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# National Agri-Environmental Standards Initiative (NAESI)

## Report No. 1-10

# Potential Models, Tools and Approaches for Developing Habitat Objectives to Conserve Biodiversity in the Agricultural Regions of Canada.

Technical Series 2005

**Photos:**
Bottom Left- clockwise

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Crop spraying: Corel CD photo # 95C2840
Elk Creek, BC: Joseph Culp, National Water Research Institute, Environment Canada
Prairie smoke and bee: Emily Wallace, Prairie Northern Region, Environment Canada

Prepared and published by
Environment Canada
Gatineau, QC

December 2005

## National Agri-Environmental Standards Initiative Technical Series

# POTENTIAL MODELS, TOOLS AND APPROACHES FOR DEVELOPING HABITAT OBJECTIVES TO CONSERVE BIODIVERSITY IN THE AGRICULTURAL REGIONS OF CANADA.

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# NOTE TO READERS

The National Agri-Environmental Standards Initiative (NAESI) is a four-year (2004-2008) project between Environment Canada (EC) and Agriculture and Agri-Food Canada (AAFC) and is one of many initiatives under AAFC's Agriculture Policy Framework (APF). The goals of the National Agri-Environmental Standards Initiative include:

- Establishing non-regulatory national environmental performance standards (with regional application) that support common EC and AAFC goals for the environment
- Evaluating standards attainable by environmentally-beneficial agricultural production and management practices; and
- Increasing understanding of relationships between agriculture and the environment.

Under NAESI, agri-environmental performance standards (i.e., outcome-based standards) will be established that identify both desired levels of environmental condition and levels considered achievable based on available technology and practice. These standards will be integrated by AAFC into beneficial agricultural management systems and practices to help reduce environmental risks. Additionally, these will provide benefits to the health and supply of water, health of soils, health of air and the atmosphere; and ensure compatibility between biodiversity and agriculture. Standards are being developed in four thematic areas: Air, Biodiversity, Pesticides, and Water. Outcomes from NAESI will contribute to the APF goals of improved stewardship by agricultural producers of land, water, air and biodiversity and increased Canadian and international confidence that food from the Canadian agriculture and food sector is being produced in a safe and environmentally sound manner.

The development of agri-environmental performance standards involves science-based assessments of relative risk and the determination of desired environmental quality. As such, the National Agri-Environmental Standards Initiative (NAESI) Technical Series is dedicated to the consolidation and dissemination of the scientific knowledge, information, and tools produced through this program that will be used by Environment Canada as the scientific basis for the development and delivery of environmental performance standards. Reports in the Technical Series are available in the language (English or French) in which they were originally prepared and represent theme-specific deliverables. As the intention of this series is to provide an easily navigable and consolidated means of reporting on NAESI's yearly activities and progress, the detailed findings summarized in this series may, in fact, be published elsewhere, for example, as scientific papers in peer-reviewed journals.

This report provides scientific information to partially fulfill deliverables under the Biodiversity Theme of NAESI. This report was written by Spatialworks. The report was edited and formatted by Denise Davy to meet the criteria of the NAESI Technical Series. The information in this document is current as of when the document was originally prepared. For additional information regarding this publication, please contact:

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# NOTE À L'INTENTION DES LECTEURS

L'Initiative nationale d'élaboration de normes agroenvironnementales (INENA) est un projet de quatre ans (2004-2008) mené conjointement par Environnement Canada (EC) et Agriculture et Agroalimentaire Canada (AAC) et l'une des nombreuses initiatives qui s'inscrit dans le Cadre stratégique pour l'agriculture (CSA) d'AAC. Elle a notamment comme objectifs :

- d'établir des normes nationales de rendement environnemental non réglementaires (applicables dans les régions) qui soutiennent les objectifs communs d'EC et d'AAC en ce qui concerne l'environnement;
- d'évaluer des normes qui sont réalisables par des pratiques de production et de gestion agricoles avantageuses pour l'environnement;
- de faire mieux comprendre les liens entre l'agriculture et l'environnement.

Dans le cadre de l'INENA, des normes de rendement agroenvironnementales (c.-à-d. des normes axées sur les résultats) seront établies pour déterminer les niveaux de qualité environnementale souhaités et les niveaux considérés comme réalisables au moyen des meilleures technologies et pratiques disponibles. AAC intégrera ces normes dans des systèmes et pratiques de gestion bénéfiques en agriculture afin d'aider à réduire les risques pour l'environnement. De plus, elles amélioreront l'approvisionnement en eau et la qualité de celle-ci, la qualité des sols et celle de l'air et de l'atmosphère, et assureront la compatibilité entre la biodiversité et l'agriculture. Des normes sont en voie d'être élaborées dans quatre domaines thématiques : l'air, la biodiversité, les pesticides et l'eau. Les résultats de l'INENA contribueront aux objectifs du CSA, soit d'améliorer la gérance des terres, de l'eau, de l'air et de la biodiversité par les producteurs agricoles et d'accroître la confiance du Canada et d'autres pays dans le fait que les aliments produits par les agriculteurs et le secteur de l'alimentation du Canada le sont d'une manière sécuritaire et soucieuse de l'environnement.

L'élaboration de normes de rendement agroenvironnementales comporte des évaluations scientifiques des risques relatifs et la détermination de la qualité environnementale souhaitée. Comme telle, la Série technique de l'INENA vise à regrouper et diffuser les connaissances, les informations et les outils scientifiques qui sont produits grâce à ce programme et dont Environnement Canada se servira comme fondement scientifique afin d'élaborer et de transmettre des normes de rendement environnemental. Les rapports compris dans la Série technique sont disponibles dans la langue (français ou anglais) dans laquelle ils ont été rédigés au départ et constituent des réalisations attendues propres à un thème en particulier. Comme cette série a pour objectif de fournir un moyen intégré et facile à consulter de faire rapport sur les activités et les progrès réalisés durant l'année dans le cadre de l'INENA, les conclusions détaillées qui sont résumées dans la série peuvent, en fait, être publiées ailleurs comme sous forme d'articles scientifiques de journaux soumis à l'évaluation par les pairs.

Le présent rapport fournit des données scientifiques afin de produire en partie les réalisations attendues pour le thème de la biodiversité dans le cadre de l'INENA. Ce rapport a été rédigé par Spatialworks. De plus, il a été révisé et formaté par Denise Davy selon les critères établis pour la Série technique de l'INENA. L'information contenue dans ce document était à jour au moment de sa rédaction. Pour plus de renseignements sur cette publication, veuillez communiquer avec l'organisme suivant :

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# INTRODUCTION

The National Agri-environmental Standards Initiative (NAESI) is responsible for the development of performance standards for agricultural in the context of four themes: water, soil, air and biodiversity. As part of the work of the Biodiversity Thematic Group, the Biodiversity Standards Project aims to produce a suite of measurable standards representing acceptable levels of biodiversity, that are applicable to all forms of agricultural production in all types of landscapes across Canada. This work includes identifying biodiversity components for standards development and developing methods for assessing those components.

The goal of this report is to summarize and review current information on models, tools and approaches that may be used to quantify, assess and predict the amount, quality and pattern of terrestrial and aquatic habitat that is required to support wildlife habitat and biodiversity across agricultural regions of Canada. Models and tools of interest include those used to:

- Assess, quantify and analyze current conditions, e.g., estimate breeding-habitat patch size, biodiversity
- Predict future conditions, e.g., simulate effects of forest management on habitat suitability
- Assess landscape pattern and structure, and its effects on habitat and biodiversity
- Identify and quantify functional or ecological relationships, e.g., correlate landscape attributes and wildlife habitat metrics
- Scale habitat assessments, predictions and relationships, e.g., scaling results of a landscape model to the farm level
- Carry out scenario planning

Of particular interest, are models and tools that will shed light on the following issues::

- What is the amount, type, pattern and quality of habitat across the landscape in agricultural regions needed to support viable populations of aquatic and terrestrial species and conserve ecological function at multiple scale?
- What proportions and parts of this habitat are the responsibility of the agricultural sector?
- What do semi-natural and cropland areas contribute to the habitat requirements to achieve Issue 1 above?
- What is the current status of habitat and where do critical shortfall or negative trends exist?
- How can habitat requirements at multiple scales be translated to standards at the farm scale? What are reasonable standards to aim for in the short, medium and long term?
- How do existing land use strategies, population level targets and habitat conservation targets fit with requirement of Issue 1?
- How do habitat standards relate to standards for the other three NAESI environmental outcome themes of water, air and pesticides?
- What are the critical knowledge and information gaps that reduce confidence in (or act as a barrier to determining) the habitat requirements used to establish biodiversity standards?

‘Models, tools and approaches’ in the context of this report are broadly defined to include analytical techniques, simulation models, predictive models, decision support systems, expert systems and knowledge bases.

The geographical areas of interest in this review are primarily the agricultural regions of Canada. However, where deemed potentially applicable, models and tools from other regions, countries and disciplines will be profiled as well. In particular, a large body of work has been developed in response to the effect of forest management practices on wildlife habitat and biodiversity; this work is reviewed here. Both terrestrial and aquatic ecosystems are considered.

The spatial scales of interest include watershed, landscape level, stand level and farm level. For those models and tools having a temporal or time-step component (e.g., predicting future forest conditions), more priority will be given to those based on a relatively short time frame (e.g., 1 to 20 years), less so to those based on long time frames (e.g., 100 years or more).

This work includes development of a database that was developed to store information on the models described in this report. A description of the database, including its tables, fields and forms, is given in Appendix A.

# HABITAT MODELS

The assessment of wildlife habitat has emerged as an important and integral component of land use planning (Puttock et al. 1996). Since the 1970s, modelling techniques have been developed to aid in making decisions regarding land use and the protection of wildlife habitat (Jones et al. 2002). In many jurisdictions, legislation requires consideration of wildlife and wildlife habitat within resource development plans (e.g. Christie and van Woudenberg 1997).

Habitat models are used to assess the suitability of an area for a species or population, based on an assessment of features such as vegetation, terrain and landscape structure. Habitat modelling has been used for several purposes, including:

- to assess the impacts of current or proposed land-use strategies on wildlife habitat
- to assess the sensitivity of wildlife to habitat perturbations
- to assess the relative contribution of habitat and landscape characteristics to the overall requirements of a species
- to predict relative habitat supply over long time periods (Buckmaster et al. 1999)
- to identify areas that are especially important for supporting high biodiversity in an ecosystem (e.g. Morrison et al. 2000)
- to predict carrying capacity (Puttock et al. 1996)
- to direct surveys, particularly of rare or endangered species, to sites with a high probability of containing the species (e.g. Christie and van Woudenberg 1997, MacDougall and Loo 2002, Gibson et al. 2004)
- to aid resource and transportation managers is planning mitigation passages for wildlife (e.g. Clevenger et al. 2002)

Models vary in generality and precision, due in part to the amount of available quantitative habitat information and the often qualitative nature of existing information. Models may be developed from literature reviews and expert opinion, or an analysis of quantitative data (e.g. presence data) or a combination thereof (Clevenger et al. 2002).

Table 1 presents references to some habitat models developed for species in Canada. For example, in Ontario Naylor et al. (1999) developed the Ontario Wildlife Habitat Analysis Models (OWHAM), a spatial habitat supply model for selected wildlife species, including moose, deer, American marten, pileated woodpecker and red-shouldered hawk (Hodson 2003). As part of the forest management planning process in Ontario, OWHAM has been used in conjunction with the Strategic Forest Management Model (SFMM) to determine suitable habitat levels necessary for conservation of species diversity (Abitibi-Consolidated 2004). The model has been used to identify marten core areas which are set aside during wood supply analysis with SFMM, to protect species habitat.

