

Effect of a large burn in the boreal forest on reproduction of American Kestrels and other birds

Russell D. Dawson and Gary R. Bortolotti

Abstract

Little is known about the proximate effects of forest fires on the reproductive ecology of birds in the boreal forest. Such information is important, especially given the interest in having anthropogenic sources of disturbance in the forest, such as logging, mimic natural processes. In 1995, a 73,220 ha forest fire on our study area gave us the opportunity to assess the effects of fire on reproduction of American Kestrels (*Falco sparverius*). We compared reproductive variables on control and burn areas both before and after the fire in a "before-after-control-impact" design. Nest box occupancy, laying date, clutch size, egg size, number of offspring fledged, and condition of young at fledging were not affected by the fire. These results are not unexpected, given that the main prey of kestrels, small mammals, were also not affected by the fire. We conclude that large scale changes in the landscape have little impact on kestrels, provided their prey base remains intact. In addition, we comment on conspicuous changes in the abundance of several other bird species after the fire.

Résumé

Peu de choses sont connues sur l'effet immédiat des feux de forêt sur l'écologie de reproduction des oiseaux de la forêt boréale. Des informations de ce type sont importantes surtout avec l'intérêt grandissant d'avoir des sources de perturbation anthropogéniques telles la coupe forestière qui ressembleraient de plus près aux processus naturels. En 1995, un feu de 73,220 ha sur notre aire d'étude nous a donné l'opportunité d'évaluer les effets du feu sur la reproduction de la Crécerelle d'Amérique (*Falco sparverius*). Nous avons comparé les paramètres de reproduction sur des parcelles contrôlées et des parcelles brûlées, avant et après feu, selon un protocole d'étude «avant-après-témoin- expérimental». Le degré d'occupation des nichoirs, la date de ponte, la taille de ponte, le nombre d'œufs, le nombre de jeunes à l'envol et leur condition à l'envol n'ont pas été affectés par le feu. Ces résultats ne sont pas surprenants, puisque les proies principales des crécerelles, les petits mammifères, n'ont pas été affectés par le feu. Nous concluons que les changements à grande échelle dans le paysage ont peu d'impacts sur les crécerelles, à condition que leur proies ne soient pas affectées. De plus, nous discutons plusieurs des changements importants dans l'abondance de plusieurs autres espèces d'oiseaux qui ont eu lieu suite au feu.

Russell D. Dawson and Gary R. Bortolotti, Department of Biology, University of Saskatchewan, 112 Science Place, Saskatoon, Saskatchewan, Canada S7N 5E2. (bortolotti@sask.usask.ca)

Introduction

Despite the fact that fire is the primary ecological factor responsible for renewal in the boreal forest, its effects on wildlife populations have received little study (see Erskine 1977; Kelsall et al. 1977; Fox 1983; Whelan 1995). Although ultimately the fate of boreal forest bird communities is linked to fire history, little is known of the proximate response of birds to the changes in habitat brought about from a forest fire. Some studies have focused on changes in avian community structure (e.g., Fox 1983; Spires and Bendell 1983; Shutler 1987), but fewer have been able to address in detail how reproductive parameters might be affected. It is difficult to generalize about the effects of fire on birds because of variation in habitats studied, specific characteristics of the burns, as well as differences in methodologies and validity of controls (see Huff et al. 1985; Shutler 1987).

The need for information on the ecology of forest fires goes beyond academic concern, as there is increasing interest in having anthropogenic sources of disturbance in the forest, such as logging, mimic natural processes and natural landscape-level patterns of age structure and species composition (e.g., Bondrup-Nielsen 1995). This is a viable objective only if logging does in fact mimic the effects of forest fires, as is so often assumed to be the case (e.g., Kelsall et al. 1977). Some studies of birds have even combined logged and burned areas in their analyses (Bendell 1974; Fox 1983). Several research programmes are currently addressing the question of how forest fragmentation by logging affects birds, yet there are few data to compare these studies to natural forces of forest fragmentation. Our long-term (9 years) study of American Kestrels (*Falco sparverius*) has provided us with an exceptional opportunity to quantitatively investigate how birds and small mammals respond to fires. In addition, given a long-term database (29 years) on the avifauna of our study area (Gerrard et al. 1996; and G.R. Bortolotti, pers. obs.), we are able to comment, at least anecdotally, on the responses of some other species.

