An integrated assessment of disturbed plant communities near the future Mackenzie Valley pipeline route, Northwest Territories, Canada

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Abstract

The impact of natural resource extraction, and subsequent transportation to market, is hypothesized to have consequences on the plant community structure of the western Canadian Arctic. The Mackenzie Valley gas pipeline project will create new transportation and disturbance corridors and it is expected that this will facilitate the movement of introduced species northward. As a part of the IPY-GAPS project, an assessment of plant community composition among different types of disturbance was conducted within the vicinity of four communities in the Northwest Territories (Fort Simpson, Fort Good Hope, Norman Wells, and Inuvik) from June – August 2008. Results indicate that the prevalence of introduced species was significantly higher in close proximity to roads, urban centres, and existing pipelines. These disturbance types had greater richness and cover of introduced species than seismic lines. The highest proportion of introduced species was found in Fort Simpson, especially along transportation corridors. The percent cover and occurrence of introduced species were found to be significantly higher along transects within 1-5 m from these roads compared to 10-20 m away. A community consultation survey was also completed on the perceptions of community members held toward the idea of invasive alien species (IAS), their willingness to participate in monitoring programs for IAS, and what role they wanted the government to play in monitoring IAS. The results of the survey suggested that people were willing to report the presence of an IAS, but would not use a website to submit that information. Furthermore, the concept of using an incentive to gather support and increase participation in a monitoring program was seen as unnecessary due to the participants' inherent connection to the land. The results of these studies suggest that future expansion of disturbances, such as roads, pipelines, and enlarged urban areas may increase the prevalence and number of introduced species within northern communities and that managing these impacts will require the development of a community based action plan geared towards the social and cultural background of each affected community.

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CHAPTER 1: Introduction and Literature Review

1.0 INTRODUCTION

The impact of warmer temperatures, melting permafrost, melting of permanent ice pack, and increased precipitation in northern regions due to climate change is predicted to allow for the spread of southern plant species into northern regions as conditions become more conducive to their establishment and dispersal (Mooney and Hobbs, 2000, Arctic Climate Impact Assessment, 2005; Hinzman, *et al.,* 2005; Huntington, *et al.,* 2007). The movement of new species is likely to disrupt ecosystem functioning, and result in unknown changes in plant community structure (Mooney and Hobbs, 2000). The Government of the Northwest Territories has described climate change as "*a serious concern*", and stated that the territory has a responsibility to control northern Greenhouse Gas (GHG) emissions in order to minimize the impacts on health, the environment, and economic opportunities (NT ENR, 2007). The rising interest in investigating concerns related to climate change and its impacts on the north has resulted in multinational and multidisciplinary programs, such as the International Polar Year, becoming much larger in their breadth, in support of research on climate change impacts on Polar Regions.

The 2 years of the International Polar Year (IPY) brought an international research focus to the Polar Regions (Government of Canada Program for International Polar Year, 2007). The ongoing IPY GAPS project (Impacts of Oil and Gas Activity on the Peoples in the Arctic Using a Multiple Securities Perspective) is an inter-disciplinary research collaboration, comprising both natural and social scientists to examine various aspects of security relating to oil and gas development in Arctic regions (Hoogensen *et* *al.*, 2006). One GAPS sub-project was aimed at examining the effects that the most recent proposed Mackenzie Valley pipeline (Joint Panel Review, 2004; Mackenzie Gas Project, 2004) will have on plant communities, because there is short and long-term potential for the introduction and expansion of introduced plant species along the pipeline routes and related disturbance corridors.

While many of the original concerns about the potential environmental impacts associated with the development of such a substantial piece of infrastructure remain (Bliss *et al.,* 1973; DiFrancesco and Anderson, 1999; Toman, 2002), other potential impacts have also emerged. These include the role that pipeline routes may play in providing points of introduction and corridors for the spread of new pathogens, pests, and invasive plant species in Arctic plant communities, as well as the ongoing impacts of climate change induced by green house gas emissions resulting from the transport and use of fossil fuels (Cody *et al.*, 2000; Mooney and Hobbs, 2000; AICA, 2005; Hansen and Clevenger, 2005). In Arctic regions of Canada, U.S., and Russia, pipelines have historically been used to transport raw and processed fossil fuels from point sources to markets (Sanierre *et al.*, 2004). For example, the currently operating Norman Wells Pipeline (869 km), which was constructed from 1983 to 1985, transports 4,800 m^3 (30,000 barrels) of oil each day, and was one the first buried pipelines in discontinuous permafrost built in Canada (Cody *et al.*, 2000). The effects of the reseeding conducted to restore habitat disturbed by pipeline construction, and the potential impacts of oil spills from the pipeline have been extensively investigated (Hutchinson and Freedman, 1978; Kershaw and Kershaw, 1987; Seburn *et al.,* 1996; Cody *et al.*, 2000).

There are many drawbacks to pipeline development, including the physical and logistical challenges associated with transporting fossil fuel resources from remote northern regions to southern refineries and markets, and the financial costs of development have historically provided the major disincentive for development (DiFrancesco and Anderson, 1999). The engineering complexities associated with extracting and transporting fossil fuels from Arctic and sub-Arctic regions include the development of drilling platforms that can withstand sea ice and the construction of pipelines over and below permafrost (DiFrancesco and Anderson, 1999; Saniere *et al.*, 2004). In addition to these financial and logistical constraints, environmental concerns over the impacts of oil and gas extraction on Arctic ecosystems, interference with traditional caribou migration routes, in particular the Arctic National Wildlife Refuge (ANWR), the calving grounds of the Porcupine Caribou herd, and unresolved local aboriginal land-claim issues have also contributed to delays in developing these oil and gas resources (McCullum and Taylor, 1975; Berger, 1977; Toman, 2002).

There are many factors supporting the rationale for conducting research into the multi-faceted cumulative impacts of pipeline development on the economic, social, and environmental well-being of the communities and regions along the proposed route of the Mackenzie Gas pipeline. For example, changes in the distribution of native plants following previous pipeline activity were documented in the 1970s (Bliss *et al.*, 1973; Berger 1977; Hutchinson and Freeman, 1978). The initial disturbance caused by previous pipeline development was shown to lead to decreased species richness and total plant cover (Bliss *et al.*, 1973; Hutchinson and Freedman, 1978). Natural revegetation was allowed to occur in some disturbed sites associated with the pipeline, but at other sites, monitoring of the habitat restoration reseeding programs subsequently found that introduced European graminoid species displaced early successional plants species (Cody *et al.*, 2000). This could have hindered the long term succession and plant community recovery to re-establish a vegetation layer thick enough to protect the ice rich permafrost from subsiding (Linell, 1973). This lack of vegetation layer could have contributed to a frost heave of the pipeline in 1997 by affecting the underlying dynamics beneath the surface (Cody *et al.*, 2000; Hagan, 2002). Generally, the effect of oil spills on the native vegetation also resulted in low survival rates of lichens and mosses, as well as a lag period between a spill and the subsequent death of some higher plants like Black spruce (*Picea mariana*) (Hutchinson and Freedman, 1978; Seburn *et al.*, 1996).

1.1 OBJECTIVES AND HYPOTHESIS

The overall goal of my research was to measure plant community composition along a range of existing and potential disturbance corridors, and to engage in a dialogue with local communities about introduced plant species, along the proposed Mackenzie Valley Pipeline route. Four communities along the proposed route were selected (Fort Simpson, Norman Wells, Fort Good Hope, and Inuvik) that were identified as having different levels of human disturbance on ecosystems, with respect to corridors created by transportation routes and pipelines (Figure 2.1). Specific objectives were:

(1) To determine the current plant community composition and species distributions in different types of corridors.

(2) To identify the presence of introduced species in these corridors.

(3) To assess the current types and amount of habitat disturbance arising from transportation and movement corridors.

(4) To engage in documented conversations with local youth, elders, community members, and professionals about introduced and non-native species. There is increasing academic-based acknowledgement that it is essential to communicate with Inuit, First Nation, and Metis peoples to gain knowledge of whether they have identified changes in plant species in their landscapes (Berkes *et al.*, 2000).

These objectives generated five main questions about plant communities along movement and disturbance corridors in the Northwest Territories.

(1) Are there varying gradients of disturbance that correlate with overall trends in the distribution and abundance of native and introduced plant species?

(2) Do the type, intensity and the frequency of the disturbance affect the overall plant species richness of associated ecosystems and correlate with increased levels of introduced species?

(3) Does the distance from the point source of the disturbance affect the species richness of native and introduced species?

(4) What are the most common introduced species across the range of disturbed habitats particular disturbance type?

(5) Are local people noticing a visible change in plant communities and what role do they think that they and the government should play in the detection, management, and eradication of introduced species?

In order to quantify potential threats posed by introduced plant species along the proposed route of the Mackenzie oil and gas pipeline it was necessary to describe the baseline plant community composition, including the presence of introduced species within these areas. The potential northward spread of introduced species in response to disturbances, such as the pipeline development, is likely to differ depending on current ranges and abilities to survive within harsh northern environments. As such, the central hypothesis of this study was that there would be identifiable gradients of richness and diversity in introduced plant species associated with existing gradients of disturbance. Specifically, higher levels of introduced plant species would be found in more southerly locations within the Northwest Territories, and in closer proximity to roads and existing pipelines. It was also hypothesized that introduced species would be particularly associated with human communities, because more urbanized portions of these communities provide an entry mechanism as well as providing the ability to detect the presence of new species and to engage in and develop a community management response.

1.2 LITERATURE REVIEW

1.2.1 History of Arctic Oil and Gas Exploration

The exploration, extraction, and use of fossil fuels have acted as catalysts for industrial development (Hubbert, 1949; McCullum and Taylor, 1975; Sabin, 1995). As the demand for fuel to power locomotives, steamships, and ultimately the automobile, has increased, new and remote sources of oil have been actively sought, including in Arctic regions (Hubbert, 1949; McCullum and Taylor, 1975). Fossil fuels as drivers for development began in earnest with the discovery of coal in the 13^{th} century in Britain, and which went on to provide the fuel to smelt the metals to build locomotives and steamships (Hubbert, 1949). This development was then augmented in the mid 19^{th} century when oil and natural gas extraction began (Hubbert 1949). The first commercial extraction of petroleum (oil) began in 1857 and within two years, Edwin Drake drilled the first American oil well in Titusville, Pennsylvania (Hubbert, 1949; U.S. Department of Energy, 2005). After only 50 years of extraction, the Naval Petroleum and Oil Shale Reserves were created from 1909 -1924 in order to protect deposits in California, Utah and Wyoming (U.S Department of Energy, 2005). However, the U.S demand for oil increased during the Second World War, after the attack on Pearl Harbour, thus some reserves were tapped and previously known sources were exploited in order to provide fuel for aircrafts, naval ships, and other military vehicles (Barry 1992, U.S. Department of Energy 2005).

A strategic location of oil extraction and development was located in the Canadian Arctic, in which raw crude from Norman Wells, NT was refined in Whitehorse, Yukon (Haulman, 1996). Norman Wells was a small topping plant first established by Imperial Oil Limited in 1921 (National Energy Board, 1977). Canada and the U.S. aligned politically to protect the Arctic's security and sovereignty during the Second World War via multiple development projects that were undertaken to increase the military presence in the north, develop infrastructure, and extract the marketable resources from the previously 'worthless' north (Brebner, 1996; McCullum and Taylor, 1975). The military presence in the north was established through the installation of the Northwest Staging Route as well as multiple military bases (Haulman 1996). The route consisted of a series of airfields constructed in the Western Arctic and Alaska to allow the American army to ferry aircrafts, troops, and supplies to Russia (Haulman 1996). It also served as an attempt to ensure the security, during the Cold War, of the Arctic and North America through a bilateral continental defence cooperation and collaboration between Canada and the U.S.A. (Brebner 1996).

A 2,600 km network of pipelines originating at the Norman Wells oils fields of the Northwest Territories to Whitehorse in the Yukon was also constructed to transport fuels extracted in the Canadian Arctic to the American market (Barry, 1992). During the short three-year lifespan (1943-1945) of this pipeline, a reported 240, 000 m^3 (1.6 million barrels) of crude oil was sold to the U.S. (Hesketh, 1996). The Alaskan highway, 830 km of gravel roads, 2,400 km of winter roads, 10 aircraft runways, and 830 km of telephone communication networks were also built (Hesketh, 1996). Consequently, the establishment of infrastructure in the north shifted development in Canada from a strictly southern perspective (specifically, in the prairies) to the north, after WWII (McCormack, 1996). The stated goal of these developments was to create a 'modern' economy that would explore and exploit the resources of the north (McCullum and Taylor, 1975). While it was pitched as a development strategy that would provide economic benefits for local northern native peoples, there were, in reality, few economic or social benefits (McCullum and Taylor, 1975; Hesketh, 1996; McCormach 1996). One of the major projects originally proposed in 1974, by the Canadian Arctic Gas Pipeline Limited, was a pipeline that would run from the oil and gas fields in Prudhoe Bay Alaska, travelling through the Yukon and into the Mackenzie delta, south to Alberta (McCullum and Taylor, 1975). This proposal subsequently developed into one of the most intensive and drawn out reviews in Canadian history (e.g., Berger, 1977). The accelerated development plans also motivated northern native peoples to intensify their claims to the land under consideration, and the demand for new and renewed negotiations of those rights has continued for decades (McCullum and Taylor 1975; Berger 1977).

1.2.2 Land claims/ Berger inquiry/Joint panel review

The rights of native peoples to their traditional lands reflect their values, culture, and a traditional lifestyle that involves, among many things, nomadic travel to seasonal hunting locations, fur trading, and an intrinsic connection to the land (McCullum and Taylor, 1975). When oil was first discovered in Norman Wells, the Federal Government signed Treaty 11 in 1921, which ceded the Mackenzie valley to the crown, and provided a family of five with 5 dollars per year, 1 acre of land, twine, nets, and ammunition (McCullum and Taylor, 1975). However, the proposed plans for a new pipeline caused a shift in public perception that culminated in the Berger inquiry and later the Joint Panel Review Board (Berger, 1977; JPR, 2004). Both were structured to observe and document the voices of the people and to understand how local peoples desired their land, culture, and economy to develop. The Berger Inquiry operated on three main assumptions; (1) that there was a need within industry for the oil and gas in the Western Arctic and its transportation along the Mackenzie River Valley to markets in the south, (2) that the federal government intentions included projecting and preserving Arctic environments indefinitely, and (3) that the rights of native peoples to their land would be honoured and their future aspirations supported (Berger, 1977; Gamble, 1978). The results of the inquiry did not predict catastrophic degradation to the Arctic ecosystems, but to the subsistence and cultural activities of the regional local peoples (Berger, 1977; Gamble, 1978; Sabin, 1995). The inquiry recommended that the development of the pipeline should be delayed by at least 10 years, and not occur until all land claims were settled (Berger, 1977) The Joint Review Panel (JRP) was appointed in 2004 by the Minister of Environment, Stéphane Dion (JPR, 2004). The review panel was in agreement with the Canadian Environmental Assessment Agency and the chairs of both the Mackenzie Valley Environmental Impact Review Board, and Inuvialuit Game Council (JRP, 2004). The focus of the JRP was designed to allow for comprehensive and transparent public involvement in exploring the environmental and socio-economic effects associated with the pipeline proposal (JRP, 2004). In November of 2007, the JRP concluded its consultation of 26 communities in NT, but delays have postponed the final report which will reflect the recommendations of the JRP from the consultations (JRP, 2007). The scale, length of time involved, and complexity of land claim negotiations may be viewed by many as a detriment to fast paced economic development, but they are necessary in order to respect the rights of native peoples in determining how they will structure their political and economic relationship to the development of a pipeline (Berger, 1977; Sabin, 1994; JRP, 2004).

1.2.3 Current oil and gas production and the proposed Mackenzie pipeline

The proposed pipeline has the potential for transporting vast quantities of marketable resources. The recent Circum-Arctic resource appraisal, conducted in 2007 by the U.S. Geological Survey (USGS) identified more than 400 onshore oil and gas fields above the Arctic Circle, which only represents 6% of the Earth's surface (Gautier *et al.*, 2009). These fields represent 10% of known global resources and consist of approximately 40 billion barrels of oil, 32 trillion m^3 of natural gas, and 30 million m^3 (8 billion barrels) of natural gas liquids, mostly from the West Siberian Basin of Russia and the North Slope of Alaska (Gautier *et al.*, 2009). As of early 2009, Canada was estimated to have 1.64 trillion m^3 of natural gas reserves, and was the largest producer and exporter of natural gas in the western hemisphere (Energy Information Administration, 2009). The Beaufort-Mackenzie Sedimentary basin, as it is presently defined, has been known as a source for fossil fuels as far back as 1789, from Alexander Mackenzie's reports, but it was not until the later discovery of gold and uranium that the extraction and transportation of northern resources was considered (National Energy Board, 1977). Due to the remote location, pipelines are frequently transporting fossil fuels from northern source points, but the costs are usually prohibitive. For example, when the Norman Wells topping plant was established in 1921, Imperial Oil Limited intended to build a pipeline south to Edmonton Alberta, but the estimated construction cost of $40 million prevented its construction until the start of the Second World War (National Energy Board, 1977; Haulman 1996).

There have been two proposals to build a pipeline in the Mackenzie Valley driving the past 40 years (Berger, 1977; National Energy Board, 1977; Mackenzie Gas Project, 2004). The first was in 1969, and was led by Mackenzie Valley Pipe Line Research Limited, a company formed by Interprovincial Pipe Line Company and Trans Mountain Oil Pipe Line Company (National Energy Board, 1977). They intended to determine the technological and economic feasibility of constructing a pipeline from Prudhoe Bay, Alaska through the Mackenzie Valley to Edmonton and into the U.S.A. (Berger, 1977; National Energy Board, 1997). In the 1990s, Imperial Oil Resources Ventures Limited, a subsidiary of Imperial Oil, the Mackenzie Valley Aboriginal Pipeline Limited Partnership, Conoco Phillips Canada (North) Limited, Exxon Mobil Canada Properties, and Shell Canada Limited developed a proposal and environmental impact statement for revisions by all involved parties (JRP, 2004). The plan was to build two 1220 km pipelines carrying liquefied natural gas (butane and pentane) and natural gas stretching from 3 sources, Taglu, Parsons Lake and Niglintgak the Northwest Territories, to a processing facility in Inuvik for transport via a pipeline south to connect with the NOVA Gas Transmission Ltd. System in Alberta (JRP, 2004; Mackenzie Gas Project, 2004; Figure 2.1). The original intention of the proposal was for all of the construction to be completed by 2010 (Mackenzie Gas Project, 2004). The pipeline has been estimated as having the potential to produce 226 million m^3 of natural gas, between 1,907 m^3 to 2,384 m^3 (12,000 to 15,000 barrels) of liquefied natural gas products each day, and to contribute $724 million dollars annually to the NTs GDP (Mackenzie Gas Project, 2004; ITI and ENR, 2007). This proposal was made nearly 30 years after the original pipeline proposal was rejected following the 1974-76 Mackenzie Valley Pipeline Inquiry (Berger, 1977). The main difference between the earlier and subsequent pipeline proposals was that some aboriginal groups in the form of the Mackenzie Valley Aboriginal Pipeline Limited Partnership were participants in the development of the new proposal and would benefit from the project (Berger, 1977; JRP, 2004). During the Berger Commission in the 1970s, aboriginal groups were uniformly against pipeline development and, following his extensive hearings and consultations, Justice Berger recommended that the development of the pipeline be delayed by 10 years until the land claims of the various First Nations groups were settled (McCullum and Taylor, 1975; Berger, 1977; Gamble, 1978). This decision was supported by the Canadian National Energy Board.

1.2.4 Climate change in Arctic regions

The moratorium placed on the first Mackenzie Valley pipeline proposal was primarily motivated by the potential negative social implications of the project that emerged from the extensive community consultation. This stands in contrast to the global environmental issue that has the potential to affect and to be affected by the current proposal for non-renewable resource extraction, namely climate change. The Intergovernmental Panel on Climate Change (IPCC) and the Arctic Climate Impact Assessment (ACIA) report link the effects of anthropogenic greenhouse gas (GHG) emissions, primarily carbon dioxide (CO_2), from the consumption of non-renewable energy sources with a warming climate (ACIA, 2005; IPCC, 2007). The IPCC and ACIA reports describe the already observed effects of global warming on Arctic ecosystems and the fact that many local peoples have already observed them (ACIA, 2005; IPCC, 2007).

Documented changes to the Arctic include: a reduction of ice sheets, glaciers, and summer sea-ice cover, melting of permafrost, erosion, changes in the ocean circulation, and shifting ranges of floral and faunal species (Serreze *et al*., 2000; ACIA, 2005; Hinzman, *et al.,* 2005; Huntington, *et al.,* 2007). These effects were projected to have both positive and negative consequences for the environment, economic development, and the social well-being of local peoples in the north (ACIA, 2005; Berger, 1977; Toman, 2002). For example, a decrease in perennial and permanent ice might allow for increased shipping routes, such as the opening of the Northwest Passage, but would also increase the chances of waterway contamination through oil and chemical spills (ACIA, 2005). Furthermore, a decrease in multi-year sea ice would expand the opportunities for resource exploration and subsequent development (ACIA, 2005). Subsequent development would also lead to changes in land-use practices, which would transform the natural landscape during the acquisition of natural resources to serve the immediate needs of humans (Dale, 1997; Houghton, 1994; Foley *et al*., 2005). Many land-use changes, particularly with respect to oil and gas exploration and extraction, will subsequently disturb and/or permanently damage the permafrost (Nelson *et al*., 2002).

Continuous permafrost is primarily located in the mid to high Arctic and is a large source of hydrocarbons, transportation networks (roads, pipelines), and other types of infrastructure (Nelson 1986; Nelson *et al*, 2002). As permafrost melts, the depth of the active soil layer increases, which results in subsidence, that in turn amplifies the release of GHG and accelerates erosion (Michaelson *et al.,* 1996 Serreze *et al*., 2000; ACIA, 2005; Hinzman, *et al.,* 2005). This feedback poses a threat to the socioeconomic conditions in northern towns, resulting in collapsed roadways, shifting building foundations, and impacts on natural resources such as forest growth and productivity (Williams, 1986; Nelson *et al*, 2002). The removal of the active vegetation cover from previous land-use activities, such as pipeline construction, has also contributed to ground subsidence by altering the albedo, absorption, and local hydrology of permafrost regions (Linell, 1973; Nelson and Outcalt, 1982). For example, the oil pipeline in Norman Wells experienced heaving due to changes in the permafrost in 1997, and a number of homes in Tuktoyaktuk, NT are no longer habitable due to melting permafrost (Cody, 2002; Canadian Press, 2009). Linell (1973) demonstrated the role of stable vegetation in preventing permafrost melting in experiments conducted near Fairbanks Alaska, where up to 6.7m of subsidence was recorded strictly as a consequence of removing the vegetation layer. The construction of the Mackenzie pipeline will require removal of the vegetation layer in order to bury the pipeline and then re-establish the vegetation layer to prevent subsidence. Previous methods used for re-vegetation were found to have hindered the establishment of an extensive vegetation layer, as well as the introduction of new species to the area (Cody *et al*, 2000; Hagan, 2002). Therefore, pipeline construction is likely to have a host of cumulative impacts on plant communities that will interact with climate change in ways that are likely to result in detrimental impacts on northern communities.

