METHODS FOR IDENTIFYING POTENTIAL CORE REPRESENTATIVE AREAS FOR THE NORTHWEST TERRITORIES PROTECTED AREA STRATEGY: TERRESTRIAL COARSE FILTER REPRESENTATION ANALYSIS

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ABSTRACT

The goal of the Northwest Territories (NWT) Protected Areas Strategy (PAS) is to protect special natural and cultural areas, and core representative areas within each ecoregion of the NWT. Core representative areas are intact areas that best represent the biological diversity of an ecoregion. Protecting core representative areas will help maintain healthy wildlife populations and ecological processes. The PAS recognizes the need to apply the methods of conservation science to identify and protect core representative areas in each ecoregion.

A methodology is being developed to identify options for core representative areas in the NWT, starting with the 16 ecoregions outlined in the Mackenzie Valley Action Plan. The method is based on the best practices in conservation planning, adapted to fit the context of the NWT. It begins with identifying areas that represent landscapes at a coarse scale. The theory and methods for this 'terrestrial coarse filter representation analysis' are described in this report.

Protecting examples of landscape features – which make up habitats – should capture the majority of species without having to consider those species individually. We use a computer site selection software called 'Marxan' to find areas which represent examples of many different landscape features using the smallest amount of land possible. Three types of features are used: physiographic units, landscape units, and vegetation types. Initial objectives for how much of each landscape feature to represent are set to total approximately 30% of the land area. It is recognized that 30% land protection alone is not

sufficient and that core representative areas must work in combination with functioning habitat outside of protected areas.

There are multiple options for meeting ecological representation. Marxan can be used to explore these options through different scenarios. Three representation scenarios are discussed. A 'blank slate' scenario shows the most efficient way (i.e. least amount of land protected) to get ecological representation. A second scenario considers areas already protected, as well as special natural and cultural areas that communities have proposed for protection, and shows what additional areas are needed to achieve ecological representation. For the 16 Mackenzie Valley ecoregions, current protected area proposals meet full representation in only one ecoregion. A final scenario shows how well representation objectives can be met when development areas related to the proposed Mackenzie Gas Pipeline are excluded. Some landscape features can no longer be fully represented under these conditions.

The Marxan terrestrial coarse filter analysis results are based on scientific data. They should be used as part of a conservation planning process in collaboration with other types of information including traditional knowledge, other development interests, fine filter information, and other scientific information to help identify and refine boundaries for protected areas. Results of various terrestrial coarse filter representation scenarios have been provided to several groups that make land use decisions. Additional customized scenarios with modified objectives can be generated for interested agencies and organizations. The results of these scenarios should be used to support protected area planning decisions in the NWT.

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1.0 INTRODUCTION

The Northwest Territories Protected Areas Strategy

In 1999 Aboriginal governments and organizations, the federal and territorial governments, non-governmental conservation organizations and industry stakeholders convened to develop the Northwest Territories (NWT) Protected Areas Strategy (PAS). The parties developed the PAS to provide a balanced approach for establishing a protected areas network throughout the Northwest Territories. It is a community-driven partnership and the partners work together to help protect the ecological quality and integrity of special areas of land and water in the NWT (NWT PAS Advisory Committee 1999). In 2004 the partners developed the Mackenzie Valley Five-Year Action Plan to foster implementation of the PAS in the Mackenzie Valley (NWT PAS Secretariat 2003).

PAS Goal

The goal of the PAS is to protect:

- Special natural and cultural areas of the NWT, and
- Core representative areas within each ecoregion of the NWT, where resource based development will not be permitted.

The goal of the PAS is stated in two parts for clarity; however, they are intricately linked and should be applied equally in the identification of protected areas. The first half of the goal aims to use traditional knowledge to identify areas of cultural and natural value to Aboriginal people; the second half emphasizes the use of scientific knowledge to expand on this by identifying areas representative of NWT ecoregions that will help foster the continued existence of most ecological values into the future. The two types of areas are not mutually exclusive; in some cases a single protected area can contribute to both parts of the goal. Local knowledge and scientific knowledge are both needed for effective protected areas design (Wiersma *et al.,* 2005).

In the Protected Areas Strategy and the Mackenzie Valley Five-Year Action Plan (NWT PAS Advisory Committee 1999; NWT PAS Secretariat 2003), the PAS partners further stipulate that protected areas be planned and managed to maintain biodiversity and ecological processes, and that "together with buffer zones and connecting wildlife corridors, a network of protected areas in the Mackenzie Valley will:

- Safeguard culturally important areas,
- Adequately represent the diversity of habitats and landscapes,
- Maintain the ecological integrity of NWT ecoregions,
- Ensure the viability of wide-ranging species such as caribou and migratory birds,
- Maintain a well-connected natural landscape, and
- Act as reference sites to provide a crucial benchmark to properly monitor, assess and mitigate impacts of the proposed Mackenzie Valley Pipeline and associated industrial development."

To achieve this vision of the protected areas network, the PAS team works with other land and water protection processes such as regional land use planning (Box 1) and agencies responsible for environmental management.

<u>Box 1: Regional Land Use Planning</u>

Regions of the NWT are in various stages of land use planning that contributes to the protected areas network. Land use planning has a three-fold contribution to the PAS and protection of biodiversity:

- Conservation zones can protect special natural and cultural areas and can contribute directly to ecological representation.
- Special management zones can act as buffers from development and corridors for species dispersal between conservation zones.
- Land use plans can stipulate development thresholds as part of the larger adaptive management framework. Thresholds on development activities can help conserve a variety of values and may be especially helpful in protecting wide-ranging species, such as barren-ground caribou, whose entire range cannot be included in protected areas and conservation zones.

Identifying Core Representative Areas

Core representative areas, mentioned in the second half of the PAS goal, are intact areas that best represent the biological diversity of an ecoregion (see Appendix A). The NWT PAS states that resource based development will not be permitted in core representative areas (NWT PAS Advisory Committee 1999). NWT communities and Land Use Planning Boards have already proposed many special natural and cultural areas for protection or conservation measures. These existing PAS proposals and land use plan conservation zones contribute to core representative areas. However, identifying core representative areas and ensuring that the full range of diversity in an ecoregion is represented requires additional scientific analysis.

In June 2005 a team was established to develop options for core representative areas in the NWT. The team (known as the PAS Science Team, formerly the Ecological Working Group) is led by the Government of the Northwest Territories Department of Environment and Natural Resources and is a joint effort with Ducks Unlimited Canada, The Nature Conservancy, Indian and Northern Affairs Canada, World Wildlife Fund Canada, and the Canadian Parks and Wilderness Society. Building upon preliminary representation work done by Tingey *et al.* (2005) for the NWT, the team is developing a methodology for identifying these areas based on the best practices in conservation planning, adapted to fit the context of the NWT. The terrestrial coarse filter representation analysis described in this report is an initial step that is based on scientific data. The resulting potential options for core representative areas should not be considered in isolation but should be used along with information on other values, such as traditional knowledge, special natural and cultural areas, development interests, fine filter information, and other scientific information to help identify and refine boundaries for protected areas.

The NWT PAS stipulates that core representative areas be identified for each of the NWT ecoregions[1]. The terrestrial ecological representation results

[1] The NWT PAS is based on the National Ecological Framework for Canada ecoregions (Ecological Stratification Working Group 1996) which were the best available data at the time that the PAS was written. NWT ecoregions are currently undergoing boundary revisions which have not yet been completed for the entire NWT. Following direction from the NWT PAS Steering Committee, we are using the National Ecological Framework for Canada ecoregion boundaries for the duration of the Mackenzie Valley Five-Year Action Plan.

shown in section 5 of this report focus on the 16 ecoregions outlined in the Mackenzie Valley Action Plan (NWT PAS Secretariat, 2003) that would be directly impacted by the planned Mackenzie Valley gas pipeline corridor and associated hydrocarbon development areas (Figure 1). We are in the process of expanding the terrestrial representation analysis to all NWT ecoregions.

This technical report describes:

- The scientific basis and rationale for regional-scale conservation planning (section 2).
- The theory and specific methodology for the terrestrial coarse filter ecological representation analysis – one of the primary tools for identifying core representative areas in the NWT (sections 3 and 4).
- One set of results from the terrestrial coarse filter representation analysis for the Mackenzie Valley ecoregions (section 5).
- Other types of information that are being developed to help identify core representative areas (section 8).

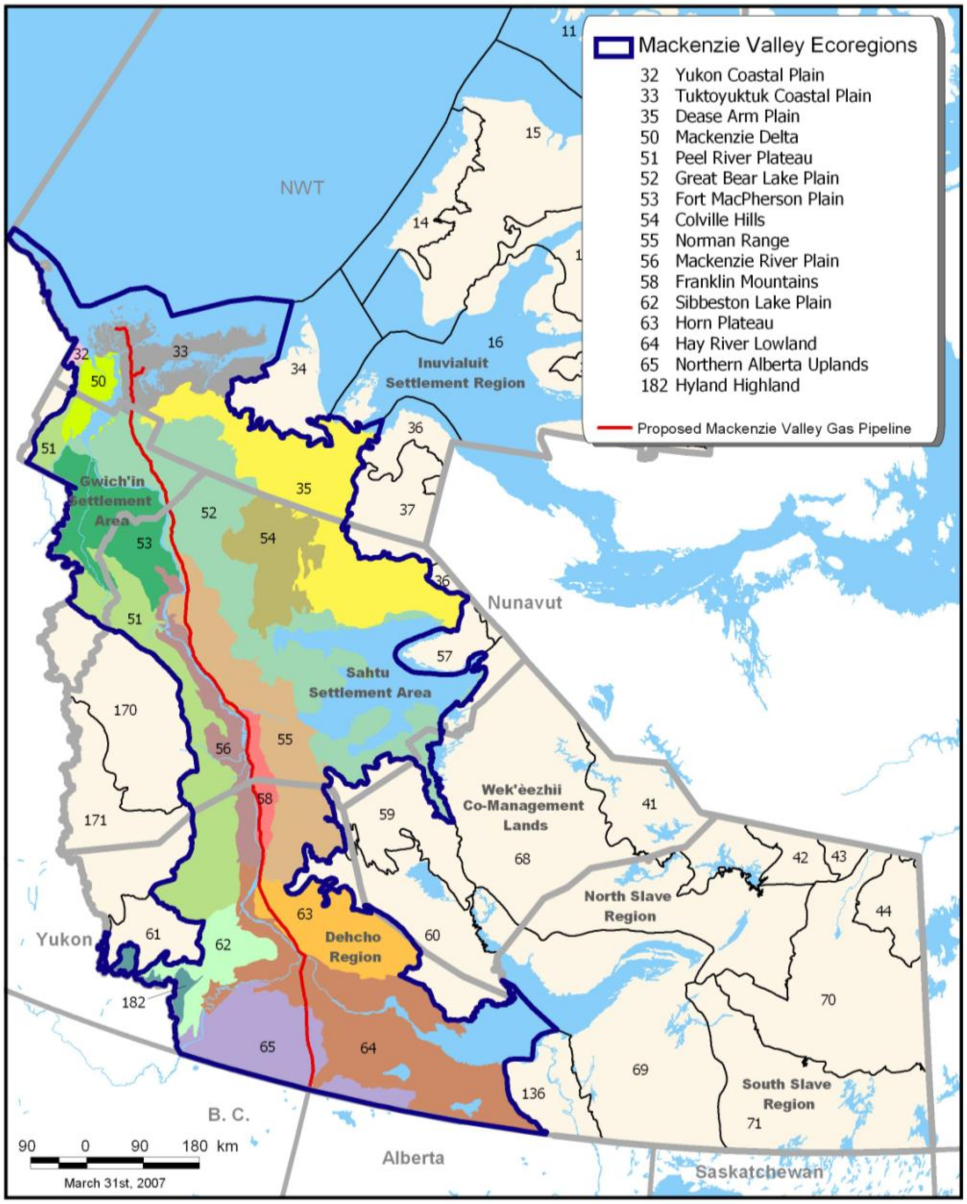

Figure 1. Mackenzie Valley and NWT ecoregions (Ecological Stratification Working Group 1996; NWT PAS Secretariat 2003).

2.0 APPROACHES AND RATIONALES FOR REGIONAL-SCALE CONSERVATION PLANNING

2.1 Large-scale Conservation Planning

The goal established by the NWT PAS clearly reflects the growing understanding of the need to plan and manage for the maintenance of viable populations and functioning ecosystem processes across appropriately large regions (Hawkins and Selman, 2002; Howard *et al.,* 2000; Jepson *et al.,* 2002; Poiani *et al.,* 2000; Soulé and Terborgh 1999; Wisdom *et al.,* 2002). Planning for the maintenance of landscape functions and species across broad areas is particularly important in regions such as the Canadian North, where ecosystem richness and productivity are maintained through large-scale disturbance regimes and other natural processes. Additionally, in systems with relatively low productivity (e.g. boreal forests and tundra) some species, such as grizzly bear, caribou, and wolf, have evolved strategies dependent on extensive landscapes to meet seasonal and annual needs for food and breeding. Habitat fragmentation puts these species at greater risk (Cardillo *et al.,* 2006). Maintaining ecologically effective populations of these species may be key to sustaining community dynamics and ecosystem complexity over the long term (Berger *et al.,* 2001; Soulé *et al.,* 2003).

2.2 Establishing Conservation Goals

Conservation scientists recommend that all planning processes start with clearly articulated goals (Groves *et al.,* 2002; Noss *et al.,* 2002; Noss and

Cooperrider 1994; Tear *et al.,* 2005) and several scientists have developed widely adopted guidelines for establishing conservation and management goals. Noss (1992) and Noss and Cooperrider (1994) proposed four goals of regional conservation that should be satisfied to achieve the overarching mission of maintaining biodiversity and ecological integrity. These goals are:

- Represent, in a system of protected areas, all native ecosystem types and seral stages across their natural range of variation.
- Maintain viable populations of all native species in natural patterns of abundance and distribution.
- Maintain ecological and evolutionary processes, such as disturbance regimes, hydrological processes, nutrient cycles, and biotic interactions.
- Design and manage the system to be resilient to short-term and long-term environmental change and to maintain the evolutionary potential of lineages.