**Table 1: Some examples of habitat models developed for species in Canada.**

| Reference | Species | Province | Region |
|---|---|---|---|
| Puttock et al. (1996) | moose (*Alces alces*) | Ontario | Great Lakes-St. Lawrence |
| Marshall (1996) | lake trout (*Salvelinus namaycush*) | Ontario | |
| Christie and van Woudenberg (1997) | flammulated owl (*Otus flammeolus*) | British Columbia | south-east<br>(Wheeler Mountain) |
| Buckmaster et al. (1999) | red-backed vole<br>(*Clethrionomys gapperi*) | Alberta | west-central (Foothills Model Forest) |
| Banks et al. (1999) | brown creeper (*Certhia americana*) | Alberta | west-central<br>(Foothills Model Forest) |
| Naylor et al. (1999) | multiple | Ontario | |
| Morrison et al. (2000) | fish species | Ontario | Great Lakes |
| Clevenger et al. (2002) | black bear (*Ursus americanus*) | Alberta | Banff National Park |
| Jones et al. (2002) | elk (*Cervus elaphus*) | Alberta | west-central |
| MacDougall and Loo (2002) | rare flora | New Brunswick | south |

**Table 1: Some examples of habitat models developed for species in Canada.**

| Reference | Species | Province | Region |
|---|---|---|---|
| Machtans and Latour (2003) | song birds | Northwest Territories | boreal forest of Liard Valley |
| Nielsen et al. (2003) | grizzly bear (*Ursus arctos*) | Alberta | Jasper National Park |
| Weclaw and Hudson (2004) | woodland caribou (*Rangifer tarandus caribou*) | Alberta | |

## Habitat suitability index models

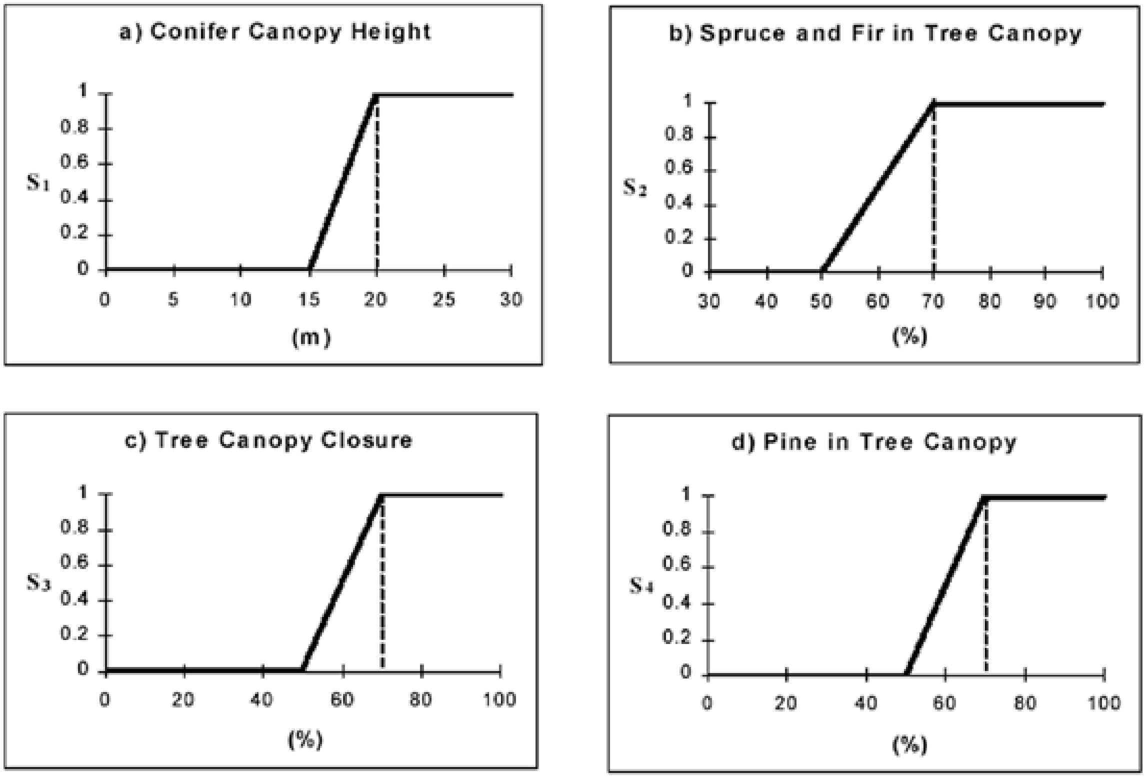
Habitat suitability indices were developed by the USDI Fish and Wildlife Service to assess the environmental impacts of proposed water and land development projects (Jones et al. 2000). Habitat suitability index models predict the suitability of habitat for a species based on an assessment of habitat attributes such as habitat structure, habitat type and the spatial arrangements between habitat features (Buckmaster et al. 1999).

The derivation of a habitat suitability index for a species begins by identifying attributes of an ecosystem that affect the species' ability to survive, grow and reproduce. An attribute may reflect the availability of food, shelter or nesting sites, protection from predators and/or protection from harvesting. For example, protection from predators may in part be affected by percent shrub cover.

An attribute may be a continuous variable, such as conifer canopy height, or a categorical variable, such as substrate type. The values of an attribute are translated into a component index value that typically ranges from 0.0 to 1.0, 0.0 being lowest suitability, 1.0 being highest suitability. This translation may be based on scientific knowledge and/or expert opinion.

For example, Banks et al. (1999) developed a habitat suitability index model for brown creeper that incorporated conifer canopy height, spruce and fir in tree canopy, tree canopy closure and pine in tree canopy (Figure 1). In this case, each attribute is a continuous variable, with values functionally and graphically mapped to the component index scale of 0 to 1.

**Figure 1: Graphical relationships between habitat attributes and HSI components in the brown creeper model (from Banks et al. 1999)**



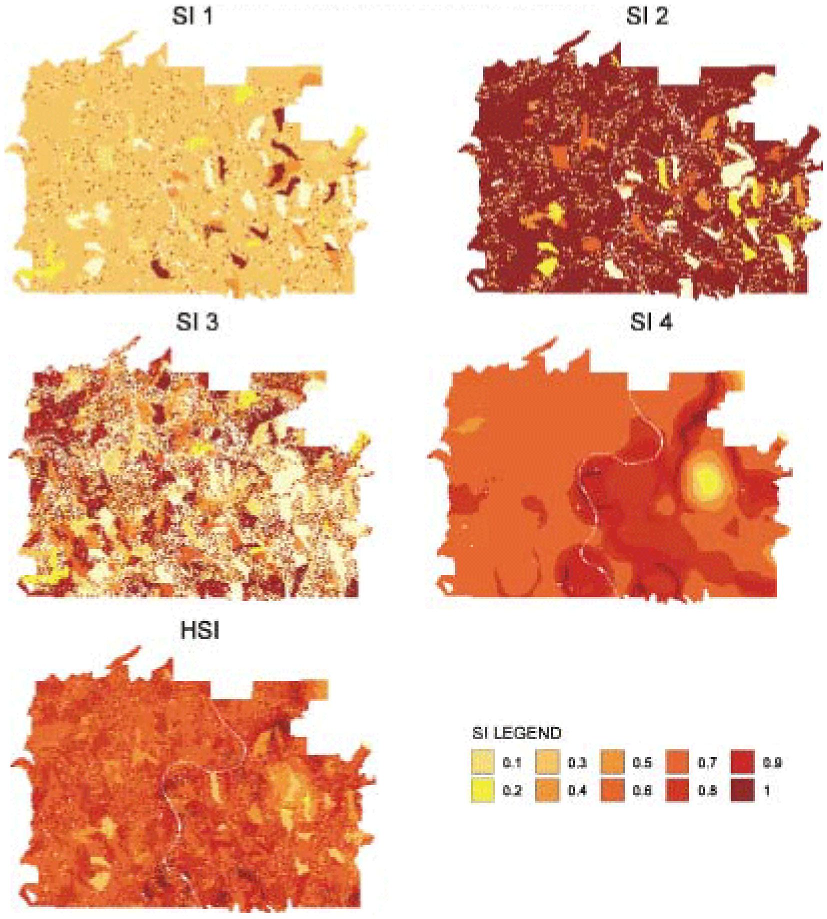
To calculate the habitat suitability index, the component index values are combined by additive, multiplicative, or logical functions in a manner that reflects the cumulative effect of the components (Burgman et al. 2001). For example, Banks et al. (1999) developed the following equation for the brown creeper:

$$HSI = S_1 \text{ x } S_3 \text{ x } (\max\{1; (S_2 + 0.02 \text{ x } S_4)\})$$

In this case, pine is assumed to be 2% as effective as spruce or fir.

Habitat suitability indices can be linked to spatially explicit data layers of habitat attributes to generate maps of habitat suitability. Larson et al. (2003) developed maps of suitability maps for several animal species using data layers of dominant tree age, species group, ecological land type, land type group and land category. For example, for wild turkey (*Meleagris gallopavo*), the habitat suitability index was based on the components of nesting and brood-rearing cover, adult cover, and hard mast production (Figure 2).

**Figure 2: Spatially explicit habitat suitability indices for wild turkey. HSI components are as follows: SI1, nesting and brood-rearing cover; SI2, mature forest for adult cover; SI3, suitability of hard mast production; and SI4, suitability of composition SI1, SI2 and SI3. HSI = (max{SI1, [(SI2 + SI3) / 2]} x SI4)$^{0.5}$. The area is approximately 5 by 7 km (from Larson et al. 2003).**



The set of component indices can be considered as an *n*-dimensional matrix, where *n* is the number indices. Each cell of the matrix represents the combined effect of the intersecting component indices. Morrison et al. (2000) developed a 3-dimensional habitat suitability matrix for Great Lakes fish species, based on the attributes of water depth (0-2 m, 2-5m, 5-10m, 10+m), substrate (e.g. bedrock, boulder, cobble, rubble) and cover (none, submergent, emergent, other). Each category of each attribute was given a suitability rating of nil, low, medium or high and given a respective score of 0.0, 0.33, 0.67 or 1.0. A suitability index value was calculated for each combination of attribute categories (e.g. 2-5m depth with cobble substrate with emergent cover) as the simple product of the individual category scores, to yield a matrix of values.

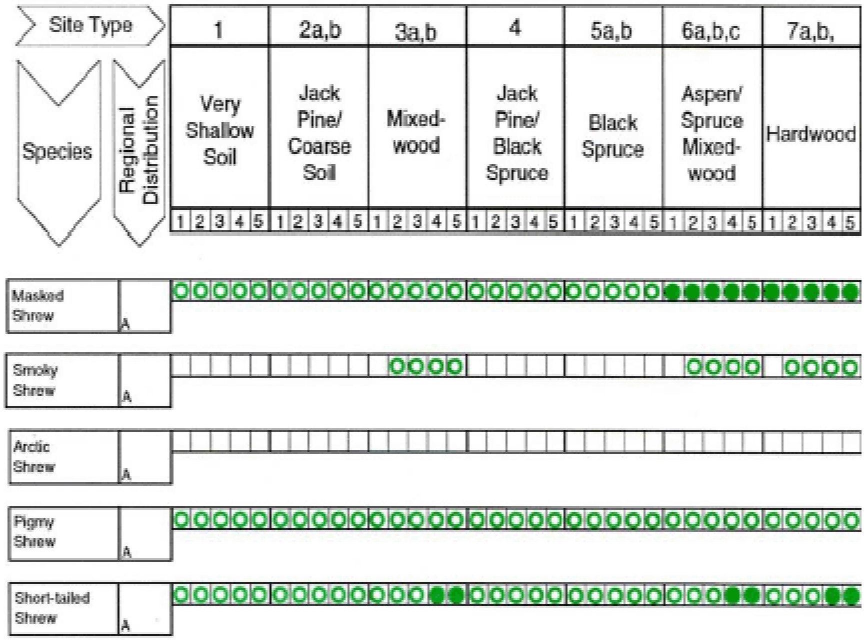
An example of the application of habitat suitability models in conservation can be found in the Milk River Basin Project (MULTISAR). The Milk River Basin, which is located southern Alberta, is a relatively small area containing several sensitive and at risk species (Downey et al. 2004). Here, the models are used to identify and prioritize important landscape and habitat features for conservation. A total of 17 HSI models were developed for MULTISAR, encompassing birds, mammals, amphibians and reptiles, and invertebrates (Downey et al. 2004).

## Habitat suitability matrices

Habitat suitability matrices model the relationship between ecological or landscape characteristics, and the habitat preference or use by a wildlife species, in a categorical manner (Neave et al. 2000). The matrices can be used to assess current habitat conditions and the potential impacts of  management decisions on future habitat (D’Eon and Watt 1994b). Habitat suitability matrices can take on a variety of forms, depending on the underlying data and the relationships that are being modelled.

D'Eon and Watt (1994a, 1994b) developed an extensive set of matrices for birds, mammal, amphibians and reptiles of northeastern Ontario (Figure 3). They scored each combination of 16 forest site types (based on the Forest Ecosystem Classification for Northeastern Ontario) and 5 stand development stages (initiation, regeneration, young, mature, old growth) as being used or preferred habitat, and identified special habitat preferences (e.g. shrubby understory).

