceae	Wahlenb.		specimen collected
Carex crinita var. gynandra	Cyperaceae	(Schwein) Schwein & Torr.		specimen collected, not listed in Anions (1994)
Carex disperma	Cyperaceae	Dewey		specimen collected
Carex echinata	Cyperaceae	Murr.		specimen collected, not listed in Anions (1994)
Carex echinata ssp. echinata	Cyperaceae	Murr.		specimen collected, not listed in Anions (1994), Carex angustior Mackenz.
Carex flava	Cyperaceae	L.		specimen collected
Carex interior	Cyperaceae	Bailey		specimen collected
Carex lenticularis	Cyperaceae	Michx.		specimen collected
Carex lenticularis var. lenticularis	Cyperaceae	Michx.		specimen collected, C. lenticularis var. eucycla Fern.
Carex leptalea	Cyperaceae	Wahl.		specimen collected
Carex nigra	Cyperaceae	(L.) Reichard		specimen collected
Carex projecta	Cyperaceae	Mackenz.		specimen collected
Carex salina	Cyperaceae	Wahlenb.		specimen collected
Carex stipata	Cyperaceae	Muhl.		specimen collected
Carex trisperma	Cyperaceae	Dewey		specimen collected
Carex vaginata	Cyperaceae	Tausch.		specimen collected
Eleocharis smallii	Cyperaceae	Britt.		specimen collected
Eriophorum callitrix	Cyperaceae	Cham.		specimen collected, not listed in Anions (1994)
Scirpus cyperinus	Cyperaceae	(L.) Kunth		specimen collected, Scirpus atrocinctus Fern.
Scirpus microcarpus	Cyperaceae	J. & C. Presl.		specimen collected, Scirpus rubrotinctus Fern.
Dicranum majus	Dicranaceae	Sm.		specimen collected
Dicranum polysetum	Dicranaceae	Sw.		
Dicranum scoparium	Dicranaceae	Hedw.		
Drosera rotundifolia	Droseraceeae	L.		
Shepherdia canadensis	Elaeagnaceae	(L.) Nutt.		
Empetrum eamesii	Empetraceae	Fern & wieg.		
Empetrum nigrum	Empetraceae	L.		

Genus and Species	Family	Authority	Alien	Comment
Equisetum arvense	Equisetaceae	L.		specimen collected
Equisetum pratense	Equisetaceae	L.		specimen collected, not listed in Anions (1994)
Equisetum sylvaticum	Equisetaceae	L.		
Andromeda glaucophylla	Ericaceae	Link		
Arctostaphylos uva-ursi	Ericaceae	(L.) Spreng.		
Chamaedaphne calyculata	Ericaceae	L.		
Epigaea repens	Ericaceae	L.		
Gaultheria hispidula	Ericaceae	(L.) Bigel.		
Kalmia angustifolia	Ericaceae	L.		
Kalmia polifolia	Ericaceae	Wang.		
Moneses uniflora	Ericaceae	(L.) Gray		
Orthilia secunda	Ericaceae	(L.) House		Pyrola secunda L.
Rhododendron canadense	Ericaceae	(L.) Torr.		
Rhododendron groenlandicum	Ericaceae	(Oeder) Kron & Judd		Ledum groenlandicum Oeder.
Vaccinium angustifolium	Ericaceae	Ait.		
Vaccinium boreale	Ericaceae	Hall and Aalders		
Vaccinium oxycoccus	Ericaceae	L.		
Vaccinium uliginosum	Ericaceae	L.		
Vaccinium vitis-idaea	Ericaceae	L.		
Euphorbia cyparissias	Euphorbiaceae	L.	A	specimen collected
Lotus corniculatus	Fabaceae	L.	A	specimen collected
Lupinus perennis	Fabaceae	L.	A	specimen collected, not listed in Anions (1994)
Medicago lupulina	Fabaceae	L.	A	specimen collected, not listed in Anions (1994)
Medicago sativa	Fabaceae	L.	A	specimen collected, not listed in Anions (1994)
Melilotus albus	Fabaceae	Medik.	A	specimen collected, Melilotus alba Desr.
Melilotus officinalis	Fabaceae	(L.) Lam.	A	specimen collected
Trifolium aureum	Fabaceae	Pollich	A	specimen collected, Trifolium agarium L.
Trifolium hybridum	Fabaceae	L.	A	specimen collected
Trifolium pratense	Fabaceae	L.	A	specimen collected
Trifolium repens	Fabaceae	L.	A	specimen collected
Vicia cracca	Fabaceae	L.	A	specimen collected
Gentianella amarella (L.) Borner ssp. acuta	Gentianaceae	(Michx.) J. Gillett		specimen collected, not listed in Anions (1994), Gentiana acuta Michx.
Halenia deflexa	Gentianaceae	(Sm.) Griseb.		specimen collected

Genus and Species	Family	Authority	Alien	Comment
Geranium pratense	Geraniaceae	L.	A	specimen collected
Geranium robertianum	Geraniaceae	L.		specimen collected
Racomitrium lanuginosum	Grimmiaceae	(Hedw.) Brid.		
Hypericum perforatum	Guttiferae	L.	A	specimen collected
Hylocomium splendens	Hylocomiaceae	(Hedw.) B.S.G		
Hylocomium umbratum	Hylocomiaceae	(Hedw.) B.S.G		
Pleurozium schreberi	Hylocomiaceae	(Brid.) Mitt.		
Rhytidiadelphus loreus	Hylocomiaceae	(Hedw.) Warnst.		
Rhytidiadelphus squarrous	Hylocomiaceae	(Hedw.) Warnst.		
Rhytidiadelphus triquestrus	Hylocomiaceae	(Hedw.) Warnst.		
Hypnum revolutum	Hypnaceae	(Mitt.) Lindb.		
Ptilium crista-castrensis	Hypnaceae	(Hedw.) De Not.		
Iris versicolor	Iridaceae	L.		
Sisyrinchium montanum	Iridaceae	Greene		
Juncus alpinoarticulatus	Juncaceae	Chaix		specimen collected, Juncus alpinus Vill.
Juncus articulatus	Juncaceae	L.		specimen collected
Juncus brevicaudatus	Juncaceae	(Engelm.) Fern.		specimen collected
Juncus dudleyi	Juncaceae	Wieg.		specimen collected
Juncus effusus	Juncaceae	L.		specimen collected
Juncus filiformis	Juncaceae	L.		specimen collected
Juncus trifidus	Juncaceae	L.		specimen collected
Luzula campestris	Juncaceae	(L.) DC.		
Luzula multiflora	Juncaceae	(Retz.) Lejeune		specimen collected
Triglochin maritimum	Juncaginaceae	L.		
Clinopodium vulgare	Labiatae	L.		specimen collected, Satureja vulgaris (L.) Fritsch
Galeopsis tetrahit	Labiatae	L.	?	specimen collected
Glechoma hederacea	Labiatae	L.	A	specimen collected
Mentha arvensis	Labiatae	(Michx.) Roy L. Taylor and MacBryde		specimen collected
Prunella vulgaris	Labiatae	L.		specimen collected
Pinguicula vulgaris	Lentibulariaceae	L.		
Allium schoenoprasum var. sibiricum	Liliaceae	(L.) Hartman		specimen collected

Genus and Species	Family	Authority	Alien	Comment
Clintonia borealis	Liliaceae	(Ait.) Raf.		
Maianthemum canadense	Liliaceae	Weber		
Streptopus amplexifolius	Liliaceae	(L.) DC.		
Streptopus lanceolatus	Liliaceae	Ait.		Streptopus roseus Michx.
Tofieldia glutinosa	Liliaceae	(Michx.) Pers.		specimen collected
Trillium cernuum	Liliaceae	L.		
Linum catharticum	Linaceae	L.	A	Specimen collected
Lythrum salicaria	Lythraceae	L.	A	specimen collected
Malva moschata	Malvaceae	L.	A	specimen collected
Mnium puncatum	Mniaceae	Hedw.		
Myrica gale	Myricaceae	L.		
Chamerion angustifolium	Onagraceae	(L.) Holub.		Epilobium angustifolium L.
Circaea alpina	Onagraceae	L.		
Epilobium ciliatum ssp. glandulosum	Onagraceae	(Lehm.) Hoch & Raven		specimen collected, Epilobium glandulosum Lehm.
Oenothera parviflora	Onagraceae	L.		specimen collected
Listera cordata	Orchidaceae	(L.) R. Br.		
Platanthera dilatata	Orchidaceae	(Pursch) Hook.		also known as Habenaria dilatata
Castilleja septentrionalis	Orobachaceae	Lindl.		specimen collected
Euphrasia nemorosa	Orobanchaceae	(Pers.) Wallr.		specimen collected
Rhinanthus minor L. ssp. minor	Orobanchaceae	L.	A	specimen collected
Osmunda cinnamomea	Osmundaceae	L.		
Abies balsamea	Pinaceae	(L.) Mill.		
Juniperus communis	Pinaceae	L.		
Larix laricina	Pinaceae	(DuRoi) K. Koch		
Picea glauca	Pinaceae	(Moench) Voss		
Picea mariana	Pinaceae	(Mill.) B.S.P.		
Digitalis purpurea	Plantaginaceae	L.	A	specimen collected
Linaria vulgaris	Plantaginaceae	(L.) Mill.	A	specimen collected, not listed in Anions (1994)
Mimulus moschatus	Plantaginaceae	Dougl.	A	specimen collected
Plantago maritima L. var. juncoides	Plantaginaceae	(Lam.) A. Gray	A	specimen collected, not listed in Anions (1994), P. juncoides Lam.
Plantago lanceolata	Plantaginaceae	L.	A	specimen collected
Plantago major	Plantaginaceae	L.	A	

Genus and Species	Family	Authority	Alien	Comment
Veronica americana	Plantaginaceae	(Raf.) Schwein.		
Veronica officinalis	Plantaginaceae	L.	?	specimen collected
Veronica serpyllifolia	Plantaginaceae	L.	A	specimen collected
Agrostis canina	Poaceae	L.		specimen collected, not listed in Anions (1994)
Agrostis mertensii	Poaceae	Trin.		specimen collected, Agrostis borealis Hartm.
Agrostis scabra	Poaceae	(Willd.)		specimen collected, not listed in Anions (1994)
Agrostis scabra var. scabra	Poaceae	Willd.		specimen collected
Agrostis stolonifera	Poaceae	L.	?	specimen collected
Anthoxanthum odoratum	Poaceae	L.	A	specimen collected
Calamagrostis canadensis	Poaceae	(Michx.) Nutt.		specimen collected
Calamagrostis canadensis var. canadensis	Poaceae	(Michx.) P. Beauv.		specimen collected, C. canadensis var. robusta Vasey
Calamagrostis pickeringii	Poaceae	Gray		specimen collected
Calamagrostis sticta (Trimm) Koeler ssp. inexpansa	Poaceae	(A. Gray) C.W. Greene		specimen collected, C. inexpansa Gray.
Cinna latifolia	Poaceae	(Trev.) Griseb.		specimen collected
Dactylis glomerata	Poaceae	L.	A	specimen collected
Dactylis glomerata ssp. glomerata	Poaceae	L.	A	specimen collected, D. glomerata var. ciliata Peterm.
Danthonia spicata	Poaceae	(L.) Beauv.		specimen collected
Deschampsia flexousa	Poaceae	(L.) Trin.		specimen collected
Elymus repens	Poaceae	(L.) Gould	A	specimen collected, Agropyron repens (L.) Beauv.
Festuca arundinacea	Poaceae	Schreb.	A	specimen collected, Festuca elatior L.
Festuca ovina	Poaceae	L.	A	specimen collected
Festuca rubra ssp. rubra	Poaceae	L.		specimen collected, Festuca rubra var. squarrossa (Fries) Holmb.
Festuca trachyphylla	Poaceae	(Hack.) Krajina	A	specimen collected, Festuca ovina var. durinuscula (L.) W.D.J. Koch
Glyceria canadensis	Poaceae	(Michx.) Trin.		specimen collected
Glyceria striata var. striata	Poaceae	(Lam.) Hitchc.		specimen collected
Hordeum jubatum	Poaceae	L.	A	specimen collected
Leymus mollis	Poaceae	(Trin.) Pilger		Elymus arenarius L.
Phalaris canariensis	Poaceae	L.	A	specimen collected, not listed in Anions (1994)

Genus and Species	Family	Authority	Alien	Comment
Phleum alpinum	Poaceae	L.		specimen collected
Phleum pratense	Poaceae	L.	A	specimen collected
Poa alpina	Poaceae	L.		specimen collected
Poa alsodes	Poaceae	Gray		specimen collected, not listed in Anions (1994)
Poa compressa	Poaceae	L.	A	specimen collected
Poa laxa ssp. fernldiana	Poaceae	(Nannf.) Hyl.		specimen collected, Poa fernaldiana Nannf.
Poa pratensis	Poaceae	L.	?	specimen collected
Poa pratensis L. ssp. alpigena	Poaceae	(E. Fries ex Blytt) Hiitonen		specimen collected, Poa alpigena (Fries) Lindm. f.
Poa pratensis L. ssp. irrigata	Poaceae	(Lindm.) Lindb. f.		specimen collected, Poa subcaerulea Sm.
Poa saltuensis	Poaceae	Fern. & Wieg.		specimen collected
Poa trivialis	Poaceae	L.	?	specimen collected
Trisetum spicatum	Poaceae	(L.) Richter		specimen collected
XElymeymus aristatus	Poaceae	(Merr.) Barkworth & D. R. Dewey	A	specimen collected, Agropyron repens Forma aristatum (Schum.) Holmb.
Fallopia japonica	Polygonaceae	(Houtt.) Decraene	A	specimen collected, not listed in Anions (1994), Polygonum cuspidatum
Persicaria hydropiper	Polygonaceae	(L.) Opiz	?	Polygonum hydropiper L.
Persicaria persicaria	Polygonaceae	(L.) J. K. Small	A	specimen collected, Polygonum persicaria L.
Persicaria vivipara	Polygonaceae	(L.) Decraene		specimen collected, Polygonum viviparium L.
Rumex acetosa	Polygonaceae	L.	A	specimen collected
Rumex acetosella	Polygonaceae	L.	A	specimen collected
Rumex crispus	Polygonaceae	L.	A.	specimen collected
Rumex longifolius	Polygonaceae	DC.	A	specimen collected, Rumex domesticus Hartm.
Rumex obtusifolius	Polygonaceae	L.	A	specimen collected
Rumex salicifolius Weinm. var. mexicanus	Polygonaceae	(Meisn.) C.L. Hitch.		specimen collected
Athyrium felix-femina	Polypodiaceae	(L.) Roth		
Dryopteris campyloptera	Polypodiaceae	(Kunze) Clarkson		Dryopters spinulosa var. americana (Fisch.) Fern.
Dryopteris carthusiana	Polypodiaceae	(Villars) H.P. Fuchs		Dryopteris spinulosa (O.F. Muell.) Watt.
Dryopteris intermedia	Polypodiaceae	(Muhl. ex Willd.) A. Gray		Dryopteris spinulosa var. intermedia (Muhl.) Underw.

