Effects of post-harvest silviculture on use of boreal forest stands by amphibians and marten in Ontario

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ABSTRACT

Much of the southern boreal forest is composed of second-growth stands that have been subjected to a variety of silvicultural treatments ranging from cut and leave to scarification, planting, and tending with herbicides. We have limited understanding of the effects that these treatments may have on wildlife species, as a result of changes to forest structures and species composition. Forest amphibians, generally, and the American marten (*Martes americana*) are species for which there has been long-standing concern about the effects of forest management. We examined the long-term effects at stand and landscape scales of a range of silviculture intensities on these species by comparing the relative abundances of some amphibians and habitat use by marten in forests that were about 32 to 50 years old. American toads (*Bufo americanus*) appeared to be unaffected by long-term changes in habitat structure and composition owing to silvicultural techniques. We observed lower relative abundance of wood frogs (*Rana sylvatica*) in treated stands 20 to 30 years old than in all other stands including uncut old forests. However, abundance in treated stands more than 32 years old did not differ from untreated or uncut stands. This effect may have resulted from lower moisture levels in treated young stands. Marten seemed to positively respond to post-harvest planting and tending treatments, suggesting that basic silviculture provided habitat attributes, notably a higher conifer content, which was favourable to marten.

Key words: post-harvest silviculture, marten, wood frog, American toad, herbicide, boreal, woody debris, Ontario

RÉSUMÉ

La majeure partie du sud de la forêt boréale est composée de peuplements de seconde venue qui ont connu plusieurs traitements sylvicoles allant de la coupe à blanc au scarifiage, suivi de plantation et entretien au moyen d'herbicides. Nous comprenons en partie les effets que ces traitements pourraient entraîner sur les espèces fauniques, suite à des modifications de la structure et de la composition des peuplements. Les amphibiens du milieu forestier, de façon générale, et la martre d'Amérique (*Martes americana*) constituent des espèces pour lesquelles des études ont été entreprises depuis longtemps sur les effets de l'aménagement forestier. Nous avons étudié les effets à long terme au niveau du peuplement et de l'écosystème de l'intensité des travaux sylvicoles sur ces espèces en comparant l'abondance relative de certains amphibiens et de l'habitat utilisé par la martre dans des peuplements âgés de 32 à 50 ans. Le crapaud d'Amérique (*Bufo americanus*) a semblé ne pas être affecté par les changements à long terme de la structure et de la composition de l'habitat suite aux travaux sylvicoles. Nous avons observé une abondance relative plus faible chez la grenouille des bois dans les peuplements traités de 20 à 30 ans par rapport aux autres peuplements incluant les vieilles forêts non exploitées. Cependant, l'abondance dans les peuplements de plus de 32 ans n'était pas différente de celle des peuplements non traités ou non exploités. Cet effet tait peut être le résultat d'un niveau d'humidité inférieur dans les jeunes peuplements traités. La martre a semblé répondre positivement à la plantation effectuée après la récolte et aux traitements d'entretien, laissant entendre que les traitements sylvicoles de base permettent d'obtenir les caractéristiques recherchées de l'habitat, notamment un contenu en conifères plus élevé, ce qui est favorable dans le cas de la martre.

Mots clés : sylviculture post-récolte, martre, grenouille des bois, crapaud d'Amérique, herbicide, boréal, débris ligneux, Ontario

Introduction

Increased use of intensive post-harvest silviculture is a potential means to mitigate effects of new protected areas, created under the Ontario Forest Accord, which reduce the available industrial land base in Ontario (Bell *et al*. 2000). There has been broad concern over the effects of forest management on biodiversity in Canada, but limited information is available on long-term effects. Generally, any long-term effects of forest management on boreal wildlife species are uncertain as yet because a full logging rotation is not complete. The oldest mechanically logged boreal forests were about 50 years old in 2000 and much of the southern boreal forest is now composed of second-growth stands that have regenerated following harvesting. Many of these managed stands have received a variety of post-harvest silviculture treatments including scarification, planting, and tending with herbicides. Our understanding of the specific effects of such post-harvest silviculture on other values besides wood production is limited

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(Thompson *et al.* 2003). Here we examine the effects of post-harvest management of boreal stands in northeastern Ontario on selected wildlife species.