Many studies of the effects of fire on bird populations have lacked adequate controls (Bendell 1974; Shutler 1987). Our approach is to employ multiple comparisons in both space and time. As is commonly done, we compare burned versus unburned "control" areas in the year following the fire. However, unlike most studies we are also able to compare these areas in the years prior to the fire to ensure that the control is representative. In addition, we are able to compare post-burn results to data collected over a

period of years prior to the fire on the burned site. Our statistical design therefore corresponds to a "before-after-control-impact" design (Stewart-Oaten et al. 1986; Wiens and Parker 1995), and provides a powerful perspective on potential effects of fire.

Materials and Methods

Study area

Birds have been studied in the vicinity of Besnard Lake, north-central Saskatchewan (55N, 106W) since 1968, and an intensive research programme on kestrels began in 1988. This area is at the transition of the Northern Coniferous and Mixedwood sections of the Boreal Forest Region (Rowe 1972) and corresponds with the southern edge of the Precambrian Shield. Much of the mature jack pine (*Pinus banksiana*) forest was clearcut from the mid-1970s to the mid-1980s, although some cutting of trembling aspen (*Populus tremuloides*) and white spruce (*Picea glauca*) continues today (Gerrard et al. 1996). Bortolotti (1994) and Gerrard et al. (1996) provide detailed descriptions of the physical and ecological attributes of the area. Our work has been focused on over 200 km of roads and logging trails accessible by truck (Figure 1).

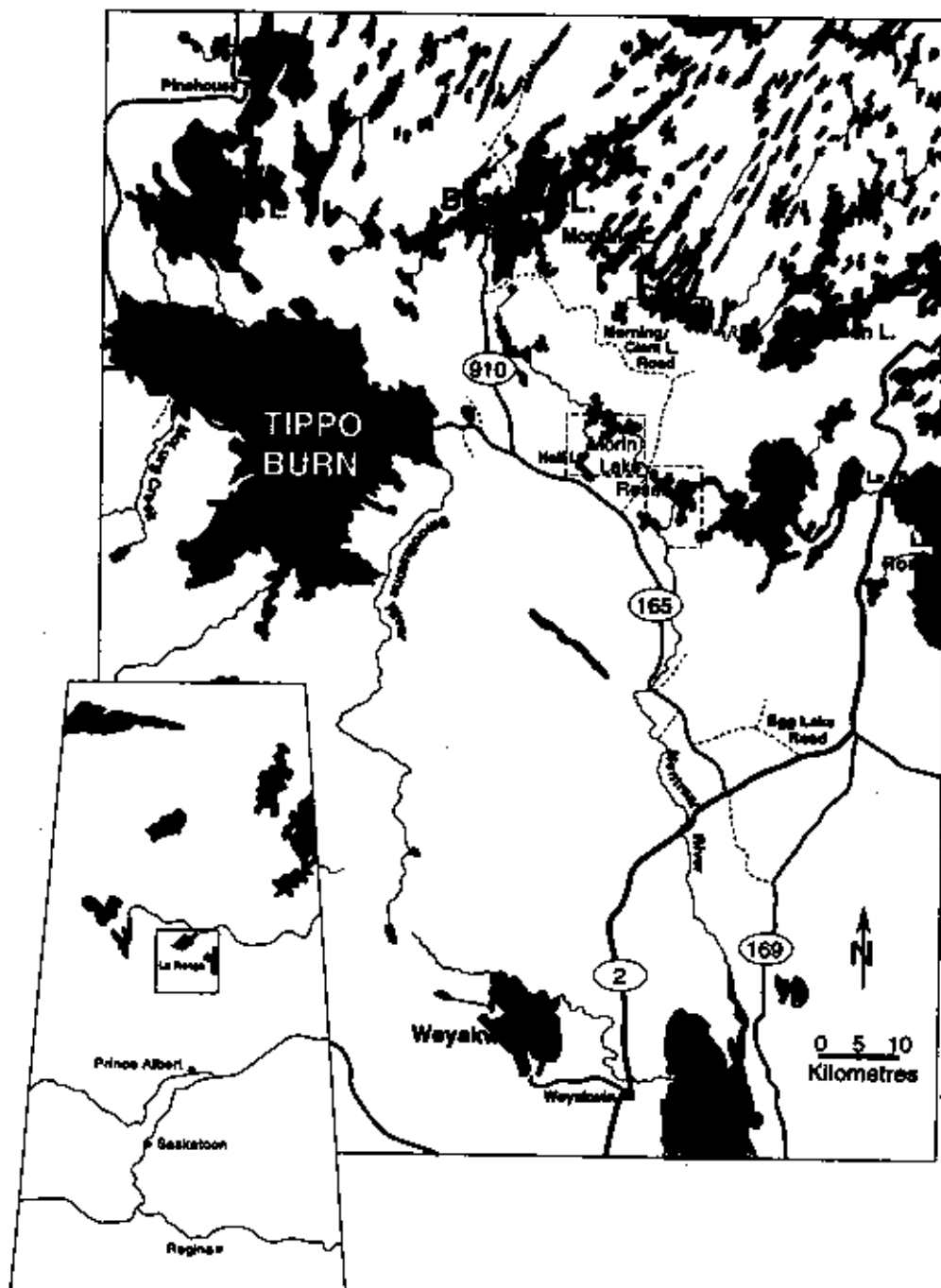
On 28 May 1995 lightning caused a fire in the westernmost portion of our study area. Despite considerable efforts by provincial forest fire-fighters, the "Tippo" fire burned continuously until it was extinguished by heavy rains on 10 July 1995. The total area of the burn was estimated to be 73,220 ha (Saskatchewan Forest Fire Management Branch, pers. comm.) (Figure 1). As is typical of fires in the boreal forest, some small patches remained partially unburned, but a considerable area was exposed to a hot fire and all trees were killed (but remained standing).

