Plantations and biodiversity: A comment on the debate in New Brunswick

by Matthew G. Betts¹, Antony W. Diamond², Graham J. Forbes³, Kate Frego⁴, Judy A. Loo⁵,
Bruce Matson⁶, Mark R. Roberts³, Marc-André Villard⁷, Renee Wissink⁸ and Lawrence Wuest⁹

ABSTRACT

The importance of biodiversity has become widely recognized but the best methods for conserving forest biodiversity are still being debated. Central to this debate is the influence of plantations and managed stands on local and landscape-scale biodiversity. A recent paper by Erdle and Pollard in *The Forestry Chronicle* (2002), which concluded that few plantations are strict monocultures in terms of the total number of tree species, could be interpreted as making the case that plantations have relatively minor consequences for biodiversity. We argue that: (1) it is not only the number of species, but also the identities and relative abundances of species that are of ecological importance, and (2) defining biodiversity in terms of tree species alone is of limited applicability. Existing research in New Brunswick on the impact of plantations on biodiversity at the stand scale reveals potentially significant biodiversity losses, at least in certain taxa. The proposal that incorporating more structural elements (e.g., snags, coarse woody debris, vertical structure) and retaining greater tree species diversity to ameliorate negative consequences of plantations remains a hypothesis to be tested in this region. Scientific information gathered in the following areas will allow better decision making: (1) to what degree are older plantations used by native species? (2) are productivity and survivorship of vertebrates in intensively managed stands similar to those in unmanaged forest? (3) are intensively managed stands suitable habitat for non-vertebrates? (4) are there thresholds in the response of some species to landscape-scale habitat loss caused by intensive forest management?

Key words: plantations, biodiversity, species composition, landscape scale, stand structures

RÉSUMÉ

L'importance de la biodiversité est acceptée de façon générale mais les meilleures méthodes de conservation de la biodiversité forestière font encore l'objet d'un débat. Au cœur de celui-ci, on retrouve l'influence des plantations et des peuplements aménagés sur la biodiversité locale et à l'échelle de l'écosystème. Un article récent publié par Erdle et Pollard dans *Le Forestry Chronicle* en 2002 qui concluait que rares sont les plantations qui constituent des monocultures absolues en terme du nombre total d'espèces d'arbres, pouvait être interprété comme énonçant que les plantations entraînent des conséquences relativement mineures au niveau de la biodiversité. Nous alléguons que (1) ce n'est pas seulement le nombre d'espèces, mais également l'identité et l'abondance relative des espèces qui sont d'importance écologique et, (2) la définition de la biodiversité en terme d'espèces d'arbres seulement est d'une applicabilité restreinte. Les recherches en cours au Nouveau-Brunswick sur les retombées des plantations sur la biodiversité au niveau du peuplement révèlent des pertes de biodiversité potentiellement significatives, du moins pour certains taxons. La proposition cherchant à incorporer plus d'éléments structuraux (par ex., les chicots, les débris ligneux grossiers, la structure verticale) et la rétention d'une plus grande diversité d'espèces d'arbres pour améliorer les retombées négatives associées aux plantations, demeure une hypothèse qui doit être testée dans cette région. L'information scientifique recueillie dans les domaines suivant permettra une meilleure prise de décision: (1) à savoir jusqu'à quel niveau les vieilles plantations sont-elles utilisées par les espèces indigènes? (2) est-ce que la productivité et la capacité de survie des vertébrés dans les peuplements sous aménagement intensif sont semblables à celles des forêts non aménagées? (3) est-ce que les peuplements sous aménagement intensif constituent un habitat adéquat pour les non vertébrés? (4) est-ce qu'il existe des seuils de réaction dans le cas de certaines espèces lors de perte d'habitat au niveau de l'écosystème occasionnée par l'aménagement forestier intensif?

Mots clés : plantations, biodiversité, composition en espèces, échelle de l'écosystème, structures du peuplement

¹Greater Fundy Ecosystem Research Group, Hugh John Flemming Forestry Centre, 1350 Regent St., Fredericton, New Brunswick E3C 2G6. E-mail: m.betts@unb.ca. Author to whom correspondence should be sent.