1.2.5 Arctic Plant Communities

The Arctic has a distinct climate that is characterized by extremes in temperature, wind, and precipitation (Hinzman *et al.*, 2005). Arctic ecosystems include a range of biomes, unique species and community assemblages of plants and animals (Bliss *et. al,* 1973). Approximately 1500 species are found in the boreal forest, polar desert, shrub communities, wet sedge meadows, grasslands, steppes, and cushion plant communities throughout the north (Abbott and Bochman, 2003; Walker 2000). The tundra is one of the Earth's youngest biomes, and its overall diversity has declined since the last glaciation (Matthews and Ovenden, 1990). The tundra was formed during the late Pliocene (5 to 2 million years ago) and was discontinuous until the formation of a circum-Arctic belt 3 million years ago (Matthews and Ovenden, 1990; Abbott and Bochman, 2003). Recently, Advanced Very High Resolution Radiometer (AVHRR) imagery has determined that of areas not permanently covered in ice, approximately 26% were erect shrubland, 18% peaty graminoid tundra, 13% mountain complexes, 12% barren, 11% mineral graminoid tundra, 11% prostrate-shrub tundra, and 7% wetlands (Walker *et al.,* 2005). Many Arctic communities can be characterized by low species diversity, extreme temperature gradients, short growing season length, low resource availability, and low annual productivity and other oscillating environmental conditions (Billings, 1987; Forbes *et al.,* 2001). However, some arctic communities, both terrestrial and aquatic, are highly productive, with long food chains (Bazely and Jefferies, 1997).

Terrestrial primary production of global plant productivity patterns are influenced by two environmental variables, temperature regime, and water availability (Bazely and Jefferies, 1997; Leuschner, 2005). Arctic plant communities have low levels of primary production overall, but if viewed independently of the length of growing season, the level of primary production is remarkably high (Leuschner, 2005). Some ecosystems are also highly productive, independent of this metric (Bazely and Jefferies, 1997). Two of the major limiting factors in the productivity of Arctic plant communities are the reduced amount of radiation and temperature (Forbes *et al.,* 2001; Walker *et al.*, 2005). Total plant cover is significant for the dynamics of permafrost and soil moisture, which in turn provides feedback into the local climate, and overall hydrology (Hinzman *et al.*, 2005). Summer temperatures not only affect the permafrost, but also play a major role in determining the dominant plant functional types, productivity, species richness, and biomass (Bliss *et al*, 1973; Forbes *et al.,* 2001). Thus, climate changes in northern regions will affect many of the local dynamics influencing the development of plant community structure. For example, in Alaska, the thawing of permafrost has affected soil drainage, resulting in forest die-back due to flooding, and increased formation of sedge meadows, bogs, and waterbodies in the flooded areas (Hinzman *et al.*, 2005).

Climate modelling for Arctic regions suggests that increased annual temperatures will potentially increase the abundance and size of shrubs (Chapin *et al.,* 1995). Tundra warming experiments conducted by Hollister *et al.,* (2005) showed a general increase in plant stature and cover of shrubs and graminoids, and a decrease in the cover of mosses and lichens. Tundra plant communities identified as being most vulnerable to climate change were those presently occurring in wet and moist conditions (ACIA, 2005; Hinzman *et al.*, 2005).

1.2.6 Introduced Plant Species

Plant invasions are not a recent development, and ecologists have noted the presence of non-native plant species in floras as early as 1905, when Stephen Dunn published *Alien Flora of Britain* (Myers and Bazely, 2003). The ecological processes that underlie invasions are complex and an understanding of basic ecological theory is fundamental to determining how invasive plant species establish and proliferate.

Generally, species found within terrestrial plant assemblages can be identified as native or introduced (Myers and Bazely, 2003). Some introduced species may be classified as invasive if they spread rapidly, but predicting which species will become invasive can be challenging until the invasion is well underway. Additionally, definitions of which species in a community are native will depend on the temporal and spatial time frame, and, depending on how these are set, almost any species can be described as native (Townsend, 2005), and it should be noted that all species have the capacity to expand their range. In Europe, if a species was known to have arrived before the year 1500 AD it is defined as an archaeophyte, whereas, if it arrived after, it is a neophyte or kenophyte (Kornas, 1990). However, many species cannot be reliably assigned to either category and are considered cryptogenic species (Carlton 1996).

Regardless of the complexities associated with placing temporal and spatial boundaries around when species arrived on a new continent or in a new region, much of the debate surrounding whether a species should be considered native or introduced pertains to societal values, rather than purely physical scientific and ecological values (Warren, 2007). Describing a species as invasive or by other adjectives such as "noxious" and "nuisance" implies direct (e.g., toxins) or indirect (e.g., decrease in the aesthetics of a natural area) harm to humans (Colautti and MacIsaac, 2004). Myers and Bazely (2003) identify a range of definitions for introduced species, including a 'naturalized' species which is considered permanent, and almost indistinguishable from a native species, and an 'established' species which is introduced and on its way to becoming naturalized. Additional terms include 'casual' species, those that do not persist locally for longer than two years, and 'persistent' species, which are those that may remain within the community for longer than two years, but do not reproduce successfully (Colautti and MacIsaac, 2004).

The term "invasive" is highly ambiguous. Richardson *et al.,* (2000) called for a biogeographical approach to defining perceived 'established', 'naturalized', and 'invasive' species. Colautti and MacIsaac (2004) rebutted the suggestions made by Richardson *et al.,* (2000), as the definitions found in invasive ecology are not limited to just those terms. Furthermore, the way in which the term "invasive" is used to describe the spatial and temporal scale of its effect on a system often reflects the underlying ecological processes. Research into the underlying processes associated with a human-mediated invasive species includes consideration of propagule pressure (Perrings *et al.*, 2002). The number of propagules (seeds, in the case of plants), has been shown to be a key factor in determining the invasibility of a community (Tanentzap and Bazely, 2009). Hettinger (2001) argued that the issue is the ecological compatibility of the species within a community, and not the physical distance from its native landscape. Thus, some argue the ecological change by an introduced species found in an ecosystem is the most important factor distinguishing an introduced from an invasive species, and, not the geographical distance.

1.2.7 Establishment of introduced species

Knowledge of the ecological principles that govern the colonization, and subsequent invasion, of terrestrial invasive plant species is necessary for determining their impacts and assessing effective control mechanisms (Myers and Bazely, 2003). Introductions of plants tend to be accidental, but just as many are deliberate. There are many reasons for deliberate introductions, such as for soil stabilization (Kudzu, *Pueraria lobata*; Myers and Bazely, 2003. Though, most are for aesthetic purposes, such as horticultural plants (Dame's violet, *Hesperis matronalis;* Myers and Bazely, 2003; Tanentzap and Bazely, 2009).

Understanding of species-area relationships is important in determining whether a plant community is being colonized and invaded by newly arriving introduced species (Myers and Bazely, 2003). Species-area curves give insight into how many species can be supported in a particular ecosystem, and they establish a relationship between the number of species and the amount of suitable habitat or sampled area (Rosenzweig, 1995). The species-area relationship provides a measure of the species richness in an area, and can give insight into the capacity for further expansion of a species, as well as whether adequate sampling of a plant community has occurred.

Williamson and Fitter (1996b) describe four stages of plant invasion as: (1) introduction, (2) circumvention and establishment, (3) naturalization, and (4) achieving invasive status. They (Williamson and Fitter 1996a) also developed the tens' rule as a method of estimating the number of species arriving in a new area that are likely become invasive. For every ten species brought into a particular region, one will appear in the wild as an introduced species, one in ten introduced will become established, and one in ten will become invasive. Thus, the ability of a species to become invasive is small, but for every species that does become invasive the ecosystem impacts can be substantial. There are many reasons why only a very few species will become established and then invasive, and these include barriers to dispersal, including biological, physical, and environmental (Parendes and Jones 2000). An example of a biological barrier includes poor dispersal or low seed production. Physical barriers are generally anthropogenic produced features, such as roads, parking lots, and/or buildings. Examples of environmental barriers are the availability of sunlight, minimum daily temperatures, water availability, soil porosity, and wind. These concepts are critically important to providing an understanding of how patterns of plant introduction can occur, and determining how they function may assist with prevention and management.

A critical ecological component of assessing the potential impacts of large-scale habitat disturbances, such as pipeline development, is the determination of the structure of the existing plant assemblages during succession, in relation to disturbance (Grime, 1974). This may be approached by an evaluation of the life history of the component plant species, as it may influence the development of the plant community as a whole. Grime (1974) outlines this in the C-S-R model of succession, in which the composition of three main plant functional groups determines the successional trajectory of the community: (1) C-Types are species that compete well with other species, (2) S-Types that are well adapted to stressful conditions, such as a low moisture gradient and soil conditions, and (3) R-Types, ruderals that favour disturbed environments, are species that are the most commonly rapidly growing plants that also have high seed production rates. Different functional groups of plant species are predicted to be more or less common during different stages of succession. Thompson (1994) applied the C-S-R classification scheme in an effort to determine if anthropogenic-facilitated disturbances improved the conditions for invasive species. Plants were scored using Grimes' classification matrix, and were also scored for canopy height, life history, seed bank, wind dispersal, dispersal weight, flowering period, and lateral spread (Thompson, 1994). Thompson (1994) also found that S-Type plant species explained the relationship between abundance and population density. Species with a high S-score had a tendency to grow more slowly than those with low S-scores. Thus, Thompson (1994) identified the regions with the highest population densities and increased abundances of low S-scoring plants. Furthermore, the other characteristics that were scored, such as canopy height, life history, and seed bank played no significant role in categorizing plant species. The variables suggested by Thompson (1994) in conjunction with species diversity and the patterns of invasion provide one approach for a screening process that can be applied to plant populations over larger scales, which is necessary when dealing with an entity like a pipeline that has the capacity to facilitate a disturbance. Establishing the baseline plant community composition allows for later exploration using environmental variables that could be used to implement these and other models on other research question in the Mackenzie River basin.

1.2.8 Disturbance

The potential for a plant community to be invaded by a new species is dependent upon the ability of an introduced species to establish and persist, or expand (Burke and Grime, 1996; Myers and Bazely, 2003). Many introductions of new species are associated with a range of disturbances (Myers and Bazely, 2003). Natural disturbance regimes are dynamic and are distinguished by multiple components such as frequency, intensity, and the extent of the disturbance (Pickett and White, 1987). Elton (1958) proposed that a community's resistance to disturbance and in particular to invasions increases in proportion to the number of species found in the communities (species richness). Elton (1958) also proposed that communities with increased species richness were less likely to be disturbed and invaded. However, the relationship between native and introduced species richness has been shown to be strongly scale-dependent (Levine and D'Antonio, 1999; Tanentzap and Bazely, 2009). In contrast to the notion that plant communities may "resist" invasions, the resilience of a plant community is defined as being how quickly a system can return to a previous state after a disturbance. The construction of a pipeline would affect a range of plant species that may be expected to vary in their resistance and resilience with respect to disturbance.

When the mosaic of a disturbance regime increases in frequency and or intensity, the overall maintenance of the ecosystem can be disrupted, potentially increasing non-native species colonization (Hobbs and Huenneke, 1992). Changes in land use tend to facilitate disturbance, and cause declines in biodiversity (Pimm and Raven, 2000; Myers and Bazely, 2003). This occurs due to the loss, fragmentation, and modification of habitats by anthropogenic activities (Dale, 1997; Pimm and Raven, 2000; Foley *et al.*, 2005). Many of these activities create corridors facilitating movement between locations (Mooney and Hobbs, 2000; Myers and Bazely, 2003; Hansen and Clevenger, 2005). Transportation corridors (e.g., roads, hydro lines, pipelines and other linear structures) have less apparent or visible effects on plant communities, but create large amounts of habitat fragmentation (Trombulak and Frissell, 2000; Hansen and Clevenger, 2005). These corridors also increase the frequency of disturbance, altering the dynamic of natural disturbance regimes found in ecosystems (Hansen and Clevenger, 2005, Auerbach *et al.,* 1997). The role of corridors in the movement of invasive species may be facilitated through the creation of long edges, altered physical conditions, increased stress on native species, easy access of humans and other vectors of plant dispersal (Trombulak and Frissell, 2000; Myers and Bazely, 2003; Hansen and Cleverger, 2005). Conversely, corridors are also championed from conservation and political perspectives as a means of creating connectivity between fragmented habitats (Damschen *et al.*, 2006). Many hypotheses related to the functioning and impacts of corridors suggest a decrease in the negative effects of fragmentation by facilitating gene flow and movement of organisms, preventing extirpation of species, and increasing species diversity (Myers and Bazely, 2003, Damschen *et al.*, 2006). Trombulak and Frisell, (2000) showed how roads, in particular, act as corridors, and increase the invasibility of a habitat by introduced species through three mechanisms: (1) altering the conditions of the existing habitat, (2) stressing or removing native species, and (3) facilitating easier movement of animal and human vectors. However, these corridors may also allow for the movement of species from one area into areas where they would otherwise not be found. The effects of constructing and maintaining a pipeline that will potentially serve as a new 1,200 km long corridor across a range of Arctic ecosystems require a multi-scaled approach to understand the movement of organisms across landscapes and necessary for understanding how invasive species could affect Arctic regions (Myers and Bazely, 2003).

CHAPTER 2: The influence of disturbance on the presence of non-native plant species in four communities along the proposed pipeline route of the Mackenzie Valley, NWT Canada

2.0 INTRODUCTION

The composition and structure of Arctic plant communities are dependent on the tolerance of each component species to the extreme environmental conditions found in northern ecosystems. The climate of the Arctic is generally characterized by severe oscillations in temperature, and abrupt transitions between annual freeze/thaw cycles (Bliss *et al.*, 1973; Hinzman *et al.*, 2000). These conditions function as a natural environmental barrier limiting the establishment and survival of many plant species (Bliss *et al.,* 1973). However, climate warming is altering these conditions, and interactions associated with the linked biological and hydrological Arctic systems and their disturbance regimes (Hinzman *et al.*, 2005; ACIA, 2005; Bliss *et al.*, 1973).

While temperature, wind, sunlight, nutrients, soil porosity, snow and ice conditions, and moisture availability all determine the northern range limit of many of the plant species occurring in these communities, as has happened in other biomes, human-induced disturbances are likely to become an increasingly significant factor in determining the range of many species in the north (Bliss *et al.*, 1974; Pickett and White, 1985; Thompson, 1994; Parendes and Jones, 2000; Bazely and Myers, 2003; Rejmánek, *et al.*, 2005). The Arctic spans several regions of distinct ecosystems, including erect shrublands, tundra, boreal forests, and wetlands (Walker *et al.*, 2005; Carrière *et al.*, 2009). Within these Arctic ecosystems, the low occurrences of non-native plant species will be influenced by changes to environmental barriers, land use changes, and anthropogenic disturbances. This has, to date, been attributed to a variety factors, including the presence of a range of physical barriers and the absence of migration corridors (Houghton, 1994; Richardson *et al.*, 2000; Hansen and Clevenger, 2005; Rejmánek *et al.*, 2005). Interestingly, anthropogenic landscape features such as roads, railroad tracks, buildings, and industrial development, may either function as a barrier to some species, or corridors for other species. This will allow for the migration of species into new habitats due to the displacement of native communities, and alteration of the micro-habitat along the disturbance gradient created by anthropogenic disturbance (Trombulak and Frissell, 2000; Myers and Bazely, 2003; Hansen and Clevenger, 2005; Rejmánek *et al.*, 2005). However, not all corridors are a consequence of anthropogenic disturbance. For example, the Mackenzie River Valley is a naturally formed corridor that may also facilitate species movement, including introduced species (Gould and Walker, 1999; Van der Windt and Swart, 2008).

The severity and frequency of disturbance regimes in Arctic systems are changing due to land-use changes, including natural resources extractions, forestry, and infrastructure development (Pickett, 1984; Chapin *et al.*, 1995). While many people view the Arctic as pristine, there are examples of naturally occurring disturbance and pollution, such as the Smoking Hills of Cape Bathurst, NWT (Freedman *et al.*, 1990). The Smoking Hills produce more sulfur dioxide, sulfuric acid, and aerosols than most known anthropogenic sources (Freedman *et al.*, 1990; Chapin *et al.*, 1997). However, while these areas of naturally occurring disturbance are of ecological interest, it is the case that both current and historic anthropogenic land-use changes are primarily responsible for providing conditions that favour the movement of invasive non-indigenous species (Hansen and Clevenger, 2005; Rejmánek *et al.*, 2005). As of 2006, one hundred and six 'invasive alien' plant species were identified in the Northwest Territories, Canada (Oldham, 2006), but it remains to be seen how many of these species are merely non-indigenous, rather than being invasive (Myers and Bazely 2003). One of the major potential disturbances and subsequent potential corridors that are likely to facilitate the introduction and movement of introduced species (Mooney and Hobbs, 2000) is the proposed Mackenzie Valley gas pipeline. In addition to the linkages between various locations that the pipeline would provide, the construction and ongoing maintenance of such a pipeline would also be continuous sources of physical disturbance to local ecosystems.

The current proposal, which underwent a three-year environmental assessment released January, 2010, is for two 1220 km pipelines of liquefied natural gas (butane and pentane) and gaseous natural gas. This pipeline would connect three sources (Taglu, Parsons Lake and Niglintgak) on the Mackenzie Delta to a processing facility in Inuvik for transport south via a pipeline to connect with the NOVA Gas Transmission Ltd. System in Alberta (JRP, 2004; Mackenzie Gas Project, 2004; Figure 2.1). The preliminary proposal of intent, filed with the National Energy Board in 2004, estimated that construction would be completed by 2010. The formal environmental review hearings did not begin until February 2006, and to date construction has not yet begun due to the various postponements of the review process (Mackenzie Gas Project, 2004;

National Energy Board, 2004; Joint Panel Review, 2006). It has been estimated that the pipeline could produce 22,800 million m^3 of natural gas, resulting in 12,000 to 15,000 barrels (1 bbl.US Liq = 0.119240 m^3) of liquefied natural gas products each day, and contribute $724 million dollars annually to the NWT's GDP (Mackenzie Gas Project, 2004; ITI and ENR, 2007). This recent pipeline proposal was released nearly 30 years after the original pipeline proposal was rejected following the 1974-1976 Mackenzie Valley Pipeline Inquiry, the Berger Commission (Berger, 1977).

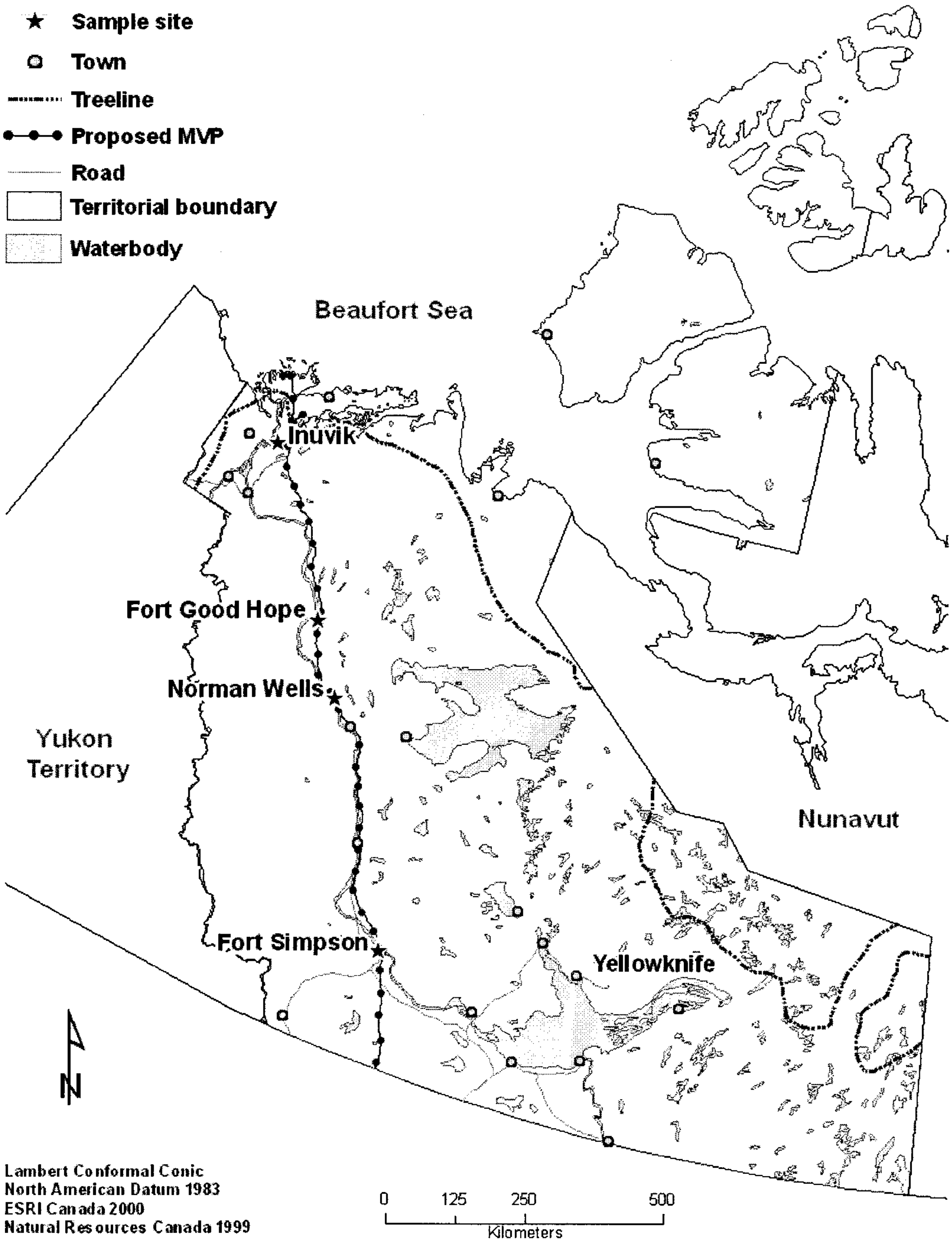

Figure 2.1 Location of sampled towns and the proposed route of the Mackenzie pipeline

The Mackenzie gas pipeline project has the potential to create new transportation and disturbance corridors, and it is likely that if it is built the construction, operation, and maintenance of the pipeline will have consequences for plant community composition, both locally and more regionally. It is most probable that the pipeline would facilitate the northern movement of non-indigenous species. To provide a baseline against which future changes may be compared, plant community composition was assessed in a range of habitat types, in human settlements along the proposed route of the Mackenzie gas pipeline proposal. Since there are pre-existing, anthropogenic transport corridors along the proposed pipeline route, plant communities, and specifically frequency and abundance of native and non-indigenous plant species were measured in:

1. Urban developments,
2. Along existing pipelines,
3. Along historic seismic lines, and
4. Along roads.

Two specific predictions were:

1. That there would be more non-indigenous plant species at more southerly sites.
2. That there would be overall higher numbers of non-indigenous plant species in the human settlements with greater numbers of transport corridors.

