Delineating conservation areas on the Oak Ridges Moraine using a systematic conservation planning approach[1]

by D. Puric-Mladenovic[2] and S. Strobl[3]

ABSTRACT
Protected lands form an essential component of landscape planning, and often extend beyond protection of existing natural areas to consider enhancement through restoration to improve existing conditions. We tested an automated conservation science-based methodology and systematic approach to delineate conservation and restoration priority areas on the Oak Ridges Moraine (ORM). The methodology comprised: a) preparing and assembling existing spatial (GIS) information and tessellating the study area to 5-ha hexagon planning units; b) conducting a gap analysis to provide a basis for setting conservation targets that protect, or that through future restoration activities might enhance, under-represented biodiversity elements; and c) applying a simulated annealing procedure (i.e., mathematical algorithm) to find solutions that optimize the set biodiversity targets. The final output of our work is a map of conservation priority area that enables the more than 50 conservation partners in this landscape to coordinate various conservation, stewardship and restoration activities by focusing on those areas that have the highest conservation value.

Key words: restoration, settled landscapes, conservation planning, mathematical algorithm

RÉSUMÉ
Les terrains protégés forment une base essentielle à la planification du paysage. La protection qu'ils offrent dépasse celles des zones naturelles en ceci que restaurer ces terrains améliore aussi les conditions générales. Nous avons testé une méthode scientifique de conservation automatisée systématique pour délimiter les zones prioritaires de conservation et de restauration sur la moraine d'Oak Ridges (ORM). Cette méthode comprenait : a) la préparation et l'assemblage de l'information spatiale (SIG) existante et la division de la zone d'étude en tesselles hexagonales d'unité de planification de 5 ha ; b) la réalisation d'une étude de carence afin de déterminer des objectifs de conservation en vue de protéger — ou de restauration future en vue d'améliorer — des éléments sous-représentés de la diversité biologique ; et c) l'application d'une procédure simulée d'optimisation (c.-à-d. un algorithme mathématique) pour trouver des solutions qui optimisent l'atteinte des objectifs de conservation de la diversité biologique. Le résultat final se présente sous la forme d'une carte des zones prioritaires de conservation. Plus de 50 partenaires de conservation de cette région pourront ainsi coordonner diverses activités de conservation, d'intendance et de restauration en mettant l'accent sur les zones qui possèdent la valeur de conservation la plus élevée.

Mots clés : restauration, écosystèmes habités, planification de la conservation, algorithme mathématique

D. Puric-Mladenovic

S. Strobl

Introduction

In human-impacted landscapes the goals of ecological or landscape planning are complex, numerous and often conflicting. For example, such planning seeks to retain and improve existing biodiversity elements, protect and enhance ecological functions, improve environmental benefits, enhance aesthetics as well as to control and guide land development, land conversion and land use. Typically, such planning identifies areas of "green" comprising larger amounts of natural and semi-natural vegetation to be conserved, protected and/or managed for public and environmental services. These green areas have been variously named in different countries: green space, green network, ecological networks, green infrastructure, ecological greenways, conservation

[1]Presented at the 5th North American Forest Ecology Workshop, Gatineau, Quebec, June 2005.
[2]Information Management and Spatial Analysis, Southern Science and Information Section, Ministry of Natural Resources, 300 Water St., 4th Floor South Tower, Peterborough, ON K9J 8M5. E-mail: danijela.puricmladenovic@mnr.gov.on.ca
[3]Information Management and Spatial Analysis, Southern Science and Information Section, Ministry of Natural Resources, 300 Water St., 4th Floor South Tower, Peterborough, ON K9J 8M5. E-mail: silvia.strobl@mnr.gov.on.ca

areas, natural heritage systems, core and corridors (Noss 1993, Fabos and Ahern 1995, Jongman and Pungetti 2004). Moreover, green areas have been delineated using various principles and methodologies, but commonly they capture larger tracts of vegetation and habitats and serve to direct future land zonings, land conversion and urban development.

Sometimes these green areas are delineated for objectives extending beyond simply their protection and consider enhancement. In some jurisdictions, besides including existing natural and semi-natural vegetation, green areas also include land that can be restored and regenerated to enhance and improve existing ecological functions and/or environmental services.

Current initiatives by the provincial government in southern Ontario, including the Greenbelt Plan (Ontario Ministry of Municipal Affairs and Housing 2005) and The Places to Grow Act (Ontario Ministry of Public Infrastructure 2005), aim to plan for the protection of ecological integrity and biodiversity of southern Ontario's landscapes by integrating existing environmental capacity and future projections of long-term population growth into current land-use planning. The outcome and ecological success of these initiatives and policies will largely depend on the identification and delineation of Natural Heritage Systems (NHSs), representing natural and semi-natural areas that should be protected from development. NHSs have become an important component of the emerging process of ecologically-based land-use planning in the settled landscapes of southern Ontario.