Bird studies

Kestrels have been studied in the area since 1988. Although cavities abound in the area, most kestrels choose to nest in boxes (Bortolotti 1994). All boxes in this study were of uniform size (23.1 x 20.3 cm at the base, a 7.5 cm diameter entrance hole) and constructed of 15 mm exterior-grade plywood (for details see Bortolotti 1994). They were nailed to trees about 4 m above ground in a variety of habitats from continuous forests to clearcuts (see Bortolotti 1994, Gerrard et al. 1996).

As there were only 20 boxes in 1988 in the area that eventually burned, we limit most of our analyses to 1989-1996. In the year of the fire, 1995, there were 64 kestrel nest boxes in the area that burned and 307 boxes outside of it. The fire destroyed 19 of the 64

Figure 1. Map of entire study area. Data were collected on areas accessible from Highways 165 and 910, and adjoining logging roads (dashed lines). Dark shading indicates area consumed by "Tippo" fire in 1995. Inset map shows general location of study area.



boxes and so, in 1996, we erected replacements in the same locale, usually the same tree. We chose to include all boxes outside of the burn as a "control", rather than *post hoc* assess what might be the area most similar for comparison. In the years prior to the fire the number of

boxes in each area varied somewhat. From 1991 to 1996, the burned area had 60-64 boxes, while the control had 285-307. In 1989, there were 34 and 235, and in 1990 there were 38 and 270 in burn and control areas, respectively.

Almost all nest boxes have complete data for occupancy, laying date (± 1 day) and clutch size given our rigorous schedule of checking nest boxes (e.g., see Bortolotti 1994; Dawson and Bortolotti 1997a). The few cases where data were imprecise have been deleted. Our data on egg size, nestling condition (see below) and brood size are from a subset of natural, unmanipulated nests because of limited availability or because there were experiments involving brood size.

Kestrels arrive on the study area in late-April and begin laying in mid-May. As the fire swept through the area during the incubation period, we were able to use the 1995 data on laying date and clutch size as the pre-fire period, and 1996 as the post-fire period. For analysis of egg size, brood size at fledging and nestling condition, we use 1994 as the pre-fire period.

For the analysis of egg size and nestling condition, it was inappropriate to treat individual measures as independent. Therefore, for egg size we used mean egg volume per clutch (see Wiebe and Bortolotti 1995). For an index of nestling condition, we used mass and tenth primary feather length of chicks measured when the first-hatched nestling of the brood was 24 days old (see Dawson and Bortolotti 1997b). We calculated means for mass and primary length of males and females separately for each nest. Subsequently, the sexes were analyzed separately rather than using sex as a factor, to avoid any one nest appearing repeatedly in any analysis.

