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# A landscape-based protected areas gap analysis and GIS tool for conservation planning.

By  
Antonio Iacobelli, M.Sc.  
Hussein Alidina,  
Angèle Blasutti  
and Kevin Kavanagh, M.Sc.

World Wildlife Fund Canada  
245 Eglinton Avenue East, Suite 410  
Toronto ON Canada  
M4P 3J1

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## **Executive Summary**

Canadian federal, provincial and territorial governments have been committed to completing their terrestrial protected areas systems since 1992, when they signed “A Statement of Commitment to Complete Canada’s Networks of Protected Areas” (WWF-Canada 2003). The National Round Table on the Environment and the Economy recently restated this commitment as a series of specific recommendations in “Securing Canada’s Natural Capital” (NRTEE 2003). Not only is accelerated conservation planning a priority recommendation in the report, it also specifically calls for a national gap analysis program in support of consistent conservation efforts across the country.

Market-based mechanisms, such as forest certification, are creating demands for resource management to include conservation planning that frequently exceeds performance required by government regulations. In particular, requirements for conservation planning under the Forest Stewardship Council (FSC) certification include the identification of High Conservation Value Forests (HCVF) as well as ecosystem protection.

In this paper, we describe the development of a national gap analysis technique to assess the ecological representation of protected areas networks and the translation of the technique into an automated Geographic Information System (GIS) routine to provide a decision-support tool for resource managers and conservation planners. The first part of the paper describes the development of the gap analysis methodology, including a discussion of the 1) development of natural region frameworks, 2) use of “enduring features” of the landscape (i.e., landforms) as geographic units of measure, and 3) conservation criteria used to assess each enduring feature for representation by protected areas.

The second part of this report describes the translation of the conservation criteria into an automated GIS-based gap analysis routine that aims to provide 1) a decision-support tool for conservation groups, industry and government, and 2) clear and explicit decision rules for representation criteria in an interactive GIS environment. Results of the automated gap analysis routine are presented. Benefits and limitations of the approach are discussed within the framework of systematic conservation planning.

## **1. Introduction**

### **1.1 Background**

The academic, resource management and environmental not-for-profit communities have arrived at a consensus of sorts on a few basic points regarding biodiversity conservation: it is best to plan over relatively large spatial areas (Groves et al. 2002); biodiversity protection requires identifying key habitats for strict protection as well as good management in intervening landscapes (NRTEE 2003, Margules and Pressey 2000); and the process of conservation planning needs to be scientifically defensible and rigorous (Noss 2003). These principles are embodied in the ecoregional conservation planning approach described by Margules and Pressey (2000) and Groves et al. (2000).

We describe a gap analysis methodology to assess the ecological representation of a core terrestrial reserve network based on physical habitat types as a surrogate for the distribution of biodiversity. An existing protected areas network or any number of scenarios for future protection can be tested against the conservation criteria of the representation assessment. We offer this landscape-based gap analysis method as an automated GIS tool to inform ecoregional conservation planning by testing reserve design options that have been developed by multi-criteria methods, such as overlay approaches, High Conservation Value Forest<sup>1</sup> assessments, or site-selection algorithms. In fact, the automated gap analysis routine can be used in real-time conservation planning in workshop settings since it often takes as little as 15-30 minutes to complete an assessment at the scale of one or more ecoregions. Furthermore, the data required for the assessment are readily available through the internet.

Much of the conceptual and technical development of the landscape-based gap analysis method occurred during WWF's *Endangered Spaces* campaign, which had a specific goal to adequately represent each of Canada's terrestrial natural regions in a system of ecologically representative protected areas by the year 2000, and marine and Great Lakes systems by 2010. Although the ten-year *Endangered Spaces* campaign concluded in July 2000 short of the overall goal<sup>2</sup>, it was successful in helping establish an additional 40 million hectares of protected areas across Canada. WWF's most recent assessments of progress published in *The Nature Audit*, show that few jurisdictions have yet achieved even 40% of representation targets.

Since government commitments to complete protected areas networks are yet to be fulfilled, there is a continuing requirement to be able to monitor the conservation status and ecological contribution of existing and proposed protected areas. The gap analysis technique originally developed as a method to measure progress towards the *Endangered Spaces* goal has been translated into an automated GIS routine to provide a decision-support tool for resource managers and conservation planners.

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<sup>1</sup> High Conservation Value Forests (HCVF) are defined by the Forest Stewardship Council and include many elements of core reserve identification, such as special elements, critical habitat of focal species, and intact landscapes.

<sup>2</sup> WWF's protected areas efforts in terrestrial and marine/freshwater ecosystems continue under different programs.

This paper is written in two parts:

- conservation science basis and development of a landscape-based gap analysis methodology during the *Endangered Spaces* campaign, and
- translation of the gap analysis methodology into an automated GIS tool.

## 1.2 Protected Areas

It is widely accepted that a vital strategy for biodiversity conservation is a connected network of conservation areas (Soule 1991). Considerable effort has focused on the required size and configuration of protected areas networks, as well as the level of protection required to maintain biodiversity. Less attention has been paid to what constitutes a completed system, and how progress toward an ecologically representative network can be assessed.

For the purposes of this paper, protected areas are the core component of a conservation network with the strictest level of protection, such as national parks and ecological reserves, for which industrial resource use is prohibited. Selection criteria for these core reserves need to reflect their role as key areas for biodiversity conservation (DellaSala et al. 2001). They also serve as ecological benchmarks, or reference areas, to assess management effectiveness and evaluate progress in achieving outputs for other land use categories under more intensive management regimes. As ecological benchmarks, protected areas serve a critical role for the purpose of improving our incomplete understanding of ecosystem function. Insisting that we can manage resources and manage impacts of our activities through a reactive regulatory system, in the absence of protected areas, is simply too great a risk to biological diversity and human well-being over the long term.

Protected areas also serve to maintain cultural values such as traditional activities and recreation. The focus in this report, however, is the role of protected areas in biodiversity conservation and an approach to determine how much and what features to set aside in core reserves using a gap analysis technique.

## 1.3 Conservation Planning

Conservation planning involves the design and implementation of specific conservation areas for the purposes of maintaining values for biodiversity and human use and enjoyment (Margules and Pressey 2000). A comprehensive conservation design includes strict protected areas as well as areas of moderately intensive management (e.g., buffers and enhanced management areas). Conservation planning, in tandem or as part of land use planning, can address the entire continuum of land use categories. Restrictions define areas of minimal management (i.e., no industrial resource extraction) and moderate management (i.e., modified prescriptions). In extensively managed areas, best practices, continuous improvement and voluntary certification are gaining favour as approaches to reduce human footprints, improve resource sustainability and contribute to biological conservation.

Gap analysis, the search for habitat and species in need of conservation attention, is one specific component of conservation planning (Davis et al. 1990). Assessing the conservation contribution of core reserves depends on the objectives we set for these areas: Should a network of strict protected areas provide high certainty for the long-term persistence of biodiversity? Is the goal of a protected areas network to anchor biological diversity, with additional conservation contribution from other conservation areas and appropriate management? The required size and configuration of a core reserve network will vary depending on the established conservation goals. WWF-Canada believes in a two-pronged approach to maintaining biodiversity that includes permanent protected areas (core reserves) and sensitive management in the intervening landscape.

A coarse-scale gap analysis based on physical habitat types provides a rapid assessment of protected areas representation of the key abiotic factors influencing species distributions (Noss and Cooperrider 1993). Furthermore, by focusing on “enduring features of the landscape” (Peterson and Peterson 1991), coarse-scale representation assessment has the advantage of focusing at scales appropriate to consider population viability for wide ranging species and the underlying ecological processes that drive natural habitat changes.

