Establishing a protected area network in Canada's boreal forest: An assessment of research needs

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Introduction

Basic principles for the design of protected area networks are well established in the scientific literature. However, the application of generically-defined concepts to a specific landscape, such as the boreal forest, is not a simple matter. In some cases considerable effort will be required in adapting concepts to the boreal setting (e.g., connectivity). In other cases site-specific information will be required for implementation (e.g., delineation of reserve boundaries).

In this paper I review the various implementation issues that will need to be addressed in the Boreal Forest Campaign (BFC). For each issue I summarize what is currently known and identify key gaps that warrant additional research. The paper begins with a brief review of fundamental design concepts to provide context for the specific implementation issues that follow. In the final section I review information sources and discuss options for how the required research might be conducted. The focus of the paper is on the portion of the boreal forest that is subject to industrial use. Issues pertaining to the protection of the forest north of the industrial use zone are discussed briefly in the section entitled *The Reverse Matrix.*

Fundamental Concepts

Representation

Protected areas maintain biodiversity by maintaining the habitat and ecosystem processes that species require for their existence (Noss, 1992). However, the habitat requirements of most species are not known (in fact, most species have not even been described). For this reason, among others, an individual-species approach to habitat conservation is unworkable (Franklin, 1993). The alternative, termed the "coarse-filter" approach, attempts to meet the habitat requirements of the majority of species by ensuring that the full spectrum of major ecosystem types is represented within the system of protected areas (Noss, 1992; Kavanagh and Iacobelli, 1995, p. 10).

Because the "coarse filter" approach provides a relatively coarse level of representation, some unique habitat types are bound to be missed. Therefore, it will be necessary to employ a complementary "fine filter" approach to ensure that unique habitat types, and the species they support, receive adequate protection (Noss, 1995, p.13). Species with very large area requirements will also require special attention (Hummel and Pettigrew, 1991).

Ecological integrity

Representation alone cannot ensure that natural processes will be maintained or that native species will survive (Noss, 1995, p. 6). Thus, a complementary goal to providing adequate representation is the maintenance of ecological integrity. Ecological integrity is defined as the degree to which all ecosystem components and their interactions are represented and functioning (Quigley et al., 1996, p. 29). Of particular importance is maintenance of natural disturbance regimes, which are responsible for much of the structure, pattern, and ultimately biodiversity of the boreal forest (Johnson et al, 1998; Schneider, 2000). Key factors in maintaining integrity are the size of the protected area and management of human activities, both within and around the protected area.

Connectivity

Protected areas that are isolated from each other, and function as habitat islands, are prone to the loss of species (Newmark, 1995). The smaller the protected area, and the more isolated it is, the greater the risk (Diamond, 1975). It follows that connectivity among protected areas must be maintained in order to maintain biodiversity within the system of reserves. Connectivity reduces the risk of species loss through five main mechanisms: (1) it reduces the magnitude of population fluctuations within individual protected areas, (2) should a species be lost from a given protected area, it enables recolonization with individuals from another (the so-called “rescue effect”), (3) it maintains gene flow among populations, (4) it facilitates the movement of wide-ranging species, whose habitat needs can only be met in the protected area system as a whole, and (5) it permits species to shift their range, as may be required in response to climate change (Simberloff et al., 1992).

Research Needs

1. Representation: implementing the “coarse filter”

The working objective of the “coarse filter” approach to representation is to ensure that all major ecosystem types are included in the system of protected areas. But what is meant by “major ecosystem types”, and how do we delineate them? Several organizations, including the Canadian Council on Ecological Areas (Peterson and Peterson, 1991; Gauthier et al., 1995), the World Wildlife Fund Canada (Kavanagh and Iacobelli, 1995), and a number of provincial governments have developed methodologies to address this issue.

A key concept that has emerged is that representation should be based on enduring features of the landscape. Enduring features are thought to be the primary source of ecological diversity and, hence, biological diversity (Kavanagh and Iacobelli, 1995, p.11). Furthermore, enduring features are, by definition, stable thus providing an appropriate basis for the establishment of a system of protected areas that is intended to be permanent.

