Spatial Prioritization of Cost-Efficient Habitat Protection for Species at Risk in Ontario

by

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Abstract

Conservation budgets are limited, so it is important to prioritize actions to efficiently protect species. Proxies for cost are frequently used as estimates for inclusion in prioritization problems to make more effective decisions. In this research, we combine real-world cost data for private land and species habitat models into a spatial prioritization problem to explore cost-efficient habitat protection possibilities for species at risk in Ontario. Our findings suggest that protecting species at risk through land purchase may be most cost efficient in areas where species-at-risk richness is relatively high and population density is low, such as in central Ontario. However, the budget required to adequately protect species at risk through land purchase is much larger than is currently available for conservation efforts. Therefore, to effectively protect species at risk in Ontario, we recommend the use of alternative conservation measures, such as easements on private land, to supplement already protected areas.

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Chapter 1: Introduction

Current extinction rates are significantly higher than natural background levels, and the rates continue to increase every year (Pimm et al., 2014; Kerr & Deguise, 2004). This is true even for countries like Canada that still have vast areas of relatively intact ecosystems (Kerr & Deguise, 2004). In Canada, common threats to species include, but are not limited to, development, human disturbance, climate change, and invasive species (McCune et al., 2013). It is suggested that conversion of natural areas to agricultural and urban land is responsible for most of the species decline in Canada (Venter et al., 2006; Kerr & Cihlar, 2004).

With the goal of better protecting species and promoting the recovery of species at risk of extinction, Canada enacted endangered species legislation, the *Species at Risk Act* (SARA), in 2002 (SARA, 2021). In Canada, when a species is suspected to be at risk of extinction, an assessment of its status is conducted by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC), which takes into consideration all relevant scientific and Aboriginal Traditional Knowledge to determine the species level of risk (COSEWIC, 2015). When the assessment is completed, COSEWIC provides a recommended listing status to the federal government, which then incorporates socio-economic considerations and decides whether to list the species on the SARA registry. If a species is listed as endangered or threatened, it and its habitat are automatically protected from harm on federal land (Creighton & Bennett, 2019; Mooers et al., 2010).

Federal, provincial, and territorial governments share responsibility for protecting species at risk (SAR) in Canada. The protection afforded by SARA only applies on federal land, leaving the protection of species outside of federal land largely up to the provinces (Mooers et al., 2010). Six of the 10 provinces and one of the three territories have their own species at risk laws (Bergman et al., 2020; Olive, 2014). Ontario passed its own legislation, the *Endangered Species Act* (ESA), in 2007 (*Endangered Species Act*, 2007). The Act gave automatic protection to species at risk and their habitat on public and private lands and was considered to be the strongest provincial legislation in Canada (Olive & Penton, 2018; Nixon et al., 2012). Similar to federal legislation, the Ontario ESA bases listing decisions on a scientific assessment of a species conducted by an independent group of experts, the Committee on the Status of Species at Risk in Ontario (COSSARO) (COSSARO, 2021). Although the initial legislation provided automatic protection to listed species and their habitats, it has since been weakened to delay protections (Bergman et al., 2020).

In 2010, as a response to the global biodiversity crisis, the United Nations Convention on Biological Diversity (CBD) established 20 objectives, known as the Aichi Targets, with a goal of slowing the decline of biodiversity by 2020 (CBD, 2010). Shortly after, Canada's federal, provincial, and territorial governments released the 2020 Biodiversity Goals and Targets for Canada (ECCC, 2016a). One objective of both the Aichi and Canadian targets, states that by 2020 at least 17% of terrestrial and inland water areas must be conserved using protected areas or "other effective area-based conservation measures" (OECMs) (ECCC, 2016a; CBD, 2010). The Aichi target states that OECMs should be well managed, connected systems that are also ecologically representative, a clause notably missing from the Canadian targets (Lemieux et al., 2019; CBD, 2010). At the end of 2019, Canada's official proportion of conserved terrestrial area was 12.1%, including 11.4% in protected areas (ECCC, 2020). Though Canada did not reach its 2020 goals, a new area-based conservation plan has been released, stating that 25% of terrestrial and inland water areas should be conserved by 2025, working toward 30% by 2030 (Trudeau, 2019).

Though well-intentioned, these quantitative, deadline-based targets are often debated in the conservation community and can lead to poor conservation outcomes. Frequently, quantitative area-based conservation targets are politically driven and not based on biological evidence; they are often referred to as inadequate and arbitrary (Svancara et al., 2005). The scientific community has long asked the question ‘how much is enough’ to conserve biodiversity. There seems to be a broad consensus that to protect current levels of biodiversity, the target for conservation of land should be much higher than it is, and this thinking has led to the ‘Nature Needs Half’ movement and the ‘Half-Earth’ project (Dinerstein et al., 2017; Locke, 2014). The exact percentage of land that should be protected has been debated. Some believe as little as 25% is sufficient, while others think as much as 75% of regions should be protected (Coristine et al., 2018). Furthermore, by putting deadlines on these quantitative targets, some jurisdictions dedicate their resources to simply increasing the quantity of protected areas by a certain date, instead of considering the quality or biological relevance of the land that should be protected (Lemieux et al., 2019). Although Canada’s more recent target of 30% protection by 2030 has improved from previous targets (17% protected by 2020) (ECCC, 2016a), decisions about adding to the protected area network should include consideration of a host of biological factors, rather than political ones. Failure to protect enough of the appropriate land will further threaten future biodiversity.

The number of protected areas in Canada has been growing significantly over the past few decades, making 'protected area' the third largest land designation in the country, behind agriculture and forest (Lemieux et al., 2011). However, conservation planning has historically not been systematic, resulting in areas designated for conservation that do not adequately represent biodiversity (Andrew et al., 2011). At one point, reserve networks in Canada included no more endangered species than what would be expected by chance (Deguise & Kerr, 2006).

Systematic conservation planning (SCP) is a structured approach to conservation that combines scientific information with social and economic factors to efficiently design and effectively implement conservation goals (Margules & Pressey, 2000). Fundamentally, SCP can be broken down into six steps: identifying the conservation goal, collecting data across the planning area (both biological and socio-economic), assessing existing conservation areas, identifying areas for expansion of the conservation area, implementing, and finally, maintaining and monitoring (Margules & Pressey, 2000). SCP is most often used for planning new protected areas but is also used for restoration activities and management. This method of planning especially excels at using resources efficiently and is known for its defensible decision-making process (Margules & Pressey, 2000).

Systematic conservation planning can also be used for spatial conservation prioritization, which uses spatial analyses to identify locations for conservation investment (Kukkala & Moilanen, 2013; Wilson, Cabeza, et al., 2009). Spatial conservation prioritization is similar to classic optimization problems in mathematics, with shared key features including the objective function or goal, state and control variables, and constraints (Wilson, Carwardine, et al., 2009). State variables symbolize the asset, or the item of conservation interest (e.g., habitat, populations). The control variables are the actions that can be taken that affect the asset (e.g., allocate money or resources). Constraints influence or limit the control variables and will determine whether the problem at hand is a maximal-coverage or minimal-coverage problem. A maximal-coverage conservation problem is one that aims to maximize conservation action without exceeding a constraint, for example, how much habitat can we conserve given a pre-determined budget. A minimal-coverage conservation problem is one where the constraint is the minimum required conservation action achieved for each asset, for example, conserving at least a certain amount of habitat for a species (Wilson, Carwardine, et al., 2009). Often, conservation problems are complex and have multiple stakeholders, creating multiple objectives that can be combined into a single objective through weighted sums (Arponen, 2012).

As stated previously, a key component in systematic planning is efficiency, which in terms of spatial prioritization often means incorporating cost (Kukkala & Moilanen, 2013; Wilson, Cabeza, et al., 2009; Naidoo et al., 2006). Integrating cost into spatial prioritizations is important because cost is not spatially homogeneous across a landscape and can be influenced by things like human population density or resource potential of the land (Naidoo et al., 2006). Costs associated with conservation can include opportunity (equal to what could have been gained by other potential land uses), acquisition (land purchase), management (costs associated with conservation programs), transaction (costs associated with exchange of resources), and damage (associated with economic damage from conservation activities) (Naidoo et al., 2006).

Costs can be incorporated into conservation planning in several ways. One of the most common methods is a cost-benefit analysis, where there is a direct comparison between the cost of conservation and the resulting benefits. However, this method requires monetary values to be placed on biodiversity, which is arbitrary and ignores the intrinsic value of biodiversity (Naidoo et al., 2006). A common method used in conservation planning is the cost-effectiveness approach. Cost-effectiveness problems are different because they keep the benefits in the initial or given units (i.e., area, number of individuals, or species; Naidoo et al., 2006). Biologists frequently use non-monetary proxies for costs in conservation planning for ease, but also due to lack of accessible cost data (Wilson, Cabeza, et al., 2009; Balmford et al., 2003). Occasionally, factors that contribute to land costs, such as forest cover or human population density, are used in a weighted sum to estimate the purchase cost of land. However, these weighted sums can be subjective, making cost models based on actual economic data potentially the most accurate (Naidoo et al., 2006). By acknowledging the spatial variability of costs and integrating it with biological factors in prioritization problems, we can reach conservation goals more efficiently (Arponen et al., 2010; Naidoo et al., 2006), with a greater chance of implementation success (Kukkala & Moilanen, 2013).

Spatial prioritization problems can help to identify areas for conservation investment, which may include more than strictly protected areas. The CBD Aichi Targets and the 2020 Biodiversity Goals and Targets for Canada mention the use of OECMs, in addition to strictly protected areas to help reach conservation targets (ECCC, 2016a; CBD, 2010). Though initially vague, in 2018, the CBD created guidelines for OECMs to properly define the concept and clarify misconceptions. An OECM was defined as “a geographically defined space, not recognized as a protected area, which is governed and managed over the long-term in ways that deliver the effective in-situ conservation of biodiversity, with associated ecosystem services and cultural and spiritual values” (CBD, 2018). These areas can be loosely categorized into three groups: areas with primary conservation objectives but the governing body of the land does not wish for the land to be a protected area, managed areas where conservation is a secondary outcome, and land where conservation objectives are not considered but are a by-product of management activities (Jonas et al., 2017).

These OECMs can be particularly useful for conservation in human-dominated landscapes where the majority of land is privately owned and land acquisition prices are high (Schuster et al., 2017). Commonly used OECMs on private land are conservation easements, which are voluntary agreements between landowners and land trusts or government agencies (Rissman et al., 2007). The easement holder, the land trust or government agency, restricts land use on privately owned land in return for payment or tax reductions to the landowner. Conservation easements are often created with the goal of reducing development and enhancing protection; however, not all easements are created equal. Easements can range from restricting all land uses, effectively creating a protected area, to allowing extensive land uses (Rissman et al., 2007). Nevertheless, conservation easements are still considered one of the most effective conservation strategies on private lands (Schuster et al., 2017). Typically, conservation easements restrict some land uses and require conservation actions to be applied for the duration of the agreement (Schuster et al., 2017). Provincial conservation programs, such as the Ontario Conservation Land Tax Incentive Program, exist to fund conservation easements.

This particular program offers full property tax exemption for provincially significant areas of natural and scientific interest, provincially significant wetlands, habitats of endangered species, and community conservation lands (OMNRF, 2019a).

In this thesis, we will integrate real-world cost data into a spatial prioritization problem to analyze area-based SAR protection possibilities in Ontario. The prioritization analysis will seek to minimize the cost of protecting the greatest amount of habitat for SAR in Ontario. More specifically, we will determine how much it will cost to protect increasing proportions of habitat for each SAR and to identify priority areas for protection. By conducting a prioritization problem with realistic cost data, we can provide realistic cost-effective conservation strategies that will allow for more effective efforts, specifically in areas where high opportunity costs make land purchase less feasible.

