

BIODIVERSITY CONSIDERATIONS IN CONSERVATION SYSTEM PLANNING: MAP-BASED APPROACH FOR NOVA SCOTIA, CANADA

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Abstract. Biodiversity considerations in conservation system planning include three main criteria: representation, special elements, and focal species. A GIS-based approach utilizing simple models was used to assess existing biophysical data relative to these criteria for conservation system planning in Nova Scotia, Canada, with potential utility in applications elsewhere. Representative samples of natural landscapes were identified on the basis of size ($\geq 10\,000$ ha) and degree of naturalness (natural cover, uneven-aged forests, low or zero road density). Special elements were selected, including hotspots of diversity and rarity, critical habitat for species at risk, significant wetlands, old and unique forests, and ecosites. Habitat requirements of viable populations of focal species (American moose, American marten, and Northern Goshawk) were identified using species distribution data, habitat suitability, and population viability analyses. Priority core areas for biodiversity conservation system planning were identified on the basis of these three sets of criteria. Key areas of habitat connectivity were delineated by selecting the least-cost paths for focal species between relevant core areas through cost–distance analyses based on habitat suitability, road density, and minimum corridor width. Collectively, these biodiversity considerations indicate that ~60% of Nova Scotia, including 32% in core areas, should be managed for conservation objectives to maintain genes, species, and ecosystems over time. Although data and modeling limitations require that our analysis of richness and diversity, habitat suitability, population viability, and core area selection be verified, the area calculations and other results are consistent with those in similar studies. Consequently, the system design and other information generated are useful for local and regional biodiversity conservation planning and management, and the methodological approach is of potential use in other regions where the necessary field-based data may be made available.

Key words: connectivity; core areas; focal species; habitat suitability index; least-cost path analysis; Nova Scotia, Canada; protected areas; rarity-weighted richness index; representation; reserve design; special elements; viable populations.

INTRODUCTION

Precise prescriptions are required for the selection and delineation of critical areas for biodiversity conservation (Shafer 1990, Noss and Cooperrider 1994, Soulé and Terborgh 1999, Pimm et al. 2001). At regional and landscape scales, critical areas are often defined in terms of core areas of high or multiple conservation values and areas of functional connectivity among them, which together comprise a biodiversity conservation system. It is currently well accepted that

conservation planning requires systematic approaches that integrate a range of biodiversity elements and processes (Soulé and Terborgh 1999, Margules and Pressey 2000, Lindenmayer et al. 2002, Noss et al. 2002, Cowling et al. 2003). A three-track approach suggests consideration of three main components: representation, special conservation elements, and focal species (Noss and Cooperrider 1994, Noss et al. 1999a). Representation refers to the protection of intact examples of each vegetation, habitat, or landscape type in a region. However, it is a coarse-filtered approach that may not capture small, localized elements of high conservation value or sufficient habitat to support viable populations of local species (Noss et al. 1999a). Accordingly, consideration is also required of special conservation elements (i.e., critical areas for species at risk, hotspots of diversity and rarity, old-growth forest remnants) and focal species, carefully selected on the basis of their functional importance, special habitat needs, and/or large area requirements. These three components (representation, special elements, and focal spe-

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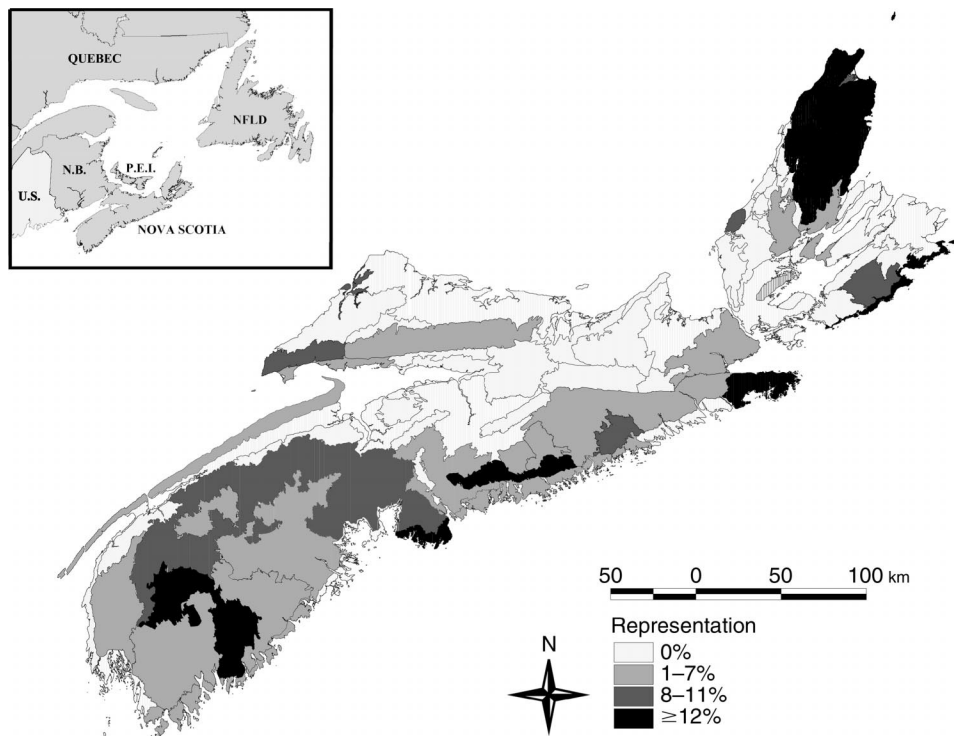


FIG. 1. Map showing the range of percentages of representation of each “natural landscape type” by existing protected areas in Nova Scotia. Natural landscape types are ecological land classes delineated by the Nova Scotia Department of Natural Resources on the basis of geology, geomorphology, climate, and dominant ecosystems (NSDNR 1994). Gray tones indicate the range of percentages of spatial area of each natural landscape type represented within protected areas. Of 80 natural landscape types, 62 have <12% of their area protected; 19 natural landscape types are not represented by existing protected areas. Inset: Nova Scotia is on the east coast of Canada, connected to continental North America by a narrow isthmus.

cies) can be used to identify lands to be managed for specific biodiversity objectives to maintain genetic, species, ecosystem, and landscape diversity across a region and over time.

To date, most applications have focused on one component or the other, typically: representation of vegetation species, communities, or ecological land classes (i.e., Strittholt and Boerner 1995, Wright et al. 2001, Jepson et al. 2002, Diamond et al. 2003, Lawler et al. 2003); hotspots of species richness, rarity, or diversity (i.e., Conroy and Noon 1996, Lombard et al. 1999, Sarkar et al. 2002); habitat for single species or groups of species (i.e., Andersen and Mahato 1995, Smith et al. 1997, Andelman and Willig 2002, Solomon et al. 2003), particularly mammalian carnivores (i.e., Noss et al. 1996, Carroll et al. 2001, 2003, 2004, Kerley et al. 2003); or a combination of representation and rarity (i.e., Scott et al. 1993, Rothley 1999, Howard et al. 2000). Although the conservation limitations of single-track approaches have been identified, the complexity, data intensity, and technical modeling associated with integrating multiple tracks across broad regions present a considerable challenge (Simberloff 1998, DeVelice and Martin 2001, Dobson et al. 2001, Scott et al. 2001, Lindenmayer et al. 2002). Consequently, very few ap-

plications integrate multiple components into regional conservation plans, with notable exceptions in Florida (Hector et al. 2000), the Klamath-Siskiyou and Greater Yellowstone ecoregions of the USA (Noss et al. 1999b, 2002), and in the Cape Floristic region of South Africa (Cowling and Pressey 2003, Cowling et al. 2003).