The WWF’s classification of the landscape according to enduring features was based primarily on the Soil Landscapes of Canada map series (Kavanagh and Iacobelli, 1995, p.11). Related efforts by some provincial governments have included additional features such as landform, climate, geology, hydrology, and major vegetative communities (e.g., Achuff, 1994). The detailed provincial natural region classifications, where they exist, will likely provide the BFC with a more appropriate basis for defining major ecosystem types than the coarse WWF system. A province by province analysis of options will need to be conducted to arrive at a final conclusion on how best to proceed.

2. Reserve design: how big and how many?

The total area available for protection is severely constrained because of competing societal demands for land use. Thus we are faced with having to decide whether it would be better to have many small protected areas, or few large ones. Having more protected areas facilitates representation and increases redundancy in the system. Having larger protected areas increases the likelihood that ecological integrity will be maintained within individual reserves. In over 25 years of scientific debate, neither alternative has been decisively shown to be better. Ironically, what stands as the best solution to the dilemma was penned by Diamond (1976) at the very outset of the debate, "If the best solution of a system of multiple large reserves cannot be achieved, the best compromise would be one refuge as large as possible plus some smaller refuges."

If we accept the argument that a hybrid system of protected areas is best (i.e., some combination of large and small reserves), we are still faced with several implementation issues. First, we must define the spatial scale at which the hybrid system is meant to apply. From the arguments presented in the preceding section on representation, it logically follows that a hybrid system is required for each major ecosystem. Although this may suffice as a general rule, exceptions will undoubtedly need to be made. For example, the Central Mixedwood Subregion in Alberta covers 154,600 km^2 (23% of Alberta). Will a single large protected area suffice for such a large region? Perhaps not, but proving otherwise will require research effort by the BFC. The scientific literature contains no direct answers.

A second implementation issue is determining the minimum size of the large core protected areas. The greatest area requirements generally arise from the objective of maintaining natural disturbance regimes. In the boreal forest natural disturbances such as fire and insect outbreaks can impact thousands of square kilometers at a time (ASRD, 2001).

Several researchers have suggested that protected areas must be substantially larger than the largest fire if the natural fire regime is to be maintained (Pickett and Thompson, 1978; White, 1987; Baker, 1992). But what exactly does "substantially larger" mean? In a computer simulation study using historical fire data from northern Alberta I determined that protected areas of 5,000 km^2 had a high probability of maintaining stable rates of burning, with full representation of the natural range of fire sizes (Schneider, 2001a). The implication is that all forest age classes and patch sizes will be continue to be represented (though not necessarily in a steady state). In contrast, burning in protected areas of 500 km^2 was highly variable, generally resulting in either inadequate or excessive amounts of burning relative to what is required to maintain full representation of forest age classes and patch sizes over ecologically-relevant periods of time (Schneider, 2001a). These findings imply that protected areas approaching or exceeding 5,000 km^2 may be required for maintaining fire regimes and, by extension, ecological integrity in the boreal forest. However, because my modeling study was specific to Alberta, and provides only broad guidance, additional research of this issue will be required by the BFC.

The only attribute that may not be maintained within core protected areas designed to maintain natural disturbance regimes is the viability of wide-ranging species. Some species have such large area requirements that viable populations cannot be achieved in individual protected areas even if they are several thousand square kilometers in size (Table 1). Given that the total area available for protection will be limited, it would not be advisable to try to meet the needs of these species by expanding the size of individual protected areas. Doing so would violate the "coarse-filter" approach intended to represent all major ecosystem types. Instead, the viability of wide-ranging species will have to be achieved by maintaining connectivity among core protected areas, so that the system as a whole can achieve what individual protected areas cannot (see below).

Table 1. Estimated area required for 1,000 individuals of wide-ranging boreal species.