²Atlantic Cooperative Wildlife Ecology Research Network, University of New Brunswick, P.O. Box 45111, Fredericton, New Brunswick E3B 6E1. E-mail: diamond@unb.ca

³Faculty of Forestry and Environmental Management, University of New Brunswick, P.O. Box 45111, Fredericton, New Brunswick E3B 6C2. E-mail: forbes@unb.ca, roberts@unb.ca

⁴Department of Biology, University of New Brunswick Saint John, P.O. Box 5050, Saint John, New Brunswick E2L 4L5. E-mail: frego@unbsj.ca

⁵Natural Resources Canada, Canadian Forest Service – Atlantic Forestry Centre, P.O. Box 4000, Fredericton, New Brunswick E3B 5P7. E-mail: jlloo@nrcan.gc.ca

⁶N.B. Department of Natural Resources, 1045 Main Street, P.O. Box 1063, Hampton, New Brunswick E5N 8H1. E-mail: bruce.matson@gnb.ca

⁷Chaire de recherche du Canada en conservation des paysages, Département de biologie, Université de Moncton, Moncton (Nouveau-Brunswick) E1A 3E9. Courriel : villarm@umoncton.ca

⁸Fundy National Park, P.O. Box 1001, Alma, New Brunswick E4H 1B4. E-mail: renee.wissink@pc.gc.ca

⁹P.O. Box 363, Stanley, New Brunswick E6B 2K5. E-mail: wuestl@nbnet.nb.ca

Since the 1992 World Convention on Biological Diversity, the importance of biodiversity has become widely understood and recognized (CCFM 1995, Chapin *et al.* 2000, NBDNR 2000). However, the best methods for conserving forest biodiversity are still debated (Lindenmayer *et al.* 2000, Baskerville 2002). Central to this debate is the influence of plantations and managed stands on local and landscape-scale biodiversity (Binkley 1997, Woodley and Forbes 1997). In New Brunswick, this debate has become controversial following the release of a consultant's report, jointly commissioned by the New Brunswick Forest Products Association and the New Brunswick Department of Natural Resources (NBDNR), that recommends doubling the wood supply on Crown land primarily through the implementation of intensive silviculture (Jaakko Pöyry Management Consulting 2002). If adopted, the recommendations of Jaakko Pöyry Management Consulting would see 42% of Crown lands devoted to plantation and 18% in otherwise intensively managed (largely precommercially thinned) forest. Such a policy has the potential to act as a precedent for other tenures within New Brunswick and in other Canadian provinces.

Science has been used to support the positions of both proponents and detractors of intensive forestry. *The Forestry Chronicle* recently published a paper by Erdle and Pollard (2002) entitled "Are plantations changing the tree species composition of New Brunswick's forest?" Their conclusion that few plantations are strict monocultures could be interpreted as indicating that plantations have relatively minor consequences for biodiversity. Indeed, the paper has been cited in several presentations at public hearings as evidence that plantations may be benign (e.g., Adams 2003, MacLean 2003). However, Erdle and Pollard (2002) also described important differences between plantations and managed forests. The purpose of this letter is twofold: (1) to summarize those conclusions of Erdle and Pollard (2002) that do not support the hypothesis that plantations are benign, and (2), using recent research from New Brunswick, to highlight impacts of plantation forestry on components of biodiversity other than tree species.

The main objective of the Erdle and Pollard (2002) study was to compare the merchantable tree-species composition of preharvest, unmanaged stands (hereafter, "natural forest") with that of plantations. To account for the biased comparison between mature, unmanaged forest and comparatively young plantations, the authors forecast the species composition and volume of plantations at maturity using the STAMAN growth model (Erdle and MacLean 1999). Erdle and Pollard (2002) drew two conclusions from their data that indicate that plantations have negative consequences for biodiversity at the stand level — even at the coarse resolution of merchantable tree species:

1. They found that the hardwood content in plantations (10%) is half that of natural forest (20%). Furthermore, it is important to note that this hardwood component in plantations is made up primarily of intolerant hardwoods (white birch (*Betula papyrifera* Marsh.), largetooth aspen (*Populus grandidentata* Michx.), trembling aspen (*Populus tremuloides* Michx.), and red maple (*Acer rubrum* L.)) at the expense of tolerant hardwoods (beech (*Fagus grandifolia* L.), sugar maple (*Acer saccharum* Marsh.), and yellow birch (*Betula alleghaniensis* Britt.)), which they replaced (Erdle and Pollard 2002). Indeed, these species groups

are characterized by different silvics (Burns and Honkala 1990), different structural attributes, and different functions as wildlife habitat or microhabitat (Flemming *et al.* 1999). The abundance of red spruce (*Picea rubens* Sarg.) is greatly reduced in plantations (it is about 1.5–7 times more common in natural forest, Erdle and Pollard 2002). As this species is considered a key component of the Acadian forest (Mosseler *et al.* 2003), such large differences are striking and should be cause for concern. The key point here, in our opinion, is that not only the *number* of species, but also the identities and relative abundances of species are of ecological importance (Balmford *et al.* 2003).