Chapter 2: A Spatial Prioritization Problem to Explore Cost-Efficient Habitat Protection Possibilities for Species at Risk in Ontario

2.1 Introduction

Globally, species face increasing pressures from land use change, human disturbance, climate change, and invasive species (Maxwell et al., 2016), which has resulted in the number of species at risk of extinction far exceeding natural levels (Pimm et al., 2014; Kerr & Deguise, 2004). Canada is no exception when it comes to the state of biodiversity, with over 700 species listed as at risk of extinction (SARA, 2021). Ontario is of specific interest for species at risk (SAR) protection, as it is Canada's most-populous province and is highly biodiverse, compared to much of the rest of Canada (Olive & Penton, 2018). In Ontario, over 200 species are considered at risk (SARO, 2018). There is a need to identify areas that should be prioritized for protection of these species and how to do so cost effectively.

To reduce extinction rates, it is critical that species are offered protection from human disturbances (Coristine et al., 2018; Myers et al., 2000). In recognition of this need and in response to the growing biodiversity crisis, national and international targets have been established, with the goal of protecting more land (ECCC, 2016a; CBD, 2010). Canadian targets aim to have 25% of land protected by 2025 (Trudeau, 2019). Currently, just over 12% of Canadian land is protected (ECCC, 2020). Ontario is in a similar state, with only 10% of land protected (ECCC, 2020). However, these existing protected areas have not necessarily been established in areas that offer the greatest protection for endangered species (Andrew et al., 2011; Deguise & Kerr, 2006; Margules & Pressey, 2000).

Southern Ontario presents a unique challenge for protected area planning. It is the most developed area of the province and contains some of the highest-quality farmland in Ontario (OMECP, 2019b), resulting in high opportunity costs for conservation (Naidoo & Adamowicz, 2006). However, it is also an important area for habitat protection because over 80% of Ontario's SAR are found in the southern portion of the province (OMECP, 2019b). Currently, less than 1% of southern Ontario is protected (OMECP, 2019b); therefore, it is crucial for species' survival that more protection is offered.

To increase the amount of protected land in Ontario and to ensure the long-term survival of SAR, conservation plans and decisions need to be systematic (Arponen, 2012; Naidoo et al., 2006). Spatial prioritization allows conservation planners to determine locations for conservation that can most effectively protect species given limited funds (Wilson, Cabeza, et al., 2009).

To ensure the greatest conservation benefits with the resources available, cost data are frequently integrated with spatial biological data in prioritization problems (Arponen, 2012; Murdoch et al., 2007; Naidoo et al., 2006). Cost, whether it be implementation, management, opportunity, or purchase cost, is an important and practical variable to include when setting conservation goals; when ignored, it often negatively impacts the successful implementation of conservation plans (Naidoo et al., 2006).

Here, we use a property cost model, built from real-world property cost data, combined with SAR habitat models, in a prioritization approach to determine the most effective areas to prioritize for protecting the most SAR in Ontario. The target for this minimal-coverage problem is that a certain percentage of habitat be protected for each SAR listed in Ontario at the least possible cost. For example, if 15% of each SAR's habitat was to be protected through land purchase, what is the minimum cost? In our case, we use a range of targets from 5% to 100% habitat conservation to examine variation in protection costs. Using the results, we can also pinpoint the best areas for protection within a defined budget.

This project differs from many others of similar scale in that we use habitat models for SAR, rather than range maps, to offer more tailored prioritization solutions. We also use real-world property cost data, which is not widely accessible; typically, proxies are used in their place, leading to skewed estimates of cost-effectiveness. The specific objectives of this research are to: 1) estimate the total area of terrestrial SAR habitat already protected in Ontario, 2) estimate the total area of terrestrial SAR habitat on Crown land, 3) identify priority areas for protection based on the ability to protect habitat for all SAR, and 4) estimate the cost of land acquisition for protecting various percentages of SAR habitat.

2.2 Methods

2.2.1 Background

Ontario is the second largest province in Canada. It covers over 1.1 million km^2, and has over 25,000 species of plants and animals (Lemieux & Scott, 2011). Currently, over 200 of those species are considered at risk in Ontario. Vascular plants and birds are the most at-risk groups in the province (SARO, 2018).

Southern Ontario, which is one of the most biologically diverse areas in Canada, has seen rapid urbanization and industrialization and is now the most densely populated region in Canada (Kraus & Hebb, 2020). Consequently, there has been significant habitat loss in the area (Kraus & Hebb, 2020), resulting in several unique and important habitats - including tallgrass prairies, savannahs, and alvars - becoming rare (Crins et al., 2009).

Approximately 10% of the province is protected land, primarily under the jurisdiction of Ontario Parks (OMECP, 2021). The various agencies that oversee protected areas in Ontario include: two federal branches of government (Parks Canada and Environment and Climate Change Canada); Ontario Parks, under the Ontario Ministry of the Environment, Conservation and Parks; numerous municipal organizations; and non-governmental organizations, notably The Nature Conservancy of Canada (Lemieux & Scott, 2011).

It is important to note that these agencies are given jurisdiction in certain areas based on whether the land is publicly or privately owned. In Canada, most of the land (89%) is publicly owned (also called Crown land), which means that it is owned by either the federal (41%) or provincial (48%) governments (Olive, 2014). In Ontario specifically, Crown lands cover most of the province, especially in the north. The majority of the Crown land in Ontario (77% of the province; OMNRF, 2020a) is managed under the *Public Lands Act* (OMNRF, 2020b), which can be used for natural resource extraction and is a source of revenue for the province. Another 10% of Ontario is Crown land classified as protected areas or conservation reserves (OMNRF, 2020a), and it is managed under the *Provincial Parks and Conservation Reserves Act* (OMECP, 2020). The remainder of the province is private land, primarily located in southern Ontario (OMNRF, 2021). Privately held land is owned by, for example, a non-governmental organization, a private individual, or a corporation.

2.2.2 Project Approach

Prioritizing species' habitats involved a three-stage approach. First, we created habitat maps of SAR and identified the overlap of each species' habitat with already protected areas. Next, we built a model to estimate the acquisition cost of properties in Ontario using property and location variables. Finally, we ran prioritization scenarios with the goal of identifying properties to protect the most habitat for SAR in Ontario at the least cost.

2.2.3 Identifying Habitats of Species at Risk

Here, we focused on all terrestrial species listed as endangered, threatened, or special concern on "The Species at Risk in Ontario List" (Table A1 in Appendix A; SARO, 2018). To create habitat maps for each species (n=175), we first recorded habitat requirements from assessment reports and recovery documents (Table A1 in Appendix A). We then paired the habitat requirements to land cover classes from the Ontario Land Cover Compilation V.2. (OMNRF, 2018b). This land cover layer consists of 29 land cover classes at a pixel resolution of 15m. Next, we selected the corresponding land cover classes from within each species' range to create habitat maps.

Many SAR range shapefiles were available in a single dataset (n=149; ECCC, 2016b). However, if a species was present on "The Species at Risk in Ontario List" but not included in the dataset from ECCC (n=26), a range was obtained from management or recovery documents (Table A1 in Appendix A for list of species range sources). We acknowledge that there are more precise habitat models available for some species, such as species-specific distribution models (e.g. Rosner-Katz et al., 2020; McCune, 2016), but we used habitat associations from recovery documents to ensure that habitat depictions had the same precision for all SAR in subsequent analysis.

To determine the extent of protection for these habitats, we compiled a network of all areas in Ontario that are currently protected. This network includes federal and provincial protected areas and private properties owned by non-governmental organizations for the purpose of protection (Table 1). We also chose to include Indigenous-managed land as protected because Indigenous lands have been found to contain equal or higher levels of biodiversity than protected areas, suggesting that these areas afford protection to species at risk (Schuster, Germain, et al., 2019). We note, however, that doing so does not imply that Indigenous lands should be considered as part of protected area portfolios contributing to non-Indigenous governments' biodiversity commitments. The areas included in the protected area network are in Table 1.

Table 1. Protected areas and their managing parties in Ontario

Layer	No. of Areas	Area Types	Managing Party
Federal Protected Areas (OMNRF, 2018a)	34	National park, national wildlife area, other federal protected area	Parks Canada, Environment and Climate Change Canada
Federal Lands (Other) (OMNRF, 2019c)	1951	Canal, community, military base, settlement, tower, other	Federal Government
Indigenous Lands (Natural Resource Canada, 2017)	424		First Nations
Provincial Conservation Reserve (OMNRF, 2019b)	295		Ontario Parks – OMNRF
Provincial Parks (OMNRF, 2019e)	343	Regulated provincial parks, protected areas under *Far North Act*	Ontario Parks – OMNRF
Provincial Enhanced Management Area (OMNRF, 2012)	8	Great Lakes Coastal Area	OMNRF

NCC Properties (Nature Conservancy of Canada, 2018)	250		Nature Conservancy of Canada
NGO Nature Reserves (OMNRF, 2019d)	24		Private organizations (e.g., Ducks Unlimited)

Finally, to measure the overlap of each species' habitat with the complied protected area network, we converted the habitat shapefiles into raster files at 100m x 100m resolution. We then calculated the number of raster cells of each species habitat that overlapped with the protected area network. The percentage of protected habitat was calculated for each species by dividing the number cells overlapping with a protected area by the total number of cells occupied by a species' inferred habitat.

As a complementary analysis, we conducted the same calculation to determine the percentage habitat that overlaps with Crown land that is not protected (i.e., not managed under the *Provincial Parks and Conservation Reserves Act*; for example general use area, natural heritage area, wilderness area) using the Ontario Crown Land Atlas dataset (OMNRF, 2012).

2.2.4 Predicting Property Acquisition Cost

To construct a model that estimates property cost, we collected cost data for 2150 rural properties across Ontario's census divisions. We selected properties using a random point generator feature in ArcGIS (ESRI Inc., 2019), which ensured properties were at least 500m from each other and therefore evenly dispersed through each census division. Fifty properties were identified in each of the 38 southernmost census divisions. However, only 25 properties were identified in each of the 10 northernmost census divisions (hereafter referred to as the northern region, including Algoma, Cochrane, Kenora, Manitoulin, Nipissing, Rainy River, Sudbury Greater, Sudbury, Thunder Bay, and Timiskaming; see Fig. B1 in Appendix B), because properties with available information were often clustered in small communities and did not meet the constraint of being at least 500m apart. Population centers, which are defined as areas with a population density of at least 400 persons per square kilometer (Statistics Canada, 2016), were removed from the analysis because they would be less feasible for protection through land purchase (Fig. B1 in Appendix B). As a result, one census division (Toronto), was completely removed from the analysis. In summary, the criteria for including a property in the analysis were that it was at least 500m from any other property already included in the analysis and that it was not located in a population center.

Using the GPS coordinates produced from the random point generator, we located the nearest property in Geowarehouse, a property information software package (TERANET, 2020). This software uses information from the Ontario Land Registry and the Municipal Property Assessment Corporation (MPAC) to report property details and price assessment information. This software operates on a cost-per-property view basis, so to manage project costs, a sample of 2150 properties was collected. For each of the 2150 properties, we collected data on the assessed property values in Canadian dollars (CAD) from 2016 (the most recent province-wide property assessment year), area in square meters, whether a property had farmland, forest, or water present based on the Ontario Land Cover Compilation V.2. (OMNRF, 2018b), and if any buildings were present on the property (OMNRF, 2017).

Finally, we constructed a log-linear model to predict property cost of private land using the following variables: property area in hectares as a continuous variable, property type given by the constructed dataset as a series of binary variables (i.e., farm, forest, water buildings), census division as a categorical variable, and property cost as a dependent variable. The model for property cost was as follows:

$$\log(\text{price}) = \log(\text{area}) + \text{census division} + \text{water} + \text{forest} + \text{farm} + \text{building}. \quad 1.$$

2.2.5 Prioritization

We used prioritizr (Hanson et al., 2021) to build conservation prioritization scenarios with the goal of identifying priority areas for conservation that can protect certain percentages of habitat for all SAR in Ontario for the least cost. Prioritizr is an R package for building and solving systematic conservation planning problems that uses integer linear programming (ILP) (Hanson et al., 2021). ILP is often used in management decisions, specifically optimization problems where objectives are minimized/maximized based on linear constraints (in our case, minimum protection target for each species) and decisions are discrete (in our case, whether to prioritize a property for protection or not) (Beyer et al., 2016). Prioritizr uses an exact algorithm solver to ensure optimal solutions, in this case Gurobi 9.0.3 (Guribi Optimization, 2021).