These four goals are often cited and have been used as the foundation for most of the significant regional conservation strategies and conservation area designs endorsed and/or developed by government agencies and conservation organizations worldwide.

Another often-cited guiding principle for conservation planning and management aims to account for both the unpredictable stochasticity of natural systems and known environmental change. The “precautionary principle” proposes that this uncertainty be explicitly acknowledged and that managers should make every effort to err on the side of caution (deFur and Kaszuba, 2002; Raffensperger and deFur, 1999; Van Den Belt and Gremmen, 2002). To be effective, conservation goals must be set such that ecosystems can remain as resilient as possible to the impacts of natural and human-caused disturbance. A resilient ecosystem will be able to absorb change and reorganize its processes and structures after a disturbance event in order to maintain crucial ecosystem functions (Peterson *et al.,* 1998). This requires planning and managing land within a flexible, adaptive framework (Chapin *et al.,* 2004). These general principles take on special meaning in the North where impacts of climate change are already apparent.

2.3 Systematic Conservation Planning

Successful large-scale conservation planning requires a systematic approach in order to meet broad goals such as the persistence of native species and ecological processes. Systematic conservation planning means developing and following transparent science-based methods. It is based on ecological principles, relies on peer-reviewed methods, and is driven by data and expert knowledge. Experience around the world has demonstrated that systematic conservation planning approaches are more effective at conserving biological diversity than are the site-by-site approaches of the past (Margules and Pressey, 2000). Site-by-site approaches often result in a biased distribution of lands and waters set aside for conservation, with the majority occurring at higher elevations, on steeper slopes, or on poorer soils. Importantly, protected areas selected primarily for political, social or cultural reasons, often do not achieve the stated goals of conserving biological diversity and maintaining viable populations and ecological functions and services (Pressey *et al.,* 1996; Scott *et al.,* 2001).

2.4 Components of a Systematic Conservation Planning Approach

At a regional scale, contemporary systematic conservation planning efforts typically employ four complementary types of information to build robust representative protected areas networks:

- Coarse filter ecosystem representation analyses (terrestrial and freshwater),
- Fine filter analyses targeting special elements (unique, rare, or sensitive features),
- Focal species analyses as described by Noss *et al.* (1999), often considered part of the fine filter approach, and;
- Explicit consideration of how species genetics and demographics and ecosystem processes are connected across the landscape (Noss *et al.,* 1999, Dobson *et al.,* 1999; Hoctor *et al.,* 2000, Taylor *et al.,* 1993).

Other analyses may further our ability to incorporate important dynamic processes. These include spatial population viability analyses and ecological process modeling (e.g. fire modeling).

2.5 Coarse Filter and Fine Filter Approach

An analysis that seeks to represent broad landscape variations is often referred to as a "coarse filter" representation analysis, because it is done at a coarse scale. In both the terrestrial and freshwater realm, species distributions are largely determined by environmental factors such as climate, substrate, and lake characteristics. Furthermore, vegetation communities and other species assemblages respond to environmental gradients across the landscape. Therefore, protecting examples of all enduring physical features in the landscape (e.g. soils, elevation) ought to capture the majority of species without having to consider those taxa individually (Noss and Cooperrider, 1994). In this way, the coarse filter representation analysis acts as a surrogate for the nearly impossible task of identifying areas that capture the full diversity of species and communities within a region. Noss (1987) estimated that setting well-informed measurable objectives could protect 85-90% of all species. This estimate may be optimistic and indeed, the precise effectiveness of the coarse filter would be difficult to test empirically. However, Noss and Cooperrider (1994) predict the relative effectiveness is highest in areas with low endemism (such as the NWT).

Some species and species assemblages do not always co-occur with certain communities or landscape features in a predictable fashion and therefore may not be captured by the coarse filter approach. It is necessary to target these elements individually to ensure they are represented. This type of analysis is often referred to as a "fine filter" representation analysis, and it involves adding in more detailed information where it exists. Many scientists (e.g. Hunter, 1991;

Noss and Cooperrider, 1994; Noss, 1996a; Kirkpatrick and Brown, 1994; Kintsch and Urban, 2002; Groves, 2003) have recommended using the coarse filter and fine filter approaches together, and many conservation organizations and government planning agencies around the world use the combined approach as a way to represent the biodiversity of a region (e.g. Manitoba's Protected Areas Initiative, 2000; Margules and Pressey, 2000; Cowling *et al.*, 2003; Heinemeyer *et al.*, 2003; Rumsey *et al.,* 2004; Henson *et al.*, 2005; The Nature Conservancy in Alaska, 2005; Parks Canada, 2007).

3.0 TERRESTRIAL COARSE FILTER REPRESENTATION ANALYSIS – RECOMMENDATIONS FROM CONSERVATION SCIENTISTS AND OVERVIEW OF NWT APPROACH

The terrestrial component of the coarse filter representation analysis for the Northwest Territories is described in this report. This analysis helps to identify potential conservation areas for land-based species and communities. It is a key initial step for identifying core representative areas as outlined in the NWT PAS and Mackenzie Valley Five-Year Action Plan (NWT PAS Advisory Committee, 1999; NWT PAS Secretariat, 2003). Some other information being developed in addition to the terrestrial coarse filter is described in section 8.

The terrestrial coarse filter representation analysis is based on scientific information. The methodology is based on the best practices in conservation planning, adapted to fit the context of the NWT.

3.1 Conservation Features for the Terrestrial Representation Analysis

The terrestrial component of a coarse filter for ecosystem representation is typically built with datasets on enduring environmental features, such as elevation, soil, and geology, combined with biotic data – usually a regional vegetation classification. When choosing conservation feature datasets for the terrestrial representation analysis, the following factors were considered:

- Datasets should be available for the whole NWT or as close to it as possible; and
- The combination of datasets should identify a variety of habitats that are most likely to capture the biodiversity of the NWT.

We used three geophysical and biological conservation feature datasets for the NWT terrestrial representation analysis:

- Physiographic units (areas defined by regional climate, broad landform types, and other factors)
- Landscape units (polygons with similar surficial geology, soil and terrain)
- Land cover (vegetation classes)

For more detailed information on the specific datasets and how and why we used them in the analysis see section 4.3.

3.2 Site Selection and Decision Support Tool

Manually identifying areas that represent the terrestrial biodiversity of multiple ecoregions is difficult because of the large number of possible combinations of selected conservation features (i.e. combinations of physiographic units, landscape units, and vegetation classes). Site selection tools (also called 'decision support tools') are algorithms embedded in computer software that quickly sort through large volumes of data and identify areas that capture a specified percentage of combinations of conservation features.

We are using the site selection tool Marxan (Ball and Possingham, 2000a; Possingham *et al.,* 2000). Marxan and similar site selection programs, such as SITES, are widely used in both terrestrial and marine conservation area design efforts (e.g. Heinemeyer *et al.,* 2003; Heinemeyer *et al.,* 2004; Rumsey *et al.*, 2004; Lieberknecht *et al.,* 2004; Conservation Law Foundation and WWF 2006; and numerous plans developed by The Nature Conservancy and Nature Conservancy of Canada and partners). Marxan is a stand-alone software package that can be downloaded at no cost from http://www.ecology.uq.edu.au/index.html?page=29780.

It is important to note that site selection tools such as Marxan should not be depended on alone to generate a conservation 'answer' for the NWT PAS. Rather, Marxan is an effective tool for exploring the spatial implications of decisions made about conservation features, objectives, and costs. The strength of the tool lies not with the certainty of its outputs (which can only be as certain as the inputs), but in the efficacy with which different scenarios can be generated and tested against established criteria and qualitative goals. Further, conservation planning must be adaptive over time and Marxan can be used to generate new 'solutions' as both ecological and socio-economic conditions change, and opportunities for conservation emerge and disappear. Finally, it is important to note that the terrestrial coarse filter representation analysis is only one of multiple types of information being developed to help identify core representative areas in the NWT.

3.3 Conservation Objectives

3.3.1 Establishing Measurable Conservation Objectives: How much is enough?

Within a systematic conservation planning framework, measurable objectives help articulate and prioritize which areas and how much area will comprise a protected areas network. Measurable objectives also drive Marxan and similar optimization tools by defining how much of each combination of conservation features should be included. The question of "how much is enough" is one of the most important and challenging in conservation science today. It is a difficult question that is not fully resolved and which becomes more difficult at larger scales and with broad qualitative goals (Tear *et al.*, 2005). Despite the difficulties of setting measurable objectives, there is some guidance in the literature and from other conservation practitioners (see Svancara *et al.,* 2005; Tear *et al.*, 2005; Rumsey *et al.,* 2004; Carrol *et al.,* 2003; Mosquin *et al.,* 1995; Noss and Cooperrider, 1994).

One of the primary challenges in setting measurable objectives is to separate science from political feasibility. To ensure the long-term protection of biodiversity, many have sought to establish measurable objectives based on the percentage of an area within a country or region that is conserved. In recent years, policy-driven objectives (e.g. the generic *a priori* 10-12% objective of the World Commission on Environment and Development and others) have frequently been faulted for their basis in political expediency and lack of biological foundation (Soulé and Sanjayan, 1998; Pressey *et al.,* 2003; Brooks *et al.,* 2004). Svancara *et al.* (2005) showed that, on average, policy-based approaches called for 13.1% of a jurisdiction and were significantly lower than evidence-based approaches, where conservation assessments and threshold assessments called for 30.6% and 41.6% of the project areas, respectively. Table 1 presents a summary of evidence-based measurable objectives for biodiversity conservation, recommended either generally or for specific regions.

To set evidence-based objectives, scientists typically rely on understanding and mapping the distribution and viability of species, ecological communities and populations. This knowledge is often gained through complex studies such as population viability analyses, determination of minimum dynamic area required for long-term species persistence, and other similar approaches. For example, Carroll *et al.* (2003) determined that at least 37% of their US-Canadian Rocky Mountain project area would need to be protected to meet population viability criteria for grizzly bear and wolf. Their modeling procedures preferentially selected the most productive habitats, based on estimates of predicted fecundity, mortality and habitat connectivity. In conservation planning efforts without this type of modeling – such as the NWT PAS – it may be impossible to identify these irreplaceable sites. In these cases, the precautionary principle suggests that higher measurable objectives be set.

Table 1. Example evidence-based goals and objectives for protected areas (adapted from Svancara *et al.*, 2005).

Source	Region	Goal	Recommended Area
Odum (1970)	Georgia	Optimize ecosystem services and quality of life in a self-sustaining ecosystem	40%
Odum and Odum (1972)	General	Optimize ecosystem services and economic and cultural well-being	50%
Noss (1993)	Oregon coast	Represent all plant species and wetland types at least once	50%
Metzgar and Bader (1992)	The Northern Rocky Mountains	Landscape required protection to support a viable population size of 500 grizzly bears	60%
Cox *et al.* (1994)	Florida	Represent all bird, mammal, and plant species at least once	33.3%
Noss and Cooperrider (1994)	Most ecosystem types	Broad review of biodiversity conservation planning initiatives to achieve ecological objectives	25 to 75%
Mosquin *et al.* (1995)	Canada	Represent all bird, mammal, reptile, and plant species at least once	35%
Ryti (1992)	San Diego Canyons	Maintain an effective population of 500 grizzly bears (total pop. = 2000)	65%
Ryti (1992)	Islands in Gulf of California	Protect all clusters of rare species and community occurrences and all primary forest; provide for carnivore recovery	99.7%
Margules *et al.* (1988)	Australian River Valleys	Protect rare species and natural communities	44.9 – 75.3%
Noss (1996b)	General	Meet well accepted conservation goals in various regions	25% - 75%
Noss *et al.* (1999)	Klamath-Siskiyou	Protect roadless areas that meet all special elements, representation, and focal species goals	60 – 65%

Source	Region	Goal	Recommended Area
Hoctor *et al.* (2000)	Florida	Capture biological priority areas and provide connectivity state-wide	50%
Rodrigues and Gaston (2001)	Tropical region	Represent each species at least once	93%
Rodrigues and Gaston (2001)	Globally	Represent each plant (and vertebrate) species at least once	74%
Hammond and Leslie (2002)	Labrador	Land use planning process incorporating conservation biology principles to address a mostly intact boreal region	50%
Noss *et al.* (2002)	Greater Yellowstone Ecosystem	Protect megasites that meet all special elements, representation, and focal species goals	43%
Carroll *et al.* (2003)	U.S.-Canada Rocky Mtns.	Protect highest-quality habitat and source areas to maintain viable populations of carnivores	37%
Cowling *et al.* (2003)	Cape Floristic Region, South Africa	Capture a comprehensive set of targets representing biodiversity patterns and processes	52%
The Nature Conservancy in Alaska (2003)	Cook Inlet Basin Ecoregion, Alaska	Represent all species, systems, and species aggregation targets across four subregions	53%
The Nature Conservancy in Alaska (2004)	Alaska Peninsula and Bristol Bay Ecoregions together	Represent all species, systems, and species aggregation targets across four subregions	62%
The Nature Conservancy in Alaska (2005)	Alaska-Yukon Arctic Ecoregion	Represent all species, systems, and species aggregation targets across four subregions	45%
The Nature Conservancy (Unpublished papers)	>50 ecoregional assessments in 11 countries	Meet multiple conservation goals, especially representation of ecosystems and protection of special elements	Mean: 30 – 40% (up to ca. 70%)

In the absence of adequate region-specific information, practitioners often turn to the species-area curve for guidance (Figure 2). Although species vary widely in their space requirements, the relationship between habitat loss and species loss is well established (MacArthur and Wilson, 1967; Rosenzweig, 1995). Given this generalized relationship, at the objective level of 10% habitat protection, 50% of the original number of species could be lost. At the objective level of 30%, between 20% and 44% of species could be lost.