#### 1.4 Ecological Representation

Noss (1992) refers to four fundamental objectives of a conservation strategy: 1) representation of all native ecosystem types and seral stages in a system of protected areas, 2) maintenance of viable populations of all native species, 3) maintenance of ecological and evolutionary processes, and 4) allowance for natural environmental change. Core reserves, among the other elements of a conservation design, must spatially represent ecosystem diversity and maintain ecological integrity. With this focus, the objectives of maintaining viable populations and ecological processes become guiding principles in the design of an ecologically representative reserve network. Furthermore, a reserve system designed with these considerations should accommodate natural environmental change. This re-alignment of Noss’ four objectives allows for a practical application of a landscape-based gap analysis as a technique to measure effectiveness of one of the key goals of a protected areas network, where representation is defined as the maintenance of the full array of habitat types and environmental gradients in reserves across all types of soils, substrates and topoclimates (Noss 1992).

Maintaining viable populations of all native species in natural patterns of abundance is perhaps the most commonly understood principle in relation to biodiversity conservation. For example, we can set a target to maintain 95% persistence over 100 years (Noss 1995). This appears to be relatively tractable since species and communities are measurable units. Yet, it is the level of effort required to complete biological surveys and develop habitat models that limit the implementation of such an approach. This is also a fine-filter approach that may overlook the underlying factors influencing species distributions. Furthermore, biological indicators often lag changes in habitat and ecological processes. Despite these drawbacks, attempts to explicitly address species persistence in conservation planning, even in modeling environments, must continue in order to improve the effectiveness of protected areas networks.

Hence, it is important also to focus on sustaining key ecological processes in order to maintain ecological integrity. Characteristics of processes such as biogeochemical cycling, hydrological and climatic regimes, and disturbance-recovery events must be incorporated into protected areas design and monitoring. Much of the effort at WWF-Canada to incorporate understanding of ecological processes in reserve design at WWF-Canada has focused on understanding the spatial and temporal dynamics of fire as a natural agent of disturbance in forest ecosystems (although in some ecosystems, other disturbance events such as insect outbreaks, windthrow, individual tree mortality and periodic flooding may be more important in shifting community types across the landscape).

## **2. Gap Analysis Methodology**

The gap analysis methodology described in this report was initially developed by WWF-Canada and the Canadian Council on Ecological Areas (Geomatics 1993). A broadly similar approach, the USGS Gap Analysis Program (GAP), launched in 1989, pioneered the development of spatial analysis, habitat identification and mapping techniques for the identification of conservation gaps. Although both gap analysis techniques are described as coarse-filter approaches, the primary methodological difference between the U.S. GAP and the method applied by WWF-Canada is one of scale. U.S. GAP attempts to predict wildlife species distributions by mapping natural plant communities, which is a finer scale of assessment than using landform types described here (Gergley 2001). Nevertheless, the basic premise of mapping potential habitats is the same and continues to be viewed as a sound, pragmatic approach (O'Connor 2003).

### **2.1 Spatial units for representation**

#### *2.1.1 Rationale for representing enduring features of the landscape*

Much of the development of a tractable solution to assessing representation by protected areas requires the use of ecological classification frameworks. Furthermore, Stan Rowe (1995) advises that the spatial units for judging representation be based on each region's eco-diversity - the diversity of physical habitats - as a surrogate for biological diversity. The eco-diversity units, hence, are coarse predictors of the range of community diversity.

Similarly, in a discussion paper for the Canadian Council on Ecological Areas, Peterson and Peterson (1991) recommended that protected areas represent enduring features of the landscape as the primary elements of ecological diversity and, hence, biological diversity. Furthermore, Peterson and Peterson (1991) suggest that enduring features be identified within a national framework of natural regions (see below), in which boundaries are delineated on the basis of broad variations in climate and physiography (Kavanagh and Iacobelli 1995). Hence, the basis for defining spatial units as surrogates for biological diversity is an assessment of landform and climate at multiple scales. This defines a coarse-scale, landscape-based assessment of ecological representation. In addition, it is

consistent with the approach defined by Jennings (1996) for delineating and mapping patterns of beta diversity<sup>3</sup>.

### *2.1.2 Natural region frameworks*

There are a number of national and provincial ecological frameworks suitable for protected areas planning, complicating the job of applying a consistent framework for conservation planning across the country. The Terrestrial Ecoregions of Canada (Ecological Stratification Working Group 1994) is the main hierarchical ecological framework in Canada. This has been adopted by several provincial and territorial jurisdictions. However, some provinces in Canada have developed specific natural region frameworks for protected areas planning. Since provinces have responsibility to manage public lands and designate protected areas, WWF-Canada applies the gap analysis for the natural region framework designated by each jurisdiction. The gap analysis results are based on the variety of natural regions and enduring features within the boundaries of each jurisdiction. Each natural region framework is checked against national frameworks (EcoRegions Working Group 1989, Bostock 1970, Marshall and Schut 1999) in order to account for potential differences in scale so that the application of the gap analysis is broadly consistent across the country. Documentation regarding the natural region frameworks used in each jurisdiction is available in Appendix 1.

### *2.1.3 Delineating enduring features*

In 1992, WWF-Canada and the Canadian Council on Ecological Areas coordinated pilot studies to delineate enduring features as recommended by Peterson and Peterson (1991). Geomatics International Inc. (1994), based on a pilot study in central Ontario, suggested a framework for identifying landforms based on topography and the texture and type of surficial deposit. A second pilot covering the grasslands zone of Saskatchewan (Gauthier 1993) developed a gap analysis using four landscape variables recorded in a nation-wide terrain database, the Soil Landscapes of Canada database (Shields et al. 1991, Centre for Land and Biological Resources Research 1996).

Based on the main results of the pilots, WWF-Canada developed a methodology to identify enduring features using the Soil Landscapes of Canada (SLC) as the primary terrain database. Criteria to code each soil landscape polygon by its predominant landform types was based on the framework developed by Geomatics International Inc. (1994) using topography and the texture and type of surficial deposit. This allows for a consistent delineation of enduring features, by natural region, across the country. A more detailed breakdown of the decision rules to code SLC polygons can be provided by WWF-Canada upon request. Figure 2.1 illustrates the distribution of enduring features for one natural region in Ontario.

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<sup>3</sup> Beta diversity: The change in diversity among different communities of a landscape; an index of between-habitat diversity (Jennings 1996).

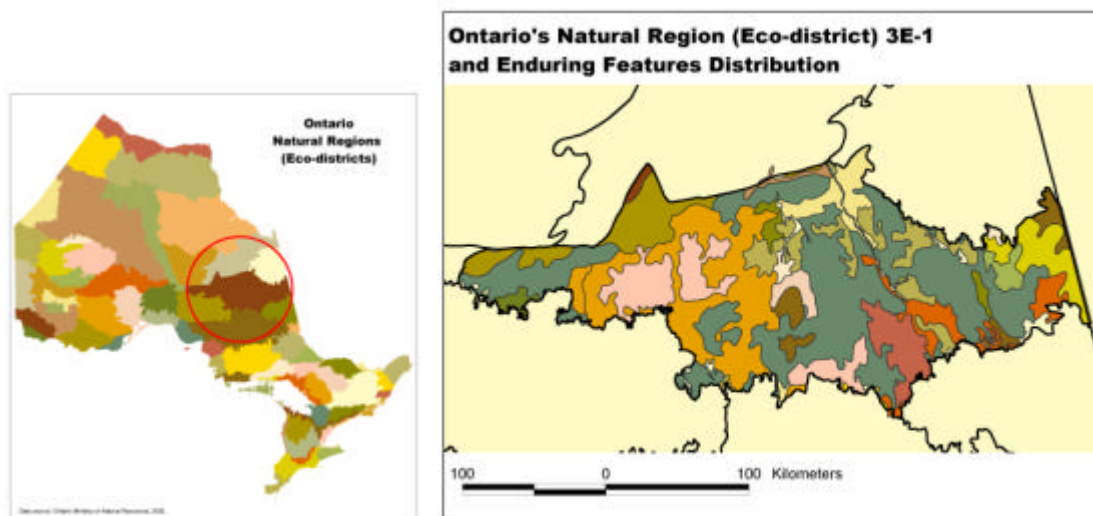


Figure 2.1. The distribution of enduring features for one natural region (Eco-district 3E-1) in Ontario.