**Figure 3: Portion of a habitat suitability matrix developed for wildlife in northeastern Ontario. Open green circles indicate 'used habitat', closed green circles indicate 'preferred habitat'. The numbers 1 to 5 represent stand development stages (initiation, regeneration, young, mature and old growth, respectively). From D'Eon and Watt (1994b).**



| Site Type | | 1 | | | | | 2a,b | | | | | 3a,b | | | | | 4 | | | | | 5a,b | | | | | 6a,b,c | | | | | 7a,b, | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Species | Regional Distribution | Very Shallow Soil | | | | | Jack Pine/ Coarse Soil | | | | | Mixed-wood | | | | | Jack Pine/ Black Spruce | | | | | Black Spruce | | | | | Aspen/ Spruce Mixed-wood | | | | | Hardwood | | | | |
| | | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 | 5 |
| Masked Shrew | A | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● |
| Smoky Shrew | A | | | | | | | | | | | | ○ | ○ | ○ | ○ | | | | | | | | | | | | ○ | ○ | ○ | ○ | | ○ | ○ | ○ | ○ |
| Arctic Shrew | A | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Pigmy Shrew | A | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| Short-tailed Shrew | A | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ● | ● | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ○ | ● | ● | ○ | ○ | ○ | ● | ● |

Neave and Neave (1998) developed habitat suitability matrices for the seven main Ecozones in which agriculture is practiced in Canada (Figure 4). The "matrices specify how various wildlife species use agricultural land to meet their habitat needs (e.g., breeding, feeding, cover, staging, winter use)" (Neave et al. 2000).

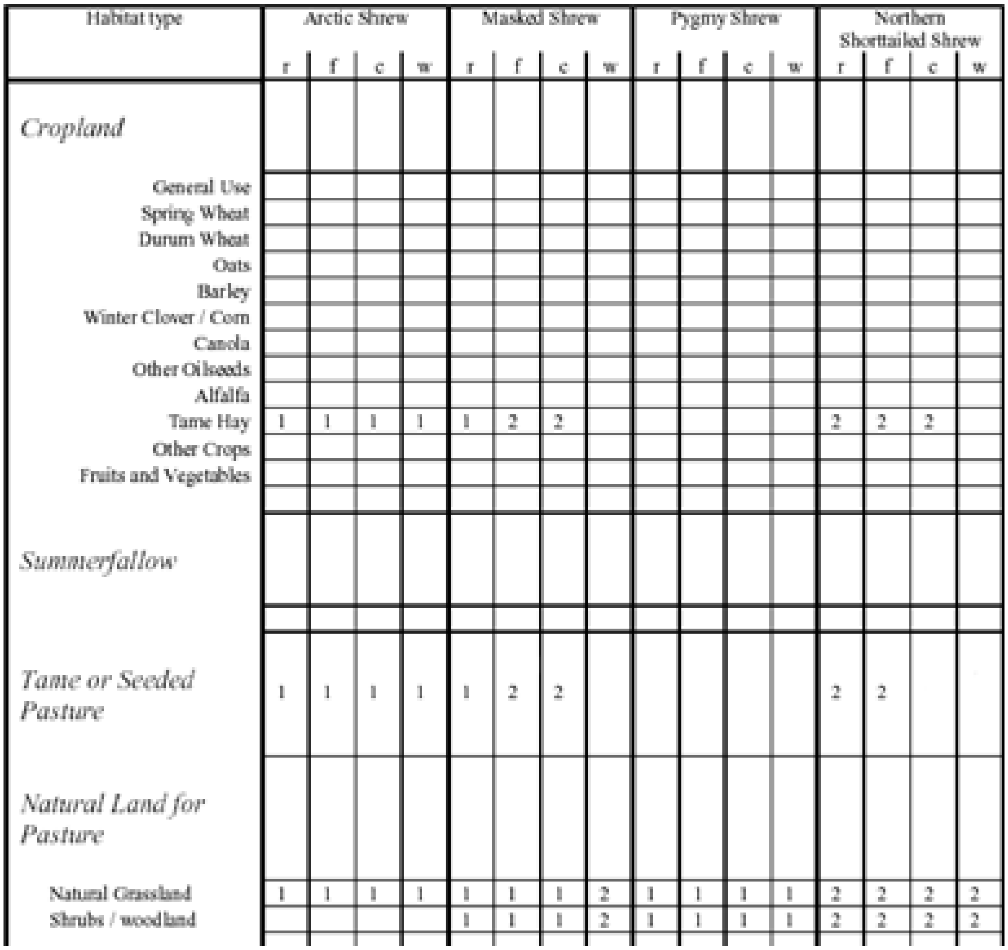
The vertical axis of the matrices consisted of five main habitat types: 1) cropland, 2) summerfallow, 3) tame or seeded pasture, 4) natural land for pasture, and 5) all other land. Some of these were divided into sub-types of more specific habitat types. The horizontal axis consisted of five habitat use categories: 1) breeding, nesting and reproduction; 2) feeding and foraging; 3) cover, resting, roosting, basking and loafing; 4) wintering; and, 5) staging (for birds only).

Cells within the matrices were scored from 1 to 3, ranked in terms of how dependant a species is on that combination of habitat type and habitat use:

- primary (1): the species is dependent on or strongly prefers the habitat type
- secondary (2): the species uses the habitat type but is not totally dependent on it
- tertiary (3): the species does not require the habitat type, but is occasionally observed there

Cells were left blank where a species does not use the corresponding habitat type, and marked with an X where a species actively avoids the habitat type. Each separate use of a habitat type by a species, regardless of the purpose (e.g. nesting or foraging), was tallied as a “habitat use” (Neave et al. 2000).

**Figure 4: Portion of a habitat suitability matrix developed for the seven main Ecozones in which agriculture is practiced in Canada. See text for description. From Neave and Neave (1998).**



| Habitat type | Arctic Shrew | | | | Masked Shrew | | | | Pygmy Shrew | | | | Northern Shorttailed Shrew | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | r | f | c | w | r | f | c | w | r | f | c | w | r | f | c | w |
| *Cropland* | | | | | | | | | | | | | | | | |
| General Use | | | | | | | | | | | | | | | | |
| Spring Wheat | | | | | | | | | | | | | | | | |
| Durum Wheat | | | | | | | | | | | | | | | | |
| Oats | | | | | | | | | | | | | | | | |
| Barley | | | | | | | | | | | | | | | | |
| Winter Clover / Corn | | | | | | | | | | | | | | | | |
| Canola | | | | | | | | | | | | | | | | |
| Other Oilseeds | | | | | | | | | | | | | | | | |
| Alfalfa | | | | | | | | | | | | | | | | |
| Tame Hay | 1 | 1 | 1 | 1 | 1 | 2 | 2 | | | | | | 2 | 2 | 2 | |
| Other Crops | | | | | | | | | | | | | | | | |
| Fruits and Vegetables | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | |
| *Summerfallow* | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | |
| *Tame or Seeded Pasture* | 1 | 1 | 1 | 1 | 1 | 2 | 2 | | | | | | 2 | 2 | | |
| *Natural Land for Pasture* | | | | | | | | | | | | | | | | |
| Natural Grassland | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 1 | 2 | 2 | 2 | 2 |
| Shrubs / woodland | | | | | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 1 | 2 | 2 | 2 | 2 |

## Empirical habitat models

Empirical habitat models are derived as a functional relationship between some measure of species presence or habitat preference (dependant variable) and underlying habitat or landscape characteristics (independent or predictor variables). Dependant variables that have been modelled include population density, population growth rate, species richness, relative abundance, nest locations, recruitment and presence/absence (Puttock et al. 1996, Özesmi and Mitsch 1997, Basquill and Bondrup-Nielsen 1999, Danks and Klein 2002, Machtans and Latour 2003). Some examples of predictor variables include herbaceous and shrub vegetation (species, percent cover), forest structure (species composition, vertical composition, crown closure, age class), landscape pattern (patch size, length of edges), terrain (slope, elevation, aspect, surface curvature), soils, geology, proximity measures (proximity to roads, industry, cover), adjacent land-use factors and composite variables (habitat complexity) (Christie and van Woudenberg 1997, Radeloff et al 1999, Andersen et al. 2000, Odom et al. 2001, Jones et al. 2002, Store and Jokimäki 2003, Gibson et al. 2004).

The general form of an empirical model is as follows:

$$m = f(p_1, p_2, p_3, \ldots\ p_n)$$

where m is a measure of species presence or habitat preference and $p_i$ represents the i'th predictor variable.

Several different statistical and analytical methods have been used to fit empirical models, including linear regression (Puttock et al. 1996), logistic regression (Özesmi and Mitsch 1997), discriminate analysis (Fielding and Haworth 1995), principal component analysis (Debinski and Brussard 1994), canonical correspondence analysis (Machtans and Latour 2003), regression tree (Andersen et al. 2000), artificial neural networks (Özesmi and Özesmi 1999) and genetic programming (Whigham 2000). The nature of the input data may dictate the type of analysis. For example, logistic regression analysis is often applied to presence-absence data, whereas step-wise multiple regression analysis may be applied to abundance data. Within each of these methods, the developer may adjust parameters and procedures in ways that can significantly affect the predictive accuracy of the resulting model (e.g. Pearce and Ferrier 2000a).

For many species, habitat requirements are related to both the immediate habitat area and the features of the surrounding landscape (Store and Jokimäki, 2003). For example, Kirk et al. (2001)

found that bird assemblages varied with the type of agricultural crop species and adjacent habitat type in southern Ontario. In these cases, habitat models may utilize GIS to quantify and model the spatial relationship of significant landscape features (e.g. Garcia and Armbruster 1997, Gibson et al. 2004).

### Effects of scale

A multiple-scale approach may be needed because the factors that affect habitat suitability for a species may operate at different spatial scales (e.g. Jokimäki and Huhta, 1996). The input data for such models may range from fine-scale high resolution data (e.g., field samples) to broad-scale low-resolution data (e.g. remote sensed data). Wu and Smeins (2000) used a multiple-scale habitat modeling approach that combined regional-, landscape- and site-scale habitat models to identify potential areas of habitat suitability for eight rare plant species. Store and Jokimäki (2003) developed a bird habitat suitability model utilizing habitat factors based on different spatial scales, while combining habitat suitability assessments for multiple species into a single, weighted index. Marshall (1996) used a hierarchical assessment of multiple-scale data to assess the habitat suitability and potential yield of lake trout (*Salvelinus namaycush*) in Ontario. The application of GIS software can facilitate the integration of multiple-scale data into a single analysis or model.

## ASSESSING POPULATION VIABILITY

Population viability analysis (PVA) refers to a collection of methods for evaluating the threats faced by populations or species, their risks of extinction or decline, and their chances of recovery (Keedwell 2004). It is often used in the development of conservation, restoration or management strategies of rare, threatened or endangered species. Lindenmayer et al. (2000) and Ellner and

Fieberg (2003) identify three roles for PVA: 1) to make absolute quantitative predictions of population viability (e.g. probability of extinction, number and distribution of animals), 2) to evaluate the relative effectiveness alternative management scenarios, and 3) to identify research needs in viability assessment. Population attributes that can be predicted through PVA include probability of extinction, number and distribution of animals among patches, total number of occupied patches and probability of patch occupancy (e.g. Lindenmayer and Lacy 2002).

McLoughlin et al. (2003) used PVA to assess the potential decline of grizzly bears (*Ursus arctos*) in Nunavut and the Northwest Territories under increased harvest rates and increases in human activities, such as mining and exploration. Also working with grizzly bears, Wielgus (2002) used PVA to estimate minimum viable population sizes and reserve sizes for the species in British Columbia.

In Québec, Nantel et al. (1996) used population viability analysis to assess the impact of several different harvesting strategies on the threatened American ginseng (*Panax quinquefolium*) and vulnerable wild leek (*Allium tricoccum*), estimating extinction thresholds and minimum viable population sizes.

Population models have been developed to study the impact of population dynamics and associated conservation options in agricultural areas. For example, Jensen and Miller (2004) applied a population model for gray wolf (*Canis lupus*) in northern Minnesota, where the wolf emigrates from wilderness refuge areas into adjacent agricultural lands, resulting in costs associated with control and lost livestock. Their results suggested that conservative control of the wolves on the refuge may in fact result in larger refuge population with less emigration to agricultural lands.

## Tools for assessing population viability

Software packages that carry out PVA include GAPPS, INMAT, RAMAS, VORTEX, PATCH, META-X and ALEX (Possingham 1995, Schumaker 1998, Brook et al. 1999, Grimm 2004). In comparing several different PVA packages, Brook et al. (1999) found that they produced significantly different results. Retrospective tests of historical data showed that the packages did not accurately predict population fluctuations or future population abundance. Lindenmayer et al. (2000) found that the accuracy of VORTEX increased with the complexity of the scenario being modelled, but was still wanting even for species with well-understood population dynamics. In spite of these short-comings, however, several authors have argued that PVA may be used to effectively compare the relative effects of different management strategies (Ellner and Fieberg 2003).

PATCH (Schumaker 1998) is a spatially explicit population viability model that tracks the demographics of a population through time, simulating the birth, death and dispersion of individuals, and predicting population size, time to extinction, and migration and recolonization rates. Carroll et al. (2003) used PATCH and a reserve selection algorithm (SITES) to develop a conservation plan for eight mammalian carnivores in the Rocky Mountains of Canada and the United States. They concluded that the carrying capacity for large carnivores would decline 15% over 25 years if no additional protected areas were established.