Genus and Species	Family	Authority	Alien	Comment
Gymnocarpium dryopteris	Polypodiaceae	(L.) Newman		
Onoclea sensibilis	Polypodiaceae	L.		
Phegopteris connectilis	Polypodiaceae	(Michx.) Watt.		not listed in Anions (1994), Dryopteris phegopteris (L.) Christens.
Atrichum undulatum	Polytrichaceae	(Hedw.) P. Beauv.		
Polytrichum commune	Polytrichaceae	Hedw.		
Polytrichum juniperinum	Polytrichaceae	Hedw.		
Lysimachia punctata	Primulaceae	L.	A	specimen collected, not listed in Anions (1994)
Primula laurentiana	Primulaceae	Fern.		specimen collected
Primula mistassinica	Primulaceae	Michx.		specimen collected
Trientalis borealis	Primulaceae	L.		
Aconitum x bicolor	Ranunculaceae	J. A. Schultes	A	specimen collected, garden escape
Anemone canadensis	Ranunculaceae	L.		
Aquilegia vulgaris	Ranunculaceae	L.	A	specimen collected, graveyard
Caltha palustris	Ranunculaceae	L.		
Coptis trifolia	Ranunculaceae	(L.) Salisb.		Coptis groenlandica (Oeder) Fern.
Ranunculus abortivus	Ranunculaceae	L.		specimen collected
Ranunculus acris	Ranunculaceae	L.	A	specimen collected
Ranunculus repens	Ranunculaceae	L.	A	specimen collected
Thalictrum pubescens	Ranunculaceae	Pursh.		Thalictrum polygamum Muhl.
Rhamnus alnifolia	Rhamnaceae	L'Her.		
Agrimonia striata	Rosaceae	Michx.		
Alchemilla filicaulis	Rosaceae	Buser		specimen collected
Amelanchier spp.	Rosaceae	Medic.		
Filipendula ulmaria	Rosaceae	(L.) Maxim.	A	specimen collected
Fragaria virginiana	Rosaceae	Duchesne (Virginian)		specimen collected
Geum macrophyllum	Rosaceae	Willd.		
Pentaphylloides floribunda	Rosaceae	(Pursh) A. Love		Potentilla fruticosa L.
Potentilla anserina	Rosaceae	L.		specimen collected
Potentilla norvegica	Rosaceae	L.		specimen collected
Prunus pensylvanica	Rosaceae	L.		
Rubus chamaemorus	Rosaceae	L.		
Rubus idaeus	Rosaceae	L.		
Rubus pubescens	Rosaceae	Raf.		

Genus and Species	Family	Authority	Alien	Comment
Sanguisorba canadensis	Rosaceae	L.		
Sibbaldiopsis tridentata	Rosaceae	(Soland. ex Ait.) Rydb.		Potentilla tridentata Ait.
Sorbus americana	Rosaceae	Marsh.		
Sorbus decora	Rosaceae	(Sarg.) Schneid.		
Galium palustre	Rubiaceae	L.		
Galium triflorum	Rubiaceae	Michx.		
Salix spp.	Salicaceae	L.		
Acer rubrum	Sapindaceae	L.		
Acer spicatum	Sapindaceae	Lam.		
Sarracenia purpurea	Sarraceniaceae	L.		
Mitella nuda	Saxifragaceae	L.		
Parnassia parviflora	Saxifragaceae	DC.		specimen collected
Ribes glandulosum	Saxifragaceae	(Pers.) Poir		
Ribes lacustre	Saxifragaceae	Grauer		
Scrophularia nodusa	Scrophulariaceae	L.		specimen collected
Verbascum thapsus	Scrophulariaceae	L.	A	specimen collected
Sphagnum spp.	Sphagnopsida	L.		
Taxus canadensis	Taxaceae	Marsh.		
Tetraphis pellucida	Tetraphidaceae	Hedw.		
Thuidium recognitum	Thuidiaceae	(Hedw.) Lindb.		
Typha latifolia	Typhaceae	L.	?	
Aegopodium podagraria	Umbelliferae	L.	A	specimen collected, garden escape
Angelica atropurpurea	Umbelliferae	L.		
Carum carvi	Umbelliferae	L.	A	specimen collected
Conioselium chinese	Umbelliferae	(L.) B.S.P.		
Heracleum maximum	Umbelliferae	L.		specimen collected
Pastinaca sativa	Umbelliferae	L.	A	specimen collected
Urtica dioica	Urticaceae	L.	A	specimen collected
Viola spp.	Violaceae	L.		

Appendix 3

Locations of alien plants found in Gros Morne National Park

Appendix 3

Locations of Alien Plants found in Gros Morne National Park

* note: most grasses, sedges, and rushes are not listed. This is due to difficulty of identification in the field.
* note: some late flowering or growing species may not have been found during the surveys of some areas.
* note: roadsides, lookouts, picnic areas, and campgrounds are not listed. Generally, are not listed these areas had high numbers of alien plants throughout the park.
* note: GPS readings were taken with the following settings: Datum = WGS 84, Units = Statue.

Site	Monitor	Comment / Description	UTM Co-ordinates		Source
			E	N	
South East Brook Falls trail		*Taraxacum officinale*, *Ranunculus acris*, *Tussilago farfara*, and *Ranunculus repens* found along trail. *Ranunculus acris*, and *Ranunculus repens* were found in dense numbers away from the trail in a wet, muddy area that is heavily disturbed by moose. *Heracleum maximum* found in high numbers on some areas of trail.	Start 452210	5479900	Map
			End 452310	5479300	Map
Coastal seashore near Lobster Cove Head		*Atriplex rosea*, *Chenopodium album* occur sporadically.	430850	5494600	Map
Berry Hill trail		*Taraxacum officinale*, *Cirsium arvense* , *Ranunculus repens*, *Tussilago farfara*, and *Heracleum maximum* found along trail, but not found off the trail.	Start 432750	5497050	Map
			End 432600	5496990	Map

James Callahan trail		Alien species were found sporadically along the forested section of trail, right to the base of Gros Morne Mountain. Alien species were not seen along the scree slope going up Gros Morne, or on the summit. Alien species re-appeared going down the mountain at Ferry Gulch. Species included *Taraxacum officinale*, *Chrysanthemum leucanthemum*, *Ranunculus acris*, *Ranunculus repens*, and *Tussilago farfara*. A few wet, muddy moose trails which branched off the hiking trail contained *R. repen*. *Hieracium pratense* and *T. farfara* were found off the trail at the top of the pond located in Ferry Gulch.	parking lot 439790	5490480	Map
			base of mountain 442290	5492250	Map
			Ferry Gulch 444521	5494008	GPS
Shallow Bay beach and sand dunes		Although this area is frequently being disturbed by wind action, alien species were only successful in sheltered areas of some dunes, where *Taraxacum officinale* was found.	Start 444450	5531450	Map
			End 445800	5533500	Map
Trout River Pond trail		Few alien species seen. No alien species were seen in the closed canopy fir forest on the first half of the trail or on the serpentine Tablelands on the last half of the trail. *Taraxacum officinale*, *Cirsium arvense*, *Ranunculus acris*, *Ranunculus repens*, and *Hieracium* spp. were found along the trail or in fields near the trail.			
Green Point field and campgrounds		This area is rich in alien species. The following species were recorded: *Taraxacum officinale*, *Cirsium arvense*, *Rumex* spp., *Heracleum maximum*, *Achillea millefolium*, *Plantago major*, *Ranunculus repens*, *Ranunculus acris*, *Carum carvi*, *Phleum pratense*, *Trifolium hybridum*, *Plantago juncoides*, *Vicia cracca*, *Chrysanthemum leucanthemum*, and *Tussilago farfara*. *Tussilago farfara* was restricted to areas with gravel. This area is representative of all fields and pastures along the coast, with some slight variation in the presence and frequency of alien species.	General area 430500	5503500	Map

Big Brook Falls trail		Peatland areas along the trail are not being invaded. There is a small clump of *Typha latifolia* at the beginning of the trail. *Typha latifolia* is invasive in some areas and should be monitored. *Ranunculus repens* often formed dense mats in wet muddy areas along the trail. Many areas along the trail are heavily disturbed by moose trampling, browsing and feces. Moose and ski trails which intersect this hiking trail in several places are being invaded by *R. repens* in wet areas. A beaver house/dam near the trail has large amounts of *Ranunculus repens* and *Tussilago farfara* on it. Other alien species found to a lesser degree on the trail include *Ranunculus acris*, *Taraxacum officinale*, and *Myosotis scorpioides*. Insect outbreaks along the trail are being colonized by *Cirsium arvense*, *R. repens*, and *Myosotis scorpioides*. *Heracleum maximum* was abundant in some areas of the insect outbreaks.	Start 432750	5497050	Map
			End 435050	5499480	Map
Western Brook Pond trail		Although this trail has very high traffic, alien species are only found on the trail or trail edge. Peatland and forest are not being invaded. *Tussilago farfara*, *Ranunculus repens*, *Cirsium arvense*, *Leontodon autumnalis*, *Plantago major*, *Taraxacum officinale*, *Ranunculus acris*, *Veronica serpyllifolia*, and *Cirsium vulgare* are present in fairly high numbers along the trail.	Start 439950	5515150	Map
			End 439400	5514400	Map
Stag Brook trail		*Hieracium* spp., *Plantago major*, *Achillea millefolium*, *Heracleum maximum*, and *Taraxacum officinale* found near the end of the trail. Overall few alien species were seen along the trail. There is a lot of moose activity in the area.	Start 438500	5514400	Map
			End 439000	5512350	Map

Mail Road trail		This trail has a number of alien species on it, but these species are not invading the surrounding closed canopy fir forest. Species present include *Heracleum maximum*, *Taraxacum officinale*, *Cirsium arvense*, *Vicia cracca*, *Achillea millefolium*, *Rumex* spp., *Centaurea nigra*, *Trifolium repens*, *Hieracium* spp., *Chrysanthemum leucanthemum*, *Carum carvi*, *Tussilago farfara*, *Ranunculus repens*, *Leontodon autumnalis*, *Ranunculus acris*, *Trifolium hybridum*, *Euphrasia* spp., *Stellaria media*, *Rumex acetosella*, and *Phleum pratense*.	Start 444450	5531380	Map
			End 445900	5533500	Map
Green Gardens trail		Not many alien species were found along the end or beginning sections of the trail that passed over the serpentine tablelands. A few species were found on the trail itself in these areas but not off the trail. These species include *Hieracium* spp., *Taraxacum officinale*, and *Chrysanthemum leucanthemum*. Once the trail passes into balsam fir forest the number of alien species increases dramatically. Species on this section of trail include *Ranunculus acris*, *Ranunculus repens*, *T. officinale*, *Hieracium* spp. *Tussilago farfara*, and *C. leucanthemum*. Once the trail starts to pass along the coast, the number of aliens is extremely high. Alien species were found on the trail, along moose trails branching off the trail, and in sheep fields. *Ranunculus repens* was found in very dense mats through out this area. *Cirsium arvense, T. farfara,* and *Hieracium* spp. were also found in high numbers. Other alien species seen include *Urtica dioica*, *C. leucanthemum*, *Trifolium* spp. and *T. officinale*.	trail head 1		
			trail head 2		
Gadd's Harbour		This abandoned community contained *Polygonum cuspidata*, *Taraxacum officinale*, *Cirsium arvense*, *Vicia cracca*, *Ranunculus acris*, and *Carum carvi*.	436550	5484310	Map

Tablelands		Alien species were found on the trail (old road bed) in small numbers. These species were *Taraxacum officinale*, *Tussilago farfara*, *Trifolium spp*., and *Carum carvi.* Alien species were not seen anywhere else on the Tablelands. Areas surveyed on the Tablelands include Winterhouse Brook valley, the summit, and the "Devil's Punch Bowl".	start 429220	5480910	Map
			Devil's Punch bowl 429770	5479850	Map
			summit 429000	5476920	Map
Lomond Campground		The diversity and abundance of alien species in this area was one of the highest in the park. Species include *Bellis perennis*, *Cichorium intybus*, *Myosotis scorpioides*, *Plantago lanceolata*, *Hieracium aurantiacum*, *Carum carvi*, *Hieracium floribundum*, *Trifolium pratense*, *Stellaria media*, *Medicago lupulina*, *Polyganum cuspidata*, *Tussilago farfara*, *Taraxacum officinale*, *Centaurea nigra*, *Barbarea vulgaris*, *Chrysanthemum leucanthemum*, *Achillea millefolium*, *Cirsium arvense* , *Plantago major*, *Lotus corniculatus*, *Urtica dioica*, *Hypericum perforatum*, *V. serpyllifolia*, *Ranunculus acris*, *Medicago sativa*, *Ranunculus repens*, *Lythrum salicaria*, *Malva moschata*, *Lysimachia punctata*, *Aegopodium podograria*, and *Rumex spp.*. This area also contains *Cypripedium reginae*, a rare plant in the park.	4448990	5478921	Map
Ski trails behind visitors center		*Ranunculus repens* found in small numbers. Trail is new (~3 years old), and is gravel with little soil. Little vegetation of any kind present.	General area 436500	5491000	Map
Lookout Hills		Few alien species seen on the Lookout Hills trail. *Taraxacum officinale*, and *Hieracium* spp. were found in very small numbers on the trail. No alien species were found off the trail. Also hiked from the lookout on this trail to the top of the Lookout Hills where the weather monitoring station is located. No alien species were seen.	Start 431651	5481650	Map
			End 430600	5482270	Map

Pole line between Deer Arm picnic area and James Callahan trail		The area around the picnic area contained *Taraxacum officinale*, *Tussilago farfara*, *Achillea millefolium*, *Phleum pratense*, *Cirsium arvense* , *Heracleum maximum*, and *Digitalis purpurea*. The pole line had a highly disturbed trail associated with it that may be disturbed by service vehicles, and snowmobiles. The area has very high moose activity in the form of trampling, feces, and browsing. Alien species found in high numbers along the pole line were *D. purpurea*, *Ranunculus acris*, *Ranunculus repens*, *T. farfara*, *T. officinale*, *Veronica serpyllifolia*, *Hieracium* spp., and *P. pratense*.	Start 439850	5489750	Map
			End 440450	5491780	Map
Mill Brook Pit		This pit is fairly new and appears to still be in use. This site contains a high diversity of alien species in abundant numbers. These include *Rumex acetosella*, *Tussilago farfara*, *Taraxacum officinale*, *Trifolium pratense*, *Trifolium hybridum* , *Centaurea nigra*, *Cirsium arvense* , *Lotus corniculatus*, *Hieracium aurantiacum*, *Chrysanthemum leucanthemum*, *Phleum pratense*, *Hieracium pratense*, *Hieracium floribundum*, *Trifolium agarium*, *Cirsium vulgare*, and *Leontodon autumnalis*. High moose activity in the area.	442856	5483734	GPS
Mill Brook clear cuts		Alien species are present throughout the clear cut area. These species include *Ranunculus repens*, *Tussilago farfara*, *Taraxacum officinale*, *Ranunculus acris*, *Rumex acetosella*, *Chrysanthemum leucanthemum*, *Hieracium aurantiacum*, *Hieracium floribundum*, *Hieracium pilosella*, *Cirsium arvense* , *Myosotis scorpoides*, and *Cirsium vulgare*. Hawkweeds (*Hieracium* spp.) are plentiful in dry areas, while damp areas contain large amounts of *R. repens*, *T. farfara*, and *M. scorpioides*. There is a very high level of moose browsing and trampling throughout the area. Undisturbed closed canopy fir forest area was not being invaded by alien species. Clear cuts occurred all the way up the valley between Big Hill and Kildevil Mountain.	Road 442943	5483439	GPS
			Farthest point in from the road 443690	5484023	GPS