We applied a multitrack approach to conservation planning in Nova Scotia, Canada, which may be useful elsewhere. Nova Scotia is a peninsular land mass of ~48 800 km² connected to the remainder of the North American continent through a 24 km wide isthmus (inset, Fig. 1). Due to its unique geological and climatic history, Nova Scotia has a relatively high diversity of species and landscapes for its size and location within the temperate region (Davis and Browne 1996). Unfortunately, this natural diversity is declining as a consequence of inadequate conservation measures. Only 26 of 80 “natural landscape types,” which are ecological land classes delineated by the Nova Scotia Department of Natural Resources (NSDNR) on the basis of geology, geomorphology, climate, and dominant ecosystems, are considered “adequately represented” by existing protected areas (NSDNR 1994); 62 have <12% of their area protected, and 19 are not represented at all (Fig. 1). Only 0.6% of forest more than

100 years old remains (Lynds and Leduc 1995). Grey wolf, woodland caribou, eastern cougar, and other species have been extirpated; 20 species are officially listed and 84 are known to be at risk but not yet listed at the provincial level (NSDNR 2003). Protected area boundaries coincide more or less completely with only one local group of the remnant population of the provincially endangered American moose, *Alces alces americana* (Snaith and Beazley 2004a, b) (Appendix A, Fig. A1). Although the deficiencies of the current system and the need for a science-based approach to broadscale conservation planning in the province have been demonstrated (Beazley et al. 2002, 2004b), no systematic assessment for conservation system planning has been undertaken for the entire land base.

Consequently, we initiated a research project with three key objectives: (1) to apply the three-track approach as a generalized methodological example for biodiversity conservation system design, using geographic information systems (GIS) and simple models; (2) to compile a broad range of relevant existing biophysical data into a conceptually valid, organizational framework for ongoing analysis and decision support; and (3) to create a spatially explicit biodiversity conservation system design at the provincial scale. We compiled and assessed existing data relevant to representation, special elements, and focal species to delineate priority core and connecting areas for maintaining biodiversity. The project is presented here to provide an example of the three-track approach in practice, including the methods, data sets, and analytical tools employed, which may be of general relevance for application in other regions.

METHODS

A methodology was developed in which the three tracks of representation, special elements, and focal species were assessed separately and then combined to identify priority areas for biodiversity conservation, similar to those described by Noss et al. (1999a, b). We defined the data required to assess the three tracks (Beazley et al. 2002), and collected and converted available data from various provincial government and nongovernment agencies and academic institutions. A small suite of focal species was selected on the basis of previous assessments (Beazley 1998, Beazley et al. 2002, Snaith and Beazley 2002) and the suitability of data sets. We contracted the Atlantic Canada Conservation Data Centre (ACCDC) to convert pre-existing species occurrence records to GIS-based format. Using these and other data and ArcInfo 7.2.1 (ESRI 1996–1998) and ArcView 3.2 (ESRI 1999) programs, we conducted separate assessments of representation, special elements, and focal species to identify conservation priorities. We then overlaid these three sets of priority sites and identified core areas where overlap occurred. We delineated connectivity among these core areas on the basis of least-cost paths and habitat effectiveness

for focal species. We then combined core areas and connectivity to delineate the spatial configuration for biodiversity conservation in Nova Scotia. Each of these methodological steps is described in greater detail in the following sections.

Representation

Although it is generally accepted that a representative sample of each vegetation, habitat, or landscape type should be included in a conservation system plan (Soulé and Simberloff 1986, Shafer 1990, Scott et al. 1993, Noss et al. 1999a, Margules and Pressey 2000), there is no standard guideline as to the size or percentage of area. For our assessment, we chose 12% as a minimum target for representation in core protected areas. Although this figure is somewhat arbitrary and not scientifically defined, it reflects a politically acceptable target for representation in protected areas in Nova Scotia, Canada, and elsewhere (WCED 1987, Hummel 1989, Environment Canada 1990, CEAC 1991, NSRTEE 1992). To define vegetative, habitat, or landscape types, we used the pre-existing ecological classification of 80 “natural landscape types,” derived from physical (enduring) features, climatic zones, and vegetation by NSDNR (1994) for the purpose of selecting protected areas to meet representation objectives. NSDNR describes natural landscape types as mosaics of different but interacting ecosystems and processes that form distinct and definable land areas, with an average size of 600 km². For the 62 natural landscape types that we identified as inadequately represented by existing protected area (those with <12% protection; see Fig. 1), we analyzed the existing land cover to locate relatively large patches of remaining natural cover as potential areas from which to select representative sites (Appendix B). To select the largest areas with the least disturbance in each natural landscape type, we created four land classifications as separate GIS coverages: (1) land cover; (2) area of contiguous natural area; (3) road density; and (4) forest cover maturity (Appendix C). From these coverages, we queried out three features: (1) contiguous natural terrestrial ecosystems ($\geq 10\,000$ ha); (2) roadless areas (0 km/km²); and (3) uneven-aged forest stands. We combined the results to create a map layer showing all three features. Areas of overlap or concentration constitute priority areas from which to select sites to represent natural landscape types. In natural landscape types that remained underrepresented, next-best options were identified by querying out areas of overlap among natural terrestrial ecosystems of smaller class sizes (2000–9999 ha, 200–1999 ha), uneven-aged stands, and/or roadless areas.

Special elements

Special elements are species and places of high conservation value such as critical areas for species at risk and geographical clusters of diversity and rarity (Noss

et al. 1999a). We analyzed four groups of special elements: (1) critical areas for species at risk; (2) rarity-weighted richness; (3) significant ecological sites; and (4) old and unique forests (Appendix D). To facilitate the assessment of critical areas for species at risk and areas of high rarity-weighted richness, observational element occurrence records (Pronych and Wilson 1993, Newell 2000, NSDNR 2001a, b) were compiled, and rare species and species listed as globally (G1–G3), nationally (N), or subnationally (S1–S3) at risk (ACCDC 2001) were mapped and provided by ACCDC as element occurrences in bitmap (.bmp) and table (.dbf) formats. Element occurrence records indicate the specific physical locations of elements of biodiversity, in this case the locations of species at risk and rare species. The existing element occurrence data are recorded at six levels of resolution or precision; however, only those recorded with the four finest levels of resolution (within radii of 5, 50, 500, and 5000 m from the record point) were included in the analysis. An exception to this is the Pronych and Wilson (1993) data set, in which species are recorded as occurring anywhere within a 10-km grid square. We converted these data into UTM NAD83 projection shape files and then separately queried out occurrences with locational precision of 1000 m or less for species at risk, and for rare species.

Rarity-weighted richness indices (RWRI) were calculated by ACCDC from the element occurrence records for rare species (Pronych and Wilson 1993, Newell 2000, NSDNR 2001a, b) to assess the relative richness of rare species across the province, using the equation

$$RWRI = \sum_{i=1}^n 1/h_i$$

where n is the number of rare species found within a 10-km square, and h_i is the total number of 10-km squares in Nova Scotia in which i th species occurs. RWRI were created for rare vascular flora, Odonata (dragonflies and damselflies), herpetofauna, and birds. Because the purpose of the analysis is to identify geographical clusters or high concentrations of rare species, and because many of the existing rare element occurrences (Pronych and Wilson 1993, Newell 2000, NSDNR 2001a, b) are recorded at coarse scales (10-km grid cells; 5000 m radius), a 10-km grid cell was selected as the analysis unit. We converted the RWRI from MapInfo into UTM NAD83 projection data and selected the highest RWRI grid cells as hotspots of rare-species richness.