The Oak Ridges Moraine (ORM) is one of the most significant landforms in southern Ontario. The moraine is a hilly upland area that stretches in an east-west direction through the central part of southern Ontario. Deposited about 12 000 years ago, it formed as two distinct glacial lobes pushed along and scraped large amounts of rock, soil, and other debris into a trough between the two lobes (Chapman and Putnam 1984, Sharpe *et al.*1999). In recent years, land development, roads, gravel pits, and other human activities have threatened the moraine's ecological and hydrological functions. To ensure protection of the moraine and its functions, the Ontario Government introduced the Oak Ridges Moraine Conservation Act (the Act) in 2001, followed by the Oak Ridges Moraine Conservation Plan (the Plan), an ecosystem-based provincial plan that aims to restrict urban development on the moraine.

As a part of this plan, a provincially-developed natural heritage system has been identified and delineated for the Oak Ridges Moraine Conservation area (Ontario Government 2002). This plan designated core and linkage areas that have higher concentrations of remnant natural features, and also identified more restrictive land use policies to ensure these natural areas are protected. The Oak Ridges Moraine Foundation (ORMF) was established to assist in furthering the Conservation Plan's objective of maintaining, improving or restoring all the elements that contribute to the ecological and hydrological functions of the ORM Area (Fig. 1), including the quality and quantity of its water and its other resources (Oak Ridges Moraine Foundation 2003). To identify a shared vision for a future ORM landscape the ORMF developed a Stewardship Strategy through multi-stakeholder input that identified the need to increase natural cover from the current 36% to close to 50%, representing an area of approximately 8000 ha. To ensure that future conservation and restoration activities were strategically-sited, we were asked to develop a systematic conservation planning approach to identify high priority conservation and restoration areas.

Restoration activities across southern Ontario have a long history with the former Ontario Department of Lands and Forests and the Ontario Ministry of Natural Resources (OMNR) planting millions of trees on both public and private land until the mid-1990s (Coons 1981, Ontario Ministry of Natural Resources 2001). Currently, many different stakeholders engage in restoration activities, but generally these are sited where available land, funding or planting stock can be secured. With few exceptions these activities are not coordinated nor are they considered a part of landscape planning. The ORMF recognized that if restoration activities are to contribute to the overall ecological and hydrological functions of the ORM Area, they would have to be strategically planned and sited.

In much of southern Ontario, including the ORM, larger remnant areas of natural and semi-natural vegetation, including plantations, are a reflection of past human land uses. In many cases these features remain on (or are returning to) the landscape because these areas were not suitable for agriculture. These include forests on abandoned agricultural fields or on highly erodable soils, or large wetlands too expensive to drain or fill. Thus, most areas thought to protect and conserve biodiversity are not systematically designed and in fact do not conserve a representative amount of the pre-settlement biodiversity of a geographic region. As such they protect a few flagship (i.e., charismatic) species without preserving other biota. In general, existing protected areas in southern Ontario and other settled landscapes, such as the core and linkage areas on the ORM, have relatively poor biodiversity representation. For example, Sarakinos *et al.* (2001) found that in Quebec's reserve networks a number of habitats were not adequately represented and they suggested a more systematic approach was needed. Similarly, we found that core areas on the Oak Ridges Moraine are protecting vegetation and habitats on sandy and gravely soils, while vegetation cover on loam and clay soils was underrepresented. Since southern Ontario's settled landscape is a reflection of the interaction between socio-political and environmental needs, defining NHSs is complex as the remaining natural areas are usually a result of past development patterns. Thus, our goal was to use and test an approach that identifies and delineates a system of natural areas that adequately represent biodiversity values and that can serve to identify high priority restoration areas that will enhance existing conditions.

The Oak Ridges Moraine Conservation Plan provides land use planning direction for the 190 000 hectares of land and water within the Moraine by dividing the moraine into four land designations: natural core area, natural linkage areas, and countryside and settlement areas, each with associated land use policies. Core and linkage area land designations were delineated using an expert-opinion approach combining some of the principles of landscape ecology (e.g., larger patch sizes and areas with higher frequency of patches), conservation biology (e.g., core areas connected by riparian areas) and field observations of rarer biodiversity elements (that have inherent biases). These areas were manually delineated on paper maps. The approach did not take advantage of recent innovations in conservation science and spatial analy-