## 2.2 Representation criteria

Each enduring feature is evaluated based on the degree of ecological representation by protected areas. As noted earlier, sustaining key ecological processes and maintaining viable populations of all native species are the guiding principles for designing representative protected area networks. The difficulty is translating these broad conservation criteria relating to ecosystem integrity into a numeric or spatial set of standards. A common assessment of ecological representation is based on a calculation of proportions, that is, what percentage of the spatial unit is protected? This is the measure of protection used in recent articles in *Conservation Science* (eg. Duffy *et al.* 1999) and some government parks policy (e.g. see section 2.3.2.1 regarding the British Columbia Protected Area Strategy for the Prince George Region Land and Resource Management Plan, <http://www.luco.gov.bc.ca/lrmp/pgeorge/toc.htm>).

For a coarse-scale gap analysis, it was determined that representation criteria should focus on protected area size guidelines, environmental variation and connectivity. Protected area size guidelines are developed based on spatial scales of ecological processes and/or faunal requirements. Representation of community variation along environmental gradients (e.g. high and low elevation areas) is considered for the protected areas network intersecting each enduring feature or landform type. The data required to address each representation criterion is described in more detail in Section 3 of this report. Furthermore, design principles regarding connectivity of a core reserve network are incorporated into the assessment.

### *2.2.1 Size guidelines*

Size guidelines for protected areas are derived based on the two guiding principles described above: 1) spatial scales of ecological processes such as natural disturbance events and 2) habitat requirements to maintain viable populations of selected focal species. Details regarding the methods and data used to determine ecological integrity size thresholds based on these two factors are provided in Appendices 1, 2 and 3. The process for this determination included the following steps:

- Natural disturbance events (primarily forest fire) and focal species data were assembled for North American ecoregions (Ricketts et al. 1999). Adjacent ecoregions that are more similar in their natural disturbance history are grouped into larger disturbance zones. Appendix 2 describes 15 natural disturbance zones and the statistical methods for comparing fire data among ecoregions. Appendix 3 defines a focal species and provides a suggested list of focal species for each natural disturbance zone.
- Fire data (Stocks et al. 2002), where relevant, and habitat requirements of selected focal species for each natural disturbance zone are analyzed to determine ecological integrity size thresholds at several scales of organization (Appendix 4).
- For each natural disturbance zone, the ecological integrity size thresholds for each spatial scale are matched to enduring feature size classes to determine linear equations for recommended minimum protected area size.

Ecological processes influence species distributions at varying temporal and spatial scales. For example, gap phase dynamics characterized by individual tree falls occur on the scale of hectares and an area on the order of hundreds to thousands of hectares may be necessary to maintain this type of disturbance-recovery cycle. Some stand-replacing events (e.g., fire) in the boreal forest cover tens to hundreds of thousands of hectares, such that maintaining a fire-driven forest ecosystem may require single areas on the order of 500,000 hectares (Walsh et al. 2000). As a result, protected areas of varying sizes can contribute to biodiversity conservation - some at stand or patch scales and some at landscape scales. Setting size thresholds at particular spatial scales and relating that to individual protected areas can be used as a guide to ensure a viable network of core reserves. For the purposes of the gap analysis technique, spatial scales of characteristic natural disturbance events have been classified into the following ecologically meaningful categories: stand, patch, landscape, and regional landscape. Appendix 4 provides a description of these spatial scales.

A key component of the effort to develop protected area size guidelines is the method of matching ecological integrity size thresholds to the enduring feature size classes in each natural disturbance zone. Although certain enduring features promote vegetation associations that effectively make them predisposed to more frequent or more severe disturbance events, their distribution on the landscape is also a significant factor in the occurrence of these events. Hence, larger enduring features should be identified to match 'landscape' scale events and smaller enduring features can be related to 'stand' or 'patch' scale events. However, this does not necessarily advocate for proportional representation. Larger enduring features are also more common. Smaller enduring features, because of their relative rarity, should be disproportionately represented (i.e.,

over-represented) since they tend to be associated with a unique array of ecological conditions. Appendix 4 provides a further rationale for this approach, as well as the statistical data and protected area size equations for each natural disturbance zone.

### *2.2.2 Environmental gradients*

This criterion attempts to quantify critical variation within an enduring feature. For example, topographic variation results in varying drainage conditions affecting soil development and moisture classes. Drier ridges, well-drained mid-slope areas and poorly drained toe-slope areas (i.e., a catena) are examples of this kind of variation within an enduring feature (Rowe 1980). Variation in soil development and drainage classes can be analyzed directly where this information exists. However, this criterion is commonly analyzed by using digital elevation models to identify elevation gradients. The range of elevation values within an enduring feature often approximates a normal distribution, and WWF has judged that a protected areas network should incorporate all but the 'tails' of the distribution.

Databases of predicted ecological communities, as they are developed nation-wide<sup>4</sup>, may largely replace the assessment of environmental gradients since the underlying factors governing the local distribution of community types will be incorporated into such a classification. The Biogeoclimatic Ecosystem Classification in British Columbia is an example of this type of database.

### *2.2.3 Important community types*

While much of the diversity in community variation within an enduring feature can be represented by an assessment of environmental gradients, certain community types require explicit identification because of the importance to wildlife or ecological processes. These include features of interest such as

- Headwaters or watershed divides that influence nutrient, detrital and temperature characteristics of water quality;
- Shoreline that provides critical wildlife habitat at aquatic-terrestrial interfaces; and
- Major riparian corridors that affect water quality, water quantity and landscape connectivity for movement of wildlife (British Columbia Ministry of Forests 1998).

Judging important community types to be represented in protected areas networks is based on the proportion of the habitat type in relation to the enduring feature. Where the habitat types can be identified at a coarse scale (1:2 M to 1:500,000 scale), then it is necessary to analyze these elements as part of the overall assessment of ecological representation.

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<sup>4</sup> NatureServe Canada in partnership with Parks Canada and the Canadian Forest Service are developing a national ecological classification system.

#### 2.2.4 Connectivity/Adjacency

This criterion, rather than referring to functional connectivity across the entire landscape, is primarily applied to smaller enduring features and is related to the SLOSS (Single Large Or Several Small) rule to ensure that protected areas include heterogeneous habitat conditions. The SLOSS rule contends that it is preferable to identify a single large site rather than several small sites. The adjacency criterion, as applied in the WWF-Canada gap analysis, is based on the conventional conservation biology notion that smaller, more isolated protected areas are less likely to maintain ecological integrity than larger, more connected ones. For example, disturbance events often can be larger than some of the smaller enduring features identified by WWF-Canada. Ensuring that adjacent enduring features are connected, in protected lands, to small enduring features ensures that a variety of physical habitat types are included in protected areas. In addition, since a high variety of physical habitats will tend to support a higher diversity of species, the application of this criterion also begins to address the “minimum representation problem” (Possingham et al. 2000), i.e., reserve selection should favour sites that “achieve comprehensive representation for the minimum cost”.

#### 2.2.5 Habitat quality (naturalness)

The assessment approach does not explicitly consider existing habitat condition. In one respect, this is a benefit since landscapes with restorative potential are not ignored. However, the representation assessment should also not ignore areas of intact or functionally intact habitat.