Kildevil Mountain	Y	Kildevil Mountain was surveyed in both 1998 and 1999 field seasons. South facing slopes on the mountain contained lush herbaceous vegetation ("alpine meadows"), and alien plants were found in these areas. In some cases these species were very close to plants considered rare in the park. Moose / caribou trails were very obvious disturbances on the mountain, and alien species were found on these trails. The presence of a species of *Taraxacum* is noteworthy in this area, it is uncertain whether it is a native species or the alien *Taraxacum officinale*.			
	Y	78 *Hieracium aurantiacum* and 5 *Hieracium pratense* within 5 square metres of this location.	447131	5482786	GPS
	Y	45 *Hieracium aurantiacum* near way point.	447208	5482733	GPS
	Y	2 *Ranunculus repens* ramets	447421	5483016	GPS
	Y	7 *Ranunculus repens* ramets	447406	5483015	GPS
	Y	25 *Ranunculus repens* ramets	447439	5483042	GPS
	Y	31 *Ranunculus repens* ramets	447212	5482837	GPS
	Y	19 *Hieracium* spp. (not flowering) occur here. Several rare plants occurred near this location including, *Arnica griscomii*, *Coeloglossum virade*, *Arabis drummondii*, and *Valeriana dioica* ssp. *sylvatica* (Anions, Pers. comm.1999).	447212	5482837	GPS
	Y	*Ranunculus repens* found on a moose trail near this location.	447870	5483405	GPS
	Y	*Ranunculus repens* found in several places on a moose trail at this location.	447404	5483008	GPS
	Y	Rosette of *Taraxacum* spp. found at this location.	447540	5483112	GPS
		Dense patch of *Hieracium pratense* 4/5 of the way up the scree slope to the summit of Kildevil Mt.. This is a west facing slope.	Unknown	Unknow n	

		Most of the southwest slope of Kildevil Mt. is fir forest. These forests contained old clear cuts, windfalls, and insect outbreaks. Fairly dry areas of these past disturbances contained *Hieracium floribundum*, *Hieracium aurantiacum*, *Digitalis purpurea*, *Hieracium pratense*, and *Taraxacum officinale*. Wet areas contained very high amounts of *Ranunculus repens*, *Ranunculus acris*, and *Tussilago farfara*.	Start 443550	5482200	GPS
			Summit 445100	5483190	GPS
Berry Hill Pond trail		*Taraxacum officinale*, *Tussilago farfara, Ranunculus acris*, *Trifolium* spp., and *Hieracium* spp. found in low numbers. *Ranunculus repens* was found in high numbers along the trail.	5498750	430760	Map
Berry Hill Hydro Station		Alien species present include *Taraxacum officinale*, *Trifolium agarium, Ranunculus acris, Hieracium pilosella, Hieracium pratense, Cirsium arvense* , *Chrysanthemum leucanthemum*, *Trifolium* spp., *Medicago lupulina*, *Tussilago farfara*, and *Arctium minus*.	433300	5495700	Map
Glenburnie salt marsh		No alien plants were seen in the active salt marsh area. The back shore flats of the salt marsh and where Mackenzies Brook flows into the marsh contained high numbers of *Centaurea nigra*, *Lotus corniculatus*, *Barbarea vulgaris*, and *Achillea millefolium*.	436250	5476200	Map
Fang Mountain clear cuts		Clear cuts to the northwest of Fang Mountain from the road, right up the valley in which the clear cuts occur contained alien species. Species present in clear cuts include *Hieracium caespitosum*, *Ranunculus repens*, and *Ranunculus acris* to a less degree. Near the road there is dense alder growth, but this did not prevent alien species in this area which included *Tussilago farfara*, *Cirsium arvense* , *Ranunculus repens*, *Trifolium* spp., *Achillea millefolium*, and *Ranunculus acris*. Alot of moose activity in the area.	Road 447550	5480490	Map
			Farthest surveyed up valley 448003	5480959	GPS

Rocky Barachois Brook pit		This area had one of the highest diversities of alien species in the park. Species in this pit which were not found anywhere else in the park include *Crepis tectorum*, and *Dianthus armeria*. This pit is still in use, and alien plant seeds preserved in the gravel from this pit may be spread to many areas of the park. Other alien species present in this area include *Hieracium pilosella*, *Hieracium aurantiacum*, *Hieracium floribundum*, *Chrysanthemum leucanthemum*, *Leontodon autumnalis*, *Medicago lupulina, Rumex crispus*, *T. agarium*, *Trifolium pratense*, *Rumex acetosella*, *Taraxacum officinale*, *Tussilago farfara*, *Matricaria matricarioides*, *Euphrasia* spp., *Senecio viscosus*, *Achillea millefolium*, *Phleum pratense*, *Cerastium vulgatum*, *Stellaria* spp., *Polygonum periscaria*, *Lotus corniculatus*, *Barbarea. vulgaris*, *Plantago major*, *Cirsium arvense*, *Cirsium vulgare*, *Leontodon autumnalis*, *Digitalis purpurea*, *Myosotis scorpioides, and Plantago major*.	general area 446881	5481405	GPS
Snowmobile trails and clear cuts near Cow Head	Y	Snowmobile trails pass through fir forest and bog, and lead to clear cuts. This area has high moose activity in the form of browsing, feces, and trampling. Alien species were not found anywhere along the bogs, but were present in high numbers along the trail in forested areas. Damp forested areas along the snowmobile trail and on moose trails were often covered in *Ranunculus repens*.This trail leads to a clear cut area about 50 minutes walk from the highway. This clear cut had high numbers of *Cirsium arvense*, *Tussilago farfara*, and *Ranunculus repens*. One area of this clear cut had a large mono-specific stand of *C. arvense*. Other alien species present in this area included *Rumex acetosella*, *Cerastium vulgatum*, *Taraxacum officinale*, and *Trifolium* spp.	Road 445330	5528870	Map
			clear cut (farthest off road) 448387	5529737	GPS
St. Paul's salt marsh		Alien species were not invading the salt marsh. But areas all around the salt marsh were rich in alien species. These areas included a graveyard, dirt road, and pasture land. Alien species present included *Taraxacum officinale*, *Ranunculus repens*, *Ranunculus acris*, several *Rumex* spp., *Trifolium* spp., *Leontodon autumnalis* and *Hieracium* spp.	440700	5523400	Map

St. Paul's golf course area		A large disturbance, which is new to the area. This disturbance is still ongoing. Little vegetation present in the area at the moment. Alien species present in small numbers include *Barbarea vulgaris*, *Taraxacum officinale*, *Tussilago farfara*, *Trifolium* spp., and *Rumex acetosella*.	general area 444600	5525450	Map
Stag Brook		*Tussilago farfara*, and *Ranunculus repens* were found in high numbers on the streambank, or on grassy flood plains along side the river. Other species found to a lesser degree in this area were *Phleum pratense*, *Ranunculus acris*, *Taraxacum officinale*, and *Trifolium repens*.	Start 437750	5511750	Map
			End 439300	5512270	Map
Western Brook sand dunes		Alien species did not appear to be invading the dunes. In sheltered areas of the dunes, where organic matter accumulated, *Taraxacum officinale* was sometimes found.	General area 438210	5519500	Map
Stuckless Pond trail		Much of this trail is on an old road bed, many alien species are present along it. Alien species present include *Hieracium* spp., *Centaurea nigra*, *Taraxacum officinale*, *Ranunculus acris*, *Tussilago farfara*, *Ranunculus repens*, *Malva moschata, Cirsium vulgare, Cirsium arvense* , *Poa* spp., *Trifolium* spp., *Lotus corniculatus*, and *Stellaria media*. Hawkweeds (*Hieracium*) were very abundant. Insect outbreaks and mud slides which occurred away from the trail were being invaded by *Ranunculus repens* in high numbers, and *T. officinale*, *R. acris*, and *Hieracium* spp. in low numbers. There is a lot of moose activity in this area. Closed canopy or *Kalmia*-spruce areas along the trail contained no alien species.	Start and end 446600	5474630	Map
Lomond River	Y	Alien species were found distributed in various places along the Lomond River from the highway (near the salmon fishing lodge) to the estuary of the river in Bonne Bay. The main species colonizing the river banks were *Tussilago farfara*, and *Ranunculus repens* with *Taraxacum officinale* and *Hieracium* spp. found to a less degree. Rare species occupying the same habitats as the alien plants were *Allium schenoprasm var. sibiricum*, and *Cypripedium calceolus*.	salmon lodge 447171	5472840	GPS
			near end of river 446496	5475625	GPS

Lomond River Estuary	Y	A grassy areas alongside the Lomond River estuary was rich in alien species, including *Chrysanthemum leucanthemum*, *Lotus corniculatus*, *Vicia cracca*, *Trifolium pratense*, *Taraxacum officinale*, *Stellaria media*, *Centaurea nigra*, *Phleum pratense*, *Ranunculus repens*, *Achillea millefolium*, *Cirsium arvense*, *Leontodon autumnalis*, and *Ranunculus acris*. The rare plant *Allium schenoprasm* var. *sibiricum* was present in this area.	446438	5476608	GPS
Snug Harbour to North Rim of Western Brook Pond		This trail had a small amount of *Tussilago farfara*, *Ranunculus repens*, *Hieracium* spp., and *Ranunculus acris* in wet areas near Snug Harbour. As the trail increased in elevation it changed from fir forest to alpine heath and tuckamore. No alien species were found along the trail in these areas.			
Norris Point Dump		Alien species present include *Capsella bursa-pastoris*, *Solanum dulcamara*, *Hieracium* spp., *Taraxacum officinale*, *Ranunculus repens*, *Ranunculus acris*, *Cirsium arvense* , *Trifolium pratense*, *Trifolium repens*, *Tussilago farfara*, *Rumex* spp., *Plantago major*, *Chrysanthemum leucanthemum*, *Phleum pratense*, *Vicia cracca*, *Leontodon autumnalis*, and *Phalaris canariensis*.	435320	548800	Map
Martin Point Area		A wet area that appeared undisturbed contained a large amount of *Ranunculus repens*, a moose trail near this also contained *Ranunculus repens*.	435300	5512175	GPS
Stanleyville trail		Many alien species occurred along the trail including *Ranunculus repens*, *Taraxacum officinale*, *Hieracium* spp., *Trifolium* spp., and *Ranunculus acris*. Insect outbreaks which occur along the trail contained numbers of *Ranunculus repens*, and lower abundances of *R. acris*, and *T. officinale*. The abandoned community of Stanleyville was rich in alien species including those previously mentioned and *Stellaria media*, *Achillea millefolium*, *Geranium pratense*, *Rumex acetosella*, *Rumex crispus*, and *Myosotis scorpioides*. Insect outbreaks, and windfalls in the area around Stanleyville contained *R. repens*, and *Digitalis purpurea*.	Start 444720	5478830	Map
			End 443650	5479450	Map

Lomond River trail	Y	This trail had many alien species present on it. All wet rivers and fens along the trail contained high amounts of *Tussilago farfara*, and *Ranunculus repens*. These species also colonized moose trails that intersected with the hiking trail. *Tussilago farfara* was restricted to moose trails in generally found in open canopy areas, while *R. repens* was found along moose trails in both open and closed canopy areas. *Tussilago farfara* was also found to be invading apparently undisturbed semi-open black spruce forest in near this area. Alien species found to a lesser degree along the hiking trail or on moose trails were *Hieracium floribundum*, *Hieracium pratense*, *Hieracium aurantiacum*, *Centaurea nigra*, *Chrysanthemum leucanthemum*, *Cirsium arvense*, *Ranunculus acris*, *Vicia cracca*, and *Taraxacum officinale*. *Cypripedium calceolus* a rare plant in GMNP was found near alien species on this trail. A native species which acted very 'weed like' on this trail was *Equisetum arvense*. The success of alien species in this area may be because the soils in this area appear basic, or neutral. The integrity of several apparently undisturbed areas along this trail appears to be altered by alien species.	Start 446380	5474910	Map
			End 445280	5477600	Map
Clear cut between Lomond and Glenburnie		This area is experiencing a high level of moose disturbance. Alien species found in this clear cut area in moderate amounts include *Ranunculus repens*, *Ranunculus acris*, *Leontodon autumnalis*, *Taraxacum officinale*, *Hieracium florentinum*, and *Galeopsis tetrahit*. Newly cut areas, and closed canopy fir forest did not contain any alien species in this area.	441269	5476770	GPS
Lomond Dump		Large number of alien species present at this site. The standard assemblage of species including *Taraxacum officinale*, *Tussilago farfara*, *Trifolium* spp. *Hieracium* spp., *Plantago major*, *Achillea millefolium*, and *Chrysanthemum leucanthemum*.	446150	5474270	Map

Big Hill		*Ranunculus repens* was very abundant on moose trails, and in clearings all the way up the western slope of Big Hill. Other species commonly found in clearings include *Cirsium arvense*, *Hieracium aurantiacum*, *Hieracium floribundum*, *Digitalis purpurea*, *Myosotis scorpioides*, *Leontodon autumnalis*, *Achillea millefolium*, and *Tussilago farfara*. The alpine heath on top of Big Hill was not found to contain any alien species. But the lush meadows on the south facing slope of Big Hill were found to contain alien species. Alien species were found along moose trails and relatively undisturbed areas in these meadow. These species locations are listed below.	Road 442099	5484055	GPS
			Top of Hill 442943	5483439	GPS
	Y	*Hieracium pratense* on south facing moose/caribou trail on top of Big Hill.	444049	5483439	GPS
	Y	3 stems of *Hieracium pratense*, and 1stem of *Hieracium aurantiacum* on south facing slope of Big Hill.	443980	5485628	GPS
	Y	Ramet of *Ranunculus repens* on south slope of Big Hill.	443894	5485656	GPS
	Y	28 *Hieracium pilosella*, 20 *Ranunculus repens*, and 17 *Hieracium pratense* near this location on the south facing slow of Big Hill.	443875	5485618	GPS
Lobster Cove Head		Many alien species found in the fields, and near lighthouse at Lobster Cove Head including *Leontodon autumnalis*, *Trifolium repens*, *Phleum pratense, Ranunculus acris*, *Cirsium arvense*, *Taraxacum officinale*, *Ranunculus repens*, *Achillea millefolium*, *Anthoxanthum odoratum*, several *Poa* spp., *Agropyron repens*, *Carum carvi*, *Hieracium* spp., *Rumex acetosella*, *Stellaria graminea*, and *Glechoma hederacea*. This site is representative of pastures, and fields along the coastline of GMNP.	430911	5494982	GPS
Lythrum salicaria locations		*Lythrum salicaria* is thought to be invasive in some wetland areas in other areas of North America. Michael Burzynski informed me of these locations, which I then surveyed.			