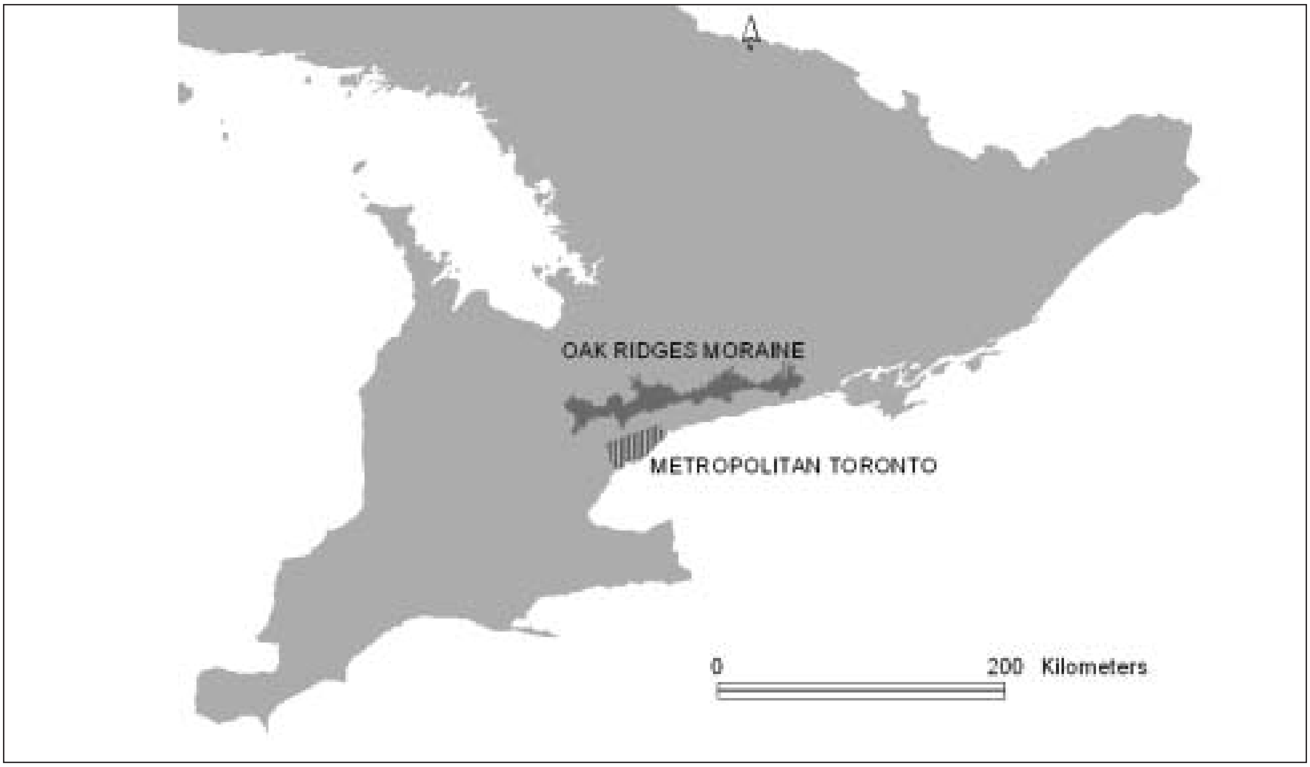

Fig. 1. The location of the Oak Ridges Moraine Conservation Plan Area in southern Ontario.

ses nor all of the available spatial information that would permit optimization of a number of biodiversity values. As such, only broad measures of conservation value such as the percentage of the total wetlands and woodlands in the ORM landscape protected by core and linkage areas can be provided. Consequently, no concrete measures of biodiversity or habitat protection can be made across this landscape. Moreover, the process used to delineate core and linkage areas had no replicable methodology that could be readily transferred at different spatial and temporal scales nor does this approach benefit from an *a priori* gap-analysis.

Currently, many conservation and natural resource agencies use systematic conservation planning approaches to evaluate land conservation values and identify and design protected areas. This has encouraged the expansion of various computational methods for designing conservation areas. Most of these methods have been developed by combining mathematical programming and optimization techniques with enhanced data preparation, processing, and display capabilities in Geographical Information Systems (GIS). These algorithms have been used efficiently to provide solutions for conservation planning in many different geographic areas and at various spatial scales (Pressey and Nicholls 1989, Pressey *et al.* 1993, Margules and Pressey 2000, Possingham *et al.* 2000). For example, optimization techniques using mathematical algorithms available in programs such as MARXAN (Ball and Possingham 2000), SPEXAN (Ball and Possingham 1999), and C-plan (NPWS 1999) have been used successfully to create optimal or near-optimal reserve and conservation area networks in terrestrial and marine environments (Noss *et al.* 2002, Groves 2003, Meir *et al.* 2004) using a methodology that is explicit, consistent, repeatable and transparent. The use of similar techniques for delineating areas with higher conservation value in land-use planning (e.g., green space, natural heritage systems, core and corridors) in settled landscapes is a novel concept.