Recently, Weclaw and Hudson (2004) developed REMUS, a non-spatial population dynamics model for woodland caribou (*Rangifer tarandus caribou*) in northern Alberta, that can be used to assess the cumulative effects of natural and anthropogenic factors on survival (Figure 5). The model considers three trophic levels: producers (moose forage, lichen, plants), primary consumers (caribou and moose), and secondary consumers (wolves, black bears and humans). It also considers abiotic factors: fire, snow and habitat loss. The model can be used to predict population density under different levels of wolf predation and lichen carrying capacity (for example, Figure 6). Based on simulations using REMUS, Weclaw and Hudson (2004) concluded that industrial development was the most significant factor negatively impacting caribou populations, and that caribou could co-exist with uncontrolled wolf populations in natural boreal ecosystems.

**Figure 5: Modules and framework of REMUS, a simulation model for the conservation and management of woodland caribou (from Weclaw and Hudson, 2004).**

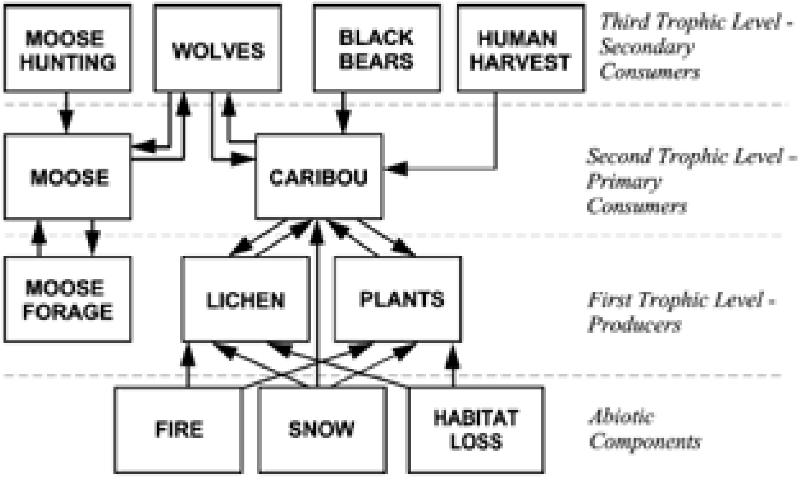
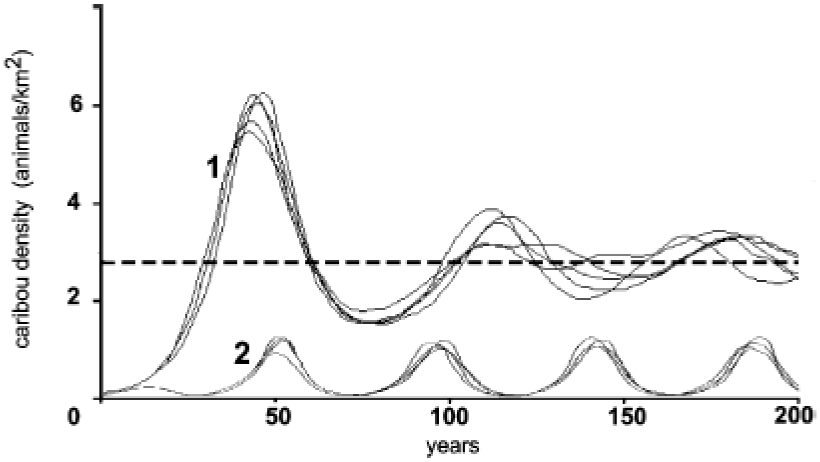


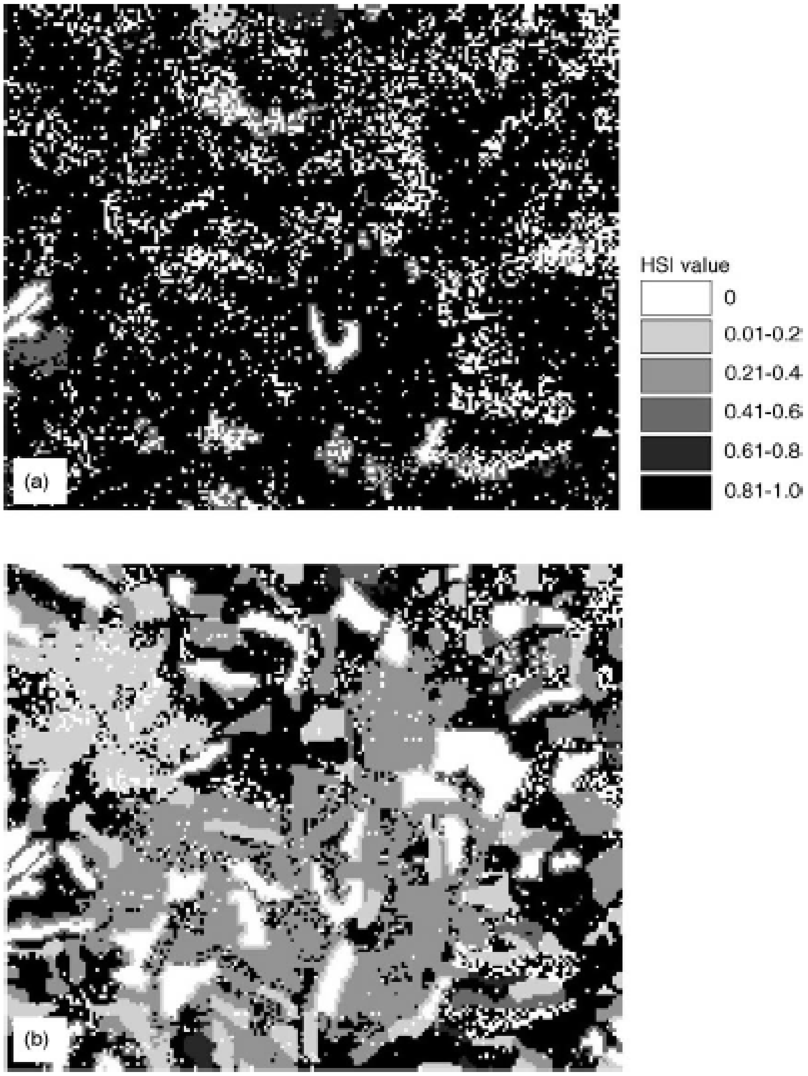
**Figure 6: Caribou density over time under (1) no wolf predation and lichen carrying capacity (K) = 870 kg/ha and (2) uncontrolled wolf predation and increased lichen carrying capacity (K) by 50% (from 870 to 1305 kg/ha) (from Weclaw and Hudson, 2004).**



## Linking landscape simulators and population models

Efforts have been made to link landscape simulations model with population viability and habitat suitability models, in an attempt to predict population dynamics under varied, future landscape scenarios. Larson et al. (2004), working with ovenbirds (*Seiurus aurocapillus*), used the landscape simulator LANDIS to simulate future forest conditions in southern Missouri under two forest management scenarios. Output from the simulations was used as input into habitat models (Figure 7), which in turn provided demographic parameter estimates for the population model, RAMAS GIS. A similar approach was used by Akçakaya et al. (2004) in a study of sharp-tail grouse (*Tympanuchus phasianellus*) in the Pine Barrens region of northwestern Wisconsin.

**Figure 7. Predicted ovenbird habitat suitability index (HSI) values in a portion (approximately 5 km wide) of a southern Missouri study area after 50 years of a simulation under (a) no harvest and (b) even-aged forest management scenarios (from Larson et al. 2004).**



# MANAGING AND USING HABITAT AND LANDSCAPE DATA AND INFORMATION

The effective use of data associated with wildlife and landscape studies can be difficult and complex. The datasets that are available to be applied to a problem often come from a variety of disparate sources. They may vary in scale, resolution, accuracy and precision. Spatial datasets may be of several forms, including points (e.g. nesting sites), polygons (e.g. parks) or lines (e.g. streams). Some datasets may have a temporal component. For these reasons, decision support systems have been developed to help manage, catalogue, query and distribute data so that it can be applied effectively and (relatively) seamlessly to a variety of projects.

An example of such a system is WILDSPACE (Wong et al. 2003), developed by the National Water Research Institute and Canadian Wildlife Service (Ontario Region) of Environment Canada. WILDSPACE is “a DSS used to study complex wildlife problems involving multiple projects and data that are temporally and spatially heterogeneous” (Wong et al. 2003). It serves as a repository of geo-referenced ecological data, and facilitates sharing and merging of data from multiple projects. Users can run spatial and non-spatial queries on wildlife habitat information from a species and/or a spatial perspective. Analytical procedures developed for one project are available to be applied in other projects that require similar analysis. WILDSPACE incorporates a spatial analysis module, a data analysis module, a visualization module and meta-data management tools.

## LANDSCAPE MODELS AND SIMULATORS

Landscape models and simulators have proven to be very effective tools in the study of the relationships between landscape disturbance, vegetation, succession and climate (Keane et al. 2004). They are used for several purposes, including:

- determining pre-settlement landscape characteristics of an area
- determining the natural bounds of variation in landscape characteristics
- predicting future landscape conditions

- predicting the potential effects of land-use management alternatives and climate change
- developing strategies for old-growth forest conservation

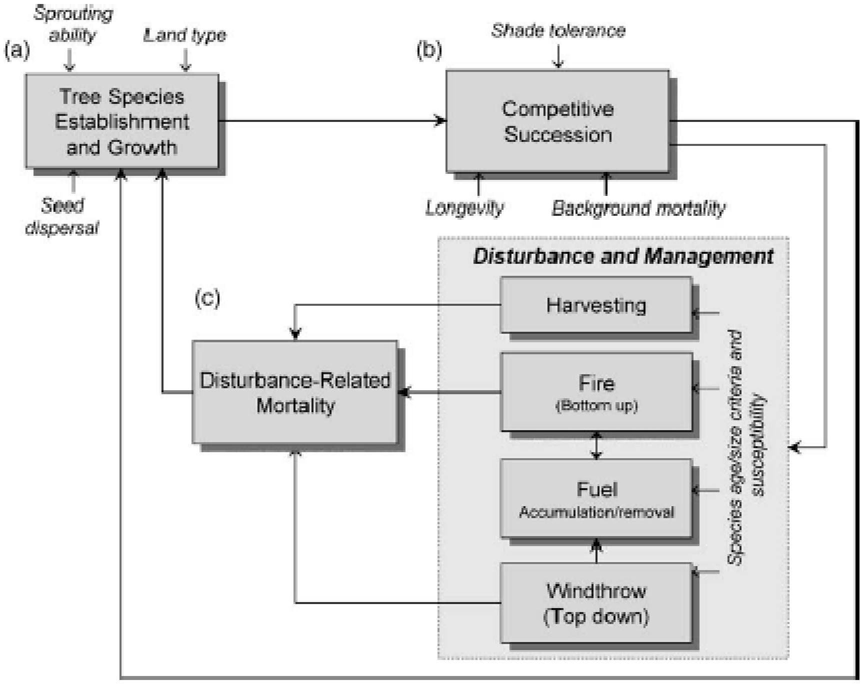
Landscape models may be categorized as 1) empirical and analytical models, such as statistical models that often have a single solution; 2) and stochastic models, which include algorithms based on random choices; these are typically simulators (Mladenoff 2004). Stochastic models do not yield a unique solution; several replicate runs of such models are required to provide an ‘average’ estimate of a solution, and perhaps an associated estimate of variance. Results may be described in terms of probabilities of outcomes or trajectories.

Landscape simulators are often spatial, simulating entities and processes in two- or three-dimensional space. An example is fire, for which fire spread may be simulated as the movement of a fire front across a row-column grid of cells representing a landscape.

The Boreal Forest Landscape Dynamics Simulator (BFOLDS) is a spatially explicit, mechanistic and stochastic model that predicts forest fire regimes, post-disturbance early recruitment, and forest cover change for large areas over the medium term (100-300 yrs) for the boreal forests of Ontario (Perera et al. 2002). The model contains two modules: a forest fire regime simulator and a vegetation transition simulator. The forest fire regime simulator is process-based, containing sub-modules of fire ignition and fire spread, which make use of indices of the Canadian Forest Fire Weather Index System and the Canadian Forest Fire Behaviour Prediction System. The vegetation transition simulator contains early recruitment, vegetation transition, and spatial bias sub-modules. BFOLDS has been used in Ontario as an exploratory tool, to generate spatially explicit null hypotheses of forest fire regimes, forest cover distribution, and aging (Perera 2004).

Another example is LANDIS (Forest Landscape Disturbance and Succession). LANDIS is a spatially explicit, stochastic forest landscape model designed to simulate large landscape ($10^3$ - $10^7$ ha) over long periods of time ($10^1$-$10^3$ years) (Mladenoff et al. 1996). It is designed to provide species level dynamics of succession and dispersal as well as the interaction of multiple disturbances including fire, windthrow and harvesting. The major modules of LANDIS include competitive succession, establishment and growth, wind and fire disturbances, fuel and harvesting (Mladenoff 2004) (Figure 8).