2. They also found that the same volume proportion made up by the four most abundant species in natural forest is restricted to two or three species in plantations. The authors conclude that this suggests reduced diversity evenness at the landscape level. Using data extrapolated from Fig. 7 (Erdle and Pollard 2002), we calculated an average decline in diversity of ~30% (Normalized Simpson index, natural forest = 0.58, plantation = 0.40)¹.

These conclusions indicate that plantations lead to a reduction in diversity, even when measured in terms of merchantable tree species.

There is also some evidence to suggest that Erdle and Pollard (2002) underestimated the negative impacts of plantations on biodiversity. First, they have used as a baseline condition a forest that has been substantially altered from its natural condition in pre-Colonial times. Therefore, the negative effects of plantations on biodiversity have been overlaid on a forest that was already negatively affected by high grading (Betts and Loo 2002). Second, data used for natural (pre-harvest) stand types were from the period 1984–1990. During and subsequent to this period, the harvest of hardwood and mixedwood stands has increased in proportion to softwood harvest. Volume of hardwood harvested in 2003 was nearly five times greater than the amount harvested in 1983, and approximately twice the harvest in 1989 (NBDNR 1983, 1989, 2003). If harvested mixedwood and hardwood areas have been planted in New Brunswick with conifers (research on the degree to which this has occurred is scant), we predict that differences in tree-species diversity would have been more pronounced had Erdle and Pollard (2002) used more recent data.

Erdle and Pollard (2002) stated that defining biodiversity in terms of tree species alone is of limited applicability. We strongly concur. Existing New Brunswick studies on structural attributes (e.g., snags, coarse woody debris; Freedman *et al.* 1994), birds (Parker *et al.* 1994), amphibians (Waldick *et al.* 1999), herbaceous plants (Ramovs and Roberts 2003), and bryophytes (Ross-Davis and Frego 2002) report reduced stand-level diversity as a result of softwood plantation in southern New Brunswick.

Indeed, even to examine species diversity alone is potentially misleading. Diversity in community types and structural diversity are also central to the definition of biodiversity (Noss and Cooperrider 1994). Estimates of the number of softwood community groups in New Brunswick range

¹The Normalized Simpson Index of Diversity, sometimes referred to as the index of equitability or evenness E is given by: $E = 1 / \sum_i p_i^2 \cdot 1/N$, where p_i is the proportion of the population in class i and N is the total number of classes (Magurran 1988).

from six to 22 (NBDNR 2000, Basquill *et al.* submitted). It would theoretically be possible to eradicate a large proportion of these community types through planting with only small decreases in species diversity. This theoretical possibility becomes more probable if about 96% New Brunswick's Crown softwood is managed intensively for fibre production, as recommended by Jaakko Pöyry Management Consulting (2002).

Furthermore, the structure of softwood plantations is simplified compared with post-budworm, naturally regenerated stands (Fleming and Freedman 1998). Research in northwestern New Brunswick indicates that reductions in structural heterogeneity, combined with short-rotation harvesting, would be detrimental to at least 12 species of passerine birds (Guénette and Villard 2005). This does not account for species that occurred too infrequently to conduct statistical analyses (e.g., Black-backed Woodpecker, *Picoides arcticus*, and American Three-toed Woodpecker, *Picoides dorsalis*). Reductions in the density of snags and coarse woody material have been demonstrated to have negative effects on birds and on many other organisms in Fennoscandia (Esseen *et al.* 1997, Siitonen 2001).

It is also critical to consider the potential landscape-scale impact of plantations on the biodiversity of New Brunswick. Under the scenario recommended by Jaakko Pöyry Management Consulting (2002), 42% of Crown land will be occupied by plantations (compared with 17% in the current planning scenario). Although knowledge of landscape-scale impacts of intensive forestry/silviculture is scant, a number of studies suggest that the relationship between habitat loss and population size is not proportional (Andrén 1999, Radford and Bennett 2004). As landscape mosaics are converted into a patchwork of plantations, managed and unmanaged second- and third-growth stands, not all habitat that is suitable at the stand scale may be occupied by certain species (Lichstein *et al.* 2002, Betts *et al.* submitted, Guénette and Villard unpublished data). This probably reflects disruptions in processes taking place over larger scales (e.g., dispersal, predator-prey dynamics) (Krawchuk and Taylor 2003). In addition, area-demanding species simply may not be able to combine scattered resource patches into a home range (Chapin *et al.* 1998). These landscape-scale impacts are of greater concern in the context of the rapid decline in unmanaged forest due to the Allowable Cut Effect (ACE), whereby unmanaged forest is harvested more rapidly (the allowable cut is increased) in anticipation of future plantation yields.