We tested a systematic approach, using data mined from numerous mapped resources, to delineate conservation and restoration priority areas on the ORM that meet several biodiversity targets. The final output is a map of high conservation priority areas that has enabled the Oak Ridges Moraine Foundation (ORMF) to coordinate the activities of over 50 conservation partners. It has made it possible for these diverse groups to strategically target future conservation and restoration activities within specific geographic areas that have the highest value for biodiversity conservation.

Methodology

The methodology consisted of: a) preparing and assembling the existing spatial (GIS) information and tessellating the study area into planning units (i.e., 5-ha hexagon resolution) ensuring that planning unit resolution was adequate for the study area; b) conducting a gap analysis; and c) applying a simulated annealing procedure (mathematical algorithm) to find an optimal solution.

Preparing and assembling spatial (GIS) information

The following spatial data layers were used: a) circa 2002 Southern Ontario Land Resource Information System (SOLRIS; OMNR 2002) woodland, evaluated wetland and built-up areas mapping; b) detailed soil survey for southern Ontario (Agriculture and Agri-food Canada); c) public land (OMNR); d) rare and threatened species occurrences as identified by naturalists and validated by biologists at the Ontario

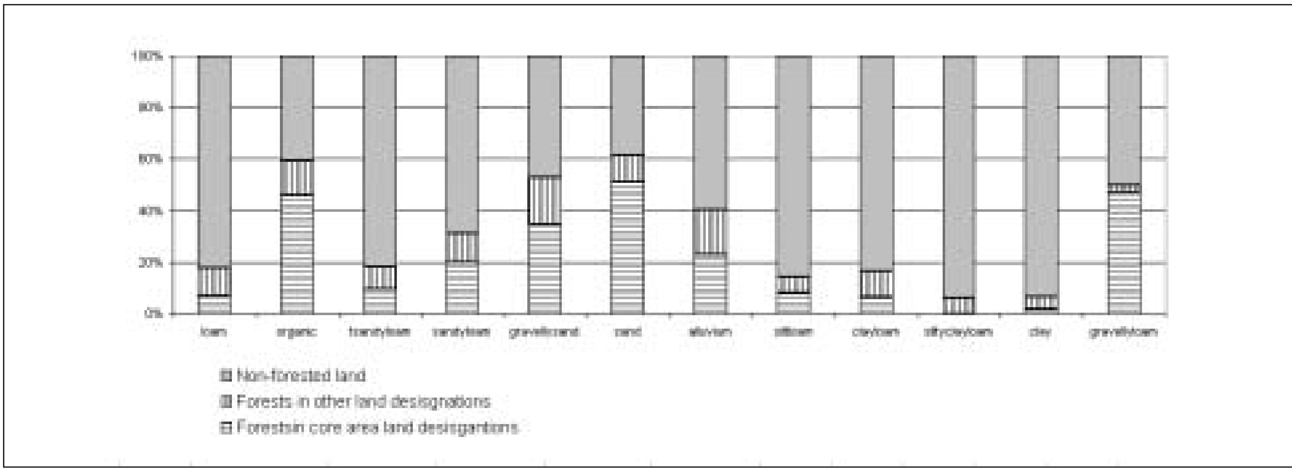

Fig. 2. Representation of forest cover by soil texture on the ORM, as a surrogate measure for vegetation type, used to identify gaps and define explicit quantitative conservation goals. The graph shows percent representation of each class (forest cover by soil texture) within core areas and other land use designations in the ORM Conservation Plan. Percent of the forest class removed or cleared from the landscape is also shown.

Ministry of Natural Resource's Natural Heritage Information Center (NHIC; OMNR); e) agricultural land use from the 15-m resolution 2002 OMNR Greenbelt Land Cover mapping (OMNR); f) mapping of remnant sand barren, savannah, and tall grass prairie vegetation (NHIC, OMNR); and (g) land designations used to support the implementation of the Oak Ridges Moraine Conservation Plan.

The biodiversity surrogates we used represent a combination of environmental data and available species data (Margules and Pressey 2000, Nix *et al.* 2000, Faith *et al.* 2001). Besides the data on occurrences of species and habitats considered to be rare and/or threatened or important in the region (NHIC, OMNR) we selected additional biodiversity surrogates primarily on the basis of availability of consistent digital spatial information across the entire landscape (Margules and Pressey 2000). Fine-scale vegetation maps are the most appropriate biodiversity surrogates across entire landscapes and although some fine-scale vegetation mapping was available for a few areas in some watersheds, this type of mapping was not available across the entire ORM landscape. Where fine-scale vegetation maps are not available, various environmental data have been used as biodiversity surrogates (Margules and Pressey 2000), and consequently, we combined the existing forest, wetland, and prairie/savannah mapping with soil texture mapping to derive a surrogate map of vegetation type diversity.