In Ontario, as elsewhere in Canada, certain wildlife species are used as indicator species, or featured species, to suggest effects of forest management and to guide habitat re-development following harvesting. It would be impractical to examine the potential impacts of forest management for the full spectrum of wildlife. Forest amphibians, generally, are species for which there has been long-standing concern over declines worldwide (Bennett *et al.* 1980) and about the possible effects from forest management (deMaynadier and Hunter 1995). American marten (*Martes americana*) is considered an indicator species for older stands in the boreal forest of many areas of Canada. In Ontario, forest management guidelines have been implemented under regulation to maintain marten populations in boreal forests (Watt *et al.* 1996). We focussed this study on marten and 2 amphibian species, in particular.

Vegetation management may affect stand structures and plant species composition that are important to wildlife (review in: Thompson *et al.* 2003), and stands can take different successional trajectories depending on the treatments used. For amphibians, Wedeles and van Damme (1995) found no long-term studies of the effects of silviculture, but deMaynadier and Hunter (1995) expected that intensive silviculture, especially the conversion from mixedwoods or deciduous stands to conifer plantations, would reduce richness and density of amphibians in the stands. Some studies of salamanders in plantation forests supported those predictions, although the plantation forests studied were young (16–25 years) (Bennett *et al.* 1980, Pough *et al.* 1987, Waldick *et al.* 1999). The latter authors suggested that reduced woody debris may have been related to low numbers of amphibians. On the other hand, correlations of amphibian numbers with amounts of coarse woody material were equivocal in western coastal forests (Bunnell *et al.* 2002). Based on this limited information, Thompson *et al.* (2003) predicted generally reduced populations of amphibians owing to an expected reduction in volumes of downed woody material and reduced ground cover structure (e.g., herbaceous plants, mosses), hence ground moisture, in stands that were heavily treated post-harvest.

In boreal forests, marten prefer mature and old conifer-dominated and mixedwood forests that are structurally complex, with dead woody material that provides habitat for denning, and the efficient pursuit and capture of prey (Buskirk and Powell 1994, Watt *et al.* 1996, Andruskiw *et al.* 2008). Intensive silviculture would be expected to reduce stand structural complexity, especially by reducing coarse woody material and snags. The reduction in woody material would reduce habitat for the major prey, such as red-backed voles (*Myodes gapperi*), although at the same time it should increase the amount of conifer cover in post-harvest stands. Overall, habitat quality should be reduced for marten because populations are closely related to prey abundance (Thompson and Colgan 1987, Poole and Graf 1996, Fryxell *et al.* 1999, Fuller and Harrison 2005).

Our purpose in this study was to examine the long-term effects, at a stand scale, of post-harvest silviculture on amphibians and marten. We assessed the relative abundances of eastern boreal forest amphibians, and habitat use by marten, in stands with a range of post-harvest treatments to determine whether convergence was occurring between natural-origin and managed forest systems.

Methods

Study area and stand descriptions

Our study area was located south of Kapuskasing, Ontario (49° 25′ N, 82° 28′ W), in Rowe's (1972) boreal northern clay forest (Region B.4), in the Gordon Cosens Forest (McPherson *et al.* 2008). The area is characterized by minimal topography and extensive lowland flats underlain by clay soils from post-glacial Lake Barlow–Ojibway. The area has extreme temperatures, ranging from about -40°C in winter to above 35°C for several weeks in summer, with an annual average temperature of 0.6°C. Annual precipitation is about 750 mm, of which about 45% falls as snow. Fire has been the major natural disturbance, but a normal long fire rotation (250+ years) often leads to old multi-aged stands, rather than even-aged boreal forests typical of other boreal forest types with shorter fire cycles (e.g., Carleton and Maycock 1978). Black spruce (*Picea mariana*) is the dominant conifer species on lowlands and uplands, and in mixed stands it occurs with white spruce (*P. glauca*), trembling aspen (*Populus tremuloides*), white birch (*Betula papyrifera*), and balsam fir (*Abies balsamea*) on mesic and upland sites. On lowland sites dominated by black spruce, richer sites also support white cedar (*Thuja occidentalis*) and on poorer sites, black spruce is often mixed with eastern larch (*Larix laricina*). Logged untreated stands on uplands regenerate to deciduous and mixedwood forests dominated by trembling aspen, white birch, and balsam fir, while lowlands regenerate to shrub-dominated communities dominated by speckled alder (*Alnus incana–rugosa*) (Carleton and MacLellan 1994, Carleton 2000). More than 90% of the study area had been logged, starting about 1925. Stands ranged in age from 0 to more than 120 years, with more than 60% aged 30 to 50 years. Even-aged management using fully mechanized logging with chainsaws and skidders began about 1960 and these machines were replaced by whole-tree harvesters by 1985. Basic post-harvest silviculture, including the use of site preparation, planting, and chemical tending, became common around 1970.