If plantations are to be used as a way of decreasing harvest pressure on unmanaged forest, it is critical that: (1) the mix of planted species be broadened, (2) natural regeneration be encouraged in patches within plantations, (3) biogeographical site conditions be considered in plantation species choice, and (4) plantation establishment be concentrated in ecological zones that are naturally most similar to plantations (Erdle and Pollard 2002). We emphasize that existing research in New Brunswick on the impact of plantations on biodiversity at the stand scale reveals potentially significant biodiversity losses, at least in certain taxa (Freedman *et al.* 1994, Waldick *et al.* 1999, Ross-Davis and Frego 2002, Veinotte *et al.* 2003, Ramovs and Roberts 2003, Guénette and Villard 2005). We recognize that much of the

previous research was conducted on young (< 20 years old) plantations and that research is continuing on older (> 50 years old) plantations. However, results from a study of plantations aged 19–64 years (Ross-Davis and Frego 2002, Ramovs and Roberts 2003) indicated that differences in species composition remain in these older plantations, at least for vascular plants. The proposal that incorporating more structural elements (e.g., snags, coarse woody debris, vertical structure) and retaining greater tree species diversity will ameliorate negative consequences of plantations remains a hypothesis to be tested in this region (Seymour and Hunter 1999). Indeed, in Fennoscandian countries, where intensive silviculture has occurred for over 80 years, about 50% of red-listed species are threatened as a result of intensive forestry (Berg *et al.* 1994, Nilsson and Ericson 1997). Many of these species are lesser known and rare species, including fungi (polypores), bryophytes, and lichens (Finnish Environment Institute 2000).

Scientific information gathered in the following areas will allow better decision making:

1. To what degree are older (> 50 years old) plantations used by native species? Most plantation-based research in New Brunswick during the 1990s was in the context of large-scale, post-budworm salvage. Planting converted a landscape composed of mature, mixed forest to young, planted forest characterized by short-rotation harvesting (Freedman *et al.* 1994). Recent trends to treat planted sites with two- to three-pass harvests will increase plantation age, and will potentially decrease structural differences between plantations and mature, unmanaged forest (Freedman *et al.* 1994). For example, older plantations are more likely to contain larger trees (> 30 cm dbh), which are important structural components for a range of forest bird species (Guénette and Villard 2005).
2. Are productivity and survivorship of vertebrates in intensively managed stands similar to those in unmanaged forest? Reliance on presence-absence or density data does not recognize the possibility that plantations may serve as sinks or ecological traps if net productivity is less than zero (Pulliam and Danielson 1991, Kristan 2003). For example, a reliance on presence-absence data does not recognize bias from processes such as sub-optimal habitat use by juvenile individuals, or that singing, territorial male birds may not indicate successful reproduction (Hagan *et al.* 1996). Under certain conditions, density does not necessarily reflect productivity (van Horne 1983).
3. Are intensively managed stands suitable habitat for non-vertebrates? There is a tendency to monitor several vertebrate species and extrapolate results to biodiversity in general. Because of their energy requirements and mobility, large vertebrates are less likely than bryophytes, vascular plants, insects, and soil biota to respond directly to stand structures.
4. Are there thresholds in the response of some species to landscape-scale habitat loss caused by forest management? For species, or populations, that use areas larger than single stands, what is the impact of the matrix becoming less usable? At present, most research is conducted at the stand scale, ignoring the influences of landscape context.

Until research in these areas is conducted, we advocate a precautionary approach to plantation establishment.

Acknowledgements

We wish to thank Caroline Simpson (Canadian Forest Service) for providing thorough editorial review and Vince Zelazny for thoughtful comments on earlier drafts of this manuscript.