2.1 METHODS

Four settled communities along the proposed route of the Mackenzie Valley oil and gas pipeline, Northwest Territories, Canada (Fig 2.1) were assessed during the summer of 2008:

1. Fort Simpson (June 17 - 29).
2. Norman Wells (July 2-16).
3. Fort Good Hope (July 17-30).
4. Inuvik (August 1-10).

These locations were selected based on their history of human disturbance (Figure 2.2), and to span a broad latitudinal gradient (61° to 68°N) over a distance of approximately 1000 km. The Enbridge pipeline originating in Norman Wells was sampled along the intersection of the Mackenzie highway in Ft. Simpson, and provided a location with which plant communities in areas with less obvious corridor-related disturbance could be compared (Figure 2.2).

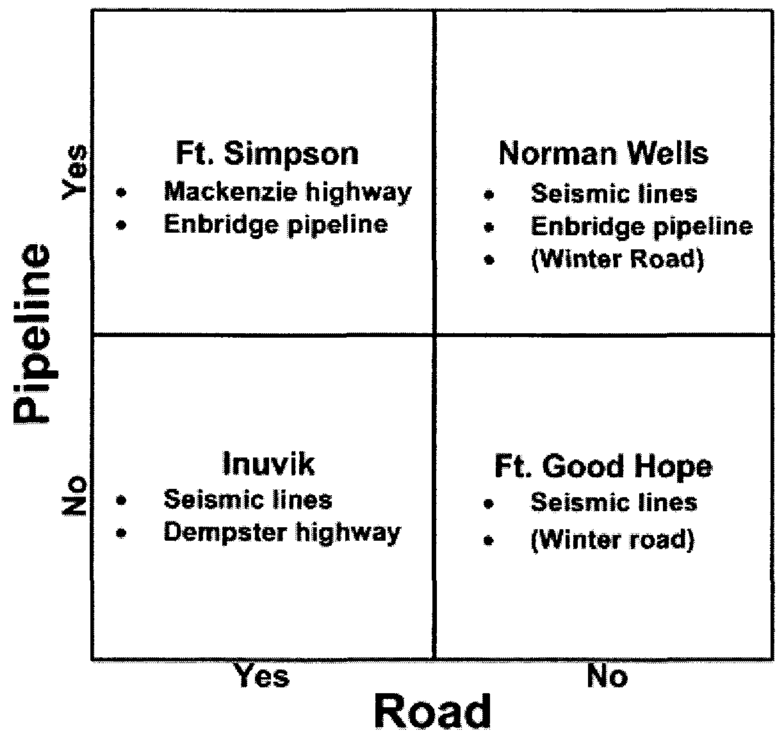

Figure 2.2 Disturbances present in the sampled towns

2.1.1Field Sampling Protocol

Vegetation up to 50 cm in height was sampled in 1 m *x* 1 m quadrats laid out along transects perpendicular to the particular disturbance corridor (e.g., roads, pipelines, seismic lines). Most transects were 20 m in length, with quadrats spaced at a maximum interval of 5 m (Figure 2.3, 2.4). Due to extremely dense brush and private property some transects were shortened to 16 m to accommodate for the varying site conditions. Transect locations were selected using random number generation. The random number was then converted into a measure of distance (kilometres, meters, or minutes) that was consistent with the mode of transportation (Truck, ATV, or by foot). A global positioning system (GPS) was used to record the coordinates of at the centre of each quadrat on a particular transect (Datum: WGS 84, Grid: UTM, Zones: 8, 9, 10). Within each quadrat, three specific datum points were recorded for plants shorter than 50 cm; (1) species identity, (2) frequency (number of individuals), and (3) the proportion of ground occupied by a species (Goldsmith *et al.*, 1986). Weather permitting; a photograph was also taken of each quadrat with an identification number to verify species cover. For certain species it was difficult to distinguish an individual plant or genet, e.g. for grass species and therefore, only the proportion of ground cover was recorded (Williams, 1950). Species that could not be identified in the field were sampled and pressed for later identification. If a species could not be indentified it was removed from the analysis. Unidentified species did not exceed eight species per community and a maximum of 30% proportion of cover in a single quadrat (Table 2.3)

Table 2.1 Number of quadrats and transects (in parentheses) sampled in each community and disturbance type

	Road	Seismic	Pipeline	Urban	Total
Ft. Simpson	70 (7)	0	40 (4)	15	15 (11)
Norman Wells	10 (1)	35 (5)	0	15	15 (6)
Ft. Good Hope	60 (6)	20 (2)	0	10	10 (8)
Inuvik	28 (3)	20 (2)	0	15	15 (5)
Total	168 (17)	75 (9)	40 (4)	55	338 (30)

The initial plan was to sample only roads and pipeline, but after consultation with local government biologists and community members, cut-lines from seismic exploration and the winter road in Fort Good Hope were identified as types of habitat disturbance that resulted in corridors, and were also sampled. Seismic lines were sampled with the transect overlaying the central area of the line, and radiating outwards into less disturbed areas (Figure 2.4). The Enbridge pipeline was sampled using the same transect methods as road disturbance types, but transects were placed on the pipeline where it intersected the road, and 500 m on either side of the pipeline. This was done to determine if the deliberate reseeding of the pipeline affected the plant communities differently from the other disturbance types. In addition to sampling plant community composition along corridors (roads, pipelines and seismic lines), sites were sampled inside the local urban areas. Instead of transects, sampling was conducted in 1×1 m quadrats laid at randomly selected locations on public sites in each community. Locations included residential units, commercial buildings, parks, abandoned lots and gardens. In total, 338 quadrats were sampled: 125 quadrats in Fort Simpson, 60 in Norman Wells, 90 in Fort Good Hope, and 63 in Inuvik (Table 2.1). A total of 137 plant species were identified to at least genus, with 115 native species, 19 introduced species, and 3 species of cryptogenic origin (Table 2.2).

Table 2.2 Total number of species in each category

Category	**Total #**
Native species	115
Introduced species	19
Cryptogenic species	3
Total	**137**

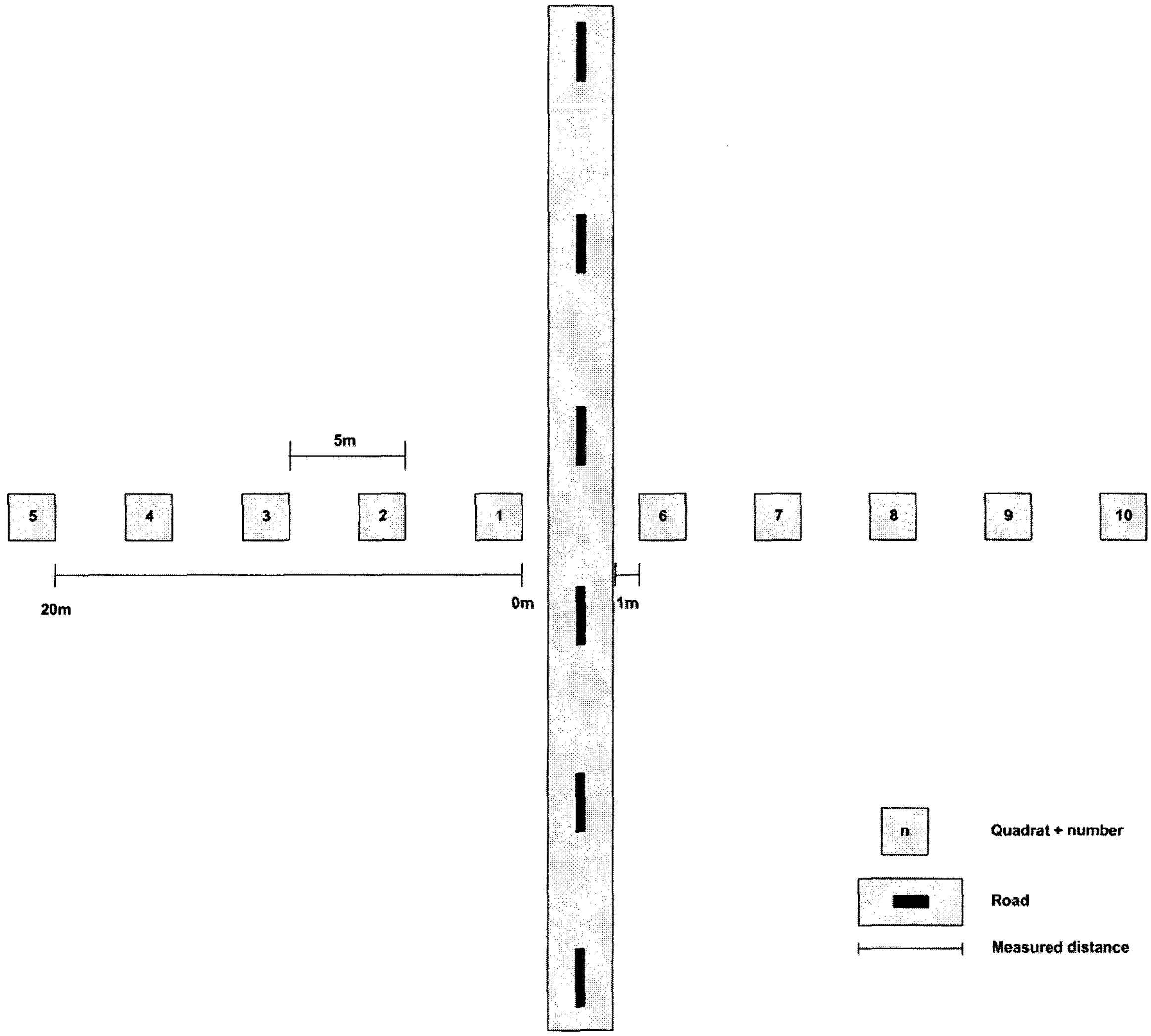

Figure 2.3 Road transect sampling setup

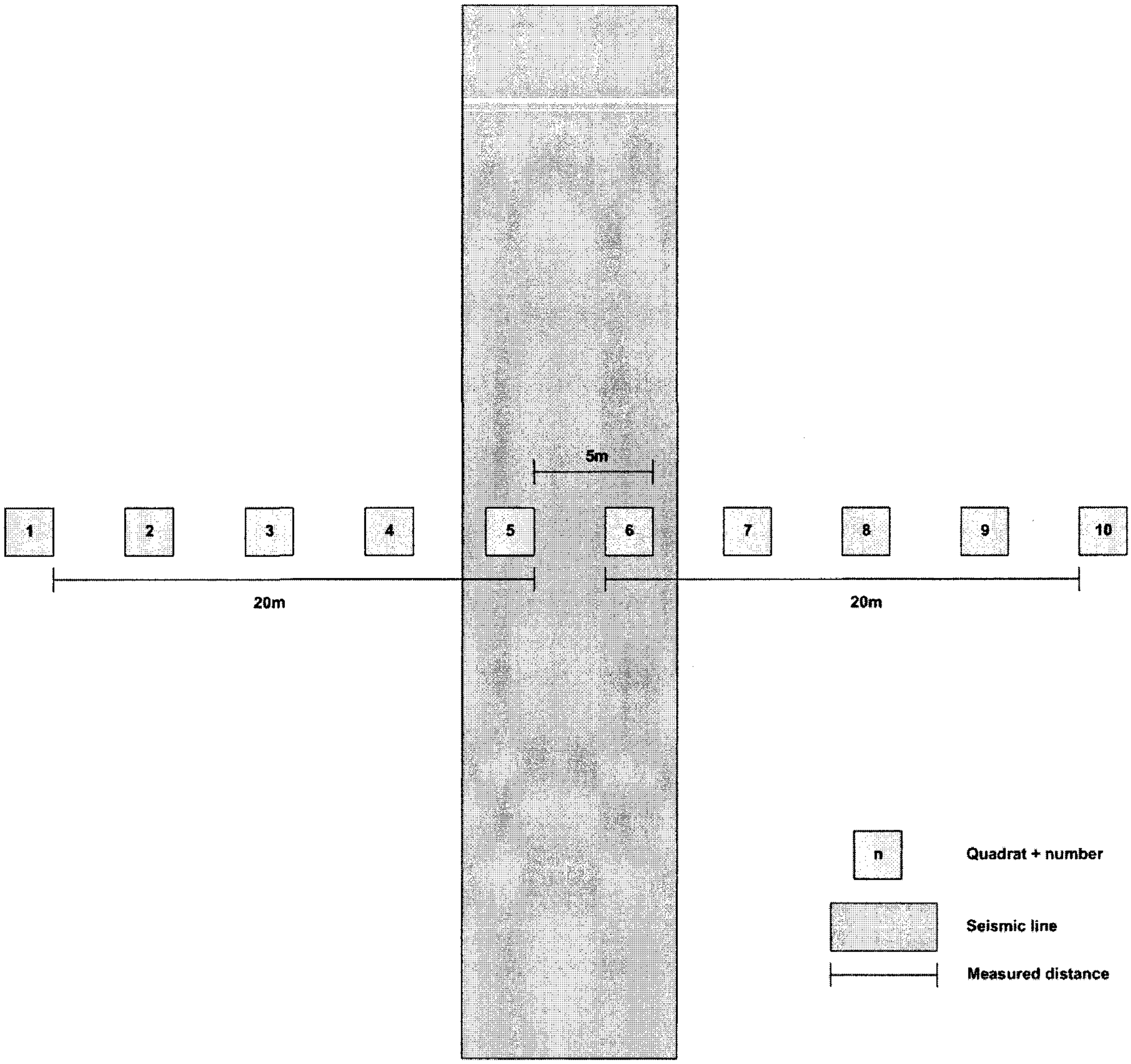

Figure 2.4 Seismic transect sampling setup

The *Flora of Alaska and neighboring territories; a manual of the vascular plants* (Hulten, 1968) was the main guide used for field identification, and supplementary taxonomic verification was made with the Integrated Taxonomic Information System (http://www.itis.gov, 2009). Species identifications, frequency, and percent cover, were then entered into Turboveg^{TM}, a comprehensive database management system for storing, selecting and exporting vegetation plot data (Hennekens and Schaminee, 2001).

Table 2.3: Number of plant species at each site, number of species not identified, and the maximum percent cover in a single quadrat of species that could not be identified, including grasses and sedges.

Site	Total #	# not identified	Maximun % cover
Ft. Simpson	83	7	30.0
Norman Wells	66	8	30.0
Ft. Good Hope	73	5	25.0
Inuvik	53	2	0.5

Species were identified and assigned to one of three categories: native, introduced, or cryptogenic according to the USDA 'PLANTS Database' and the GNWT Environment and Natural Resources species Infobase (GNWT ENR, 2006; USDA, NRCS, 2009). Cryptogenic species were defined as species that cannot be clearly assigned to either of the first two categories, because they have likely been introduced and naturalized at some unknown time (e.g., *Taraxcum sp.*- common dandelion). A second reason for assigning a species to the cryptogenic category was in the case where it could be identified to genera but, due to the presence of only vegetative characteristics, could not be identified to species, and within the genus, there were known to be both native and non-indigenous species present in an area. For example, *Festuca* grass species, which lacked flowers, were assigned to the cryptogenic category.

2.1.2 Sample Sites

All four main study locations were in the Northwest Territories along the Mackenzie River. The river is one of the most dominant topographic features in the territory, with both cultural and historical significance. The Mackenzie Valley has two dominant ecozones; most of the valley area consists of Taiga plains, while a smaller portion to the west is Taiga Cordillera (Carrière *et al.*, 2009). Study site selection was based on the desired mix of disturbance corridors shown in the matrix (Figure 2.2) and National Topographic Database maps. Ft. Simpson has a permanent year-round road, and the Enbridge pipeline that originated in Norman Wells intersected with the road, making it accessible for sampling. Norman Wells was never a community with a First Nations or aboriginal origin, and was an industrial town (Cody *et al.*, 2000). It has a long history of construction activities involving the movement of equipment, supplies, and personnel (McCormack, 1996). Consultations with local community members and further research revealed that previous agricultural activities were conducted by the Federal Government in Ft. Simpson and Ft. Good Hope throughout much of the early 20th century (Johnson and Smith, 1986). The purpose of the experiments was to test the varying soil conditions found in the Northwest Territories for the viability of domestic animal husbandry, the development of cereals, orchard crops, and the study of seeds, fertilizers, plant diseases, and pests (Johnson and Smith, 1986). In addition, to the legacy of the experimental agriculture, Ft. Good Hope is accessible by plane year round, and a winter road decreases the amount of potential disturbance (Figure 2.2). Inuvik is located the furthest north (68

□N) and consultations revealed that the community may be affected by church led agricultural practices, in addition to the Dempster highway (Figure 2.2).

2.1.3 Statistical Analysis

One of the challenges associated with conducting any type of field sampling is to determine the appropriate sample size for adequately describing the desired variable of interest, in this case, species richness and percent cover. In order to verify whether the sample sizes captured a large enough area to detect overall species richness and percent cover, a species area relationship was determined using cumulative species richness and cumulative area curves constructed for the communities as a whole, each sample location (town), and disturbance type. Sequential random numbers were generated to select each quadrat, and the number of new species sampled within each additional quadrat was plotted against the cumulative area sampled (Rosenzweig, 1995).

Species richness and percent cover data were normalized, where necessary, with square root and logarithmic (log x+1) transformations. If the data could not be normalized and therefore it did not meet assumptions of homogeneity of variance, then non parametric Kruskal-Wallis tests, (two-tailed, $\alpha = 0.05$) were performed (Zar, 1999). To describe the overall trends in the communities, four common diversity indices were calculated: species richness (R = total number of species), Shannon index (H□), Evenness, and the Simpson index (Magurran, 1998). Cryptogenic species richness and species cover was not analyzed, due to the low number of species assigned to this category (Table 2.1, n = 3). The indices were calculated on a quadrat basis, normalized, and compared using one way Analysis of Variance (ANOVA) with SPSS 17.0 for

Windows. If the null hypothesis was rejected, Tukey and Gamble Howell multiple comparisons were preformed to establish which samples were significantly different (Zar, 1999). If sample size was unequal, the harmonic mean was used for the multiple comparison tests to increase the sensitivity to the smaller values and decrease the weight of outliers (Zar, 1999). If there was heterogeneity of variance and unequal sample size Brown-Forsythe F* tests were used increase the robustness of the ANOVA (Maxwell and Delaney, 2004). Kruskal-Wallis, a non parametric test that rank orders all observations (two-tailed, $\alpha = 0.05$), was used to compare non-normal datasets (Zar, 1999, Maxwell and Delaney, 2004).

In order to address the shortcomings of a univariate approach, a multivariate approach was also taken to describe plant community composition. A detrended correspondence analysis (DCA) was performed using CANOCO v4.53 (ter Braak and Šmilauer, 1998) on road transect quadrats. This allowed for the observation of any comparisons of the distances among quadrats. The DCA analysis utilized the calculated percent abundance of taxa, as the percentage of the total identifiable individuals. Rare taxa were identified as those that had percent abundances less than 2% in at least 2 quadrats, and were excluded from the DCA analysis.

2.2 Results

The baseline composition of plant communities, and the prevalence of introduced species, was examined across several disturbance types and along gradients of disturbance within several communities along the proposed route of the Mackenzie Valley gas pipeline. This was done by (1) indentifying differences in native and introduced species richness and cover between towns and disturbance types, (2) comparing richness, cover, and abundance between disturbance types in each town, (3) examining the same variables for only road quadrats between towns and the distance from the point source of disturbance and (4) analysis for the examination of overall trends in relative abundance along the road gradient.

2.2.1 Adequacy of sampling: species-area curves

Species area curves calculated for different spatial scales indicated that the overall sample size adequately described species present in disturbed anthropogenically-influenced habitats in the Mackenzie Valley, since the curve reached an asymptote after approximately 150 quadrats (Figure 2.5, n=338). Cumulative species-area curves levelled off in each of the four communities (Figures 2.6-2.9), and species area curves for Ft. Simpson suggest that the overall area was sampled adequately (Figure 2.6, n = 125). When comparing individual disturbances types, quadrats sampled along roads within the Ft. Simpson area had the largest overall species richness and the species-area relationship indicated an adequate number of samples had been conducted (Figure 2.6, n=75). An asymptote was not reached for the urban and pipeline disturbance types (n = 15, n = 40) suggesting that more quadrats and transects may be needed to fully capture the total species richness. The overall sample size for quadrats sampled near Norman Wells was well represented (n = 60), and seismic lines were sampled sufficiently, as the asymptote was reached at approximately 22 m^2 (n = 35; Figure 2.7). However, the levelling off of the species-area curve was not observed for the roads and urban area samples (Figure 2.7, n = 10 and n = 15). While the Ft. Good Hope sampling location overall reached an asymptote (Figure 2.8, n = 90), the individual disturbance type samples in Ft. Good Hope did not. In contrast, the species area curve for Inuvik suggests that the roads and town quadrats were sufficiently sampled as they reached asymptote at $19m^2$ and $9m^2$ (Figure 2.9 n =28, n = 15). This suggests that there was more local variation in plant species composition in the more southerly locations.