We have also kept records on the distribution of other species of birds in the area for most of the summer months for 4 (RDD) and 16 (GRB) years. In addition to studies of kestrels, ornithologists have been working near-continuously in the area since 1968 and have provided an unusually thorough annotated list of the birds of the region (see Gerrard et al. 1996); however, we believe that we could detect only dramatic changes with reasonable certainty.

Small mammal populations

As part of our work on kestrels, small mammals were snap-trapped each year since the project's inception to quantify prey abundance. Each trap line coincided with a kestrel territory. Our largest sample of lines for the pre-fire years was 1994, when 10 lines were trapped in the burn and 79 lines outside of the burn. In the post-fire year, 1996, we trapped at 20 lines in the burn and 34 outside of it. Each line was situated parallel to, and 10 m from, a road. At each line there were 10 stations spaced 30 m apart. At each station there were 2 snap traps baited with peanut butter. The traps were open for 3 consecutive days and any that

were triggered were reset each morning. At stations where both traps had been sprung, it was assumed that the traps were available for only half the time and so a corrected number of available traps was used. We present data on the mean number of all species of small mammals per 100 traps sampled in early July each year. We repeated the statistical analyses using only voles (almost all were red-backed voles *Clethrionomys gapperi*), but the results were the same so we present data only on total small mammals. Although this index would seem to be a coarse measure of food availability, it correlates well with kestrel reproduction (e.g., Bortolotti et al. 1991; Wiebe and Bortolotti 1992, 1994, 1995). Many predatory birds are dependent on small mammals and so these data are likely also relevant to predicting the response of other similar species of birds to fires.

Results

American Kestrels

Prior to the fire in 1995, 31 of 64 (48.4%) boxes were occupied on the burn and 117 of 307 (38.4%) were used on the control area. Occupancy after the fire in 1996 was 27 of 60 (45.0%) in the burn versus 115 of 297 (39.4%) in the control area. We used logistic regression with box occupancy as a binary dependent variable, and year and area as categorical explanatory variables. Occupancy of nest boxes was not different between years ($\chi^2 = 0.08$, $df = 1$, $p = 0.78$), but the burn area had marginally higher occupancy than the control area ($\chi^2 = 2.93$, $df = 1$, $p = 0.087$; Figure 2). There was no interaction between year and area ($\chi^2 = 0.17$, $df = 1$, $p = 0.68$), suggesting the fire had little impact on nest box occupancy.

Figure 2. Nest box occupancy by American Kestrels in north-central Saskatchewan in burn and control areas. Arrow denotes onset of the fire.

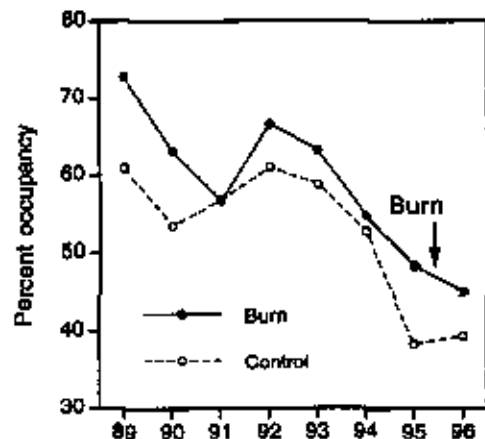


Table 1. Reproductive parameters of American Kestrels breeding before (1994, 1995) and after (1996) the "Tippo" forest fire of 1995. Mean egg size was calculated using means of eggs in each nest.

Variable	Year	AREA					
		Burn			Control		
		Mean	S.D.	N	Mean	S.D.	N
Clutch size	1995	4.8	0.71	19	4.9	0.40	102
	1996	4.6	0.58	25	4.6	0.59	101
Laying date	1995	141.4	7.69	24	141.2	5.71	106
	1996	145.8	7.93	23	146.0	8.35	107
Egg volume (cm ³)	1994	14.1	0.80	10	13.8	1.46	73
	1996	13.7	0.84	19	13.8	1.17	76
Brood size	1994	3.5	1.61	13	3.2	1.23	33
	1996	3.9	1.24	25	3.7	0.95	49

There was remarkable similarity between burn and control areas in all reproductive parameters that we measured both before and after the fire (Table 1). For laying date, a 2-way analysis of variance (ANOVA) of year (1995 versus 1996 corresponding to pre- and post-burn, respectively) and area (burn and control) showed a highly significant year effect ($F_{[1,255]} = 14.88$, $p < 0.001$). If the burn caused any effect on laying date, we predicted that there would be a significant interaction between year and area, but there was none ($F_{[1,255]} = 0.02$, $p = 0.88$). There was also no significant effect of area, suggesting that the control was representative ($F_{[1,255]} = 0.001$, $p = 0.98$).