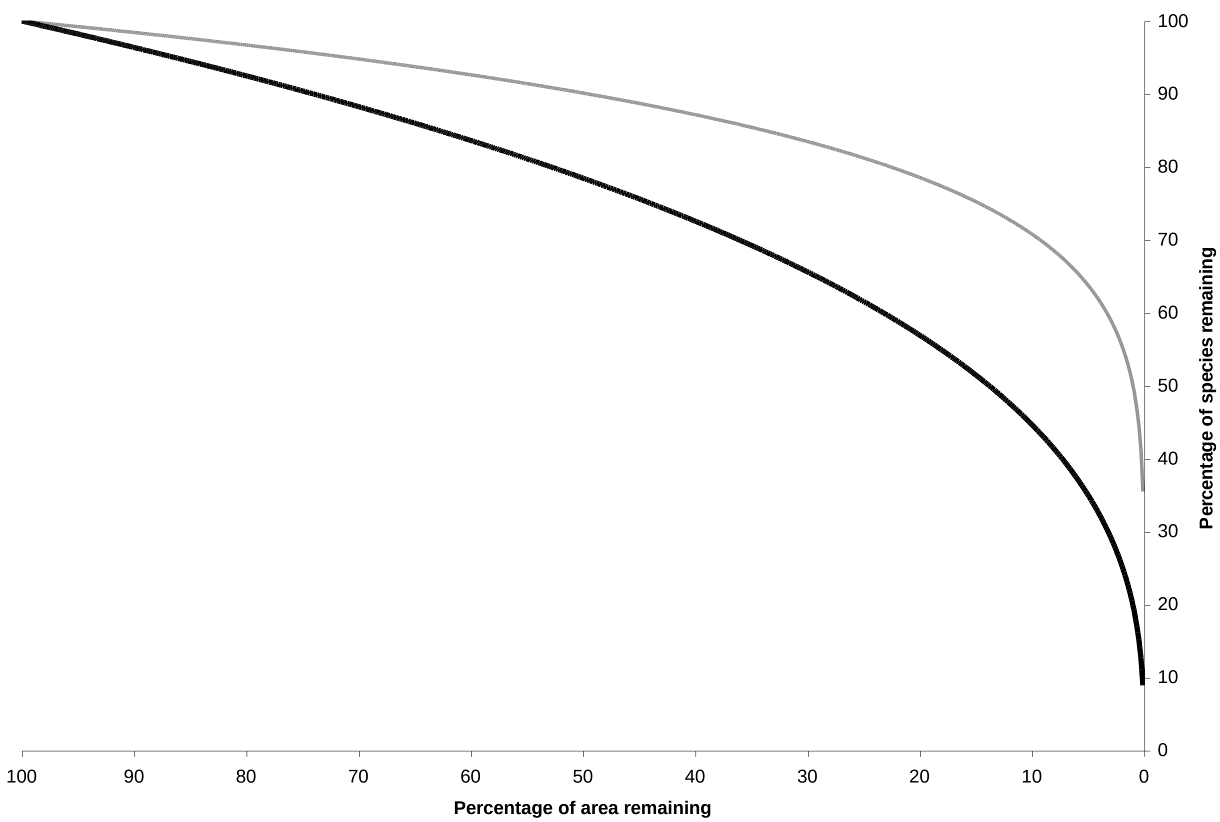

Figure 2. Estimated species loss with percent area of habitat loss over time (modified from Dobson (1996)). Species loss is higher for isolated islands than for continuous landscapes. Z = the slope of the log-log species-area relationship; the upper bound (grey line; z = 0.15) represents a continuous landscape; the lower bound (black line; z = 0.35) represents isolated islands.

While the species-area curve provides information about the level of species diversity that can be expected to be maintained by protecting a specified percentage of habitats, it does not provide any information about which species will be lost and which will remain. The species that are likely to be lost first are those which have habitat requirements with certain ecological limitations or which are under threat from human activities. These species may be area-limited, dispersal-limited, resource-limited or process-limited (Lambeck, 1997). This reinforces the importance of building on the results of the coarse filter analysis with a fine filter approach, to capture species with large home ranges (e.g. grizzly), which are migratory (e.g. barren-ground caribou) or which are unable to disperse across certain landscapes (e.g. marten).

It is also important to note that the species-area curve describes a generalized distribution of species within an ecosystem. Boreal systems tend to have communities with a small number of dominant species, resulting in species abundance distributions that produce a steeper slope in the curve. The species-area relationship can be used as a theoretical framework, but the precise values need to be identified through assessing regional patterns with actual data. Objectives based on this relationship as well as objectives for species should be treated as hypotheses and need to be tested and refined through time.

3.3.2 Measurable Representation Objectives for the NWT

The information outlined in section 3.3.1 was used to develop two options for quantitative representation objectives for the NWT analysis: one set of relatively low objectives (with a relatively high risk of species loss) and one set of higher objectives (with a lower risk of species loss). The PAS Steering Committee decided to use initial measurable objectives for all conservation features that, when applied together, would add up to approximately 30% of the total land area of the NWT. These were the relatively low objectives (the relatively high risk option). They were chosen because they result in less total land area being selected. It was recognized that the objectives totalling 30% are useful for helping to identify potential core representative areas, but at the low end of recommendations (Table 1). It was also recognized that 30% land protection alone is not sufficient for the maintenance of all species and ecosystems in the long term. It is assumed that the landscape outside of protected areas will be managed to retain some ecological values.

From a conservation perspective, the initial PAS 30% objective is better than many policy-driven objectives in that it is closer to the 30.6% and 41.6% objectives Svancara *et al.* (2005) found in their review. With that said, the PAS 30% objective is not rooted in real or modeled data on NWT species or systems, as that type of information is not currently available. Based on information from similar systems, however, we do know that many species in the NWT require more than 30% of the landscape to maintain viable populations. This is especially true for those species that are migratory or that have large home ranges.

The NWT protected areas network, once established, will exist within a matrix of other land uses, but the exact types and spatial distribution of those land uses is unknown. What is known is that much change is coming to the landscape. Land uses outside protected areas will greatly influence their integrity and determine the degree of success in meeting the qualitative goals of the PAS. Schmiegelow *et al.* (2006) have proposed the “reverse-matrix model,” a proactive conservation-planning model in which protected areas are ‘no-go’ zones within a matrix of land uses that sustain ecological integrity. A variety of land uses can still occur in this matrix, but will be regulated based on certain thresholds on development. This type of conservation matrix is not yet in place for the NWT, but may be achieved through regional land use planning initiatives and the regulatory process.

Given the uncertainties, we recommend that 30% be viewed as a minimum objective. We also emphasize that objectives can easily be changed and the Marxan tool can and should be used to explore different objectives and scenarios.

Proportional representation objectives for all conservation features were adopted to achieve the 30% total objective. This means that objectives are higher for small or relatively rare conservation features. Protecting a larger portion of small or rare features minimizes edge effect and helps ensure resilience of rare ecosystems. The proportional representation objectives are discussed further in section 4.4.2 and Table 4. We set these objectives to run Marxan, and can easily run the program with different objectives to explore different scenarios.

The actual percentage of the land area selected during initial runs of the representation analysis varied from a low of 27.25% to a high of 36.6% of the landscape depending on what other variables we included (e.g. if areas selected by communities through the PAS were to always be selected as part of the representative areas). See section 5 for more information and for one set of results of the analysis for the 16 Mackenzie Valley ecoregions.

4.0 METHODS OF SPATIAL ANALYSIS

The following methods are being applied to all NWT ecoregions. However, only one set of results are reported on here: the 16 ecoregions of the Mackenzie Valley.

4.1 Spatial Stratification

The NWT Protected Area Strategy stipulates that core representative areas be identified for each of the NWT ecoregions (NWT PAS Advisory Committee, 1999). We stratified most conservation features by ecoregion in order to capture multiple examples of those features across the project area. Stratification means that a conservation feature that occurs in multiple ecoregions is treated separately for each ecoregion. For example, a tall shrub vegetation class in a southern ecoregion may support a different suite of biota than a tall shrub class in a northern ecoregion. Therefore, the tall shrub/southern ecoregion class is analyzed independently from the tall shrub/northern ecoregion class, and both must be represented.

To stratify the data, we spatially intersected the landscape unit and land cover datasets with the ecoregions, resulting in a combined conservation feature / ecoregion code. We then assigned representation objectives based on the total area, in hectares, for each new combined code. Physiographic units were not stratified by ecoregion.

4.2 Planning Units

Marxan requires users to define spatially discrete planning units, which can be any shape and size. We divided the project area into a grid of 2,000 ha hexagon-shaped planning units. Hexagonal units minimize the edge to area ratio of the resulting grid. Smaller planning units tend to produce more efficient site selections in terms of total area required to meet representation objectives (Pressey and Logan, 1998; Warman *et al.,* 2004). However, there are limitations to the number of planning units on which Marxan can operate and increasing the number of units significantly increases computing time.

For the 16 Mackenzie Valley ecoregions, a planning unit size of 2,000 ha created a total of almost 29,000 planning units. This number was an effective balance between efficient site selection and software / computing time constraints for this project. Figure 3 illustrates the planning units covering a portion of NWT ecoregions.

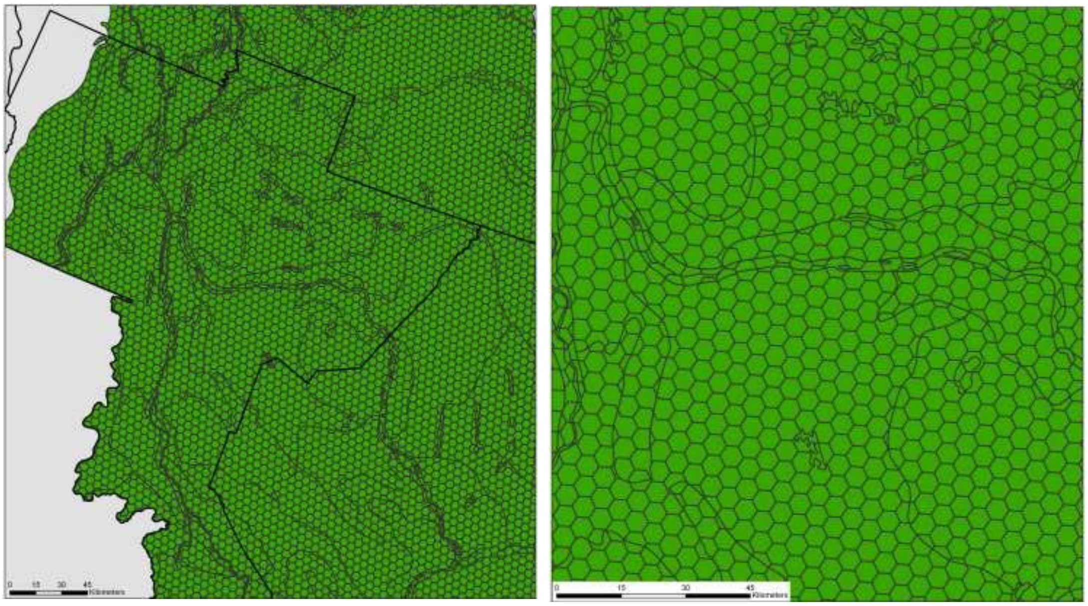

Figure 3. 2,000 ha hexagonal planning units covering a portion of NWT ecoregions.

For the purposes of this analysis, planning units were aligned with the ecoregion boundaries and large water bodies (Arctic Ocean, Great Bear Lake and Great Slave Lake). Some planning units along the boundaries were split and were not exactly 2000 ha. This allowed us to summarize and analyse results by ecoregion, and to easily exclude large water bodies that are not part of the terrestrial representation analysis.

The Marxan analysis requires a summary of the amount of each conservation feature contained within each planning unit. To generate this summary we spatially intersected the planning units with the individual conservation feature datasets and then calculated the total area in hectares of each conservation feature within each planning unit.

4.3 Description and Processing of Input Data

We used three geophysical and biological conservation feature datasets that cover the entire project area (Figure 4, Appendices B and C):

- Physiographic units (areas defined by regional climate, broad landform types, and other factors)
- Landscape units (polygons with similar surficial geology, soil and terrain)
- Land cover (vegetation classes)

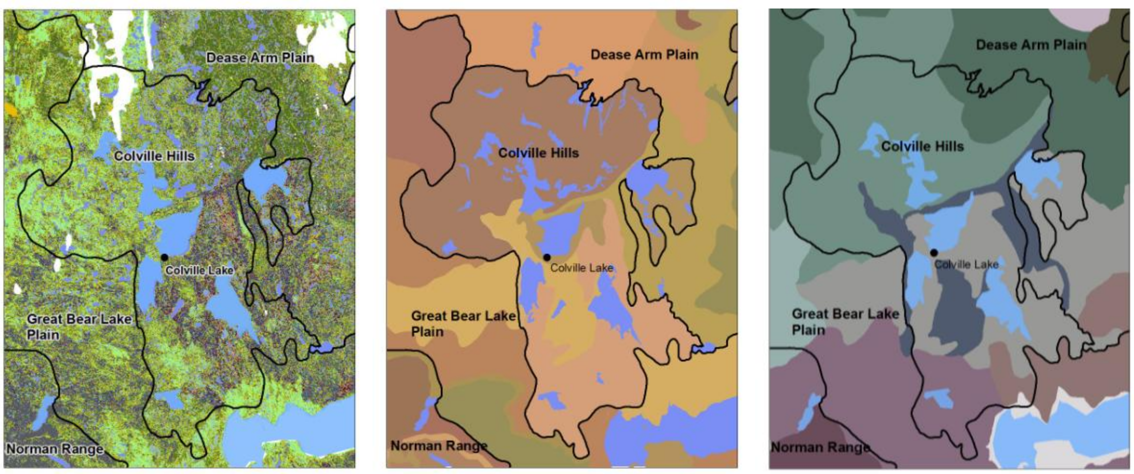

Figure 4. Conservation feature datasets in Ecoregion 54 (Colville Hills). From left to right: land cover (vegetation), landscape units, and physiographic units.