For amphibians, 4 stand types were studied: (1) "natural" – stands created following a (circa) 1895 wild fire, (2) "extensive" – stands logged and left for natural regeneration, (3) "basic 1" – stands that were logged, planted, and treated with herbicides (tended), and (4) "basic 2" – stands that were logged, scarified, planted, and treated with herbicide. Extensive and basic 1 stands were further stratified into 2 age classes, 20 to 30 years and 32 to 50 years, based on Forest Resource Inventory (FRI) data. Stands defined as basic 2 were only available between 20 and 30 years of age. For marten, none of the stands that were old enough for marten to inhabit had been scarified; we used 3 stand treatments all aged 35 to 45 years: (1) extensive – as above, (2) stands that had been tended only and (3) basic 1 – as above. All stands were located within an area of about 600 km^2.

Stand vegetation and coarse woody material

We were interested in forest structures to which marten and amphibians respond and that might be influenced by post-harvest silviculture, so we collected detailed information mainly on woody vegetation that was living and dead. We collected data in 5 to 7 stands (>50 ha) in each combination of treatment and age class, although we had no data for stands that were tended only. Stands were selected using geographic information system (GIS) layers for stand age, stand type, and post-harvest silvicultural treatments. We digitized the latter information from maps to create the GIS layer. Stands were surveyed for trees (>10 cm dbh), small trees (<10 cm dbh but >3 m tall), and snags (dead tree) densities and species composition. Woody vegetation data were collected systematically at 50 to100 points per stand, depending on statistical variance, using the point-distance technique of Batcheler (1975). Coarse woody material (>10 cm diameter) volumes were calculated from 5 to10 random 90-m triangular transects per stand (McRae *et al*. 1979), depending on variance after 5 transects. More detail on the methods used and results of this vegetation work were reported in Corbett (2007).

Amphibians

Amphibians were captured in pitfall traps from early August to late September in 2001 and 2002. We sampled 18 or 19 stands of each post-harvest stand type and 5 uncut stands. We placed 5 traps in an array in the form of a cross, with outside traps separated by 10 m, and with 1 pitfall trap placed in the centre. We used 20-cm tall drift fences to connect the outer 4 traps to the centre. Pitfall traps were constructed from 2 plastic flower pots with a 20-cm diameter opening placed one inverted on top of the second, for a depth of 60 cm, taped together, and inserted into the ground with the exposed lip just below the surface of the ground covers. Traps were checked daily and amphibians were removed, measured, and released away from the pitfall array. Amphibians that we observed within the array, but not trapped, were also recorded, as this was the only way that we were able to capture spring peepers (*Hyla crucifer*), for example. We analysed log-transformed mean total captures, which included young-of the-year, juveniles, and adults, over the 2 years for the late-summer/fall period by ANOVA, followed by least significant difference tests (LSD) among the treatments (stand types).

Marten

Marten were live-captured from 2003 to 2007 in fall and early winter. We used a sample of 44, 47, and 49 traps, in extensive, tended only, and basic 1 stands, respectively, aged 35 to 50 years. Traps were set for an equal number of nights in all years. Captured marten were fitted with 30-g radio transmitters and followed regularly to determine home range sizes and habitat use. Home ranges were determined for animals with a minimum of 18 fixes, using the parametric kernel estimator (Worton 1989).