Rather than determining the levels of habitat condition (or modification) for each enduring feature, the protected areas overlapping an enduring feature are assessed with respect to the degree of human disturbance using proxy measures of habitat quality such as road density and/or other similar measures of habitat fragmentation (e.g., logging history, habitat conversion). For protected areas that are fragmented by roads or other linear disturbances, for example, the blocks of lowest road density are considered in the assessment as well as the total area under protected status.

### 2.3 Ranking enduring features and natural regions

Each enduring feature can be scored for adequacy of representation based on the outcomes of the representation criteria. Portions of a natural region that score below a minimum threshold can be identified as a gap in the core reserve network. Moreover, the scores based on each representation criterion provide guidance to modify the placement and configuration of candidate protected areas. Since enduring features are nested within natural regions, an overall assessment of protected areas representation for each natural region can be determined by considering the scores for individual enduring features (Figure 2.2). Section 3 of this report provides a breakdown of the ranking system for enduring features and natural regions.

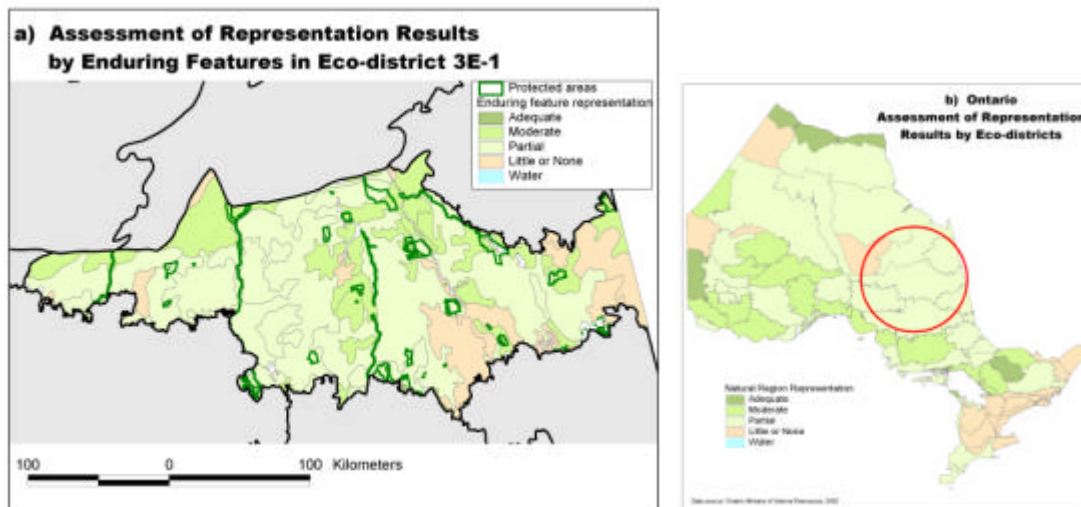


Figure 2.2. Thematic map of representation scores in four classes (a) for enduring features for one natural region (Eco-district 3E-1) in Ontario and (b) summarized for all natural regions in Ontario (WWF 2003).

### 3. Development of an Automated GIS Tool to Assess Ecological Representation

#### 3.1 The need for an automated routine

In seeking to make the gap analysis methodology more consistent, objective and widely available to conservation planners, WWF-Canada has developed an automated GIS tool to assess ecological representation. This section describes the decision rules and data used to interpret the representation criteria described above for the landscape-based gap analysis methodology. Results obtained to date are presented and prospects for the future development and application of the routine are highlighted.

#### 3.2 A framework for the representation assessment

The basis of the routine is a scoring scheme for the level of representation of each enduring feature by a number of conservation criteria (discussed in Section 2). The criteria incorporated into the automated routine include protection size, adjacency, environmental gradients, important community types and habitat quality. Individual criteria are scored on the basis of explicitly defined decision rules and with generically available data mapped at a scale of 1:250,000 or smaller. The scoring matrix for each criterion is summarized in Table 3.1.

##### 3.2.1 *Protected area size and adjacency criteria*

Recommended amount of protection is determined from linear equations that express the relation between enduring feature size (x-axis) and recommended protected area size (a continuum of spatial scales from patch to landscapes scales on the y-axis). A number of geographically specific linear equations have been developed through analyses of natural disturbance events (mostly fire) and size requirements for maintaining viable populations

of focal species (described in Section 2 of this paper and Appendices 1 to 3). Figure 3.1 illustrates an example of an equation relating protected area size guidelines to enduring feature sizes.

Assessing the adequacy of the protected area amount for each enduring feature is undertaken in three separate steps. The first step considers only the size of the largest unfragmented protected portion of the enduring feature while the second step considers the total protection of one or multiple reserves. Thirdly, a score for adjacency is determined by considering the total size of the entire protected area complex overlapping the enduring feature. The score for protected area size accounts for 50% of the total score and the score for adjacency accounts for 10% of the total score. The protected area size and adjacency criteria are accorded the highest weight in the overall scoring system with a potential score of 5 out of total of 8.

Step 1 (Size A): Using protected area/candidate area boundaries, the largest contiguous protected area mass on each enduring feature is identified. The following decision rules are applied.

If the largest contiguous area of the enduring feature protected is:

- w < 200 ha<sup>5</sup> then do not consider automatically score = 0
- w Between 0-25% of the recommended size guideline, then score size A as 0.5
- w Between 25-50% of the recommended size guideline then, score size A as 1
- w Between 50-75% of the recommended size guideline then, score size A as 2
- w Between 75-95% of the recommended size then score size A as 3
- w >=95% of the recommended size then score size A as 4.

The Size A score will have values between 0-4.

Step 2 (Size B): Using protected area/candidate area boundaries, the total area of the enduring feature protected is determined. This area would include all contiguous and non-contiguous blocks of area on the enduring feature. If any feature scores 4 on the Size A Score, then it is not scored for Size B. The following decision rules are applied.

If the total area protected on the enduring feature is:

- w At least 50% of recommended size then score size B as 0.5
- w >= 95% of recommended size then score size B as 1.

The size B score will have values of between 0-1.

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<sup>5</sup> 200 hectares was selected to represent the minimum size for a core reserve. An area of this size begins to address (a) small-scale disturbances, such as individual tree mortality, over longer periods of time and (b) the conservation of sufficient interior habitat (i.e., not affected by edge) to sustain populations (Riley and Mohr 1994).

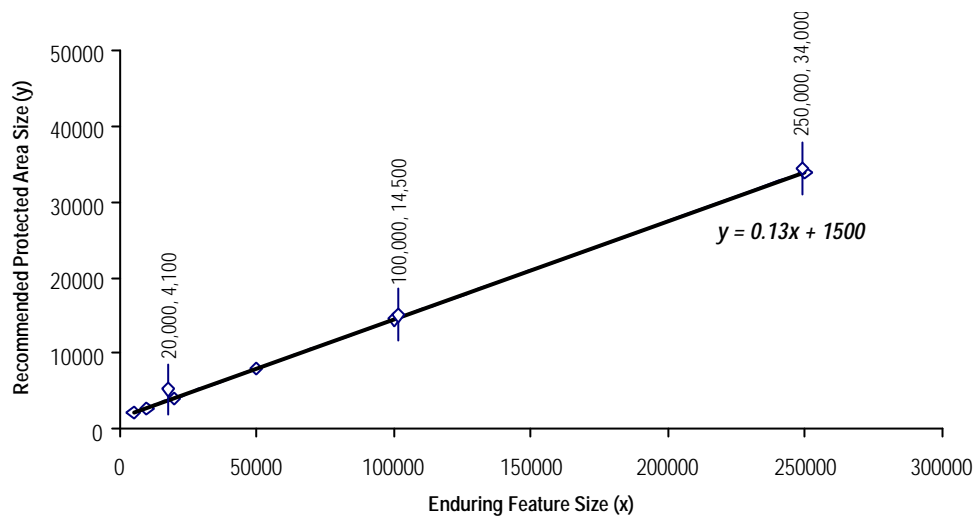


Figure 3.1. Example relationship between enduring feature size and recommended protected area size. See Appendix 4 for details of all protected area size guidelines.