We ran multiple protection scenarios ranging from 5% to 100% of habitat protected for all SAR in Ontario. Our problem objective was to minimize the cost of the solution, while our target was to ensure the given habitat percentage was met for all species. We chose to include an argument that ensured Crown land properties were selected in the solution. We added Crown land with zero cost to reflect what we feel is a realistic scenario: the government choosing to prioritize land that they already hold for protection, rather than purchasing private land. However, we note that our analysis accounts for private land costs only. We acknowledge that protecting Crown land comes with non-zero costs as well as opportunity costs, but we assume that these costs would be lower than purchasing private land. Finally, we set the decision function to be binary, so that the solution either prioritized whole properties or it did not.

2.3 Results

2.3.1 Identifying Habitats of Protected Species at Risk

Greater concentration of SAR habitat is found in the southern region Ontario (Fig. 1). Our analysis shows that the most commonly used habitat types by SAR in Southern Ontario include deciduous forest, agriculture, and tallgrass habitats, with up to 33 (19%) SAR relying on those habitat types. The most commonly used habitat types in the northern region were mixed forest, coniferous and deciduous forests, which were home to up to 10 (6%) SAR. The least commonly used habitat types, in both the southern and northern regions, were wetland habitat types (e.g., marsh, swamp, fen, bog, and heath).

Protected areas represent about 12% of the terrestrial area in Ontario, located mostly in the northern region of the province (Fig. 1). Only 4% of protected areas (by area) are in the southern portion of the province.

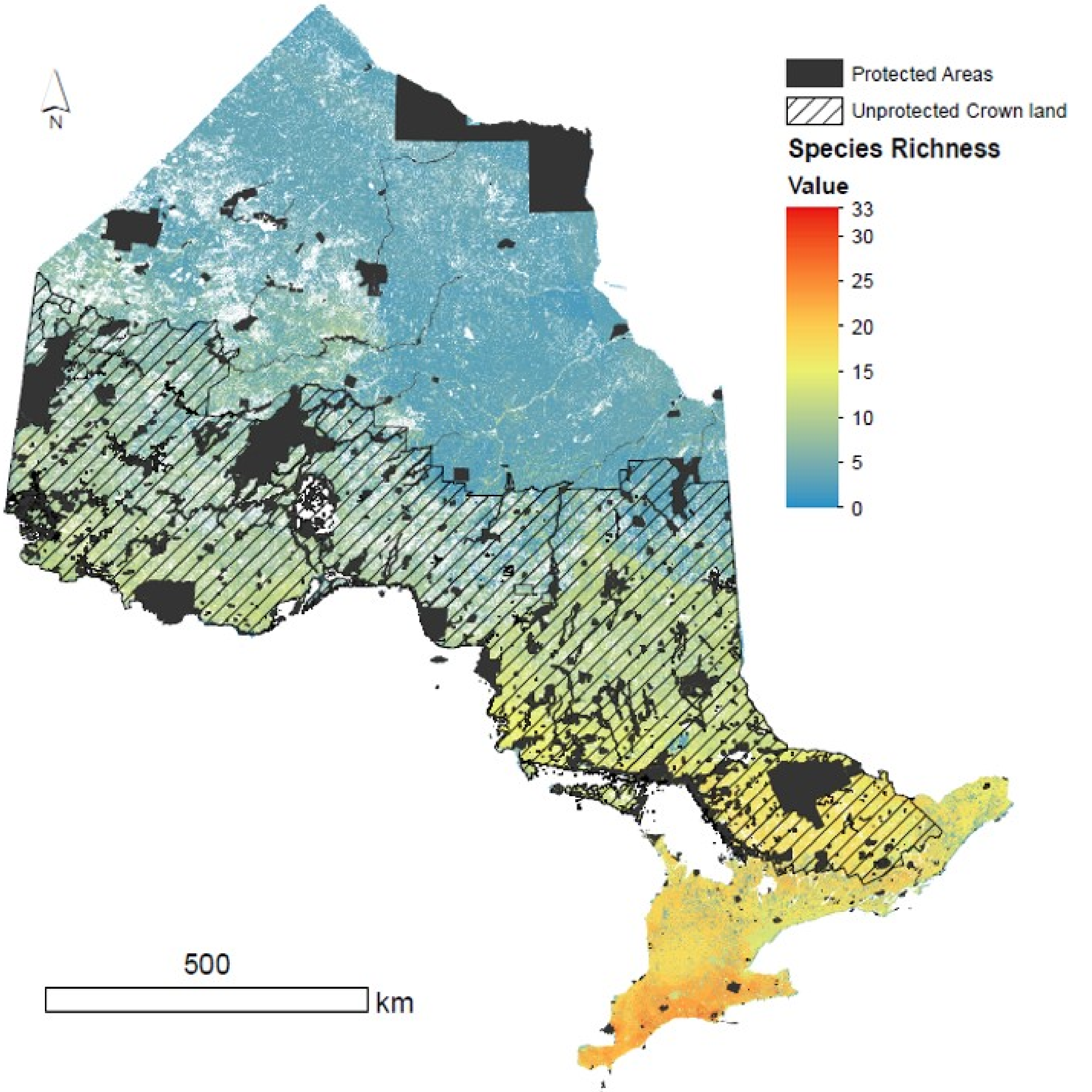

Figure 1. Protected areas and unprotected Crown land in Ontario with heat map indicating richness of species at risk

When assessing the overlap between existing protected areas and the habitats of 175 species at risk, we found that half (n=88) of all species at risk had less than 10% of their habitat protected by existing protected areas and most species (n=133 or 76%) had less than half of their habitat protected (Fig. 2). Six percent of species (n=11) had none of their habitat protected, which included eight plant species, one mollusk, one amphibian, and one insect (Table A2 in Appendix A). However, 8% of species (n=14) had over 90% of their habitat protected, including two species, the lakeside daisy (*Tetraneuris herbacea*) and white prairie gentian (*Gentiana alba*), which exist completely within protected areas.

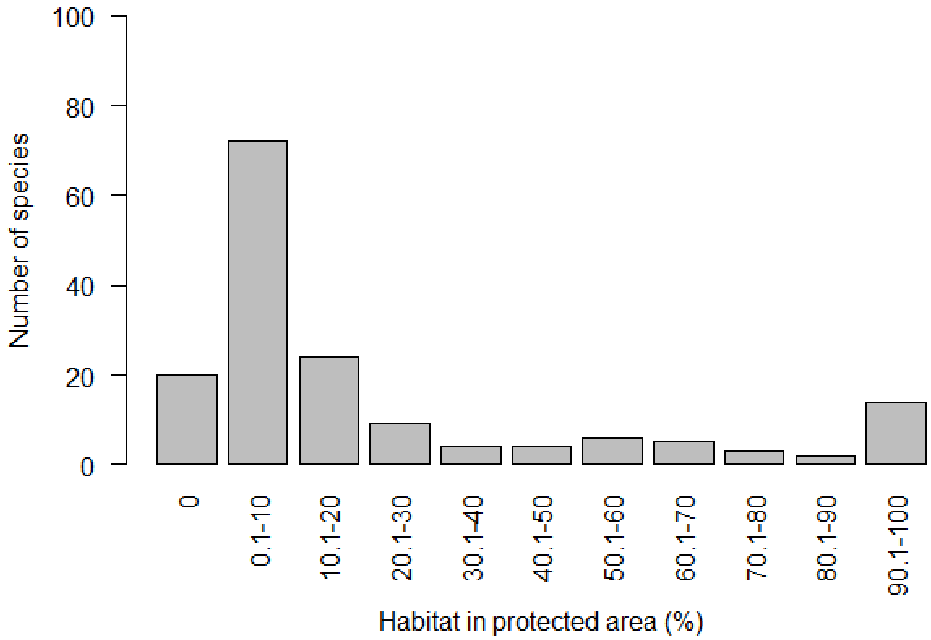

Figure 2. Distribution of percent protected habitat for species at risk in Ontario (n=175)

Over one-third (n=67) of the species' habitats did not overlap at all with Crown land and most of the species (n=138 or 78%) had less than half of their habitat overlap with Crown land (Fig. 3). Fifteen percent of species (n=26) had between 50% and 90% habitat overlapping with Crown land and no species' habitat overlapped Crown land by more than 90%.

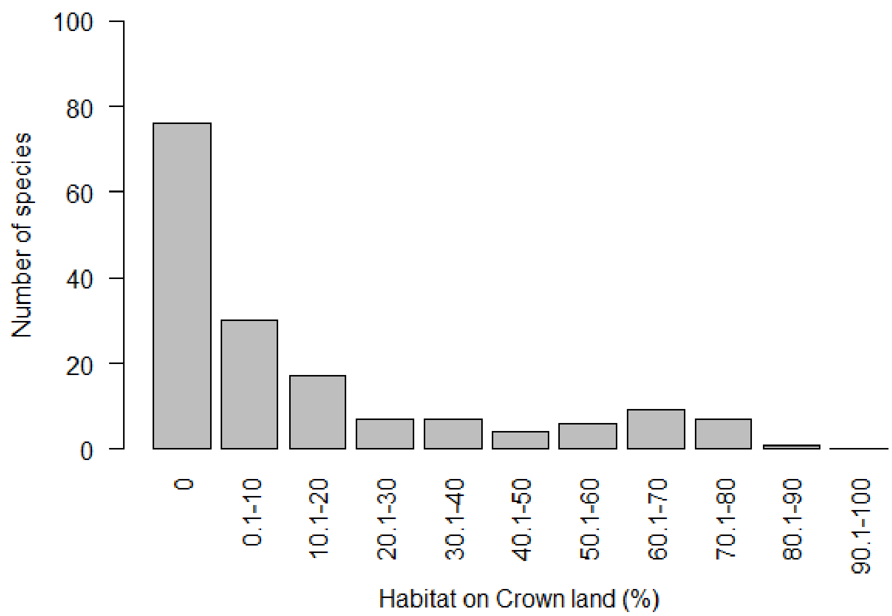

Figure 3. Distribution of percent habitat on Crown land for species at risk in Ontario (n=175)

2.3.2 Prioritization

The cost of protecting SAR habitat increases with greater percentages of habitat protected (Fig. 4; Table A3 in Appendix A). Figure 4 shows a habitat protection-cost curve for all species at risk in Ontario. The cost curve starts with a very shallow slope, indicating that at lower percentages of habitat protection there is a smaller cost increase for additional protection through land purchase. However, with higher percentages of habitat protection the slope progressively steepens, indicating a rapid increase in land acquisition cost. Correspondingly, the relative amount of Crown land parcels included in each protection scenario exhibits a decreasing trend (Fig. 4).

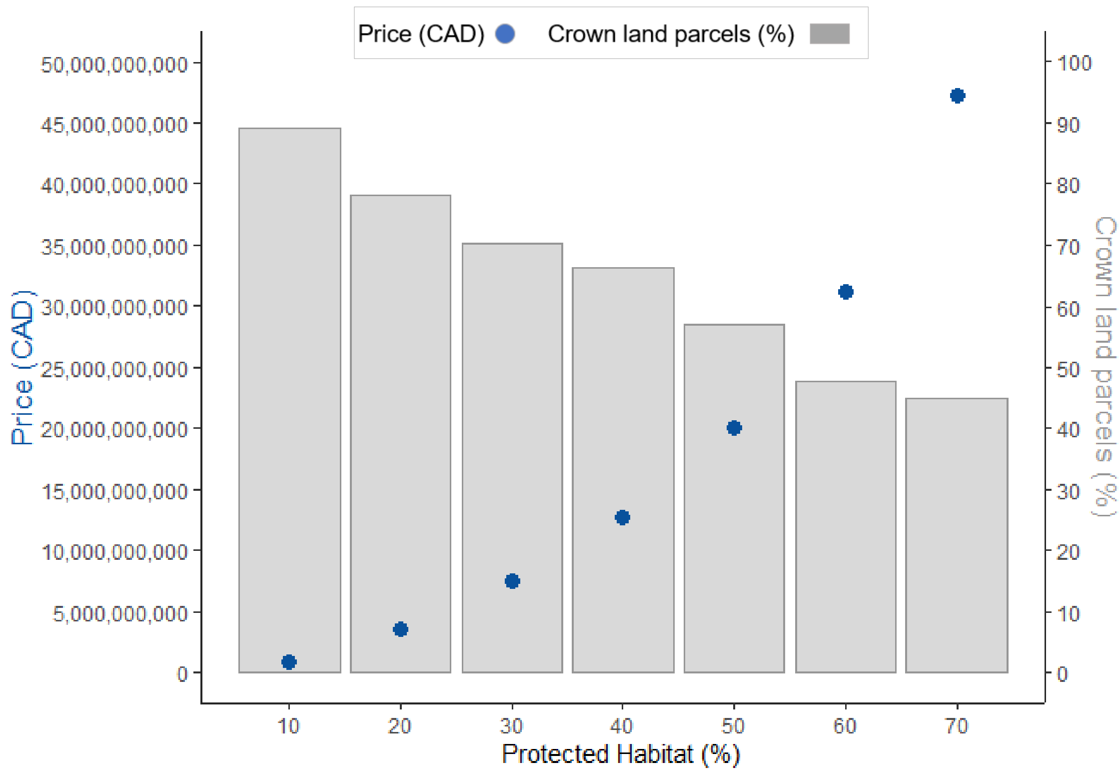

Figure 4. Total cost of purchasing a percent habitat for each species at risk with the amount of Crown parcels included to reach a given percent habitat. As an example, if we want to protect 30% of each species habitat, it would cost about $7.5 billion and 70% of the parcels would be Crown land. Costs for increments from 70% to 100% can be found in Table A3 in Appendix A.