	Y	Lomond campground. There is a large patch of *Lythrum salicaria* in the fields, near a boardwalk, and around a picnic shelter at this site. The number of stems seen were too numerous to count (over 100). In one area *L. salicaria* is found growing very close to *Cypripedium reginae*, a rare plant in the park.	444996	5478921	GPS
	Y	Road to Lomond Campground. A small gravel pit along this road contained at 35 to 40 stems of *Lythrum salicaria*. This site is also noteworthy because the opposite road shoulder at this site had *Medicago sativa* growing along side it in two locations. *M. sativa* was not found anywhere else in the park. The high density of *Lotus corniculatus* at this site makes it very difficult to find *M. sativa* when it is not in flower.	*Lythrum salicaria* 445517	5477269	GPS
			M. sativa #1 445515	5477118	GPS
			M. sativa # 2 445476	5477066	GPS
	Y	Lomond River Lodge. A wet meadow behind the canteen contained 90 stems of *Lythrum salicaria*. The proximity of this site to the Lomond River is a concern because *L. salicaria* seeds have the potential to be dispersed downstream. *Centaurea nigra*, and *Ranunculus repens* were also at this site.	447171	5472840	GPS
	Y	Parks Canada, administration building, Rocky Harbour. Eight stems of *Lythrum salicaria* were removed from this area. The patch is found between a small shed and the corner of the administration building. Besides the standard assemblage of alien species at this site, other noteworthy species include *Typha latifolia*, and *Senecio vulgaris*.	434614	5492416	GPS
	Y	School in Norris Point. Two patches of *Lythrum salicaria*, for a total of 35- 40 stems was found alongside a dirt road behind the school.	436859	5487304	GPS

	Y	Wigwam Pond. A high number of *Lythrum salicaria* is found over a lar ge area at this site. *Lythrum salicaria* is distributed from a beaver pond and then down a small stream to Wigwam Pond. It is difficult to determine how much *L. salicaria* is at this site because most stems may not have been in flower, and the high density of alders in much of this area makes it difficult to see. *Lythrum salicaria* may be invasive at this site, and has the potential to spread in the future. Disturbance by beavers, moose, and past human activities in this area appear to have contributed to invasion. Other alien species present in high numbers in disturbed areas at this location include *Cirsium arvense* , *Ranunculus repens*, *Myosotis scorpioides*, *Tussilago farfara, Taraxacum officinale*, *Rumex* spp., and *Galeopsis tetrahit*.	beaver dam 455340	5472473	GPS
			Wigwam Pond 455112	5472519	GPS
Baker's Brook		Alien species found along the stream bank surveyed were *Taraxacum officinale*, *Tussilago farfara*, *Ranunculus repens*, and *Cirsium arvense* . The native species *Equisetum arvense* occurred in high numbers in some areas along this stream. Large slumps all along the river were being colonized in large amounts by *T. farfara* and *E. arvense*, and to a lesser degree by *T. officinale*. *Ranunculus repens* occurred frequently along muddy moose trails and in alder thicket alongside the stream.	highway bridge 430950	5500700	Map
			Farthest point up river 432297	5500673	GPS
Green Point snowmobile trail		The snowmobile trail passed over bog, and fir forest. No alien species were found along bog areas. Insect outbreaks, clear cuts, and moose trails in fir forest contained *Ranunculus repens*, and *Ranunculus acris* to a lesser degree.			
		Clear cuts, and moose trails containing *Ranunculus repens* and *Ranunculus acris*.	433989	5503981	GPS
	Y	Beaver dam, and shore of nearby pond in a wet fen area contained at least 40 - 50 ramets of *Tussilago farfara*.	434775	5503935	GPS

		A moose trail in an insect outbreak contained over 100 ramets of *Tussilago farfara*.	435072	5504196	GPS
Stream on lowlands near Green Point		Flood plain area of a small stream contained a lot of alien species including *Vicia cracca, Ranunculus repens, Ranunculus acris, Taraxacum officinale*, and *Cirsium arvense*. This area is experiencing high a level of moose disturbance.	432840	5503751	GPS
Snug Harbour trail		Alien species found along the trail all the way into Snug Harbour include *Hieracium floribundum*, *Ranunculus repens*, *Tussilago farfara*, and *Cirsium arvense* . Other species which occur more sporadically on the trail include *Taraxacum officinale*, *Cirsium vulgare*, *Cerastium vulgatum*, *Ranunculus acris*, *Stellaria media*, and *Ranunculus acris*. Insect outbreaks (windfalls ?) along the trail were found to contain *C. arvense*, *R. repens*, and *T. officinale*. A stream flowing into Western Brook Pond just before Snug Harbour had *R. repens*, *T. farfara*, *C. arvense* , and *T. officinale* along its banks. *T. farfara* was in very high numbers along gravel banks of the stream.	trail start 439560	5515579	GPS
			Snug Harbour 441954	551019	GPS
			Stream 441954	551019	GPS
			Insect outbreak 441691	551469	GPS
Trout River Pond Campground		Alien species found at this site include *Trifolium repens*, *Trifolium pratense*, *Matricaria matricarioides*, *Cirsium arvense*, *Cirsium vulgare*, *Ranunculus acris*, *Ranunculus repens*, *Achillea millefolium*, *Leontodon autumnalis*, *Plantago major*, *Plantago lanceolata*, *Taraxacum officinale*, and *Hieracium* spp.			
Trout River Pond Lookout		This area contained the following alien species: *Trifolium hybridum*, *Trifolium repens*, *Vicia cracca*, *Achillea millefolium*, *Tussilago farfara*, *Hieracium pratense*, *Hieracium pilosella*, *Cirsium arvense*, *Chrysanthemum leucanthemum*, *Carum carvi*, *Ranunculus acris*, *Ranunculus repens*, and *Plantago lanceolata*.			

Pit near Lomond River Lodge		Alien species present include *Trifolium agarium*, *Medicago lupulina*, *Lupinus perennis*, *Tussilago farfara*, *Taraxacum officinale*, *Trifolium pratense*, *Trifolium hybridum*, *Cirsium arvense*, *Centaurea nigra*, *Lotus corniculatus*, *Ranunculus acris*, *Ranunculus repens*, and *Plantago lanceolata*.			
Deer Arm River	Y	Section of Deer Arm River from the pole line which crosses the stream to the estuary area near the highway contained alien species. *Tussilago farfara*, *Taraxacum officinale*, *Ranunculus repens*, and *Hieracium floribundum* were found sporadically alongside the stream. Alder thicket near the stream which is disturbed by flooding and moose contained high numbers of *R. repens*. The Deer Arm estuary area contained the above mentioned species, along with *Chrysanthemum leucanthemum*, *Ranunculus acris*, and *Cirsium arvense*. This area also contained the rare plant *Allium schenoprasm* var. *sibiricum*.	Pole line 439600	5492100	Map
			Estuary 439413	5490779	GPS

Appendix 4

Study Site Descriptions and Locations

Appendix 4: Description and Location of Study Sites in Gros Morne National Park

Site Type	Study Site	Symbol	Number of Transects	Number of quadrats by disturbance regime				UTM Coordinates		Description / Comments
				H	M	L	U	E	N	
insect outbreak	Bakers Brook trail insect outbreak #1	BBT#1	2	2	6	6	2	443387	5498382	~ along Bakers Brook Falls trail; insect outbreak occurred in 1987 ~ transects runs from open canopyto closed canopy fir forest ~ moose activity in the form of browsing, trampling, and feces ~ moss dried up in some areas ~ *Ranunculus repens* , *R.acris* , and *Myosotis scorpioides* present
insect outbreak	Bakers Brook trail insect outbreak #2	BBIO#2	2	_	7	15	5	433004	5497929	~ along Bakers Brook Falls trail; insect outbreak occurred in 1987 ~ transects run from open canopy to closed canopy fir forest ~ moss dried up in some areas ~ moose activity in the form of browsing, trampling, and feces ~ *Ranunculus repens* ,and *Cirsium arvense* present
insect outbreak	Martin Point insect outbreak	MPI	1	_	_	12	2	435300	5512175	~ site is located east of the highway at Martin Point ~ insect outbreak is at least 20 years old ~ transect runs from open canopy to closed canopy spruce and fir ~ many standing dead trees in the area ~ no alien species present
insect outbreak	Stuckless Pond insect outbreak	SPI	3	_	_	22	_	448182	5475150	~ insect outbreak occurred in 1987 ~ transect runs from open canopy to semi-open canopy of birch/fir ~ many standing dead trees in the area ~ moss dried up in some areas ~ *Ranunculus repens* , *R. acris* , and *Hieracium* spp. present
insect outbreak	Snug Harbour insect outbreak	SHIO	2	_	_	7	2	441691	5514469	~ disturbance appears to have occurred in 1992 ~ this may be predominantly a windfall rather than insect ~ transects run from an outbreak to closed canopy spruce and fir ~ *Cirsium arvense* , *R. repens* , and *Taraxacum officinale* present
hiking trail	Western Brook Pond trail fir forest	WBPTFFT	1	3	_	1	1			~ transect runs from gravel trail to fir forest ~ many alien plant species found on Western Brook Pond Trail
hiking trail	Western Brook Pond trail bog	WBPTBT	1	_	4	_	_			~ transect runs from edge of board walk into bog ~ areas where gravel occurred had alien species ~ undisturbed bog was not being invaded by alien species ~ *Ranunculus acris* , *Taraxacum officinale* present
hiking trail	Lobster Cove Head	LCHT	2	3	3	6	4	430911	5494982	~ transects run from a gravel trail, across field into tuckamore ~ right beside Lobster Cove Head Lighthouse ~ near ocean cliffs

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Site Type	Study Site	Symbol	Number of Transects	Number of quadrats by disturbance regime				UTM Coordinates		Description / Comments
				H	M	L	U	E	N	
										~ many alien species present
hiking trail	Green Gardens trail birch	GGTBT	1	2	_	2	2	424587	5483981	~ transect runs from trail into a small area of birch ~ semi-open canopy area ~ no aliens present
hiking trail	Green Gardens trail fir	GGTFT	2	4	3	6	1	423040	5486153	~ transects run from a semi-closed trail to a closed fir forest ~ damp in some areas ~ moose activity in the form of trampling, and feces ~ *Ranunculus repens* present in high numbers
hiking trail	Mail Road field transect	MRFT	2	4	2	16	6	445656	5532336	~ transects run from middle of trail across a field and into fir forest ~ many alien species present
roadside	Deer Arm road transect	DRT	3	6	5	9	3	438897	5491217	~ transects run from roadside to closed canopy forest ~ many alien species present
roadside	Western Brook Pond road bog	WBRBT	2	3	_	15	5	437295	5516368	~ transects run from road shoulder to undisturbed bog ~ disturbed bog off the road contained many rushes and sedges ~ construction of the road altered drainage to a large area of bog
roadside	Wiltondale road transect	WRT	3	6	6	25	_	455005	5474152	~ transects run from edge of road to closed canopy fir forest ~ fir forest in this area still shows signs of past disturbance ~ many alien species present
moose trail	Lomond River trail fen moose trail	LFMTT	2	0	6	3	3	446149	5475342	~ transects run from fen across moose trail and into black spruce ~ damp ~ undisturbed areas or very slightly disturbed contained aliens ~ *C.nigra* , *T.farfara* , *R.repens* , *Chrysanthemum leucanthemum* ~ *Trifolium* spp., *Hieracium* spp., *Leontodon autumnalis* , *R.acris*
hiking and moose trail	Lomond River trail canopy moose trail	LCMTT	1	_	7	_	4	446133	5475848	~ transect runs from fir forest, across a hiking and moose trail ~ moose trail may have been an abandoned woods path ~ closed canopy fir forest ~ alien species found along moose trail ~ *Taraxacum officinale* , *Ranunculus repens* present
moose trail	Kildevil Mountain	KT	4	6	1	7	9	447870 447404 447131 447208	5.5E+07 5483008 5482786 5482733	~ alpine meadow (lush herbaceous vegetation) ~ transects located on the south facing slope of Kildevil Mountain ~ 3 transects run from tuckamore to herbaceous vegetation ~ 1 transect runs from alpine heath to herbaceous vegetation ~ above three transects cross moose trails ~ moose trails found throughout area

Appendix 4: Description and Location of Study Sites in Gros Morne National Park

Site Type	Study Site	Symbol	Number of Transects	Number of quadrats by disturbance regime				UTM Coordinates		Description / Comments
				H	M	L	U	E	N	
										~ *Ranunculus repens* , *Hieracium auranticum* present
moose trail	James Callahan trail moose trail	JCMT	1	3	4	_	2	439767	5490920	~ transect runs from trail into the forest along a moose trail ~ *Ranunculus acris* , and *Ranunculus repens* are present
moose trail	Big Pond Moose trail	BPMT	2	2	_	_	2	446972	5529474	~ transect runs from a moose trail to a closed canopy fir forest ~ very wet and muddy on the moose trail ~ Ranunculus repens present
moose trail	Big Hill	BHT	3	2	_	3	4	443789	5485522	~ south facing alpine meadow ~ transects run from tuckamore onto alpine meadow ~ *Ranunculus repens* , *Hieracium pratense* , *H.pilosella* present
esturary and hiking trial and moose trail	Lomond River 1	LRT1	1	1	2	6	_	446238	5476608	~ transect runs from the edge of Lomond river estuary into fir forest ~ transect crosses through alder thicket, and then over trail ~ transect runs parallel to a moose trail, and a stream ~ closed canopy fir forest shows signs of past disturbance ~ *Vicia cracca* , *Phleum pratense* , *Ranunculus acris* , *R.repens* ~ *A.millefolium* , *L. autumnalis* , *L.corniculatus* , *T.pratense* ~ *Centaurea nigra* , *Cirsium arvense* , *C.leucanthemum* ~ rare plant *Allium schenoprasm* var. *sibiricum* present
estuary river	Deer Arm River	RDAT	4	8	1	6	4	439513 439441 439299 439322	5490779 5490805 5490976 5491082	~ two transects run from the estuary area into fir forest ~ two transects run from Deer Arm Brook into fir forest ~ all four transects run through alder thicket ~ *Allium schenoprasm* var.*sibiricum* found near estuary transects ~ *Hieracium florentinum* , *Myosotis scorpioides* ~ *Ranunculus repens* , *Taraxacum officinale* , *Tussilago farfara*
river	Lomond River 2	LRT2	1	2	_	3	2	446496	5475625	~ tranect runs fromrRiver across alder thicket and into spruce ~ wet, and muddy near stream and in alder thicket ~ *R.acris* , *Centaurea nigra* , *Taraxacum officinale* near stream
river	Bakers Brook	BBRT	3	3	_	3	3	431260	5500998	~ transect runs from river to closed canopy fir forest ~ *Tussilago farfara* , *Taraxacum officinale* , *R.repens* present
river	Green Point River	GPRT	1	1	1	1	1	432840	5503751	~ transect runs from river through alders thicket and into spruce ~ transect passes over moose trail ~ *C.arvense* , *R.repens* , *T.officinale* , and *Vicia cracca* present
river	Western Brook	WBT	2	2	_	_	2	439560	5515579	~ transect runs from river to closed canopy fir forest ~ *R. repens* , *Taraxacum officinale* , and *Tussilago farfara* present
river	Snug Harbour River	SHRT	2	5	_	1	2	441954	5514019	~ transects run from brook in to closed canopy fir forest