Existing data sets of “significant ecosites” and “significant old and unique forests” identified on provincial Crown lands were provided by the Nova Scotia Department of Environment and Labour (NSDEL) as UTM NAD83 projections. These data layers were originally created by NSDNR (1995) from the 1988–1995

aerial photograph series and the Nova Scotia forest inventory database (NSDNR 1992) at a scale of 1:10 000. Significant ecosites are outstanding examples of specialized physical land units with associated characteristics or obligate biotic communities, such as shrub fens, salt marshes, and dunes, as defined by NSDNR. The four resulting special-element data layers were subsequently combined to create a coverage from which we selected areas of overlap and concentration as priority areas for special-element conservation.

Focal species

Focal species include those that (1) are of disproportional functional importance in an ecosystem, (2) have large area requirements, (3) have specialized habitat needs and/or are habitat quality indicators, (4) are special or vulnerable populations, and/or (5) have charismatic appeal that will provide a flagship function for conservation initiatives (Noss 1991, Miller et al. 1998–1999). Because the natural land cover in Nova Scotia is predominantly forest, we selected three forest-dwelling vertebrate species, American moose (*Alces alces americana*; mainland populations), American marten (*Martes americana*), and Northern Goshawk (*Accipiter gentilis*; see Plate 1), based on previous systematic assessments of potential focal species in Nova Scotia (Beazley 1998, Beazley et al. 2002, Beazley and Cardinal 2004, Snaith and Beazley 2002) and other pragmatic considerations such as the availability of data and the interests of the researchers.

We created species/population distribution coverages in ArcView for each of the selected focal species. We derived American moose population distribution based on data from Pulsifer and Nette (1995), interviews with key experts at NSDNR, and provincial pellet-group inventories (NSDNR 1979–2000, Snaith and Beazley 2004a, b). We obtained American marten locational data from the status report (Scott 1998) and NSDNR (2002). A map of Northern Goshawk distribution was created from confirmed breeding locations recorded by Erskine (1992). Although these distributional data are coarse and incomplete, they provide a counterpoint to habitat suitability analyses, which do not always correspond fully with species occurrences, as has been demonstrated in Nova Scotia with respect to American marten in Cape Breton (Scott 1998) and American moose on the mainland (Snaith et al. 2004).

To determine the minimum critical area of habitat required to support a viable population of American moose, we conducted a series of calculations (Snaith and Beazley 2004a). First, we estimated minimum viable population size on the basis of Franklin’s (1980) genetic-minimum-ideal-breeding-population guideline of 50 individuals for short-term viability (decades). We calculated a corresponding minimum-census-population size of 500 based on a 10:1 census-to-breeding population ratio, derived by averaging the findings of Ryman et al. (1981) and Arsenault (2000). We selected



PLATE 1. This watercolor painting, “Spirit of the Deep Forest, Eigg Mountain-James River Protected Area,” nicely illustrates the dominant landforms and forest (hardwood-dominated) of the recently designated Wilderness Area. The Northern Goshawk is a key element, given its preference for contiguous, older forest. Painting copyright: Alice Reed (used by permission, all rights reserved).

an average home range size of 42.5 km² from estimates of 30 to 55 km² found in the literature (Crossley and Gilbert 1983, Crete 1987, Leptich and Gilbert 1989, McNicol 1990; Brannen, *personal communication*) and a density of 0.05 moose/km² by averaging those of 0.01–0.09 moose/km² reported by Pulsifer and Nette (1995). From these minimum-census-population, home range, and density figures, we estimated the minimum critical habitat area required to support a short-term viable population of American moose (Snaith and Beazley 2004a) as between 10 000 ha, based on minimum-census-population size and density (500/0.05), and 21 250 ha, based on minimum-census-population and home range sizes (500 × 42.5).

To locate the areas of highest habitat suitability to fulfill the area requirements of the focal species, we conducted simple quantitative habitat suitability analyses. In the case of American moose (Snaith et al. 2004), we modified the Habitat Suitability Index (HSI) Model II of Allen et al. (1987), which was developed for moose habitat evaluation in the Lake Superior Region of Ontario, Canada, and has been applied and validated in a number of studies and modified for use in other regions (Allen et al. 1991, Naylor et al. 1992, Puttock et al. 1996, Rempel et al. 1997). The model calculates relative amounts of required habitat components, but does not account for characteristics and variables such as mineral licks, calving sites, and non-habitat mortality factors (i.e., poaching, predation, and

human land use). Nonetheless, it is useful because it is relatively simple, relies on readily accessible forest cover data, and can be used for rapid, low-resolution evaluation of large areas (Naylor et al. 1992). To examine the effects of human land use on moose habitat selection, we subsequently incorporated road density as an index of human influence to indicate overall habitat effectiveness.

We modified HSI Model II of Allen et al. (1987) for application in Nova Scotia based on extensive literature review and local expert opinion. Specifically, we incorporated a roving window technique (Duinker et al. 1991, 1993) to accommodate unpredictable ranging patterns, and developed five alternatives to the original equation to account for local conditions where (1) mature forest (thermal cover) may be especially critical, (2) wetlands may be less important (Telfer 1984), and (3) forage beyond 200 m of cover may be of little value (Appendix E) (refer to Snaith et al. [2004] for a detailed description of the habitat suitability analysis for moose). Using the original and alternative HSI equations, we assessed the provincial Forestry GIS Database (NSDNR 1992), provided as an ArcInfo GIS coverage (UTM NAD83 projection), in terms of the proportional availability of critical habitat components of forage (SI₁); softwood cover (winter cover, SI₂); hard or mixed-wood cover (forage/summer cover, SI₃); and wetlands (aquatic forage, SI₄) (Appendices F and G). These analyses resulted in maps of the theoretical spa-

tial distribution of habitat suitability across mainland Nova Scotia (Snaith et al. 2004). For an example, refer to Appendix A, Fig. A2.

To test the validity of the six HSIs, we conducted statistical analysis to identify significant correlations with presence/absence of moose pellets, which we assumed to indicate moose habitat selection (Snaith et al. 2004). We converted raw data from a provincial fall/winter moose pellet-group inventory (PGI) provided by NSDNR (1979–2000) into the UTM NAD83 projection and coordinate system plotted in ArcInfo, and overlaid it with the HSI coverages. Logistic regression analyses were used to determine the ability of the HSI to predict the presence/absence of moose pellets. Because no significant correlations were found (chi-square values for HSI_1 – HSI_6 ranged from 0.000 to 1.567 [$P < 0.05$]), we ran additional regression analyses to determine the ability of road density, and road density combined with HSI distribution, to predict moose pellet presence/absence. The results of logistic regression analyses indicated that roads alone (chi-square 14.927 [$P < 0.05$]) and, once roads were accounted for, HSI_2 and HSI_5 , forage (SI_1), and forage in proximity to cover (SI_{1m}) were able to predict pellet presence (respective chi-square values for HSI_2 , HSI_5 , SI_1 , and SI_{1m} are 5.178, 4.022, 21.248, and 20.605 [$P < 0.05$]) (Appendix H). These results should not be accepted as conclusive, because the validation using the PGI data does not account for summer habitat selection, and statistical validation is limited by the incomplete nature of the data. Nonetheless, a combination of relatively high suitability values and low road densities occurs in areas known to contain moose populations in mainland Nova Scotia (Beazley et al. 2004a, Snaith et al. 2004). This is consistent with findings from other studies that human developments such as roads affect habitats and distributions of sensitive species such as large herbivores (Lyon 1983, Carroll et al. 2001). Consequently, given the demonstrated relationship among habitat selection, HSI, and road density, and the hypothetical importance of proximity between forage and cover components, areas of highest habitat suitability derived from HSI_5 and corrected for road density were used to select habitat for moose (Appendix A, Fig. A3). Using a similar process, we produced habitat suitability coverages for American marten and Northern Goshawk; however, we have not conducted validity tests of the HSIs for these species. Priority conservation areas for focal species were delineated based on species distribution, habitat suitability, and road density.