**Figure 8: Major LANDIS model dynamics and modules, including (a) species-site quality interactions, (b) succession dynamics, and (c) disturbance (from Mladenoff 2004).**



As with many spatially and temporally extensive simulation models, LANDIS is not intended for the precise prediction of landscape conditions at a particular point in space and time. Rather, it is intended to provide an understanding of the cumulative and interacting long-term effects of natural disturbances and forest management practices.

# ASSESSING LANDSCAPE PATTERN AND STRUCTURE

Habitat suitability, species richness and other ecological properties are directly affected by landscape pattern and structure (e.g. Glennon and Porter 1999, Penhollow and Stauffer 2000, Fearer and Stauffer 2004). Natural events and anthropogenic activities can have a significant impact on the landscape and thereby modify these properties. As a result, there is much interest in the development and application of indices or metrics that quantify landscape patterns.

## Landscape pattern effects on habitat

Many studies have found links between landscape pattern and habitat preference or species abundance. For example, in southern Saskatchewan, Bayne and Hobson (1998, 2000) found that the relative abundance of several small mammal species was correlated with some metrics (e.g. contiguity) but not others (e.g. forest patch size). Fearer and Stauffer (2004) found that ruffed grouse (*Bonasa umbellus*) in southwest Virginia preferred areas with high densities of smaller than average patches of uniform size and shape, with high contrast edge. Glennon and Porter (1999) linked landscape metrics as determined from Landsat imagery to the relative abundance of wild turkey (*Meleagris gallopavo*) in southwestern New York, finding a positive correlation with edge density, interspersion and juxtaposition, patch per unit area, and amounts of agriculture and open cover types. Species richness and the likelihood of attaining critical biodiversity (i.e., the level of species richness at which communities are most susceptible to disturbance) may be affected by landscape structure (With and King 2004).

Landscape pattern analysis provides a means of objectively assessing and monitoring the impacts of land-use decisions. Sachs et al. (1998) measured several landscape metrics on classified Landsat TM imagery to study the effect of harvesting on landscape structure over a 17-year period in interior British Columbia. Harvesting typically produced patches that were smaller, of simpler shape, and with a lower perimeter/area ratio than natural conifer patches. Egbert et al. (2002) measured changes in landscape structure in Finney County, Kansas, to assess the impacts of the Conservation Reserve Program, CRP (the conversion of cropland to grassland, woodland, and other conservation uses that took place in the U.S. between 1986 and 1995). They concluded that CRP increased the potential habitat for species requiring large areas of grassland. Working on a watershed in Queensland, Australia, Apan et al. (2002) assessed changes in riparian landscape structure by measuring landscape metrics on two years of Landsat TM imagery (1973 and 1997). They found that vegetation corridors became more fragmented, smaller and more isolated, chiefly due to conversion to pasture, raising concerns about the health of the watershed.

## Tools for assessing landscape pattern

Hundreds of different landscape metrics have been developed, but generally they can be used to quantify four general types of landscape pattern:

- spatial point patterns (e.g. trees in a stand)
- linear network patterns (e.g. stream network)
- surface patterns (e.g. DEM)
- categorical or thematic map patterns (e.g. landcover)

Of particular interest in habitat and biodiversity studies are categorical/thematic pattern metrics of composition (e.g. richness, evenness, diversity) and spatial configuration (e.g. patch size distribution, patch shape complexity, core area, isolation/proximity, contrast, dispersion, connectivity).

Often, the underlying computations and algorithms of metrics are complex and computationally intensive, particularly when applied to extremely large landscapes. As a result, several software tools have been developed to carry out the calculations and streamline the underlying data management issues. One of the first was FRAGSTATS, originally released in 1995 (McGarigal and Marks 1995, McGarigal et al. 2002). FRAGSTATS is designed to compute a wide variety of landscape metrics for categorical maps. Metrics are grouped according to the component of pattern they measure (patch, class, and landscape) and include metrics for area, density, edge, shape, core area, contrast, connectivity and diversity.

A software program related to FRAGSTATS is LEAP II (Perera et al. 1997). LEAP II uses FRAGSTATS for the underlying computations, but provides a user-friendly interface for setting program properties, generating classifications, viewing tabular output, and generating graphs and maps of results. LEAP II allows the user to:

- explore landscapes from many perspectives including fragmentation, edge content, spatial geometry, connectivity;
- monitor and track temporal changes in ecological criteria following implementation of management and policy options; and
- assess results of spatial simulations of management and policy options, when applied with other DSS tools, such as landscape simulators.

FRAGSTATS*ARC (Berry et al. 1998) links the metric calculations of FRAGSTATS with the GIS capabilities of ARC/INFO®. FRAGSTATS*ARC can generate all the indices generated by FRAGSTATS, and includes several others as well, while leveraging the data management, analysis, mapping and display capabilities of ARC/INFO.

Another program developed for the assessment of landscape structure is Patch Analyst (Rempel and Carr 2003). Patch Analyst facilitates the spatial analysis of landscape patches and modelling of attributes associated with patches. It is implemented as an extension to ArcView GIS®. Patch Analyst 3.1 contains analysis and modeling functions related to vector/polygon maps, while Patch Analyst (Grid) 3.1 extends analysis capabilities to raster maps. Attribute modeling capabilities allow the user to translate vegetation age and composition into habitat units, or forest age/seral classes, according to pre-defined rules. Users can classify each polygon or grid clump (e.g., to a vegetation class, seral stage, habitat unit).

## ASSESSING THE IMPACT OF LAND-USE MANAGEMENT ALTERNATIVES

A number of decision support systems and simulation models have been developed that allow the user to study the effects of land-use management alternatives on habitat suitability, biodiversity and resource sustainability at large scales. Increasingly, these types of tools have been brought to bear as stakeholders require land managers to demonstrate the implications of proposed objectives, management strategies and policy options, particularly in the context of multiple-resource development. Many of these tools are spatially and temporally explicit, and are linked to GIS systems that map the distribution of predicted attributes, such as timber harvest, habitat suitability, water quality, land use conflicts, conservation areas and biodiversity (e.g. Garcia and Armbruster 1997, Roloff et al. 1999, Crist et al. 2000, Putz et al. 2003, Rudner et al. 2004).

An example of such a tool is LEEMATH, Landscape Evaluation of Effects of Management Activities on Timber and Habitat (Li et al. 2000). LEEMATH is a spatially and temporally explicit tool that integrates several modules: habitat attribute, habitat suitability, stand growth, spatial habitat attribute and landscape habitat. The user can specify a management regime defined by a harvest schedule, a silvicultural treatment plan, the spatial distribution of stands, and the target wildlife species. Outputs from the simulation include timber growth and harvest (e.g. total basal area), habitat attributes (e.g. mean habitat patch size) and habitat suitability (e.g. total habitat area).

Seely et al. (2004) constructed a decision support system for a 288,000 ha forest in northeastern British Columbia. Their spatially and temporally explicit model includes stand-level, forest estate, habitat and visualization modules, and predicts a wide array of attributes including harvest volume, gross profit, carbon storage, patch-size distribution and snag density. They used their system to compare two alternative harvest strategies against a natural disturbance baseline regime. A similar system was developed for use in west-central Alberta (Van Damme et al. 2003).

SIMFOR is a decision support tool designed to help forest managers and researchers evaluate the impacts of forest management alternatives on landscape and wildlife indicators. It was developed under the direction of Dr. Fred Bunnell at the Centre for Applied Conservation Research (CACR), University of British Columbia, Faculty of Forestry (Vancouver, British Columbia). SIMFOR is spatially and temporally explicit and uses GIS-based information, such as stand age and composition. It can be used to evaluate the response of forest vegetation to harvesting treatments or natural disturbance events, and predict consequent landscape characteristics and species-specific habitat suitability (Wells and Moy 2002).

Kangas et al. (2000) describe a general framework for landscape ecological forest planning, with emphasis on the boreal forest. Their decision support system considers the natural species composition of the area, with special attention to endangered and vulnerable species. The major process steps of the system are:

1. identification and structuring of the decision problem;
2. preliminary analysis of objectives (including ecological goals);
3. description of forest conditions (including ecological features);
4. description of possible treatment schedules;
5. examination of the production possibilities;
6. generation of forest plan alternatives;
7. analysis of objectives and preferences;
8. comparison of alternative forest plans; and
9. compilation of the selected plan.

The process may be iterative and interactive, with steps being repeated as different production possibilities and alternative forest plans are assessed. The process utilizes GIS software, optimization algorithms and simulation.

BOREAL is a tactical planning decision support system that predicts the effects of alternative forest management strategies in terms of forest product yields, revenues, and habitat area and distribution (Puttock et al. 1998). Puttock et al. (1998) used the system to study the effects of forest policies on timber production and moose (*Alces alces*) habitat on a 5,000 ha area of Algonquin Park, Ontario.

Working at a finer scale and stand level, Kolström and Lumatjärvi (1999) developed a simulation model that integrated climate, soil conditions, individual tree attributes, stem decay, succession and forest management options to model habitats of beetle and polypore species in boreal forests of Finland.

## ASSESSING BIODIVERSITY AND CONSERVATION POTENTIAL

Several procedures and tools have been developed to assess and map biodiversity of existing landscapes. For example, Morrsion et al. (2000) describe a method for identifying areas of high biodiversity in aquatic environments using habitat supply analysis, and the use of this approach to help prioritize habitat restoration and preservation efforts**.**

Various resolutions and dates of remotely sensed images have been used in assessing existing biodiversity. Remotely sensed data (e.g. AVHRR) and their derivatives (e.g. NDVI) provide a means of economically assessing large areas of the earth's surface at regular intervals. As the spatial and spectral resolutions of satellite sensors has improved, the potential for using remote sensing to estimate biodiversity has been demonstrated (e.g., Nagendra and Gadgil 1999, Gould 1999, Turner et al. 2003). Working in an agricultural area of Finland, Luoto et al. (2000) derived estimates of landscape variables from Landsat TM images and related them to species richness using multiple regression analysis. The final models explained 46-51% of the variation in the species data and were used to predict the patterns of total and rare species richness in an agricultural area of 601 $km^2$.

Selecting and prioritizing areas based on biodiversity content is an explicit goal of conservation planning and is necessary to achieve effective biodiversity conservation in areas supporting multiple land use objectives (Sarkar 2004). Church et al. (1997) developed the Biodiversity Management Area Selection model (BMAS) to help select areas in a forest region that should be managed to enhance long-term levels of biodiversity. The model consists of the following process steps:

1. assemble input data of land cover, habitat distribution and species presence;
2. forecast land use change due to human activities and conversion; use this to identify reductions in habitat that support various elements (e.g. species, communities, old growth stands); and
3. identify which elements are at risk and determine how much protected area is necessary to keep each element from being at risk.

The model helps managers explicitly quantify and select those areas that would be most useful in maintaining a minimum distribution of specific elements that are determined to be at risk. A similar approach is described by Balram et al. (2004), who developed a system that integrates expert knowledge with spatial environmental data through GIS software to establish priority areas for biodiversity conservation. The system provides a framework for establishing assessment criteria, integrating knowledge with data and building consensus.

The Biodiversity Expert System Tool, BEST, (Crist et al. 2000) is a spatially explicit software system that provides predictions of conflict between proposed land uses and biotic elements, and is intended for use at the start of the land use development review process. BEST incorporates tables that translate named land uses into habitat impact categories, linked to tables that specify the sensitivity of biotic elements to those habitat impact categories. Supporting data layers include roads, streams, land cover, predicted terrestrial vertebrate distribution and critical habitats.

Sarkar et al. (2002, 2004) describe the process of ‘place prioritization’ on the basis of biodiversity content for a systematic conservation planning process, which they have encapsulated in the software program ResNet. The process emphasizes the selection of places containing rare species (the principle of rarity), and places which add as many under-represented species as possible to a set of selected places (the principle of complementarity). The ResNet algorithms are particularly pertinent to reserve designs for conservation of rare species. Using this approach, Sarakinos et al. (2001) prioritized areas for potential protection in Québec, and concluded among other things that the existing network of protected areas in Québec does a poor job of protecting the biodiversity surrogates considered in the study.

C-Plan (Conservation Planning System) is another software tool designed for supporting place prioritization and conservation planning decisions in heavily influenced landscapes[1]. C-Plan was developed by the New South Wales National Parks and Wildlife Service of Australia. It displays the relative contribution of land areas towards predefined conservation goals, based on a biological database of modelled species or forest distributions and/or actual survey results (Warman and Sinclair 2000). It is spatially explicit, interactive, Windows-based and links to a GIS (ArcView®) to map the options for achieving conservation goals. C-Plan applies a complementarity approach by building on existing conservation networks, selecting new areas to support species or habitats not yet adequately represented (Warman and Sinclair 2000). It can model alternative land-use activities, such as timber harvesting, to minimize the impact of conservation on the costs associated with those activities (e.g. loss of timber revenue in conservation reserves) [2].