We assessed use of stand types by marten in 2 ways. First, we calculated the number of marten caught per 100 trap nights in each year, in each of the stand types. For this analysis, we examined habitat use by ANOVA. Second, we compared habitat at radio locations (fixes) from 13 animals, with at least 10 fixes (mean = 31) each, compared to habitats available within the surrounding landscape, by compositional analysis (Aebischer *et al*. 1993). We determined a probability value by randomization of 1 treatment 1000 times. Among these 13 marten, 5 maintained home ranges (i.e., had more than 18 fixes) but 2 of these were very small (<0.5 km^2) and so were clearly incomplete. The surrounding landscape was delimited in a geographic information system by using a 3-km distance from all access roads, lakes, and streams from which we could survey by radio-telemetry. Three km represented the maximum distance at which we could obtain a radio signal from our marten radio-collars based on fence-post tests.

Results

Stand vegetation

There were significant differences ($P \leq 0.05$) among the stands that originated from different post-harvest treatments, for many of the vegetation variables that we measured (Table 1). Tree and small tree densities were lower in treated than in untreated stands in the youngest age class, but not in stands more than 30 years old. Post-harvest silvicultural treatment

Table 1. Selected stand variables describing 6 stand types originating from different post-harvest silvicultural prescriptions following clearcutting, and for fire-origin stands, which differed among treatments, near Kapuskasing, Ontario. Values followed by the same letter are not significantly different from *post hoc* tests following ANOVA among stand types.

			Extensive (logged untreated)				Basic 1 (logged, tended, planted)				Basic 2 (logged, scarified, planted, tended)	
	Natural		20–30 years		32–50 years		20–30 years		32–50 years		20–30 years	
Variable	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Trees ≥10 cm, density/ha	496a	49	711b	78	1160c	137	386a	84.7	1111c	25	306a	41
Trees <10 cm and >3 m, density/ha	934a	194	3275b	211	1676c	307	2044c	510	1676	307	2118c	166
Tree percent conifer	71a	9	45b	9	52b	7	87a	5	83a	5	76a	9
White birch >3m, density/ha	73a	21	465b	106	450b	90	17a	14	13a	7	99c	43
Snags >10 cm, density/ha	102a	32	45b	7	98a	43	40bc	15	52bc	8	23c	7
Downed woody material >10 cm, m^3/ha	81.4a	10.9	88.4a	12	56.6b	22.7	63.4b	11.3	63.8b	13.7	95.2a	20.2
Conifer downed woody material, >10 cm, m^3/ha	41.0a	4.3	10.4b	2.4	15.6b	6.8	16.3b	10.1	16.7b	4.5	9.7b	4.3

(basic 1 and 2) resulted in about twice the conifer density that was observed in naturally regenerating harvested stands (i.e., extensive silviculture). The tree density of treated stands approximated the tree density seen in natural stands. The gradient of silvicultural intensity of treatment, from extensive to basic 2 in the young forest age class, produced a trend in tree density from highest to lowest, respectively (Table 1). Extensive silviculture led to stands dominated by balsam fir and trembling aspen, but basic silviculture resulted in stands dominated by black spruce, balsam fir, and trembling aspen, regardless of age class. Large white birch (*Betula papyrifera* Marsh.) was absent, or nearly so, from all treated stands, regardless of age, and among the mean of 99 birch stems/ha in young basic 2 stands, only 6 were trees.

Although the volume of coarse woody material did not differ among stand types, the amount of conifer-origin woody material was much higher in natural stands than in the managed stands (Table 1). Woody material in the managed stands was predominantly comprised of unharvested trembling aspen and white birch that had fallen in the years after harvesting, whereas woody material found in the natural stands was derived from many tree species. Snag density was highest in untreated older stands and in natural stands, but was highly variable among stands and within treatments, and large snags (>20 cm diameter) were most abundant in natural stands. Corbett (2007) discriminated among managed stands primarily along one axis that described a species composition gradient from deciduous to conifer, consistent with the lack of white birch in treated stands.