Selecting core areas

Core areas are those portions of the landscape that are managed with biodiversity values as the primary objective, and in which natural processes predominate and human activities are minimized. Core areas are selected based on their high conservation value and are

intended to sustain species and processes that are most sensitive to human activities (Noss et al. 1999a). To select core areas, we overlaid the priority area coverages for representation, special elements, and focal species. We then manually selected areas of overlap and concentration among the three sets of priority areas to achieve at least 12% representation of each natural landscape type. In natural landscapes where priority areas for all three coverages of representation, special elements, and focal species did not overlap, we delineated core area boundaries that incorporated priority areas from one or two of the coverages.

Selecting areas for connectivity

Areas of connectivity provide critical and supplemental habitat for focal species and opportunities for migration and dispersal among core areas and populations. Consequently, these areas should be of sufficient width to accommodate the home range size and shape of the species in question. Because American marten tend to have circular or elliptical home ranges of 250–400 ha (Harrison 1992), we assumed that the width of a home range for marten should be no less than half of its typical width. Thus, we estimated that a home range size of 400 ha (typically 2×2 km) translates into a roughly rectangular shape of 4×1 km within areas of connectivity, for a minimum corridor width of 1 km, which subsequently should be buffered against edge effects.

We selected areas of connectivity by conducting cost–distance analyses among core areas containing focal species populations and habitat. Cost–distance analyses result in the selection of least-cost paths between relevant patches for the species in question. The least-cost path presents the least amount of resistance (or highest chance of success) to movement for the species and is a function of width, length (or distance), habitat suitability, and obstacles or barriers such as roads and human settlements. We created cost–surface maps for American marten and American moose by combining habitat suitability and road density coverages (Appendix I). We overlaid these cost–surface layers with maps of population distribution and core areas for these species. Based on the assumptions just described, we defined minimum path widths for American marten as 1 km and American moose as 10 km. Cost–distance analyses were completed in ArcView 3.2 (ESRI 1999) with spatial analysis extension and least-cost-path application to select paths across cost–surface grids. Least-cost paths were identified between relevant core areas for each of the species.

Combining core areas and connectivity for systems planning

We overlaid the priority core and connectivity layers to create a synthesis layer. Where critical habitat requirements for focal species were not met in priority core and connectivity areas, additional HSI grid cells

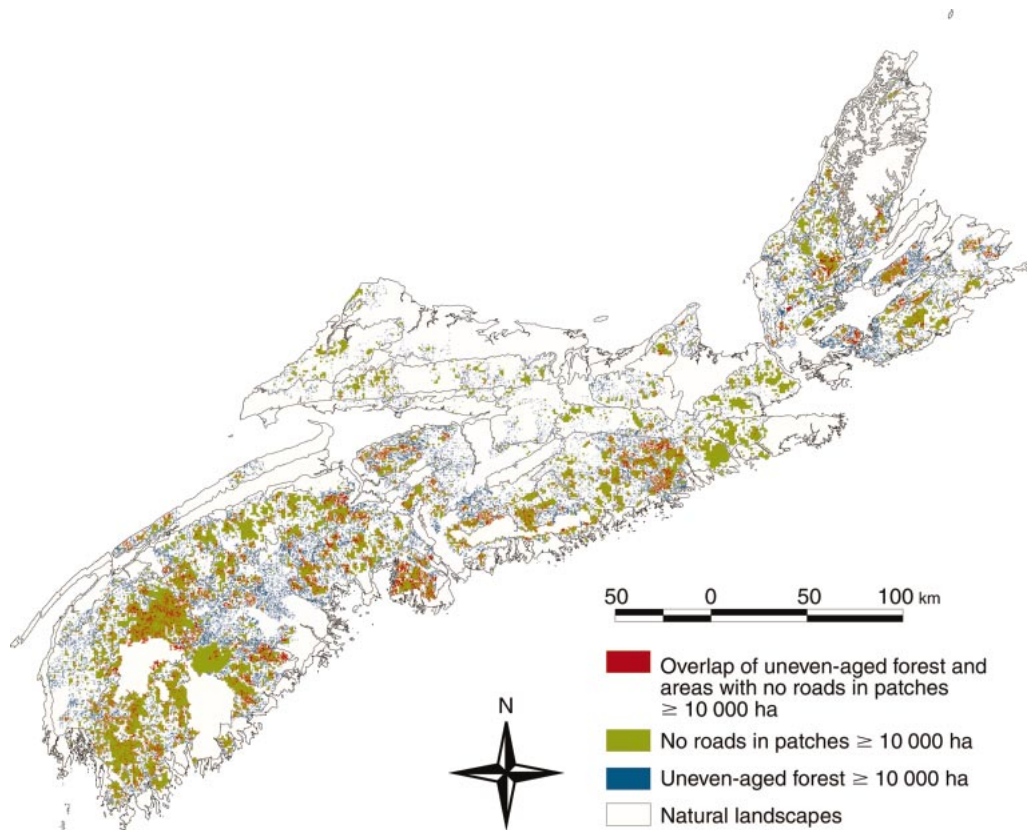


FIG. 2. Priority layer for selecting sites for representation of natural landscape types that are not adequately represented by existing protected areas. Representation classes (natural landscape types) are delineated as polygons. Priority areas are the largest remaining patches of natural land cover, identified on the basis of patch size ($\geq 10\,000$ ha), no roads (zero road density), and uneven-aged forest stands. Red areas are of highest priority within each natural landscape type (those in which all three characteristics occur or overlap). Green and blue patches indicate areas of secondary priority (where two of the three characteristics overlap). Green areas are patches $\geq 10\,000$ ha in size with no roads; blue areas are uneven-aged forest stands in patches $\geq 10\,000$ ha.

were selected to provide sufficient habitat for short-term viability. We also selected cells with the highest HSI values for American moose to provide connectivity to the remainder of the continent via the narrow isthmus. This was based on our estimation that a connection is required to conserve the genetic and demographic diversity of the species by (1) increasing the probability of long-term population viability in Nova Scotia through occasional immigration and the formation of a larger regional metapopulation, and/or (2) facilitating northward dispersal from the province in response to probable climate change (Snaith and Beazley 2004a), since moose in mainland Nova Scotia are at the southern limit of their range.

RESULTS

Representation

Key coverages for assessing representation criteria are contiguous natural terrestrial ecosystems $\geq 10\,000$ ha in size (Appendix A, Fig. A4), roadless areas (Appendix A, Fig. A5), and uneven-aged forest stands (Appendix A, Fig. A6). When we overlaid these coverages,

it was apparent that many natural landscape types have remaining natural areas $\geq 10\,000$ ha in size that are roadless and contain uneven-aged forest stands; however, there are also several natural landscape types that do not (Appendix A, Fig. A7). Next-best options were sought to fill these gaps by selecting areas where two of these criteria were met (Appendix A, Fig. A8). Five natural landscape types still remained unrepresented; consequently, we selected smaller patches of natural, unroaded and/or uneven-aged stands in these landscapes. Fig. 2 illustrates priority areas for representative sites within all natural landscape types that are currently not adequately represented by existing protected areas.

Special elements

Critical areas for species at risk consist of 492 element occurrences for at-risk floral and faunal species (Appendix A, Fig. A9). Hotspots of rarity are represented by 33 of the highest RWRI grid cells, which include eight for birds, two for Odonata, three for herpetofauna, and 20 for vascular flora (Appendix A, Fig.