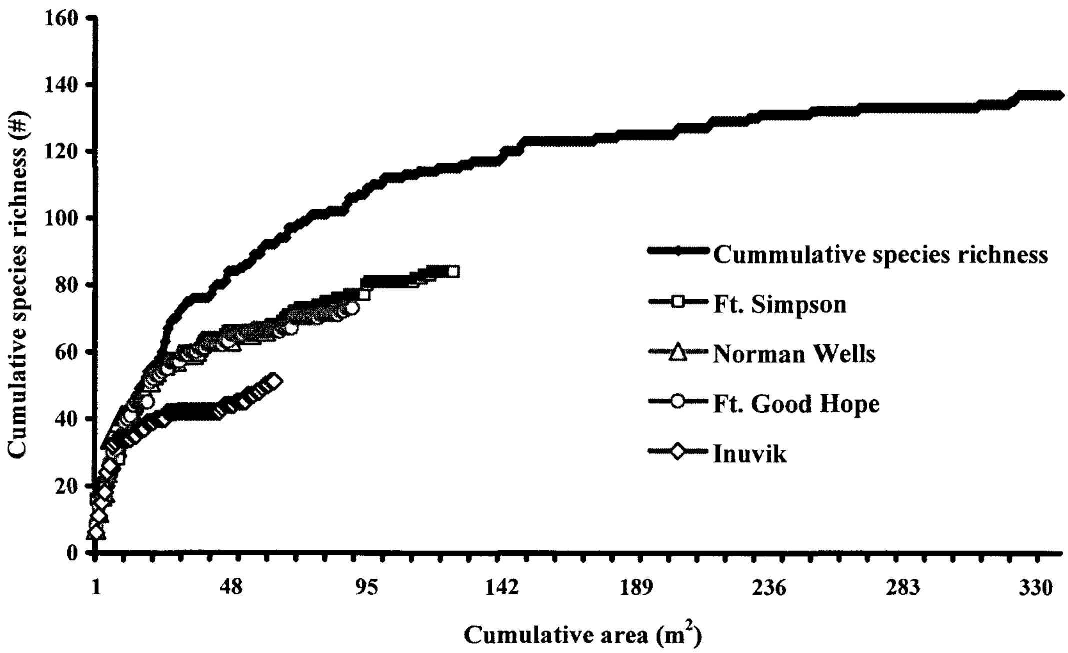

Figure 2.5 Cumulative species richness area curve for all sampled towns in NWT

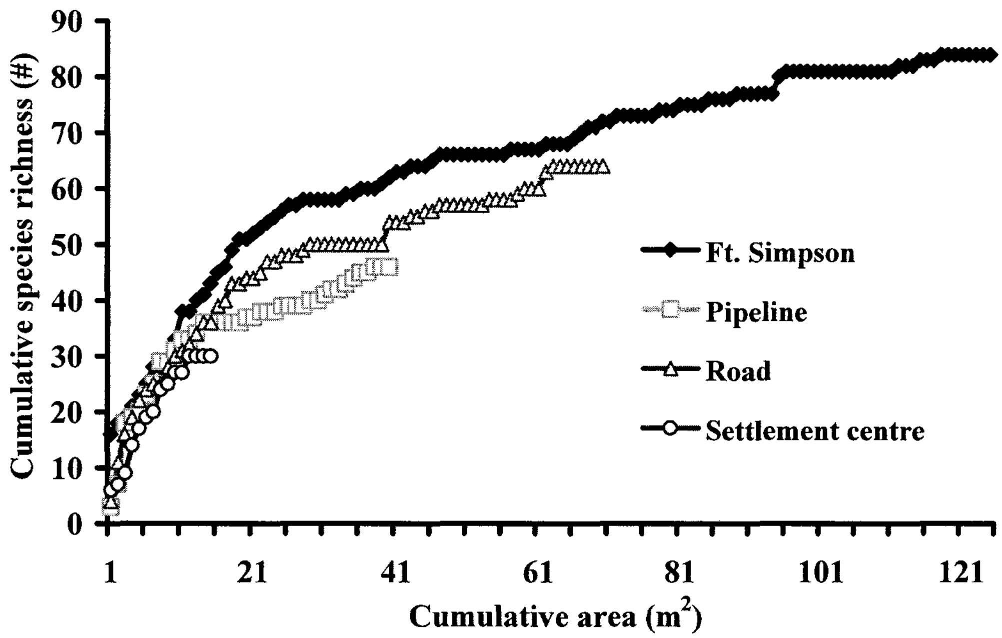

Figure 2.6 Cumulative species richness area curve of Ft. Simpson

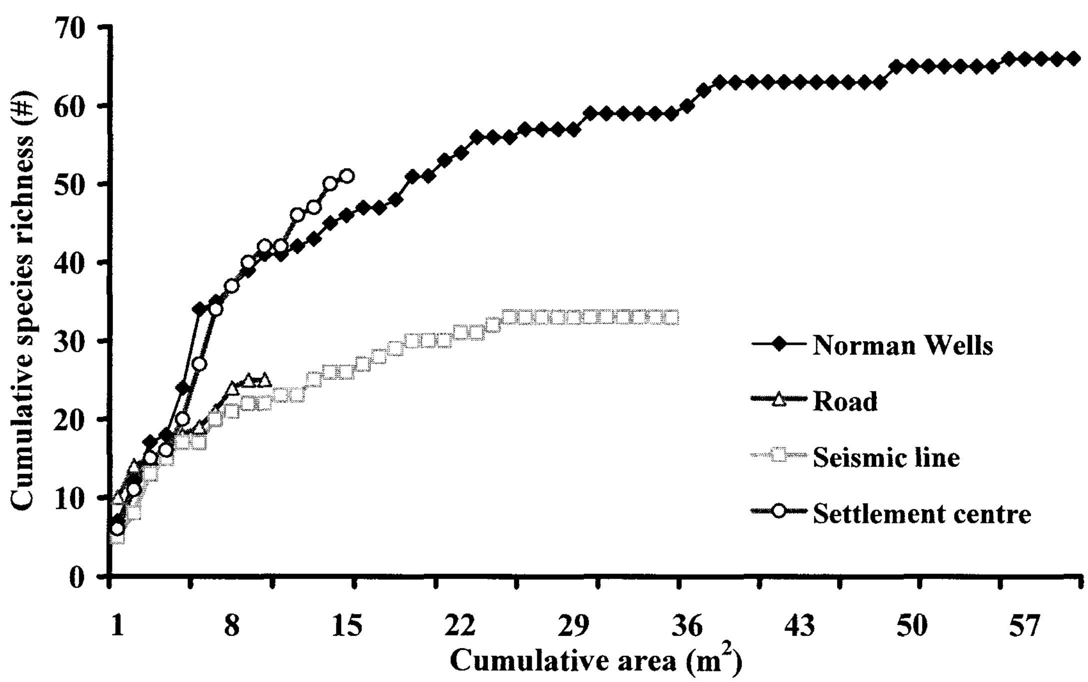

Figure 2.7 Cumulative species richness area curve of Norman Wells

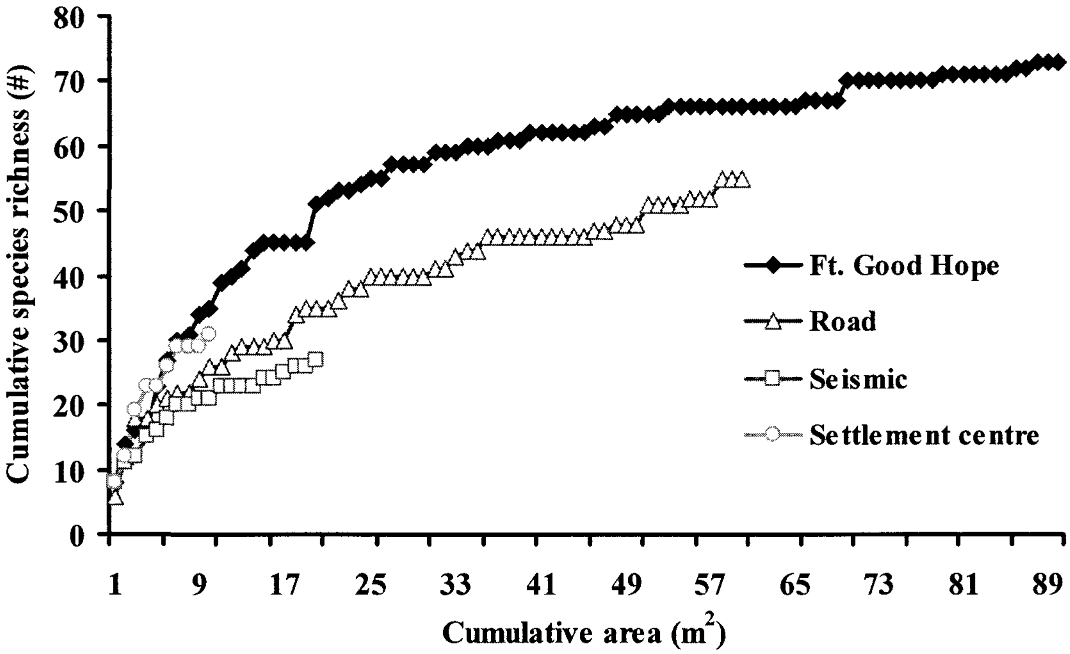

Figure 2.8 Cumulative species richness area curve of Ft. Good Hope

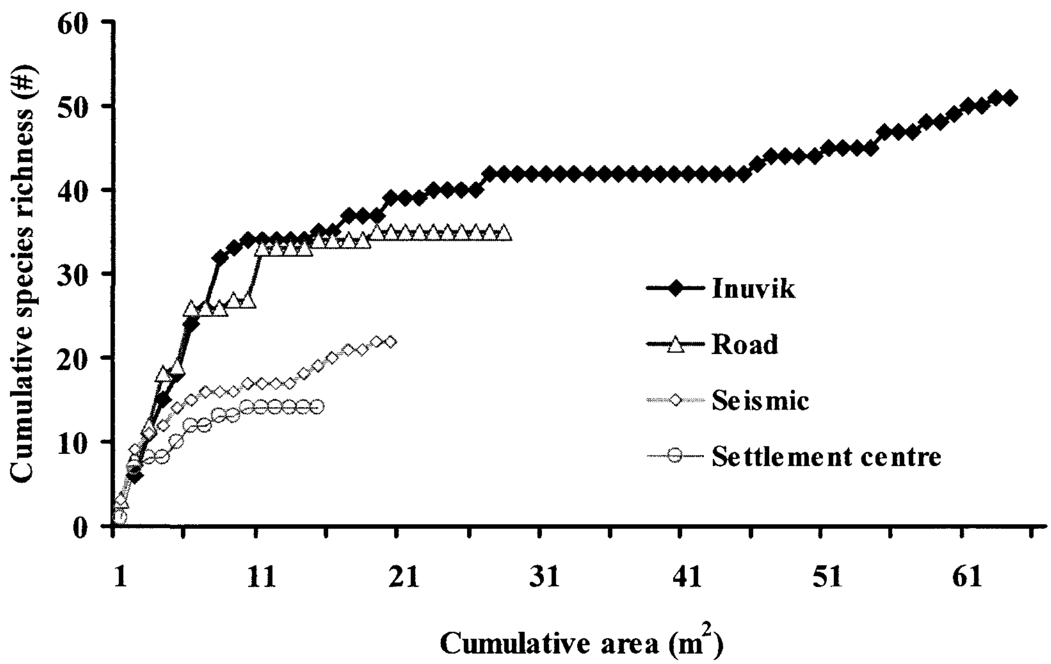

Figure 2.9 Cumulative species richness area curve of Inuvik

2.2.2 Diversity and percent cover between towns

The overall mean species richness was greatest in Norman Wells and Ft. Good Hope, at 7.27 and 7.01 species per quadrat respectively, but the differences among the four main sample locations were not significant (Table 2.4). A significant difference was found for native species richness among the four settlements ($F_{3,337} = 19.61$, $p < 0.0001$) due to Ft. Simpson having a lower native species richness (Table 2.4). Conversely, the highest species richness for introduced species was in Ft. Simpson, with 1.67 mean species per quadrat (Table 2.4). Generally, introduced species richness, cover, and relative abundance were all significant in their comparison between the sampled towns (Table 2.5).

Table 2.4: Overall species richness in each settlement. Mean, standard deviation (SD), and standard error (SE) indicated for each category.

		Ft. Simpson	Norman Wells	Ft. Good Hope	Inuvik
	n	125	60	90	63
Overall species richness	Mean	6.47	7.27	7.01	6.70
	SD	2.91	2.21	2.61	2.98
	SE	0.26	0.29	0.27	0.38
Native species richness	Mean	4.26[a]	6.65[ab]	6.33[ac]	6.51[ad]
	SD	2.39	2.15	2.63	3.13
	SE	0.21	0.28	0.28	0.39
Introduced species richness	Mean	1.67[a]	0.45[ab]	0.57[ac]	0.11[ad]
	SD	1.52	0.91	1.01	0.32
	SE	0.14	0.24	0.11	0.04
Cryptogenic species richness	Mean	0.54	0.17	0.10	0.08
	SD	0.63	0.38	0.30	0.33
	SE	0.06	0.12	0.03	0.04

[a] significant $p < 0.05$

Table 2.5: Summary of statistical tests performed on quadrats sampled between towns. Abbreviations; Relative Abundance (RA), F values for ANOVA, F* values for Brown-Forsythe, and H values for Kruskal – Wallis.

Metric	Species category	Test	d.f	F, F*, H	p
Richness	All quadrats	ANOVA	3, 337	1.39	0.245
Richness	Native	ANOVA	3, 337	19.61	<0.0001
Richness	Introduced	Brown-Forsythe	3, 159	45.66	<0.0001
Cover	Native	Kruskal-Wallis	3	5.99	0.112
Cover	Introduced	Kruskal-Wallis	3	86.59	<0.0001
RA Introduced	Introduced	Kruskal-Wallis	3	85.32	<0.0001
Shannon	All quadrats	Brown-Forsythe	3, 163	1.57	0.191
Evennes	All quadrats	Brown-Forsythe	3, 163	1.86	0.109
Simpson	All quadrats	ANOVA	3, 337	0.42	0.735

Tukey-type multiple comparison tests, using the harmonic mean for unequal sample size, indicated that native and introduced species richness in Ft. Simpson sample sites was significantly different from that in the other settlements (Table 2.5). Introduced species richness was also significantly different among these settlements (Table 2.4, Table 2.5). As with native species richness, similar multiple comparisons identified that there was a significant difference between Ft. Simpson and all other towns ($p < 0.0001$). Native species had the highest richness, and they also accounted for the largest percent cover within quadrats (Table 2.4; Table 2.6; Figure 2.10). Ft. Good Hope quadrats had lower mean percent cover of native species than the other sampling locations (Table 2.6, Figure 2.10). Ft. Simpson had the highest percent cover for introduced species, while the Norman Wells, Ft. Good Hope, and Inuvik were relatively similar (Figure 2.10).

Table 2.6: Percent cover of species category in each settlement. Mean, standard deviation (SD), and standard error (SE) indicated for each category.

		Ft. Simpson	Norman Wells	Ft. Good Hope	Inuvik
	n	125	60	90	63
% cover Native species	Mean	21.79	21.75	15.29	22.26
	SD	27.48	23.51	16.49	25.92
	SE	2.46	3.03	1.74	2.73
% cover Introduced species	Mean	8.29[a]	1.58[ab]	0.92[ac]	1.60[ad]
	SD	17.48	7.99	3.40	10.22
	SE	1.56	1.03	0.36	1.08
% cover Cryptogenic species	Mean	1.61	0.67	0.09	0.01
	SD	6.33	2.31	0.43	0.03
	SE	0.57	0.30	0.05	0.00

[a] significant $p < 0.05$

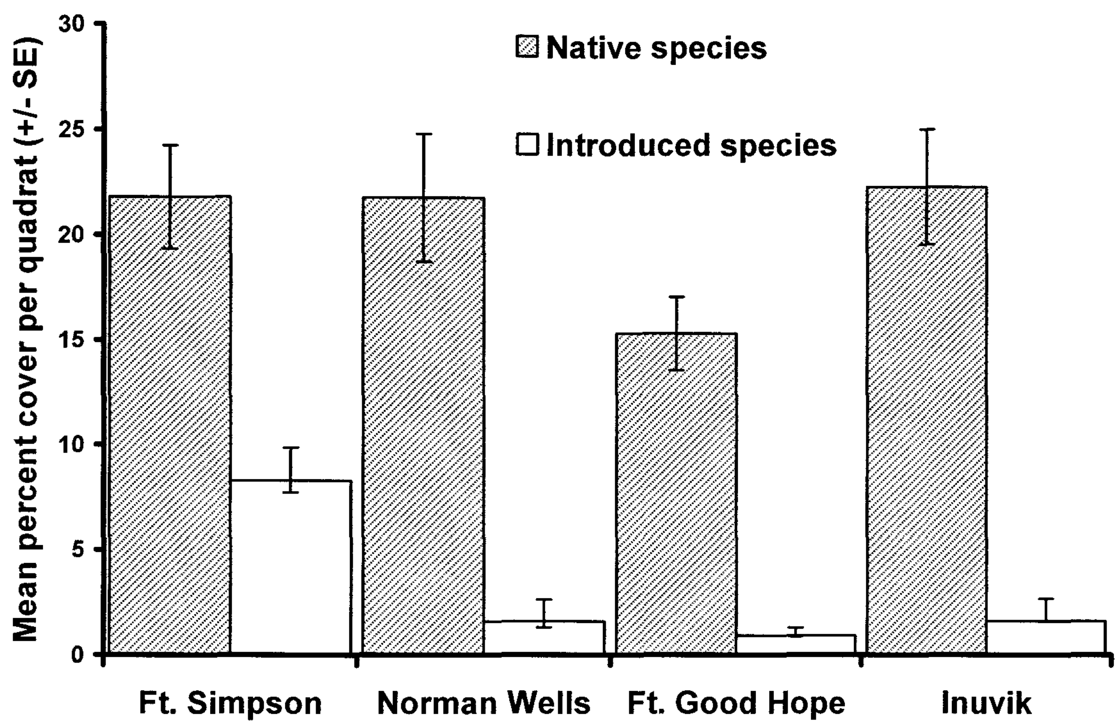

Figure 2.10: Percent cover of species categories by sample site. (Mean ± SE)

The percent cover of native species was not significant among towns, but there was a significant difference between introduced species cover (Table 2.6). The relative abundance of introduced species was significantly different among the sampled towns (Table 2.5). No significant difference was found among the Shannon, Evenness, and Simpson diversity indices (Table 2.5).

2.2.3 Patterns of species richness and percent cover along disturbance corridors

Native species richness was significant among the disturbance types (Table 2.7), and Tukey type multiple comparison tests using the harmonic mean identified that seismic lines were significantly different from all other types disturbance types ($p < 0.05$). Introduced species richness was significantly different among disturbance types in the different towns ($H = 80.474$, $p < 0.05$, d.f. = 3).

Table 2.7: Summary of statistical tests performed on quadrats sampled between disturbance types. Abbreviations; Relative Abundance (RA), F values for ANOVA, F* values for Brown- Forsythe, and H values for Kruskal – Wallis.

Metric	Species category	Test	d.f	F, F*, H	p
Richness	All quadrats	Brown-Forsythe	3, 172	2.58	0.055
Richness	Native	ANOVA	3, 337	21.34	<0.0001
Richness	Introduced	Kruskal-Wallis	3	80.47	<0.0001
Cover	Native	Kruskal-Wallis	3	83.61	0.083
Cover	Introduced	Kruskal-Wallis	3	83.61	<0.0001
RA Introduced	Introduced	Kruskal-Wallis	3	77.74	<0.0001
Shannon Index	All quadrats	Kruskal-Wallis	3	17.33	0.001
Evenness	All quadrats	Kruskal-Wallis	3	14.93	0.002
Simpson	All quadrats	ANOVA	3, 337	1.03	0.381

Contrary to species richness, the percent cover of native species was not significant among disturbance types. However, the percent cover of introduced species, the Shannon index and the Evenness of the community were significantly different among disturbance types (Table 2.7).

2.2.3 Ft. Simpson

In Ft. Simpson, the overall species richness was lowest in quadrats sampled in the settlements, while species richness was similar along roads and the pipeline (Table 2.8). The mean species richness of native species was also lowest in the urban areas, and conversely, introduced species richness was highest in the town core (Table 2.8). Road and pipeline sample sites both had similar native and introduced species richness (Table 2.8).

Table 2.8: Species richness in Ft. Simpson by disturbance. Mean, standard deviation (SD), and standard error (SE) indicated for each category.

		Road	**Pipeline**	**Town**
	n	70	40	15
Overall species richness	Mean	6.60	6.50	5.80
	SD	2.88	3.13	2.46
	SE	0.34	0.49	0.63
Native species richness	Mean	4.5[a]	4.57[ab]	2.33[abc]
	SD	2.29	2.57	1.35
	SE	0.27	0.41	0.35
Introduced species richness	Mean	1.56[ac]	1.45[ab]	2.80[a]
	SD	1.36	1.66	1.42
	SE	0.16	0.26	0.37
Cryptogenic species richness	Mean	0.54	0.48	0.73
	SD	0.65	0.60	0.59
	SE	0.08	0.09	0.15

[a] significant $p < 0.05$

There was a significant difference between native species richness across these three disturbance types ($F_{2,122} = 6.026$, p = 0.004, d.f. = 124). Tukey-type multiple comparison tests using harmonic means showed that the native species richness along road and pipeline transects were significantly higher than that in core town areas (p = 0.003 and p < 0.05, Appendix B). Introduced species richness was significantly different between disturbance types (Table 2.7) and Tukey-type multiple comparison tests showed within the town the richness of introduced species was significantly different from road and pipeline disturbance types (p = 0.011 and p = 0.009). Shannon index, Evenness, and Simpson index were not significantly different among the three disturbance types in Ft. Simpson (Appendix B).

Table 2.9: Percent cover of species categories in Ft. Simpson by disturbance type. Mean, standard deviation (SD), and standard error (SE) indicated for each category.

		Road	Pipeline	Town
	n	70	40	15
% cover Native species	Mean	21.86	25.24	12.31^{a}
	SD	28.90	28.48	13.55
	SE	3.45	4.50	3.50
% cover Introduced species	Mean	7.06^{a}	5.28^{b}	22.02^{ab}
	SD	16.36	10.26	29.31
	SE	1.96	1.62	7.57
% cover Cryptogenic species	Mean	2.61	0.22	0.66
	SD	8.33	0.44	0.94
	SE	1.00	0.07	0.24

$^{a, b}$ significant $p < 0.05$

The highest percent cover of introduced species occurred in quadrats located in the urbanized areas (towns), while pipeline disturbance had the greatest native species cover (Table 2.9). Ft. Simpson had the highest mean introduced species cover and it was significant among the disturbance types (Table 2.6; Table 2.9). The relative abundance of introduced species was significant between the disturbance types in Ft. Simpson ($F_{2, 124}$ = 6.397, p = 0.002).

2.2.3 Norman Wells

The town of Norman Wells was the second sampling location visited. The dominant disturbance type sampled were seismic lines (Appendix B).

Table 2.10: Species richness of Norman Wells by disturbance type. Mean, standard deviation (SD), and standard error (SE) indicated for each category.

		Road	Seismic	Town
	n	10	35	15
Overall species richness	Mean	7.70	6.83	8.00
	SD	2.50	1.92	2.54
	SE	0.79	0.32	0.65
Native species richness	Mean	7.60	6.63	6.07
	SD	2.72	1.88	2.28
	SE	0.86	0.32	0.59
Introduced species richness	Mean	0.10	0.06	1.60[a]
	SD	0.32	0.24	1.18
	SE	0.10	0.04	0.31
Cryptogenic species richness	Mean	0.00	0.14	0.33
	SD	0.00	0.36	0.49
	SE	0.00	0.06	0.13

[a] significant $p < 0.05$

Overall species richness of quadrats sampled at Norman Wells was greatest at the core town sites (Table 2.10). While native species richness was highest at road sites, introduced species richness was greatest in the town, and cryptogenic species richness was low in all sample sites (Table 2.10). There were no significant differences among disturbance types in native species richness (Appendix B). There was a significant difference in introduced species richness among disturbance types (H = 30.751, $p < 0.05$, d.f. = 2). Of the disturbance types, multiple comparison tests identified a significant difference between seismic and core town quadrats (H = 26.675, $p < 0.05$, d.f. = 2).

Table 2.11: Percent cover of species categories in Norman Wells by disturbance type. Mean, standard deviation (SD), and standard error (SE) indicated for each category.

		Road	Seismic	Town
	n	10	35	15
% cover Native species	Mean	18.91	21.24	24.81
	SD	11.81	18.62	37.16
	SE	3.73	3.15	9.59
% cover Introduced species	Mean	0.3^{ac}	0.06^{ab}	6.01^{a}
	SD	0.95	0.34	15.51
	SE	0.30	0.06	4.00
% cover Cryptogenic species	Mean	0.00	0.35	1.87
	SD	0.00	0.34	3.64
	SE	0.00	0.06	0.94

^{a} significant $p < 0.05$

The percent cover of introduced species in quadrats in Norman Wells was low in comparison to those in Ft. Simpson (Table 2.6, Figure 2.10). Similar to Ft. Simpson the greatest cover introduced species occurred in quadrats sampled within the town (Table 2.9; Table 2.12). There was a significant difference between disturbance types for introduced species cover and the relative abundance of introduced species (Appendix B). Native species was not significant in Norman Wells (Appendix B).