Clutch size showed a pattern of variation similar to laying date. Mean clutch sizes were nearly identical for burn and control areas (Table 1). Most kestrels laid either 4 or 5 eggs, but we could not detect any difference in clutch size between the burn and control areas ($F_{[1,243]} = 0.02$, $p = 0.88$). The pre- versus post-fire comparison suggests a change in clutch size occurred between years ($F_{[1,243]} = 7.86$, $p = 0.005$), but this is clearly annual variation independent of area because the interaction between year and area was not significant ($F_{[1,243]} = 0.45$, $p = 0.50$; Table 1).

To examine the response of egg size to the burn we first investigated other potential sources of variation such as laying date and clutch size. We limited our analyses to the most common clutch sizes of 4 and 5 eggs. Only clutch size proved to be significant (see also Wiebe and Bortolotti 1995). We then performed a 3-way ANOVA including clutch size (4 and 5), year (1994 versus 1996, corresponding to

pre- and post-burn, respectively), and area (burn and control). Clutch size did not contribute to the model and so was dropped. The subsequent 2-way ANOVA of the potential effects of year and area showed no significant effects (area: $F_{[1,174]} = 0.11$, $p = 0.74$, year: $F_{[1,174]} = 0.57$, $p = 0.45$, area \times year: $F_{[1,174]} = 0.98$, $p = 0.32$).

Brood size at fledging was similar between the burn and control areas (Table 1; $F_{[1,116]} = 0.87$, $p = 0.35$), but there was a trend for brood size to be larger in 1996 than in 1994 ($F_{[1,116]} = 2.99$, $p = 0.09$). The year by area interaction was not significant ($F_{[1,116]} = 0.001$, $p = 0.99$).

There are several variables that may influence nestling condition. We therefore used an ANOVA model that incorporated not only area and year, but also hatching date and brood size as potential factors. The most important result would be an interaction between year (pre- versus post-burn) and area, but for neither males nor females was there any result approaching significance (all $p > 0.12$) for mass or tenth primary length. Similarly, area was always nonsignificant ($p > 0.60$) (see Table 2).

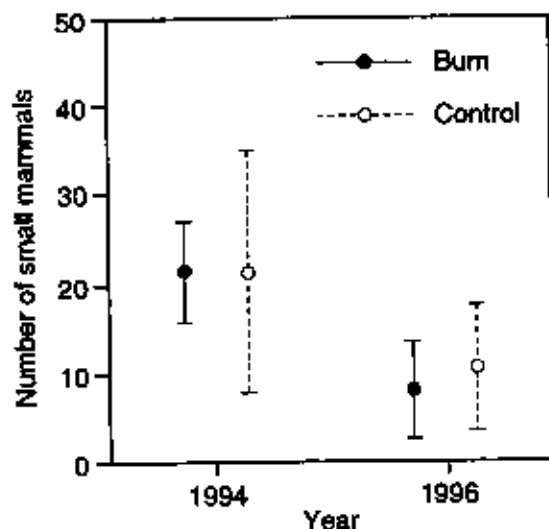
Small Mammals

Similar to our results for kestrel reproduction, the number of small mammals did not appear to be affected by the burn (Figure 3). A 2-way ANOVA with year (1994 and 1996) and area as factors showed significant differences between years in the number of small mammals ($F_{[1,139]} = 25.70$, $p < 0.0001$); however, no area effects could be detected ($F_{[1,139]} = 0.21$, $p =$

Table 2. Mean weight (g) and tenth primary length (mm) \pm SD of male and female American Kestrels at 24-days old (minimum fledging age) from north-central Saskatchewan. 1994 represents the pre-burn year while 1996 is the post-burn year. Sample sizes refer to number of nests.