Figure 5 shows parcels that were the most cost-effective solution for protecting 30% habitat (Canada's 2030 conservation target; Trudeau, 2019) for each species through land purchase. Central Ontario is the most densely prioritized region, whereas the southernmost region of the province has sparely selected properties. Noticeable areas that are not prioritized are the Ottawa region, the Algonquin park area, and the northern portion of the province.

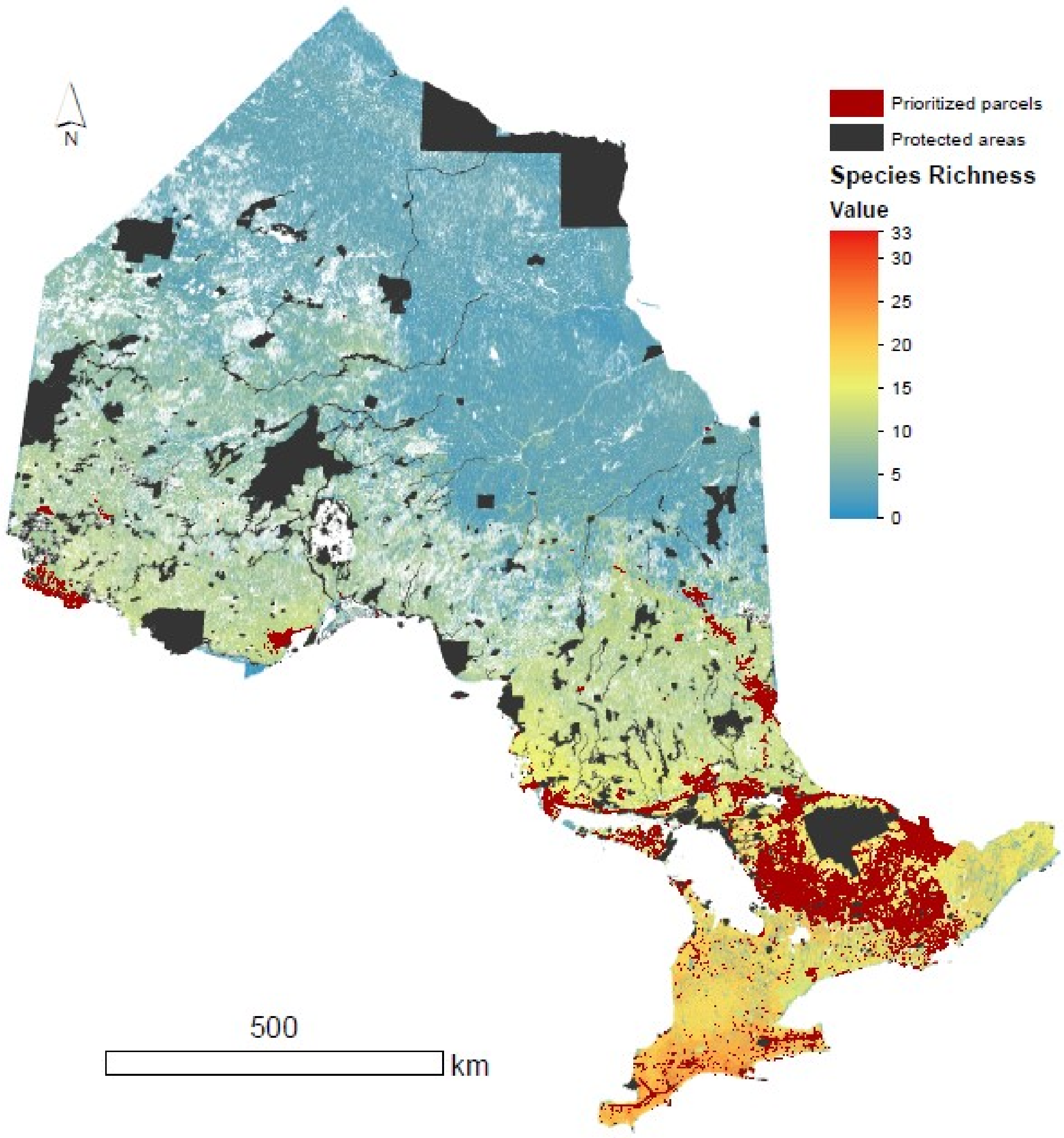

Figure 5. Areas prioritized for protection of 30% habitat for each species at risk in Ontario

2.3.3 Predicting Property Acquisition Cost

The model we created proved to be a good predictor of property cost in Ontario (R^2 = 0.649, P< 0.001). Every predictor variable had a significant influence on the model (see Appendix C for model summary).

Model estimates of average land cost per hectare were much higher in the more southern census divisions, specifically those with higher population density (Fig. 6; see Table A4 in Appendix A). The census division with the highest land cost per hectare was Peel, which is located directly to the west of Toronto, while the census division with the lowest land cost per hectare was Algoma, which is located north of Manitoulin Island.

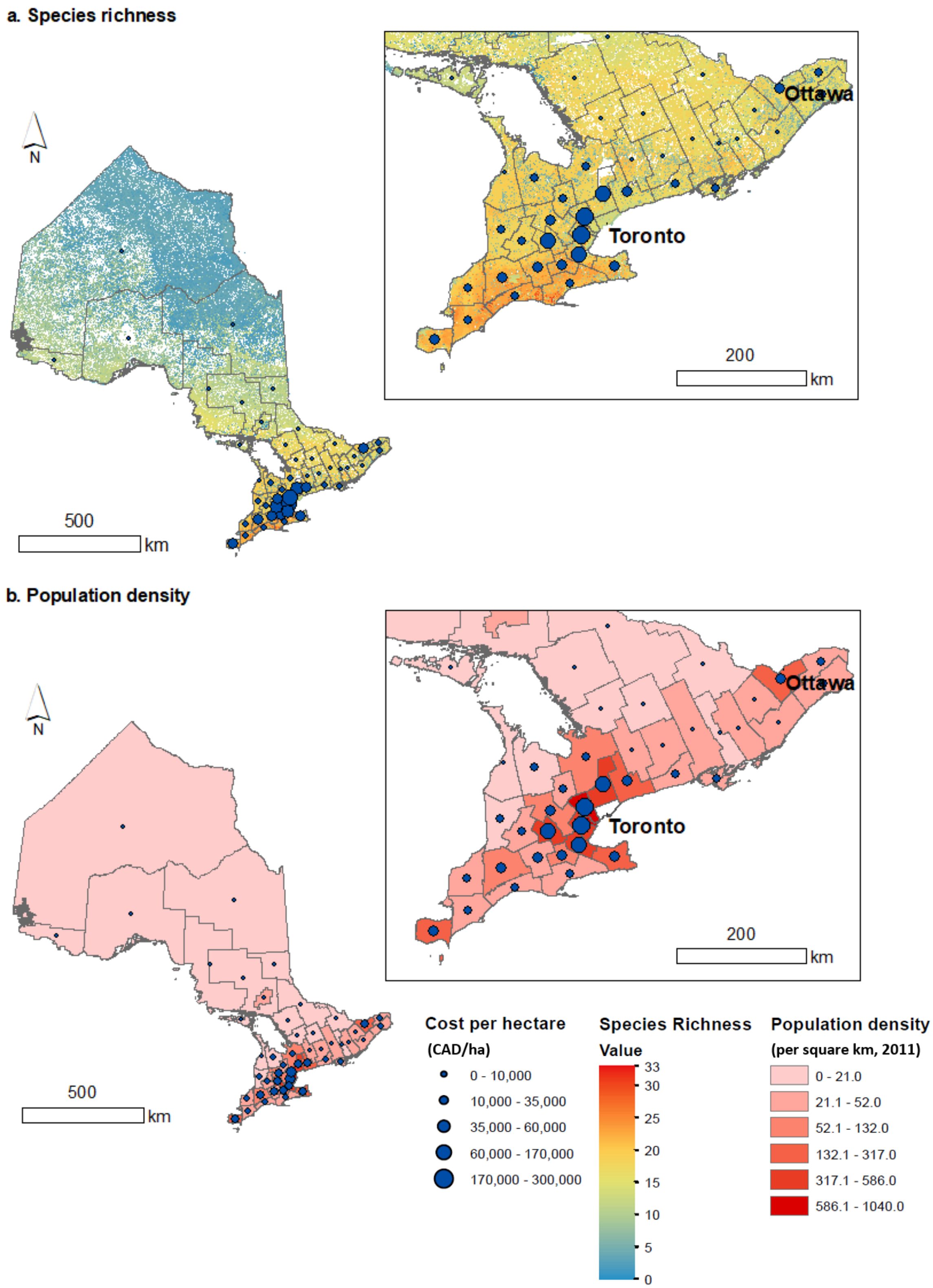

Figure 6. Average land cost per hectare (bubble size) with a) species at risk richness and b) population density per square kilometer (2011) in Ontario

2.4 Discussion

In most cases, if cost is included in conservation prioritization problems, a proxy is used to estimate property cost. Typically, cost is equated with area (e.g. Schuster, Wilson, et al., 2019; Stewart & Possingham, 2005). Here, we incorporate real-world cost data for private land into a spatial prioritization problem to explore habitat protection possibilities in Ontario. More specifically, we identify priority areas for protecting different amounts of habitats for SAR for a minimum cost to support practical and cost-effective conservation planning. Further, we use habitat models for SAR, rather than range models, which provides a more tailored prioritization solution than many other projects of similar scale (e.g., Bolliger et al., 2020).

2.4.1 Identifying Habitats of Protected Species at Risk

Assessing the current state of protection for terrestrial SAR and their habitats in Ontario is important for evaluating the usefulness of the existing protected area network and for planning future protected areas when trying to meet conservation targets. Currently, Ontario's protected area network does not effectively offer protection for SAR and their habitats. Given that most SAR habitat is in the southern region of the province and the largest and most numerous protected areas are in the northern region, it is clear why the majority of SAR have less than half of their habitat protected (Fig. 1).

The inefficiency of existing protected areas in Ontario, and nationally, has been previously acknowledged, especially for SAR (Bolliger et al., 2020; Deguise & Kerr, 2006). More recently, it was recognized by the Auditor General of Ontario that protected areas, specifically in southern Ontario, need to better protect SAR (Lysyk & DeMarco, 2020). Areas with high biodiversity tend to overlap with areas of dense human population and are therefore more vulnerable to land conversion (Andrew et al., 2011; Cincotta et al., 2000). Additionally, protected areas tend to be established in less populated and less biodiverse areas (e.g., Arctic and boreal regions) like northern Ontario. These protected areas in less diverse regions also tend to be much larger than those in more biodiverse areas (Andrew et al., 2011; Deguise & Kerr, 2006). This results in the most imperiled species and habitats, like in southern Ontario, receiving much less formal protection. When they are afforded protection, they are more likely to be affected by surrounding land use pressures and less likely to accommodate dispersal of species among habitats (Andrew et al., 2011).