Species	Density/Home Range (km^2)[1]	Area for 1,000 Individuals (km^2)[2]	Source[3]
Marten	2.3 (HR: females)	1,150	Powell, 1994
Pileated woodpecker	4.1 (HR: pair)	2,050	Bull and Holthausen, 1993
Black bear	7.5 (HR: females)	3,750	Fuller and Keith, 1980a
Moose	4.0 (D)	4,000	Schneider and Wasel, 2000
Great-horned owl	9-16 (D)	12,500	Rusch et al., 1972
Fisher	27.8 (HR: females)	13,900	Pinsonneault et al., 1997
Goshawk	15-50 (HR: pair)	16,250	Schaffer, et al., 1996
Lynx	3.3-33.3 (D)	18,300	Poole, 1994
Grizzly bear	33-50 (D)	41,500	Mace and Waller, 1997
Wolverine	105 (HR: females)	52,500	Whitman et al., 1986
Wolf	90-158 (D)	124,000	Fuller and Keith, 1980b
Caribou	711 (HR)	several thousand[4]	Stuart-Smith et al., 1997

[1]Density (D) listed if available (animals per km^2), otherwise home range (HR) is listed (total area, in km^2).

[2]Area = Density*1,000. For species for which density is unknown a crude estimate of the area is calculated as: Mean Home Range/2*1,000 (assuming that female territories cover the entire landscape, without overlap, and that the number of males is equal to the number of females).

[3]Data from Alberta, unless unavailable.

[4]Because caribou exist in herds their density cannot be determined from home range estimates.

3. Reserve design: implementing the "fine filter"

Once major ecosystems have been defined, decisions will have to be made regarding the exact location and configuration of the core and satellite reserves. The focus is to ensure that fine-scale landscape attributes not addressed by the "coarse filter" approach are represented in the system. Fine-scale attributes dictate the boundary of the large core protected area and determine which features remain to be incorporated through satellite reserves. This includes consideration of the needs of rare or endangered species with unique habitat requirements or restricted range. Design issues related to the maintenance of ecological integrity must also be addressed at this stage.

The scientific literature pertaining to "fine filter" strategies is voluminous. Fortunately, an accessible and comprehensive overview was prepared by Noss (1995) for WWF Canada. I recommend that this document be used by the BFC as a core reference on design issues. Applying the design concepts summarized by Noss to specific landscapes will require substantial research effort on the part of the BFC. It will involve fine-scale ecosystem mapping, collecting detailed information on the existing human footprint (e.g., road density), mapping of biodiversity "hotspots" and concentrations of rare species, and mapping indicators of economic potential, as well as other features (Noss, 1995, p. 14). In some provinces most of this information is currently available; in others, only basic data exist. Once the required information for a given region is available an analysis can be conducted to weigh options (within the context of the aforementioned reserve design principles) and arrive at the "best" reserve design.

4. Connectivity and buffers

Although the need for connectivity among protected areas has been well established (see *Fundamental Concepts*), methods for achieving connectivity are still a matter of scientific debate (e.g., Noss, 1987; Simberloff and Cox, 1987). In particular, there is only limited evidence that conventional movement corridors do in fact provide connectivity in real landscapes (Beier and Noss, 1998). Some researchers have suggested that alternative approaches should be considered (Simberloff et al., 1992). Furthermore, virtually all applied research on connectivity and corridors has been conducted on particular focal species in highly fragmented agricultural landscapes or mountainous regions (Bier and Noss, 1998). It would be inappropriate to directly apply the findings of these studies to the boreal forest because there are substantive differences in our landscape, our species of interest, and the objectives of the BFC. We can expect that the implementation strategy we develop for maintaining connectivity in the boreal forest will be novel and will require research effort on our part.

As we proceed to develop a connectivity strategy for the BFC, several important features of the boreal forest and the objectives of our campaign must be recognized and addressed:

1. Given that one of our objectives for maintaining connectivity is to enable species to modify their range in the face of climate change, the system we design must in principle be able to accommodate the movement needs of any and all species.
2. Given the enormous size of the boreal forest, the distance between core protected areas is likely to be large (i.e., >100 km) in many cases. This implies that, for many species, movement of individuals between protected areas will not occur in single dispersal episodes, but over a period of many years. This means that corridors must not only facilitate movement, but also supply long-term habitat requirements (Harrison, 1992).
3. At present, neither natural landforms nor human disturbance are significant barriers to animal movement in most regions of the boreal forest. The major barriers that will arise in the future, if current land-use practices continue, are (1) the road network and associated infrastructure that is constructed to provide access for forestry and other industrial operations, and (2) the loss in continuity of certain habitat types, such as old-growth, as a consequence of regeneration practices under conventional and intensive forestry. Clear-cuts themselves will generally not constitute a significant barrier to movement at the spatial scales and time scales being discussed, so long as they are regenerated quickly and conventional limits on size and overall amount apply.