Gap analysis

The term gap analysis is most often used for assessing the protection status of parks and large natural areas. Here, however, we used gap analysis to provide insight into the level of the existing representation of vegetation types across the ORM as well as their representation within the existing core areas. As pre-settlement or potential natural vegetation maps (Puric-Mladenovic 2003) were not available to set biodiversity targets across the ORM study area, the level of representation of existing vegetation-soil types (e.g., woodlands on loamy soil, woodlands on organic soil, woodlands on sandy loam soil) was assessed. This analysis identified gaps in representation of vegetation types and facilitated the establishment of biodiversity targets as illustrated in Fig. 2. For example, we identified a target of 36% representation for each forest vegetation type based on the existing forest cover of the moraine (i.e., we should protect 36% of all woodlands on each possible soil type that occurs in this landscape). Currently, the core area land designations on the ORM protect over 70% of woodlands on dry, sandy soils and no woodlands on silty clay loams. About 95% of woodlands on silty clay loams have been removed from the Oak Ridges Moraine landscape and yet none of the remaining 5% of these woodlands is captured within the core areas (Fig. 2).

Prior to European settlement, prairie and/or savannah vegetation types represented about 8% of the ORM landbase. Today, as a result of land conversion, suppressed natural disturbances, and natural and human-influenced forest succession, these diverse and unique vegetation types represent about 0.25% of the moraine's landbase, scattered as small remnants. Since over 95% of these habitats have been lost, we set a target of protecting all of the remaining patches. More than two-thirds of the estimated pre-settlement wetland cover has been lost and wetlands currently only represent 4.9% of the moraine's landbase. As a result we set a target of protecting most of the remnant wetland habitats.

A simulated annealing procedure (mathematical algorithm)

A simulated annealing algorithm available in MARXAN (Ball and Possingham 2000) was used to identify high conservation priority areas on the ORM. The algorithm was used to achieve the quantitative conservation targets identified through the gap analysis and identify areas that can contribute the most to biodiversity protection and enhancement. This methodology enabled us to incorporate the following factors that influence the identification of conservation areas: a) existing natural areas and land uses; b) potential for ecological restoration (e.g., availability of land with low agricultural potential) and c) location of public land that already has a high level of protection (as nuclei for expanding conservation areas). The specific model inputs were:

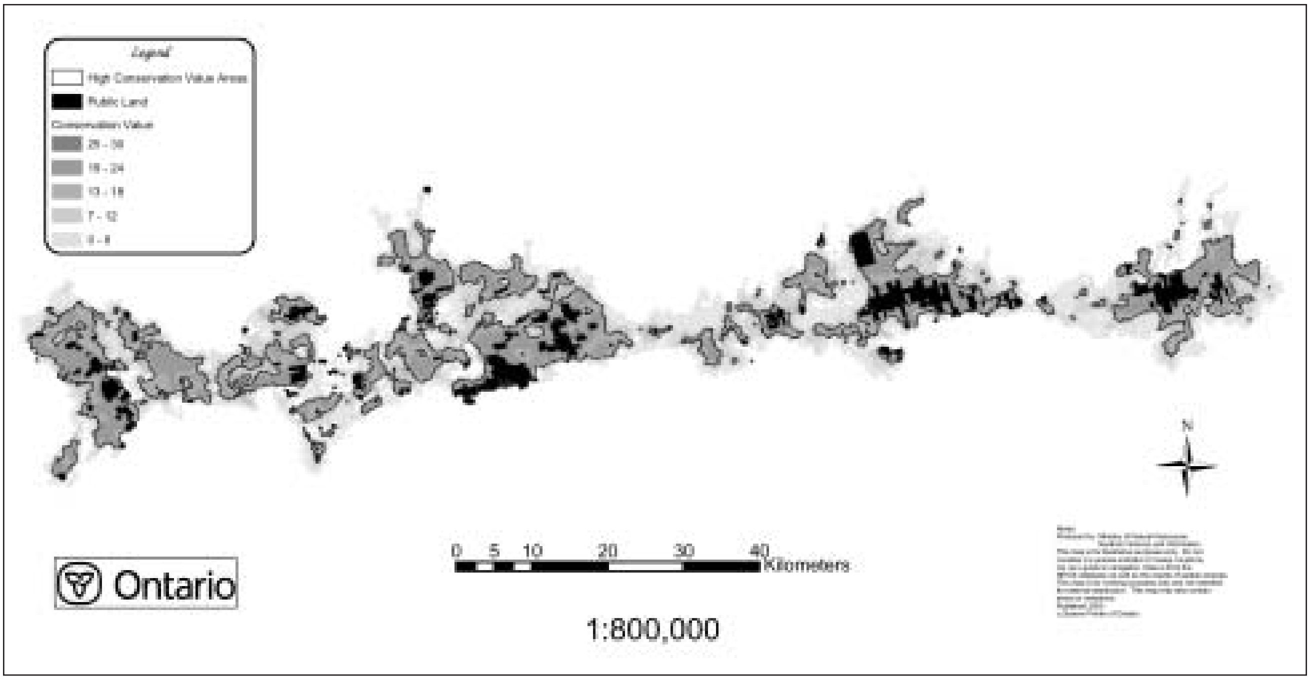

Fig. 3. The conservation and restoration priority areas represent a number of broad regions across the moraine that have higher conservation values (i.e., comprising aggregations of 5-ha planning units that were selected 19 or more times out of the 30 runs of the model used to optimize the conservation targets).

- The more than 200 000 ha-ORM area was first tessellated into 5-ha hexagon planning units. A finer resolution planning unit was not possible due to the algorithm's current limitation of 40 000 planning units.
- Based on the gap analysis and the existing percent cover on the ORM, a conservation target of 36% representation for each vegetation type was set.
- For the remnant habitats of prairie and savannah a conservation target of 100% protection was set.
- For remnant wetland habitats a conservation target of 80% was set.
- For each planning unit occurrences of rare and endangered species were assigned.
- Each unit was defined as either public, partially public, urban, agriculture or other open land. Public land that already has a high level of protection was designated as a required input (to be included in all model runs) and served as nuclei for expanding conservation areas.
- The cost was defined as opportunity cost or management cost or friction surface, and was based on the percent of non-marginal open land available for each planning unit. The higher the amount of non-marginal open land in the planning unit the less its value for restoration. We assumed that marginal land had a higher likelihood to be restored while there is little likelihood that active and productive land will be available for restoration.

Based on this data for each of the planning units, the simulated annealing algorithm available in the MARXAN program (Ball and Possingham 2000) was used to find reasonably efficient solutions to the problem of selecting a system of spatially cohesive sites that meet the suite of targets. The program is run many times, each time finding one possible solution. Given reasonably uniform data on biodiversity surrogates (woodland × soil vegetation types and NHIC species occurrences) for the 40 388 planning units, the algorithm minimized the cost (represented as the area of non-marginal land) while meeting the defined biodiversity targets. Since larger natural areas are preferable for effective natural heritage system management, targeting restoration and better ecological functioning, the boundary length file was set to 1, which weighted towards a higher degree of planning unit aggregation. The output of the analysis was a map showing a conservation value for each planning unit ranging from 0 to 30. These values represent the number of times (over the 30 runs of the algorithm) that a planning unit was selected.

Units selected in every one of the 30 runs indicate that the biodiversity values represented by that geographic location have a 100% probability of meeting the set of biodiversity targets. This can also be interpreted to mean that these planning units are irreplaceable. To target restoration activities to the most important areas first, we identified planning units that had a higher probability of being selected (i.e., in 60% or more of the runs) as being essential for efficiently meeting biodiversity targets. Based on this threshold, we defined high conservation priority areas on the ORM (Fig. 3).

Results and Discussion

The systematic conservation planning approach we used to identify high conservation priority areas on the ORM enabled us to mine existing spatial information on biodiversity and to optimize a complex set of biodiversity targets. Moreover, we identified gaps in information and have since scoped future mapping needs that will enable the more effective incorporation of mathematical algorithms for the identification of NHSs. For example, we identified the need for standard fine-scale vegetation maps of existing and reference conditions.

Such maps will provide more information on species composition and structure defining "growing" environments (e.g., climate, topography across landscapes) in more detail than simply by soil mapping alone. In addition, there is a need for improved procedures to incorporate updated species occurrence and specific habitat mapping. For example, recent occurrence records of Jefferson salamander identified at a local scale were not available for this analysis and a local stakeholder noted the omission of their study area from the areas delineated as high conservation priority areas. This raises the importance of engaging stakeholders in the process of setting biodiversity targets, and also in compiling information collected at different scales and by different stakeholders in a standardized format. Thus, like all models, conservation planning and mathematical algorithms are sensitive to the input information. While mathematical algorithms traditionally used in conservation planning can help to find the most optimal solutions as well as setting more complex socio-ecological targets, the data used to feed these algorithms is the most important input.

Spatial complexity of biodiversity can be captured and described by species or species group occurrences, species assemblages, vegetation types, habitat types, or environmental domains. More detailed vegetation maps serve as the most appropriate surrogates of overall biodiversity across a landscape. Spatially consistent, fine-scale vegetation maps with a sufficient level of detail have been successfully used as surrogates for biodiversity assessment and planning of conservation areas (Nix *et al.* 2000). However, fine-scale and detailed vegetation maps of either existing or reference conditions (e.g., potential natural vegetation or historical vegetation) for assessing biodiversity are not currently available for most of southern Ontario. Consequently, we used soil-vegetation maps to conduct a gap analysis and to assess the existing vegetation. In particular we examined the representation of woodland vegetation types currently protected in the core and linkage planning area designations of the ORM Conservation Plan.