In areas like southern Ontario with large populations and increasing land use, establishing new protected areas or expanding existing ones may be difficult (Arponen, 2012; Deguise & Kerr, 2006). However, it is worth noting that the addition of smaller protected areas can provide protection for small populations of at-risk species and habitat remnants (Bennett & Arcese, 2013; Andrew et al., 2011). This could be particularly useful for the remaining small patches of tallgrass habitats found in southern Ontario, which we found to be heavily relied upon by SAR. A good example of the utility of small protected areas is the Ojibway Prairie Provincial Nature Reserve in southern Ontario, which contains one of the largest remaining tallgrass prairie habitat patches in Ontario (Ontario Parks, 2002) and is relied upon by many SAR, such as slender bush clover (*Lespedeza virginica*; COSSARO, 2007).

Nevertheless, SAR in Ontario are not adequately protected by the current network and although the existing small protected areas may protect select small populations, they do not provide protection for the SAR that exist outside of those small areas. Therefore, in areas such as southern Ontario, the majority of SAR may have to rely upon alternative protection measures, such as OECMs.

2.4.2 Prioritization

When applying a cost-effectiveness problem to a land purchase prioritization for SAR in Ontario, the prioritization identified areas required to meet habitat targets for the lowest costs. For example, if aiming to protect 30% habitat for all SAR in Ontario, the prioritization suggests that most of the land purchase should occur in south-central Ontario, with scattered purchases in southern Ontario (Fig. 5). This example illustrates the balance that can be achieved through prioritization problems. If the prioritization were to target SAR habitats without considering cost, or if it were to consider area as a proxy for cost as is typical in some priority-setting exercises (e.g. Schuster, Wilson, et al., 2019; Stewart & Possingham, 2005), it would recommend land purchase in areas with the highest species richness (i.e., southern Ontario). However, land purchase in that area is highly impractical due to high cost (Fig. 6). Additionally, if the prioritization were to only minimize cost to achieve an area-based target regardless of SAR habitat requirements, it would suggest land purchase in the northern region where land cost is lower, but it would not benefit many SAR. Therefore, to be as efficient as possible with conservation funds, land purchase for the protection of SAR would be most effective in areas where there is still a relatively high SAR richness, but human population density (and land cost) is also low, resulting in a lower purchase cost (Balmford et al., 2003).

When trying to achieve protection targets, the use of Crown land offers a viable strategy. Like existing protected areas, the majority of Crown land is located in the northern and central portions of Ontario, making the overlap with SAR habitat generally low (Fig. 1). When protecting smaller overall percentages of SAR's habitat, Crown land is a viable option for reaching protection targets at a lower cost. However, as habitat protection targets increase, it becomes increasingly necessary to include private land purchase, causing purchase costs to increase exponentially (Fig. 4).

2.4.3 Predicting Property Acquisition Cost

In establishing new protected areas, it is important to consider economic variables to create efficient conservation plans (Arponen, 2012; Wilson, Carwardine, et al., 2009; Naidoo et al., 2006). This is especially important because often when conservation targets are agreed upon, the cost associated with meeting those targets is unknown (McCarthy et al., 2012). Here, we used real-world cost data to build a model to estimate the cost to purchase properties in Ontario for SAR protection and found that properties in the southern region of the province, specifically those near dense human populations, were the most expensive. Purchase cost is more likely to be higher in areas that are valuable for uses other than conservation, specifically for development and agricultural use (Robillard & Kerr, 2017) (where proximity to infrastructure and population is important (Balmford et al., 2003)). This explains the purchase cost pattern seen in southern Ontario, where population density is the highest, purchase cost is the highest (i.e., greater Toronto area and Ottawa) and where there are large areas of land suitable for agriculture, purchase cost is also high (Fig. 6). Although potential purchase cost proxies like population and opportunity cost may show similar patterns to that of our cost model, those variables remain somewhat subjective and do not achieve the accuracy that comes from using actual cost data (Wilson, Cabeza, et al., 2009; Naidoo et al., 2006).

Although this prioritization problem aims to reach the conservation target for the least possible cost, it is clear that costs of habitat conservation beyond a low level such as 5% would be substantial (Fig. 4 and Table A3 in Appendix A). The estimated cost for protection rapidly increases above 5%, so when considering the recent protection targets of 30% by 2030 (Trudeau, 2019) - which would cost approximately $7.5 billion - protection through mechanisms other than strict protection, such as OECMs, should be explored to help achieve targets while being more cost effective.

2.4.4 Implications

Ontario has not significantly added to the protected area network in the last five years, and there is no long-term plan to expand the network in the future (Lysyk & DeMarco, 2020). Furthermore, given the unrealistic costs associated with land purchase, especially in locations with the most SAR, exploring alternative protection measures on private lands will be necessary. Strictly protected areas can be supported by OECMs on private lands that offer refuge to species, but are not recognized as protected areas (Dudley et al., 2018). OECMs were first introduced in the CBD's Aichi target 11 as a complimentary approach to protected areas to conserve important biodiversity (Lemieux et al., 2019).

The most common approach to private land conservation is a voluntary conservation easement (Kamal et al., 2015). Conservation easements are legal agreements between private landowners and a non-profit land trust or government organizations in which landowners retain title but agree to certain conservation actions or land-use restrictions (Schuster et al., 2017; Kamal et al., 2015). In return, landowners are given incentives such as payments or tax reductions (Rissman et al., 2007). Easements have much lower initial costs compared to land acquisition (Schuster et al., 2017), which makes them well suited for limited budget scenarios. These agreements are especially effective for non-agricultural lands where financial compensation is less important (Drescher et al., 2017).

Conservation easements on private land can be particularly important in areas like southern Ontario, where our prioritization suggests that land acquisition is impractical and there is limited Crown land available. They can help fill protection gaps and increase connectivity for species whose ranges may be in areas with little or no protection (Rissman et al., 2007).

Although OECMs and easements are becoming increasingly important for achieving successful conservation (Drescher et al., 2017), they do have their challenges, including landowner's willingness to participate and compliance (Schuster et al., 2017). Easements are certainly not meant to replace strictly protected areas and should only be considered in specific circumstances where protected areas are impractical. Furthermore, OECMs are important for more than just meeting conservation targets, because even if those targets are reached, protected areas completely isolated from other natural areas by developed land will not provide long-term benefits to many species (Dudley et al., 2018).

2.4.5 Scope and Limitations

This study focuses on the spatial prioritization of SAR habitat in Ontario using a purchase cost model, which identifies the most cost-efficient areas to purchase to protect SAR. The scope of this study does not reach beyond the boundaries of Ontario and strictly focuses on species listed on the Species at Risk in Ontario List. Nonetheless, ideas presented here can be applied more widely, beyond Ontario. We acknowledge that there are costs associated with protected areas beyond purchase cost, such as land transfer, management, and potential restoration costs. However, this study focuses only on illustrating the approximate magnitude and heterogeneity of costs to purchase SAR habitat across Ontario.

We chose to use SAR habitat as our biological metric in the prioritization problem. Other metrics, such as genetic diversity (Ottewell et al., 2016) and endemism (Bode et al., 2008) have been used in similar studies. Although these alternative metrics are useful, we felt that by using a simpler variable (i.e., SAR richness), we were able to accomplish the goal of our study, which was to provide cost-effective protection scenarios for SAR. More importantly, SAR have certain legal protections in Ontario (*Endangered Species Act*, 2007), while other potential conservation goals, such as genetic diversity and endemism, do not.

Additionally, when constructing our own habitat models, we aimed to balance overestimating and underestimating species occurrences. By using species habitats rather than species ranges, we could have underestimated the occurrence of species because some species can occupy habitat types other than those listed in recovery documents. Furthermore, we could have overestimated species occurrences because species do not always fully occupy the available habitat. However, we believe that, when studying SAR, using a habitat model may be more appropriate than using range maps that may overestimate species occurrences (Jetz et al., 2008). We acknowledge that there may be more accurate species distribution data for *some* of the species used in this study (e.g., Rosner-Katz et al., 2020; McCune, 2019), but we are not aware of a dataset that provides more accurate information on *all* habitats of SAR in Ontario.

When using economic data, it is also important to emphasize that costs will likely change over time. Specifically, purchase costs can be expected to increase over time (Robillard & Kerr, 2017). This could affect the outcomes of the prioritization and underscores the importance of implementing conservation actions without delay. In addition, our prioritization assumes that property owners would be willing to sell their properties, which would not always be the case. Where sellers would be unwilling, then less cost-efficient properties would have to be chosen, likely driving up actual costs.

In addition, this study does not consider current or future threats to SAR and how they may affect their protection in the future. Further spatial prioritization studies for SAR in Ontario should consider how species ranges may shift due to climate change, which would require species distribution models for all SAR. Another variable to consider in potential prioritizations is land use changes and how those changes may affect future habitat loss. Including either climate change or land use change or both in a spatial prioritization, similar to the one conducted here, would require more extensive data analysis and likely more factors, such as connectivity, but would also reflect the future needs of species for conservation planning.

2.5 Conclusion

Given that conservation budgets are constrained, it is important to determine the most cost-efficient strategies to protect SAR (Naidoo et al., 2006; Margules & Pressey, 2000). Our prioritizations suggest that when considering land purchase for the protection of SAR in Ontario, it may be most cost-efficient to purchase land in areas like central Ontario, where SAR richness is relatively high and population density is low. However, purchasing land to adequately protect SAR would require a budget much larger than is currently available for conservation efforts. Therefore, to effectively protect SAR, we recommend the use of OECMs, such as conservation easements on private land, to supplement protected areas.

We recognize that the conservation of SAR is not as simple as purchasing land and creating protected areas. There are many other factors that go into successful conservation, such as appropriate funding, cooperation with landowners, data availability and accessibility, the management of protected areas after they have been established, and much more. However, given that habitat loss and disturbance is the greatest threat to biodiversity globally and in Canada (Maxwell et al., 2016; McCune et al., 2013; Kerr & Deguise, 2004), protecting habitat for species at risk should be a cornerstone of any future conservation strategy.

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Appendix A: Supplemental Tables

Table A1. Species and their threat level listed on the Species at Risk in Ontario List (SARO, 2018) with habitat requirements and range information source

Species	Threat level	Habitat Types*	Source
Acadian Flycatcher	Endangered	dtr mtr swp	(ECCC, 2016b)
Algonquin Wolf	Threatened	mtr ctr	(COSSARO, 2016)
Allegheny Mountain Dusky Salamander (Carolinian population)	Endangered	mtr dtr str ctr	(ECCC, 2016b)
Allegheny Mountain Dusky Salamander (Great Lakes / St. Lawrence population)	Endangered	mtr dtr str ctr	(ECCC, 2016b)
American Badger jacksoni subspecies	Endangered	tgp tgs snd agr	(ECCC, 2016b)
American Badger jeffersonii subspecies (Eastern population)	Endangered	tgp tgs snd agr	(ECCC, 2016b)
American Chestnut	Endangered	tru	(ECCC, 2016b)
American Columbo	Endangered	tru dtr swp tgw str	(ECCC, 2016b)
American Ginseng	Endangered	drt	(ECCC, 2016b)
American Water–willow	Threatened	shr mud msh swp fen bog	(ECCC, 2016b)
American White Pelican	Threatened	bdr snd alv mud str shr	(American White Pelican Recovery Team, 2011)
Aweme Borer	Endangered	tgp tgs snd	(ECCC, 2016b)
Bald Eagle	Special Concern	str dtr ctr mtr tru tgw	(Armstrong, 2014)
Bank Swallow	Threatened	snd shr sgm com agr	(ECCC, 2016b)
Barn Owl (Eastern population)	Endangered	com	(ECCC, 2016b)