Together, these features suggest that connectivity among protected areas in the boreal forest may best be achieved through special management of the intervening landscape, and not through the conventional concept of species-specific linear travel corridors (Simberloff et al., 1992). "Special management" means that habitat requirements for all species are maintained to a very high degree, and barriers to movement are minimized. The approach most likely to achieve these objectives is the strict application of ecological forest management (AFMSC, 1997; Schneider, 2000) together with limits on the maximum density of roads. Intensive forestry and other intensive industrial operations, if they are to proceed at all, would be restricted to landscapes that are not between protected areas.

The scientific literature pertaining to ecological forest management is substantial. The major elements of ecological forest management as applied to the boreal mixedwood forests of western Canada were reviewed by the Alberta Forest Management Science Council (1997) and Schneider (2000). A similar review is being produced for the eastern boreal forest by the CPAWS Wildlands League (T. Gray, pers. comm.). These documents should provide a suitable basis for developing a set of basic principles that can be applied across the boreal forest as part of the BFC. Site-specific implementation issues such as defining the boundaries of the special management zones, developing detailed management prescriptions, and determining appropriate maximum road densities will all require additional research effort.

Special management will also be required in buffer zones around protected areas, primarily to facilitate the maintenance of ecological integrity within reserves. Essentially the same issues and research questions identified for connectivity apply to these buffer regions.

5. Old-growth

The maintenance of old-growth forests, and the species they harbour, presents a special challenge for the BFC. Old-growth stands in the boreal forest have special importance because they have the highest overall diversity of species, including many rare species, relative to other age classes (Stelfox, 1995, p. *vi*). Furthermore, many species have their greatest abundance in old-growth (Schieck and Nietfeld, 1995). Finally, under traditional "sustained-yield" forestry, old-growth stands are preferentially targeted for harvest and are eventually eliminated from the landscape.

Using conventional protected areas to maintain old-growth in the boreal forest is problematic because old-growth stands are a transient feature of the landscape (a consequence of the high rate of fire) and widely dispersed (Schneider, 2001b). Protected areas selected on the basis of enduring landscape features may not provide sufficient amounts of old-growth of all forest types, especially after large fire events. Consequently, special management of old-growth on the industrial landscape will likely also be required (Burton et al., 1999). Special management may include targets for the minimum proportion of old-growth that must be maintained on the landscape by forestry companies (Bergeron et al., 1999). It may also include the use of "floating" old-growth reserves designed to ensure that a significant proportion of the old-growth is maintained in large contiguous blocks (Schneider, 2001b). The "floating" nature of the reserves is a tactic for maintaining some large blocks at all times, in face of fires that periodically fragment or eliminate them.

6. Climate change

Although there is now general agreement within the scientific community that significant climate change will occur over the next 50-100 years, the implications for the boreal forest are still unclear. This is because the reliability of climate models applied to specific landscapes is not known, and because it is difficult to predict the ecological consequences of projected climate changes. In particular, because both temperature and precipitation are expected to increase in the boreal forest it is unclear how the rate of fire is likely to respond (Flannigan et al., 1998). If the rate of fire increases substantially, as some researchers predict, there will be major changes in the structure and composition of the forest, and many species will have to shift their range (Scott and Suffling, 2000).

Environment Canada recently commissioned a major study on the potential impact of climate change on national parks, (Scott and Suffling, 2000). Rather than conducting its own research on climate change, the BFC should use the Environment Canada report for guidance. Additional research may be warranted in the future to refine predictions in light of increased understanding of climate change and its ecological impacts. In the short term, research efforts by the BFC should focus on design issues pertaining to the maintenance of connectivity among protected areas (Halpin, 1997).