Physiographic Units

The physiographic units we used are the Level IV ecoregions defined by the Ecosystem Classification Group (2007). This dataset is the result of recent revisions to the ecological land classification of the NWT portion of the Taiga Plains ecozone. The revisions are based on regional climate, landforms (including broad landform types, elevation, slope, and aspect), broad similarities in vegetation and soils, and extensive air and ground verification (Ecosystem Classification Group, 2007). The revised Level IV ecoregions are not nested within the old ecoregions (from Ecological Stratification Working Group, 1996) and are generally much smaller than the old ecoregions.

The physiographic unit dataset is useful for a terrestrial representation analysis because landforms, climate and soils are relatively persistent over time. It is particularly useful in this analysis because it includes information on climate and elevation that is not included in the other conservation feature datasets. Using the revised Level IV ecoregions as a physiographic units layer allowed us to make use of the most current and ground-truthed information while still identifying areas representative of the ecoregions from the National Framework for Canada (Ecological Stratification Working Group, 1996) as directed by the PAS Steering Committee.

The physiographic units dataset is at a 1:1 million scale and covers most of the Mackenzie Valley ecoregions except for a small north-eastern portion of ecoregion 35 (Dease Arm Plain) and the coastal area of ecoregion 33 (Tuktoyuktuk Coastal Plain). There are 67 unique physiographic units in the Mackenzie Valley project area. Due to the large size of the physiographic units, most planning units contain only one physiographic unit. Physiographic units were not stratified by ecoregion because they represent revisions of the National Ecological Framework for Canada (Ecological Stratification Working Group 1996) ecoregion boundaries and are neither nested within those boundaries nor do they always line up with them. Therefore stratifying physiographic units using the “old” ecoregion boundaries is not ecologically meaningful.

Landscape Units

The landscape unit classification was developed by the Government of the Northwest Territories’ former Department of Resources, Wildlife and Economic Development (RWED), now Department of Environment and Natural Resources (ENR), and covers all of the NWT. A detailed description of the methods used to classify landscape units can be found in Appendix B.

Landscape units are based on the 1:1 million scale Soil Carbon Digital Database of Canada (Tarnocai and Lacelle, 1996), a dataset of Soil Landscape polygons within the Canadian Soil Information System (CanSIS). CanSIS is part of the National Soils Database of Canada, developed by Agriculture and Agri-Foods Canada (Centre for Land and Biological Resources Research, 1996). In the NWT, Soil Landscape polygons are the smallest unit within the National Ecological Framework for Canada (Ecological Stratification Working Group, 1996) and are nested within the larger units of this framework (ecodistricts, ecoregions, etc).

Landscape units are groupings of Soil Landscape polygons with similar parent material (surficial geology), soil development, soil texture and combined slope and local surface form. Parent material, soil and terrain are relatively stable through time. The landscape unit dataset contains more detailed information on soils and surficial geology than the physiographic unit dataset.

Due to the fairly large size of the landscape units, after intersecting landscape units with planning units, most planning units contained only one landscape unit. While not all landscape units occurred across multiple ecoregions, stratification by ecoregion increased the number of unique landscape unit codes from 153 to 219.

LAND COVER (VEGETATION CLASSES)

We used two sources of land cover data for the analysis: Ducks Unlimited Canada's (DUC) earth cover mapping (DUC 2002; DUC 2003; DUC 2006) and Natural Resources Canada's Earth Observation for Sustainable Development of Forests (EOSD) land cover mapping (Wulder *et al.,* 2004; Natural Resources Canada, 2006). Both are based on Landsat satellite imagery at 25-metre resolution. Appendix C contains a more detailed discussion of how these datasets were processed.

The land cover datasets contain more detailed information on vegetation than the physiographic units. The inclusion of land cover data allows smaller-scale variations in landscapes, reflected in plant communities, to be captured in the representation analysis. It is recognized that species distributions do shift, so the particular species represented in an area may change over time.

The EOSD land cover classification covers the entire NWT, whereas at the time of the analysis the DUC classification covered only portions of 6 ecoregions. We used the DUC data for this analysis where they covered more than 85% of an ecoregion, which was the case for only two ecoregions: 53 (Fort McPherson Plain) and 50 (Mackenzie Delta). If the DUC data covered more than

85% of an ecoregion, but less than 100%, the remaining area was left void of land cover data. We analyzed those areas using only landscape units and physiographic units. For all other ecoregions where DUC land cover data were unavailable or covered less than 85% of an ecoregion, the EOSD land cover data were used (Figure B.1).

The EOSD and the DUC land cover classes differ in level of detail and class descriptions and definitions (e.g. different definitions for open and dense forest, different heights for tall and low shrub), which made it impossible to crosswalk the DUC classification scheme and EOSD legend. Therefore, we treated both classifications as separate input data layers.

The EOSD land cover data lack the detail and intense ground truthing of the DUC data and, as no error matrix is available for the EOSD data, the classification accuracy is unknown. Natural Resources Canada did account for some uncertainty by combining classes that were difficult to distinguish (Wulder and Nelson, 2003). Also of concern were large cloud holes and sections of missing data that might bias the site selection. Nevertheless, in the absence of an alternative dataset at a similar scale, we concluded that using the EOSD data was better than defining representation using abiotic data alone.

Following extensive pre-processing (Appendix C), we excluded large water bodies (Beaufort Sea, Great Bear Lake and Great Slave Lake) from selection by setting their pixel value to “NODATA”. We also excluded classes that were not useful for the terrestrial representation analysis (e.g. cloud and shadow).

Both the DUC and the EOSD land cover classification datasets are at a much more detailed scale than the landscape unit and physiographic units datasets. Rather than generalize the land cover data to a coarser resolution, we decided to keep most of the detail in the land cover classifications where possible and apply a minimum mapping unit of 1.4 hectares in order to eliminate single pixels and very small land cover patches (see Appendix C). Using finer scale data gives us a better chance of representing the variety of plant communities and microhabitats present in the project area. Due to the large size of the planning units relative to the small size of the land cover patches, this generally resulted in numerous land cover classes within each planning unit.

Stratifying the DUC land cover data by ecoregion increased the number of unique land cover class codes from 33 to 59; the EOSD codes increased from 20 to 280.

4.4. Using Marxan To Identify Representative Areas

4.4.1 Marxan and Reserve Selection

Marxan was designed to objectively evaluate project area planning units to identify efficient options for a reserve network, where efficient means holding the area required to meet representation objectives to a minimum. We refer to one set of options for the entire project area (i.e. one set of selected planning units) as a “solution”.

In order for Marxan to find efficient solutions, it must have some basis by which to compare alternate solutions (i.e. combinations of planning units). This is done through the use of a mathematical Objective Cost Function that gives a total cost value for a combination of planning units based on various costs of that combination and a penalty for not meeting representation objectives. The lower the total cost, the more efficient the solution.

The Objective Cost Function as used for this analysis is shown below, followed by a brief explanation of the elements of the cost function. Each element is explained in more detail in section 4.4.2.

Total Cost of Solution = (Planning Unit Cost) + (Boundary Length Modifier x Boundary Length) + (Species Penalty)

Marxan attempts to minimize the total cost of the solution. Planning Unit Cost can be the number of hectares in all planning units selected, or other costs such as economic cost of including the set of planning units in a reserve network. Boundary Length is a cost determined by the total length of the boundary of all planning units selected for the solution, where a fragmented solution will have a higher boundary cost than a compact one. Boundary Length Modifier is optional and determines the importance given to boundary length relative to the other costs. Species Penalty is a cost imposed for failing to meet the representation objectives set on the conservation features.

Marxan finds efficient solutions by implementing a site optimization algorithm called “simulated annealing with iterative improvement”. This involves generating a random collection of planning units as an initial solution, then iteratively selecting and discarding planning units and re-evaluating the cost formula through multiple iterations per run. The objective cost function gives each possible solution a total cost, and allows the software to compare any two solutions to determine which one is better (i.e. lower cost; Ball and Possingham, 2000b).

Different solutions can be generated by varying the inputs to the objective cost function (e.g. increasing or decreasing the boundary length modifier), setting different objectives to assess different levels of risk, including or excluding planning units from selection, or changing other Marxan parameters.

4.4.2 Marxan Parameters

In our analysis, total cost relates primarily to the amount of land identified; more land equals a higher cost. Total cost is also influenced by the fragmentation of the solution. A solution where planning units are scattered throughout the project area has a higher cost than a solution where the selected planning units are clustered together. Marxan attempts to minimize the total cost of the solution by selecting the fewest possible planning units (smallest overall area) needed to meet as many objectives as possible, and by selecting clustered planning units rather than dispersed ones to reduce boundary length. Additional types of “costs” can be used in Marxan but were not used in our analysis.

The values we used for the primary Marxan parameters are summarized in Table 2. We describe the importance of each parameter in more detail in the following sections, as well as why we chose these values for the analysis.

Table 2. Values for Marxan parameters used in the terrestrial representation analysis.

Marxan Parameter	Value
Planning unit cost	Size of planning unit (in hectares)
Boundary length modifier	0.34
Boundary length	Total length of the boundaries of all areas selected
Species penalty	A penalty applied for not meeting representation objectives; equals 0 when all representation objectives are met, and >0 when some representation objectives are not met
Iterations per run	10 million
Repeat runs	100
Planning unit status	Dependent on scenario
Representation objective	Dependent on relative amount of individual conservation feature

1. PLANNING UNIT COST

We used the size of planning units in hectares as the cost of each planning unit, resulting in roughly the same cost for all planning units. All else being equal, a solution that includes more planning units will have a higher total cost.

In more complex implementations of Marxan the planning unit cost variable can reflect other costs, such as human impact or the cost of resource revenues lost by protecting a particular planning unit. This would cause planning units with lower levels of human impact or lower economic values to be selected over those with higher levels of impact or higher economic value as long as all other factors are equal.

2. Boundary Length Modifier (BLM) and Boundary Length

For a variety of reasons, including management feasibility and ecological integrity, it may be desirable to reduce fragmentation in the representative area selection. For any representative area solution of a fixed size, the lower its total boundary length, the more clustered the solution will be. The BLM is a tool to control the clustering of planning units.

In order to add the boundary length to the cost equation, it is necessary to convert units of boundary length to a different scale that is compatible with other units in the cost equation. The BLM is the multiplier used to accomplish this (Ball and Possingham, 2000b). For example, if a highly clustered result is desired, a BLM value that converts units of boundary to a scale that is greater than the units of planning unit cost should be used (species penalty is ignored here for simplicity). If a result that strongly avoids units with high planning unit cost is desired, a BLM that converts units of boundary to a scale that is less than the units of planning unit cost should be used. If a balance is desired, a BLM that converts units of boundary to around the median of the planning unit cost range should be used.

We used a BLM of 0.34, which converts the units of boundary length to around the median of the planning unit cost range. In this way, the amount of conservation feature in the planning unit can drive the solution, which leads to results that meet all representation objectives without significant over-representation of conservation features. However, this results in a somewhat more fragmented solution.

3. SPECIES PENALTY

Species penalty is a cost imposed for failing to meet the representation objectives set on the conservation features (Ball and Possingham, 2000b). The penalty is based on the principle that if a conservation feature is not fully represented, then the penalty should be the cost of the least expensive planning units required to raise that conservation feature to full representation.

The species penalty allows Marxan to evaluate intermediate solutions generated during the iterative improvement process. All else being equal, a selection of planning units that does better at meeting the representation objectives has a lower cost. When all representation objectives are met, the species penalty cost is zero and differences in total cost reflect differences in amount of land selected (area) and fragmentation (boundary length).

In some instances, the addition of planning units to fully meet representation goals may increase the cost of the solution more than the gain in penalty reduction. This can result in representation objectives not being met. In such cases, the species penalty can be weighted using an optional conservation feature penalty factor (CFPF). If the CFPF is set to a value of > 1, this increases the species penalty cost for not meeting representation objectives. This guides Marxan to seek solutions that maximize representation over solutions that minimize area and boundary cost.

In our analysis, all representation goals were met for scenarios where no areas were locked out of the solution. Therefore, no CFPF needed to be set.

4. NUMBER OF ITERATIONS PER RUN

As described above, Marxan attempts to select the most efficient solution by changing the planning units selected and re-evaluating the objective cost function through multiple iterations per run. The number of iterations determines how long the simulated annealing algorithm will run. It will always come up with a final solution, but the more iterations per run, the more likely it will arrive at a better solution (in terms of lower overall cost). However, if the number of iterations is too large, the amount of improvement for the extra processing time may not be worthwhile. It might be more profitable to increase the number of runs instead (Ball and Possingham, 2000b).

We programmed Marxan to perform 10 million iterative evaluations to identify the minimum cost solution for each simulated annealing run. Performing fewer than 10 million iterations resulted in a fairly fragmented area solution that didn’t improve much even when increasing the BLM. Performing more than 10 million iterations resulted in minimal improvement in clustering, and did not warrant the considerable increase in processing time.

5. REPEAT RUNS

In order for Marxan to find multiple solutions, the iterative process must be carried out multiple times. Marxan was programmed to do 100 repeat runs for each scenario generated. This number of repeat runs is widely used (Rumsey *et al.,* 2004; Conservation Law Foundation and WWF-Canada, 2006; Lieberknecht *et al.,* 2004; Heinemeyer *et al.,* 2003). Marxan calculates a total cost for each run. The best solution out of 100 runs is the one with the lowest cost because a low cost indicates that the area and boundary length are minimized and the objectives are maximized.

6. PLANNING UNIT STATUS

Planning units need to be assigned a status, which determines how Marxan treats them during the analysis.

Regardless of their contribution to meeting representation objectives, planning units can be

- "Locked in" to the analysis (these planning units *must* be selected)
- "Locked out" of the analysis (these planning units *cannot* be selected)
- Free to either become part of the solution or not, in which case their contribution to meeting representation goals plays a significant role.

We ran many scenarios to test the effects of changing various Marxan input parameters and to arrive at the final input parameters used. The scenarios described here are examples of how we can use the Marxan tool for exploring different conservation options. Any planning unit can be locked in or out, depending on conservation or development priorities. For example, we can lock in land use plan conservation zones or lock out mineral development areas. Three of the scenarios that we ran are summarized in Table 3 and described further in section 5.