		agr	
Barn Swallow	Threatened	com agr	(ECCC, 2016b)
Bashful Bulrush	Endangered	dtr str tgs	(ECCC, 2016b)
Bent Spike-rush (Great Lakes Plains population)	Endangered	shr mud msh	(ECCC, 2016b)
Bird's–foot Violet	Endangered	tgs	(ECCC, 2016b)
Black Tern	Special Concern	msh swp	(Burke, 2012)
Blanding's Turtle (Great Lakes / St. Lawrence population)	Threatened	msh swp fen bog	(ECCC, 2016b)
Blue Ash	Threatened	dtr shr mud	(ECCC, 2016b)
Blue Racer	Endangered	het agr alv tgp tgs tgw str	(ECCC, 2016b)
Bluehearts	Endangered	snd shr tgp het	(ECCC, 2016b)
Blunt–lobed Woodsia	Endangered	clf bdr dtr	(ECCC, 2016b)
Bobolink	Threatened	het tgp tgs agr	(ECCC, 2016b)
Bogbean Buckmoth	Endangered	fen	(ECCC, 2016b)
Branched Bartonia	Threatened	bog fen	(ECCC, 2016b)
Broad–banded Forestsnail	Endangered	dtr mtr ctr alv tru str	(ECCC, 2016b)
Butler's Gartersnake	Endangered	het bog fen msh agr	(ECCC, 2016b)
Butternut	Endangered	dtr	(ECCC, 2016b)
Canada Warbler	Special Concern	dtr ctr mtr tgw	(ECCC, 2016b)
Caribou (Eastern Migratory)	Special Concern	msh fen bog het str dtr mtr	(COSEWIC, 2017)

		ctr pla tru	
Cerulean Warbler	Threatened	dtr tru str	(ECCC, 2016b)
Cherry Birch	Endangered	dtr	(ECCC, 2016b)
Chimney Swift	Threatened	com	(ECCC, 2016b)
Climbing Prairie Rose	Special Concern	tgp agr het	(ECCC, 2016b)
Colicroot	Endangered	het tgp tgs agr	(ECCC, 2016b)
Common Hoptree	Special Concern	shr	(ECCC, 2016b)
Common Nighthawk	Special Concern	str bdr bog shr alv mud	(ECCC, 2016b)
Crooked–stem Aster	Special Concern	str	(ECCC, 2016b)
Cucumber Tree	Endangered	dtr mtr swp	(ECCC, 2016b)
Deerberry	Threatened	dtr ctr mtr str	(ECCC, 2016b)
Dense Blazing Star	Threatened	tgp tgs snd agr	(ECCC, 2016b)
Drooping Trillium	Endangered	dtr	(ECCC, 2016b)
Dwarf Hackberry	Threatened	shr alv tgs snd	(ECCC, 2016b)
Dwarf Lake Iris	Special Concern	ctr swp alv str	(ECCC, 2016b)
Eastern Banded Tigersnail	Endangered	dtr ctr mtr	(Wyshynski et al., 2019)
Eastern Flowering Dogwood	Endangered	dtr mtr	(ECCC, 2016b)
Eastern Foxsnake (Carolinian population)	Endangered	agr msh hed shr tgp	(ECCC, 2016b)
Eastern Foxsnake (Great Lakes / St. Lawrence population)	Threatened	agr msh hed shr tgp	(ECCC, 2016b)
Eastern Hog–nosed Snake	Threatened	shr tru dtr mtr	(ECCC, 2016b)

		ctr str snd agr tgp tgw	
Eastern Meadowlark	Threatened	agr tgp tgs	(ECCC, 2016b)
Eastern Mole	Special Concern	dtr ctr tru mtr str tgw tgp tgs agr com	(ECCC, 2016b)
Eastern Musk Turtle	Special Concern	msh	(ECCC, 2016b)
Eastern Prairie Fringed–orchid	Endangered	bog fen swp tgp	(ECCC, 2016b)
Eastern Prickly Pear Cactus	Endangered	shr snd alv tgs tgp str	(ECCC, 2016b)
Eastern Ribbonsnake (Great Lakes population)	Special Concern	msh swp bog fen	(ECCC, 2016b)
Eastern Small-footed Myotis	Endangered	com clf sgm str mtr dtr ctr	(Humphrey, 2017)
Eastern Whip–poor–will	Threatened	tgs tgp tgw str agr ctr dtr mtr tru	(ECCC, 2016b)
Eastern Wood–pewee	Special Concern	dtr mtr str tgw	(ECCC, 2016b)
Evening Grosbeak	Special Concern	mtr ctr com	(COSEWIC, 2016)
False Hop Sedge	Endangered	swp msh str	(ECCC, 2016b)
False Rue–anemone	Threatened	dtr	(ECCC, 2016b)
Five-lined Skink (Carolinian population)	Endangered	snd str tgw	(ECCC, 2016b)

		msh swp bog fen	
Five-lined Skink (Great Lakes / St. Lawrence population)	Special Concern	snd str bdr alv	(ECCC, 2016b)
Forked Three–awned Grass	Endangered	tgp agr tgs snd	(ECCC, 2016b)
Four-leaved Milkweed	Endangered	dtr str	(ECCC, 2016b)
Fowler's Toad	Endangered	shr mud snd msh swp fen	(ECCC, 2016b)
Gattinger's Agalinis	Endangered	alv tgp tgs	(ECCC, 2016b)
Golden Eagle	Endangered	clf agr str tru mtr dtr trgw ctr	(Wyshynski & Pulfer, 2015)
Golden-eyed Lichen	Endangered	mtr str ctr dtr shr tru tgw	(Knight, 2019)
Goldenseal	Threatened	str dtr	(ECCC, 2016b)
Golden–winged Warbler	Special Concern	str pla hed agr	(ECCC, 2016b)
Grasshopper Sparrow, pratensis subspecies	Special Concern	tgp tgs agr alv	(ECCC, 2016b)
Gray Fox	Threatened	msh dtr	(ECCC, 2016b)
Gray Ratsnake (Carolinian population)	Endangered	agr dtr tgp tgw tgs	(ECCC, 2016b)
Gray Ratsnake (Great Lakes / St. Lawrence population)	Threatened	dtr msh swp fen bog agr bdr	(ECCC, 2016b)
Green Dragon	Special Concern	dtr	(Donley et al., 2013a)

Gypsy Cuckoo Bumble Bee	Endangered	mtr dtr ctr agr tgp tgs com	(ECCC, 2016b)
Hart's–tongue Fern	Special Concern	dtr	(OMECP, 2019a)
Heart–leaved Plantain	Endangered	alv pla dtr	(ECCC, 2016b)
Henslow's Sparrow	Endangered	tgp tgs agr	(ECCC, 2016b)
Hill's Thistle	Threatened	alv tgp tgs snd	(ECCC, 2016b)
Hine's Emerald	Endangered	swp bog fen	(ECCC, 2016b)
Hoary Mountain–mint	Endangered	tgs	(ECCC, 2016b)
Hoptree Borer	Endangered	shr	(Harris, 2018)
Horned Grebe (Western population)	Special Concern	msh swp	(ECCC, 2016b)
Houghton's Goldenrod	Threatened	snd shr alv	(ECCC, 2016b)
Jefferson Salamander	Endangered	dtr	(ECCC, 2016b)
Juniper Sedge	Endangered	alv tgs str	(ECCC, 2016b)
Kentucky Coffee–tree	Threatened	msh str	(ECCC, 2016b)
King Rail	Endangered	msh shr	(ECCC, 2016b)
Kirtland's Warbler	Endangered	ctr mtr	(ECCC, 2016b)
Lake Erie Watersnake	Special Concern	shr	(Willson & Cunnington, 2015)
Lake Huron Grasshopper	Threatened	shr snd	(Jones, 2018)
Lakeside Daisy	Threatened	tgp tgs alv	(ECCC, 2016b)
Large Whorled Pogonia	Endangered	mtr dtr	(ECCC, 2016b)
Laura's Clubtail	Endangered	mtr dtr ctr	(ECCC, 2016b)
Least Bittern	Threatened	msh fen bog swp	(ECCC, 2016b)
Little Brown Myotis	Endangered	com clf sgm tgw ctr dtr mtr str	(COSEWIC, 2013)

		tru	
Loggerhead Shrike Eastern subspecies	Endangered	alv tgp tgs tgw agr	(ECCC, 2016b)
Loggerhead Shrike migrans subspecies	Endangered	alv tgp tgs tgw agr	(ECCC, 2016b)
Louisiana Waterthrush	Threatened	ctr dtr mtr tgw tru	(ECCC, 2016b)
Massasauga (Carolinian population)	Endangered	tgp tgw bog msh shr alv dtr ctr mtr str	(ECCC, 2016b)
Massasauga (Great Lakes population)	Threatened	tgp tgw bog msh shr alv dtr ctr mtr str	(ECCC, 2016b)
Monarch	Special Concern	tgp str tgs agr	(ECCC, 2016b)
Mottled Duskywing (Boreal population)	Endangered	alv tgp tgs snd str	(ECCC, 2016b)
Mottled Duskywing (Great Lakes Plains population)	Endangered	alv tgp tgs snd str	(ECCC, 2016b)
Nine-spotted Lady Beetle	Endangered	agr com mtr ctr dtr str tru tgp tgs tgw mud fen	(Linton & McCorquodale, 2018)
Nodding Pogonia	Endangered	dtr	(ECCC, 2016b)
Northern Barrens Tiger Beetle	Endangered	tgs	(ECCC, 2016b)

		tgw ctr mtr	
Northern Bobwhite	Endangered	tgp tgs tgw agr	(ECCC, 2016b)
Northern Dusky Salamander (Carolinian population)	Endangered	dtr ctr mtr	(ECCC, 2016b)
Northern Myotis	Endangered	clf sgm ctr dtr mtr str tru	(COSEWIC, 2013)
Olive–sided Flycatcher	Special Concern	mtr ctr msh fen bog swp	(ECCC, 2016b)
Pale–bellied Frost Lichen	Endangered	mtr dtr tru str pla	(ECCC, 2016b)
Peregrine Falcon anatum/tundrius	Special Concern	com clf	(ECCC, 2016b)
Pink Milkwort	Endangered	tgp tgs tgw snd	(ECCC, 2016b)
Piping Plover circumcinctus subspecies	Endangered	snd shr	(ECCC, 2016b)
Pitcher's Thistle	Threatened	shr snd	(ECCC, 2016b)
Polar Bear	Threatened	shr	(ECCC, 2016b)
Prothonotary Warbler	Endangered	swp msh dtr	(ECCC, 2016b)
Proud Globelet	Endangered	mtr ctr dtr tgw tru	(Wyshynski & Nicolai, 2018)
Purple Twayblade	Threatened	tgw tgs mtr dtr alv msh swp pla	(ECCC, 2016b)
Pygmy Snaketail	Endangered	dtr ctr mtr	(ECCC, 2016b)
Rapids Clubtail	Endangered	dtr ctr mtr	(ECCC, 2016b)
Red Knot rufa subspecies	Endangered	mud shr	(ECCC, 2016b)
Red Mulberry	Endangered	dtr	(ECCC, 2016b)

		ctr mtr str alv	
Red–headed Woodpecker	Special Concern	dtr ctr mtr str tgw com	(ECCC, 2016b)
Red–necked Phalarope	Special Concern	msh	(ECCC, 2016b)
Riddell's Goldenrod	Special Concern	tgp	(ECCC, 2016b)
Riverine Clubtail (Great Lakes Plains population)	Endangered	ctr mtr dtr	(ECCC, 2016b)
Round-leaved Greenbrier (Great Lakes Plains population)	Threatened	dtr str mtr msh	(ECCC, 2016b)
Rusty Blackbird	Special Concern	crt msh bog fen swp agr	(ECCC, 2016b)
Rusty–patched Bumble Bee	Endangered	agr com tgs str tgw snd tgp	(ECCC, 2016b)
Scarlet Ammannia	Endangered	mud swp msh shr	(ECCC, 2016b)
Short–eared Owl	Special Concern	tgp tgs msh alv het agr	(ECCC, 2016b)
Showy Goldenrod (Boreal population)	Threatened	tgp tgs	(ECCC, 2016b)
Showy Goldenrod (Great Lake population)	Endangered	tgp tgs	(ECCC, 2016b)
Shumard Oak	Special Concern	dtr swp hed	(Donley et al., 2013b)
Skinner's Agalinis	Endangered	tgp	(ECCC, 2016b)
Slender Bush–clover	Endangered	tgp	(ECCC, 2016b)
Small White Lady's–slipper	Endangered	fen tgp tgs	(ECCC, 2016b)
Small Whorled Pogonia	Endangered	dtr mtr ctr	(ECCC, 2016b)
Small–flowered Lipocarpha	Threatened	shr mud	(ECCC, 2016b)
Small–mouthed Salamander	Endangered	mtr dtr agr	(ECCC, 2016b)

		tgp	
Snapping Turtle	Special Concern	snd sgm agr	(ECCC, 2016b)
Spoon–leaved Moss	Endangered	dtr het swp msh tgp	(ECCC, 2016b)
Spotted Turtle	Endangered	msh bog swp	(ECCC, 2016b)
Spotted Wintergreen	Threatened	dtr mtr ctr tgw	(ECCC, 2016b)
Swamp Rose–mallow	Special Concern	fen msh bog shr	(ECCC, 2016b)
Toothcup	Endangered	shr	(ECCC, 2016b)
Transverse Lady Beetle	Endangered	agr com mtr ctr dtr str tru tgp tgs tgw mud fen	(Linton & McCorquodale, 2019)
Tri-coloured Bat	Endangered	com clf sgm tgw ctr dtr mtr str tru agr	(COSEWIC, 2013)
Tuberous Indian–plantain	Special Concern	shr fen msh swp agr tgp	(ECCC, 2016b)
Unisexual Ambystoma (Jefferson)	Endangered	mtr dtr	(Linton et al., 2018)
Unisexual Ambystoma (Small-mouthed)	Endangered	mtr dtr	(Hossie, 2018)
Virginia Goat's–rue	Endangered	str ctr tgp tgs snd	(ECCC, 2016b)
Virginia Mallow	Endangered	shr msh alv	(ECCC, 2016b)
West VIrginia White	Special Concern	dtr pla	(Burke, 2013)
Western Silvery Aster	Endangered	tgs	(ECCC, 2016b)