2.2.3 Ft. Good Hope

Ft. Good Hope was selected as the sample location that was expected to exhibit the least amount of disturbance with respect to introduced species (Figure 2.2). Variables tested involving introduced species overall were significant (Appendix B). Overall species richness in Ft. Good Hope was highest in seismic disturbance quadrats, and lowest on roads (Table 2.11). Introduced species richness was highest in core town plots in comparison to other disturbance types (Table 2.12, Appendix B).

Table 2.12: Species richness of Ft. Good Hope by disturbance type. Mean, standard deviation (SD), and standard error (SE) indicated for each category.

		Road	Seismic	Town
	n	60	20	10
Overall species richness	Mean	6.18	9.00	8.00
	SD	2.34	2.05	2.83
	SE	0.30	0.46	0.89
Native species richness	Mean	5.7^{ab}	8.95^{a}	4.9^{ac}
	SD	2.20	2.01	2.85
	SE	0.28	0.45	0.90
Introduced species richness	Mean	0.42	0.05	2.6^{a}
	SD	0.74	0.22	0.97
	SE	0.10	0.05	0.31
Cryptogenic species richness	Mean	0.07	0.00	0.50
	SD	0.25	0.00	0.53
	SE	0.03	0.00	0.17

[a] significant $p < 0.05$

Table 2.13: Percent cover of species categories in Ft. Good Hope by disturbance type. Mean, standard deviation (SD), and standard error (SE) indicated for each category.

		Road	Seismic	Town
	n	60	20	10
% cover Native species	Mean	17.25	14.05	6.02
	SD	18.99	9.12	5.08
	SE	2.45	2.04	1.61
% cover Introduced species	Mean	0.22[ac]	0.005[ab]	6.92[a]
	SD	0.95	0.02	7.94
	SE	0.12	0.01	2.51
% cover Cryptogenic species	Mean	0.04	0.00	0.57
	SD	0.26	0.00	1.06
	SE	0.03	0.00	0.33

[a] significant $p < 0.05$

The percent cover of introduced species was the highest in quadrats within the urbanized areas of Ft. Good Hope (Table 2.13). Introduced species cover was found to be significantly different among disturbance types (H = 39.817, p = <0.0001, d.f. = 2). Ft. Good Hope also had the lowest cover of native species of the towns, but the richness of the native species was not significant (Table 2.12; Table 2.13; Figure 2.10). Native percent cover was not significant, but introduced cover was significant among disturbance types in Ft. Good Hope (H = 39.817, p = < 0.0001, d.f. = 2). Furthermore, the Shannon index was significantly different among disturbance types ($F_{2, 89} = 7.282$, p = 0.01). While the Evenness index was not significant among disturbance types in Ft. Good Hope, but Simpson index was (Appendix B).

2.2.3 Inuvik

Inuvik was the final and most northern town sampled. With the exception of the Simpson index, all of the variables tested were significant (Appendix B). Overall species richness and native species richness was highest in road disturbance types in Inuvik (Table 2.14). Quadrats sampled within the towns had the highest introduced species richness (Figure 2.14). Native and introduced species richness between the disturbance types was also significant ($F^*_{2,39} = 39.129$, p = < 0.0001, d.f = 62; H = 16.52, p = <0.0001, d.f =2). The total cover of native species in Inuvik was similar to Ft. Simpson and Norman Wells (Figure 2.10).

Table 2.14: Species richness of Inuvik by disturbance type. Mean, standard deviation (SD), and standard error (SE) indicated for each category. (Mean, SD, SE)

		Road	Seismic	Town
	n	28	20	10
Overall species richness	Mean	7.61	7.35	4.13
	SD	3.42	1.73	1.85
	SE	0.65	0.39	0.48
Native species richness	Mean	7.57[ac]	7.35[ab]	3.40[a]
	SD	3.48	1.73	1.55
	SE	0.66	0.39	0.40
Introduced species richness	Mean	0.03[ac]	0[ab]	0.4[a]
	SD	0.19	0.00	0.51
	SE	0.04	0.00	0.13
Cryptogenic species richness	Mean	0.00	0.00	0.33
	SD	0.00	0.00	0.62
	SE	0.00	0.00	0.16

[a] significant $p < 0.05$

Table 2.15: Percent cover of species categories in Inuvik by disturbance type. Mean, standard deviation (SD), and standard error (SE) indicated for each category.

		Road	Seismic	Town
	n	28	20	15
% cover Native species	Mean	12.84[abc]	23.43[ab]	38.25[a]
	SD	15.57	24.18	35.52
	SE	2.94	5.41	9.17
% cover Introduced species	Mean	0.00	0.00	6.68[a]
	SD	0.00	0.00	35.52
	SE	0.00	0.00	9.17
% cover Cryptogenic species	Mean	0.00	0.00	0.03
	SD	0.00	0.00	0.06
	SE	0.00	0.00	0.02

[a] significant $p < 0.05$

Introduced species cover could only be detected in quadrats found within Inuvik, and the amount was similar to other sampled towns (Table 2.15). The cover of native species was lowest in road sample sites and among disturbance types it was significant (Table 2.15; Figure 2.10; $F_{2,63} = 4.473$, p= 0.015). The cover of introduced species was the same as Norman Wells and it was significant between the disturbance types (Table 2.15; H = 16.914, p = <0.05, d.f. = 2). The relative abundance of introduced species was significant among the different disturbance types (Appendix B). Shannon diversity index was also significant between disturbance types in Inuvik ($F_{2,60} = 17.246$, p < 0.0001).

2.2.4 Gradients in species richness and cover perpendicular to road edges

Quadrats sampled along transects perpendicular to roads were analysed for the presence of a gradient in species richness from the edge of the road into nearby undisturbed habitat. In comparing various metrics related to species richness, across different species richness categories, introduced species tended to have the most significant variation among the four main sample locations (Ft. Simpson, Norman Wells, Ft. Good Hope and Inuvik) (Table 2.16). These trends were explored further using the same metrics by comparing the set distances from the edge of the road (Table 2.17).

Table 2.16: Summary of statistical tests performed on road quadrats sampled between towns. Abbreviations; Relative Abundance (RA), F values for ANOVA, F* values for Brown- Forsythe, and H values for Kruskal – Wallis.

Metric	Species category	Test	d.f	F, F*, H	p
Richness	All quadrats	ANOVA	3, 167	2.14	0.097
Richness	Native	ANOVA	3, 167	12.31	<0.0001
Richness	Introduced	Kruskal-Wallis	3	57.12	<0.0001
Cover	Native	Kruskal-Wallis	3	2.84	0.418
Cover	Introduced	Kruskal-Wallis	3	56.41	<0.0001
RA Introduced	Introduced	Kruskal-Wallis	3	26.92	<0.0001
Shannon Index	All quadrats	ANOVA	3, 167	1.03	0.38
Evenness	All quadrats	ANOVA	3, 167	1.83	0.908
Simpson Index	All quadrats	ANOVA	3, 167	3.02	0.031

Native species richness was significantly different in road samples among the four towns ($F_{3,167} = 12.309$, $p < 0.0001$). Both overall and native species richness showed a non-linear relationship with distance from the road edge, being lowest both next to and furthest from the road; however, native species was lowest at 1 m from the road edge (Figure 2.11, Table 2.18). Both overall and native species richness was greatest at mid-transect point (10m) and differences between these intervals were significant (Table 2.17).

Table 2.17: Summary of statistical tests performed on road quadrats sampled between the distances from the edge of the road. Abbreviations; Relative Abundance (RA), F values for ANOVA, F* values for Brown- Forsythe, and H values for Kruskal – Wallis.

Metric	Species category	Test	d.f	F, F*, H	p
Richness	All quadrats	ANOVA	4, 167	3.59	0.008
Richness	Native	ANOVA	4, 167	5.16	0.001
Richness	Introduced	Kruskal-Wallis	4	27.76	<0.0001
Cover	Native	Kruskal-Wallis	4	13.74	0.008
Cover	Introduced	Kruskal-Wallis	4	33.14	<0.0001
RA Introduced	Introduced	Kruskal-Wallis	4	35.87	<0.0001
Shannon Index	All	ANOVA	4, 167	2.65	0.035
Evenness	All	ANOVA	4, 167	1.84	0.123
Simpson Index	All	ANOVA	4, 167	2.65	0.059

Tukey-type multiple comparison tests identified a significant difference occurred in native species richness between 1 to 15 m ($p = 0.04$), and 1 to 20 m ($p = 0.004$). Introduced species richness was significantly different among the towns in road disturbance ($H = 57.118$, $p < 0.0001$, d.f. = 3). The distribution of introduced species richness was linear in its relationship, decreasing the further away the quadrat was from the edge of the road ($r^2 = 0.9753$; Figure 2.12). The percent cover of native species at road disturbances was not significant among towns (Figure 2.13). However, it was significant among the distance intervals along the road gradient ($H = 13.741$, $p = 0.008$, d.f. = 4) and the greatest mean coverage occurred at 20 m from the edge of the road (Table 2.19). Ft. Simpson had the highest richness and coverage of introduced species along roads (Table 2.6; Table 2.8).

Table 2.18 Road gradient species richness by species categories Mean, standard deviation (SD), and standard error (SE) indicated for each category.

		1m	5m	10m	15m	20m
	n	34	34	34	34	32
Overall species richness	Mean	5.94	7.06	7.91	6.76	5.69
	SD	3.17	2.80	2.37	2.32	2.89
	SE	0.54	0.48	0.41	0.40	0.51
Native species richness	Mean	4.08^{a}	5.56^{ab}	6.85	6.18	5.44
	SD	3.09	2.56	2.13	2.25	3.02
	SE	0.53	0.44	0.37	0.39	0.53
Introduced species richness	Mean	1.41^{a}	1.18	0.88^{ab}	0.35^{ac}	0.19
	SD	1.42	1.38	1.15	0.60	0.59
	SE	0.24	0.24	0.20	0.10	0.10
Cryptogenic species richness	Mean	0.44	0.32	0.18	0.24	0.06
	SD	0.66	0.59	0.46	0.43	0.25
	SE	0.11	0.10	0.08	0.07	0.04

[a] significant $p < 0.05$

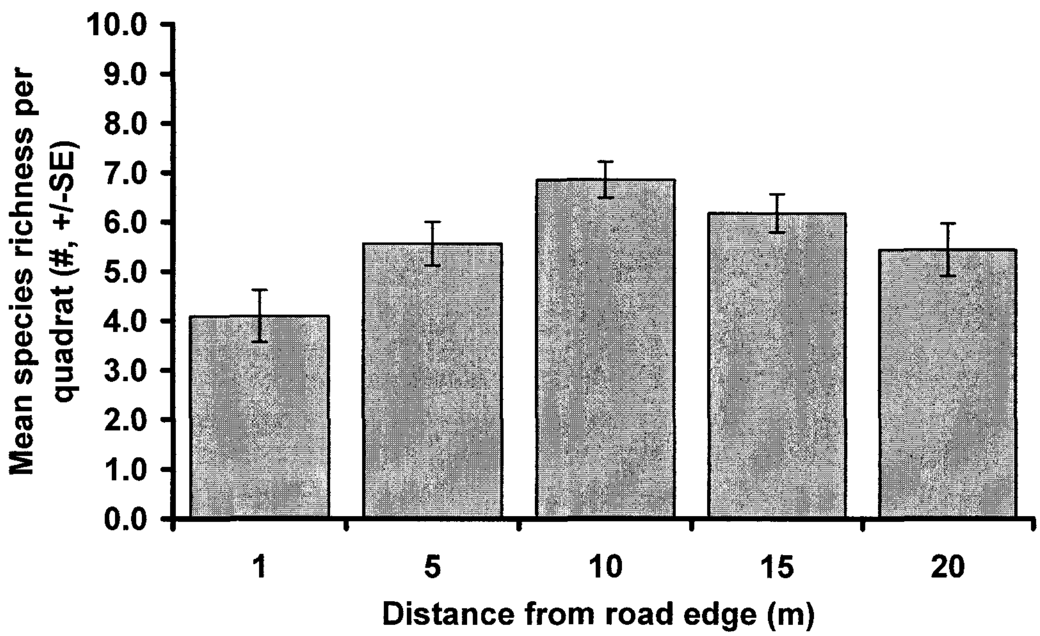

Figure 2.11: Native species richness per quadrat along the road gradient (Mean, ± SE).

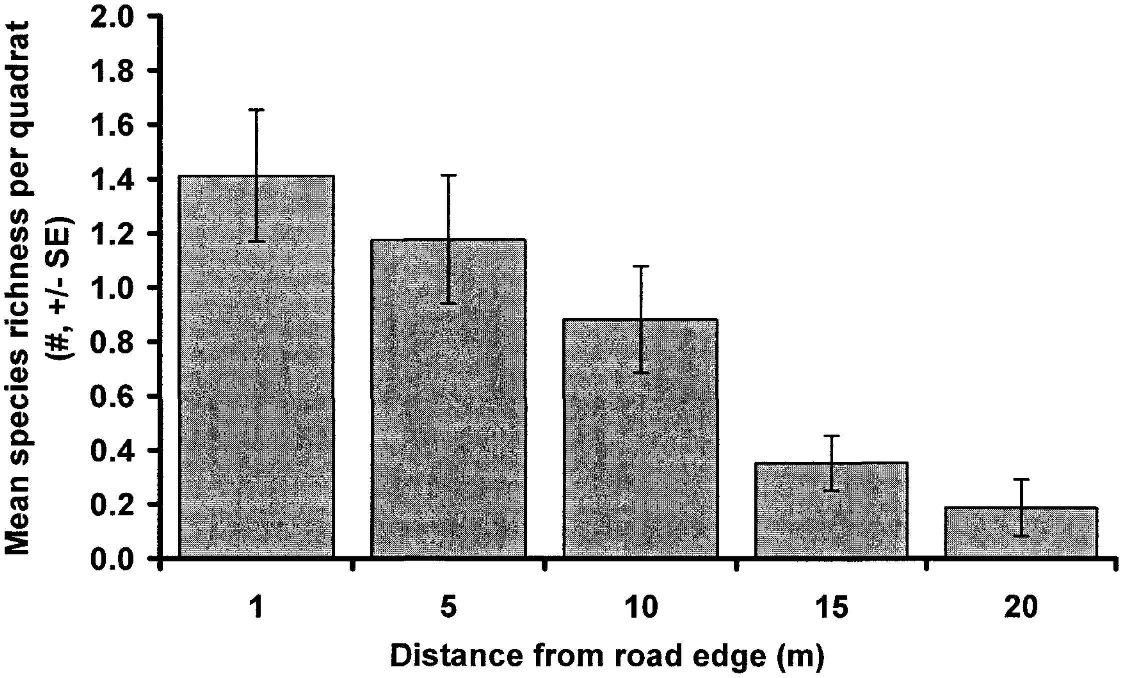

Figure 2.12: Introduced species richness per quadrat along the road gradient (Mean, ± SE)

Table 2.19 Road gradient percent cover of native, introduced, cryptogenic species, and the relative abundance of introduced species. Mean, standard deviation (SD), and standard error (SE) indicated for each category.

		1m	5m	10m	15m	20m
	n	34	34	34	34	32
% cover Native species	Mean	10.24	16.49	17.35	21.51	27.62
	SD	16.06	16.69	19.34	24.44	32.75
	SE	2.75	2.86	3.32	4.19	5.79
% cover Introduced species	Mean	5.35	5.16	3.57	0.93	0.01
	SD	10.54	18.27	11.54	4.28	0.03
	SE	1.81	3.13	1.98	0.73	0.01
% cover Cryptogenic species	Mean	0.54	3.65	0.87	0.38	0.01
	SD	1.57	11.60	2.50	1.22	0.04
	SE	0.27	1.99	0.43	0.21	0.01
Relative Abundance Introduced species	Mean	32.90	15.21	9.40	5.86	0.11
	SD	37.72	29.26	21.32	20.05	0.39
	SE	6.47	5.02	3.66	3.44	0.07

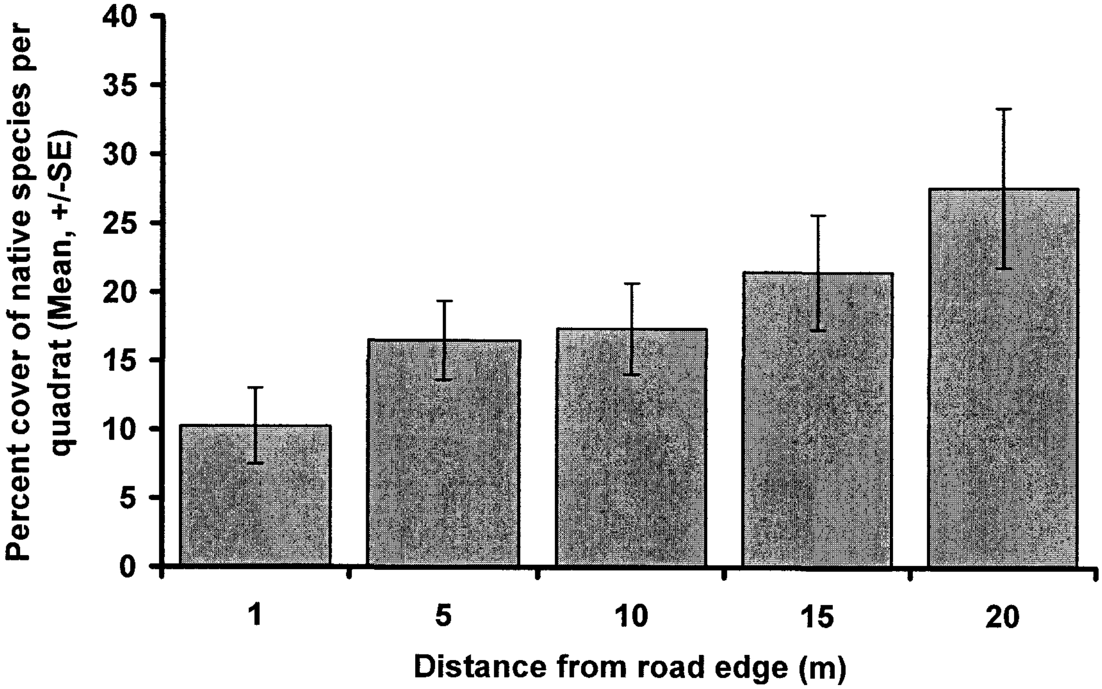

Figure 2.13: Percent cover of native species per quadrat in road quadrats (Mean ± SE)

Introduced species cover did not exceed that of native species, but the largest abundance occurred at 1m from the edge of the road (Table 2.19). At 10 m from the road, native cover was far greater than that of introduced species (Table 2.19). Introduced species cover was significant between towns (Table 2.16). Introduced species cover decreased as the distance from the road edge increased (Table 2.19). The cover of introduced species was significant among the intervals from the edge of the road ($H = 33.139$, $p < 0.0001$, d.f. = 4). Along the intervals from the edge of the road the Shannon index of diversity was significant ($F_{4,167} = 2.652$, $p = 0.035$). Unlike species richness, where significance was found closer to the edge of the road, the multiple comparison test identified the significance in the Shannon index to be between 10 to 20 m ($p = 0.014$, Table 2.19).

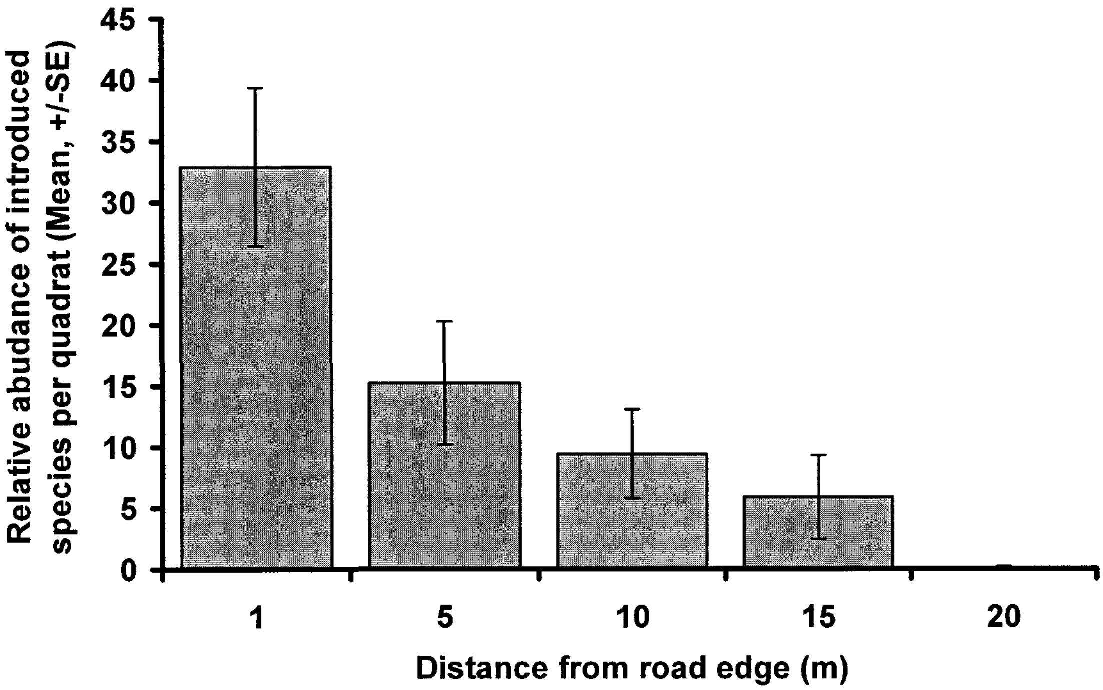

Figure 2.14 The relative abundance of introduced species in each quadrat along a road gradient (Mean, ± SE)

A detrended correspondence analysis of road quadrat was completed using the relative abundance. Quadrats at 15 m and 20 m were lumped in order to improve the ease of interpreting the output graph (Figure 2.15). The DCA does indicate a south to north gradient from left to right on the 1^{st} axis (Figure 2.15). Most of the quadrats at the different distances overlapped, indicating that the same species were found at each distance. However, Ft. Simpson does appear to separate from the other communities along the DCA1 axis (Figure 2.15). The first axis had a represented variance of 5.1% and the gradient was 7.49 in length (Appendix C). The second axis had a represented variance of 9.0% and a gradient of 6.23 S.D (Appendix C).