Amphibians

We captured 4 amphibian species: American toad (*Bufo americanus*), wood frog (*Rana sylvatica*), spring peeper, and blue-spotted salamander (*Ambystoma laterale*). However, there were sufficient sample sizes to test for American toad and wood frog only. We found no differences in capture rates among the stand types for American toads (Fig. 1, $F = 0.4$, df 5, 83, $P = 0.81$). This result did not differ for adult or juvenile toads. There was a significant difference in capture rates for wood frogs among some stand types (Fig. 1, $F = 2.42$, df 5, 83, $P < 0.05$). Wood frogs were significantly less abundant in the youngest basic stand types (1 or 2) compared to in all other treatments (LSD tests, Ps < 0.05), except for natural origin old forests (LSD test, Ps > 0.23). Similar captures rates for wood frogs occurred in young extensive stands, all 32- to 50-year-old stands, and for natural-origin old stands.

Marten

Capture rates of marten were low in the managed forest. Only 5 marten maintained home ranges in mechanically-harvested second-growth forests during the 4 years of study. These ranged in size from less than 1 km^2 to more than 20 km^2, for 1 adult female, 3 juvenile females, and 1 adult male, which was caught as a juvenile in 2003. Home ranges were occupied from 4 months to more than 3 years, with a mean occupancy of 1.16 years. The 2 animals that survived the longest had very large home ranges (by Ontario standards), of 17 and 23 km^2. In contrast, home range sizes in natural stands, about 20 km away, averaged less than 6 km^2 with a maximum of 11.8 km^2. The 2 smallest home ranges were of animals that were commercially trapped in the same fall as their live-capture, thereby truncating home range estimation.

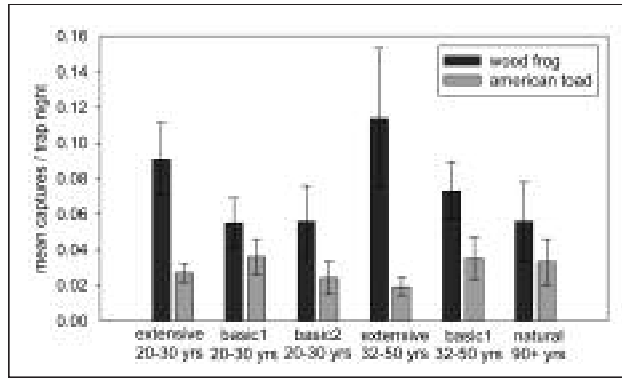

Fig. 1. Mean captures/trap night of American toads (*Bufo americanus*) and wood frogs (*Rana sylvatica*) in late summer-fall in forest stands of various harvested stand origins and in natural stands (N = 5–19 stands/treatment), near Kapuskasing, 2001 to 2002.

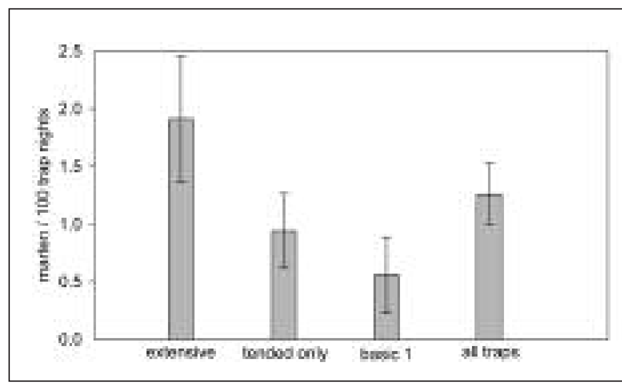

Fig. 2. Mean number of marten caught per 100 trapnights in forests regenerating following various post-harvest treatments, in a landscape where the forest age was approximately 35 to 45 years old, from 2003 to 2007.

Comparison of live-capture rates among the 3 stand treatments, for 38 different marten, suggested that there was no difference in marten occurrence (Fig. 2; $F = 1.64$, df 2, 12, $P = 0.23$). Based on 399 radio locations for 13 marten, for which we obtained more than 10 fixes, there was significantly greater use of basic 1 stands compared to either other treatment (Table 2, Lambda = 0.28, $P_{(randomized)} = 0.001$). Stands that were not treated were used similarly to stands that were only tended and in approximate proportion to their availability.