Appendix 4: Description and Location of Study Sites in Gros Morne National Park

Site Type	Study Site	Symbol	Number of Transects	Number of quadrats by disturbance regime				UTM Coordinates		Description / Comments
				H	M	L	U	E	N	
										~ river flows into Snug Harbour of Western Brook Pond ~ *Tussilago farfara* , *Taraxacum officinale* , *R.repens* present
clear cut	Lomond Glenburnie clear cut old	LGCCOT	2	_	16	1	2	441269	5476770	~ transects run from a patch of undisturbed fir forest to a clear cut ~ clear cutting occurred in 1993 ~ moose browsing, trampling and feces obvious ~ moss layer is dried up in areas ~ tranect passes over a skidoo trail ~ *Leontodon autumnalis* , *Galeopsis tetrahit* , *Hieracium pratense* ~ *Ranunculus repens* , *Ranunculus acris*
clear cut	Lomond Glenburnie clear cut new	LGCCNT	1	_	14	_	4	441276	5476709	~ clear cutting occurred in the previous winter (freshly cut boughs) ~ transects run from fir forest to a clear cut ~ on a steep hill ~ moss layer still intact ~ no alien species present
clear cut	Big Pond clear cut transect	BPCCT	2	_	20	1	4	448387	5529737	~ transects run from clear cut to a closed canopy forest ~ moose browsing, trampling and feces obvious ~ *C.arvense* , *T.officinale* , *R.repens* , and *T.farfara* present
clear cut	Fang Mountain clear cut	FMCC	2	1	4	_	2	448003	5480959	~ clear cut in 1987, is small and shaded by forest on all sides ~ transects run from closed canopy fir forest to a small clear cut ~ moose browsing, trampling, and feces present ~ dried up moss in some areas of clear cut ~ *Ranunculus repens* , *Hieracium caespitosum* present
clear cut	Mill Brook clear cut	MBCCT	2	3	3	1	1	443582	5484094	~ clear cut in 1995 ~ transects run from closed canopy fir forest to a clear cut ~ moose browsing, trampling, and feces present ~ *Ranunculus repens* , *Myosotis scorpioides* present
pit	Rocky Barachois Brook pit	RBBP	1	_	8	1	2	446881	5481405	~ transect runs from pit to black spruce forest ~ many alien species found at this pit
pit	Mill Brook pit	MBP	1	_	8	1	2	442856	5483734	~ transect runs from pit, through alders, to closed canopy fir forest ~ fairly recent pit (later than 1990) ~ many alien species present

Appendix 5
Functional Group Analysis Symbols and Definitions

Life Form (Raunkiaer's Scheme) (From McIntyre et al.1995)
1= Therophyte (Annual)
2 = Geophyte - Persistant Buds buried to a depth of 2-3 cm
3 = Chamaephyte (Persistent Buds >1 cm and < 20 - 30 cm above ground surface
4 = Phanerophyte Persistent Buds > 20 - 30 cm on stems above the ground
Hemicryptophyte - Persistent buds are in the immediate vicinity of the soil surface only, maximum height 1cm.
Within Hemicryptophytes
5 = Flat or Versatile Rosette - all leaves radical; leaves flat or erect, depending on growing conditions
6 = Partial rosette - Radical and cauline leaves, largest leaves on the lowest portion of the stem.
7 = Proto-hemicryptophyte - All leaves cauline; largest leaves towards the middle of the stem.

Success
1 = Successful - Alien species commonly found in GMNP which were found to successfully invade areas remote from high human activity several times.
2 = Occasional - Alien species which were found to successfully invade areas remote from high human activity on one or two occasions, but do not appear to be problematic species.
3= Unsuccessful - Alien species commonly found in GMNP which did not successfully invade any areas of high human activity

Vegetative reproduction
Vegetative reproduction refers to asexual reproduction which does not disperse alien species long distances, but instead maintains or increases a species abundance in an areas already colonized.
1 = no
2 = yes

Dispersal of Asexually Produced Propagules
Dispersal of asexually produced propagules refers to asexual reproduction which dispersed alien species through apomixis, self-fertilization, or vegetative fragmentation.
1 = no
2 = uncertain
3 = yes

Flowering Period
1 = Early (May, June,July)
2 = Middle (June, July, August)
3 = Late (July, August, September)
4 = Throughout (Greater than 3 months, May - August, June -September)

Seed Dispersal Unit Morphology
1 = Adhesion (prescense of spines, hooks, awns, barbs or callus hairs)
2 = Ingestion (Fleshy dispersal Units)
3 = Wind (Wings or Pappus)
4 = Mobile (largest dimension < 0.6mm)
5 = Dehiscent
6 = Uncertain or more than one of the above

Maximum Flowering Height
1 = 0 - 499 mm
2 = 500 - 999 mm
3 = 1000 mm or greater

Seed Weight
1 = Very Small = < 0.1 mg
2 = Small = 0.1 - 0.5 mg
3 = Medium = 0.5 - 1.5 mg
4 = Large = 1.5 - 3.0 mg
5 = Very Large = > 3.0 mg

Appendix 6

Plant Species Codes

Note: most recent species nomenclature according to Meades et al. (2000) is listed in the species list (Appendix2)

* indicates species is considered alien.

? indicates the origin of species is questionable, maybe alien.

aka = also known as.

AA = Angelica atropurpurea

AAA = Agrostis alba?

AB= Abies balsamea

ABS = Achillea borealis

AC=Anemone canadensis

ACA = Agrostis canina

AD = Arabis drummondi

AF = Athyrium felix-femina

AFS = Alchemilla filicaulis

AG = Andromeda glaucophylla

AGA = Agrostis geminata

AGBO = Agrostis borealis

AHS = Agrostis hyemalis

AM = Achillea millefolium*(only some populations are alien).

AM spp. = Amelanchier spp.

AMA = Anaphalis margaritacea

AMS = Arctium minus

AN = Aralia nudicaulis

ANA = Aster novae-angliae

ANB = Aster novae-belgii

ANS = Aster nemoralis

AO = Anthoxanthum odoratum*

AP = Aster puniceus

APE = Agrostis perennans

AR = Alnus rugosa

ARS = Agropyron repens*

ARu = Acer rubrum

AS = Acer spicatum

ASA = Agrostis scabra

ASM = Allium schoenoprasum var. sibiricum

Aspp=Aster species

AT = Agrostis tenuis

AU = Aster umbellatus

AUI = Arctostaphylos uva-ursi

AUM = Atrichum undulatum

BG = Betula glandulosa
BP = Betula papyrifera
BPS = Bellis perennis
CAA = Circaea alpina
CAAD = Carex adusta
CACA = Carex canescens
CACO = Carex concinna
CACR = Carex crinita
CAE = Cirsium arvense*
CALA = Carex leptalea
CAM = Chenopodium album
CAR = Carex angustior
CAST = Carex stipata
CAU = Carex aurea
CB = Clintonia borealis
CBP = Capsella bursa-pastoris
CBS = Carex brunnescens
CC = Cornus canadensis
CCA = Chamaedaphne calyculata
CCAS = Carex capillaris
CCE = Conioselinum chinese
CCI = Carum carvi*
CCS = Calamagrostis canadensis
CD = Carex disperma
CE = Carex echinata
CF = Carex flava
CG = Coptis groenlandica
CI = Calamagrostis inexpansa
CIR = Carex interior
CL = Chrysanthemum leucanthemum*
CLA = Cinna latifolia
CLS = Carex lenticularis
CM = Cirsium muticum
CN = Centaurea nigra*
CNI = Carex nigra
Cp = Campylium polyganum
CPA = Carex projecta
CPI = Calamagrostis pickeringii
CPS = Caltha palustris
CR = Campanula rotundifolia
CS = Cornus stolonifera
CSA = Carex salina

CT = Carex trisperma
CV = Cerastium vulgatum*
CVA = Carex vaginata
CVE = Cirsium vulgare*
DD=Dryopteris disjuncta
DF = Deschampsia flexousa
DG = Dactylis glomerata*
DM = Dicranum majus
DP = Dicranum polysetum
DPA = Digitalis purpurea*
DPS=Dryopteris phegopteris
DR = Drosera rotundifolia
DSA = Danthonia spicata
DSM = Dicranum scoparium
DSvarA = Dryopteris spinulosa var. americana
DSvarI = Dryopteris spinulosa var. intermedia
DSvarT = Dryopteris spinulosa var. typicum
E sp = Eupharasia spp.
EA = Epilobium angustifolium
EAE = Equisetum arvense
EAS = Elymus arenarius
EC = Eriophorum callitrix
EE= Empetrum eamesii
EG = Epilobium glandulosum
EM = Eupatorium maculatum
EN = Empetrum nigrum
EP = Equisetum pratense
ER = Epigaea repens
ES = Equisetum sylvaticum
ESI = Eleocharis smalli
FE = Festuca elatior*
FO = Festuca ovina*
FV = Fragaria virginiana
GA = Gentiana acuta
GP = Galium palustre
GH = Gaultheria hispidula
GHA = Glechoma hederacea
GM = Geum macrophyllum
GS = Glyceria striata var. striata
GT= Galium triflorum
GTT = Galeopsis tetrahit*?
HA = Hieracium aurantiacum*

HC = Hieracium caespitosum*
HCE= Hieracium canadense
HD = Halenia deflexa
HF = Hieracium floribundum*
HFM = Hieracium florentinum*
HM = Heracleum maximum
HP = Hieracium pratense*
HPA = Hieracium pilosella*
HR = Hypnum revolutum
HS = Hylocomium splendens
HU = Hylocomium umbratum
HYP = Hypericum perforatum
IC = Impatiens capensis
IV = Iris versicolor
JA = Juncus alpinus
JAS = Juncus articulatus
JB = Juncus brevicaudatus
JBA = Juncus bulbosa
JC = Juniperus communis
JD= Juncus Dudleyi
JE = Juncus effusus
JF = Juncus filiformis
JM = Juncus militaris
JT = Juncus trifidus
KA = Kalmia angustifolia
KP = Kalmia polifolia
L spp. = Lactuca spp.
LA = Leontodon autumnalis*
LB = Linnaea borealis
LC = Lotus corniculatus*
LCA = Listera cordata
LG = Ledum groenlandicum
LL = Larix laricina
LLI = Liparis loeselli
LM = Luzula multiflora
LS = Lythrum salicaria
LV = Linaria vulgaris
Ly spp. = Lycopodium spp.
MC = Maianthemum canadense
MG = Myrica gale
MM = Matricaria matricarioides
MN = Mitella nuda

MP = Mnium puncatum
MS = Myosotis scorpioides
MU = Moneses uniflora
NM= Nemopanthes mucronata
OC = Osmunda cinnamomea
OS = Onoclea sensibilis
P spp = Pyrola spp. (not in flower at the time)
PA = Prenanthes alba
PAA = Potentilla anserina
PAM = Phleum alpinum
PAS = Poa alsodes
PC = Polytrichum commune
PCA = Poa compressa*
PCC = Ptilium crista-castrensis
PCM = Polygonum cuspidatum
PD = Platanthera dilatata
PF= Philantis fontona
PFA = Potentilla fruticosa
PG = Picea glauca
PH = Polyganum hydropiper
PHP = Phleum pratense*
PJM = Polytrichum juniperinum
PM = Picea mariana
PMA = Primula mistassinica
PMJ = Plantago major*
POFE = Poa fernaldiana
POSU = Poa subcaerulea
PP = Prunus pensylvanica
PPA = Parnassia parviflora
Pper = Polygonum persicaria
PPS = Poa pratensis?
PrA = Prenanthes alba
PS = Pleurozium schreberi
PSA = Pyrola secunda
PSS = Poa saltuensis
PT = Potentilla tridentata
PTA = Prenanthes trifoiliata
PTS = Poa trivialis?
PUPA = Puccinellia paupercula
PV = Prunella vulgaris
PVM = Polyganum vivipariuim
PVS = Pinguicula vulgaris

R spp. = Ribes spp.
RA = Ranunculus acris*
RAA = Rhamnus alnifolia
RAB = Ranunculus abortivus
RAS = Rumex acetosella*
RC = Rhinanthus crista-galli
RCE = Rhododendron canadense
RCS = Rubus chamaemorus
RG = Ribes glandulosum
RI = Rubus idaeus
RL = Rhytidiadelphus loreus
RLE = Ribes lacustre
RLM = Racomitrium lanuginosum
RP = Rubus pubescens
RR = Ranunculus repens*
RS = Rhytidiadelphus squarrous
RT = Rhytidiadelphus triquestrus
RUA = Rumex acetosa
RUC = Rumex crispus
RUO = Rumex obtusifolius
SA = Sorbus americana
SAS = Streptopus amplexifolius
SC = Sagina procumbens
SCAS = Scirpus atrocinctus
SCRU = Scirpus rubrotinctus
SCS = Sanguisorba canadensis
SD = Sorbus decora
SGA = Stellaria graminea*
SH = Solidago hispida
SHC = Shepherdia canadensis
SJ = Senecio jacobea
SM = Stellaria media*
SMA = Solidago macrophylla
SMM = Sisyrinchium montanum
SOA = Sonchus asper
SOO = Sonchus oleraceus
SP = Sambucus pubens
Sper spp. = Spergularia spp.
Sph spp. = Sphagnum spp.
SR = Solidago rugosa
SRS= Streptopus roseus
SU = Solidago uliginosum

SVI = Senecio viscosus
SVU = Senecio vulgaris
SVS = Satureja vulgaris?
Sx spp. = Salix spp.
TA = Trifolium agarium*
TB = Trientalis borealis
TC = Trillium cernuum
TCS = Taxus canadensis
TF = Tussilago farfara*
TG = Tofieldia glutinosa
TH= Trifolium hybridum*
TL = Typha latifolia
TM = Triglochin maritimum
TO = Taraxacun officinale*
TP = Trifolium pratense*
TPA= Tetraphis pellucida
TPM = Thalictrum polygamum
TR= Thuidium recognitum
TRS = Trifolium repens*
TS = Trisetum spicatum
VA = Vaccinium angustifolium
VB = Vaccinium boreale
VC = Vicia cracca
VCS = Viburnum cassinoides
VE = Viburnum edule
VO = Vaccinium oxycoccus
VOF = Veronica officinalis
Vt = Viola spp.
VTM = Viburnum trilobum
VU = Vaccinium uliginosum
VV = Vaccinium vitis-idaea