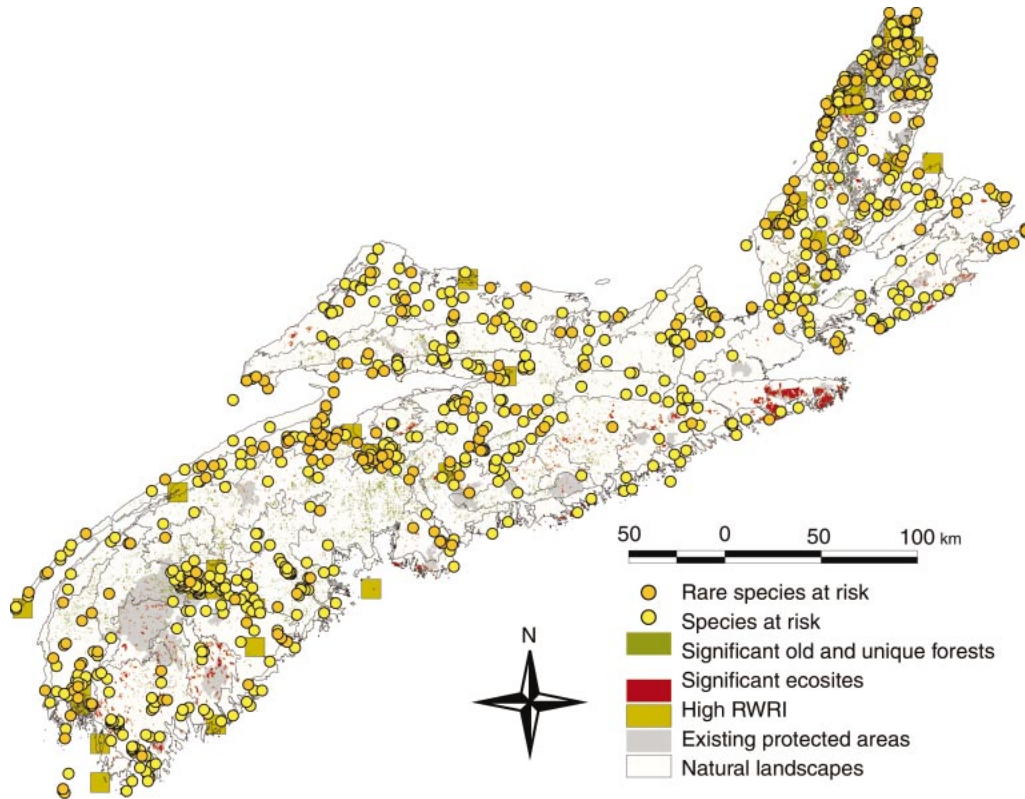


FIG. 3. Priority layer for special elements, showing clusters of critical habitat of species at risk, high rarity-weighted richness values (RWRI), significant ecological sites (ecosites), and significant old and unique forests. Element occurrences of rare species and species at risk are indicated by orange and yellow circles, respectively; high RWRI are indicated as 10-km squares; significant ecosites, such as outstanding examples of shrub fens, salt marshes, dunes, and barrens, are red patches; and significant old and unique forests are green patches. Existing protected areas are shown as gray polygons, and natural landscape types are delineated in black.

A10). Significant ecosites include 26 outstanding examples of specialized ecological sites such as shrub fens, salt marshes, and dunes, as defined and identified by NSDNR (1995) (Appendix A, Fig. A11). We selected all occurrences of significant old and unique forests as special elements (Appendix A, Fig. A12). When these layers were combined to identify areas of highest conservation value, clusters became evident, along with the relatively even distribution of ecosites and old and unique forests (Appendix A, Fig. A13). However, many natural regions did not contain clusters or hotspots; consequently, we selected 21 additional grid squares with high RWRI, and threatened and vulnerable (S2 and S3) species occurrences. The resulting clusters represent priority areas for conservation of special elements and, thus, potential sites for core areas (Fig. 3). This information also proves useful when it is necessary to choose among sites that otherwise exhibit similar values, such as for representation.

Focal species

Habitat suitability maps derived for American moose, American marten, and Northern Goshawk delineated the spatial distribution of suitable habitat

across the province (Appendix A, Figs. A14, A15, and A16). According to the models, there is little remaining high-quality habitat for any of the focal species. However, selection of the areas of highest habitat suitability and population distribution for each of the three species results in a clustering of habitat and occurrences (Fig. 4). These clusters represent priority areas for all three focal species. Because large areas are required to meet the calculated minimum habitat requirements for viable populations of moose, marten, and Northern Goshawk, both core areas and areas of connectivity will be key elements for the conservation of these focal species.

Core areas

When priority areas for representation, special elements, and focal species were overlaid, 47 core areas were initially identified. Not all natural-landscape types were found to be adequately represented (12% or greater) by the 47 core areas (Appendix A, Fig. A17). Through subsequent reassessment to address this gap, we selected 12 additional core sites for a total of 59 core areas, in addition to existing protected areas (Fig. 5). Although the criteria for selection were relaxed with each subsequent assessment, we remained unable to

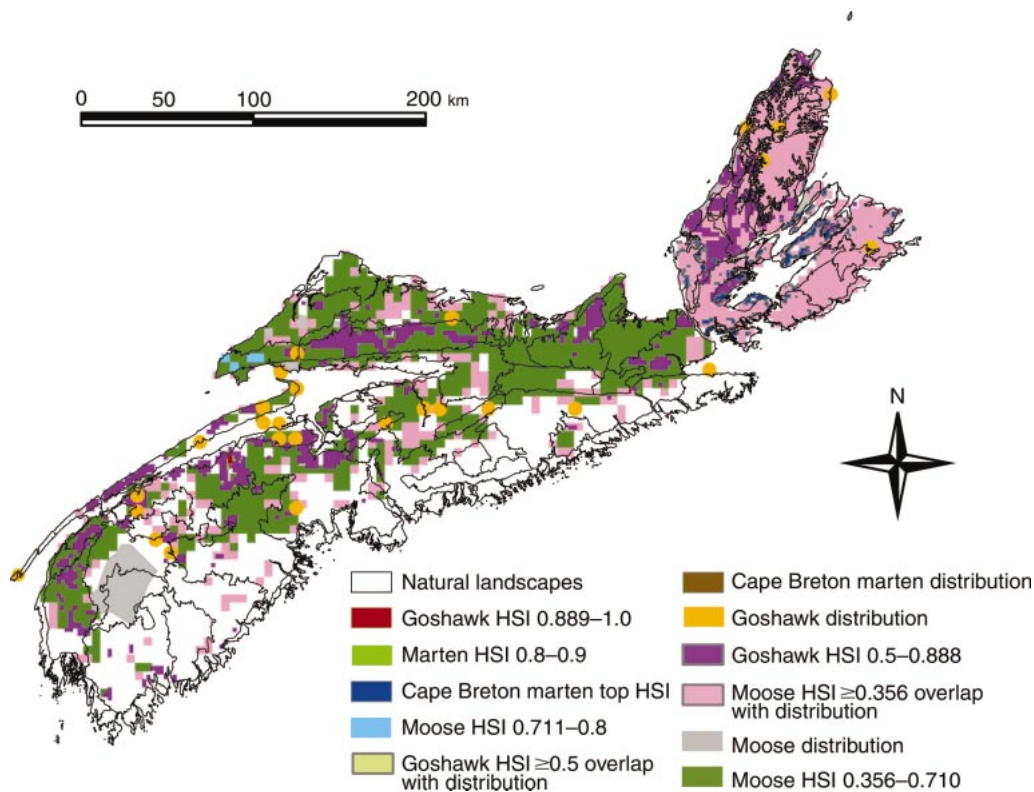


FIG. 4. Priority layer for focal species, combining areas of highest habitat suitability and population densities for American moose, American marten, and Northern Goshawk. For American moose, priority areas include those with HSI value classes of 0.356–0.710 and 0.711–0.8, locations of moose populations, and overlapping areas of moose population distribution and HSI values of ≥ 0.356 . For American marten, priority areas include those with HSI values of 0.8–0.9 throughout Nova Scotia, as well as marten population distribution and HSI 0.8–0.9 in Cape Breton Island, where small, isolated, native populations of marten remain. For Northern Goshawk, priority areas include those with HSI values of 0.5–0.888 and 0.889–1.0, areas of goshawk distribution, and overlapping areas of goshawk distribution with HSI of 0.5 and higher.

achieve the target of 12% representation in 14 natural landscape types; achieving such representation within these areas may also require restoration measures. Nonetheless, 59 new core areas were delineated on the basis of overlap among priority areas for representation, special elements, and focal species, encompassing $\sim 24\%$ of the Nova Scotia land base. Together with existing protected areas, they comprise $\sim 32\%$ of the province and achieve the representation target of $\geq 12\%$ in 66 of 80 natural landscape types; 14 landscapes remain underrepresented, with 3.7–11.6% in core areas.