References

- Adams, G. 2003. Role of Silviculture in Changing Environments. Brief presented to the New Brunswick Legislature's Select Committee on Wood Supply. J.D. Irving, Ltd. Saint John, NB.
- Andrén, H. 1999. Habitat fragmentation, the random sample hypothesis and critical thresholds. *Oikos* 84: 306–308.
- Balmford, A., R.E. Green and M. Jenkins. 2003. Measuring the changing state of nature. *Trends in Ecology and Evolution* 18: 326–330.
- Baskerville, G. 2002. Editorial. *The Forestry Chronicle* 78: 586–590.
- Basquill, S., M. Betts and J. Loo. Submitted. Forest community groups in the Greater Fundy Greater Ecosystem. In M. Betts and G. Forbes (eds.). *Forest Management Guidelines to Protect Native Biodiversity in the Fundy Model Forest*. Greater Fundy Ecosystem Research Group, Fredericton, NB.
- Berg, A., B. Ehnstrom, T. Gustafsson, M. Hallingback and M. Jonsell. 1994. Threatened plant, animal and fungus species in Swedish forests: distribution and habitat associations. *Conservation Biology* 8: 718–731.
- Betts, M. and J.A. Loo. 2002. A comparison of pre-European settlement forest characterization methodologies. *The Forestry Chronicle* 78: 422–432.
- Betts, M., A.W. Diamond, G.J. Forbes, M.-A. Villard and J. Gunn. Submitted. Autologistic models for predicting occurrence of forest birds using ground-based vegetation plots and air photo forest inventory (GIS) data. *Ecological Modelling*.
- Binkley, C. 1997. Preserving nature through intensive plantation forestry: The case for forest land allocation with illustrations from British Columbia. *The Forestry Chronicle* 73: 553–559.
- Burns, R.M. and B.H. Honkala. 1990. *Silvics of North America*, Vol. 2 Hardwoods. *Agriculture Handbook* 654, USDA Forest Service, Washington, D.C.
- Canadian Council of Forest Ministers (CCFM). 1995. *Defining Sustainable Management: a Canadian Approach to Criteria and Indicators*. Canadian Council of Forest Ministers, Ottawa, ON.
- Chapin, F.S., E.S. Zavaleta, V.T. Eviner, R.L. Naylor, P.M. Vitousek, H.L. Reynolds, D.U. Hooper, S. Lavorel, O.E. Sala, S.E. Hobbie, M.C. Mack and S. Diaz. 2000. Consequences of changing biodiversity. *Nature* 405: 234–242.
- Chapin, T.G., D.J. Harrison and D.D. Katnik. 1998. Influence of landscape pattern on habitat use by American marten in an industrial forest. *Conservation Biology* 12: 1327–1337.
- Erdle, T. and D.A. MacLean. 1999. Stand growth model calibration for use in forest pest impact assessment. *The Forestry Chronicle* 75: 141–152.
- Erdle, T. and J. Pollard. 2002. Are plantations changing the tree species composition of New Brunswick's forest? *The Forestry Chronicle* 78: 812–821.
- Esseen, P.-A., B. Ehnström, L. Ericson and K. Sjöberg. 1997. Boreal forests. *Ecological Bulletins* 46: 16–47.
- Finnish Environment Institute. 2000. Available at <http://www.ymparisto.fi/default.asp?node=8366&lan=en> Accessed Sept. 1, 2004.
- Fleming, T.L. and B. Freedman. 1998. Conversion of natural, mixed-species forests to conifer plantations: implications for dead organic matter and carbon storage. *Ecoscience* 5: 213–221.
- Flemming, S.P., G.L. Holloway, E.J. Watts and P.S. Lawrence. 1999. Characteristics of foraging trees selected by pileated woodpeckers in New Brunswick. *Journal of Wildlife Management* 63: 461–469.
- Freedman, B., S. Woodley and J.A. Loo. 1994. Forestry practices and biodiversity with particular reference to the Maritime provinces. *Environmental Reviews* 2: 33–77.
- Guénette, J.-S. and M.-A. Villard. 2005. Thresholds in forest bird response to habitat alteration as quantitative targets for conservation. *Conservation Biology* 19: in press.
- Hagan, J.M., W.M. van der Haegen and P.S. McKinley. 1996. The early development of forest fragmentation effects on birds. *Conservation Biology* 10: 188–202.
- Jaakko Pöyry Management Consulting. 2002. *New Brunswick Crown Forests: Assessment of Stewardship and Management*. Jaakko Pöyry Management Consulting, New York, NY. Available at <http://www.gnb.ca/0078/reports/jpmc.asp>.