White Prairie Gentian	Endangered	tgw tgs	(ECCC, 2016b)
White Wood Aster	Threatened	str dtr tru	(ECCC, 2016b)
Wild Hyacinth	Threatened	str tgw het	(ECCC, 2016b)
Willowleaf Aster	Threatened	tgs	(ECCC, 2016b)
Wolverine	Threatened	dtr mtr ctr str het tru	(ECCC, 2016b)
Wood Thrush	Special Concern	mtr dtr	(ECCC, 2016b)
Wood Turtle	Endangered	str mtr ctr dtr tgp swp agr fen	(ECCC, 2016b)
Woodland Caribou (Boreal population)	Threatened	str tru mtr	(ECCC, 2016b)
Woodland Vole	Special Concern	dtr	(ECCC, 2016b)
Wood–poppy	Endangered	mtr dtr	(ECCC, 2016b)
Yellow Rail	Special Concern	msh fen bog tgp	(ECCC, 2016b)
Yellow-banded Bumble Bee	Special Concern	str mtr ctr dtr tru tgw tgp tgs agr fen com	(OMECP, 2019c)
Yellow-breasted Chat virens subspecies	Endangered	msh het tgp tgs agr fen	(ECCC, 2016b)

***Abbreviations**: agr = agriculture/rural; alv = alvar; bdr = bedrock; bog = bog; clf = cliffs and talus; com = community/infrastructure; ctr = coniferous treed; dtr = deciduous treed; fen = fen; hed = hedge row; het = heath; msh = marsh; mtr = mixed treed; mud = mudflats; pla = plantation, sgm = sand, gravel, mine; shr = shoreline; snd = sand barren/dune; str = sparse treed; swp = swamp; tgp = open trallgrass prairie; tgs = tallgrass savannah; tgw = tallgrass woodland; tru = treed upland.

Table A2. Percent protected habitat and percent habitat on Crown land for each species on the Species at Risk in Ontario List

Species	Protected Habitat (%)	Habitat on Crown Land (%)
Acadian Flycatcher	6.3	4.0
Algonquin Wolf	26.9	67.9
Allegheny Mountain Dusky Salamander (Carolinian population)	6.2	0.0
Allegheny Mountain Dusky Salamander (Great Lakes / St. Lawrence population)	1.2	0.0
American Badger jacksoni subspecies	1.4	1.7
American Badger jeffersonii subspecies (Eastern population)	2.2	0.0
American Chestnut	6.8	0.1
American Columbo	2.5	0.0
American Ginseng	4.5	18.4
American Water–willow	74.9	6.8
American White Pelican	11.7	88.4
Aweme Borer	60.4	6.5
Bald Eagle	6.3	33.1
Bank Swallow	1.2	14.7
Barn Owl (Eastern population)	2.0	0.0
Barn Swallow	1.2	14.4
Bashful Bulrush	0.0	0.0
Bent Spike-rush (Great Lakes Plains population)	93.3	0.0
Bird's–foot Violet	0.0	0.0
Black Tern	3.4	26.6
Blanding's Turtle (Great Lakes / St. Lawrence population)	6.2	23.8
Blue Ash	8.2	0.0
Blue Racer	2.5	0.0
Bluehearts	55.2	7.5
Blunt–lobed Woodsia	14.2	0.0
Bobolink	0.9	10.9
Bogbean Buckmoth	0.0	68.0
Branched Bartonia	14.5	85.6
Broad–banded Forestsnail	23.7	0.0
Butler's Gartersnake	4.1	0.0
Butternut	5.7	43.4
Canada Warbler	13.4	68.3
Caribou (Eastern Migratory)	14.6	0.4
Cerulean Warbler	7.9	14.0
Cherry Birch	0.0	0.0
Chimney Swift	1.6	17.0

Climbing Prairie Rose	3.0	0.0
Colicroot	13.6	0.0
Common Hoptree	52.7	0.0
Common Nighthawk	6.8	33.6
Crooked–stem Aster	0.0	0.0
Cucumber Tree	11.0	0.1
Deerberry	6.2	0.0
Dense Blazing Star	5.8	0.0
Drooping Trillium	0.0	0.0
Dwarf Hackberry	50.1	4.6
Dwarf Lake Iris	29.9	16.9
Eastern Banded Tigersnail	41.2	0.0
Eastern Flowering Dogwood	5.7	0.0
Eastern Foxsnake (Carolinian population)	3.9	0.0
Eastern Foxsnake (Great Lakes / St. Lawrence population)	49.2	41.8
Eastern Hog–nosed Snake	13.0	47.0
Eastern Meadowlark	1.0	10.2
Eastern Mole	0.9	0.0
Eastern Musk Turtle	4.2	16.9
Eastern Prairie Fringed–orchid	4.8	3.8
Eastern Prickly Pear Cactus	92.7	0.0
Eastern Ribbonsnake (Great Lakes population)	4.2	19.8
Eastern Small-footed Myotis	15.4	72.3
Eastern Whip–poor–will	11.5	53.3
Eastern Wood–pewee	14.1	79.7
Evening Grosbeak	6.7	35.9
False Hop Sedge	0.7	0.0
False Rue–anemone	0.8	0.0
Five-lined Skink (Carolinian population)	84.8	6.2
Five-lined Skink (Great Lakes / St. Lawrence population)	39.6	60.8
Forked Three–awned Grass	1.1	0.0
Four-leaved Milkweed	2.9	0.0
Fowler's Toad	45.5	2.5
Gattinger's Agalinis	97.0	0.0
Golden Eagle	9.0	66.1
Golden-eyed Lichen	95.9	0.0
Goldenseal	22.7	0.0
Golden–winged Warbler	4.2	20.8
Grasshopper Sparrow, pratensis subspecies	1.2	8.0
Gray Fox	8.8	34.7
Gray Ratsnake (Carolinian population)	3.2	0.0

Gray Ratsnake (Great Lakes / St. Lawrence population)	2.5	7.8
Green Dragon	4.9	0.0
Gypsy Cuckoo Bumble Bee	11.4	58.0
Hart's–tongue Fern	6.3	0.0
Heart–leaved Plantain	3.0	0.0
Henslow's Sparrow	1.9	2.9
Hill's Thistle	70.8	0.0
Hine's Emerald	6.5	0.0
Hoary Mountain–mint	0.0	0.0
Hoptree Borer	88.6	0.0
Horned Grebe (Western population)	10.9	6.3
Houghton's Goldenrod	52.2	0.0
Jefferson Salamander	7.6	0.0
Juniper Sedge	17.3	0.0
Kentucky Coffee–tree	91.6	0.0
King Rail	34.3	0.3
Kirtland's Warbler	45.0	31.9
Lake Erie Watersnake	0.0	0.0
Lake Huron Grasshopper	0.0	0.0
Lakeside Daisy	100.0	0.0
Large Whorled Pogonia	0.0	0.0
Laura's Clubtail	4.9	0.0
Least Bittern	6.8	22.8
Little Brown Myotis	13.2	71.3
Loggerhead Shrike Eastern subspecies	1.5	22.1
Loggerhead Shrike migrans subspecies	1.4	21.7
Louisiana Waterthrush	5.6	32.1
Massasauga (Carolinian population)	12.4	0.0
Massasauga (Great Lakes population)	21.6	62.7
Monarch	5.4	40.0
Mottled Duskywing (Boreal population)	93.3	6.7
Mottled Duskywing (Great Lakes Plains population)	21.8	51.8
Nine-spotted Lady Beetle	11.7	37.8
Nodding Pogonia	16.9	0.0
Northern Barrens Tiger Beetle	54.8	3.4
Northern Bobwhite	1.6	0.0
Northern Dusky Salamander (Carolinian population)	0.0	0.0
Northern Myotis	13.6	72.2
Olive–sided Flycatcher	8.6	39.3
Pale–bellied Frost Lichen	1.6	65.8
Peregrine Falcon anatum/tundrius	1.3	20.5
Pink Milkwort	61.3	0.0
Piping Plover circumcinctus subspecies	92.6	0.0

Pitcher's Thistle	98.8	19.0
Polar Bear	0.0	0.0
Prothonotary Warbler	10.7	0.4
Proud Globelet	0.0	0.0
Purple Twayblade	5.4	0.0
Pygmy Snaketail	22.2	77.8
Rapids Clubtail	2.6	54.6
Red Knot rufa subspecies	79.3	33.6
Red Mulberry	4.8	0.0
Red–headed Woodpecker	15.3	73.6
Red–necked Phalarope	67.1	14.3
Riddell's Goldenrod	94.2	0.0
Riverine Clubtail (Great Lakes Plains population)	5.3	0.0
Round-leaved Greenbrier (Great Lakes Plains population)	11.6	0.0
Rusty Blackbird	8.2	17.2
Rusty–patched Bumble Bee	1.6	8.9
Scarlet Ammannia	32.9	0.0
Short–eared Owl	2.6	12.4
Showy Goldenrod (Boreal population)	0.0	0.0
Showy Goldenrod (Great Lake population)	94.3	0.0
Shumard Oak	5.5	0.2
Skinner's Agalinis	99.1	0.0
Slender Bush–clover	0.0	0.0
Small White Lady's–slipper	97.1	2.9
Small Whorled Pogonia	0.0	0.0
Small–flowered Lipocarpha	0.0	0.0
Small–mouthed Salamander	12.9	0.0
Snapping Turtle	1.2	10.9
Spoon–leaved Moss	0.6	0.0
Spotted Turtle	3.8	12.9
Spotted Wintergreen	27.2	0.0
Swamp Rose–mallow	67.5	0.3
Toothcup	0.0	0.0
Transverse Lady Beetle	9.8	50.9
Tri-coloured Bat	10.5	61.1
Tuberous Indian–plantain	4.2	0.0
Unisexual Ambystoma (Jefferson)	6.9	0.0
Unisexual Ambystoma (Small-mouthed)	39.4	0.0
Virginia Goat's–rue	64.4	0.0
Virginia Mallow	0.0	0.0
West VIrginia White	15.8	57.9
Western Silvery Aster	0.0	0.0

White Prairie Gentian	100.0	0.0
White Wood Aster	3.7	0.0
Wild Hyacinth	0.0	0.0
Willowleaf Aster	56.1	0.0
Wolverine	9.2	20.1
Wood Thrush	14.8	78.9
Wood Turtle	25.7	67.7
Woodland Caribou (Boreal population)	12.4	56.5
Woodland Vole	7.1	0.0
Wood–poppy	0.0	0.0
Yellow Rail	27.4	13.8
Yellow-banded Bumble Bee		58.5
Yellow-breasted Chat virens subspecies	1.3	0.7