Step 3 (Size C/Adjacency): Using protected area/candidate area boundaries, the total area of the protected complex connected to or adjacent to the areas protected on the enduring feature is determined. The following decision rules are applied.

If the sum of the area protected on the enduring feature and area connected to protected portions of an enduring feature is

- w At least 50% of recommended size then score size C as 0.5
- w  $\geq$  95% of recommended size then score size C as 1.

The size C score will have values of between 0-1.

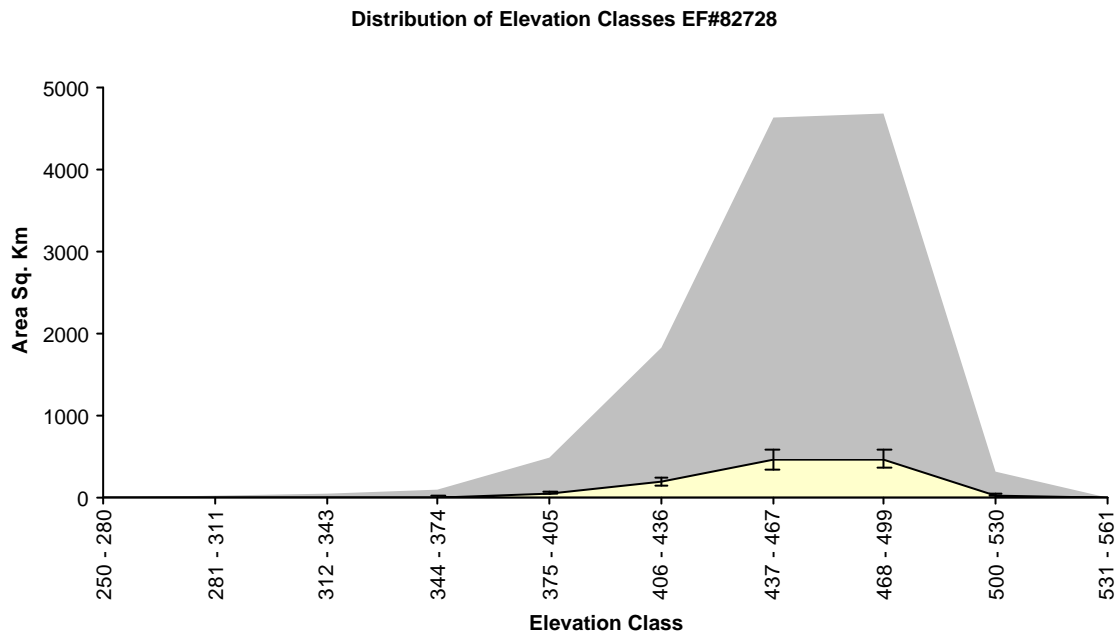
The sum of size scores A and B and C will have values of between 0-5. The data required for assessing the criteria are WWF-Canada's enduring feature layer<sup>6</sup> or equivalent and protected area/candidate area boundaries in a polygonal format. The size guidelines are provided with the automated GIS tool.

### 3.2.2 Environmental gradients criterion

The environmental gradients criterion is assessed on the basis of how elevation classes across the enduring feature are represented within the protected portion of the enduring

<sup>6</sup> The enduring feature layer is available from WWF-Canada. It combines the Soil Landscapes of Canada data with additional fields summarizing the landform components of each soil landscape polygon and identifying the associated natural region.

feature. The data required for assessing this criterion are a grid/raster data set of continuous elevation data. Elevation classes are pre-determined by the GIS user. Elevation range in any enduring feature often approximates a normal distribution. The effective elevation range (EER) is defined as the range that contains at least 80% of the distribution of the elevation values. An expected frequency for each elevation class in the EER is calculated based on the ratio of the area of the enduring feature protected and the total area of the enduring feature (Figure 3.2). The following decision rules are applied.



*Figure 3.2. Distribution of elevation classes for an enduring feature. The yellow portion indicates the expected distribution for a protected area that is approximately 10% of the size of the enduring feature. To reach an elevation score of 1, protected portions of the enduring feature would be expected to have 80% of their elevation classes in the range of classes spanned by the yellow portion of the distribution.*

If the observed frequency (i.e., of cell values from a grid) in each class for a particular enduring feature is at least 75% of the expected frequency then assign that elevation class a frequency score of 1.

- If 80% of the frequency scores for the effective elevation range of the enduring feature have a value of 1, then assign an environmental gradients score of 1;
- If 50-80% of the frequency scores for the effective elevation range of the enduring feature have a value of 1, then assign an environmental gradients score of 0.5;
- If <50% of the frequency scores for the effective elevation range of the enduring feature have a value of 1, then assign an environmental gradients score of 0.

The score for environmental gradients will have values of between 0 and 1 and accounts for 10% of the total representation score in the matrix.

### 3.2.2 Important community type criterion

Representation of important community types is assessed on the basis of how well shoreline and stream habitat are represented within the protected portion of the enduring feature. The proportion of shoreline per unit area of enduring feature is determined and the following decision rules are applied (Figure 3.3).

If the proportion of shoreline per unit area protected is:

- w  $\geq$  the proportion of shoreline per unit area of enduring feature then, score community types as 1.
- w If the proportion of the shoreline per unit area protected  $\leq$  proportion of shoreline per unit area of enduring feature AND the proportion of shoreline protected per unit area protected is  $> 0$ , then score community types as 0.5.
- w Otherwise, community types score = 0.

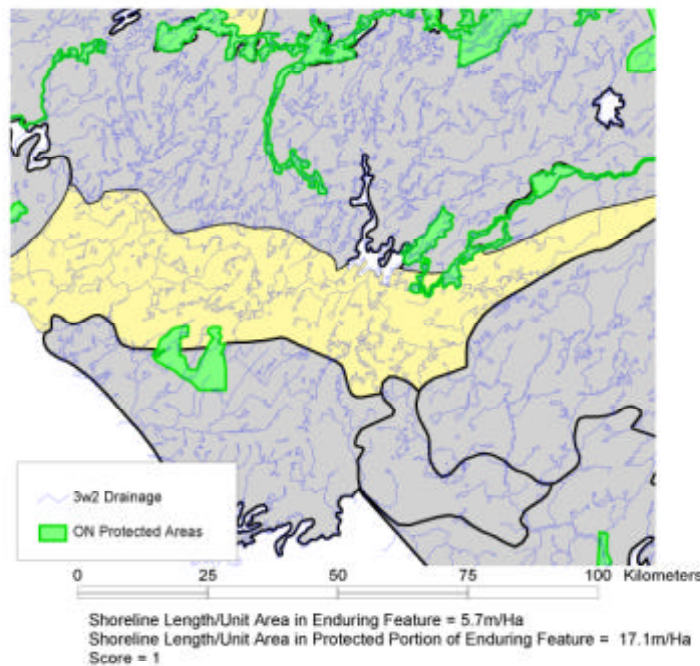


Figure 3.3. Illustration of the criterion used to score for important community types (shoreline) for the enduring feature shaded yellow. Drainage data are used to calculate shoreline length/hectare for the enduring feature and the protected portion of the enduring feature.

The score for the important community type criterion (shoreline) will be between 0-1 and accounts for 10% of the total representation score. The data required for assessing this criterion are drainage layers with line topology that delineate shorelines for water bodies, streams and rivers.