Connectivity

The cost-surface layer for American marten illustrates the synthesis of habitat suitability and road density (Appendix A, Fig. A18). Least-cost-path analysis resulted in the identification of 1 km wide corridors between relevant core areas for American marten (Appendix A, Fig. A19). Similar analyses resulted in the selection of corridor locations for American moose. Based on the location of the least-cost paths, the distribution of suitable habitat and low road density, and the total area requirements for viable populations, we

further delineated areas of connectivity. Fig. 6 illustrates the approximate spatial extent (14 547 km²) and distribution of critical habitat area required to support a short-term viable population of American moose (500 individuals), selected from among the grid squares with the highest HSI values and lowest road density. Because long-term viability requires approximately one-order-of-magnitude-larger population size and habitat area, we also selected the highest HSI-value grid squares to provide a link to the larger region through a narrow isthmus at the provincial border.

Spatial delineation of the biodiversity conservation system

Existing protected areas, proposed core areas, and areas of connectivity together delineate the spatial extent of the biodiversity considerations for conservation systems planning (Fig. 7). Collectively, it incorporates $\sim 60\%$ of the Nova Scotia land base and represents natural landscape types, concentrations of special elements and critical habitat area for viable populations of selected focal species.

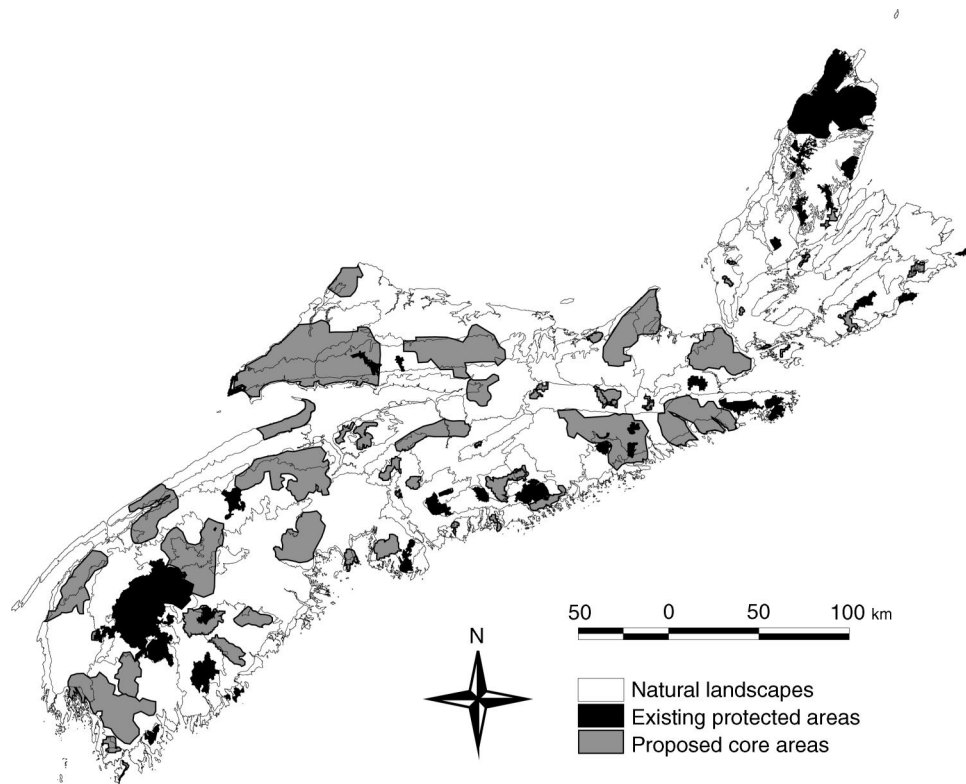


FIG. 5. We identified 59 new core areas (constituting $\sim 24\%$ of the Nova Scotia land base) to encompass, along with existing protected areas, overlapping areas of representation of natural landscape types, clusters of special elements, and critical habitat for focal species. Together, new and existing core and protected areas meet representation targets of 12% for 66 of 80 natural landscape types (14 remain underrepresented, with core areas capturing 3.7–11.6% of these natural landscape types), and comprise $\sim 32\%$ of the provincial land base. Natural landscape types are delineated by polygons, existing protected areas are indicated as black polygons, and new core areas are indicated by a gray tone.

DISCUSSION

The application of the three-track approach integrates a broad range of relevant data and analysis for biodiversity conservation system planning using well-accepted methods and simple GIS-based models. Although the methods and models are of general relevance for application in other regions, there are several limitations that are common in multitrack approaches applied across large regions. In this case, the limitations occur primarily with lack of representation of all landscape types, and the data, models, and methods of analysis for rare and at-risk species, habitat suitability, population viability, and optimal selection of core areas.

Incorporating large patches of uneven-aged forests with low or no road density substantially improves the representation of natural landscape types in Nova Scotia; however, landscapes that are more highly utilized for agriculture, forestry, and urban developments remain inadequately represented. Identifying relatively large and natural areas within rich and productive landscape types is commonly a challenge, and representation often requires the incorporation of lands for restoration that are privately owned and valued for other uses (DeVelice and Martin 2001, Scott et al. 2001,

Cowling et al. 2003). Further research is required to select restoration sites and to integrate social and economic considerations.

Occurrence records for rare and at-risk species are unevenly distributed across the study area and have a wide range of locational precision, resulting in sampling bias and scale-related issues that may influence the results. Landscape measures such as presence/absence, richness, and diversity are sufficiently sensitive to scale and sampling effects that correlations can reverse at different scales of analysis; thus, their utility in landscape planning is questioned (Alatalo 1981, Smith and Wilson 1996, Lombard et al. 1999, Stirling and Wilsey 2001, Walker et al. 2004). Alternatives to the RWRI (rarity-weighted richness indices) that are independent from richness in specific grid cells, or separate assessments of diversity and rarity, may be preferable. The RWRI, however, does provide useful preliminary information, because it locates clusters of rare species found in relatively few areas in Nova Scotia. Nonetheless, further assessment is needed to determine the degree to which sampling, scale, and analyses influence the results, and systematic field inventories are required to reduce sampling bias and increase locational precision.