Table A3. Total price, area, and number of parcels prioritized in each protection scenario

Habitat Protected (%)	Total Parcels	Total Area (ha)	Total Price (10^6 CAD)
5	13,292	97,479	6.3
10	61,101	489,223	838
20	100,955	1,339,726	3,532
30	135,882	2,326,241	7,446
40	187,354	4,087,012	12,670
50	225,190	5,339,499	20,078
60	299,108	6,508,248	31,245
70	451,416	7,987,821	47,223
80	584,128	9,529,129	69,256
90	805,687	11,605,624	101,754
100	2,438,558	15,335,992	302,171

Table A4. Estimated land cost, total population, and population density from 2011 census for each census division

Census Division	Cost per Hectare (CAD)	Total Population in 2011	Population Density (per square km)
Algoma	396	115,870	2
Brant	58,340	136,035	124
Bruce	9,848	66,102	16
Chatham-Kent	33,793	104,075	42
Cochrane	536	81,122	1
Dufferin	21,108	56,881	38

Durham	55,657	608,124	241
Elgin	29,331	87,461	46
Essex	51,531	388,782	210
Frontenac	7,311	149,738	40
Greater Sudbury	1,917	160,376	50
Grey	15,264	92,568	21
Haldimand-Norfolk	23,364	109,118	38
Haliburton	2,297	17,026	4
Halton	198,881	501,669	520
Hamilton	107,934	519,949	465
Hastings	4,266	134,934	22
Huron	31,557	59,100	17
Kawartha Lakes	10,061	73,214	24
Kenora	1,560	57,607	0
Lambton	25,400	126,199	42
Lanark	3,709	65,667	22
Leeds and Grenville	9,443	99,306	29
Lennox and Addington	5,398	41,824	15
Manitoulin	1,024	13,048	4
Middlesex	49,115	439,151	132
Muskoka	3,395	58,047	15
Niagara	55,237	431,346	233
Nipissing	554	84,736	5
Northumberland	19,505	82,126	43
Ottawa	51,617	883,391	317
Oxford	40,405	105,719	52
Parry Sound	2,049	42,162	5
Peel	257,092	1,296,814	1040
Perth	32,731	75,112	34
Peterborough	11,800	134,933	35
Prescott and Russell	18,738	85,381	43
Prince Edward	16,179	25,258	24
Rainy River	1,310	20,370	1
Renfrew	2,225	101,326	14
Simcoe	35,271	446,063	92
Stormont, Dundas and Glengarry	19,440	111,164	34
Sudbury	793	21,196	1
Thunder Bay	616	146,057	1
Timiskaming	1,494	32,634	2
Waterloo	104,891	507,096	370
Wellington	45,023	208,360	78
York	165,620	1,032,524	586

Appendix B: Supplemental Figures

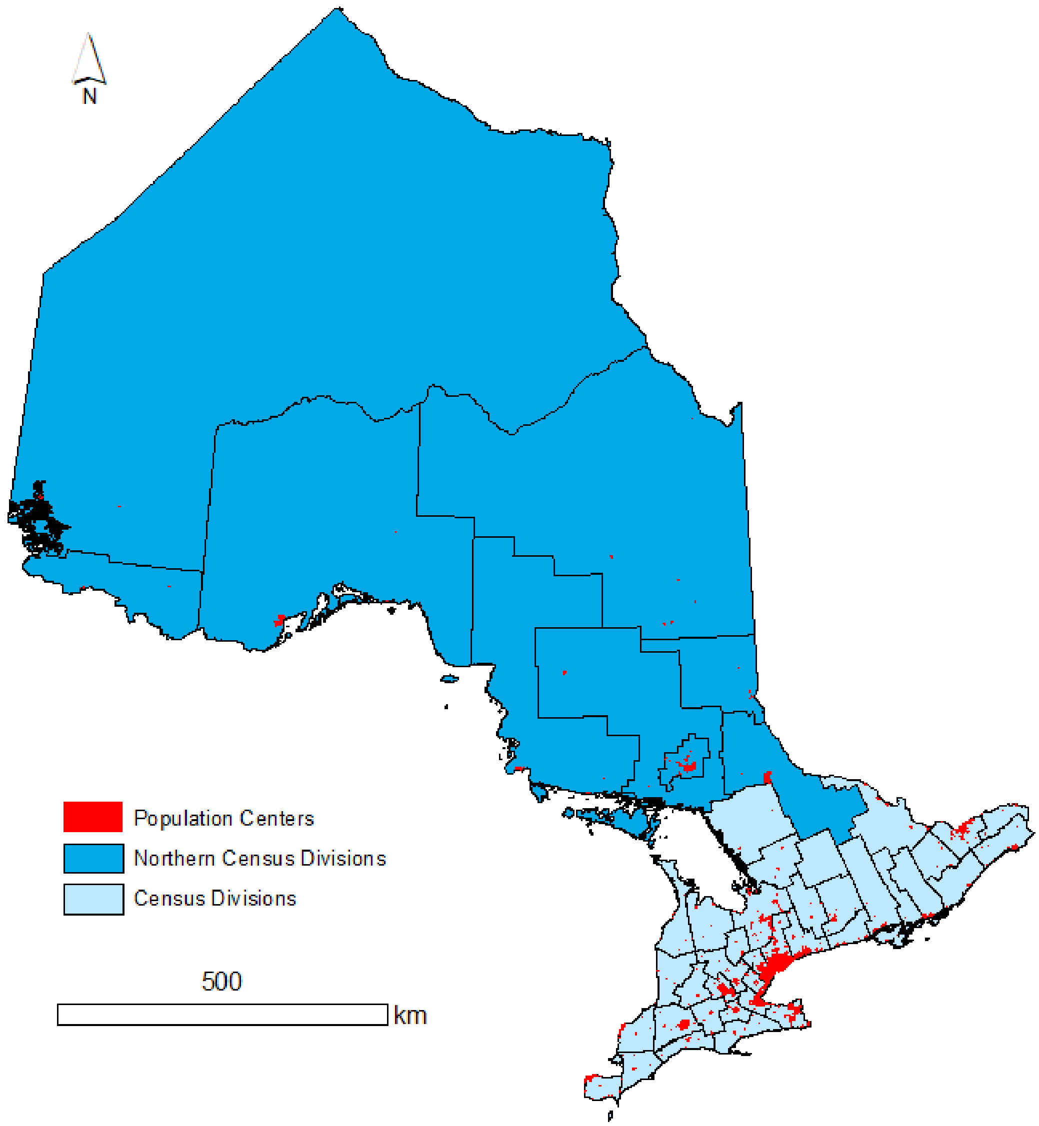

Figure B1. Northern census divisions and population centers (Statistics Canada, 2016) in Ontario

Appendix C: Model Summary

```
lm(formula = log(price) ~ (CDNAME) + log(Area) + as.factor(BinWater) +
    as.factor(BinBuild) + as.factor(BinFarm) + as.factor(BinForest),
    data = CDdatadummy, na.action = na.omit)

Residuals:
    Min      1Q  Median      3Q     Max
-3.5452 -0.3539  0.0155  0.3677  2.5803

Coefficients:
                              Estimate Std. Error t value Pr(>|t|)
(Intercept)                   10.11535    0.13498  74.941  < 2e-16 ***
CDNAMEBrant                    1.94962    0.15946  12.227  < 2e-16 ***
CDNAMEBruce                    1.04368    0.15896   6.566 6.52e-11 ***
CDNAMEChatham-Kent             1.99751    0.16033  12.459  < 2e-16 ***
CDNAMECochrane                -0.40367    0.18044  -2.237 0.025378 *
CDNAMEDufferin                 1.68260    0.15880  10.596  < 2e-16 ***
CDNAMEDurham                   1.76493    0.15910  11.094  < 2e-16 ***
CDNAMEElgin                    1.80048    0.15953  11.286  < 2e-16 ***
CDNAMEEssex                    1.53722    0.15898   9.669  < 2e-16 ***
CDNAMEFrontenac                0.59794    0.15707   3.807 0.000145 ***
CDNAMEGreater Sudbury          0.86341    0.18179   4.749 2.18e-06 ***
CDNAMEGrey                     1.43777    0.15858   9.067  < 2e-16 ***
CDNAMEHaldimand-Norfolk        1.53103    0.15913   9.621  < 2e-16 ***
CDNAMEHaliburton               1.12552    0.15704   7.167 1.06e-12 ***
CDNAMEHalton                   2.46182    0.15855  15.527  < 2e-16 ***
CDNAMEHamilton                 1.89926    0.15970  11.893  < 2e-16 ***
CDNAMEHastings                 0.59639    0.15746   3.788 0.000156 ***
CDNAMEHuron                    2.24650    0.15997  14.043  < 2e-16 ***
CDNAMEKawartha Lakes           1.14939    0.15821   7.265 5.24e-13 ***
CDNAMEKenora                   0.81329    0.18339   4.435 9.70e-06 ***
CDNAMELambton                  1.80971    0.16056  11.271  < 2e-16 ***
CDNAMELanark                   0.80620    0.15821   5.096 3.79e-07 ***
CDNAMELeeds and Grenville      0.78018    0.15778   4.945 8.23e-07 ***
CDNAMELennox and Addington     0.69191    0.15744   4.395 1.17e-05 ***
CDNAMEManitoulin               0.21850    0.17989   1.215 0.224642
CDNAMEMiddlesex                1.98052    0.15979  12.395  < 2e-16 ***
CDNAMEMuskoka                  1.00057    0.15707   6.370 2.31e-10 ***
CDNAMENiagara                  1.44574    0.15949   9.065  < 2e-16 ***
CDNAMENipissing                0.64131    0.17976   3.568 0.000369 ***
CDNAMENorthumberland           1.25469    0.15940   7.871 5.59e-15 ***
CDNAMEOttawa                   1.61792    0.15836  10.217  < 2e-16 ***
CDNAMEOxford                   2.11389    0.15938  13.263  < 2e-16 ***
CDNAMEParry Sound              0.42516    0.15775   2.695 0.007092 **
CDNAMEPeel                     2.36406    0.15881  14.886  < 2e-16 ***
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CDNAMEPerth                         2.15307    0.16041  13.422  < 2e-16 ***
CDNAMEPeterborough                  1.14242    0.15761   7.249 5.91e-13 ***
CDNAMEPrescott and Russell          1.34080    0.15801   8.486  < 2e-16 ***
CDNAMEPrince Edward                 1.26636    0.15832   7.999 2.07e-15 ***
CDNAMERainy River                   0.35613    0.17986   1.980 0.047829 *
CDNAMERenfrew                       0.46432    0.15814   2.936 0.003360 **
CDNAMESimcoe                        1.59471    0.15788  10.101  < 2e-16 ***
CDNAMEStormont, Dundas and Glengarry   1.50317    0.16006   9.391  < 2e-16
***
CDNAMESudbury                       0.44021    0.18153   2.425 0.015392 *
CDNAMEThunder Bay                   0.10576    0.18170   0.582 0.560613
CDNAMETimiskaming                   0.58020    0.18007   3.222 0.001292 **
CDNAMEWaterloo                      2.15496    0.16031  13.443  < 2e-16 ***
CDNAMEWellington                    2.14371    0.15895  13.487  < 2e-16 ***
CDNAMEYork                          2.18074    0.15852  13.757  < 2e-16 ***
log(Area)                           0.17244    0.01007  17.120  < 2e-16 ***
as.factor(BinWater)1                0.74901    0.05222  14.344  < 2e-16 ***
as.factor(BinBuild)1                0.91092    0.03550  25.659  < 2e-16 ***
as.factor(BinFarm)1                 0.22550    0.04041   5.580 2.71e-08 ***
as.factor(BinForest)1              -0.35651    0.08431  -4.229 2.45e-05 ***
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Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 0.6216 on 2084 degrees of freedom
  (13 observations deleted due to missingness)
Multiple R-squared:  0.6575,  Adjusted R-squared:  0.649
F-statistic: 76.94 on 52 and 2084 DF,  p-value: < 2.2e-16
```