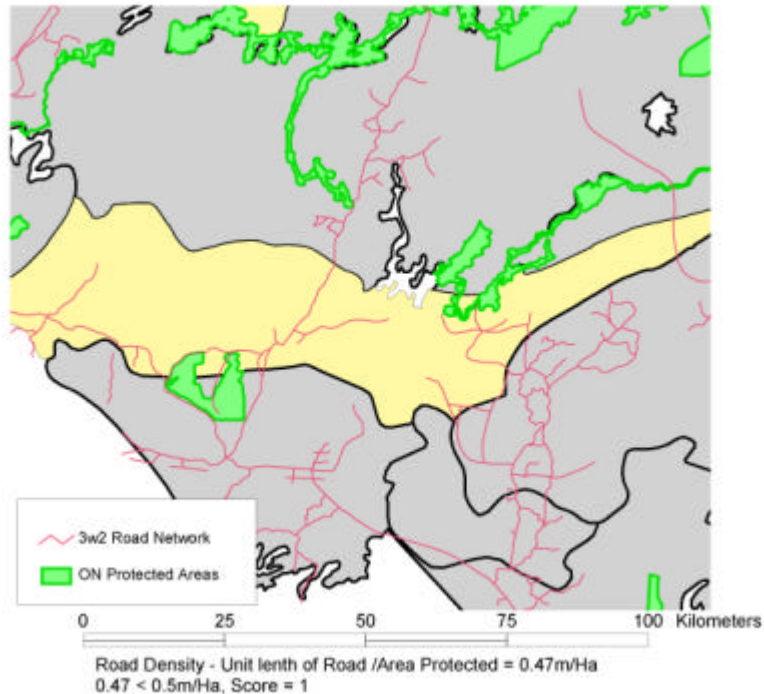
#### 3.2.4 Habitat quality criterion

The habitat quality criterion is assessed on the basis of permanent road and transportation corridor density serving as an indicator of habitat fragmentation and dissection (Figure 3.4). Road density values of 0.5 m/ha and 1.75 m/ha as identified by Noss (1995) are used as lower and upper thresholds for this criterion, where a lower threshold is a surrogate for better habitat condition. The following decision rules are applied.

If the calculated road density value is:

- $\leq 0.5$  m/ha (0.05 km/sq. km), then score habitat quality as 1 (*integrity* – high habitat integrity within the protected portion of the enduring feature).
- Between 0.5 m/ha to 1.75m/ha (0.05 to 0.175 km/sq. km), then the habitat quality score is 0.5 (transitioning to more disturbed, ecological integrity decreasing). This range is not explicitly indicated in the Noss (1995). It has been determined as the midpoint between the values for what Noss terms as *integrity* and *disintegrity*.
- $\geq 1.75$  m/ha (0.175 km/sq. km) then the habitat quality score is 0 (*disintegrity* - disturbed to compromised ecological integrity in the protected portion of the enduring feature).

The score for habitat quality (fragmentation) will have values of between 0 and 1 and accounts for 10% of the total representation score in the matrix. The data required for assessing this criterion are road and utility line data with line topology.



*Figure 3.4. Illustration of the criterion used to score habitat quality for protected portions of the enduring feature (shaded yellow). Road density values for the protected portion of the enduring feature are calculated and compared to thresholds in the decision rules.*

### 3.3 Assessment score

A final representation score for each enduring feature is calculated based on the scores of the individual criteria and translated to one of four representation classes: Adequate (score 6.5 - 8), Moderate (score 4 - 6), Partial (score 1 - 3.5) and Little/None (score 0-0.5). The representation classes offer the user a relative overview of the overall gap analysis results although the individual scores provide more information on the protected area status of the enduring features. The threshold for determining adequate representation by protected areas is a subjective judgment, but in this interpretation requires at least four and often all five of the conservation criteria to be addressed (size, connectivity, environmental gradients, important habitat types, and habitat quality).

Table 3.1: Representation criteria decision rules and thresholds for enduring features in the automated gap analysis tool.

Score Interpretation: 6.5-8 (Adequately Represented), 4-6 (Moderately Represented), 1-3.5 (Partially Represented), 0-0.5 (Little or No Representation)

Representation Criteria	Scoring Guidelines for Representation Criteria (scores are indicated in brackets)						Maximum Possible Score
PROTECTED AREA SIZE AND ADJACENCY	Largest Single Protected Area Block on Enduring Feature:	Meets size guideline (>95% of recommended size is protected) (4)	Is at least 75% of the recommended size (3)	Is at least 50% of the recommended size (2)	Is at least 25% of the recommended size (1)	Is > 200 ha and <25% of the recommended size (0.5)	4
	Total Area Protected on Enduring Feature:	Meets size guideline (>= 95% of recommended size is protected) (1)			Is at least 50% of the recommended size (0.5)		1
	Size of Contiguous Protected Area Complex Intersecting the Enduring Feature (Adjacency):	Meets size guideline (>= 95% of recommended size is protected) (1)			Is at least 50% of the recommended size. (0.5)		1
	5						
GRADIENTS	80% of elevation classes within effective range captured in a portion of the protected area. (1)	50-80% of elevation classes within effective range captured in a portion of the protected area. (0.5)		<50% of elevation classes within effective range captured in a portion of the protected area. (0)			1
COMMUNITY TYPES (SHORELINE)	Shoreline habitat in protected areas proportionate to distribution in the enduring feature. (1)	Shoreline habitat in protected areas but in lower proportion than occurs in the enduring feature. (0.5)		No shoreline habitat in protected areas. (0)			1
HABITAT QUALITY	Protected portion is relatively intact: road density < 0.5m/ha. (1)	Protected portion is less intact: road density > 0.5m/ha and < 1.75m/ha. (thresholds interpreted from Noss 1995) (0.5)		Protected portion is not intact: road density > 1.75m/ha. (0)			1

### 3.4 Implementing and automating the framework in ArcView GIS

The decision rules and scoring matrix described in section 3.2 have been implemented as an extension (named WWF-Canada Assessment of Representation Analyst) within ArcView Version 3. The application provides the user with the ability to conduct an assessment of enduring feature representation based on the scoring matrix in Table 3.1. A Users Manual detailing the most recent version of this extension is also available (Appendix 5).

The extension requires the user to select the necessary datasets for assessing the representation criteria (Figure 3.5). The natural disturbance zone must also be selected from a drop-down menu to establish the protected areas size guidelines appropriate for the area of study. These equations describe the numerical relationship between enduring feature size and recommended protected area size (see Appendix 4 for all equations and ecological basis for their development).