Discussion

Stand vegetation

Post-harvest silviculture clearly affected stand species composition and structures, reflecting degree of, and time, since treatment. Treatments following harvesting resulted in conifer-dominated stands, whereas stands that were untreated had regenerated as mixedwood stands with roughly equal numbers of conifers and deciduous trees. This result was consistent with those of Carleton and MacLellan (1994) and Carleton (2000), who also reported a high percentage of trembling aspen in young untreated boreal stands in the same general area, and with the results of several other studies in eastern boreal stands that showed increased conifer content

Table 2. Compositional analysis of stand use by 13 marten of 3 forest treatments following harvesting, near Kapuskasing, from 2003 to 3007. (Table reads across rows, i.e., basic 1 [+++] is significantly different from extensive and tended only.) Single symbols +/- indicate relative but not significant difference in use. The higher the number rank the more preferred is the treatment.

Treatment	Extensive (logged no silviculture)	Tended only	Basic 1 (planted, tended)	Rank
Extensive		+	—-	2
Tended only	-		—-	1
Basic 1	+++	+++		3

with intensity of post-harvest treatment (Prevost 1996, Bell and Newmaster 2002, Pitt and Bell 2005). In the young age class, we had expected responses relative to level of impact, ranging from untreated, through planted, to the more heavily treated stands that had also been scarified. Instead, we observed similarity among all treated stands for most variables, which was similar to results from other studies in boreal forests (Haeussler *et al.* 2002, 2004; Bell and Newmaster 2002). One purpose of scarification is to facilitate planting by reducing downed woody material and felling dangerous snags, and so we had expected volume of coarse woody material to differ between basic 1 and basic 2 stands. The lack of significant differences suggested that most snags and woody debris from more than 20 years ago had already decayed, reducing any original differences between the 2 stand types for this structure.

The proportion of conifer trees in the treated stands approximated that in the natural stands, considerably more than in stands that were left to undergo natural regeneration following harvesting. Differences in forest structures and species composition observed between the oldest treated and natural stands suggested that convergence is unlikely. Some differences were explained by the younger age of treated stands, including size and height of trees, size of snags, possibly snag density, and volume of large-diameter conifer coarse woody debris. Nevertheless, other differences clearly will persist over time in the managed stands and will continue to differentiate them from natural stands on similar sites, including a greater proportion of spruce trees and a lower proportion of trembling aspen and balsam fir than in natural stands. The very low density of white birch trees in herbicide-treated stands, especially in basic 2 stands, compared to untreated stands and natural stands suggests that there will a long-term reduction in the density of this species. Large snag density in natural stands was greater than in the oldest managed stands, consistent with models of forest development (e.g., Arseneault 2001). The majority of the largest snags in natural stands were trembling aspen (>50%) and the relatively low aspen density in treated managed stands indicates that there will be a lower eventual density of large aspen snags in managed stands than in natural stands when the former become mature to old. Tending of all stands with herbicides would also have reduced the differences between the 2 types, by reducing the numbers of white birch (Sullivan *et al.* 1996, Boateng *et al.* 2000, Bell and Newmaster 2002).

Amphibians

Limited information exists on the effects of forest management on amphibians and most studies have been concerned with changes to riparian habitat and woodland pools (e.g., Herrmann *et al.* 2005, Hannon *et al.* 2002, DiMauro and Hunter 2002). Near Kapuskasing, woodland pools are highly abundant and widespread and unlikely to be a limiting factor, prior to, or following harvesting. We found no long-term effects of timber harvesting or post-harvest silviculture on numbers of American toads 20 to 50 years after logging, suggesting that observed effects on species composition and stand structure were insufficient to affect this species. That American toads were common in these forests was in contrast to other studies suggesting that the toads prefer non-forest areas or deciduous stands (DeGraaf and Rudis 1990, Guerry and Hunter 2002, Gibbs *et al.* 2005). For wood frogs, we cannot relate the low numbers in young basic 1 and basic 2 stands, compared to most other stand types, to any of the variables that we measured. Waldick *et al.* (1999) also found that young conifer stands did not support high densities of wood frogs in New Brunswick and Patrick *et al.* (2006) reported that wood frogs in Maine preferred uncut old forests and partially cut forests. If the effect of low numbers in young treated stands was owing to high percent of conifer alone, then the older basic 1 and uncut stands should also have had similarly small numbers of wood frogs, but numbers were higher. Forest floor substrate is important to amphibians generally (deMaynadier and Hunter 1995) and moist substrates, such as deciduous leaves, is a factor implicated for wood frogs (Baldwin *et al.* 2006). We recorded our highest values in extensively managed stands that had the highest deciduous tree components, and it may be that young basic 1 and basic 2 stands were too dry for wood frogs until after 30 or more years when possibly the litter layer becomes deeper and mosses are better developed. Most studies have shown a reduction in amphibians immediately following harvesting and for at least 20 years (deMaynadier and Hunter 1995, Karraker and Welsh 2006), but no studies have looked at the long-term effects in boreal forests. Our results indicated different effects for 2 amphibian species, consistent with other studies that have suggested that generalizing amphibian responses to forest management is not possible (e.g., deMaynadier and Hunter 1995, Patrick *et al.* 2006).