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[1] From http://members.ozemail.com.au/~cplan
[2] From http://www.geog.ubc.ca/courses/klink/g470/class02/hlindh/introduction.htm

## Forest Fragmentation: Affects of Forestry and Agriculture

In addition to causing direct reductions in habitat areas, forestry and agricultural practices can affect landscape structure in ways that impact wildlife. In particular, forest fragmentation and its effect on forest patch size, patch distribution and forest edge can affect species abundance and composition (e.g. Bouliner et al. 1998).

Working in the southern boreal mixedwood forests of Saskatchewan, Bayne and Hobson (1998) used analysis of variance to assess relative abundance of several small mammal species in forest patches in contiguous, logged and agricultural areas. They determined that abundance was lower in forest patches isolated by logging than in farm woodlots surrounded by agricultural land. There was no difference in abundance between small (10 ha) and large (> 20 ha) woodlots. In the same region, Bayne and Hobson (2000) assessed the effects of agriculturally induced fragmentation on the North American red squirrel (*Tamiasciurus hudsonicus*). They conducted stepwise multiple regression of relative abundance (dependent variable) against several landscape and vegetation attributes (independent variables), including forest-fragment size, distance to nearest forest patch, and forest-fragment shape. The results suggest that relative abundance was positively correlated with forest-fragment size, and that squirrels were significantly more abundant in forest fragments than in contiguous forests.

Kolozsvary and Swihart (1999) studied the effects of agriculturally induced fragmentation of forests and wetlands on several amphibian species in the midwestern U.S., using logistic regression to develop predictive models of occurrence in response to forest and wetland patch and landscape variables. Factors affecting occurrence varied among species, and included forest patch area, proximity of wetlands and degree of wetland permanency. Species richness was greatest for wetlands with intermediate degrees of permanency.

Agricultural practices may also directly affect adjacent forest patches. Boutin and Jobin (1998) conducted a detailed assessment of vegetation composition in woodlots and hedgerows adjacent to agricultural fields associated with three different farming intensities in the Richelieu River watershed, Québec. Using multivariate analysis of variance and principle coordinate analysis, they determined that species composition varied considerably with farming regime: weedy, short-lived grassy-type plants were favoured next to intensively farmed fields, whereas species typical of native maple-tree associations were favoured next to less intensively managed fields. Boutin and Jobin (1998) suggest that buffer strips around agricultural fields may aid in preserving native plants and wildlife in adjacent woodlots.

## SCENARIO PLANNING AND ALTERNATIVE FUTURES

Scenario planning is a strategic planning tool or method for improving decision making against a background of uncertainty. “The central idea of scenario planning is to consider a variety of possible futures that include many of the important uncertainties in the system rather than to focus on the accurate prediction of a single outcome” (Peterson et al. 2003b).

A scenario is a structured account or story of a possible future; a future that could occur given certain, plausible circumstances. Scenarios are based on the question “what will happen if” and not on the more certain question “what will happen”. However, the set of assumptions underlying each scenario build on logic, coherence and consistency (Tress and Tress 2003).

Scenario planning provides a creative forum for stakeholders to exchange ideas and opinions, to negotiate, and to evaluate and reassess their own beliefs about a system. Because uncertainty is accepted as part of the process, scenario planning may facilitate this process more so than other forms of planning.

Peterson et al. (2003b) identify six interacting steps in scenario planning:

1. identification of a focal issue: specifying an issue, problem or question, which will define the system of interest
2. assessment: evaluating the people, institutions, ecosystems and linkages among them that define the system;
3. identification of alternatives: defining plausible and relevant ways in which the system may evolve;
4. building scenarios: creating a set of scenarios based on understanding gained during previous steps;
5. testing scenarios: assessing scenarios for consistency and plausibility; and
6. policy screening: using scenarios to test and analyze current policies, or create new ones.

These steps may be carried out in an iterative manner as the planning progresses, with earlier steps being repeated in light of results from latter steps. The outcomes of scenarios may be visualized with charts, tables, plans, maps, drawings and/or GIS modelled landform surfaces (Tress and Tress 2003).

Peterson et al. (2003a) used scenario planning in the Northern Highland Lake District of Wisconsin, an area which is undergoing a transition from sparsely to more densely populated, to explore future development and ecosystem service alternatives. In the context of key social and ecological issues of the area, they developed three 20-year scenarios that differed substantially in the projected ecosystem quality, residential development and property values. Each of the scenarios presented plausible future, given certain assumptions. The process provided a starting point for participatory discussions of alternative futures by stakeholders.

Tress and Tress (2003), working in an agricultural area of Denmark, developed four extreme 20-year scenarios to illustrate possible future states of the countryside. Each of the scenarios represented a different, single land-use: industrial farming, recreation and tourism, nature conservation, and residential expansion. To visualize the alternative futures, Tress and Tress (2003) took a birds-eye view aerial photo of the study area at an angle that effectively profiled features of the landscape. For each scenario, the photo was photo-realistically modified in software by adding or removing features based on the effects of the scenario, by, for example, adding the image of a residential neighbourhood (Figure 9). These realistic image visualizations provided stakeholders with an effective demonstration of the consequences of the four alternatives, facilitating discussions about future land-use.

In Canada, scenario planning is being used as an integral component of the forest management planning process (Wade 2000, Marsland and Wolfe 2003). In New Brunswick for example, MacLean et al. (1999) used scenario planning to develop 25 scenarios that weighed the effects of alternative means of riparian management, road construction, vegetation and insect control, harvesting, biodiversity maintenance and plantation establishment. The effect of each scenario was assessed in terms of factors such as timber supply, forest structure, biodiversity and wildlife habitat, and a preferred management scenario was then selected by stakeholders.

**Figure 9: Photo-realistic images visualizing an agricultural area (a) and four alternative future scenarios (b to e) under different management regimes (from Tress and Tress 2003).**

**a. Initial condition of study area**

**b. Industrial agriculture scenario**

**c. Tourism and recreation scenario**

**d. Nature conservation scenario**

**e. Residential expansion scenario**

Berger and Bolte (2004) describe a model used to assess alternative futures to the year 2050 in the agricultural region of the Willamette River Basin, Oregon. The model uses a spatially explicit, multi-attribute, decision-making process to simulate land cover change, integrating crop rotation, water allocation and land conversion policies (Figure 10). A group of stakeholders developed three policy alternatives to determine land use: continuation of current trends (Plan Trend 2050), an increased reliance on market forces (Development 2050), and an increased emphasis on environmental restoration programs (Conservation 2050). The agronomic and environmental effects of each scenario were determined by assessing the following characteristics on the resultant landscapes: farmland conversion, crop distribution, soil erosion, groundwater vulnerability, riparian cover and wildlife habitat quality (for example, Figure 11). The simulations showed that the restoration scenario generally enhanced wildlife habitat across the region, and was particularly effective in improving riparian habitat; both the market-driven and restoration scenarios converted 15% or more of agricultural land to other uses (Berger and Bolte 2004).

Bringing together experts in agronomy, plant and animal ecology, wetlands ecology, water quality, hydrology, agricultural policy, agricultural extension and GIS, Santelmann et al. (2004) designed three alternative future scenarios for agricultural landscapes in two watersheds in Iowa, USA:

- Production Scenario: profitable agricultural production is the dominant objective, with emphasis on large-scale, high-input agriculture on all productive lands;
- Water Quality Scenario: agricultural practices are modified in response to policies aimed at enhancing water quality standards and reducing soil degradation
- Biodiversity Scenario: preservation and enhancement of biodiversity is a priority, aimed

at increasing the abundance and diversity of native plants and animals

The alternative futures were compared to one another and to present conditions using maps, GIS-based models and digital simulations (e.g. Figure 12), and assessed in terms of water quality, economic return, farmer preference, and impacts on native plants and animals (risks to biodiversity). For the later, two methods were used: 1) calculation of change in habitat area, weighted by habitat quality, and 2) spatially explicit population models (SPEMs) to estimate relative densities for mammal species after 100-years. Results suggested that the Biodiversity Scenario ranked higher than the Production and Water Quality Scenarios in all criteria except profitability and water quality, respectively. However, the Biodiversity and Production Scenarios ranked scored similarly in profitability (Santelmann et al. 2004), leading the authors to suggest that innovative agricultural practices may reduce negative environmental impacts of agriculture, while still being acceptable to farmers.

**Figure 10: Program flow for a landscape evolution model used to assess alternative futures, in the agricultural region of the Willamette River Basin, Oregon (from Berger and Bolte 2004).**

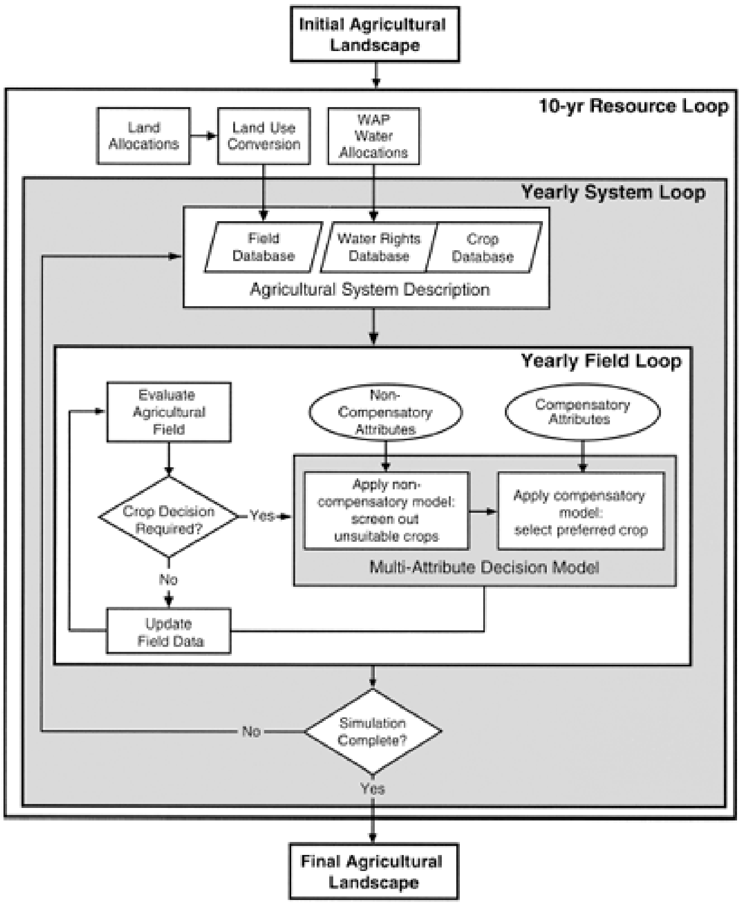


**Figure 11: Crop diversity as measured by Shannon's evenness index, in the agricultural region of the Willamette, as it was in 1990 and as predicted in 2050 under three alternative future scenarios River Basin, Oregon (from Berger and Bolte 2004).**