Variable	AREA											
	Burn						Control					
	1994			1996			1994			1996		
Mean	S.D.	N	Mean	S.D.	N	Mean	S.D.	N	Mean	S.D.	N	
Male weight	109	7.9	7	111	8.8	17	114	9	11	113	6.6	9
Female weight	119	5.3	7	121	11	17	123	8.6	10	123	8.4	9
Male 10 th primary	52.4	8.7	7	60.9	4.9	17	59	8.6	11	59	6.3	9
Female 10 th primary	56.3	4.1	7	62.3	5.6	17	60.4	9.8	10	62.5	6.3	9

Figure 3. Number of small mammals per 100 trap nights on kestrel territories before (1994) and after (1996) the 1995 forest fire. Error bars represent ± 1 standard deviation.



0.65), nor was there an interaction between area and year ($F_{1,139} = 0.40$, $p = 0.53$).

Other birds

We did not systematically survey birds in the burn, but three species showed an apparent positive response to the burn. Northern Hawk-owls (*Surnia ulula*) were seen only 7 times in 27 years in the entire study area (Gerrard et al. 1996) prior to the fire. In both 1996 and

1997, it was possible to observe hawk-owls in the burn almost daily. In 1996, one bird was captured there with a bal-chatri trap (Berger and Mueller 1959); this bird possessed a brood patch, so it is reasonable to assume it was breeding. In 1997, two hawk-owls were captured in the same area.

Two species of passerines bred for the first time in our nest boxes in the year after the burn. In 1996, Tree Swallows (*Tachycineta bicolor*) laid eggs in 3 (5%) of the 60 kestrel boxes available in the burn that year. Two other partial nests were built that we attributed to Tree Swallows. Similarly, House Wrens (*Troglodytes aedon*) also laid in 3 (5%) boxes as well. None of the 297 control boxes in 1996, or any of the 2,541 previous years' boxes (summed 1988-1995) had ever been used by these two species.

Discussion

The continued presence of kestrels after the fire was not unexpected, as they are an adaptable species and occur over a wide range of habitat types in our study area (from lakeshores with continuous mature forest, to muskeg, to clearcuts and road allowances) and across their North American range (forests, farmland, deserts). That there was no change in box occupancy rate or any other reproductive parameter was, however, surprising. Results for the burn and control areas were remarkably similar (Table 1). The few minor differences pre- and post-burn were clearly annual effects independent of area. So, despite a major change in the habitat, kestrels did not respond.

This lack of response may be less surprising when one considers the data on prey populations. Several reproductive parameters of American Kestrels in our area, including egg size (Wiebe and Bortolotti 1995) and nestling condition (e.g., Bortolotti et al. 1991; Wiebe and Bortolotti 1992), but not box occupancy rate (G.R. Bortolotti, unpubl. data), correlate with food supply. There did not appear to be any response of small mammals to the burn (Figure 3). Although the literature reports variable responses for small mammals, many studies show no effect of fire consistent with our results (see Bendell 1974; Kelsall et al. 1977; Whelan 1995). Even if population size of small mammals did not change, one would expect availability of prey to hunting kestrels to be greatly enhanced given the lack of post-fire cover. If such occurred, it did not translate into enhanced reproduction for the kestrels. We do not know what happened to populations of other common prey of kestrels such as frogs and dragonflies. However, whatever changes may have occurred in prey abundance or availability, kestrels appeared to have adapted well as they fledged the same number and quality of offspring on and off the burn (Tables 1 and 2). Little information on other raptors is available for comparison, but Yensen et al. (1992) reported that fires appear to have a negative effect on raptors of the Snake River Birds of Prey Area, Idaho, by creating an unstable prey base.

We do not have data on how large-scale logging might be comparable to the burn, but we suspect that results would differ. Although kestrels are abundant in the clearcuts we were working in, logging occurred 10 to 20 years ago in most of the area. The few kestrel territories where small-scale (<200 ha) logging has occurred have been abandoned immediately afterward, and generally we do not see kestrels in such areas for a few years after cutting. Again this may be expected if small mammal numbers are lower on recent clearcuts. As with fires, the effect of clearcutting is likely variable and site-dependent. Jones (1978) studied small mammal populations in the boreal mixedwood forest of Saskatchewan approximately 125 km south of our area. He found that populations of red-backed voles (by far the kestrels' main prey; G.R. Bortolotti, pers. obs.) were lower in the year following harvest on the clearcut compared to the uncut adjacent forest. The same was true in clearcut jack pine stands in Manitoba (Simms and Buckner 1973). On the burn site, there was an immediate and lush regeneration of herbaceous growth. In contrast, it seems to take much longer for most cutovers we have seen to regenerate, and there is

always a proportion of the land that has little vegetation on it for years to come (e.g., landings, slash piles, compacted soil).