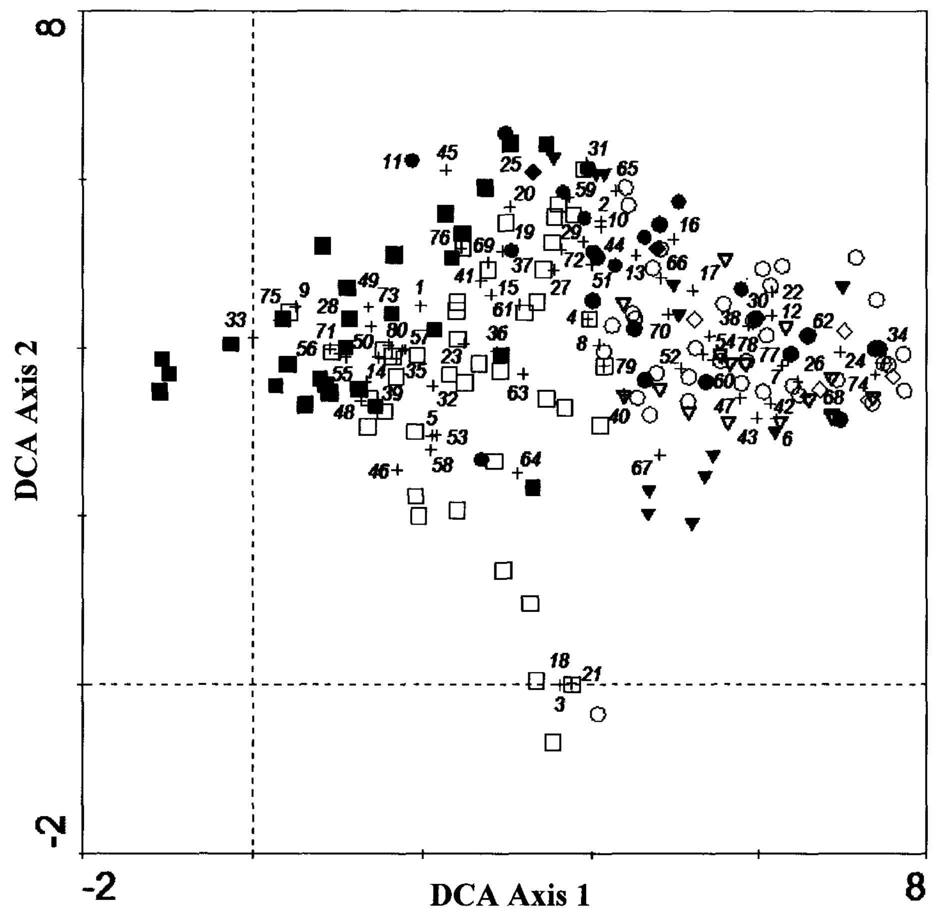

Figure 2.15: Relative percent cover (%) of major taxa identified from road quadrats across all NT sampling locations. Symbols; ▼ Inuvik Roads 1m from road, ▼ Inuvik Roads 5m from road, ▽ Inuvik Roads 10-20m from road, ● Fort Good Hope 1m from road, ● Fort Good Hope 5m from road, ○ Fort Good Hope 10-20m from road, ◆ Norman Wells 1m from road, ◆ Norman Wells 5m from road, ◇ Norman Wells 10-20m from road, ■ Fort Simpson 1m from road, ▪ Fort Simpson 5m from road, □ Fort Simpson 10-20m from road. Taxa: *1. A. mille, 2. Asibir, 3. A. crispa, 4. Anem, 5. A. rosea, 6. A. latif, 7. A. rubra, 8. A. uva, 9. A. anser, 10. A. tilesi, 11. A. alpin, 12. B. nana, 13. B. papy, 14. B. inerm, 15. Calama, 16. C. inexp, 17. Carex, 18. C. raupi, 19. C. canad, 20. C. elegan, 21. C. passe, 22. D. flori, 23. Descha, 24. D. integ, 25. E. repens, 26. E. nigru, 27. E. angus, 28. E. palust, 29. E. arven, 30. E. scirpo, 31. Erioph, 32. F. ovina, 33. F. rubra, 34. Festuca, 35. F. virgin, 36. G. boreal, 37. G. macou, 38. G. livid, 39. G. aleppi, 40. H. jubatu, 41. L. ochro, 42. L. groenl, 43. L. decum, 44. L. boreal, 45. L. usitat, 46. L. dioica, 47. L. arctic, 48. M. lupuli, 49. M. alba, 50. M. panic, 51. P. palust, 52. P. frigid, 53. P. praten, 54. P. marian, 55. P. major, 56. Poa. , 57. P. balsam, 58. P. tremu, 59. P. norveg, 60. P. grand, 61. R. groenl, 62. R. lappon, 63. R. acicul, 64. R. idaeus, 65. S. candi, 66. S. exigua, 67. Salix, 68. S. angust, 69. Senecio, 70. S. canade, 71. S. arvens, 72. S. albus, 73. Taraxa, 74. T. pusill, 75. T. hybrid, 76. T. praten, 77. V. uligin, 78. V. idaea, 79. V. edule, 80. V. ameri*

2.2.5 Dominant species

Table 2.20: Species found in all sampled towns by status in North America, frequency, maximum cover, and mean relative abundance (Mean abun.) when present in a quadrat.

Species[1]	**Status in N. A**[2]	**Freq.**	**Max cover**	**Mean abun. (%)**
Equisetum arvense	Native	133	39	11.74
Rosa acicularis	Native	124	80	24.66
Arctostaphylos rubra	Native	81	55	22.89
Taraxacum sp.	Cryptogenic	66	60	9.71
Carex species	Native	64	75	11.44
Picea mariana	Native	64	23	10.99
Dasiphora floribunda	Native	62	29	15.29
Salix sp.	Native	53	30	22.21
Epilobium angustifolium	Native	43	90	14.61
Pyrola grandiflora	Native	36	10	3.43
Elytrigia repens v. repens	Introduced	32	60	18.24
Linnaea borealis	Native	32	98	26.33
Populus balsamifera s. trichocarpa	Native	28	21	16.31
Shepherdia canadensis	Native	27	90	13.36
Poa sp.	Cryptogenic	19	20	15.98

1 – IT IS, 2009
2 – USDA NRCS, 2009

Generally, the same introduced species were present in each of the sample location towns (e.g., *Achillea millefolium, Bromus inermis, Elytrigia repens v. repens*), as were many native species of the North (*Arctostaphylos rubra, Vaccinium vitis-idaea s. minus, Rosa acicularis*) (Table 2.20). The most abundant introduced species was *Elytrigia repens v. repens. Equisetum arvense* was the most common native species (Table 2.20). Species that were identified as the most frequent were not the same species that were the most abundant. There was not a single specific native or introduced species that were significantly more abundant than another was.

Table 2.21: All introduced species identified (Frequency occurrence, maximum cover, and mean relative abundance when present).

Species[1]	Freq. (n)	Max Cover (%)	Mean abun. (%)
Achillea millefolium	64	10	5.51
Bromus inermis	60	75	18.78
Elytrigia repens v. repens	32	60	18.24
Festuca rubra	28	97	31.68
Plantago major	22	4	5.60
Melilotus alba	15	10	14.27
Festuca ovina	11	30	19.99
Phleum pratense	11	7	6.59
Medicago lupulina	7	30	21.23
Trifolium repens	7	2	3.82
Linum usitatissimum	6	5	7.05
Medicago sativa	6	70	43.76
Dactylis glomerata	5	20	25.98
Trifolium pratense	5	16	13.82
Sonchus arvensis	4	3	4.47
Trifolium hybridum	4	8	13.32
Chenopodium album	3	80	30.49
Polygonum aviculare	3	27	76.56
Thlaspi arvense	1	0.1	0.74

1 – IT IS, 2009
2 – USDA NRCS, 2009

Of the introduced species identified *Achillea millefolium* was the most frequent (Table 2.21). *Chenopodium album* and *Polygonum aviculare* were only identified 3 times, but their mean abundance when present in a quadrat exceeded a more common species (Table 2.21).

Table 2.22: Species found with a frequency of 20 or greater in road disturbance type quadrats (status, frequency, maximum cover, and mean relative cover abundance when present)

Species[1]	**Status in N.A**[2]	**Freq. (n)**	**Max cover (%)**	**Mean abun. (%)**
Rosa acicularis	Native	68	80	24.2
Equisetum arvense	Native	66	25	16.55
Vaccinium vitis-idaea s. minus	Native	55	30	25.57
Vaccinium uliginosum	Native	43	20	12.8
Ledum groenlandicum	Native	41	5	9.85
Bromus inermis	Introduced	40	60	17.25
Arctostaphylos rubra	Native	39	25	22.04
Picea mariana	Native	36	15	11.69
Achillea millefoium	Introduced	33	3	5.83
Fragaria virginiana s. glauca	Native	33	20	10.19
Taraxacum species	Cryptogenic	32	60	14.01
Equisetum scirpoides	Native	31	3	7.13
Carex species	Native	30	75	7.8
Geocaulon lividum	Native	26	3	5.6
Pyrola grandiflora	Native	26	2	3.36
Dasiphora floribunda	Native	22	20	10.34
Salix species	Native	21	12	22.85
Arctostaphylos uva-ursi	Native	20	95	43.4
Dryas integrifolia s. chamissonis	Native	20	35	29.62
Elytrigia repens v. repens	Introduced	14	17	18.07
Festuca rubra	Introduced	10	97	44.04
Fesuca ovina	Introduced	10	30	21.97

1 – IT IS, 2009
2 – USDA NRCS, 2009

The species found most frequently along roadside disturbances were native species, but *Bromus inermis* was the most frequently documented introduced species (Table 2.22). While the introduced species *Festuca rubra* was not the most frequent species documented when present, it was the most abundant. *Fragaria virginiana s. glauca* was generally found most commonly in Ft. Simpson.

2.3 Discussion

Various studies have documented Arctic plant community response to disturbances, including oil and gas development (Linell, 1973; Bliss and Wein 1972; Chapin and Shaver, 1981; Kershaw and Kershaw, 1987; Seburn *et al.,* 1996; Auerbach et al., 1997; Rausch and Kershaw, 2007) as well as habitat restoration following disturbances at Arctic sites (Chapin and Chapin, 1980; Chapin and Shaver, 1981; Forbes and Jefferies, 1994; Jorgenson and Joyce, 1994; Hagen, 2002). These studies identified that restoration of disturbed sites generally utilized non-native species to re-establish vegetation cover, and that long term studies are needed to determine what native species can be used in long term restoration of native plant species assemblages (Linell, 1973; Chapin and Chapin, 1980; Chapin and Shaver, 1981; Forbes and Jefferies, 1994; Jorgenson and Joyce, 1994; Auerbach et al., 1997). In general, sites where natural revegetation of disturbed habitats has occurred had lower overall species richness and total plant cover, and full recovery, via secondary succession, was not demonstrated after several decades (Chapin and Shaver, 1981; Bliss and Wein, 1972; Felix and Raynolds, 1989; Kershaw and Kershaw, 1987).

This study of plant community composition among different types of disturbance, transportation corridors, and disturbance gradients in the Northwest Territories found that town centres, roads, and the pipeline generally had greater richness and cover of introduced species than seismic lines. The richness and cover of introduced species in these disturbance types also suggests that the frequency and intensity of the disturbance may facilitate the introduction of new species and perpetuate their abundance (Pickett and

White, 1985; Auerbach *et al.,* 1997; Trombulak and Frissell, 2000). The differences in richness and cover of introduced species might indicate a change in species composition. Auerbach *et al.* (1997) noted similar changes and suggested that changes in species composition may be due to abiotic (changes in substrate) and biotic factors, but it was difficult to determine the amount of change and the exact causes.

Ft. Simpson was initially identified as likely to have a greater intensity and frequency of disturbance, due to the presence of a year round, permanent road, and existing pipeline that intersected the highway (Figure 2.2; Pickett and White, 1985: Trombulak and Frissell, 2000). As predicted, Ft. Simpson had the greatest richness, cover, and abundance of introduced plant species, and the difference among the four northern towns was significant with respect to native and introduced species richness. Additionally, plant communities in the urbanized portions of the towns tended to have significantly different characteristics from other disturbance types (Table 2.8; Table 2.19; Appendix II). However, it should be noted that these urban core areas were likely under sampled.

In contrast, Ft. Good Hope was identified as potentially having the least amount of disturbance that would have influenced historic plant community composition. However, it was discovered that both Ft. Simpson and Ft. Good Hope had federally run experimental agricultural farms during the 20th century (Johnson and Smith, 1986). In Inuvik the church also had community gardens that local people maintained and benefited from (Johnson and Smith, 1986). Local residents, including those who had been employed by the experimental farms, spoke of various livestock, grains, and potentially economically viable plants that were brought into the communities. For example, *Caragana arborescens* (Siberian Pea Tree) was introduced during the lifetime of the experimental farms along the river banks in Ft. Simpson as a measure to prevent soil erosion by the river (Carrière *et al.*, 2009; USDA, 2009). Many of the species identified within these communities may have been from the 'legacy disturbances' that originated within experimental farms.

Nevertheless, Ft. Good Hope (66° N) is only accessible by plane (or boat during the summer months), and a seasonal winter road connects the settlement with Norman Wells to the south and Inuvik to the north (Northwest Territories Transportation, 2007). In contrast to our prediction, the introduced species richness in the core urban area was both the greatest of the three sampled disturbance types within Ft. Good Hope, and across all settlements for this disturbance type the second highest (Table 2.12). The species *Bromus inermis* (Smooth brome) was indentified in Ft. Simpson and Ft. Good Hope (Table 2.20; Table 2.21), and likely a result of the legacy of agriculture community consultation revealed. *B.inermis* was introduced into Canada around 1888 as a forage and hay crop (Anstey, 1986). Otfinowski *et al.*, (2007) found that *B.inermis* can decrease native species richness, and dominate Canadian prairies and grasslands. In addition to the agricultural history, another source of seeds may be shipping containers that had been transported up the Mackenzie River by barges (Figure 2.17).

Norman Wells (65°N) is a settlement with a long history of industrial development, was the second site sampled along the proposed route of the Mackenzie Valley pipeline. Field sampling efforts were significantly reduced due to flooding in

2008. Additionally, the layout of the town prevented the sampling of many roads, because the areas were either on the edge of the Mackenzie River, on private property, or too dangerous, due to industrial activity. The seismic lines sampled had very low richness and cover of introduced species overall (Table 2.10; Table 2.11). This may have been due to the age of the seismic lines affecting how much succession may have occurred restoring native plant populations (Kemper, 2006). Most of the areas sampled within the town were near active industrial sites that appeared to have a constant movement of materials and containers that related to the industrial nature of the town (Figure 2.16).

Figure 2.16: Overhead view of an industrial area in Norman Wells. Photo: M. Elliott

Figure 2.17: Sample site in the town of Ft. Good Hope that was later filled with shipping containers. Photo by M. Elliott

Unlike the other settlements that were sampled, Inuvik (68° N) is not located on the banks of the Mackenzie River, but within the delta itself. The Dempster Highway provides year round access from the Yukon Territory to Inuvik and in the winter, an ice road is constructed to several outlying towns (NTT, 2007). Sampling of the different disturbance types in Inuvik showed quadrats within close proximity to the town centre as significant in introduced richness and cover (Table 2.14, Table 2.15, Appendix II). One area in particular that was sampled was identified by Aurora Research Institute staff as an area where sled dogs were bedded down with hay from the south. Inuvik also has a very active gardening community with an old ice rink that was converted into a community greenhouse (Community Garden Society, 2009). Soil, compost, and plants used to establish and maintain the greenhouse may contribute to the presence of current and future introduced species.

2.3.1 Gradients in species richness and percent cover along roads

The types of transportation corridors for motor vehicles vary throughout the territory consisting of permanent paved and gravel surfaces and temporary winter and ice roads (NTT, 2007). A road corridor refers to the surface travelled and the maintained roadsides (Forman and Alexander, 1998). The presence of discontinuous permafrost increases the complexity in the planning, construction, use, and subsequent maintenance of paved roads (Auerbach *et al.*, 1997). The cycles of freezing and thawing generally result in heaving, shifting, and breakage of paved roads, making it more cost effective to use gravel roads (Auerbach *et al.*, 1997). The maintenance of gravel roads requires measures of dust control and surface grading, thus creating a different disturbance regime than permanent paved roads (NTT, 2007; Pickett and White 1985). The winter and ice roads are constructed each year during the winter, but general maintenance during the summer is necessary to prevent trees and shrubs from impeding the corridor (NTT, 2007). Heavy traffic on roads can have direct and indirect impacts including altered hydrology, gravel spray, dust deposition, and the introduction of both biological and toxic contaminants (Walker *et al.,* 1987; Auerbach *et al.*, 1997; Trombulak and Frissell, 2000). Consultation in Ft Simpson indicated that the sides of the road may have been deliberately reseeded with seed mixes from local hardware stores, and/or graded with gravel. There was no indication given of what species were included in the seed mixes and if they were native or non-native.

While the populations in the communities are not large (Ft. Simpson 1,216; Norman Wells 761; Ft. Good Hope 557; Inuvik 3,484; Statistic Canada, 2009), cars, trucks, and all-terrain vehicles are the most common forms of transportation. The constant passage of motorized vehicles often alters the disturbance regime at the edges by disturbing the soil and vegetation increasing the abundance of introduced species (Trombulak and Frissell, 2000). The low species richness of introduced species at 15 m and 20 m from the road edge suggested that the effect of vehicles travelling the road has a greater impact on native and introduced species closer to the road. At these two intervals there was a decrease in the mean coverage of native species, and introduced species (Figure 2.6). The decrease in mean overall species richness from the edge of road may be a result of the sampling protocol. Many of the 20 m quadrats were located in forested areas. As a result, many of the plants were > 50 cm in height and therefore, not included in the sample.

Failure to obtain sampling permission on the pipeline corridor itself, the pipeline was only sampled where it intersected the highway. However, a visual inspection of the pipeline from the roadside indicated that the pipeline is maintained through the removal of large shrubs and trees. The pipeline in Norman Wells, and was not sampled due to how it was situated in the town, and it did not cross a public road. Thus, the pipeline would be subjected to the same stressors as the road. When it was constructed, the pipeline was deliberately reseeded to re-establish the vegetation cover primarily to reduce erosion (Cody, 2002). The physical removal of vegetation and soil is a disturbance that is often associated with the establishment of introduced species, especially when they are intentionally seeded in (Hobbs and Huenneke, 1992; Tyser and Worley, 2003). *Festuca rubra* was included with five to seven other species in the seed mix used for the re-vegetation of the pipeline and is a commonly used species for restoration even though it is native to Europe (Cody, 2002; Hansen and Clevenger, 2005; Table 2.22). The issue of revegetation had been a concern for the Berger Inquiry (Berger, 1977). It identified the need for the re-vegetation of the original proposed pipeline, but the primary focus was on the speedy recovery of a continuous cover in an effort to preserve the hydrology and decrease erosion (Berger, 1977). This lack of focus on species composition of seed mixes may lead to the introductions of new species that could further affect Arctic ecosystems (Cody, 2002; Hagen, 2002; Hansen and Clevenger, 2005; Carrière *et al.*, 2009).

Of the sampled disturbance types, seismic lines had the lowest species richness of introduced species and generally high native species richness. Seismic exploration has been used in the West Arctic for oil and gas exploration (Kemper, 2006). Early methods using seismic exploration were conducted in the early summer using tractors and tracked vehicles over thawed ground, which had extensive detrimental effects on the vegetation and permafrost (Hernandez, 1973; Bliss and Wein, 1972; Felix and Raynolds, 1989). The lack of introduced species on seismic lines currently may be due to several effects including the length of time since the original disturbance, changes in the season (summer to winter) for exploration, and improvement in technology (Kemper, 2006). In the Mackenzie Delta, seismic lines two to three years after their construction had a decrease in plant cover, reduced productivity and an increased depth to permafrost (Kemper, 2006). In contrast, historical seismic lines had greater plant cover, and productivity than more recently disturbed seismic lines (Kemper, 2006). The historical seismic lines, as well as other disturbed trails, have been shown to be more productive than undisturbed tundra (Forbes *et al.,* 2001; Kemper, 2006). The low richness and cover of introduced species found on seismic lines at all sampled sites suggests that the seismic lines sampled were at a later stage of succession (Tables 2.10; 2.11; 2.12; 2.13; 2.14; 2.15).

CHAPTER 3: Invasive Species in the Canadian Arctic: a social perspective aimed at bridging the science □ policy gap

3.1 Introduction

Increased development of natural resources, infrastructure, and the impacts of climate change will create new opportunities for species to establish and expand into the Canadian Arctic (Environment Canada, 2004, Hobbs *et al.,* 2006; Carrière, *et al.*, 2009). Canada's national strategy defines invasive alien species (IAS) as ''harmful alien organisms whose introduction or spread threatens the environment, the economy, or society, including human health'' (Environment Canada, 2004). Collectively, government officials, scientist, conservationists, and environmental managers are faced with increased pressure to address the multiple consequences of introduced IAS in the Arctic, across diverse ecological spatial and temporal scales (Environment Canada, 2004; Hulme, 2006; Buckley, 2008; Hobbs *et al,* 2006). The management of IAS usually occurs through their prevention, control, and eradication, but there are high costs and challenges associated with each of these steps (Williams, 1997; Myers and Bazely, 2003, Hulme, 2006; Buckley, 2008). The prevention and early detection of IAS, followed by rapid assessment and response, has been identified as a means of preventing the prohibitive costs that are associated with control of IAS after their establishment (Williams, 1997; Myers and Bazely, 2003; Hulme, 2006). An optimal strategy for the detection, monitoring, and eradication involves engaging citizen scientists (Vaughan *et al.*, 2007) as participants in regular monitoring programs.

Community monitoring protocols that engage citizen scientists may involve participation at varying degrees of intensity, ranging from manipulative or passive transmission of information from locals to professionals, to systems that develop independent initiatives (McCall and Minang, 2005; Sharpe and Conrad, 2006). In the past, scientists have been reluctant to accept data generated by 'citizen science' due to a lack of accredited auditing that validates the use of the data for academic purposes (Delaney *et al.*, 2008). The scientific community depends on a heavily structured methodological platform and anonymous peer-review process, aimed at maintaining the quality and validation of their research initiatives, which can further complicate monitoring programs that rely on local community members (Boudreau and Yan, 2004). A community monitoring protocol usually requires scientists or government to provide the initial platform that determines the appropriate scientific and societal data to be collected, and scientists must have the ability to communicate the necessary information in a meaningful way (Delaney *et al.*, 2008). The local community must also know how to engage with the scientists to express their knowledge or concerns appropriately, and use the new technologies made available by scientists (Sharpe and Conrad, 2006; Delaney *et al.*, 2008). Many times when a new monitoring protocol fails, it can be traced to the scientists assuming that the community was homogenous (McCall and Minang, 2005). Differences in ethnicity, economic class, education, socio-economics, technology structures, and gender, can all affect the interactions between scientists and local community members (McCall and Minang, 2005; Delaney *et al.*, 2008). Stakeholder groups may also not exist or be representative of the whole population, due to small populations that span large geographical areas, which is the case for most communities within the Northwest Territories. Even with these challenges, community monitoring programs have the potential to provide a wealth of information about IAS, population structures, behaviours, and distributions, and to assist with species conservation (Nicholson *et* al., 2002; Delaney *et al.*, 2008).

The N.W.T. Biodiversity Action Plan (NWT Biodiversity Team, 2006) calls for improved documentation and monitoring of existing and potential IAS. However, the plan does not specifically encourage or rely on the participation by local people as citizen scientists as a means for the detection and monitoring of IAS. In order to explore the role that local people may be able to play as citizen scientists, and how they would be able to engage in these activities, community consultations using presentations, surveys, and personal conversations were conducted. This information is viewed as essential for the success of future monitoring programs, and the development of community engagement protocols that will be developed with the aim of early detection and monitoring of IAS.