Marten

Marten use of all forests aged 35 to 45 years post-harvesting, whether the stands treated with silviculture or left untreated, was very low in comparison to marten use of natural forests in the same area (J. Fryxell, I. Thompson, and J. Baker, unpublished data) and in new forests near Manitouwadge (Thompson and Colgan 1987), located about 250 km to the west. The densities in managed stands at Kapuskasing were similar to the low densities recorded in untreated managed forests of about the same age during the Manitouwadge study (Thompson and Colgan 1987).

The inconsistency between our live-trapping and radiolocation samples indicated some uncertainty in our results. We place greater emphasis on the latter result, however, as it provided a much more robust dataset that was not biased by attraction by bait to traps and was not affected by mostly transient animals in the live-capture sample, 86% of which moved away from the area or were caught by commercial trappers within 3 months. Further, the radio-location data were mostly from animals that, at least temporarily, lived in the landscape and would have been actively selecting habitats, including the 5 known resident marten.

The significant effect of planting and tending on stand use by marten suggested that post-harvest silviculture conferred some positive effect for marten living in managed forests, at least during the fall and winter, when most of our sample was derived. We have no information directly pertaining to comparative food levels, but there were similar levels of woody debris in all stands (Table 1). Therefore, perhaps food levels for marten may have been higher in planted and scarified stands than in the other treatments, possibly because higher conifer (spruce species) seed abundance resulted in more small mammals (e.g., Fryxell *et al.* 1998). Food has been implicated as a major factor in habitat selection by marten (Thompson and Colgan 1987, Poole and Graf 1996, Fuller and Harrison 2005).

Management and Conservation Implications

Our results suggested convergence of managed forests with fire-origin forests for some wildlife species but not for others. American toads appeared to be unaffected by changes in habitat structure and composition resulting from basic silviculture by 20 years post-harvest. Marten responded somewhat positively to "basic 1" treatments within the context of the managed portion of the landscape, suggesting that silviculture provided habitat attributes, notably a higher conifer content, favourable to marten (e.g., Thompson and Colgan 1987, Payer and Harrison 2003). Although marten used these more intensively managed stands, such evidence does not imply that marten populations can be sustained at high levels over the long term, if large areas of the boreal forest were managed intensively. Further, the results must be viewed in the context of better habitat quality provided by uncut older forests that maintains at least twice the density of marten (Thompson and Colgan 1987; I. Thompson, J. Fryxell, and J. Baker, unpublished data). Twelve of 13 marten in our sample were juveniles and all but 2 were harvested by trappers before reaching adulthood. These intensively managed stands are more accessible due to the road infrastructure than are uncut natural forests, and thus marten occupying these stands are highly vulnerable to mortality from commercial trapping (e.g., Thompson and Colgan 1987). In contrast to toads and marten, there was an apparent negative effect of post-harvest silviculture on wood frogs that lasted about 30 years, but which was absent in the older managed stands suggesting that convergence was occurring for wood frogs as the stands aged. We conclude that intensive silviculture, when viewed within a landscape mosaic of unmanaged, extensive, and intensively managed stands (see McPherson *et al.* 2008) can contribute to maintaining forest composition and future wood supply, while supplying habitat attributes for certain wildlife species, and that these effects can change with age of the stands.

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