- Krawchuk, M. and P. Taylor. 2003. Changing importance of habitat structure across multiple spatial scales for three species of insects. *Oikos* 103: 153–161.
- Kristan, W.B. 2003. The role of habitat selection behavior in population dynamics: source-sink systems and ecological traps. *Oikos* 103: 457–468.
- Lichstein, J.W., T.R. Simons and K.E. Franzreb. 2002. Landscape effects on breeding songbird abundance in managed forests. *Ecological Applications* 12: 836–857.
- Lindenmayer, D.B., C.R. Margules and D.B. Botkin. 2000. Indicators of biodiversity for ecologically sustainable forest management. *Conservation Biology* 14: 941–950.
- MacLean, D.A. 2003. UNB Faculty of Forestry and Environmental Management submission to the New Brunswick Legislature's Select Committee on Wood Supply. FOREM, University of New Brunswick, Fredericton, NB.
- Magurran, A.E. 1988. *Ecological Diversity and Measurement*. Princeton University Press, Princeton, NJ.
- Mosseler, A., J.A. Lynds and J.E. Major. 2003. Old-growth forests of the Acadian Forest Region. *Environmental Reviews* 11: 47–77.
- New Brunswick Department of Natural Resources (NBDNR). 1983. *Annual Report 1982–1983*. Government of New Brunswick, Fredericton, NB.
- New Brunswick Department of Natural Resources (NBDNR). 1989. *Annual Report 1988–1989*. Government of New Brunswick, Fredericton, NB.
- New Brunswick Department of Natural Resources (NBDNR). 2000. *A Vision for New Brunswick's Forests*. Government of New Brunswick, Fredericton, NB.
- New Brunswick Department of Natural Resources (NBDNR). 2003. *Annual Report 2002–2004*. Government of New Brunswick, Fredericton, NB.
- Nilsson, S. and I. Ericson. 1997. Conservation of plant and animal populations in theory and practice. *Ecological Bulletins* 46: 117–139.
- Noss, R.F. and A.Y. Cooperrider. 1994. *Saving Nature's Legacy. Protecting and Restoring Biodiversity*. Island Press, Washington, D.C.
- Parker, G., D.G. Kimball and B. Dalzell. 1994. Bird communities breeding in selected spruce and pine plantations in New Brunswick. *Canadian Field Naturalist* 108: 1–9.
- Pulliam, H.R. and B.J. Danielson. 1991. Sources, sinks, and habitat selection: a landscape perspective on population dynamics. *American Naturalist* 137: S50–S66.
- Radford, J.Q. and A.F. Bennett. 2004. Thresholds in landscape parameters: occurrence of the White-Browed Treecreeper *Climacteris affinis* in Victoria, Australia. *Biological Conservation* 117: 375–91.
- Ramovs, B. and M. Roberts. 2003. Understorey vegetation and environment responses to tillage, forest harvesting and conifer plantation development. *Ecological Applications* 13: 1682–1700.
- Ross-Davis, A.L. and K.A. Frego. 2002. Comparison of three managed forest types in the Acadian forest: diversity of forest floor bryophyte community and habitat features. *Canadian Journal of Botany* 80: 21–23.

- Seymour, R. and M.L. Hunter. 1999. Principles of ecological forestry. *In* M. Hunter (ed.). Maintaining biodiversity in forest ecosystems. Cambridge University Press, Cambridge, UK.
- Siitonen, J. 2001. Forest management, coarse woody debris, and saproxylic organisms: Fennoscandian boreal forests as an example. *Ecological Bulletins* 49: 11–41.
- Waldick R.C., B. Freedman and R.J. Wassersug. 1999. The consequences for amphibians of the conversion of natural, mixed-species forests to conifer plantations in southern New Brunswick. *Canadian Field Naturalist* 113: 408–418.
- Woodley, S. and G. Forbes (eds.). 1997. Forest Management Guidelines to Protect Native Biodiversity in the Fundy Model Forest. New Brunswick Cooperative Fish and Wildlife Research Unit, University of New Brunswick, Fredericton, NB.
- van Horne, B. 1983. Density as a misleading indicator of habitat quality. *Journal of Wildlife Management* 47: 893–901.
- Veinotte, C., B. Freedman, W. Maass and F. Kirstein. 2003. Comparison of the ground vegetation in spruce plantations and natural forest in the Greater Fundy ecosystem, New Brunswick. *Canadian Field Naturalist* 117: 531–540.