Based on the results of the gap analysis we identified woodland vegetation types that are inadequately represented within the existing core planning areas. The results of the gap analysis confirmed that the expert-opinion system, based solely on spatial representation (e.g., forest and wetland polygons without associated composition and structure information), used to identify core and linkage areas on the ORM is inadequate for ensuring representation of vegetation biodiversity. For example, the results of gap analysis showed that over 80% of forests on the most productive soils such as silt-loam, clay-loam, silty-clay-loam, and clay soils have been removed, and that only a small percentage of forests on these soils is represented within the core land designation areas. In contrast, although forests on gravelly-sand and sandy soils are more predominant on the ORM landscape they are over-represented in the core areas. Remnants of forests on these less-productive soils represent larger patches (identified by size and shape) that are valuable for many wildlife and bird species. However, in terms of vegetation composition they do not adequately represent the diversity of forest habitats and plant species in the ORM landscape. Within this broad category of forest on sandy soils there is certainly more variation and diversity that needs to be further explored and captured by more detailed vegetation maps. The results of the gap analysis indicate that by basing conservation only on one forest class, and considering only the distribution of larger remnants on the landscape, we are not protecting nor managing for full biodiversity, nor do we adequately protect many forest species (i.e., trees, plants and associated wildlife) and their habitats.

The analysis indicated how many times a 5-ha planning unit was selected to contribute to overall biodiversity while minimizing the inclusion of active agricultural land. Of the 40 388 planning units, 12% (or 24 232 ha of the moraine) were not selected in any of the runs and thus have a conservation value of 0 based on the stated biodiversity targets; 74% (or 149 435 ha) of the units were selected at least once; 3% (or 6058 ha) of the units were selected in every run, and thus have irreplaceable value in terms of biodiversity. Seventy-eight per cent of the irreplaceable units were within the existing core and linkage land designations of the ORM Conservation Plan. This high level of congruency may indicate that both the identification of core and linkage areas (through expert opinion) as well as the identification of conservation priority areas (through a systematic conservation planning approach) placed an emphasis on both occurrence data for rare and threatened species and mapping of public, or already conserved, land. Marugules and Pressey (2000) noted that many species occurrences and observation data are biased in that they represent increased sampling intensity within certain areas (usually public land), areas closer to roads, areas easier to access, and represent observations of species that are easier to sample or identify. The effect of such biased input data to systematic conservation planning approaches needs to be evaluated further. Regardless, the results of our analysis suggest that the existing "core" and "linkage" land use policy areas on the ORM could be extended and re-shaped to improve biodiversity conservation.

As the project's objective was to target future restoration activities in the most valuable areas for biodiversity conservation, we set a 60% threshold (i.e., units that had a high probability of being selected in 60% or more of the model runs) to outline high priority conservation areas. These areas comprise 45% (or 90 873 ha) of the ORM and are concentrated around existing public land.

The conservation planning approach and simulated annealing algorithm used to delineate conservation and restoration priority areas was more efficient in capturing wetlands, prairie, savannah and forests on more productive soils than the expert-based approach to delineate core and linkage areas for the ORM Conservation Plan. For example, conservation priority areas captured 20% more wetland area than was included in the core land designations (that have the most restrictive land use policies). Similarly, 10% more prairie and savannah was captured with the conservation and restoration priority areas than was included in the core land designation (Fig. 4). While the core areas included 27% of the forest cover on clay soils and only 2% of the forest cover on silty-clay-loam soils, the conservation and restoration priority areas included 51% and 72%, respectively, of the area remaining in these forest cover types (Fig. 4). Given that only 8% of the natural distribution of these rarer forest cover types remains, ensuring that a larger proportion of them are included in the core land designation (associated with the