Appendix 7

Additional Results from CCA Analysis used in Thesis

<u>Summary of CCA for the relationship of species with significant environmental variables in all quadrats sampled in GMNP</u>

Axes	1	2	3	4	Total inertia
Eigenvalues	0.403	0.234	0.156	0.149	10.801
Species-environment correlations	0.847	0.755	0.693	0.688	
Cumulative percentage variance of species data	3.7	5.9	7.4	8.7	
Cumulative percentage variance of species-environment relation	29.1	46	57.3	68.1	
Sum of all unconstrained eigenvalues					10.801
Sum of all canonical eigenvalues					1.385

<u>Summary of Monte Carlo Test</u> (199 permutations)
Test of first canonical axis: eigenvalue = 0.403
F -ratio = 5.665
P-value = 0.0050
Test of significance of all canonical axes: trace = 1.385
F- ratio = 2.387
P-value = 0.0050

Summary of CCA for the relationship of species with significant environmental variables within forested areas of GMNP

Axes	1	2	3	4	Total inertia
Eigenvalues	0.191	0.131	0.123	0.069	5.018
Species-environment correlations	0.757	0.718	0.753	0.556	
Cumulative percentage variance of species data	3.8	6.4	8.9	10.2	
Cumulative percentage variance of species-environment relation	37.2	62.8	86.7	100	
Sum of all unconstrained eigenvalues					5.018
Sum of all canonical eigenvalues					0.514

Summary of Monte Carlo Test (199 permutations)
Test of first canonical axis: eigenvalue = 0.191
F -ratio = 3.050
P-value = 0.0050
Test of significance of all canonical axes: trace = 0.514
F- ratio = 2.196
P-value = 0.0050

Summary of CCA for the relationship of species with significant environmental variables within riparian areas of GMNP

Axes	1	2	3	4	Total inertia
Eigenvalues	0.388	0.25	0.204	0.57	5.374
Species-environment correlations	0.832	0.797	0.812	0	
Cumulative percentage variance of species data	7.2	11.9	15.7	26.3	
Cumulative percentage variance of species-environment relation	46.1	75.8	100	0	
Sum of all unconstrained eigenvalues					5.374
Sum of all canonical eigenvalues					0.843

Summary of Monte Carlo Test (199 permutations)
Test of first canonical axis: eigenvalue = 0.388
F -ratio = 3.272
P-value = 0.0050
Test of significance of all canonical axes: trace = 0.843
F- ratio = 2.604
P-value = 0.0050

Summary of CCA for the relationship of species with significant environmental variables in areas containing alien species in GMNP

Axes	1	2	3	4	Total inertia
Eigenvalues	0.298	0.19	0.143	0.12	7.055
Species-environment correlations	0.811	0.773	0.736	0.726	
Cumulative percentage variance of species data	4.2	6.9	8.9	10.6	
Cumulative percentage variance of species-environment relation	35.8	58.7	75.9	90.4	
Sum of all unconstrained eigenvalues					7.055
Sum of all canonical eigenvalues					0.83

Summary of Monte Carlo Test (199 permutations)
Test of first canonical axis: eigenvalue = 0.298
F -ratio = 2.994
P-value = 0.0050
Test of significance of all canonical axes: trace = 0.830
F- ratio = 1.813
P-value = 0.0050

<u>Summary of CCA for the relationship between functional characteristics of alien species to invasion success in GMNP</u>

Axes	1	2	3	4	Total inertia
Eigenvalues	0.27	0.216	0.784	0.73	2
Species-environment correlations	0.52	0.465	0	0	
Cumulative percentage variance of species data	13.5	24.3	63.5	100	
Cumulative percentage variance of species-environment relation	55.5	100	0	0	
Sum of all unconstrained eigenvalues					2
Sum of all canonical eigenvalues					0.486

<u>Summary of Monte Carlo Test</u> (199 permutations)
Test of first canonical axis: eigenvalue = 0.270
F -ratio = 7.652
P-value = 0.0050
Test of significance of all canonical axes: trace = 0.486
F- ratio = 0.7.872
P-value = 0.0050

Appendix 8

Additional Results

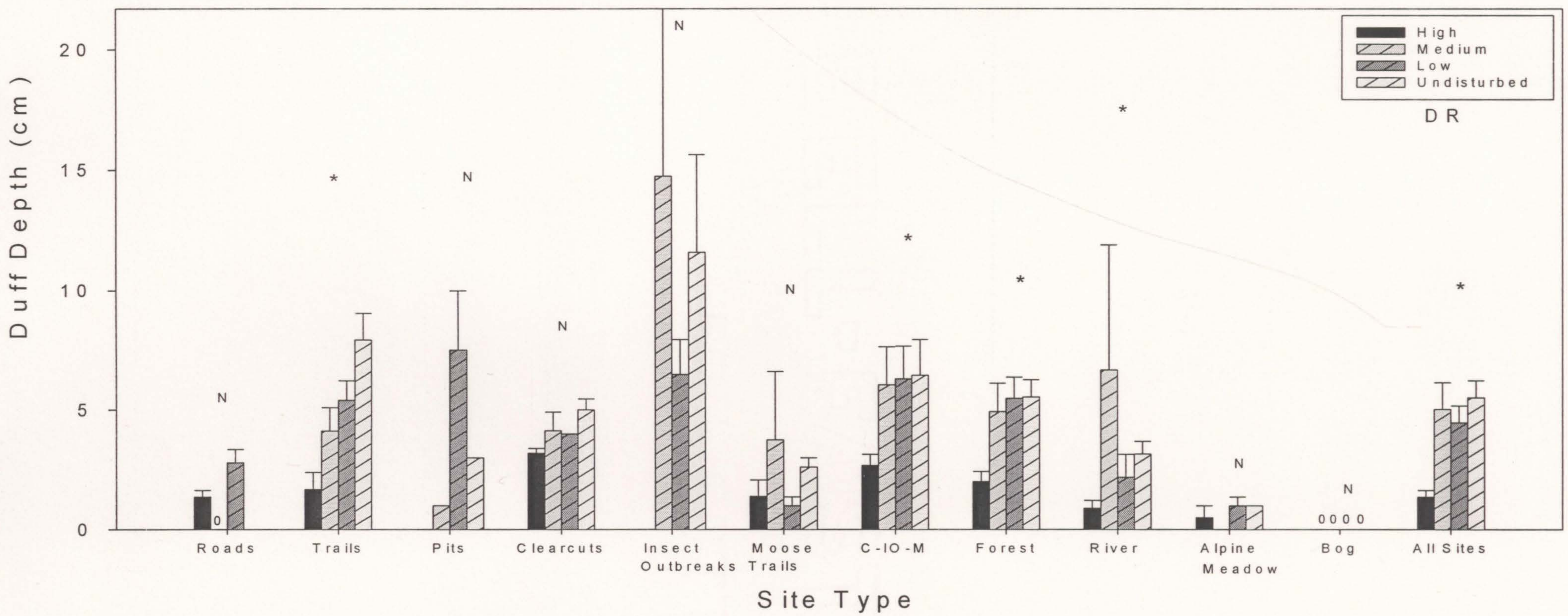

Figure 1: Change in Duff Depth with Disturbance Regime at Disturbance Types and Vegetation Types Sampled in GMNP

0 = indicates that disturbance regime was sampled for duff depth with a value of zero.

C-IO-M = Remote forest disturbances = Clearcuts, insect outbreaks, and moose trails combined.

Forest = All disturbance types sampled which occurred in forest vegetation (roads, pits, trails, clearcuts, moose, insect).

* = Significant difference (at 0.05) between high and undisturbed disturbance regimes.

N = Significant difference between high and undisturbed disturbance regimes was not tested.

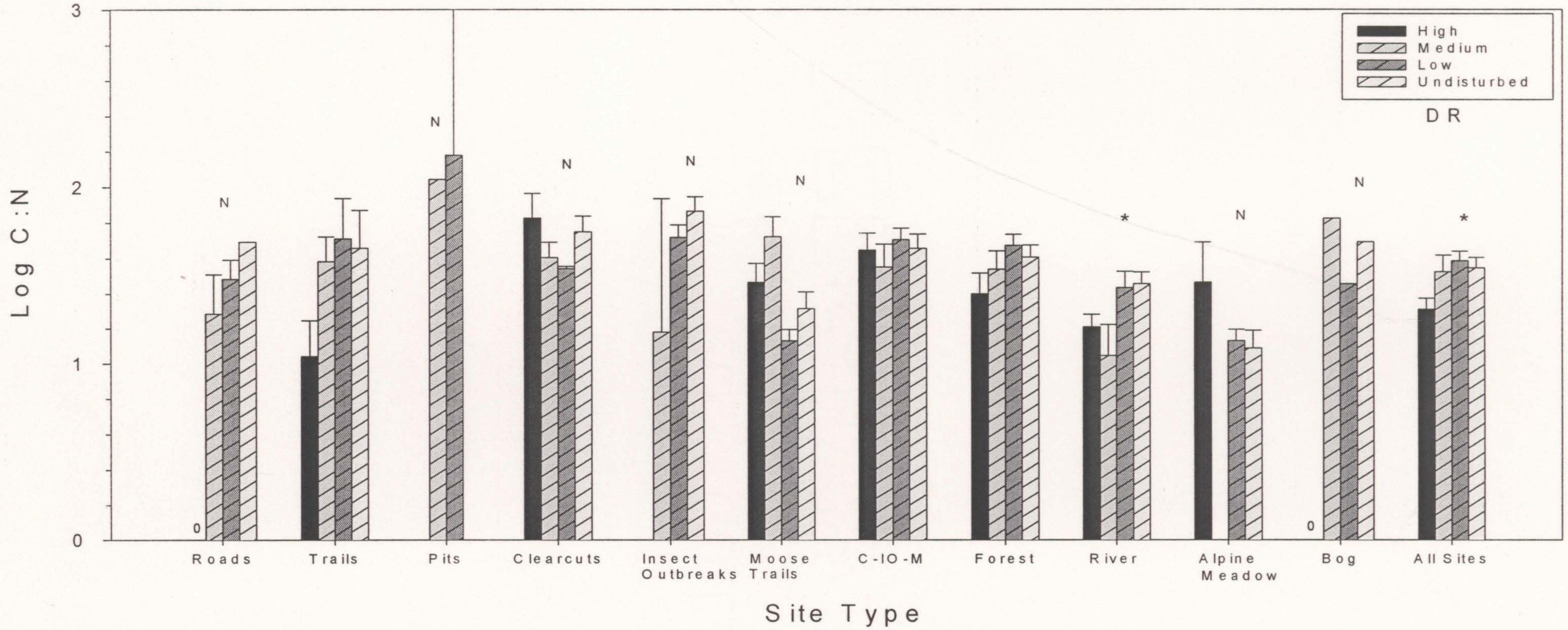

Figure 2: Change in Log C:N with Disturbance Regime at Disturbance Types and Vegetation Types Sampled in GMNP

0 = indicates that disturbance regime was sampled for log C:N with a value of zero.

C-IO-M = Remote forest disturbances = Clearcuts, insect outbreaks, and moose trails combined.

Forest = All disturbance types sampled which occurred in forest vegetation (roads, pits, trails, clearcuts, moose, insect).

* = Significant difference (at 0.05) between high and undisturbed disturbance regimes.

N = Significant difference between high and undisturbed disturbance regimes was not tested.

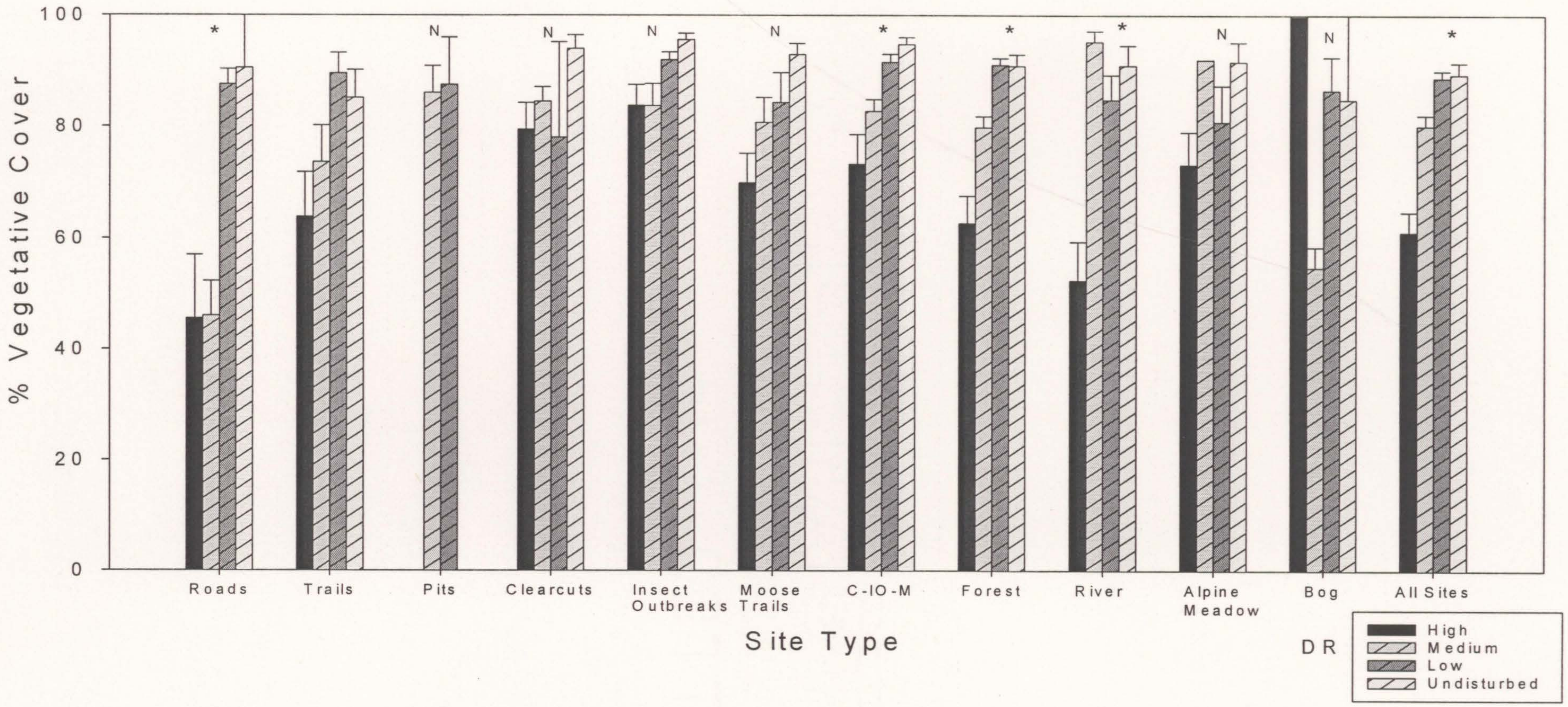

Figure 3: Change in % Vegetative Cover with Disturbance Regime at Disturbance Types and Vegetation Types Sampled in GMNP

C-IO-M = Remote forest disturbances = Clearcuts, insect outbreaks, and moose trails combined.