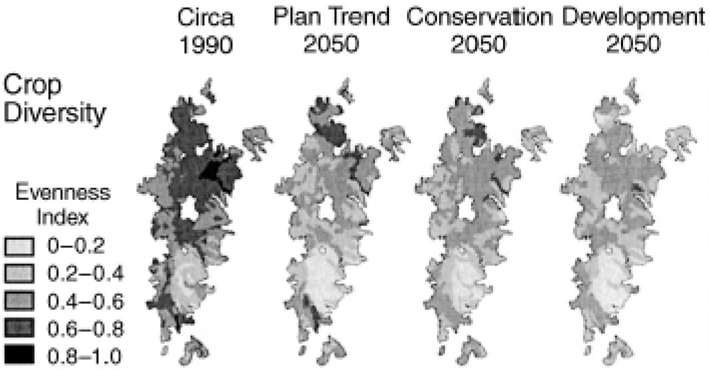
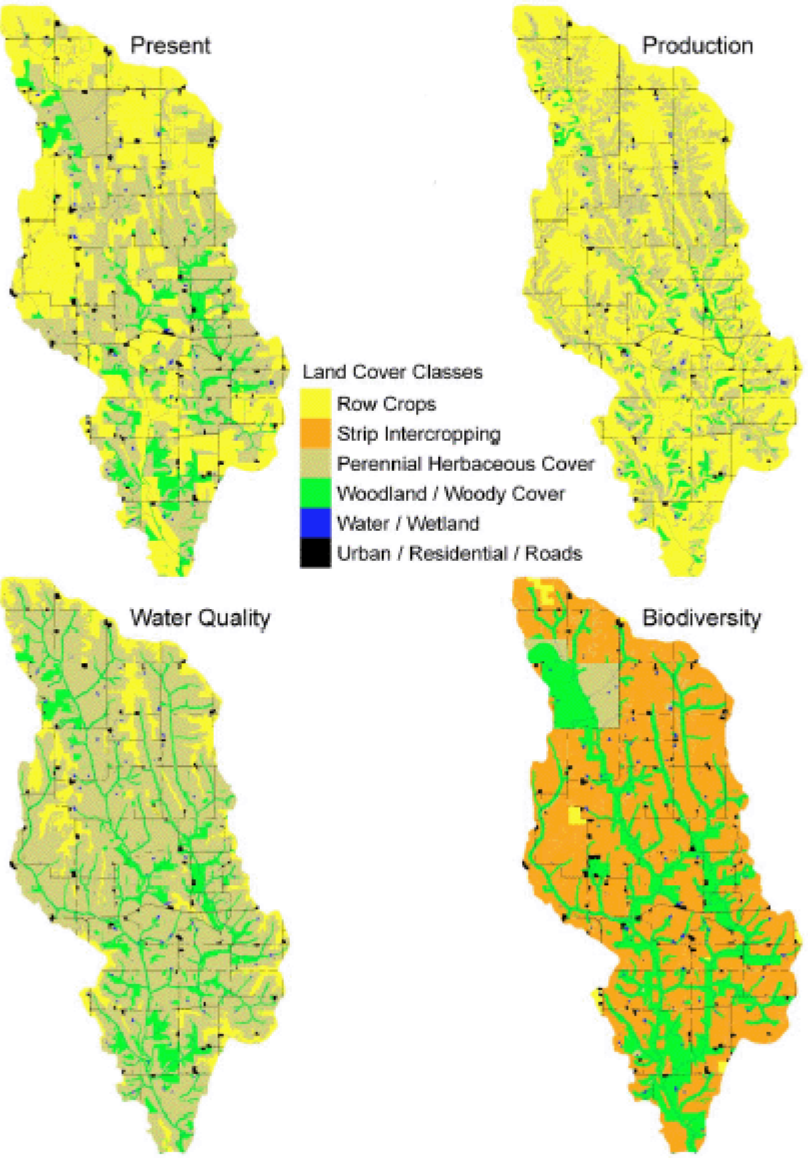


**Figure 12: Land cover classes as they occur presently (Present) and under three alternative future scenarios (Production, Water Quality and Biodiversity) for the Buck Creek watershed in Iowa, USA (from Santelmann et al. 2004).**



NatureServe (http://www.natureserve.org), a non-profit conservation organization that provides information and tools for conservation, is developing an alternative futures type decision support system to help planners incorporate biodiversity considerations into planning efforts. NatureServe Vista "is a collection of desktop and Internet software tools and information resources, supported by a network of experts to apply them to real-world land use and conservation decisions."[3] The system allows users to consider and assess biological and ecological issues, community conservation values and goals, and planning and policy options.

NatureServe Vista is intended for a wide range of users and agencies, including planners, conservation groups, land trusts, and local governments. It can be used to:

- assess the existing biodiversity resources and values in their area;
- identify the ecologically sensitive areas that should be conserved, and also those places where development presents fewer conflicts;
- assess the biodiversity implications of alternative land use scenarios; and
- dynamically plan for changing conditions.[3]

Topping et al. (2003) developed a comprehensive and detailed model framework, ALMaSS (Animal, Landscape and Man Simulation System), to assess the effects of land-use and management alternatives, including agricultural practices, on Danish landscapes and wildlife. ALMaSS includes sub-models for farm management and animals (Figure 13). The farm management simulator considers alternative farm types and crop growth models. The animal models incorporate detailed species-specific life history information. They are agent-based,

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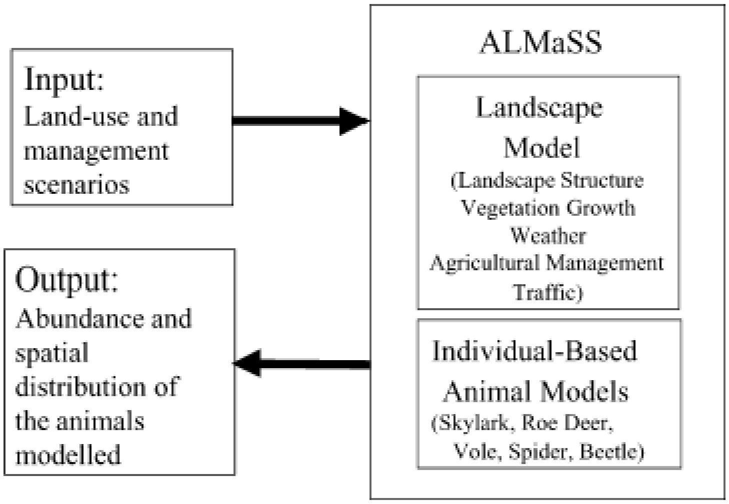
[3] From NatureServe, http:// www.natureserve.org

allowing each animal to interact with other animals and the environment. The model has been used to assess the impacts of agricultural management alternatives (crop rotation, crop diversity, pesticide use, and ground water protection) on insects, birds and mammals (Topping et al. 2003, Topping and Odderskær 2004, Jepsen et al. 2004).

**Figure 13: Overview of the ALMaSS simulation model framework (from Jepsen et al. 2004).**



# INTEGRATED LANDSCAPE MANAGEMENT MODELS

Integrated Landscape Management Models (ILMMs) refer to a group of tools that use computer simulations to predict and assess potential future trends based on policy, management, and strategic options[4]. As with Alternative Futures and Scenario Planning approaches, a key component of ILMMs is the involvement of stakeholders in assessing social, economic and ecological priorities, and in identifying potential conflicts and resolutions. And as with these other approaches, ILMMS are often concerned with general patterns of future trends in the face of uncertainty, rather than in precise predictions of future outcomes.

ILMMs can be grouped into three general categories[4]:

- integrative models, which integrate data on all indicators of potential importance, ranging from economic indicators to species diversity;
- planning models, which focus on planning and coordinating the integration of sub-models into a single system; and
- objective-specific models, which may consider multiple indicators, but only in the context of a specific interest, such as forestry or agriculture.

Examples of ILMMs in use in Canada include GB-QUEST and ALCES.

GB-QUEST is being applied in the Georgia Basin Futures Project (GBFP) on the west coast of British Columbia. The purpose of the GBFP is to "increase the level understanding of how complex ecological, social and economic systems interact and to discover new ways of achieving a sustainable future for the region."[5] The project brings together the expert knowledge of researchers with the input of individuals from business, education, government and the general community, and includes private, public and non-profit organizations.

The GBFP uses GB-QUEST to engage the general public in creating and assessing alternative futures to the year 2040. GB-QUEST is a spatially explicit simulation model that utilizes a 'backcasting' approach, which allows users to specify a desirable future scenario and then explore the trade-offs in consumer and policy preferences required to achieve it. It allows for different levels of expertise among users. The model considers several topics, including population change,

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[4] From the Policy Research Initiative, Government of Canada, Briefing Note, Sustainable Development Project, Integrated Landscape Management Tools for Sustainable Development and Policy-Making, http://policyresearch.gc.ca

[5] From the Georgia Basin Futures Project, http://www.basinfutures.net

government, urban growth, forestry, agriculture, fisheries, transportation, energy, climate change, air and water quality, and habitat.

The general steps to using the GB-QUEST are as follows:

- Invent a future: by considering world views, values, goals and targets;
- Choose policies: for example, in transportation, housing, lifestyle, land use, government, and industry;
- View consequences of policy choices at the end of each decade; and
- View the overall 40 year scenario. [5]

Another example of an ILMM is ALCES, a comprehensive simulation model that enables resource managers, researchers and the general public to study the potential impact of multiple land-use practices and natural disturbances on the landscape[6] (Figure 14). ALCES can track a variety of land-use practices and processes, including forestry, energy sector development, human population dynamics, parks and tourism, aboriginal peoples and their features, and landscape composition and dynamics. Natural processes that the model can track include fire regimes, insect disturbances, aquatics, carbon pool dynamics, and wildlife habitat and population dynamics.

ALCES is a generic model that requires users to provide data describing initial landscape composition, initial land-use footprint, projected land-use trajectories, growth and yield curves for merchantable forest trajectories, and the demographic characteristics and environmental responses of wildlife species.[6]

Other examples of ILMMs are presented in Table 2.

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[6] From Forem Technologies, http://www.foremtech.com/

**Figure 14: Capabilities and components of the ALCES integrated landscape management tool (from Forem Technologies, http://www.foremtech.com)**

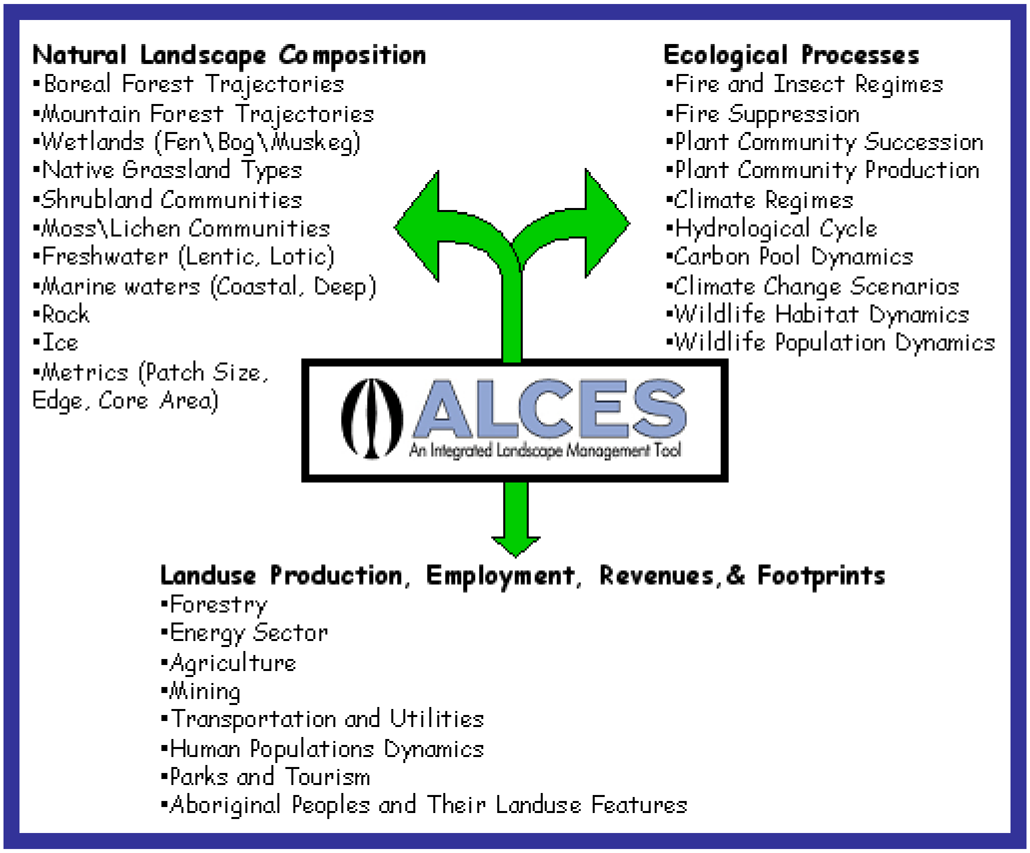

**Table 2: Examples of Integrated Landscape Management Models that are currently available*.**

| Name | Type | Application | Organization / Website URL |
|---|---|---|---|
| GB-QUEST | integrative | | Georgia Basin Futures Project, British Columbia<br>http://www.basinfutures.net |
| ALCES | integrative | | Forem Technologies, Alberta<br>http://www.foremtech.com |
| SELES | integrative | | Simon Fraser University, British Columbia<br>http://www.cs.sfu.ca/research/SEED |
| TOPIC | planning | | WL \| Delft Hydraulics, Netherlands<br>http://www.wldelft.nl/rnd/intro/topic/topic/index.html |
| IWR-PLAN | planning | | US Army Corp of Engineers Institute for Water Resources<br>http://www.pmcl.com/iwrplan/ |
| Tarsier | planning | | http://science.csumb.edu/~tarsier/ |
| SWAT | objective | watersheds | USDA Agricultural Research Service, USA<br>http://www.brc.tamus.edu/swat/ |

**Table 2: Examples of Integrated Landscape Management Models that are currently available*.**

| Name | Type | Application | Organization / Website URL |
|---|---|---|---|
| WAMADSS | objective | watersheds | Center for Agricultural, Resource and Environmental Studies, Missouri, USA<br>http://www.cares.missouri.edu/projects/completed/WM.html |
| RIBASIM | objective | river basins | WL \| Delft Hydraulics, Netherlands<br>http://www.wldelft.nl/rnd/intro/topic/ribasim-63 |
| WLM | objective | waste emissions, surface water | WL \| Delft Hydraulics, Netherlands<br>http://www.wldelft.nl/rnd/intro/topic/wlm |
| TELSA | objective | terrestrial, forests | ESSA Technologies<br>http://www.essa.com/downloads/telsa |
| (multiple) | objective | soil, water, pollution | US Environmental Protection Agency, USA<br>http://www.epa.gov/ceampubl |
| WhAEM2000 | objective | ground water | US Environmental Protection Agency, USA<br>http://www.epa.gov/ceampubl/gwater/whaem |
| TMDL USLE | objective | soil loss, watershed | US Environmental Protection Agency, USA<br>http://www.epa.gov/ceampubl/swater/usle |

** Adapted from the Policy Research Initiative, Government of Canada, Briefing Note, Sustainable Development Project, Integrated Landscape Management Tools for Sustainable Development and Policy-Making, http://policyresearch.gc.ca*

## SUMMARY AND RECOMMENDATIONS FOR FUTURE DEVELOPMENT

A large body of work in the field of wildlife habitat and biodiversity assessment has been developed in the past several decades. This work has furthered our understanding of underlying biological, ecological and anthropomorphic factors and relationships, and lead to the development of models and tools useful for assessment, monitoring and prediction.