Table 3. Analysis scenarios

Scenario	Locked In	Locked out
Open	Existing National Parks[2]	None
Closed	Existing National Parks and Areas Proposed for Protection Through the NWT PAS[3]	None
Closed Locked Out	Existing National Parks and Areas Proposed for Protection Through the NWT PAS	Existing and Proposed Oil and Gas Development Areas

7. REPRESENTATION OBJECTIVES

Marxan requires objectives to be set on all conservation features used in the representation analysis. We set proportional objectives for these features (see 3.3.2). This means that small or relatively rare conservation features are represented proportionately more than larger ones. The proportional objectives ranged from 10% to 25% for most features, and 100% for rare and small features (Table 4). The sum of the

[2] Land use plan conservation zones and migratory bird sanctuaries not included.
[3] As of July 1006.

objectives for all features achieved the approximate 30% total area objective across all Mackenzie Valley ecoregions (see section 3.3 for further explanation). In addition, if the representation objective for an individual conservation feature was met by 90% or more we considered it to be fully represented. We made this decision for practical reasons, recognizing that it is difficult to meet the 100% objectives in our project area without capturing very large areas, and that the landscape outside of conservation zones and protected areas will be managed to retain some ecological values.

Table 4. Representation objectives. The actual size range for each category differs between conservation features.

Relative amount of conservation feature	**Percent of conservation feature captured**
Very large	10
Large	15
Medium	20
Small	25
Very small	100

We determined the size categories by summing the total area of each conservation feature in each input data layer (landscape units, physiographic units, DUC land cover data and EOSD land cover data) by ecoregion. For landscape units and physiographic units, we considered those units very small or "rare" if they had a total area of less than 10,000 hectares in any given ecoregion. As the total area of individual land cover classes (in both the DUC and EOSD classifications) within an ecoregion is much smaller than the total area of landscape units or physiographic units, we considered land cover classes with a total area of less than 1,000 ha very small. We classified all other landscape units, physiographic units, and vegetation classes into the remaining size categories using the Jenks natural breaks classification (Jenks, 1967).

We set objectives for all water attributes within the landscape unit and physiographic unit datasets to zero as we felt that water was more accurately captured by the land cover datasets. We adjusted the representation objectives for three DUC land cover classes with a very small total area in ecoregion 50 (Mackenzie Delta) from 100% to 25% in order to prevent these classes from driving the site selection too heavily (see Appendix C for more detail). Finally, we set representation objectives for EOSD land cover classes in ecoregions 50 (Mackenzie Delta) and 53 (Fort McPherson Plain) to zero because we used the DUC land cover data for those ecoregions.

4.4.3 Performing a Gap Analysis

Performing a gap analysis is a way to assess how well a specific set of protected areas meet the representation objectives. It allows us to compare different scenarios to our overall goal and to identify which specific conservation features are not being captured in a given scenario. We performed a gap analysis to assess the ability of existing and proposed protected areas to capture representative conservation features within the project area.

For the analysis, we locked all planning units within existing protected areas and current NWT PAS proposals into the solution while locking out all other planning units. When running Marxan in this way, the solution will always be the same, regardless of how many times the scenario is run, so that one run suffices. The purpose of running Marxan on a predefined solution is to generate the Missing Values Table for a specific solution. The Missing Values Table lists all conservation features and shows the degree to which they are represented. The results and a discussion of the gap analysis can be found below in section 5.2.

4.4.4 Marxan Outputs

INDIVIDUAL SOLUTIONS AND BEST SOLUTION

The best solution (out of 100 runs in our analysis) is the one that meets the most representation objectives at the lowest cost, meaning within the smallest possible area and with the shortest total boundary length. The remaining 99 solutions have higher costs. Often a number of solutions are nearly as good as the best one and these can serve as viable alternatives. The alternative solutions usually overlap with the best solution to some degree.

For each individual solution produced by a Marxan run, and for the best run, two tables are generated. The first table is a simple two-column table that lists the planning units that constitute a solution. For each individual run these tables take on the names *_001.txt to *_100.txt, or *_best.txt in the case of the best run, where * is the user-defined name of the scenario. These tables can be linked to a Geographic Information System (GIS) to map the planning units in a solution.

The second table describes how well the individual solutions and the best solution performed in terms of meeting representation objectives for all conservation features. This is referred to as the table of missing values information (Ball and Possingham, 2000b). The tables for each run are named *_mv001.txt to *_mv100txt and the table for the best run is *_mvbest.txt.

Summed Solution

The summed solution table (*_ssoln.txt) contains a list of all the planning units in the project area and the number of solutions in which the planning unit was selected. This table can be linked to a GIS to produce a summed solution map.

Typically, a number of planning units are included in all or nearly all of the solutions (e.g. 100 solutions for our project). These are planning units that probably contain conservation features that cannot be found elsewhere in the project area and one or more representation objectives cannot be met without them. They are sometimes referred to as "irreplaceable" (Ball and Possingham, 2000b; Rumsey *et al.*, 2004; Stewart and Possingham, 2003). Planning units may also be relatively irreplaceable because they contain a high diversity of conservation features. Planning units with the highest irreplaceability are needed as part of the solution, and do not offer much flexibility during site selection. Those that are selected less frequently are more replaceable because the conservation features found within them can also be found within other planning units. These constitute a pool of more replaceable planning units that offer more flexibility in generating a solution. In order to meet representation objectives for all conservation features, not only the highly irreplaceable planning units are required, but also a collection of less irreplaceable planning units.

We built a representative area solution based on the summed solution using a trial and error process. We performed three gap analysis runs locking in planning units selected in more than 26, 28 and 30 solutions and locking out all other planning units. For this analysis, planning units that were selected in 28 or more solutions out of 100 met all representation objectives in both the open and the closed scenario. The dissolved boundaries of the planning units selected 28 or more times can be overlaid onto the summed solution output (Figure 5). This was the preferred way of mapping all results in the sections that follow because it shows areas of varying levels of irreplaceability and the total amount of area required to fully meet representation objectives. It should be noted that a solution generated this way uses more area than the best solution, but it ensures that the irreplaceable planning units are given high consideration and it is less fragmented than the individual solutions.

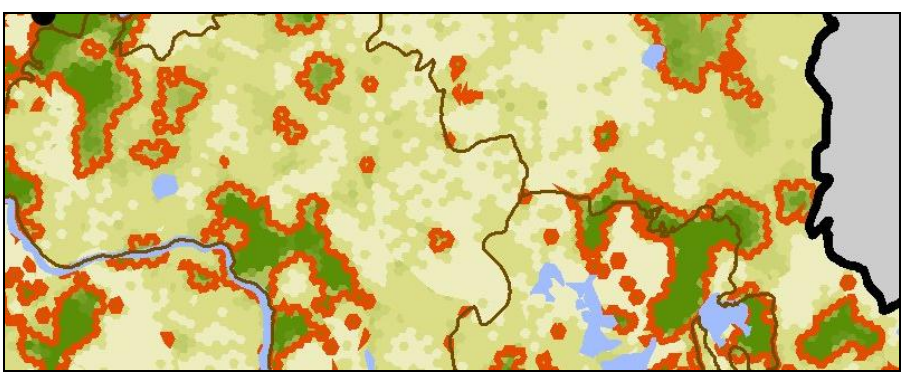

Figure 5. A representative area solution derived from summed solution results. Dark green areas were selected most often out of 100 runs; light green areas were selected least often. The red boundaries contain planning units that were selected 28 or more times, and together fully meet the representation objectives.

5.0 RESULTS

5.1 Comparative Scenarios

One of the advantages of using a site selection tool such as Marxan is the ability to quickly generate comparative solutions. To demonstrate comparative solutions we provide examples below of three different scenarios we ran: open, closed and closed with development locked out (Table 3). Figures 6 and 7 show results of the summed solution. Areas appear in darker shades of green the greater number of times (out of the 100 runs) they were selected as part of the solution. This can be considered a measure of how irreplaceable a particular area might be, indicating that there may be limited options for meeting the objectives for the conservation features it contains. Areas outlined in red are those selected 28 or more times and together fully meet the representation objectives.

On our maps we have called the areas outlined in red "potential core representative areas" because, if kept intact, they would do a good job of capturing landscape diversity at a coarse scale. However, it is important to note that the results are based on representation only. Marxan makes no assumptions about how an ecosystem works, and it is not designed to include minimum protected area size or connectivity. Where the areas selected by Marxan are dispersed or fragmentary, but it is not possible to protect all the land, there may be a trade-off between representation and ecological integrity. It is the task of those involved in protected areas planning to evaluate these options and to make decisions about trade-offs.

5.1.1. Open Scenario

The open scenario allows us to determine which areas within the Mackenzie Valley ecoregions would be required for meeting representation objectives for all conservation features using the least amount of area, with only moderate fragmentation. Only planning units within existing National Parks were locked into the solution. Because only portions of two National Parks exist within the 16 Mackenzie Valley ecoregions, most planning units in the project area had an equal chance of being included in the solution. This solution is only possible if the project area is unconstrained by any current or proposed land uses, therefore it is not usually a realistic scenario.

The summed solution output based on planning units selected 28 times or more resulted in approximately 12,638,100 ha or 27.25% of the project area being selected (Figure 6).

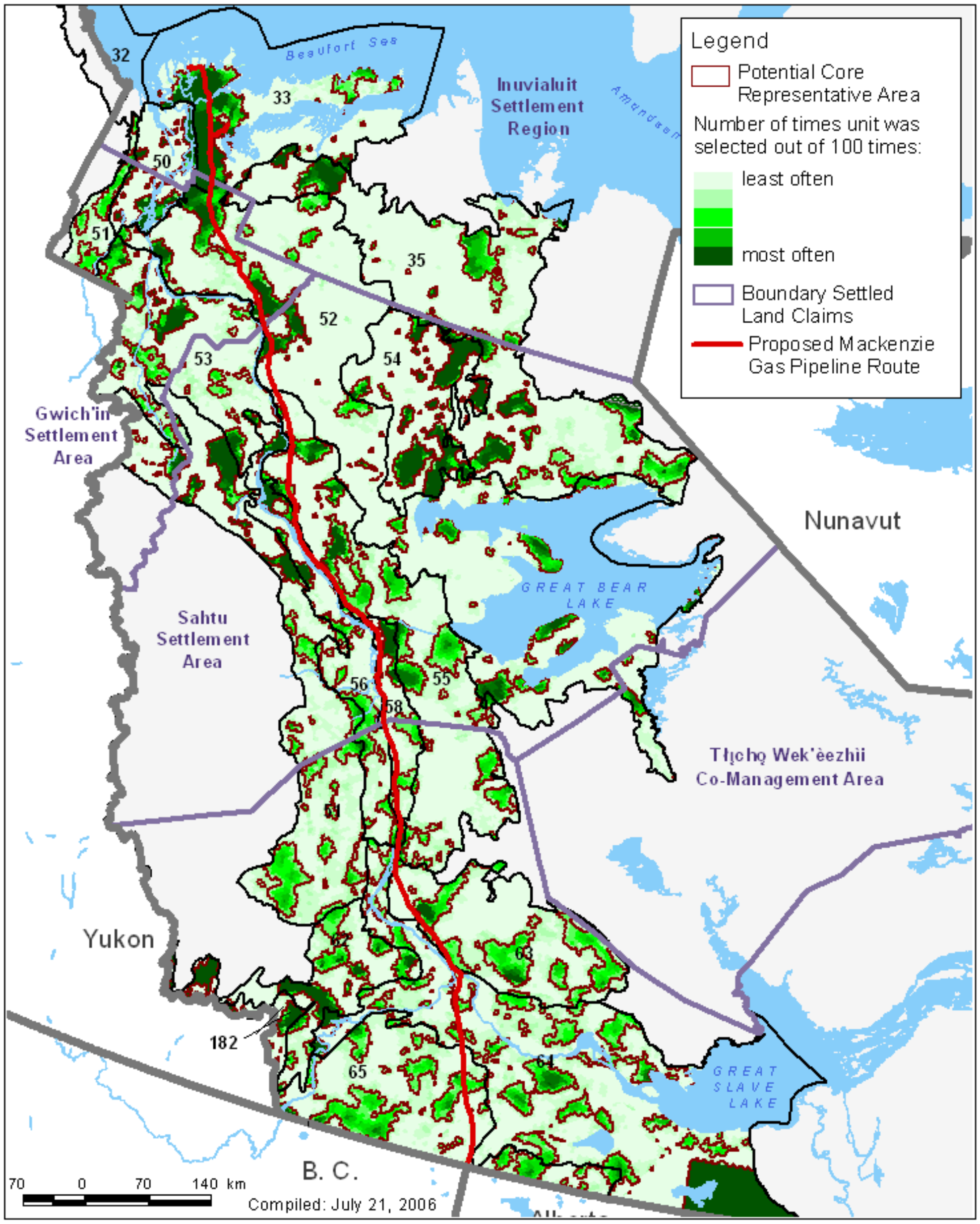

Figure 6. Open scenario – summed solution output based on planning units selected in 28 or more out of 100 runs.

5.1.2. Closed Scenario

NWT communities have already put forward numerous proposals of areas they want to protect under the Protected Areas Strategy. Because these areas will contribute to meeting ecological representation objectives, locking them into the solution produces a more realistic scenario and demonstrates how both traditional and scientific knowledge can work together.

We ran a closed scenario to identify which areas would be required to meet representation objectives in addition to existing protected areas and PAS proposals. In this scenario we locked both National Parks and PAS proposals into the solution. For a closed scenario all planning units that are locked in are forced to become part of the solution, regardless of how well they contribute to meeting representation objectives. Planning units outside of the locked in areas are only selected if they include conservation features for which the locked in areas alone cannot meet the objectives. The result uses more area than the open scenario and some conservation features may exceed their representation objectives.