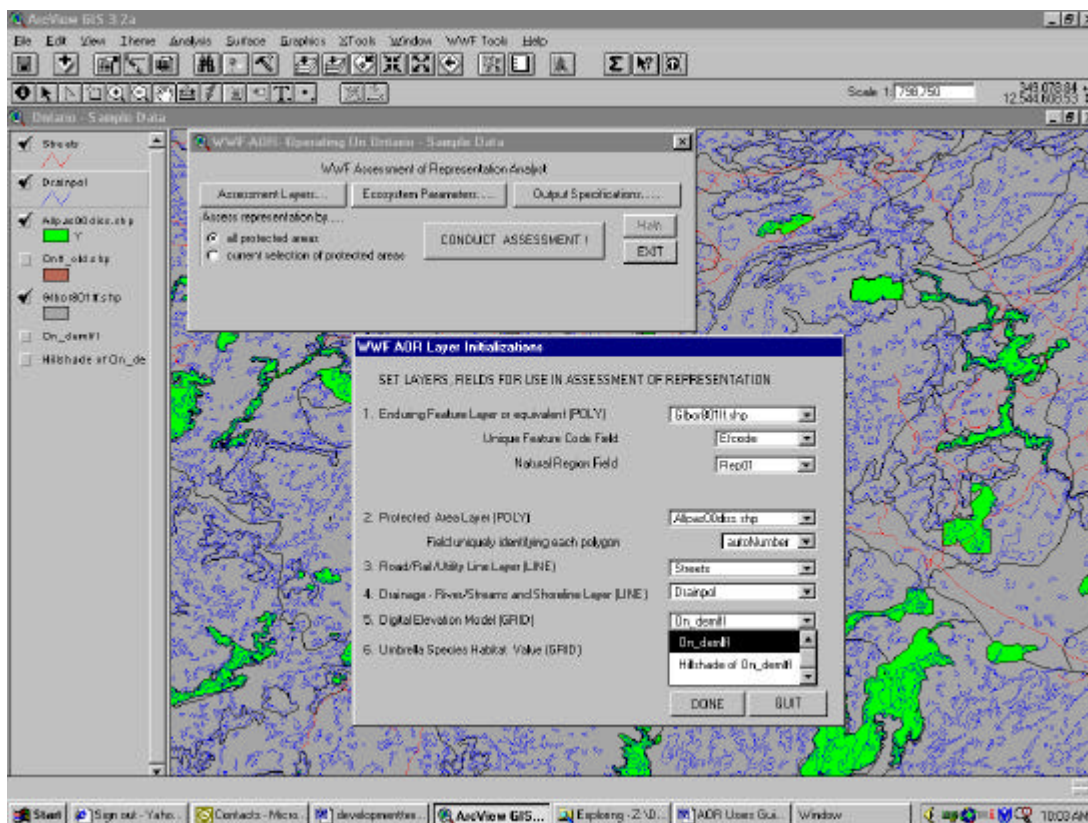


Figure 3.5. The selection menu identifying datasets to use in the assessment.

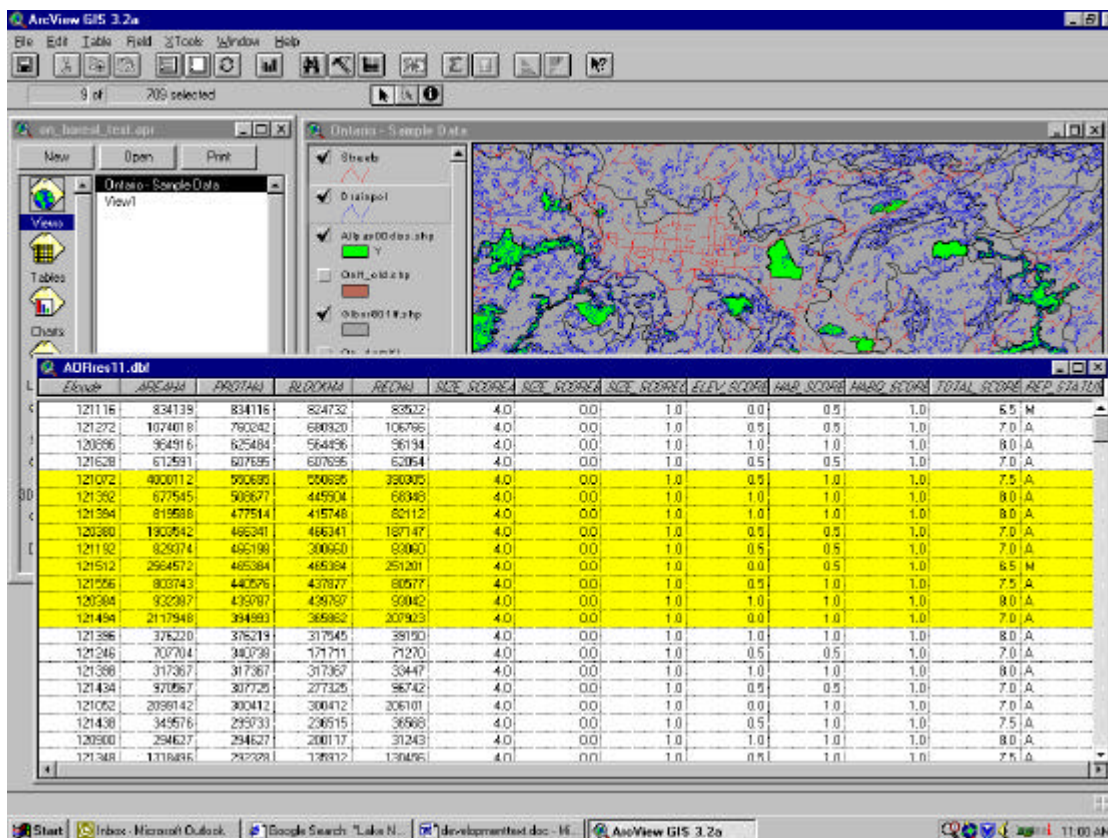


Figure 3.6. Sample output table with scores for each criterion and the total representation score.

The extension consists of a number of scripts within the Avenue programming language<sup>7</sup> that execute the automatic processing and decision rules for evaluating each criterion. A number of geo-processing functions, such as overlay intersects, zone histograms, and tabular summaries, are employed and processing time varies in length depending on input data size and resolution. Output from the routine is in the form of a table that contains the total representation score for each enduring feature and a breakdown of how that feature scored on each criterion (Figure 3.6, Table 3.2).

The routine also incorporates a calculation for assessing natural region representation based on the decision rules developed by WWF Canada (Appendix 6). The calculation summarizes the enduring feature representation results into a single score for the natural region, based on the appropriate natural region framework for the jurisdiction.

<sup>7</sup> WWF and ESRI will be translating the AOR Analyst to ArcGIS 8 in early 2004 for use within any ArcGIS 8 compatible software.

### 3.5 Automated routine results

An example of the application of the automated gap analysis routine to assess ecological representation is provided in Figures 3.7 and 3.8 for one natural region in western Saskatchewan (natural region #5 – Mid Boreal Uplands). General location and the distribution of enduring features across this natural region are illustrated in Figure 3.7 and the representation results are depicted in Figure 3.8.

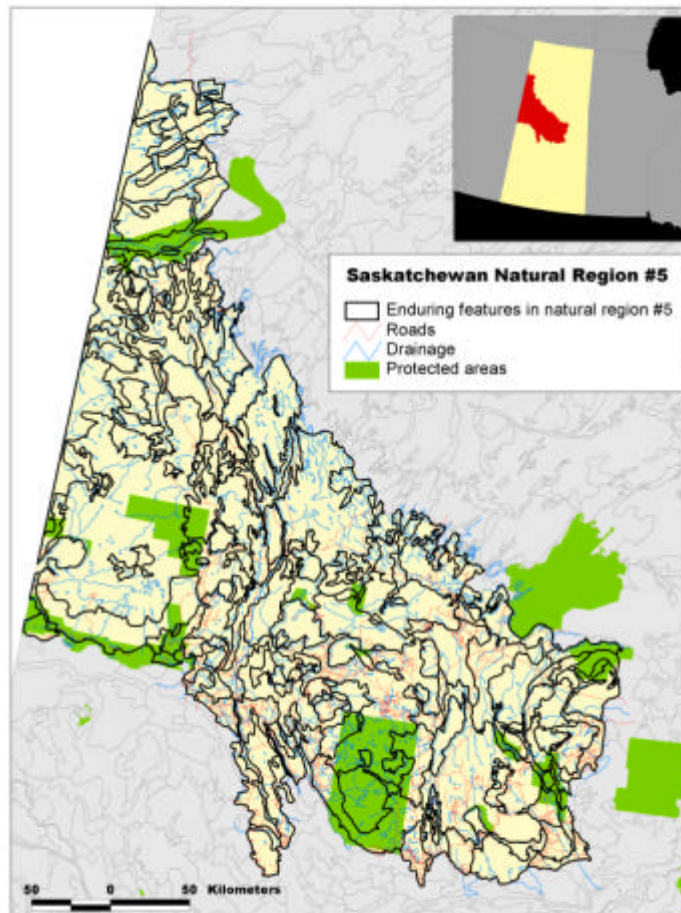


Figure 3.7. Location of the Mid Boreal Uplands (natural region #5) in Saskatchewan and enduring feature distribution. Summary statistics: Size of the natural region = 8,270,000 ha; area under protection = 993,000 ha; # of enduring features = 58.