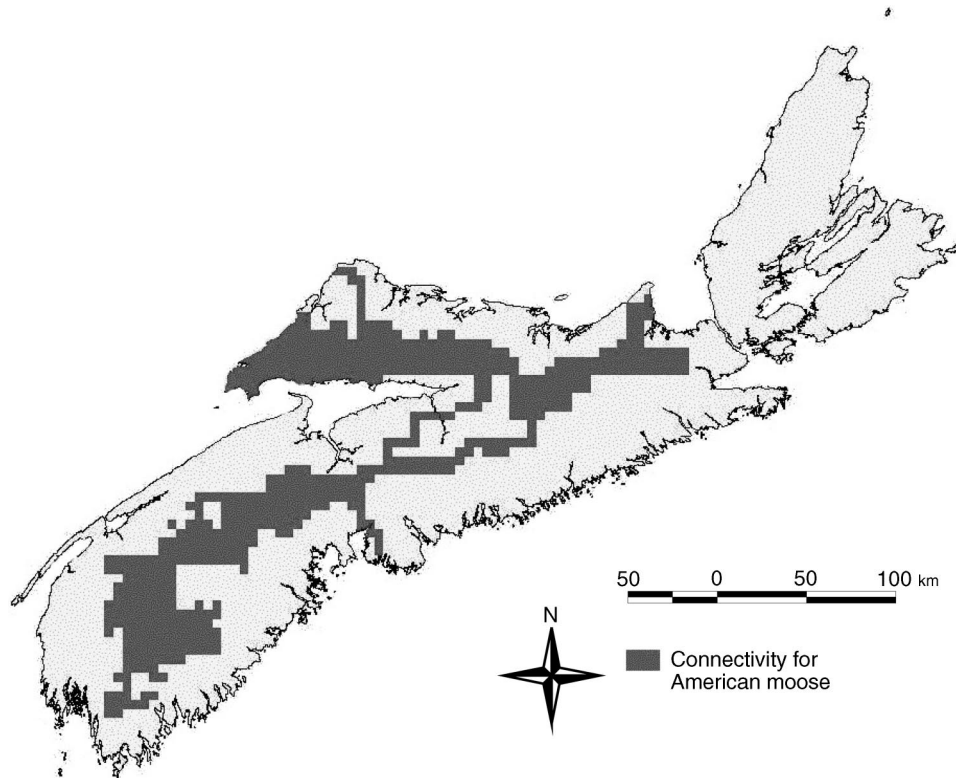


FIG. 6. Spatial representation of minimum critical habitat and connectivity for American moose, based on minimum critical area requirements for a short-term viable population (decades). Sufficient grid cells were selected in areas with highest habitat suitability for moose, known moose populations, and low road density. Long-term viability (centuries) probably will require connectivity beyond Nova Scotia; thus a route is identified across the narrow isthmus from Nova Scotia to New Brunswick.

Regionally specific data and models for habitat suitability and population viability assessments in Nova Scotia are unavailable or incomplete and, as such, our results require further verification. Future research should apply metapopulation viability analysis and spatially explicit population models such as VORTEX and PATCH to incorporate additional demographic, ecological, and environmental factors (see Lindenmayer et al. 1995, Schumaker 1998, and Carroll et al. 2003). When more-comprehensive, year-round field-based data on moose pellet presence/absence or density become available, the habitat suitability analysis should be assessed to determine the effects of roads and other human land-use practices, and to validate its ability to delineate suitable habitat. Although our results should be interpreted with caution, they indicate that suitable habitats identified through the HSI model are generally not occupied by moose unless they are of low road density. This is consistent with findings elsewhere suggesting that: (1) road density is an accurate predictor of habitat effectiveness for sensitive species such as large herbivores (Lyon 1983, Thiel 1985, Noss and Cooperrider 1994, Noss et al. 1999a); (2) decreases in moose populations are correlated with hunting success and hunter access by roads (Boer 1990); and (3) the

presence of human developments influences the distribution of species and habitats (Carroll et al. 2001, Dobson et al. 2001). Thus, assessments of habitat effectiveness for species, such as moose, that are sensitive to human activities should incorporate species distribution and road density data along with habitat suitability modeling, as was done in this case.

Efficient and repeatable selection of core areas may be better facilitated by the use of site selection programs such as SITES (Possingham et al. 2000), MARXAN (Ball and Possingham 2004), and C-Plan (Pressey et al. 1995), which use optimization algorithms or irreplaceability indices to generate spatially efficient designs to achieve conservation targets. Because current selection algorithms do not readily incorporate connectivity and other factors important for wide-ranging species, they should be used in combination with a spatially explicit population model such as PATCH (Schumaker 1998), as demonstrated by Carroll et al. (2003). Nonetheless, approaches such as the one presented here provide a basis upon which to assess the effectiveness of quantitative optimization programs, which is a requirement identified by Rothley (1999).

According to our assessment, ~60% of the Nova Scotia land base is required to conserve natural land-

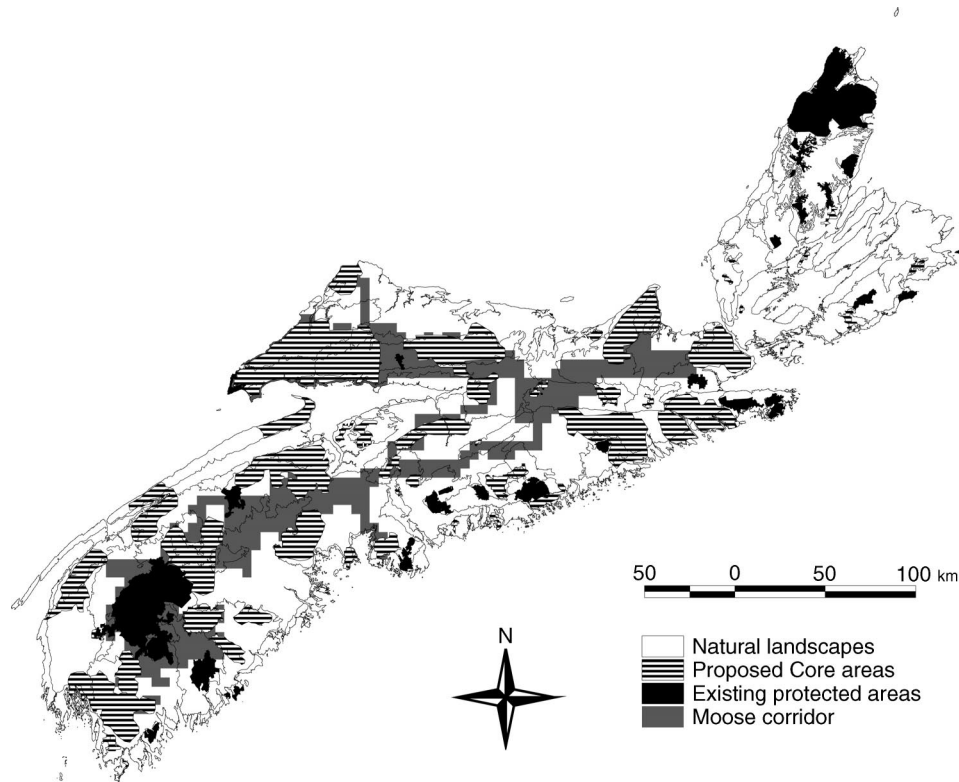


FIG. 7. Map of spatial distribution of important biodiversity values for conservation system planning, delineated as potential areas of core and connectivity. Connectivity is based on minimum critical habitat area requirements for American moose, as shown in Fig. 6.

scape types, special elements, and focal species (32% in strictly managed core protected areas, and the remainder managed with conservation objectives in mind). These figures are within the range of estimates that 25–75% of a region is required to capture important elements of biodiversity (see Noss and Cooperrider [1994] and Soulé and Sanjayan [1998] for reviews). They are strikingly similar to the results of a conservation plan for the Klamath-Siskiyou ecoregion, USA (Noss et al. 1999b), which was based on similar considerations and which places ~34% of the region in core protected areas and 60–65% in strict and moderate levels of protection. In the Cape Floristic Region of South Africa, Cowling et al. (2003) determined that 52% in addition to existing reserves is required to conserve the biota.