For the closed scenario, the summed solution output based on planning units selected 28 times or more resulted in approximately 16,983,700 ha or 36.6% of the project area being selected (Figure 7), 9.35% more than for the open scenario.

The solutions for both the open and closed scenarios can be compared to see how the closed scenario results are being driven by land-use decisions.

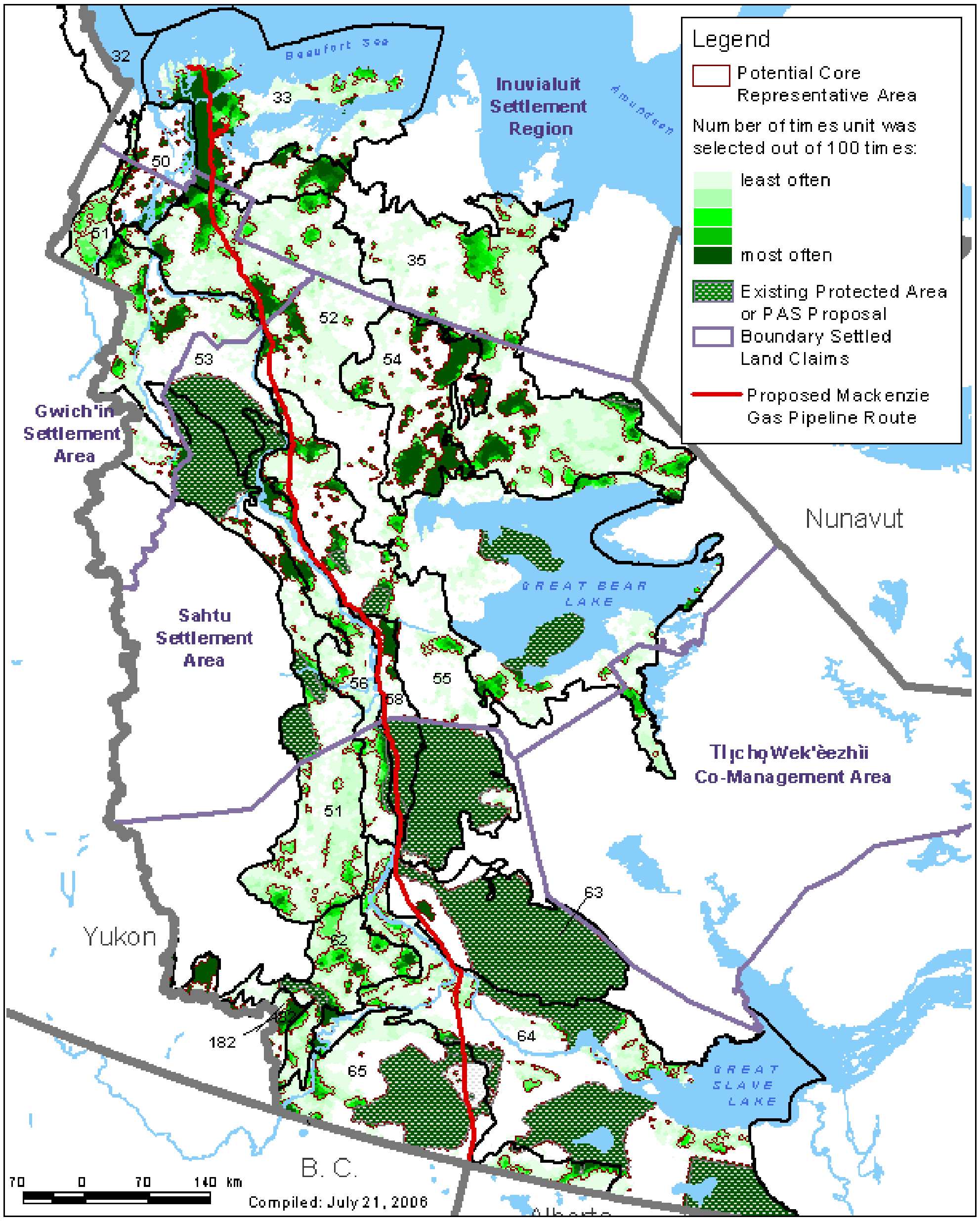

Figure 7. Closed scenario – summed solution output based on planning units selected in 28 or more out of 100 runs.

5.1.3. Closed Locked Out Scenario

We ran a scenario to determine how well representation objectives could be met when development areas related to the proposed Mackenzie Gas Pipeline were excluded from representative area selection. In this scenario we locked in the existing National Parks and NWT PAS proposals, and we also locked out oil and gas leases (production licences and significant discovery licences) as well as the 1 km wide proposed Mackenzie Gas Project corridor.

The mapped summed solution results for this scenario look similar to those for the closed scenario in Figure 7. To determine what effect locking out development areas had on our ability to meet the representation objectives, we performed a gap analysis whereby we took the results from the summed solution and locked in the areas selected in 28 or more of the 100 runs, then locked out all other planning units. This allowed us to create a Missing Values Table of the conservation features showing how well they met their representation objectives in this solution.

Table 5 lists the conservation features for which representation objectives can no longer be met when the pipeline corridor and significant discovery and production licenses are locked out. Figure 8 shows the seven ecoregions (in pink) where representation objectives for some conservation features cannot be fully met.

Table 5. Conservation features for which representation objectives can no longer be fully met when oil and gas development areas are locked out.

Ecoregion	**Conservation Feature Type**	**Conservation Feature Name**[4]	**Percent of Objective Met**
33 Tuktoyaktuk Coastal Plain	EOSD land cover EOSD land cover	Broadleaf open Wetland treed	84 69
50 Mackenzie Delta	landscape unit DUC land cover	C.T.m.m Dwarf shrub other	89 88
55 Norman Range	landscape unit EOSD land cover	L.T.f.w Mixedwood dense	66 36
56 Mackenzie River Plain	EOSD land cover	Rock/Rubble	80

[4] Definitions of these conservation features can be found in Appendices B and C.

58 Franklin Mountains	EOSD land cover EOSD land cover	Herbs Wetland herb	28 82
64 Hay River Lowland	landscape unit	C.M MP.MP m.f m.m	42
182 Hyland Highland	EOSD land cover	Wetland shrub	84

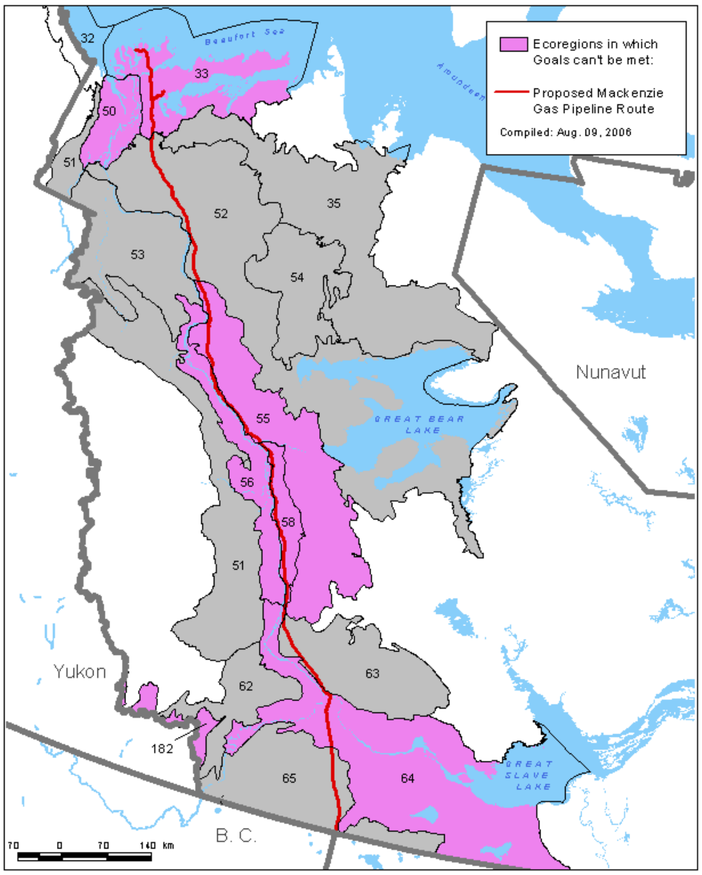

Figure 8. Ecoregions where representation objectives cannot be fully met when oil and gas development areas are excluded from selection.

As explained in section 4.4.2, when Marxan does not meet the representation objectives for particular conservation features, the conservation feature penalty factor (CFPF) can be increased for those features. In this scenario, however, increasing the CFPF would have no effect. With the oil and gas development areas locked out, representation objectives for several infrequently occurring conservation features can no longer be fully met because there is not enough remaining area of these features available for selection. This underscores the sense of urgency to protect areas within the Mackenzie Valley before more representation opportunities are lost.

5.2 Gap Analysis

We performed a gap analysis of existing protected areas and PAS proposals to determine how well these areas meet representation objectives for all conservation features.

36% of all physiographic units are fully represented (i.e. 90% or more of the representation objective is met)[5]. Objectives are met for all land cover features and most landscape units in ecoregion 63 (Horn Plateau) because one PAS proposal, the Edéhzhíe Candidate Protected Area with Interim Protection, covers this ecoregion almost entirely. For all other ecoregions, the existing protected areas and current PAS proposals alone do not fully meet all representation objectives, so that additional areas will be required in those ecoregions (Table 6).

[5] Physiographic units are not stratified by ecoregion.

Table 6. Contribution of existing protected areas and NWT PAS proposals to meeting representation objectives for landscape units and land cover classes in the Mackenzie Valley ecoregions.

	Percentage of features with representation objective 'fully' met (i.e. >90% met)	
Ecoregion	**Landscape Units**	**Land cover classes**
32 Yukon Coastal Plain	0	0
33 Tuktoyaktuk Coastal Plain	0	0
35 Dease Arm Plain	0	0
50 Mackenzie Delta	0	0
51 Peel River Plateau	25	26
52 Great Bear Lake Plain	20	21
53 Fort McPherson Plain	33	48
54 Colville Hills	0	0
55 Norman Range	37	61
56 Mackenzie River Plain	18	22
58 Franklin Mountains	40	63
62 Sibbeston Lake Plain	0	0
63 Horn Plateau	93	100
64 Hay River Lowland	33	61
65 Northern Alberta Uplands	42	61
182 Hyland Highland	0	0

6.0 DISCUSSION

We derived the representative area solutions from the summed solution (planning units selected in 28 or more of the 100 solutions). These require more area on the ground than the best solution. However, the summed solution identifies irreplaceable units that are required for a solution to meet representation objectives. This information allows us to clearly evaluate choices between efficiency and capturing a full range of terrestrial representative areas.

Many single planning units or small clusters of planning units were selected in both the best and the summed solutions. On closer inspection of our analysis we found that the selection of these individual and small clusters of planning units was being driven by the land cover classes. This is due to the detailed scale of the land cover patch size relative to the size of the planning units. Attempts to try to clean up the results so that individual planning units would not be selected were unsuccessful. This suggests that those planning units contained land cover classes that occur less frequently in the landscape and were therefore required to meet representation objectives. Lowering the representation objectives for rare land cover classes may produce less fragmentary results.

Marxan makes no assumptions about how an ecosystem works. Therefore, in making decisions about the size and configuration of protected areas, it is important to consider that the ecological representation solution that uses the least amount of area is not always the one that makes the most ecological sense. We know from conservation science that the size and connectivity of protected areas are important in protecting biodiversity over the long term (Wiersma *et al.,* 2005). People involved in the conservation planning process must decide whether such considerations are more or less important than including individual planning units required for fully meeting the representation objectives. In some cases, a trade-off between ecological representation, efficiency and ecological integrity may need to be made. For example, if the elements we wish to represent are dispersed throughout an ecoregion, it may be more ecologically meaningful to capture most of those features in one large protected area (and accept that a few features will not be represented) than to capture all features in several small protected areas.

Many of the common conservation features are found in multiple locations throughout the project area. Because of the extensive spatial distribution of these features on the landscape, Marxan can find multiple solutions for a given set of conservation features and objectives. However, in any particular solution, all planning units selected are complementary, and together they fully meet the representation objectives. When using the results to explore conservation options, it is important to remember that each piece of the solution is part of the whole.

Marxan will always try to select the most efficient solution to meet the representation objectives. It should be used as a decision-support tool that can help identify various options based on ecological, social, or economic criteria that are fed into Marxan. In this analysis, the only criteria we specified involved representing a certain percentage of the different landscape units, physiographic units, and land cover classes. Coarse filter representation results alone should not define the protected area network; rather, people involved in protected areas planning should use the results together with other information and values that are important to all stakeholders on the ground and make decisions accordingly. These other kinds of information include, but are not limited to:

- traditional knowledge;
- information on special natural and cultural areas, many of which have already been identified for protection by NWT communities and land use planning boards;
- development interests, since the NWT PAS states that wherever possible, protected areas proposals for core representative areas will give priority to areas of low commercial value (NWT PAS Advisory Committee 1999);
- fine filter information, including special elements and focal species; and
- other information described in section 8.

The results presented here are driven by the data and criteria described in this report and we recommend that they be interpreted as such. As new and updated data become available, this information should be included to continually improve upon the results presented here.

7.0 CONCLUSION

The Northwest Territories Protected Area Strategy recognizes the need to protect special natural and cultural areas important to the people of the NWT and the need to apply methods of conservation science to protect core representative areas in each ecoregion of the NWT (NWT PAS Advisory Committee, 1999). Regional-scale conservation planning has been shown to be more effective at protecting biodiversity over the long-term than site-by-site methods of identifying areas for protection (Margules and Pressey, 2000). Protecting core representative areas assists us in planning and managing for the maintenance of viable populations and functioning ecosystem processes.