Other attributes of clearcuts are likely to make them even more inhospitable to kestrels than the depression in prey numbers. Current logging practices typically involve the complete removal of all trees. Previously in our area, only softwoods were removed and so clumps of aspen were left behind, thus providing hunting perches and potential nest sites. The standing timber left by fire has the same benefits.

It seems reasonable that the positive responses by Northern Hawk-owls, Tree Swallows and House Wrens were the result of fire and not merely the opening of the habitat as would be created by logging. While Tree Swallows have been reasonably common breeding birds in our study area, they never used our kestrel boxes except in the burn. In 1994, we erected 21 small nest boxes in clearcuts specifically for swallows. Only one of these appears to have been used that year (Gerrard et al. 1996), and 6 of these monitored in both 1995 and 1996 remained unused. Because we observed swallows in the area of these boxes we assume cavities were likely not limiting reproduction. It is unlikely that fewer absolute number of cavities existed in the burn after the fire, as most trees remained standing after being killed. However, the swallow population may have increased, resulting in a relative shortage of nest sites. The burn therefore may have been an attractive habitat for swallows. Smith (1996) includes "burnt lands" as the nesting habitat for tree swallows in Saskatchewan.

Both Northern Hawk-owls and House Wrens seemed to be absent as breeders in the area until after the fire. There were no records of House Wrens in the entire study area between 1968 and 1995 (Gerrard et al. 1996, and G.R. Bortolotti, pers. obs.); however, they have been seen in Beauval, approximately 60 km by air from our burn (Gerrard et al. 1996). There are three breeding records of Northern Hawk-owls in Saskatchewan, but they are believed to prefer burns and open bogs for nesting and foraging (Smith 1996). The breeding records of House Wrens reported here are more northern than any summarized in Smith (1996). Apparently, wrens in the boreal forest favour regenerating burns or other dry brushy sites (Smith 1996). While this species certainly responded to the burn in our area, they appear to be absent from brushy areas.

Although intuitively one expects bird populations to respond to major habitat alterations, such was not the case for American Kestrels. In contrast, it appears

that other species, like Northern Hawk-owls, House Wrens, and perhaps Tree Swallows, did respond positively to the fire. Clearly, generalizations must be made with caution and a clear statement of which species are evaluated. Our suggestion that logging and forest fires do not have comparable impacts on birds warrants further study, especially given the current interest in having anthropogenic sources of disturbance in the forest mimic natural processes.

Acknowledgements

The authors couldn't care less whose name went first on this paper as our contributions were equal. We are grateful to many people who helped us collect data, especially Jeff Ball, Carla Fehr, Miranda Hart, Mike Miller, Suzanne Tomassi and Jennifer Willson. We thank two anonymous referees whose comments improved the manuscript. Funding was provided by the Natural Sciences and Engineering Research Council of Canada in a grant to GRB and a scholarship to RDD. The Northern Scientific Training Programme, Canadian Wildlife Federation and University of Saskatchewan provided additional funding to RDD. The Forest Fire Management Branch of Saskatchewan kindly provided information on the fire.