In general, the results obtained by the routine are comparable to the results of assessments that were conducted manually during the *Endangered Spaces* campaign (Figure 3.8). Overall, the assessment of representation scores are slightly lower using the routine, which has highlighted a number of subjective decisions made in the manual assessment process. Consistent treatment of recommended protected area size guidelines is likely the main factor explaining the difference between the manual assessments and the automated gap analysis routine. In other instances, however, manual assessments

were able to better evaluate overall conservation design elements, such as connectivity. Moreover, the relationship between recommended protected area size and enduring feature size is currently defined by linear equations. It is probably more appropriate to define this as a non-linear relationship emphasizing the representation of smaller and/or unique landforms and relaxing the thresholds for larger, more common landforms. The tabular output provided by the GIS tool is useful in explicitly highlighting the criteria that score poorly (Table 3.2).

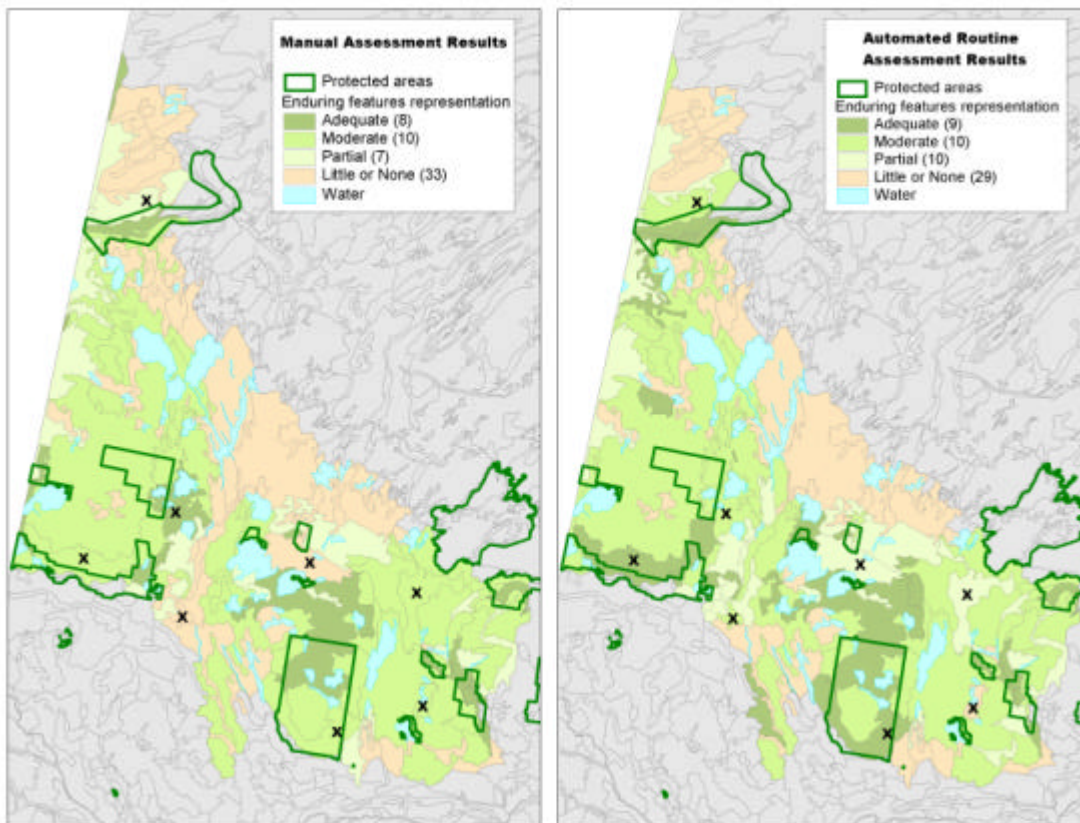


Figure 3.8. Comparison of gap analysis results between manual assessments and the automated GIS tool in the Mid Boreal Uplands (natural region #5) in Saskatchewan. X's mark some areas of disagreement.

The current version of the routine is still in its testing and calibration phase. Calibration is being performed on two levels. On one level, the thresholds and decision rules for each of the individual representation criteria can be adjusted based on the desired conservation objectives of a core reserve network. On a second level, the ranges of the final score are being tested and refined for the interpretation of representation classes (“adequate”, “moderate”, “partial” and “little or none”). The verified results from the historical assessments completed manually serve as a benchmark for both levels of calibration. Site selection algorithms based on explicit species persistence targets can also be used to verify the assumptions used in the landscape-based gap analysis tool.

Table 3.2. A sample of the tabular results of an assessment of representation conducted for natural region #5 in Saskatchewan.

Efcode	Area (ha)	Protected (ha)	Largest Block (ha)	Recommended Area (ha)	Size Score A	Size Score B	Size Score C	Elevation Score	Habitat type Score	Habitat Quality Score	Total Score	Rep. Status
150357	107,966	36,897	24,739	24,757	4.0	0.0	1.0	0.5	1.0	0.5	7.0	A
150601	139,875	38,405	38,405	32,073	4.0	0.0	1.0	0.5	1.0	1.0	7.5	A
150627	246,047	46,949	46,583	56,143	3.0	0.5	1.0	0.5	1.0	0.5	6.5	A
150521	9,263	6,261	6,261	2,124	4.0	0.0	1.0	0.5	0.0	0.5	6.0	M
150523	65,310	2,422	2,422	14,976	0.5	0.0	1.0	0.5	1.0	1.0	4.0	M
150561	150,957	17,992	17,659	34,614	2.0	0.5	1.0	0.0	0.5	1.0	5.0	M
150349	6,374	479	479	1,462	1.0	0.0	0.5	0.5	0.0	0.5	2.5	F
150333	73,933	2,594	2,594	16,953	0.5	0.0	1.0	0.0	1.0	0.0	2.5	F
150603	283,869	17,039	9,771	63,117	0.5	0.0	1.0	0.5	1.0	0.5	3.5	F
150581	28,994			6,648	0.0	0.0	0.0	0.0	0.0	0.0	0.0	N
150625	38,148	82	82	8,747	0.0	0.0	0.0	0.0	0.0	0.0	0.0	N

#### 4. Discussion and Conclusions

Translating conservation design concepts into an automated GIS tool for the purposes of assessing ecological representation by protected areas has been successful as measured against previous assessments completed during the *Endangered Spaces* campaign. The GIS routine increases the consistency of application of the assessment across the country. Furthermore, the decision rules used in the routine are explicit and consistently applied, offering greater opportunity for other practitioners to recommend improvements either to the ecological thresholds or to the programming. Speed, consistency and reliability are the main benefits of the approach we describe.

Furthermore, a focus on landform and climate at multiple scales as a key factor influencing species distributions ensures that an entire planning region can be assessed, rather than relying on incomplete biological inventories. However, the treatment of long-term species persistence through a set of general assumptions and coarse-filter approach is not ideal. Developing more reliable and easily applied methods of explicitly addressing species persistence (fine-filter approach) must continue in order to improve conservation planning efforts.

The automated gap analysis tool is intended for use by conservation planners and resource managers to provide a quick and consistent coarse-filter status assessment of existing protected areas and/or candidate scenarios. This is most appropriately used within comprehensive conservation planning projects. In this case, the conservation snapshot provided by the gap analysis routine can inform land use decisions together with the best site selection assessments. Whether accurate biological data are sparse or where reliable species and habitat modeling are available, the coarse-filter approach can identify important gaps in ecological diversity that should be addressed in a conservation network design.

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