7. Management of protected areas

Once established, protected areas will need to be managed appropriately to ensure that ecological integrity is maintained. Issues that may require research support include restoration (where industrial activities have modified the landscape prior to it being protected), maintenance of natural disturbance regimes in protected areas less than 1,000 km^2 in size, and appropriate management of human recreational and hunting activities. A detailed discussion of management issues is beyond the scope of this paper. However, the Panel on the Ecological Integrity of Canada's National Parks has produced a comprehensive review of the issue (PCA, 2000), which should be used by the BFC for guidance.

8. The reverse matrix

North of the commercial forestry zone (or "cut-line") forests are still predominately in a wilderness state. CPAWS has proposed that a "reserve matrix" model of protection be implemented in this northern region. In the "reverse matrix" model wilderness forms the matrix, and human communities and industrial activity areas exist as islands within it, connected by roads or other travel routes.

Because the majority of the landscape is protected in the "reverse matrix" model, design issues such as the size of protected areas, representation, and connectivity have little relevance. This is not to say that research will not be required for the implementation of the "reverse matrix" model. But the until the model is more completely developed it is difficult to identify the research questions that may need to be addressed. At this time socio-economic issues pertaining to local native communities in the north would seem to be of primary concern, and not issues pertaining to the maintenance of biodiversity.

Getting the Answers

As a result of various national and provincial initiatives much work has already been completed with respect to the establishment of a protected area network in the boreal forest of Canada. GIS maps of key landscape features are now available in most provinces, and in some provinces candidate sites have been identified and are being established. The BFC should build on these existing initiatives to the greatest extent possible. One particular initiative, the Muskwa-Kechika in northeastern B.C (www.muskwa-kechika.com), provides a working model of how all of the various elements described in this report can be integrated into a functional system. In contrast to most other protected area initiatives in the boreal region, which inadequately address the issues of integrity and connectivity, the Muskwa-Kechika initiative is based on integrated regional planning that incorporates core protected areas of various sizes and special management of the intervening matrix.

The research needs described in this report demonstrate that the fundamental concepts of reserve design are well developed, but much research will be required for the implementation of these concepts in a boreal landscape. In my review of the scientific literature I found that few reports directly address implementation issues in the boreal forest, and the reports that do exist are essentially limited to the so-called “gray” literature (such as government and ENGO reports and conference proceedings). Although the “gray” literature is by its nature difficult to search thoroughly, the references cited in this report provide what I believe is a reasonably comprehensive overview of the most relevant and reliable reports that exist.

Academic researchers, government agencies, and conservation organizations have all been active in research on protected areas and are potential candidates for addressing the research needs of the BFC. Academic researchers have conducted most of the conceptual research on protected areas, and have been somewhat involved in implementation issues (though not, to any extent, in the boreal forest). If funding for graduate students were made available it should be possible to find academic researchers that would take on some of our more broad research questions. These researchers may be less inclined to become involved in site-specific implementation issues, such as boundary delineation, because this type of research is difficult to publish in peer-reviewed journals.

Most of the existing research on implementation issues specific to the boreal forest has been conducted by government agencies and conservation organizations. This research has been conducted by staff and through the use of consultants. With additional funding for staff and consultants, conservation organizations would be well-suited to addressing many of the remaining site-specific implementation questions related to the BFC. The best approach might be to establish a set of regional research centres, based out of conservation organizations with existing research capacity. A regional approach is necessary to ensure that local information and unique features of the landscape (both ecological and industrial) are fully incorporated in the design of the protected area network. A national research centre could be established to conduct and coordinate research on broad issues and to provide general direction and communication support for the regional centres.

Collaboration with government agencies may be possible on specific topics, but the lack of alignment between government agendas and the BFC imply that close coordination is unlikely.

Suggested Reading

Representation (coarse filter): Gauthier et al., 1995; Kavanagh and Iacobelli, 1995
Reserve design (fine filter): Peterson and Peterson, 1991; Noss, 1995
Connectivity: Harrison, 1992; Beier and Noss, 1998.
Ecological forest management: AFMSC, 1997; Schneider, 2000
Old-growth conservation: Schneider, 2001b
Management of protected areas: PCA, 2000
Climate change: Scott and Suffling, 2000

Literature Cited

Achuff, P. 1994. Natural regions, subregions, and natural history themes of Alberta.