References

- Bendell, J.F. 1974. Effects of fire on birds and mammals. Pages 73-138 in *Fire and ecosystems* (T.T. Kozlowski and C.E. Ahlgren, eds.). Academic Press, New York.
- Berger, D.D. and H.C. Mueller. 1959. The bal-chatri: a trap for the birds of prey. *Bird-banding* 30: 18-26.
- Bondrup-Nielsen, S. 1995. Forestry and the boreal forest: maintaining inherent landscape patterns. *Water, Air and Soil Pollution* 82: 71-76.
- Bortolotti, G.R. 1994. Effect of nest-box size on nest-site preference and reproduction in American Kestrels. *Journal of Raptor Research* 28: 127-133.
- Bortolotti, G.R., K.L. Wiebe and W.M. Iko. 1991. Cannibalism of nestling American Kestrels by their parents and siblings. *Canadian Journal of Zoology* 69: 1447-1453.
- Dawson, R.D. and G.R. Bortolotti. 1997a. Total plasma protein level as an indicator of condition in wild American Kestrels (*Falco sparverius*). *Canadian Journal of Zoology* 75: 680-686.
- Dawson, R.D. and G.R. Bortolotti. 1997b. Variation in hematocrit and total plasma proteins of nestling American Kestrels (*Falco sparverius*) in the wild. *Comparative Biochemistry and Physiology* 117A: 383-390.
- Erskine, A.J. 1977. Birds in boreal Canada: communities, densities and adaptations. Canadian Wildlife Service Wildlife Report No. 41, Ottawa, Ontario.
- Fox, J.F. 1983. Post-fire succession of small-mammal and bird communities. Pages 155-180 in *The role of fire in northern circumpolar ecosystems* (R.W. Wein and D.A. MacLean, eds.). John Wiley and Sons, New York.
- Gerrard, J.M., G.R. Bortolotti and K.L. Wiebe. 1996. Birds of the Besnard Lake area north-central Saskatchewan, 1968-1994. *Nature Saskatchewan*, Regina, Saskatchewan.
- Huff, M.H., J.K. Agee and D.A. Manuwal. 1985. Postfire succession of avifauna in the Olympic Mountains, Washington. Pages 8-15 in *Fire's effects on wildlife habitat* (J.F. Lotan and J.K. Brown, eds.). U.S. Department of Agriculture, Forest Service, General Technical Report Int-186. Ogden, Utah.
- Jones, G.R. 1978. The influence of clearcutting on small mammal populations in the southern boreal forest of Saskatchewan. Unpublished M.Sc. thesis, University of Saskatchewan, Saskatoon, Saskatchewan.
- Kelsall, J.P., E.S. Telfer and T.D. Wright. 1977. The effects of fire on the ecology of the boreal forest, with particular reference to the Canadian north: a review and selected bibliography. Canadian Wildlife Service Occasional Paper No. 32, Ottawa, Ontario.
- Rowe, J.S. 1972. Forest regions of Canada. Canadian Forest Service Publication No. 1300, Ottawa, Ontario.
- Shutler, D. 1987. Post-fire bird communities and vegetation complexity. Unpublished M.Sc. thesis, McGill University, Montreal, Québec.
- Simms, H.P. and C.H. Buckner. 1973. The effect of clearcutting and burning of *Pinus banksiana* forests on the populations of small mammals in southeastern Manitoba. *American Midland Naturalist* 90: 228-231.
- Smith, A.R. 1996. Atlas of Saskatchewan birds. Environment Canada and Nature Saskatchewan, Regina, Saskatchewan.
- Spires, S. and J.F. Bendell. 1983. Early postfire effects on some invertebrates, small mammals and birds in north-central Ontario. Pages 308-318 in *Resources and dynamics of the boreal zone* (R.W. Wein, R.R. Riewe and I.R. Methven, eds.). Association of Canadian Universities For Northern Studies, Ottawa, Ontario.

- Stewart-Oaten, A., W.H. Murdoch and K.R. Parker. 1986. Environmental impact assessment: "pseudoreplication" in time? *Ecology* 67: 929-940.
- Whelan, R.J. 1995. *The ecology of fire*. Cambridge University Press, Cambridge, England.
- Wiebe, K.L. and G.R. Bortolotti. 1992. Facultative sex ratio manipulation in American Kestrels. *Behavioural Ecology and Sociobiology* 30: 379-386.
- Wiebe, K.L. and G.R. Bortolotti. 1994. Food supply and hatching spans of birds: energy constraints or facultative manipulation? *Ecology* 75: 813-823.
- Wiebe, K.L. and G.R. Bortolotti. 1995. Egg size and clutch size in the reproductive investment of American Kestrels. *Journal of Zoology (London)* 237: 285-301.
- Wiens, J.A. and K.R. Parker. 1995. Analyzing the effects of accidental environmental impacts: approaches and assumptions. *Ecological Applications* 5: 1069-1083.
- Yensen, E., D.L. Quinney, K. Johnson, K. Timmerman and K. Steenhof. 1992. Fire, vegetational changes, and population fluctuations of Townsend's ground squirrels. *American Midland Naturalist* 128: 299-312.