Forest = All disturbance types sampled which occurred in forest vegetation (roads, pits, trails, clearcuts, moose, insect).

* = Significant difference (at 0.05) between high and undisturbed disturbance regimes.

N = Significant difference between high and undisturbed disturbance regimes was not tested.

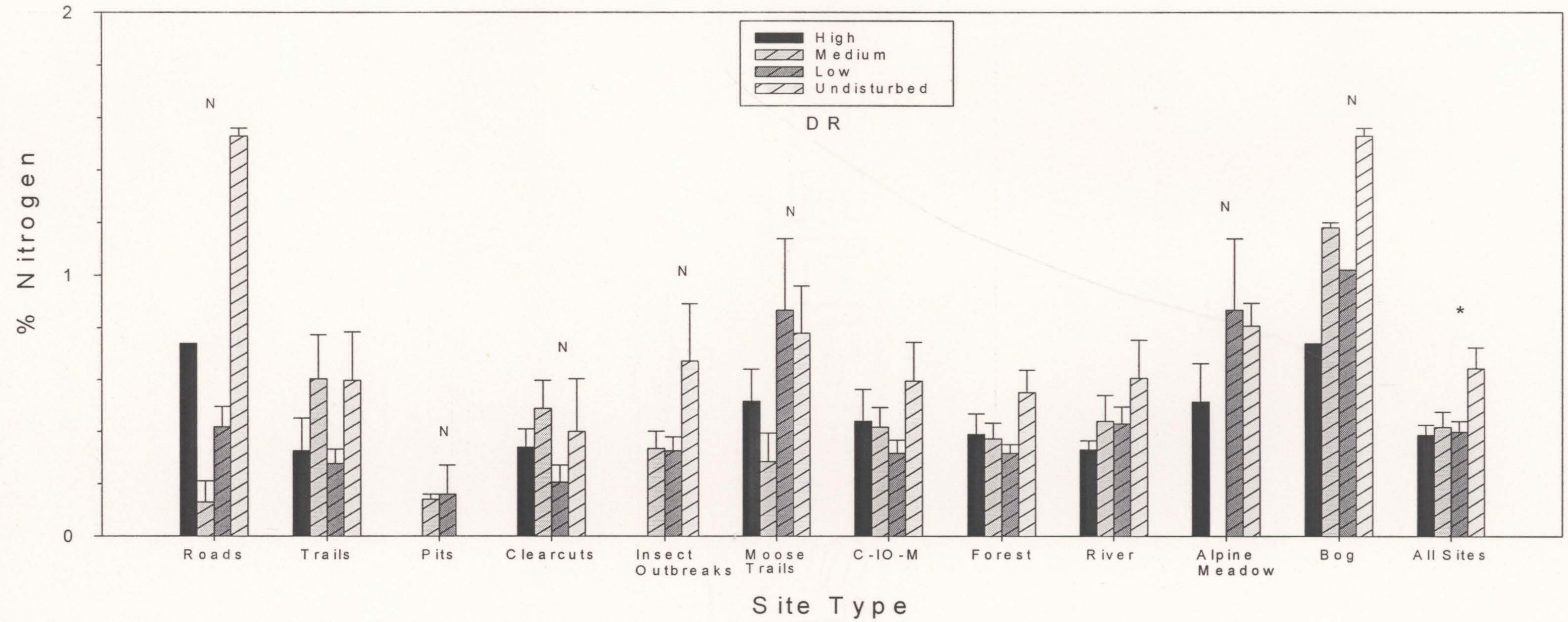

Figure 4: Change in % Nitrogen with Disturbance Regime at Disturbance Types and Vegetation Types Sampled in GMNP

C-IO-M = Remote forest disturbances = Clearcuts, insect outbreaks, and moose trails combined.

Forest = All disturbance types sampled which occurred in forest vegetation (roads, pits, trails, clearcuts, moose, insect).

* = Significant difference (at 0.05) between high and undisturbed disturbance regimes.

N = Significant difference between high and undisturbed disturbance regimes was not tested.

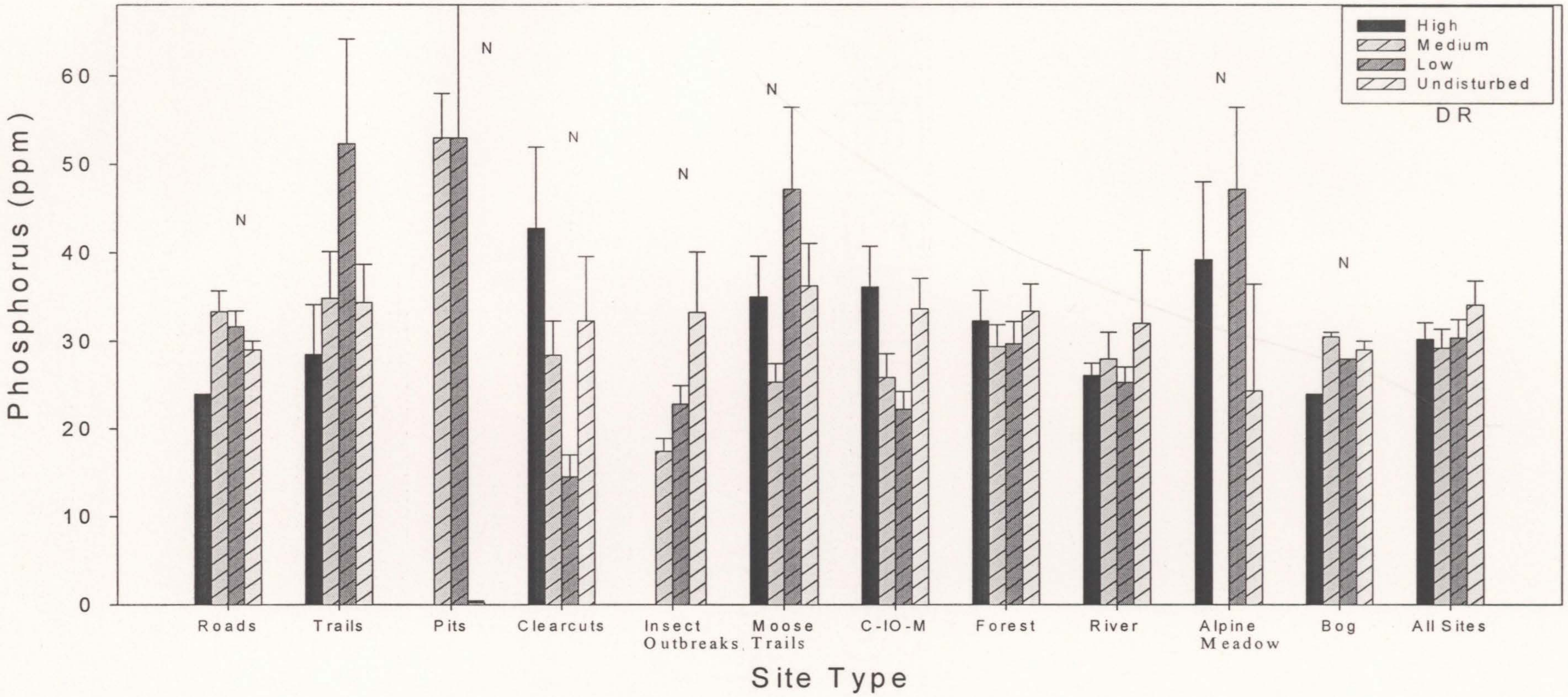

Figure 5: Change in Phosphorus with Disturbance Regime at Disturbance Types and Vegetation Types Sampled in GMNP

C-IO-M = Remote forest disturbances = Clearcuts, insect outbreaks, and moose trails combined.

Forest = All disturbance types sampled which occurred in forest vegetation (roads, pits, trails, clearcuts, moose, insect).

* = Significant difference (at 0.05) between high and undisturbed disturbance regimes.

N = Significant difference between high and undisturbed disturbance regimes was not tested.

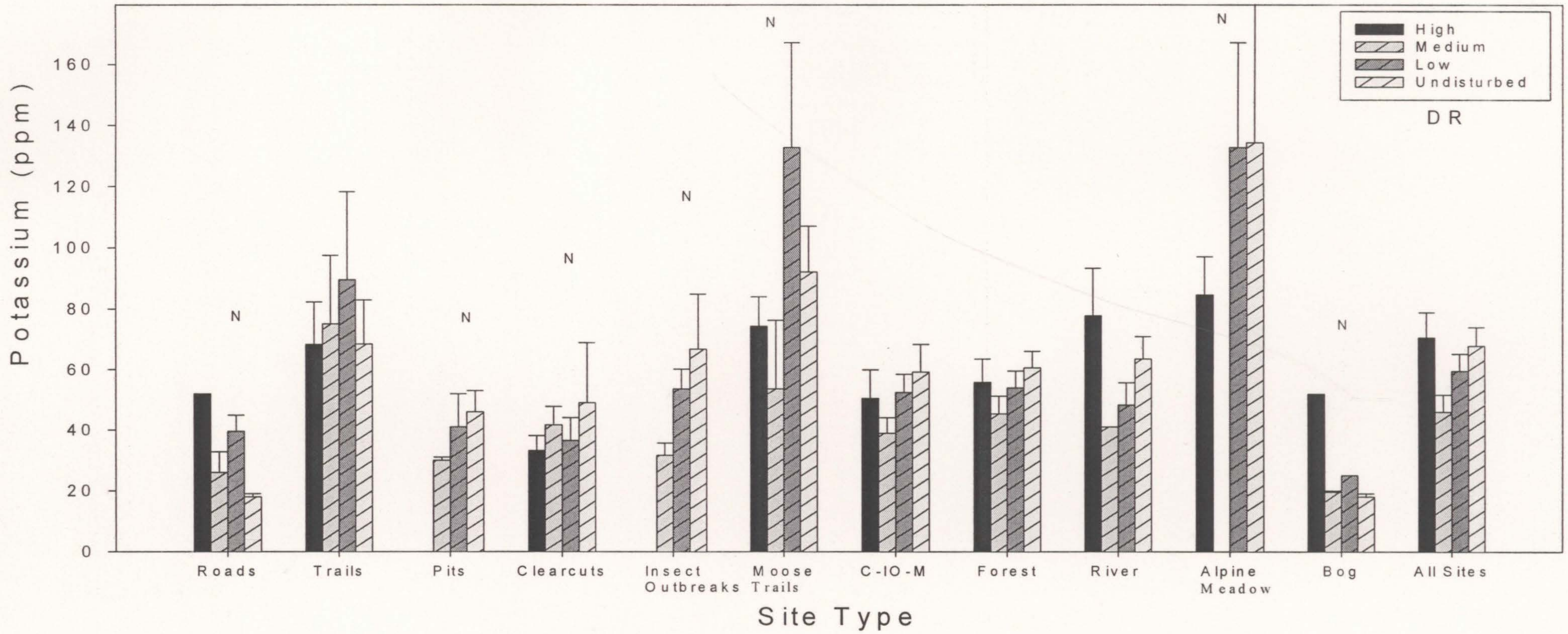

Figure 6: Change in Potassium with Disturbance Regime at Disturbance Types and Vegetation Types Sampled in GMNP

C-IO-M = Remote forest disturbances = Clearcuts, insect outbreaks, and moose trails combined.

Forest = All disturbance types sampled which occurred in forest vegetation (roads, pits, trails, clearcuts, moose, insect).

* = Significant difference (at 0.05) between high and undisturbed disturbance regimes.

N = Significant difference between high and undisturbed disturbance regimes was not tested.

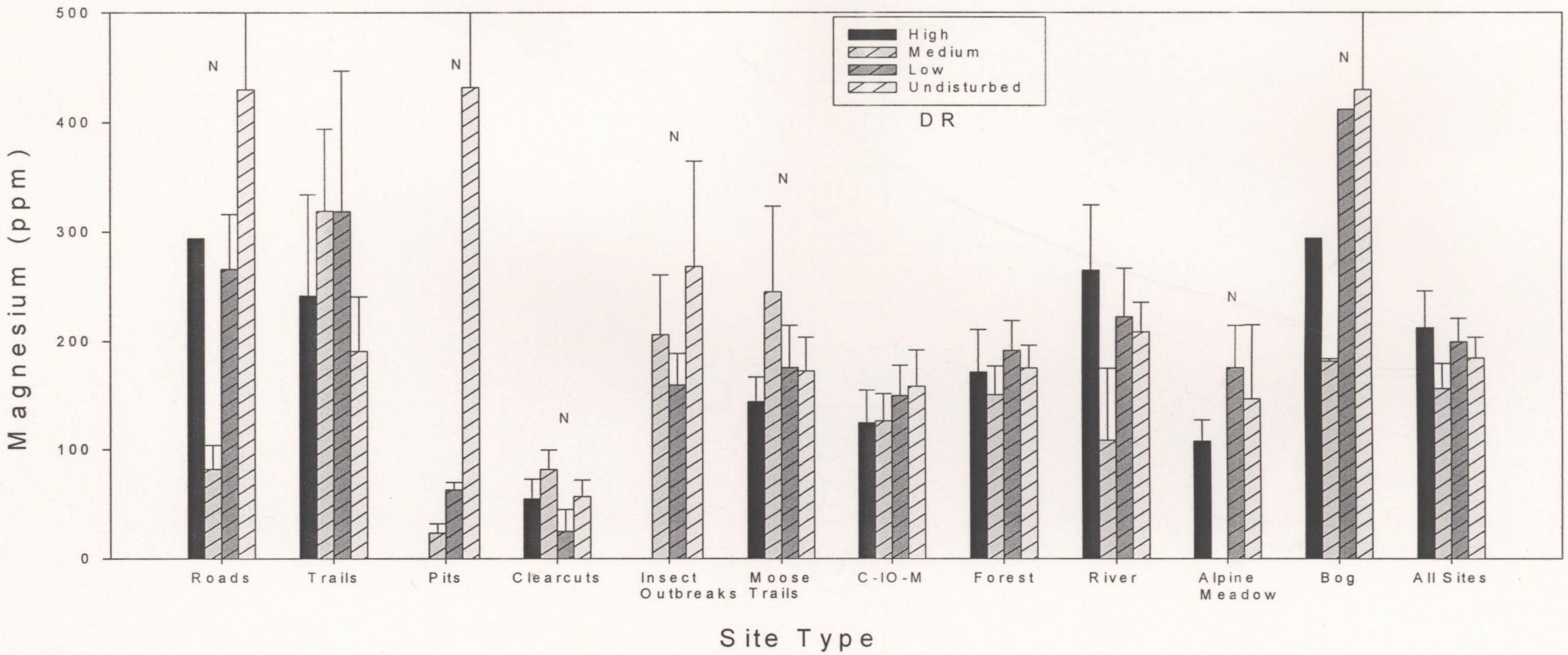

Figure 7: Change in Magnesium with Disturbance Regime at Disturbance Types and Vegetation Types Sampled in GMNP

C-IO-M = Remote forest disturbances = Clearcuts, insect outbreaks, and moose trails combined.