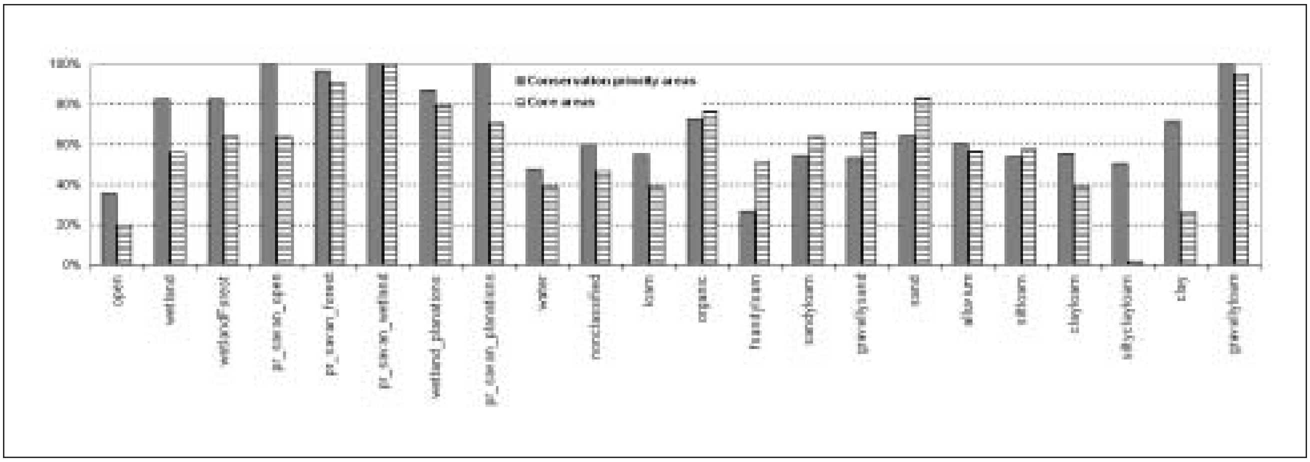

Fig. 4. Percent of forest and other natural features on different soil textures identified by the conservation and restoration priority area analysis (described in this paper) and core area land use policy designations on the Oak Ridges Moraine.

fewest permissible development activities) would provide enhanced conservation status (Fig. 2). The linkage areas, a land designation that permits more development activities than the core areas, captured an additional 24% of the moraine area. Compared to the woodlands and wetlands identified in our conservation priority analysis, the core and linkage land designation areas total 62% of the moraine's land area and capture more underrepresented woodlands on clay and silty-clay-loam soils as well as wetlands. However, this is at the cost of capturing an additional 26% of the agricultural landbase as well as capturing more well-represented woodlands on sandy soils, and without adding any more underrepresented prairie or savannah sites. The conservation priority areas, however, are only directly comparable to core areas since our biodiversity targets were not designed to identify linkages or corridors. Nevertheless, the above comparison of representation efficiency demonstrates the benefits of using a systematic conservation planning approach and mathematical algorithms to identify high-value conservation areas by optimizing biodiversity targets and human uses (e.g., agriculture) in a landscape.

The ORM is a human-dominated landscape and 90% of its landbase is privately owned. Restoration efforts are dependent on the availability of land and willing landowners. Since this information was not available, the amount of marginal land in each planning unit was used as an input cost in the algorithm to represent an indication of restoration potential. We assumed that landowners would be more willing to restore marginal than active agricultural land and that marginal land was adequately mapped in the available 2002 Landsat-derived land cover mapping. Results suggest that marginal land comprises 16% (or 32 310 ha) of the identified high priority conservation areas.

We plan to continue to improve the use of this methodology for identification of NHSs as well as improve the spatial information available for fine-scale vegetation in southern Ontario. The conservation planning approach needs further exploration to understand the effects of scale and resolution of input information, spatial scale and tessellation of a landscape into planning units, setting targets and ecological cost (constraints) for identification of conservation areas, defining thresholds for defining NHSs, as well as testing different mathematical algorithms. For example, defining conservation targets for forest, prairie-savanna and wetland conservation needs to be further explored and tested using information about the pre-settlement distribution of these vegetation communities. Further work is also needed to substantiate the identification of minimum ecological targets. We need to test the models with social preference scenarios that both exceed or fall short of the proposed biodiversity targets and develop criteria and indicators to evaluate the resulting impact of different NHSs on biodiversity conservation.

Conclusion

As is the case in many other jurisdictions, the identification of conservation and restoration priority areas or NHSs and protected areas in Ontario has been largely influenced by opportunities rather than strategic and systematic planning. Simulated annealing and similar reserve-siting algorithms are now commonly used in designing protected area systems, but few examples of their application to the identification of NHSs are available.

The approach we used for the ORM enabled us to test the use of a systematic conservation planning approach and simulated annealing algorithm for identifying areas having higher conservation value across the entire landscape. Our work suggests that these algorithms are a powerfully explicit tool to find a number of optimal solutions for conserving stated biodiversity targets and minimizing costs. These approaches are defensible and transparent and also make the most effective use of the available resources and information (Pressey *et al.* 1993, Margules and Pressey 2000). However they are opportunistic in that they rely on available information (Possingham *et al.* 2000). To realize the full advantage of these tools we need better biodiversity surrogates both in terms of fine-scale vegetation maps as well as more comprehensive coverage for species occurrence and habitat mapping, and we need to ensure that information on the distribution and abundance of biodiversity is updated, improved and applicable across larger landscapes and different scales.

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