Habitat modelling, population modelling and landscape pattern analysis can form an important component in an overall strategy of assessment and monitoring of wildlife habitat and biodiversity. Techniques of habitat suitability and population modelling are well developed and documented. The models are typically species and site specific, however, and would likely require parameterization for new species and regions. Several tools and hundreds of metrics for assessing landscape pattern and structure have been developed. Some or most of the landscape metrics ultimately selected as standards in the Project may already be available in these tools.

Many of the software tools reported here, while not specifically developed for agricultural regions, may, with little or no modification have applicability to the Standards Project. For example, the software Fragstats and related programs (LEAP, Fragstats*Arc) that are used to assess landscape metrics can likely be used as is. Other software, such as WILDSPACE, could potentially be upgraded to incorporate the unique data management requirements associated with agricultural areas.

If new software is to be developed, the system analysis and design phase should include a review of similar existing software to identify potentially useful functions and features, and where available, should include analysis of existing program source code and algorithms. In some cases, existing off-the-shelf software components may be integrated into new software to save development time and costs. The most significant example of this, frequently demonstrated among the models and tools reviewed here, is in the area of GIS. Where the management, analysis and visualization of spatial data is required, use of existing commercial GIS systems is strongly recommended. Other commercially available components that may be of use in software development include spreadsheet components for display of tabular data and image components for graphs and charts.

Any model or tool developed to assess wildlife habitat and biodiversity will require data. The models reviewed here have data requirements that range in extent from a few square metres to thousands of hectares, range in scope from the individual to entire populations, range in time from one growing season to hundreds of years, range in technology from direct visual assessment of an individual to remote sensing of entire landscapes. To a large extent, the data that is available (or can be made available in the near future) determines the type of models or tools that should be developed; good methods for which there is no supporting data are of little value. Hence, the selection of standards for the Project must be made with the underlying data requirements in mind. In cases where the data required for a method is lacking, other available data may act as a surrogate. In fact, this approach is commonly used; for example, in the absence of population survey data, the use of readily available vegetation data applied to a habitat suitability model may be used to predict the potential distribution of a species. Minimally, such data may help focus survey efforts.

Scenario planning has already been effectively implemented in the context of agricultural landscapes, yielding good examples of how it can be applied in the agricultural regions of Canada. Though the process may not yield ‘measurable standards’ per se, it provides an excellent method of facilitating discussions among stakeholders in assessing alternative land-use strategies and their consequences.

The following sub-section summarizes results and recommendations in terms of some of the questions that motivated this review:

- What is the amount, type, pattern and quality of habitat needed to support viable populations?

  *Habitat suitability index models applied to spatially explicit data through geographically information systems (GIS) can be used to generate species habitat maps that reflect current conditions. These maps can used to: 1) quantify the total* *area of available habitat, 2) study the distribution and spatial pattern of habitat areas, for example, in terms of fragmentation and corridors, and 3) identify critical areas for conservation. Several examples in the literature provide useful, proven frameworks for this type of analysis (e.g. Larson et al. 2003, Downey et al. 2004).*

*When linked to an interactive and iterative analytical approach, habitat models can be used to asses "what-if" scenarios that explore the effects of alternative management options on the area, distribution and spatial structure of habitat. This approach can be used to help maximize available habitat for multiple species, while minimizing effort, costs and stresses on other land uses. Most GIS software (for example, ArcGIS® from ESRI) have the functions and features that support this type of analysis in a manual, exploratory context. Such efforts can be applied in conjunction with software and models designed explicitly for optimizing the spatial distribution of conservation areas, such as C-Plan or SITES, which have effectively been used for this purpose in Australia and North America.*

- What is the current status of habitat, critical shortfalls or negative trends?

*The approaches outlined above can be used to assess current habitat conditions, for those species for which habitat and population models have been developed, and for which the underlying data is available. As data is updated to reflect changes in a landscape over time (for example, due to harvesting or natural disturbance such as fire), the models can be re-run to determine the effect of those changes on habitat and population viability. In this way, real-time temporal trends can be monitored so that negative trends or critical shortfalls can be identified as soon as possible.*

*In a more predictive approach to this issue, simulated landscapes can be generated that will reflect the effect of proposed land-use alternatives and/or anticipated natural disturbances, with the aim of predicting landscape* *characteristics to some point in the future. Alternatively, landscapes can be generated that reflect characteristics at some point in the past (e.g. pre-settlement conditions) and/or potential natural vegetation. These simulated landscapes can be generated using landscape simulation models, alternative future and scenario planning approaches or integrated landscape management models. Habitat and population models can then be applied to these landscapes to assess their potential effects on wildlife. A good example of this approach can be found in the work of Larson et al (2004), who used LANDIS to generate the simulated landscape, and the RAMAS GIS population model.*

- What proportions and parts of habitat are the responsibility of agriculture sector? What do semi-natural and cropland areas contribute to the habitat requirements?

*Spatially explicit data has and will continue to play an important role in wildlife habitat and biodiversity planning, monitoring and management. Many, if not most, of the models, tools and approaches reviewed here utilize it. Indeed, many models interface directly with or function through GIS software or utilize datasets created through a GIS.*

*Spatial data in conjunction with a GIS make it possible to develop spatially explicit habitat models, population models and conservation plans. For example, given the necessary habitat attribute data in the form of data map layers, a GIS can be used to generate a corresponding habitat suitability index map based on an existing HSI model. Further, using overlays of existing units of interest (for example, semi-natural and cropland areas), the area and distribution of habitat within each unit can be readily determined. Generally, these analyses can be carried out with existing GIS functionality, without the need for specialized software development.*

*Some GIS software provide access to underlying data management, visualization and geo-processing capabilities to the software programmer, while allowing for the development of software extensions to meet specific end-user requirements* *(for example, habitat modelling). This reduces the cost and time of programming spatial algorithms, and facilitates the rapid development of specialized, spatially explicit applications. ArcObjects® from ESRI is a good example of this, and one for which there is substantial technical support and broad acceptance. During the analysis and design phase of any spatially explicit model or tool, the capabilities of existing GIS software should be assessed to determine the cost/benefit of integrating with these systems. While they are generally expensive, GIS may provide the most cost effective means of developing spatial applications.*

- How do existing land use strategies, population level targets and habitat conservation targets meet requirements for sustained habitat suitability and population viability?

  *This issue requires the prediction of future landscape conditions based on current and anticipated management activities in light of uncertainty. Alternative futures analysis and scenario planning have proven effective for this purpose. When developed with spatially explicit data, these techniques can yield output data layers that quantitatively represent the landscapes of possible futures, for example, in terms of forest cover species and age structure. These layers in turn can be used as the input data for spatially explicit habitat suitability and/or population viability models. The analysis of these results can thereby be used to predict the effects of land use strategies and conservation policies on future habitats and populations. This approach can be applied in an iterative manner, to study the effects of alternative strategies and policies. Good examples of this approach in an agricultural context are the work of Santelmann et al. (2004) and Berger and Bolte (2004).*

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# APPENDICES

## APPENDIX A: DATABASE DESCRIPTION

The database stores information on many of the models presented in the report. The database is stored in Microsoft Access. A list of the fields in the database, divided into logical sections, is presented in Figure A-1.

A single table, Main, contains all of the model information. There are several supporting tables that provide data used in the drop-down lists of table Main. The name of each of these tables has the prefix ‘dom’. General users of the database can ignore these tables.

The database contains forms that partition the fields into sub-groups to simplify viewing. The forms are named as follows:

- Model Description
- Geography, Ecology, Wildlife
- Input and Output
- Analysis
- Contact and Related Resources

The database also contains a form called Main, which displays all the fields.

A wide array of different models were reviewed for this project. Not all fields in the database are applicable to all types of models. Furthermore, a wide range of varied sources of literature, web-sites and developers provided the information, not all providing the same type of information or level of detail. Consequently, the type and detail of information available for the models varied widely. As a result, the database is not fully populated, with entries left blank where a field was not applicable or not specified for a particular model.

**Figure A-1a: Fields of the database, grouped into logical sections**

| Section | Field Caption | Field Name |
|---|---|---|
| | | |
| **Model Description** | Model ID | MD_ModelID |
| | Lead Author | MD_LeadAuthor |
| | Model Name | MD_ModelName |
| | Model Acronym | MD_Acronym |
| | Organization | MD_Organization |
| | Model Type | MD_ModelType |
| | Model Class | MD_ModelClass |
| | Model Form | MD_ModelForm |
| | Description | MD_Description |
| | Modules | MD_Modules |
| **Spatial Context** | Spatial | SP_SpatialComponent |
| | Spatial Scale | SP_SpatialScale |
| | Spatial Resolution | SP_SpatialResolution |
| **Temporal Context** | Temporal | TM_TemporalComponent |
| | Temporal Extent | TM_TemporalExtent |
| | Time Step | TM_TimeStep |
| | Seral Stage | TM_SeralStage |
| **Geographical Context** | Country | GC_Country |
| | Province/State | GC_ProvinceState |
| | Region | GC_Region |
| **Ecological Context** | Community | EC_Community |
| | Ecotype | EC_Ecotype |
| | Habitat Type | EC_HabitatType |
| | Ecozone | EC_Ecozone |
| | Ecoregion | EC_Ecoregion |
| | Ecodistrict | EC_Ecodistrict |
| | Other | EC_Other |
| **Wildlife** | Species Type | WL_SpeciesType |
| | Common Name | WL_SpeciesCommon |
| | Scientific Name | WL_SpeciesScientific |
| | Species Guild | WL_SpeciesGuild |
| | Taxonomic Group | WL_TaxanomicGroup |
| **Input Data** | Data Type | ID_DataType |
| | Data Format | ID_DataFormat |
| | Data Source | ID_DataSource |
| | Data Resolution | ID_DataResolution |
| | Data Extent | ID_DataExtent |
| | Parameters | ID_Parameters |
| | Data Format | OD_DataFormat |

**Figure A-1b: Fields of the database, grouped into logical sections**

| Section | Field Caption | Field Name |
|---|---|---|
| | | |
| **Output Data** | Results | OD_Results |
| | Data Format | OD_DataFormat |
| **Analysis** | Transformations | AN_Transformations |
| | Statistical Techniques | AN_StatisticalTechniques |
| | Statistical Models | AN_StatisticalModels |
| | Modelling Techniques | AN_ModellingTechniques |
| | Spatial Techniques | AN_SpatialTechniques |
| | Independent Variables | AN_IndependentVariables |
| | Dependent Variables | AN_DependentVariables |
| | Supporting Models | AN_SupportingModels |
| | Supporting Relationships | AN_SupportingRelationships |
| | Supporting Software | AN_SupportingSoftware |
| **System Requirements** | Disk Space for Model | SR_DiskSpaceModel |
| | Disk Space for Data | SR_DiskSpaceData |
| | Operating System | SR_OperatingSystem |
| | Programming Language | SR_ProgrammingLanguage |
| | Minimum Processor | SR_MinimumProcessor |
| | Minimum Memory (RAM) | SR_MinimumMemory |
| **Distribution** | Available | DS_Available |
| | Method | DS_Method |
| | Source Code | DS_SourceCode |
| | Cost | DS_Cost |
| | License Terms | DS_LicenseTerms |
| | Restrictions | DS_Restrictions |
| | Technical Support | DS_TechnicalSupport |
| | Documentation | DS_Documentation |
| **Contact** | Contact Name | CN_Name |
| | Organization | CN_Organization |
| | Address | CN_Address |
| | Phone | CN_Phone |
| | Email | CN_Email |
| **Related Information** | References | RI_References |
| | Website | RI_Website |
| | Related Models | RI_Related Models |
| | Related References | RI_Related References |