Our findings indicate that ~45% of mainland Nova Scotia is required to support a short-term viable population of moose. This is consistent with other studies: 50% of the African savanna is required to capture viable populations of an herbivore assemblage alone (Solomon et al. 2003), and 36% of the Rocky Mountain region is required to avoid loss of current carrying capacity for mammalian carnivores (Carroll et al. 2003). These results support the conclusion of Carroll et al. (2001) that the viability of large herbivores and carnivores may define threshold values in habitat area

and connectivity in conservation system design. Our 60% figure is also consistent with percolation studies in which 60% is identified as a threshold for habitat cover, below which there is a significant decrease in the probability that a continuous habitat pathway or linkage across the landscape can be found (Gardner et al. 1989, 1992), and at which a disturbance or pest may be able to spread throughout the landscape or become endemic (O'Neill et al. 1992). The combined area identified through consideration of representation, special elements, and focal species, which delineates the biodiversity conservation system for Nova Scotia, arguably represents a minimum critical area or landscape-scale, spatial threshold for the maintenance of these surrogates and, consequently, many other components of biodiversity. Defining threshold values such as these in specific biogeographic contexts serves to reduce inherent uncertainty related to design criteria, such as how much area is enough to maintain viable populations of species.

Because Nova Scotia is relatively small yet diverse, it is feasible that a relatively large percentage of the province would be required to conserve biodiversity. The 60% figure may indeed be low, because several components were excluded such as: (1) a full suite of carefully selected focal species, including those from other classes and habitat types; (2) achievement of the

representation target of 12% in all natural landscape types; (3) special elements that have not been systematically and accurately inventoried and mapped throughout the province; (4) areas to buffer biodiversity values from incompatible activities on adjacent lands; (5) fine- or local-scale considerations, which are not adequately captured in broadscale assessments (Lombard et al. 1999, Rouget 2003); (6) critical habitat to maintain viable long-term populations of moose, or to re-establish extirpated top predators; (7) natural disturbances and other processes; and (8) aquatic, marine, and coastal components. Further research should focus on addressing these deficiencies, especially identifying areas for restoring ecosystems in natural landscapes that are not adequately represented; incorporating additional focal species, disturbance regimes, and aquatic and marine components; and integrating broader regional assessments for re-establishment of top predators.

Although the figures of 32% and 60% may be defensible, they are very high in comparison with the 8% that is currently protected in Nova Scotia and the 12% goal often cited for protected areas (WCED 1987, Hummel 1989). This highlights the need to implement biodiversity objectives across the entire region and to set short-term (decadal) priorities that focus on the most irreplaceable and vulnerable sites (Pressey and Tafts 2001). In Nova Scotia, these sites include: large patches of roadless, uneven-aged forest stands in natural landscape types with little or no representation; areas of low road density and high habitat suitability for American moose and American marten, especially those that provide connectivity between isolated populations in Nova Scotia and to the remainder of the continent; critical habitat for species at risk of extirpation; and old-forest remnants.

CONCLUSION

This project provides a methodological example for biodiversity conservation design using GIS and simple models of population viability, habitat suitability, and richness. It describes a biodiversity conservation design plan for Nova Scotia based on generally well-accepted methods and analytical techniques for three conservation priorities: representation of landscape types, special conservation elements, and focal species. By focusing on these three components, we have incorporated considerations of both species and habitats, which compensates for deficiencies that arise from a singular approach. We analyzed a wide range of factors, identifying priority areas for each of the three components. Although multitrack approaches present considerable challenges, this project serves to illustrate that a relatively simple approach using existing data and models can produce a system design that supplements existing protected areas and provides a more integrated solution than a single-track approach.

In Nova Scotia, as elsewhere, limitations exist with respect to the quality and availability of existing, geographically specific data and models for assessing critical elements such as habitat suitability. Because the assessment is based on existing data and models, there is inconsistency with respect to data availability, sampling, scale, and locational precision, and the accuracy of models. Although these limitations are not uncommon in broad, regional assessments, further research, analysis, and monitoring is recommended to incorporate new data and refined models and to verify the underlying hypotheses. Nevertheless, the project provides an example of the three-track approach in practice, which is of general relevance and potential utility for application in other regions where the necessary data may be made available. It also delineates a preliminary system of core and connecting areas in Nova Scotia, which provides a biodiversity conservation vision and useful science-based information for local government and nongovernment organizations, and complements larger, cross-border efforts in the Northern Appalachian/Acadian (USA/Canada) ecoregions. The results demonstrate that a large percentage of the land base must be managed for conservation objectives if we wish to maintain biodiversity over time, and may represent a minimum-size-and-spatial-configuration threshold for biodiversity conservation. Because the results indicate that Nova Scotia is of insufficient size on its own to maintain viable populations of moose over the long term, broad, regional assessments that extend beyond political boundaries will be necessary to incorporate the conservation needs of wide-ranging species such as large herbivores and top predators. We encourage researchers elsewhere to conduct similar assessments so that the methods, techniques, and the spatial extent of systems for biodiversity conservation planning can be more thoroughly understood and broadly communicated.

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APPENDIX A

Maps of Nova Scotia showing distribution of (Fig. A1) moose populations and protected areas; (Fig. A2) moose habitat suitability values; (Fig. A3) road density and moose pellet presence/absence; (Fig. A4) contiguous natural cover ≥ 10000 ha; (Fig. A5) roadless areas; (Fig. A6) uneven-aged forest stands; (Fig. A7) combined cover for contiguous natural cover ≥ 10000 ha, roadless areas, and uneven-aged forest stands; (Fig. A8) areas of primary priority combining natural areas ≥ 10000 ha, uneven-aged forest stands, and roadless areas; (Fig. A9) species at risk globally or provincially; (Fig. A10) highest rarity-weighted richness values; (Fig. A11) significant ecosites; (Fig. A12) significant old and unique forest stands; (Fig. A13) areas of primary priority for special elements; highest habitat suitability and population densities for (Fig. A14) American moose, (Fig. A15) American marten, and (Fig. A16) Northern Goshawk; (Fig. A17) 47 core areas selected by priority sites for representation, special elements, and focal species; (Fig. A18) cost-surface for American marten; and (Fig.

A19) least-cost paths for American marten are available in ESA's Electronic Data Archive: *Ecological Archives* A015-068-A1.

APPENDIX B

A coarse-filter representivity-assessment framework is available in ESA's Electronic Data Archive: *Ecological Archives* A015-068-A2.

APPENDIX C

A table showing classes for assessing site potential for representation is available in ESA's Electronic Data Archive: *Ecological Archives* A015-068-A3.

APPENDIX D

A table showing coverages for assessing site potential for special elements is available in ESA's Electronic Data Archive: *Ecological Archives* A015-068-A4.

APPENDIX E

A table showing habitat suitability index (HSI) equations is available in ESA's Electronic Data Archive: *Ecological Archives* A015-068-A5.

APPENDIX F

A table showing habitat component composition and associated forest cover attributes for moose HSI is available in ESA's Electronic Data Archive: *Ecological Archives* A015-068-A6.

APPENDIX G

A figure showing the derivation of suitability index (SI) for each habitat component is available in ESA's Electronic Data Archive: *Ecological Archives* A015-068-A7.

APPENDIX H

A table showing chi-square values from regression analysis to determine the ability of habitat values and road density to predict moose pellet presence on transects is available in ESA's Electronic Data Archive: *Ecological Archives* A015-068-A8.

APPENDIX I

A flow chart indicating overlay process and data layers for cost-distance analysis is available in ESA's Electronic Data Archive: *Ecological Archives* A015-068-A9.