We have provided terrestrial coarse filter representation analyses for several proposed protected areas being put forward by communities, including Edéhzhíe, Edaiila, Ka'a'gee Tu, and Pehdzeh Ki Ndeh (see www.nwtpas.ca for a map of these areas). We offer to work with regional land use planning boards during the design and review phases of their land use plans, and have completed analyses for the Gwich'in and Sahtu Land Use Planning Boards showing how their conservation zones or draft conservation zones contribute to ecological representation. A presentation by the Government of the Northwest Territories to the Mackenzie Gas Project Joint Review Panel (www.jointreviewpanel.ca) identified potential core representative areas and gaps in the protection of ecoregions, and described the effect of the proposed pipeline on ecological representation in the Mackenzie Valley.

Information from the terrestrial coarse filter representation analyses should not be used in isolation. It should be used along with information on other values to help identify and refine boundaries for protected areas.

Our initial results demonstrate that computerized site selection tools can be used in the NWT to help evaluate conservation options and make well-informed decisions. We are available to create additional, customized scenarios with modified objectives using different areas locked in or out of the solutions. These scenarios should be used throughout the planning process to support decisions in implementing protected areas in the Northwest Territories.

8.0 NEXT STEPS

The methods presented in this report describe the terrestrial coarse filter representation analysis. Other types of information are also being developed to help identify core representative areas. These other types of information are summarized below and may be the subject of future reports.

8.1 Representation of Freshwater Systems

The terrestrial coarse filter representation analysis captures limited aspects of freshwater diversity (e.g. presence of lakes; some wetland types). A hierarchical hydrography classification is being developed that will serve as the foundation for a freshwater representation analysis. The classification describes the regional patterns of environmental conditions that influence freshwater ecosystems and biotic patterns, such as geology and elevation within catchments, and will help to identify a broad range of freshwater habitats. It will also have ongoing utility for freshwater and fisheries planning and management.

8.2 Fine Filter and Focal Species Analyses

Some important species, habitats and natural processes may not be captured through "coarse filter" representation analyses, so a combination of coarse filter and fine filter approaches is recommended (see section 2 for a discussion of this). Two types of "fine filter" information are being examined:

- Special elements – These are unique, rare, and sensitive features on the landscape. We are compiling available mapped information on a variety of special elements including rare plants, karst topography, thermal springs, mineral licks and NWT key migratory bird Terrestrial Habitat Sites. A map of important wildlife habitat areas is being developed by Environment and Natural Resources.

- Focal species habitat – Comprehensive habitat maps for most NWT species do not exist. We will investigate if developing habitat models for certain species would be helpful in fulfilling the goals of the PAS.

Traditional knowledge plays a large role in the identification of protected area proposals in the NWT. Some special elements and focal species habitats are identified through traditional knowledge. Traditional knowledge can also include aspects of ecosystem functioning.

Many special elements and focal species are already being considered in the protected areas proposals that communities have put forward. For example, boreal woodland caribou habitat and a NWT key migratory bird terrestrial habitat site were both important reasons behind the identification of the Edéhzhíe Candidate Protected Area. We will investigate what elements and species still need to be targeted and how this can best be done. Information on what communities value will help with this process.

8.3 Ecological Benchmarks

The Mackenzie Valley Five-Year Action Plan calls for protected areas to serve as benchmarks, which provide ecological baselines that increase our understanding of natural systems and act as controls within an adaptive management framework (NWT PAS Secretariat, 2003). Implicit in this is the assumption that protected areas protect functioning ecosystems and maintain ecological integrity, regardless of the impacts of natural or human-induced change within the protected area or the surrounding landscape. This will require careful consideration of the size and relative location of the various NWT protected areas. We are working with the University of Alberta BEACONs project to develop recommendations for benchmark protected areas in the NWT.

8.4 Climate Change

The impacts of climate change are magnified in the north and are already being felt by northern communities. Numerous Aboriginal communities and scientists have documented changes in recent decades. While both science and traditional knowledge confirm that climate change is occurring, we don't know exactly how this will affect wildlife and ecological systems. However, there is information that helps to project likely vegetation, permafrost and habitat changes over the next 100 years or more in the NWT. We are working with climate change experts to develop this information and make recommendations for designing the NWT protected areas to be as resilient as possible to the impacts of climate change.

8.5 Protected Area Networks

While the PAS calls for a network of protected areas and outlines some parameters (e.g. that each ecoregion in the NWT should have a "core representative" protected area; NWT PAS Advisory Committee 1999), some uncertainty remains about how individual protected areas will or will not be knit together in a “network”. Central to this question are the theories of ecological connectivity, protected area size and reserve replication. A briefing paper has been drafted for the PAS Steering Committee to summarize the current scientific literature on ecological connectivity and reserve design, outline how other jurisdictions have defined and designed protected areas networks, and frame all the information in the context of the NWT and its northern environment.

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APPENDIX A.

Defining Core Representative Areas

The Protected Areas Strategy (NWT PAS Advisory Committee 1999) provides the following direction on what core representative areas are:

- Core representative areas contribute to the conservation of the entire diversity of life forms and their habitats in the NWT.
- Core representative areas are the backbone of a zoned system of protected areas and have the strictest protection. They lie within less restrictive buffer zones and may be linked with corridors to other core representative areas.
- A core representative area is an area that is part of a network of permanent protected areas that collectively represent all habitats, comminutes, species or other natural features, and thus warrants the highest possible level of conservation protection.
- Resource based development such as mining, logging, hydro-electric projects, agricultural, oil and gas surface work, and associated infrastructure will not be permitted in core representative areas.
- Wherever possible, protected areas proposals for core representative areas will give priority to areas of low commercial value.

The NWT PAS supporting document states that protected areas should be planned and managed to maintain biodiversity and ecological processes. It also states that a protected area should ideally be large enough to incorporate successional stages of habitat and accommodate normal disturbances such as fire; include many types of wildlife habitat and preserve biologically productive and diverse examples of those habitats; maintain self-sustaining land and water systems resistive to environmental changes; and conserve sensitive species and the processes supporting them (NWT PAS Advisory Committee, 1999).

Additional work is needed to fully define which of the above functions a **core representative area** will achieve versus another type of **protected area** or a **network of protected areas**. We are exploring the definition, role and implementation of core representative areas and networks, and what is achievable through the PAS. In this document, a core representative area is defined as “an intact area that best represents the biological diversity of an ecoregion”.

APPENDIX B.

Determining Landscape Units

The Northwest Territories has adopted the National Ecological Framework for Canada (Ecological Stratification Working Group 1996) and the 1:1 million Soil Carbon Digital Database of Canada (Tarnocai and Lacelle 1996), a discrete layer of soil polygons within the Canadian Soil Information System (CanSIS; Centre for Land and Biological Resources Research 1996), as the basis for determining landscape units. Soil polygons in the CanSIS database can contain up to nine different components, which are described in the database but not mapped. Components differ in one or more of their characteristics, or attributes. One or more components and their attributes can be used to describe different soil polygons.

Some jurisdictions (e.g. Manitoba, Saskatchewan) use only the single largest soil polygon component and relevant attributes to describe each polygon (Watkins *et al.* 1994; Beveridge *et al.,* 1998). In many cases this means that the characteristics of a component comprising less than 30% of a polygon may be used to actually describe that polygon. The approach used by World Wildlife Fund Canada (WWF), as part of its Endangered Spaces Campaign, requires that one or more components comprise at least 75% of the soil polygon in order to describe the polygon (World Wildlife Fund 1995).

Northwest Territories uses 65% component coverage and four attributes - parent material, soil development, texture, and topography (slope and local surface form combined) to describe soil polygons as unique landscape units believed to be best correlated with biodiversity. Northwest Territories has followed WWF's approach to group texture classes, and on the advice of CanSIS staff has combined classes for slope and local surface form.

Examples of soil polygon descriptions that use one, two or three components and which comprise 65% or more of a soil polygon are presented in Table B.1; every soil polygon description is linked to an identical corresponding landscape unit.

Table B. 1 Examples of soil polygon descriptions

# of Components equal to at least 65% of a polygon	Soil Classification Code	Key to Soil Classification Codes
1	**A/R/f/w**	A = alluvial, R = regasolic, f = fine texture, w = weakly broken
2	**M.L/5.F/m.f/w.vw**	M.L = morainal and lacustrine, 5.F = brunosolic turbic cryosolic and grey luvisolic, m.f = medium or fine texture, w.vw = weakly or very weakly broken
3	**A.M.B/M.F.Y/m.f.-/w.w.vw**	A.M.B = alluvial, morainal and bog, M.F.Y = eutric brunisolic, grey luvisolic and mesisol, m.f.- = medium or fine, or no texture (for organic soils), w.w.vw. = weakly or very weakly broken

APPENDIX C.

Land Cover Data

1. Ducks Unlimited Canada – Earth Cover Classification Scheme

Areas covered by DUC earth cover data at the time of analysis are shown in Figure C.1. The DUC earth cover classification scheme is outlined in Table C.1. Although the classification scheme included a relatively detailed level of classes, it was anticipated that not all the observed classes could actually be mapped in the final classified images. The cost of collecting an adequate number of field sites required to map all classes at the most detailed level was far beyond the budget of the projects. Also, the inherent limits of the TM sensor often do not allow for this level of vegetation discrimination. Therefore, it was assumed that some of the observed classes would be “rolled up” through the hierarchical classification scheme and combined into more general mapped classes based on their spectral separability and the number of field sites collected for each class. For more background on the development of the DUC earth cover classification scheme, see for example "Middle Mackenzie Project Earth Cover Classification User's Guide" (Ducks Unlimited, Inc. 2006).

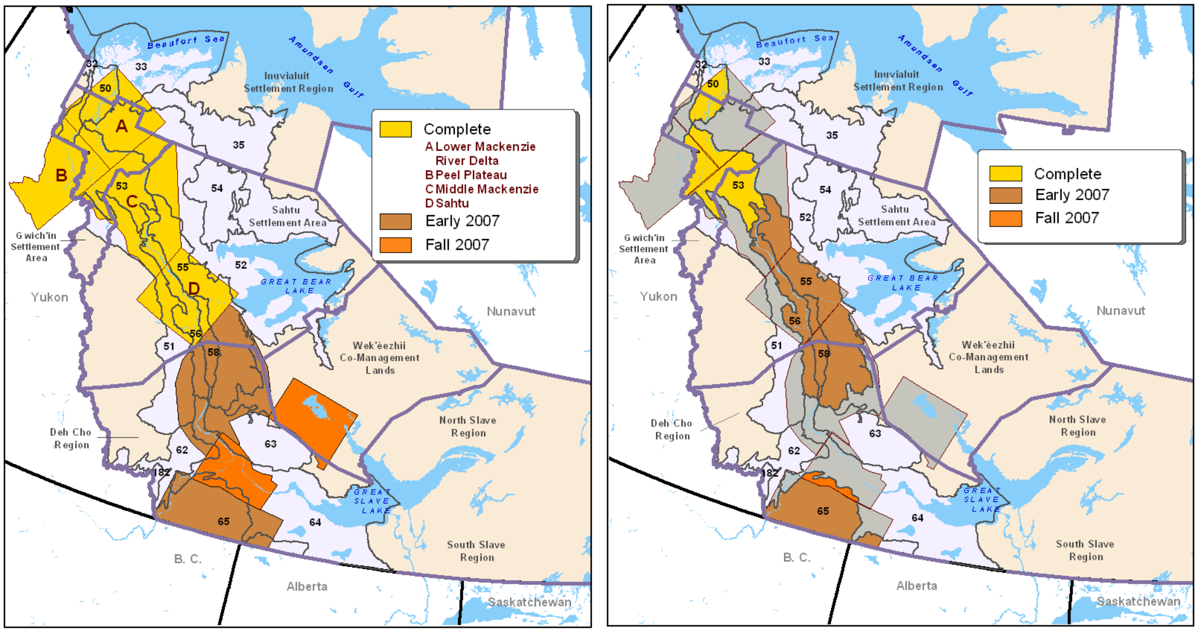

Figure C. 1 DUC Earth Cover classification projects in the NWT (left) and ecoregions with more than 85% DUC coverage (right)

Table C. 1 Middle Mackenzie earth cover classification scheme

Level II	Level III	Level IV	Level V
1.0 Forest	1.1 Closed Needleleaf (NL)	1.11 Closed Spruce	
		1.12 Closed Pine	
		1.13 Closed Tamarack	
		1.14 Closed Fir	
		1.13 Closed Mixed Needleleaf	
	1.2 Open Needleleaf	1.21 Open Spruce	1.211 Open Spruce / Lichen
			1.212 Open Spruce / Moss
			1.213 Open Spruce / Other
		1.22 Open Pine	1.221 Open Pine / Lichen
			1.222 Open Pine / Moss
			1.223 Open Pine / Other
		1.23 Open Tamarack	1.231 Open Tamarack / Lichen
			1.232 Open Tamarack / Moss
			1.233 Open Tamarack / Wet Graminoid
			1.234 Open Tamarack / Other
		1.24 Open Fir	1.2.41 Open Fir / Lichen
			1.2.42 Open Fir / Moss
			1.2.43 Open Fir / Other
		1.25 Open Mixed Needleleaf	1.251 Open Mixed Needleleaf / Lichen
			1.252 Open Mixed Needleleaf / Moss
			1.253 Open Mixed Needleleaf / Other
	1.3 Woodland Needleleaf	1.31 Woodland Needleleaf / Lichen	
		1.32 Woodland Needleleaf / Moss	
		1.33 Woodland Needleleaf / Other	
	1.4 Closed Deciduous	1.41 Closed White Birch	
		1.42 Closed Aspen	
		1.43 Closed Poplar	
		1.44 Closed Mixed Deciduous	
	1.5 Open Deciduous	1.51 Open White Birch	
		1.52 Open Aspen	
		1.53 Open Poplar	
		1.54 Open Mixed Deciduous	
	1.6 Closed Mixed NL/Deciduous		
	1.7 Open Mixed NL/Deciduous	1.71 Open Mixed NL/Deciduous Lichen	
		1.72 Open Mixed NL/Deciduous Moss	
		1.73 Open Mixed NL/Deciduous Other	
2.0 Shrub	2.1 Tall Shrub	2.11 Closed Tall Shrub	
		2.12 Open Tall Shrub	2.121 Open Tall Shrub / Lichen
			2.122 Open Tall Shrub / Moss
			2.123 Open Tall Shrub / Other
	2.2 Low Shrub	2.21 Low Shrub / Tussock Tundra	
		2.22 Low Shrub / Lichen	
		2.23 Low Shrub / Moss	
		2.24 Low Shrub / Willow-Alder	
		2.25 Low Shrub / Herbaceous	
		2.26 Low Shrub / Other	
	2.3 Dwarf Shrub	2.31 Dwarf Shrub / Lichen	
		2.32 Dwarf Shrub / Other	