3.2 Study background

Three local communities in the Northwest Territories along the Mackenzie River valley (Fort Simpson, Fort Good Hope, and Inuvik) were surveyed for their awareness of IAS. Three of the study communities were those where plant ecology field work was carried out previously (Figure 2.1). Interviews were carried out in the summer of 2008 and from September 28 to October 23, 2008. This project, initially named "Developing Options for Community-based Protocols to Detect Invasive Alien Plants and Insects in the Northwest Territories" is the basis of an integrated community monitoring program for invasive alien species by the Government of Northwest Territories, Department of Environment and Natural Resources.

3.3 Methods

During the summer of 2008, informal conversations were held through general canvassing of the community with professionals, elders, youth, and several individual members. Some conversations were recorded with the permission of the participant, and were later transcribed. During the community consultations that occurred during October 2008, a questionnaire was developed that employed a simple check box survey with an additional comment section to allow participants to express whatever they felt was necessary (Appendix IV). Check boxes were used in an effort to avoid a labour intensive survey, requiring too much of the participants' time. The survey was designed to document whether local people were aware of new species, who they thought they could communicate this knowledge to, and what role they wanted the Territorial government to play in the management of invasive alien species.

The surveys were administered in three settlement communities: Fort Simpson, Fort Good Hope, and Inuvik, in the Northwest Territories. A short presentation was developed to inform the audience about the basic concept of invasive alien species, their potential range expansions, and the role of a monitoring program. Informal conversations usually occurred at the home of the participant, or in the accommodations of the researchers. If explicit permission was given, conversations were recorded. There was no defined structure to conversations to prevent the participants from feeling as if they were being consulted, something that has been a constant activity with increasing development (Sabin, 1995). The survey was approved through the York University Ethics procedure (http://www.yorku.ca/research/support/ethics/).

3.4 Survey

Participants were made aware of all the information about the project before being given the survey to make informed decisions about the questions posed to them. A community dinner was held during the presentations catered by local individuals as an incentive for individuals to participate in the survey, and to promote a relationship between the community and the researchers. Door prizes were also provided. Communities were notified in advance, of the arrival of the research team, and extensive canvassing was done throughout to encourage the participation of youth, elders, community members, and professionals to gather a large spectrum of response.

3.5 Results

Overall, the consultations and survey indicated that community members were willing to look for IAS, but that they would require a source of educational information about what to look for (Table 3.2). Survey responses also suggested that a website may not be the most desirable way for a participant to communicate information about a potential IAS that they may have found (Table 3.5). Furthermore, consultations suggested that participants would be willing to provide the information to a government official, elder, or respected community member, who would be designated with relaying their reports to appropriate departments and managers. Community members felt comfortable discussing the environment with 'respected community members' rather than one single agency or department (Table 3.3). It was also noted that it may not be the department specifically, but the individual who was employed in that department. Specific survey responses are outlined below.

The survey identified that 75 % of participants were aware of the term 'invasive species' previous to the survey (Table 3.1). Inuvik had the highest proportion of individuals who identified with this term (Table 3.1), and other synonymous terms were also recognized with consistency. Ninety-five percent of participants indicated that they would report an introduced species (Table 3.2). They also indicated that when a new or alien invasive species was discovered by them, they would provide that information to either an Elder or a professional associated with the Department of Natural Resources (Table 3.3). The Department of Environment and Natural Resources in Ft. Simpson currently collects specimens from concerned community members, identifies population locations, and attempts to keep other departments informed. In the comment section some participants said that they would only report on species that they believed were harmful to wildlife or to their health (Appendix V).

Table 3.1: Survey responses to the question, "Which of these terms have you heard of?"

	Ft. Simpson		Ft. Good Hope		Inuvik		Total	
n	26		14		20		60	
	Freq	%	Freq	%	Freq	%	Freq	%
Invasive species	20	76.9	6	42.9	19	95.0	45	75.0
Non-native species	16	61.5	7	50.0	14	70.0	37	61.7
Non-indigenous species	17	65.4	5	35.7	14	70.0	36	60.0
Introduced species	17	65.4	6	42.9	16	80.0	39	65.0

Table 3.2: Survey responses to the question "Would you be willing to report an introduced species if you found one?"

	Ft. Simpson		Ft. Good Hope		Inuvik		Total	
n	26		14		20		60	
	Freq	%	Freq	%	Freq	%	Freq	%
Yes	25	96.2	13	92.9	19	95.0	57	95.0
No	0	0	0	0	1	5.0	1	1.7

Unlike participants in Ft. Simpson and Inuvik, those questioned in Ft. Good Hope did identify that they were *more* likely to report IAS to the Renewable Resource Council, instead of the ENR office (Table 3.3). The community consultation found that in Ft. Good Hope, community members tended not to identify with a particular government office, but rather, with the specific individual who happened to be employed within that office.

Table 3.3: Survey responses to the question "Who do you think is the best person or group to pass on your information about the presence of introduced species to a program?"

	Ft. Simpson		Ft. Good Hope		Inuvik		Total	
n	26		14		20		60	
	Freq	%	Freq	%	Freq	%	Freq	%
Yourself	12	46.2	7	50.0	14	70.0	33	55.0
Elders	6	23.1	7	50.0	7	35.0	20	33.3
Teacher	7	26.9	3	21.4	6	30.0	16	26.7
Someone at the greenhouse	2	7.7	2	14.3	3	15.0	7	11.7
ENR	20	76.9	5	35.7	15	75.0	40	66.7
RRC	10	38.5	8	57.1	9	45.0	27	45.0
Parks Canada	13	50.0	2	14.3	9	45.0	24	40.0
Band Office	4	15.4	3	21.4	2	10.0	9	15.0
RCMP	1	3.8	2	14.3	0	0.0	3	5.0
Northern Store	0	0.0	0	0.0	0	0.0	0	0.0
Health Centre	1	3.8	2	14.3	0	0.0	3	5.0

Table 3.4: Survey responses to the question "Which of the following information would you be willing to report?'

	Ft. Simpson		Ft. Good Hope		Inuvik		Total	
n	26		14		20		60	
	Freq	%	Freq	%	Freq	%	Freq	%
Description	20	76.9	10	71.4	19	95.0	49	81.7
Name and contact	13	50.0	4	28.6	12	60.0	29	48.3
Photo	18	69.2	5	35.7	14	70.0	37	61.7
Location	18	69.2	5	35.7	13	65.0	36	60.0
GPS Point	9	34.6	1	7.1	9	45.0	19	31.7
Habitat	16	61.5	6	42.9	13	65.0	35	58.3

Several participants also stated that while communicating information on potential IAS that they found was acceptable, providing personal information to accompany these details was undesirable (Table 3.4). Many participants also expressed concerns about being able to use and access a global positioning system (GPS) in order to correctly pinpoint the location of any identification of potential IAS and expressed reluctance about revealing the location of the species, because it may be located near specific hunting and/or foodstuff locations (e.g., berry patches).

Table 3.5: Survey responses to the question "What is your preferred option for reporting new invasive species?"

	Ft. Simpson		Ft. Good Hope		Inuvik		Total	
n	26		14		20		60	
	Freq	%	Freq	%	Freq	%	Freq	%
Website	7	26.9	2	14.3	10	50.0	19	31.7
Email	13	50.0	3	21.4	9	45.0	25	41.7
In person	13	50.0	9	64.3	9	45.0	31	51.7
Guiding expert	11	42.3	7	50.0	6	30.0	24	40.0

Table 3.6: Survey responses to the question "Would you feel more comfortable or more inclined to participate in such a program if an incentive was offered? (i.e., t-shirt, baseball cap, toque, etc.)"

	Ft. Simpson		Ft. Good Hope		Inuvik		Total	
n	26		14		20		60	
	Freq	%	Freq	%	Freq	%	Freq	%
Yes	10	38.5	11	78.6	8	40.0	29	48.3
No	14	53.8	3	21.4	10	50.0	27	45.0

The preferred methods of reporting IAS also differed among communities, but the most common response was in person, at 51 % of the time (Table 3.5). Many expressed a lack of interest in the use of a website as a means of communication (Table 3.5). Reasons for this are discussed later, but were most likely due to the poor Internet service and lower computer availability within northern communities in comparison to southern communities. Written and spoken comments received also suggested that direct communities. Written and spoken comments received also suggested that direct communication with hunters and Elders would be more effective at collecting information.

Survey participants were divided about the use of incentives as means of encouraging the participation in programmes aimed at detecting IAS (Table 3.6). Respondents in the smaller community of Ft. Good Hope stated that they were more likely to participate if an incentive was provided (78.6%), but in general, the comments suggested that due to their close identification with land that incentives are generally unnecessary.

3.6 Discussion

Governments and local communities across the Canadian Arctic have identified themselves as lagging behind other North American jurisdictions when it comes to the prevention, management and eradication of alien invasive species (Carrière, *et al.*, 2009). The management of invasive alien species will continue to be a persistent and increasing problem as ecosystems continue to be invaded (Buckley, 2008; Hobbs *et al.*, 2008). Whitelaw *et al.* (2003) views community based monitoring as a process in which citizens, government agencies, industry, and scientists must all collaborate to monitor and respond to a concern. These survey results support the possibility of establishing such a program in communities in the Northwest Territories. However, in order for such a program to be effective, the engagement of all community members is essential, and understanding how they would wish to participate prior to the development of sampling and data collection protocols will be key to the success of such a program. Interactions between community members and designated government departments need to be sought from the community-level up to the departments (Bradshaw, 2003; Sharpe and Conrad, 2006). The information collected from community members can increase the existing GNWT Environment and Natural Resources species Infobase (GNWT ENR, 2006).

Though community members were willing to report an IAS, there were some concerns about the use of incentives to gather the information. While incentives have sometimes been used as a means to increase the number of individuals participating in a monitoring program, their use may not inspire participants that truly wish to participate as long term citizen scientists (Delaney *et al.*, 2008). Survey responses indicated that the use of a website was not a desirable means of communication. This may be due to the high cost and limited speed of internet service in the north. Airware ™, the residential broadband service is available for $60/month with a maximum burst speed of 256 kbps (SSI Micro, 2009). This does not include the cost of the computer and initial setup fees, which make widespread computer and Internet access a costly resource for individual families. Survey responses also indicated that community members reported that they feel that their ties to the land compel them to be stewards of their own environment. Thus, incentives could actually decrease the quality and reliability of the data collected (Sharpe and Conrad, 2006).

Previous experiences with other programs indicate that if a participant does not feel that the information provided is responded to in some matter, they usually never participate again. Consultations also revealed that many individuals had reported abnormal occurrences in their environment or wildlife and never received a response. However, after consultations with this project, Dr. Carrière (GNWT ENR Ecosystem Management Biologist) has directed her department to respond to any inquiry provided to them in this nature. Thus, streamlining the process of reporting across multiple territories, government agencies, and departments therein may benefit from a single database that would be linked to multiple government stakeholders as a solution for keeping track of community reporting (Sharpe and Conrad, 2006; Fields *et al.,* 2007; Buckley, 2008). This could allow for the data collected to be implemented in conservation management actions, as well as better reporting on the outcomes from the analysis of the data (Fields *et al.*, 2007).

Legislative matters were not explored within the scope of this survey, but they have been identified by the N.W.T. Biodiversity Action Plans (NWT Biodiversity Team, 2006) as a means of controlling the introduction of new species. The Action plan focuses specifically on industry, but further suggestions include importing sterilized soil for recreational gardening purposes, local seed mixes, and cleaning of construction equipment before it enters the territory. From the consultations, survey, and general conversations with local people, the possibility of developing the necessary protocols to monitor existing and new invasive alien species has the likelihood of being accomplished if it is developed from the perspective of local people with an accessible, flexible relationship with government departments.

CHAPTER 4: Conclusions and future directions

The general perception that boreal and Arctic biomes have not been subject to invasions by non-native plant species was supported in this study, in that very low levels of non-native plant species were found in comparison with plant communities in southern Canada (Myers and Bazely 2003). While the presence of non-native plant species was generally low, a range of plant species have been introduced, primarily as a result of agricultural initiatives dating to the 1950s, in the more southern towns in the Northwest Territories. At the present time, these introduced species were not found in the undisturbed plant communities beyond road edges. In other words, they have not yet "jumped into the forest". However, as projected climate warming occurs, the non-native plant species already present along road edges and in human settlement areas will have increased potential for range expansion. If physical habitat disturbance increases, such as that associated with construction, then these species will also have increased potential for expansion.

The relationships between the species richness and cover of plant communities and human disturbance at the locations sampled along the proposed Mackenzie oil and gas pipeline sampled showed that site history and management drives the introduction and spread of non-native plant species. In the Northwest Territories, town centres and road edges had higher species richness and a larger percent cover of non-native plant species compared with nearby forest and taiga ecosystems.

Gradients in plant species diversity were found at both local and landscape scales: local gradients in plant species composition were observed, in which non-native plant species increased with proximity to road disturbance types, and latitudinal gradients in both native and non-native plant species richness were observed from the southernmost to the northernmost human settlement (DCA analysis, Figure 2.15). This trend was consistent with the disturbance matrix (Figure 2.2) that guided the choice of each sampling location, and in which it was predicted that Ft. Simpson was most likely to have the greatest levels of human-induced disturbance resulting from the roads and presence of the pipeline. This was also reflected in high non-native plant species richness, cover, and the presence of a gradient in relative abundance among road intervals (Table 2.8; Table 2.9; Figure 2.15).

A significant gradient in non-native plant species richness, cover, and relative abundance (Table 2.16; Table 2.17; Figure 2.14; Figure 2.15) was found along roads. This suggests that types of transportation corridors may facilitate the movement of introduced species intro 'natural' areas.

One major gap in this study was that plant communities along one of the most ancient human transportation corridor, the Mackenzie River, were not sampled. It is a major transportation route that could contribute to the transport of invasive species into northern systems. The data for this study were only sampled in one season, and an increased number of within-season sample dates and sample years would give a better understanding of plant community variation. This would also allow for the recording of the plant communities in each state of floristic development, which is lost due to the short

Arctic summer and large spatial extent of these study areas. In addition, the use of a helicopter, or further access via seismic lines, would provide control plots further from the towns for reference samples to the disturbed sites. These reference samples, and further examination of Norman Wells, would provide a better indication of whether human activity or industrial development within these areas contributes more to the potential for the establishment of invasive species.

Overall, towns, roads, and pipeline disturbance types all had increased richness of introduced species in all sampled towns in comparison to seismic lines (Table 2.8; Table 2.10; Table 2.12; Table 2.14). There were also direct and indirect effects of the disturbances that may have played a role in the richness of introduced species. These could include; deliberate reseeding of disturbed areas, gardening within the towns, and the amount vehicle traffic. This supported the hypothesis that towns may provide the largest point-source for the introduction of new species. The distance from the edge of the road also affected the richness and cover of introduced and native species (Figure 2.13; Figure 2.14). The edges of roads were found to have significantly increased richness and cover of introduced species (Table 2.15; Table 2.17; Figure 2.14). This corresponded to an increase in native species richness with increased distance from the edge of the road that was also significant (Table 2.17; Table 2.18; Figure 2.11). In contrast, both the richness and cover of introduced species decreased with increased distance from the edge of the road (Figure 2.13; Figure 2.14). It was noted that many roadsides were deliberately reseeded using seed mixes from hardware stores, with little information being available of what species were contained within the mix. In addition, further study into how the amount of vehicle traffic and roadside substrate composition affect plant communities would promote a better understanding of how introduced species may be affecting plant communities along roadsides.

No single introduced species was found to dominate in any of the sample locations. Species that were found along roads were also common to quadrats within each town (Figure 2.15). This may suggest that introduced species may arise from within each local community, and are transported along disturbance corridors by human activity. As a corridor, roads may provide the best comparison for the conditions that a pipeline would represent. However, it would be ideal to acquire permission to further sample the existing Enbridge pipeline to quantify the amount of disturbance, the species composition, and the richness and cover of known species from the original seed mix used to reseed the pipeline. This may provide further support for local seed mixes for development and remediation measures in the future. Samples collected along roads and pipelines could then be compared with other disturbance corridors, such as seismic lines, which were already identified as having very low abundances of introduced species. This may allow for the determination of whether the type or the frequency of a disturbance facilitates the introduction of invasive species.

Local people, living in the towns where vegetation was sampled, have noted changes in their environment, but not necessarily in the plant communities. While there is a desire to participate in monitoring for new species, an effective and amenable means of communication for local concerns needs to be developed in order to respond to potentially rapid future changes. The use of incentives as a means of increasing local participation in a monitoring program should also be explored in more detail as it may not enhance the likelihood of both data collection, and data quality.

The worldwide demand for natural resources will not subside overnight, nor will the issues and effects of introduced species. It is important to identify and to seek to minimize the potential impacts of natural resource extraction, and the subsequent transportation corridors that will be built in conjunction with resource development, on Arctic plant communities. A more detailed understanding of the current composition of plant communities, as provided in this study, is needed in order to assess future changes, driven by climate change and resources extraction, which may be rapid (Bliss *et al.*, 1977; Overpeck, 1997; Hinzman *et al.*, 2005; Hollister *et al.*, 2005; IPCC, 2007). This study provided a baseline against which future changes in plant community composition may be compared in the Northwest Territories.

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Appendix A: Species list

Table 1: Summary of all species identified in NT (Mean cover, Maximum cover, and mean relative abundance)

Species[1]	Status in N.A[2]	Freq.	Ft. Simpson	Norman Wells	Ft. Good Hope	Inuvik	Mean cover	Max Cover	Mean abun.
Taraxacum species	Cryptogenic	66	X	X	X	X	3.10	2.33	9.71
Festuca species	Cryptogenic	7		X	X		3.83	3.90	24.26
Poa species	Cryptogenic	19	X	X	X	X	4.15	3.65	15.98
Achillea millefolium	Introduced	64	X	X	X		1.56	0.66	5.51
Bromus inermis	Introduced	60	X		X		6.49	5.65	18.78
Elytrigia repens v. repens	Introduced	32	X	X	X	X	3.50	3.45	18.24
Festuca rubra	Introduced	28	X				11.57	11.59	31.68
Plantago major	Introduced	22	X	X	X		1.31	0.62	5.60
Melilotus alba	Introduced	15	X		X		1.94	1.53	14.27
Festuca ovina	Introduced	11	X				6.51	6.92	19.99
Phleum pratense	Introduced	11	X	X	X		1.23	0.93	6.59
Medicago lupulina	Introduced	7	X				5.73	7.19	21.23
Trifolium repens	Introduced	7	X	X			1.35	0.64	3.82
Linum usitatissimum	Introduced	6	X	X	X		1.31	1.30	7.05
Medicago sativa	Introduced	6	X				13.44	19.17	43.76
Dactylis glomerata	Introduced	5	X				4.03	5.44	25.98
Trifolium pratense	Introduced	5	X				2.73	3.36	13.82
Sonchus arvensis	Introduced	4	X				1.30	1.03	4.47
Trifolium hybridum	Introduced	4	X		X		2.59	3.78	13.32
Chenopodium album	Introduced	3				X	14.02	27.37	30.49
Polygonum aviculare	Introduced	3			X	X	8.83	17.33	76.56
Thlaspi arvense	Introduced	1			X		10.03	0.10	0.74
Eauisetum arvense	Native	133	X	X	X	X	2.01	1.40	11.74

1 – IT IS, 2009
2 – USDA NRCS, 2009

Rosa acicularis	Native	125	X	X	X	X	8.08	7.31	24.66
Vaccinium vitis-idaea s. minus	Native	94		X	X	X	3.85	3.42	22.18
Ledum groenlandicum	Native	91		X	X	X	2.84	2.18	13.43
Arctostaphylos rubra	Native	82	X	X	X	X	5.79	5.03	22.89
Vaccinium uliginosum	Native	73		X	X	X	2.73	2.22	15.18
Carex species	Native	64	X	X	X	X	3.81	3.23	11.44
Picea mariana	Native	64	X	X	X	X	2.79	2.05	10.99
Dasiphora floribunda	Native	63	X	X	X	X	2.90	2.43	15.29
Salix species	Native	53	X	X	X	X	3.57	3.19	21.70
Fragaria virginiana s. glauca	Native	50	X	X			3.29	1.94	9.53
Dryas integrifolia s. chamissonis	Native	47		X	X	X	5.57	5.46	29.39
Epilobium angustifolium	Native	43	X	X	X	X	7.57	7.05	14.61
Geocaulon lividum	Native	43		X	X		1.19	0.69	5.24
Equisetum scirpoides	Native	40		X	X	X	0.65	0.38	6.23
Galium boreale	Native	39	X	X	X		1.30	0.50	2.19
Pyrola grandiflora	Native	37	X	X	X	X	1.01	0.36	3.43
Betula nana	Native	32		X	X	X	7.51	7.37	22.28
Linnaea borealis	Native	32	X	X	X	X	11.59	12.15	26.33
Rubus idaeus s. strigosus	Native	31	X	X	X		7.27	6.85	9.83
Rhinanthus minor s. groenlandicus	Native	29	X	X	X		1.53	0.52	3.50
Arctostaphylos uva-ursi	Native	28	X	X	X		14.91	15.73	39.49
Populus balsamifera s. trichocarpa	Native	28	X	X	X	X	2.82	1.73	16.31
Salix exigua	Native	28		X	X	X	4.89	4.63	22.21
Shepherdia canadensis	Native	27	X	X	X	X	4.30	4.44	13.36
Arctagrostis latifolia	Native	24				X	0.29	0.25	2.29
Vicia americana	Native	24	X	X	X		1.34	0.42	1.67
Hordeum jubatum	Native	20	X	X	X	X	5.06	5.37	28.93
Astragalus alpinus	Native	17		X	X	X	14.56	16.25	29.85
Empetrum nigrum s. hermaphroditum	Native	17		X	X	X	2.06	2.30	13.26
Argentina anserina	Native	16	X				9.56	10.35	30.61
Cornus canadensis	Native	16	X	X			3.04	2.55	13.47
Alnus viridis s. crispa	Native	15	X	X	X	X	17.57	20.22	36.57