Forest = All disturbance types sampled which occurred in forest vegetation (roads, pits, trails, clearcuts, moose, insect).

* = Significant difference (at 0.05) between high and undisturbed disturbance regimes.

N = Significant difference between high and undisturbed disturbance regimes was not tested.

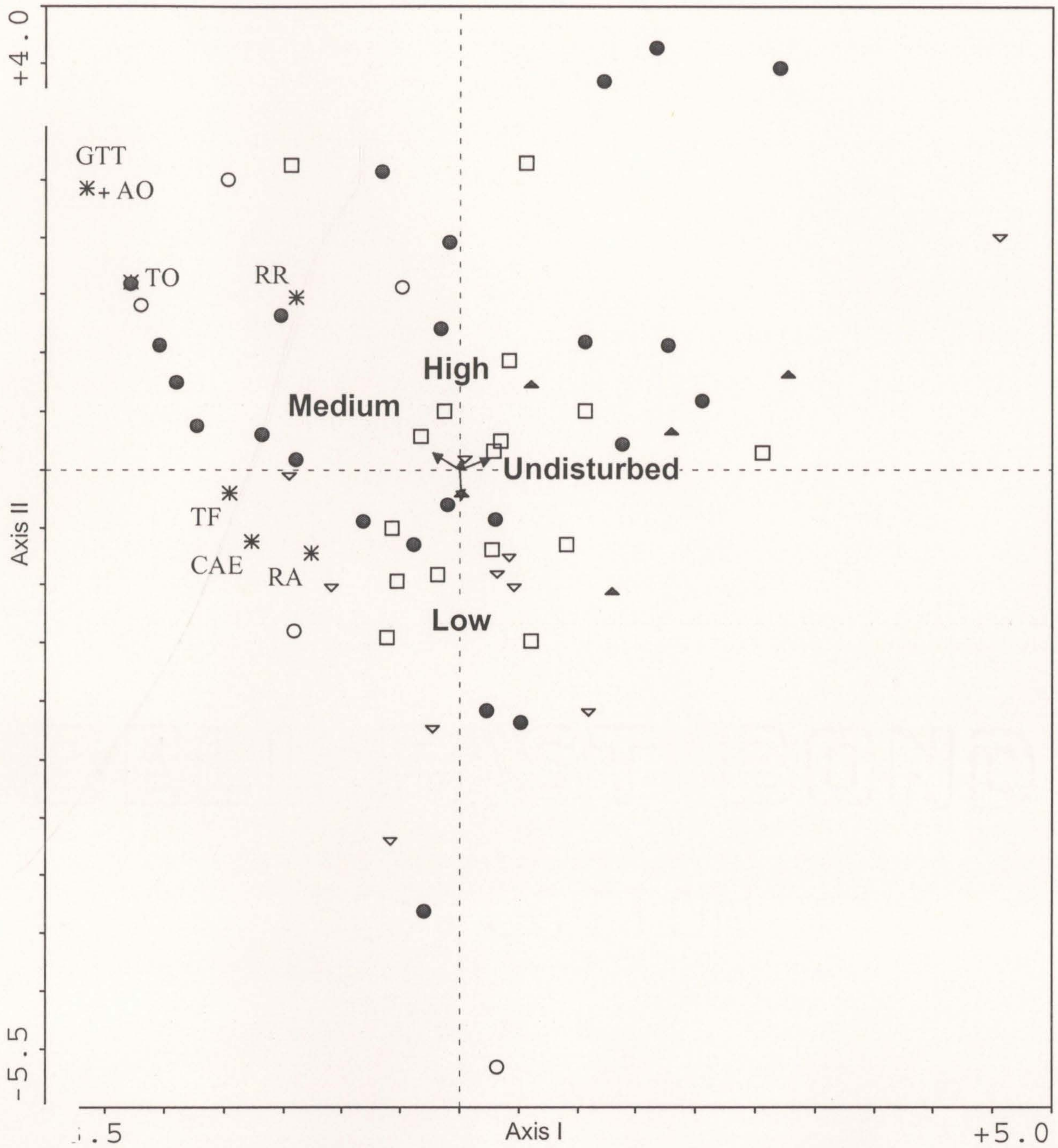

Fig. 8: CCA Ordination Diagram of the Relationship of Species to Disturbance Regime in Remote Forest Disturbances of GMNP

Note: Samples from balsam fir, and black spruce forest were analysed. Disturbance types present in the samples included clear cuts, insect outbreaks, and moose trails. These disturbance types were considered to occur away from high human activity.

Disturbance regime of samples: High = 13, Medium = 79, Low = 69, Undisturbed = 36

Legend: ✳ = Alien Forb + = Alien Grass ● = Native Forb ○ = Native Grass □ = Bryophytes
▲ = Evergreen Trees / Shrubs ▽ = Deciduous Trees / Shrubs
See Appendix 2 for species legend.

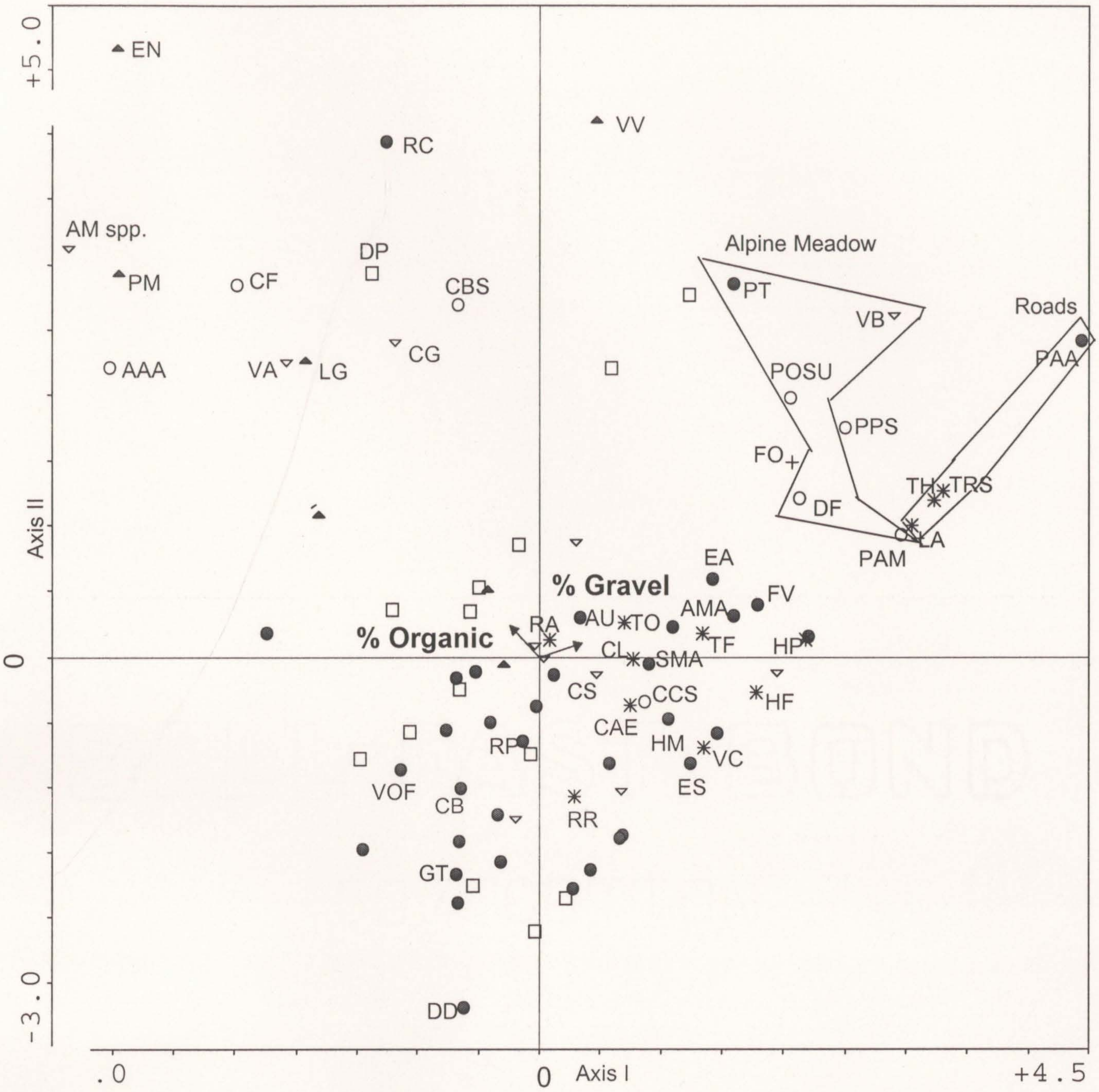

Figure 9: CCA Ordination Diagram of the Relationship of Species with Significant Soil Substrates in GMNP

Notes: Substrate types included in analysis were gravel, silt, sand, clay, and organic.

Disturbance regime of samples: High = 44, Medium = 36, Low = 67, Undisturbed = 45

Legend: ✳ = Alien Forb + = Alien Grass ● = Native Forb ○ = Native Grass □ = Bryophytes ▲ = Evergreen Trees / Shrubs ∇ = Deciduous Trees / Shrubs

Note: Boxes surrounding species represent the disturbance or vegetation types in which the species were most frequently found.

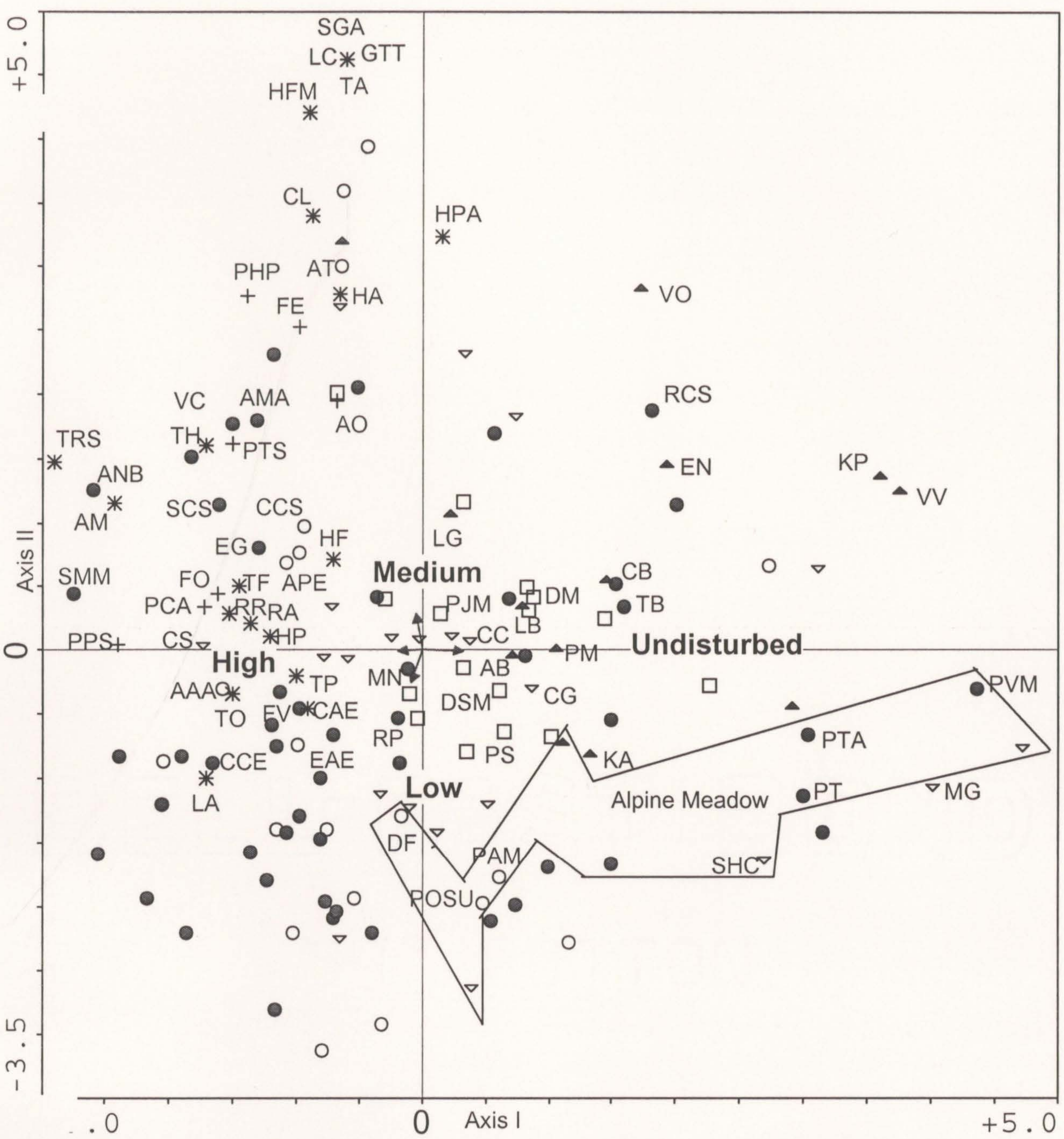

Figure 10: CCA Ordination Diagram of the Relationship of Species to Disturbance Regime in GMNP

Disturbance regime of samples: High = 74, Medium = 129, Low = 183, Undisturbed = 89

Legend: ✳ = Alien Forb + = Alien Grass ● = Native Forb ○ = Native Grass □ = Bryophytes ▲ = Evergreen Trees / Shrubs ∇ = Deciduous Trees / Shrubs

Note: Boxes surrounding species represent the disturbance or vegetation types in which the species were most frequently found.

Sorensen Coefficient's (Kent and Coker 1992)

Table 1: Species Overlap Between Disturbance Regimes Over All Sites in GMNP

Disturbance Regime Overlap	# Species Common to Both DR	# Species High	# Species Medium	# Species Low	# Species Undisturbed	Sorensen coefficient
High - Medium	97	115	135			0.437
High - Low	105	115		149		0.443
High - Undisturbed	65	115			88	0.39
Medium - Low	120		135	149		0.458
Med. - Undisturbed	66		135		88	0.371
Low - Undisturbed	77			149	88	0.394

Table 2: Alien Species Overlap Between Disturbance Regimes Over All Sites

Disturbance Regime Overlap	# Species Common to Both DR	# Species High	# Species Medium	# Species Low	# Species Undisturbed	Sorensen coefficient
High - Medium	24	24	34			0.453
High - Low	21	24		27		0.452
High - Undisturbed	3	24			4	0.176
Medium - Low	27		34	27		0.469
Med.- Undisturbed	4		34		4	0.174
Low - Undisturbed	3			27	4	0.162