AFMSC (Alberta Forest Management Science Council). 1997. Sustainable forest management and its major elements. Report prepared for Alberta Environmental Protection, Edmonton, AB. (Available at: www.borealcentre.ca/reports/reports.html)

ASRD (Alberta Sustainable Resource Development). 2001 Historical wildfire database. Available on-line at http://envweb.env.gov.ab.ca/env/forests/fpd

Baker, W. 1992. The landscape ecology of large disturbances in the design and management of nature reserves. Lands. Ecol. 7:181-194.

Beier, P., and R. Noss. 1998. Do habitat corridors provide connectivity? Cons. Biol. 12:1241-1252.

Bergeron, Y., B. Harvey, A. Leduc, and S. Gauthier. 1999. Forest management guidelines based on natural disturbance dynamics: stand and forest-level considerations. For. Chron. 75:49-54.

Bull, E. L., and R. S. Holthausen. 1993. Habitat use and management of pileated woodpeckers in northeastern Oregon. J. Wildl. Manage. 57:335-345.

Burton, P., D. Kneeshaw, and D. Coates. 1999. Managing forest harvesting to maintain old growth in boreal and sub-boreal forests. For. Chron. 75:623-631.

Diamond, J. M. 1975. The island dilemma: Lessons of modern biogeographic studies for the design of natural reserves. Biol. Cons. 7:129-145.

Diamond, J. M. 1976. Island biogeography and conservation: Strategy and limitations. Science 193:1027-1029.

Franklin, J. 1993. Preserving biodiversity: species, ecosystems, or landscapes? Ecol. Applic. 3:202-205.

Flannigan, M. D., Y. Bergeron, O. Engelmark, and B. M. Wotton. 1998. Future wildfire in circumboreal forests in relation to global warming. J. Veg. Sci. 9:469-476.

Fuller, T., and L. Keith. 1980. Summer ranges, cover-type use, and denning of black bears near Fort McMurray, Alberta. Can. Field Nat. 94:80-83.

Fuller, T. K., and L. B. Keith. 1980. Wolf population dynamics and prey relationships in northeastern Alberta. J. Wildl. Manag. 44:583-602.

Gauthier, D., K. Kavanagh, T. Beechey, L. Goulet, and E. Wiken. 1995. Framework for Developing a Nation-wide System of Ecological Areas Part 2 - Ecoregion Gap Analysis. Occasional Paper No. 13. Canadian Council on Ecological Areas.

Halpin, P. N. 1997. Global climate change and natural-area protection: management responses and research directions. Ecol. Applic. 7:828-843.

Harrison, R. 1992. Toward a theory of inter-refuge corridor design. Cons. Biol. 6:293-295.

Hummel, M., and S. Pettigrew. 1991. Wild hunters: predators in peril. Key Porter, Toronto, ON.

Johnson, E. A., K. Miyanishi, and J. M. H. Weir. 1998. Wildfires in the western Canadian boreal forest: landscape patterns and ecosystem management. J. Veg. Sci. 9:603-610.

Kavanagh, K., and T. Iacobelli. 1995. A protected areas gap analysis methodology: planning for the conservation of biodiversity. World Wildlife Fund, Toronto, ON.

Mace, R. D., and J. S. Waller. 1997. Spatial and temporal interaction of male and female grizzly bears in northwestern Montana. J. Wildl. Manag. 61:39-52.

Newmark, W. D. 1995. Extinction of mammal populations in western North American national parks. Cons. Biol. 9:512-526.

Noss, R. 1992. The wildlands project: land conservation strategy. Wild Earth 1:10-25.

Noss, R. 1995. Maintaining ecological integrity in representative reserve networks.

World Wildlife Fund, Toronto, ON.

Noss, R. 1987. Corridors in real landscapes: A reply to Simberloff and Cox. Cons. Biol. 1:159-164.

Parks Canada Agency. 2000. "Unimpared for future generations"? Conserving ecological integrity with Canada's national parks. Report of the panel on the ecological integrity of Canada's national parks. Parks Canada Agency, Ottawa, ON.

Peterson, E., and M. Peterson. 1991. A first approximation of principles and criteria to make Canada's protected area systems representative of the nation's ecological diversity. Canadian Council on Ecological Areas.