Ledum palustre s. decumbens	Native	15				X	8.06	9.14	23.66
Anemone parviflora	Native	14		X	X		0.44	0.10	0.71
Anemone species	Native	14	X			X	0.75	0.13	1.90
Artemisia tilesii	Native	13		X	X	X	1.19	1.32	4.72
Crepis elegans	Native	13	X		X	X	0.46	0.10	4.51
Deschampsia species	Native	13	X		X		3.79	3.82	17.62
Calamagrostis stricta s. inexpansa	Native	12				X	0.20	0.17	1.70
Geum aleppicum	Native	11	X		X		1.30	0.65	5.83
Populus tremuloides	Native	11	X	X	X		2.64	2.45	11.61
Tofieldia pusilla	Native	11		X		X	2.61	2.05	15.75
Betula papyrifera	Native	10	X	X	X	X	3.36	3.47	14.55
Saussurea angustifolia	Native	10			X	X	0.72	0.33	3.88
Zigadenus elegans	Native	10	X	X	X	X	0.72	0.23	2.18
Parnassia palustris	Native	9	X	X	X	X	0.39	0.30	5.04
Petasites frigidus	Native	9	X			X	2.11	2.70	11.92
Poa arctica	Native	9				X	0.14	0.19	1.40
Juniperus horizontalis	Native	8		X			2.20	2.03	3.93
Lathyrus ochroleucus	Native	8	X				2.03	1.29	6.03
Rhododendron lapponicum	Native	8		X	X	X	1.85	1.54	16.34
Argentina egedii	Native	7			X	X	1.76	2.51	9.61
Antennaria rosea	Native	6	X				2.61	2.58	6.60
Larix laricina	Native	6		X	X		2.80	3.53	12.67
Senecio species	Native	6	X				1.86	1.45	7.51
Achillea sibirica	Native	5		X	X		0.49	0.18	6.29
Anemone multifida	Native	5	X	X			1.60	0.76	9.27
Corydalis sempervirens	Native	5		X	X		0.31	0.10	1.23
Epilobium palustre	Native	5	X	X	X		0.81	0.10	1.81
Erigeron humilis	Native	5	X	X	X		1.29	1.46	10.74
Erigeron philadelphicus	Native	5	X				0.85	0.36	4.74
Juniperus communis	Native	5	X	X			8.26	12.22	28.90
Potentilla pulchella	Native	5		X			2.16	1.46	15.90
Salix candida	Native	5			X		2.88	4.60	36.31

Symphoricarpos albus	Native	5	X				1.44	1.30	12.47
Viburnum edule	Native	5	X				1.81	1.90	11.74
Alnus incana	Native	4				X	0.19	0.33	3.99
Calamagrostis species	Native	4	X	X			2.37	3.15	17.84
Castilleja raupii	Native	4	X	X			1.14	1.00	9.59
Cypripedium passerinum	Native	4	X	X			1.11	0.45	3.21
Hedysarum boreale s. mackenziei	Native	4	X	X	X		1.33	1.83	1.78
Lupinus arcticus	Native	4				X	1.17	1.55	5.28
Potentilla norvegica	Native	4	X		X		0.40	0.20	1.84
Arabis holboellii	Native	3	X				0.55	0.10	2.11
Carex atratiformis	Native	3		X			2.02	3.03	18.35
Deschampsia cespitosa	Native	3				X	1.18	1.37	3.04
Descurainia sophioides	Native	3			X		0.12	0.23	2.61
Elymus trachycaulus	Native	3				X	0.12	0.23	1.50
Erigeron elatus	Native	3		X			1.12	0.23	1.61
Gentianopsis macounii	Native	3			X		0.62	0.23	2.04
Pedicularis species	Native	3			X		0.12	0.23	1.95
Rubus chamaemorus	Native	3				X	0.12	0.23	1.83
Stellaria species	Native	3	X				0.63	0.27	1.52
Andromeda polifolia	Native	2				X	1.02	1.55	13.32
Astragalus americanus	Native	2			X		0.22	0.55	2.32
Betula occidentalis	Native	2				X	0.22	0.55	5.83
Dracocephalum parviflorum	Native	2		X			0.64	0.10	1.03
Eriophorum species	Native	2		X	X		1.02	2.05	15.33
Lonicera dioica	Native	2	X				2.20	4.50	18.90
Mertensia paniculata v. paniculata	Native	2	X				2.60	5.50	12.37
Viola species	Native	2	X				0.82	1.05	15.24
Amelanchier alnifolia	Native	1	X				0.75	2.00	2.77
Aquilegia brevistyla	Native	1	X				0.38	0.50	25.00
Artemisia species	Native	1	X				0.75	2.00	10.93
Betula nana	Native	1				X	0.28	0.10	1.43
Cnidium cnidiifolium	Native	1			X		0.25	1.00	7.41

Deschampsia cespitosa	Native	1	X				0.50	1.00	6.33
Erigeron species	Native	1		X			0.28	0.10	4.35
Gentianella propinqua	Native	1				X	0.03	0.10	0.32
Hedysarum alpinum	Native	1				X	1.75	7.00	27.03
Juncus species	Native	1	X				0.28	0.10	1.92
Lotus corniculatus	Native	1	X				0.50	1.00	0.97
Mitella nuda	Native	1	X				0.75	2.00	39.22
Orthilia secunda	Native	1	X				0.28	0.10	1.23
Oxytropis species	Native	1	X				1.00	3.00	16.95
Pedicularis lapponica	Native	1	X				0.28	0.10	1.10
Pinus banksiana	Native	1	X				3.00	10.00	45.05
Plantago canescens	Native	1			X		0.50	1.00	9.35
Platanthera stricta	Native	1			X		0.03	0.10	0.92
Primula stricta	Native	1	X				0.63	0.50	3.65
Pulsatilla patens s. multifida	Native	1			X		0.03	0.10	2.00
Ranunculus pensylvanicus	Native	1	X				0.75	2.00	4.37
Sisyrinchium montanum	Native	1	X				0.53	0.10	0.63
Solidago multiradiata v. multiradiata	Native	1			X		0.03	0.10	0.57
Spiraea stevenii	Native	1				X	0.38	0.50	3.36
Stachys palustris s. pilosa	Native	1			X		0.25	1.00	9.35

1 – IT IS, 2009
2 – USDA NRCS, 2009

Appendix B: Summary statistics of disturbance types in each town

Ft. Simpson

Metric	Type	Test	d.f	F, F*, H	p
Richness	All quadrats	ANOVA	2, 124	0.46	0.628
Richness	Native	ANOVA	2, 124	6.03	0.004
Richess	Introduced	ANOVA	2, 124	5.09	0.008
Cover	Native	ANOVA	2, 124	1.71	0.184
Cover	Introduced	ANOVA	2, 124	7.75	0.001
RA Introduced	Introduced	ANOVA	2, 124	6.39	0.002
Shannon Index	All quadrats	ANOVA	2, 124	0.64	0.528
Evenness	All quadrats	ANOVA	2, 124	0.74	0.479
Simpson	All quadrats	ANOVA	2, 124	1.66	0.194

Norman Wells

Metric	Species category	Test	d.f	F, F*, H	p
Richness	All quadrats	ANOVA	2, 59	1.75	0.183
Richness	Native	ANOVA	2, 59	1.553	0.220
Richness	Introduced	Kruskal-Wallis	2	30.751	<0.0001
Cover	Native	ANOVA	2, 59	0.08	0.920
Cover	Introduced	Kruskal-Wallis	2	28.184	<0.0001
RA Introduced	Introduced	Kruskal-Wallis	2	26.816	<0.0001
Shannon Index	All quadrats	ANOVA	2, 59	1.27	0.287
Evenness	All quadrats	ANOVA	2, 59	3.96	0.024
Simpson index	All quadrats	ANOVA	2, 59	0.09	0.911

Ft. Good Hope

Metric	Type	Test	d.f	F, F*, H	p
Richness	All quadrats	ANOVA	2, 89	11.9	<0.0001
Richness	Native	ANOVA	2, 89	18.17	<0.0001
Richness	Introduced	Kruskal-Wallis	2	36.82	<0.0001
Cover	Native	ANOVA	2, 89	1.17	0.315
Cover	Introduced	Kruskal-Wallis	2	39.81	<0.0001
RA Introduced	Introduced	Kruskal-Wallis	2	37.37	<0.0001
Shannon Index	All	ANOVA	2, 89	7.28	0.01
Evenness	All	ANOVA	2, 89	0.92	0.399
Simpson index	All	ANOVA	2, 89	3.54	0.033

Inuvik

Metric	Species category	Test	d.f	F, F*, H	p
Richness	All quadrats	Kruskal-Wallis	2	16.18	<0.0001
Richness	Native	Brown-Forsythe	2, 62	39.13	<0.0001
Richness	Introduced	Kruskal-Wallis	2	16.52	<0.0001
Cover	Native	ANOVA	62	4.47	0.015
Cover	Introduced	Kruskal-Wallis	2	16.91	<0.0001
RA Introduced	Introduced	Kruskal-Wallis	2	16.22	<0.0001
Shannon Index	All quadrats	ANOVA	2, 62	17.25	<0.0001
Evenness	All quadrats	ANOVA	2, 62	15.62	<0.0001
Simpson	All quadrats	ANOVA	2, 62	2.79	0.07

Appendix C: DCA species list and DCA axis values

Table 2.1: Species list for identified species in Northwest Territories with scientific names and DCA short forms.

Scientific name	DCA
Achillea sibirica	A. sibiric
Amelanchier alnifolia	A.alnif
Astragalus alpinus	A.alpin
Astragalus americanus	A.ameri
Argentina anserina	A.anseri
Aquilegia brevistyla	A.brevi
Argentina egedii	A.egedii
Arabis holboellii	A.holb
Alnus incana	A.incana
Arctagrostis latifolia	A.latif
Achillea millefolium	A.millef
Anemone multifida	A.multif
Anemone parviflora	A.parvi
Andromeda polifolia	A.polif
Antennaria rosea	A.rosea
Arctostaphylos rubra	A.rubra
Artemisia tilesii	A.tilesi
Arctostaphylos uva-ursi	A.uva
Alnus viridis s. crispa	A.viridi
Anemone species	Anemo

Artemisia species	Artemi
Bromus inermis	B.inerm
Betula nana	B.nana
Betula occidentalis	B.occid
Betula papyrifera	B.papyr
Chenopodium album	C.album
Carex atratiformis	C.atrati
Cornus canadensis	C.canad
Crepis elegans	C.elegan
Cypripedium passerinum	C.passer
Castilleja raupii	C.raupii
Corydalis sempervirens	C.sempi
Calamagrostis stricta s. inexpansa	C.stricta
Calamagrostis species	Calama
Carex species	Carex
Cnidium cnidiifolium	C.cnidi
Deschampsia cespitosa	D.cesp
Dryas integrifolia s. chamissonis	D.chami
Dasiphora floribunda	D.florib
Dactylis glomerata	D.glom
Dracocephalum parviflorum	D.parvif
Descurainia sophioides	D.sophi
Deschampsia species	Descham
Epilobium angustifolium	E.angus
Equisetum arvense	E.arvens
Erigeron elatus	E.elatus
Erigeron humilis	E.humili
Empetrum nigrum s. hermaphroditum	E.nigrum
Epilobium palustre	E.palus
Erigeron philadelphicus	E.phila
Elytrigia repens v. repens	E.repens
Equisetum scirpoides	E.scirp
Elymus trachycaulus	E.trachy
Erigeron species	Eriger
Eriophorum species	Erioph
Fragaria virginiana s. glauca	F.glauca
Festuca ovina	F.ovina
Festuca rubra	F.rubra

Festuca species	Festuca
Geum aleppicum	G.alepp
Galium boreale	G.boreal
Geocaulon lividum	G.livid
Gentianopsis macounii	G.macou
Gentianella propinqua	G.prop
Hordeum jubatum	H. jubat
Hedysarum boreale s. mackenziei	H.boreal
Hedysarum alpinum	H.alpin
Juniperus communis	J.commun
Juniperus horizontalis	J.horiz
Juncus species	Juncus
Ledum groenlandicum	L. groenl
Lupinus arcticus	L.arctic
Linnaea borealis	L.boreal
Ledum palustre s. decumbens	L.decum
Lonicera dioica	L.dioica
Lathyrus ochroleucus	L.ochrol
Linum usitatissimum	L.usita
Larix laricina	Larix
Lotus corniculatus	L.corni
Melilotus alba	M.alba
Medicago lupulina	M.lupul
Mertensia paniculata v. paniculata	M.pani
Medicago sativa	M.sativa
Mitella nuda	M.nuda
Orthilia secunda	O.secun
Oxytropis species	Oxytr
Poa arctica	P.arctica
Polygonum aviculare	P.avicu
Populus balsamifera s. trichocarpa	P.balsa
Petasites frigidus	P.frigid
Pyrola grandiflora	P.grand
Plantago major	P.major
Picea mariana	P.maria
Potentilla norvegica	P.norve
Parnassia palustris	P.palust
Phleum pratense	P.prate

Potentilla pulchella	P.pulch
Populus tremuloides	P.tremu
Pedicularis species	Pedi
Pedicularis lapponica	P.lapp
Pinus banksiana	P.bank
Plantago canescens	P.cane
Platanthera stricta	Pl.stric
Poa species	Poa
Primula stricta	P.strict
Pulsatilla patens s. multifida	P.patens
Rosa acicularis	R.acicul
Rubus chamaemorus	R.chama
Rubus idaeus s. strigosus	R.idaeus
Rhododendron lapponicum	R.lappo
Rhinanthus minor s. groenlandicus	R.minor
Ranunculus pensylvanicus	R.pens
Symphoricarpos albus	S.albus
Saussurea angustifolia	S.angus
Sonchus arvensis	S.arven
Shepherdia canadensis	S.canad
Salix candida	S.cand
Salix exigua	S.exigua
Salix species	Salix
Senecio species	Senecio
Sisyrinchium montanum	S.mont
Solidago multiradiata v. multiradiata	S.multir
Spiraea stevenii	S.stevei
Stachys palustris s. pilosa	S.palu
Stellaria species	Stella
Thlaspi arvense	T.arven
Trifolium hybridum	T.hybri
Trifolium pratense	T.prat
Tofieldia pusilla	T.pusil
Trifolium repens	T.repens
Taraxacum species	Tarax
Vicia americana	V.ameri
Viburnum edule	V.edule
Vaccinium vitis-idaea s. minus	V.minus

Vaccinium uliginosum	V.uligin
Viola species	Viola
Zigadenus elegans	Z.elegan

Table 2.2: DCA axis values.

Axes	**1**	**2**	**3**	**4**
Eigenvalues	0.8	0.61	0.47	0.38
Lengths of gradient	7.49	6.23	5.09	5.22
Cumulative percentage				
Variance of species data	5.1	9	12	14.4
Sum of all eigenvalues				15.59

Appendix D: Community consultation survey

The government of the Northwest Territories has a Biodiversity Action Plan. As part of this plan they would like to increase their awareness of new species moving into the NWT. The government recognizes that members of local communities are in the best position to see changes and to understand them as they occur. The need for local communities to be involved is widely recognized around the world. The public desire for better management is growing and community members are often interested in helping to collect information. Furthermore, the body of professionals, however large, is limited in its ability to do this work.

For all questions, please check all that apply.

1. Which of these terms have you heard of?

- ☐ Invasive species
- ☐ Non-native species
- ☐ Non-indigenous species
- ☐ Introduced species

2. Where should you be able to go to get information about these species?

- ☐ Elders
- ☐ Band Office
- ☐ The local newspaper
- ☐ The library
- ☐ Postings at The Northern Store or The North Mart
- ☐ The local Environment & Natural Resources (ENR) office
- ☐ The Renewable Resources Council (RRC)
- ☐ Parks Canada
- ☐ The Health Centre
- ☐ The Internet
- ☐ Other ______________________________

3. If you see a plant or animal that you have never seen before, who would you be most likely to tell or ask about it?

- ☐ Elder
- ☐ Teacher
- ☐ Someone at the community garden or greenhouse
- ☐ Environment and Natural Resources person (ENR)
- ☐ Renewable Resources Council person (RRC)
- ☐ Parks Canada person
- ☐ Someone at the Band Office

- ☐ RCMP
- ☐ Someone at the Northern Store
- ☐ Someone at the Health Centre

4. Would you be willing to report an introduced species if you found one?

- ☐ Yes
- ☐ No

5. Who do you think is the best person or group to pass on your information about the presence of introduced species to a program?

- ☐ Yourself, if there is an internet reporting form
- ☐ Elder
- ☐ Teacher
- ☐ Someone at the community garden
- ☐ Environment and Natural Resources person (ENR)
- ☐ Renewable Resources Council person (RRC)
- ☐ Parks Canada
- ☐ Someone at the Band Office
- ☐ RCMP
- ☐ Someone at the Northern Store
- ☐ Someone at the health centre

6. Which of the following information would you be willing to report?

A description of the plant or insect

- ☐ Your Name and contact information for follow-up questions
- ☐ Photo
- ☐ Location
- ☐ GPS Point
- ☐ Habitat (i.e. lake, swamp, river, forest, tundra)

7. What language would you want to report the find:

- ☐ Your own language, ____
- ☐ English

8. Do you have access to the Internet to report?

- ☐ Yes
- ☐ No

9. Where do you have access to the Internet?

- ☐ Home

- ☐ Library
- ☐ School
- ☐ Friendship/Wellness Centre

10. What is your preferred option for reporting a new invasive species:

- ☐ Website
- ☐ Email
- ☐ In person
- ☐ Guiding an expert to the location

11. Would you be willing to look for introduced species when you are out on the land?

- ☐ Yes
- ☐ No

12. Would you be willing to collect a sample of an introduced species if you find one?

- ☐ Yes
- ☐ No

13. Would you feel more comfortable or more inclined to participate in such a program if an incentive was offered? (i.e. t-shirt, baseball cap, toque, etc.)

- ☐ Yes
- ☐ No

14. Do you have any comments?

Thank you very much for participating in this survey.

Appendix E: Community consultation survey comments

Community Protocols Survey Comments

2. Where should you be able to go to get information about these species?
    - Face-to-face with community members
    - Radio (x2)
    - College presentations
    - Visitor Centre – summer
    - Regional Wildlife Boards
    - Hunters & Trappers (x2)
    - Aurora Research Inst. (x2)
    - Inuvik Comm. Greenhouse
    - IRC
    - TV
    - Word of Mouth
    - Other community bulletin boards
    - Health centre if it affects health

3. If you see a plant or animal that you have never seen before, who would you be most likely to tell or ask about it?
    - Aurora Research Institute

5. Who do you think is the best person or group to pass on your information about the presence of introduced species to a program?
    - IRC
    - Comment – Not the RCMP's mandate

6. Which of the following information would you be willing to report?
    - GPS point, make sure you ask for datum of GPS points!

7. What language would you want to report the find:
    - Would be good to have native/aboriginal language translated info brochures
    - Gwich'in (x3)
    - Inuvialuktun
    - South Slavey
    - Aboriginal dialects should be available
    - French
    - Slavey

9. Where do you have access to the Internet?
    - Work (x6)

11. Would you be willing to look for introduced species when you are out on the land?
    - Just for moose

12. Would you be willing to collect a sample of an introduced species if you find one?
    - Maybe - depending what it is and how to preserve

13. Would you feel more comfortable or more inclined to participate in such a program if an incentive was offered? (i.e. t-shirt, baseball cap, toque, etc.)
    - No answer, other than "not necessarily"
    - Yes and "anything"

14. Do you have any comments?
    - It would be very good to have a website where you can report anything new that you have not seen before.
    - I think that this program is very important, because our livelihoods depends on the research done. It is also important that the research be done, because of the exploration work that is happening, on our land.
    - It would be great to have some means of reporting back to people that i.e. 5 hummingbird moths have been spotted in 2007 or so people would like to know what is being spotted and how often. There has to be feedback - if the program is to be successful
    - I don't think we should encourage people to pick/remove unkown species in case they are not invasive but rare. It's good to point out that invasive non-native wildlife species may follow these non-native plant/insects as people up north are really concerned about their wildlife. RRCs are not working at full capacity and ENR is busy but there are regional co-management boards that work directly with RRCs and can help with reports of invasive species. Handout of common invasive species would be good for communities. Where will the "invasive kits" be located?, and any training to use GPS. Any school/youth programs/presentations? Any ENR regulations?
    - I have a degree in Environmental Science, therefore I am comfortable with vegetation ID, collecting samples, etc. I like the idea of the card with invasive and rare species. The ENR person in each community will be a VERY important part of your communication chain in putting out information on what to do when you find a rare species, and in teaching them ho to upload things to a website.
    - Offering suggestions of who to report to needs to be only to agencies or groups who have this mandate. The RCMP have a mandate of dealing with crime. They have neither the time, nor the inclination to deal with issues that do not fit within their mandate. Seeing the RCMP on the list may lead community people to beleive that they should report there. You could loose the information when the RCMP send them away. Have one reporting site for plants, insects, animals, etc. People then only have to go to one site or agency to make a report.

- I believe this project is very good for us & our land & I would be willing to help in any way I can
- Would not feel inclined unless they were fatal to someone or wildlife
- What is the best reseeding mixture for our location in the ISR or GSA and where can we get that info?
- I believe this is a good initiative, but I'm skeptical that a lot of information will be collected. I have experience in trying to get reports of unusual species and find a very low response rate. Also, many reports of unusual things turn out to be relatively common species that had just not been noticed before. It is my experience that the most knowledgeable local people are not likely to use a web-based system. Talking one on one is usually a much better approach when possible.
- Protecting the environment/land should need no incentive
- Finding new species must be reported - public knowledge; Let the public be aware of where they can report such sightings
- In order to know what is introduced, we would need to know what is indigenous
- How can I identify a new specie if I am new in this area and don't completely know what is the natural habitat. Do you have a reference book showing the original plants? We need more tools to be able to help in Search.
- Enjoyed the presentation! It is a good idea to include members of the community to help out with this ongoing project. Hope we can make a difference.
- would a list of current invasive species be provided to confirm which species are newly non-native?
- ENR is probably best people (most knowledgeable) to present info. The problem is they have very little interaction with the community, so people probably wouldn't contact them. Their most interaction is for wildlife problems. As far as getting infor out in our community, the best is through school kids or posting on community bulletin boards ex bank, northern, hotel, hardware store, restaurant, etc.
- Spent 2 weeks this summer in the Nahanni Park and was amazed at the cleanliness and preservation of northern plant

Community Protocol Survey Discussion Comments

Fort Good Hope

- People should go straight to ENR or the RRC
- We've seen magpie birds
- Should be able to upload information on a website
- Should be able to both use a website or see somebody in person
- We need to be educated, so that we know what we are looking for
- The program needs to be centered in the community – i.e. training for what to do with the information. Maybe we should send people to get training.

- There should be books or a book at the library
- What effects is the exploration work having?
- Could use "wanted" posters
- Reclamation – seeds are being brought in from outside the territory
- A few years ago there were a lot of caterpillar larvae on plants, and the birds weren't eating them
- Elders need education to know what questions to ask
- Need berry pickers, fishermen and hunters on board
- Need to exchange information with other communities – some sort of alert system
- Should use the radio
- Flyers are a good idea
- Must have transparency – to get answers back

Inuvik

- Strange tree spotted on the side of the road
- Would be good to have some sort of action kit, which you could lend out from RRC or ENR and would come with a digital camera, vials or envelopes for samples, GPS, nets for collecting insects, tags for identifying samples, etc.
- GRRB
- The Infobase is buried in the ENR website – very difficult to find.
- Staff is not fully used – they have more capacity than what their job allows them to do – i.e. biologists not being fully used

Fort Simpson

- Need to know what the native population of plants and insects is
- Are seeing lots of new animal species – deer, cougars
- Steve Gooderham
- ENR Ft. Simpson has ideas on how to perpetuate the development of a native seed mix in Ft. Simpson
- Have a system for allowing individuals who want to report something new, but do not want to reveal its exact location. This includes kilometer makers from the highway and latitude and longitude of an area rather than a specific point. Other option is a map that can be clicked on to identify the eco-zone using a website.
- The Ft. Simpson ENR office has the skills to identify most species, but is also willing to contact other to indentify unknowns.
- There are existing programs done though ENR to involve local school children is forestry activities (e.g. management, identification, and forest health).