Level II	Level III	Level IV	Level V
3.0 Herbaceous	3.1 Bryoid	3.11 Lichen 3.12 Moss	
	3.2 Wet Herbaceous	3.21Wet Graminoid 3.22 Wet Forb	
	3.3 Mesic/Dry Herbaceous	3.31 Mesic/Dry Graminoid 3.32 Mesic/Dry Forb 3.33 Tussock Tundra / Other 3.34 Tussock Tundra / Lichen	
4.0 Aquatic Veg.	4.1 Aquatic Bed 4.2 Emergent Vegetation		
5.0 Water	5.1 Snow 5.2 Ice 5.3 Clear Water 5.4 Turbid Water		
6.0 Barren	6.1 Sparsely Vegetated 6.2 Rock/Gravel 6.3 Non-Veg. Soil 6.4 Recent Burn		
7.0 Urban			
8.0 Agriculture			
9.0 Cloud/Shadow	9.1 Cloud 9.2 Shadow		
10.0 Other			

2. EOSD Land Cover Classification

EOSD land cover data (Wulder *et al.*, 2004; Natural Resources Canada 2006) are available for download from ftp://www4.saforah.org (password: eosd4free). The data on this website are in .tif format, split into 1:250,000 National Topographic Database (NTDB) map sheet tiles, and are in UTM projection. A total of 68 map sheets cover the Mackenzie Valley ecoregions that extend into 3 different UTM zones. While EOSD data on the Saforah website are only available for the forested areas of the NWT and extend only to the 68th parallel, further investigation revealed that more data were actually available further north (Morgan Cranny, Acting EOSD Remote Sensing Data and Product Coordinator, Canadian Forest Service, Pacific Forestry Centre, personal communication, March 2nd, 2006). These additional data were made available to us and hence the entire Mackenzie Valley project area was covered except for the very north-eastern tip of ecoregion 35 (Dease Arm Plain).

The .tif files were converted to ESRI ArcInfo Grid format, then tiles belonging to the same UTM zones were merged. The individual merged UTM zones were projected to an Albers Equal Area projection and merged into one dataset covering all of the Mackenzie Valley ecoregions.

Large water bodies (Beaufort Sea, Great Bear Lake and Great Slave Lake) were masked out, meaning their value was set to NODATA, as were classes that were not of interest for the coarse filter analysis (cloud and shadow; Figure C.2).

The EOSD land cover classification scheme is outlined in Table C.2. The same MMU (1.4 ha) as that applied to the DUC land cover classification was also applied to the EOSD data. This resulted in losing EOSD class 223 (broadleaf sparse) in ecoregions 63 and 62. This class occurred only in single pixels and in patches that are so small they may not have been accurate to begin with.

Table C. 2 EOSD land cover classification scheme (Wulder and Nelson 2003)

EOSD Class	Class Description
No Data	
Cloud	
Shadow	
Snow/Ice	Includes glacier, snow, ice
Rock/Rubble	Bedrock, rubble, talus, blockfield, rubbley mine spoils, or lava beds
Exposed Land	River sediments, exposed soils, pond or lake sediments, reservoir margins, beaches, landings, burned areas, road surfaces, mudflat sediments, cutbanks, moraines, gravel pits, tailings, railway surfaces, buildings and parking, or other non-vegetated surfaces.
Water	Lakes, reservoirs, rivers, streams, or salt water.
Shrub - tall	At least 20% ground cover which is at least one-third shrub; average shrub height greater than or equal to 2 m.
Shrub - low	At least 20% ground cover which is at least one-third shrub;

	average shrub height less than 2 m.
Herb	Vascular plant without woody stem (grasses, crops, forbs, gramminoids); minimum of 20% ground cover or one-third of total vegetation must be herb.
Bryoids	Bryophytes (mosses, liverworts, and hornworts) and lichen (foliose or fruticose; not crustose); minimum of 20% ground cover or one-third of total vegetation must be a bryophyte or lichen.
Wetland - Treed	Land with a water table near/at/above soil surface for enough time to promote wetland or aquatic processes; the majority of vegetation is coniferous, broadleaf, or mixed wood.
Wetland - Shrub	Land with a water table near/at/above soil surface for enough time to promote wetland or aquatic processes; the majority of vegetation is tall, low, or a mixture of tall and low shrub.
Wetland - Herb	Land with a water table near/at/above soil surface for enough time to promote wetland or aquatic processes; the majority of vegetation is herb.
Coniferous - Dense	Greater than 60% crown closure; coniferous trees are 75% or more of total basal area.
Coniferous - Open	26-60% crown closure; coniferous trees are 75% or more of total basal area.
Coniferous - Sparse	10-25% crown closure; coniferous trees are 75% or more of total basal area
Broadleaf - Dense	Greater than 60% crown closure; broadleaf trees are 75% or more of total basal area.
Braodleaf - Open	26-60% crown closure; broadleaf trees are 75% or more of total basal area.
Braodleaf - Sparse	10-25% crown closure; broadleaf trees are 75% or more of total basal area
Mixed Wood - Dense	Greater than 60% crown closure; neither coniferous nor broadleaf tree account for 75% or more of total basal area
Mixed Wood - Open	26-60% crown closure; neither coniferous nor broadleaf tree account for 75% or more of total basal area.
Mixed Wood - Sparse	10-25% crown closure; neither coniferous nor broadleaf tree account for 75% or more of total basal area

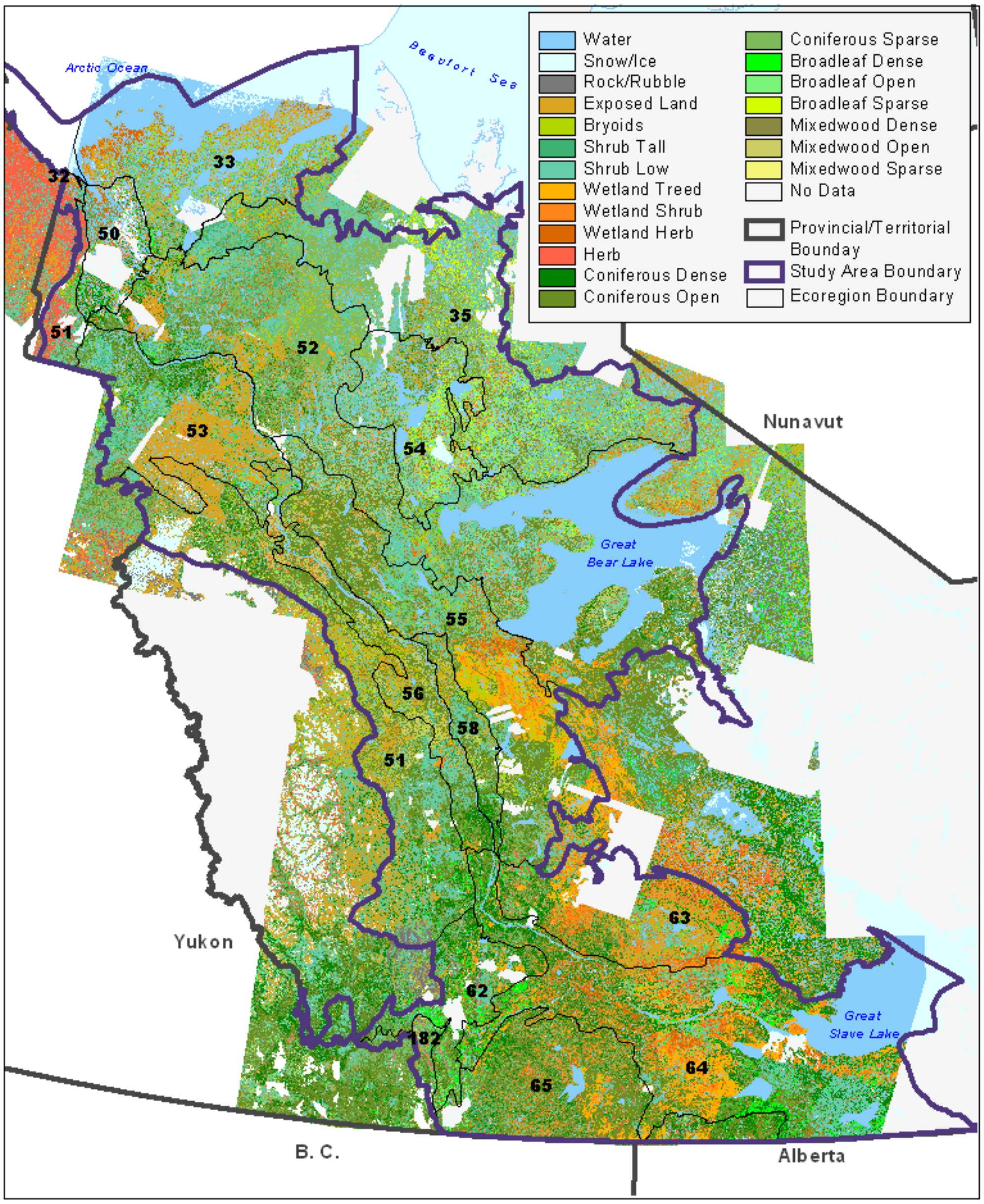

Figure C. 2 NODATA areas in the EOSD Land Cover Classification as of January 2006.

3. Land Cover Data Pre-processing

The DUC earth cover classification available at the time of the analysis consisted of four separate land cover classifications performed at different times, and using imagery acquired on different dates (DUC 2001; DUC 2002; DUC 2003; DUC 2006). The land cover class codes differed for each of the four land cover classifications and the level of detail classified in the different images varied as well. Therefore, the class codes had to be matched and the level of detail collapsed to the lowest level of detail present in any of the four land cover classifications. Following that, the four land cover classifications could be merged into one dataset resulting in a total of 33 land cover classes (Table C.3).

Figure C. 3 DUC land cover classes present in classifications available for this analysis

Value	Land Cover Class
1	Closed Spruce
2	Open Spruce Lichen
3	Open Spruce Moss
4	Open Spruce Other
5	Closed Mixed Needleleaf Deciduous
6	Open Mixed Needleleaf Deciduous
7	Open Mixed Needleleaf Other
8	Closed Deciduous
9	Open Deciduous
10	Woodland Needleleaf Lichen
11	Woodland Needleleaf Moss
12	Woodland Needleleaf Other
13	Tall Shrub
15	Low Shrub Other
16	Low Shrub Lichen
17	Low Shrub Willow/Alder
18	Low Shrub Tussock Tundra
19	Dwarf Shrub Lichen
20	Dwarf Shrub Other
21	Tussock Tundra
22	Tussock Tundra Lichen
23	Lichen
24	Mesic Dry Herbaceous
26	Wet Herbaceceous
28	Aquatic Bed
29	Emergent Vegetation
30	Clear Water
31	Turbid Water
32	Sparse Vegetation
33	Rock/Gravel
34	Non-vegetated Soil
38	Burn
231	Moss

Two different classification methods had been used, which proved problematic. The Lower Mackenzie River Delta (LMRD) and Peel River Plateau classifications, which cover the entire ecoregion 50 and the north-western half of ecoregion 53, were classified using a pixel-based supervised/unsupervised classification method, as was the Sahtu image. The resulting land cover classifications have a very noticeable "salt and pepper" appearance, which results from a large number of single pixel or very small land cover patches. The Middle Mackenzie classification, which covers the south-western half of ecoregion 53, was largely performed using a so-called object-based classifier (eCognition), which resulted in large contiguous land cover patches. A pixel-based classifier was also used to identify additional classes that could not be separated using the eCognition classifier; this added some speckle to the end result. No post classification smoothing filters to remove speckle had been applied to any of the classifications.

The large number of single pixel and small land cover patches presented challenges when using the DUC data in the site selection process, such that the entire ecoregion 50 and north-western half of ecoregion 53 were repeatedly selected. While we initially assumed that the varying levels of detail (land cover classes ranging from level 2 to level 5 of the DUC classification scheme) in the DUC land cover classification were driving the site selection, it later became obvious that the numerous single pixel and very small land cover patches in relation to the 2,000 ha planning units caused all or most of the planning units to be swept into the solution in order to meet representation goals.

DUC image analysts and other image analysis experts advised us to eliminate single and very small groups of pixels as they are more likely to be inaccurate than to represent actual detail on the ground (Ruth Spell, Remote Sensing Analyst, Ducks Unlimited Inc., personal communication, March 2006). After examining various methods available in the GIS software to eliminate single pixels without losing detail (these included applying a majority filter, using other filtering methods such as "Blockmajority", resampling techniques, rolling up the DUC classes to a coarser level and applying a minimum mapping unit (MMU)), we opted for applying a MMU. This allowed us to have control over which information we were losing when removing single pixels and small patches.

We tested various different MMUs and found that when applying a MMU of 16 pixels (1.4 ha), only 3 "rare" land cover classes (open mixed needleleaf other, low shrub willow/alder, emergent vegetation) in ecoregion 50 were still driving the site selection to some degree. Research on MMUs confirmed that it appears to be common practice to use MMUs of 1.5 hectares or larger for land cover classifications based on Landsat imagery. Therefore, we decided to eliminate all land cover patches smaller than 1.4 ha from the DUC land cover classification and to use the remaining patch sizes greater or equal to 1.4 ha in the Marxan analysis. The holes resulting from eliminating patches smaller than 1.4 ha were not filled but left as NODATA.

The goals on the three conservation features mentioned above were lowered from 100% to 25% so that they would no longer drive the site selection. Another possible solution would have been to set the goals for these features to zero and treat them as special elements.