Pickett, S., and J. N. Thompson. 1978. Patch dynamics and the design of nature reserves. Biol. Cons. 13:27-37.

Pinsonneault, Y., L. D. Roy, and B. E. Grover. 1997. Winter habitat use by fishers (*Martes pennanti*) in harvested and unharvested forests, northeast Alberta. Alberta Research Center, Vegreville, AB.

Poole, K. G. 1994. Characteristics of an unharvested lynx population during a snowshoe hare decline. J. Wildl. Manag. 58:608-618.

Powell, R. 1994. Structure and spacing of Martes populations. Pages 101-121 in Buskirk, S., A. Harestad, M. Raphael, and R. Powell, editors. Martens, sables, and fishers: biology and conservation. Cornell University Press, Ithaca, NY.

Quigley, T. M., R. W. Haynes, and R. T. Graham. 1996. Integrated scientific assessment for ecosystem management in the interior Columbia basin and portions of the Klamath and Great Basins. U.S. Forest Service, Pacific Northwest Research Station, Gen. Tech. Rep. PNW-GTR-382., Portland, OR.

Rusch, D. H., E. C. Meslow, P. D. Doerr, and L. B. Keith . 1972. Response of great horned owl populations to changing prey densities. J. Wildl. Manag. 36:282-296.

Schaffer, W., B. Beck, J. Beck, R. Bonar, and L. Hunt. 1996. Northern goshawk breeding habitat. Pages 175-186 in Beck, B., J. Beck, J. Bessie, R. Bonar, and M. Todd, editors. Habitat suitability index models for 35 wildlife species in the Foothills Model Forest. Foothills Model Forest, Hinton, AB.

Schieck, J., and M. Nietfeld. 1995. Bird species richness and abundance in relation to stand age and structure in aspen mixedwood forests in Alberta. Pages 115-157 in Stelfox, B., editors. Relationships Between Stand Age, Stand Structure, and Biodiversity in Aspen Mixedwood Forests in Alberta. Alberta Environmental Centre, Vegreville, AB. (Available at: www.borealcentre.ca/reports/reports.html)

Schneider, R. R. 2000. The natural disturbance model of forest harvesting. Alberta Centre for Boreal Studies, Edmonton, AB. (Available at: www.borealcentre.ca/reports/reports.html)

Schneider, R.R. 2001a. Maintaining a natural fire regime within protected areas. Submitted to Ecol. Model. (Available at: www.borealcentre.ca/reports/reports.html)

Schneider, R.R. 2001b. Old-growth forests in Alberta: ecology and management. Alberta Centre for Boreal Studies, Edmonton, AB. (Available at: www.borealcentre.ca/reports/reports.html)

Schneider, R. R., and S. Wasel. 2000. The effect of human settlement on the density of moose in northern Alberta. J. Wildl. Manag. 64: 513-520.

Scott, D., and R. Suffling. 2000. Climate change and Canada's national park system: A screening level assessment. Parks Canada, Ottawa, ON. (Available at: http://www.msc-smc.ec.gc.ca/airg/pubs/parks.htm)

Simberloff, D., and J. Cox. 1987. Consequences and costs of conservation corridors. Cons. Biol. 1:63-71.

Simberloff, D., J. A. Farr, J. Cox, and D. W. Mehlman. 1992. Movement corridors: conservation bargains or poor investments? Cons. Biol. 6:493-504.

Stelfox, J. B. 1995. Relationships Between Stand Age, Stand Structure, and Biodiversity in Aspen Mixedwood Forests in Alberta. Alberta Environmental Centre, Vegreville, AB. (Available at: www.borealcentre.ca/reports/reports.html)

Stuart-Smith, K., C. Bradshaw, S. Boutin, D. Hebert, and B. Rippin. 1997. Woodland caribou relative to landscape patterns in northeastern Alberta. J. Wildl. Manag. 61:622-633.

White, P. 1987. Natural disturbance, patch dynamics, and landscape pattern in natural areas. Nat. Areas J. 7:14-22.

Whitman, J. S., W. B. Ballard, and C. L. Gardner. 1986. Home range and habitat use by wolverines in southcentral Alaska. J. Wildl. Manag. 50:460-463.