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Marten Use of Logging Debris Piles in Clearcuts

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Abstract

Extensive clearcutting in the dry interior of southern British Columbia has caused concern for marten that depend on forested habitats. Retention of woody debris piles after clearcutting was examined as a method to at least partially mitigate habitat loss from clearcutting by providing either resting or hunting areas within clearcuts. During the winters of 1991-1994, I examined marten winter use of clearcuts up to 5 years after timber harvest both with and without woody debris piles comparing types of piles (long windrows or spot piles) as well as comparing cutblock use to surrounding forest use. I used an index of relative marten use of clearcuts and forests from snow-track transects, and tabulated the use of debris piles within cutblocks by following marten trails. Marten use of recent clearcuts without debris piles was very low, averaging 2.8% of the use in adjacent forests, which was only increased to 11% by retaining windrow piles. Marten regularly used windrow piles for foraging, especially when close to forest edges with 72% of the

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106 marten trails followed within cutblocks using these piles. Cutblock distances of 400 m were only regularly crossed by marten using windrow piles but, even at best, were less effective than forested corridors. In one cutblock, a 520-m long forested corridor 100-250 m wide was removed after the first winter of the study and replaced by a series of windrow piles with marten use dropping by 74%. Spot piles at any density were not used except where the distance across a clearcut was <135 m or the spot piles were adjacent to riparian stream corridors with understory retention. Retention of logging debris piles in cutblocks can be used particularly in conjunction with forest corridors or partial retention corridors to maintain some marten winter connectivity across cutblocks.

Keywords: clearcutting, debris piles, marten, woody debris

Introduction

Marten are of particular interest in British Columbia (B.C.) for three reasons: first, they are found throughout the province, whether that be American Marten (*Martes americana*) or Pacific Marten (*M. caurina*); second, they have ranked first in economic value of furbearers (Hatler et al., 2003; Stordeur, 1986); and finally, they have been used as an indicator species for the general health of the old growth forest vertebrate community since they both use and require large tree cavities for denning (Stordeur, 1986; Thompson, 1988).

Marten, including possibly both Pacific Marten, American Marten, and hybrids (Colella et al., 2024), are relatively common throughout the upland forests of the southern interior of British Columbia. In those upland forests, clearcutting has become the major agent of forest renewal, replacing previous large wildfires. However, clearcutting and wildfire do not create similar forest habitat for marten as the forests regenerate. In burns, many of the fire-killed conifers fall within 20 years, creating many access points for marten to their subnivean prey, e.g., in the Vermilion Pass burn in Kootenay National Park (Poll et al. 1984). Clearcuts less than 25 years old and wider than 250 m are only rarely used by marten (Snyder & Bissonette, 1987). Even after 40 years, regenerating clearcuts are generally not considered suitable marten habitat because the lack of downed woody debris (Andruskiw et al., 2008)

in such areas results in a decrease in overall marten densities (Soutiere, 1979; Steventon & Major, 1982; Thompson, 1988). Loss of habitat due to clearcutting has been raised as an issue for marten populations throughout the species' range (e.g., Thompson, 1991, 1994).

If all trees are removed in clearcutting and any logging debris burned, then marten may not return to a site until regenerating trees reach an age when they start self-thinning and falling (Lofroth & Steventon, 1990). While this may start about 80 years into regeneration for lodgepole pine (*Pinus contorta*) forests (Gyug, 2000), the accumulation of woody debris does not match the amount of down material after a fire until the stand is >200 years old. That is well beyond the typical rotation age of lodgepole pine forests of 80-100 years, at which time the stand would likely be clearcut again. Clearcutting is therefore likely to cause a severe long-term reduction in woody debris and a long-term habitat loss for marten.

In the dry southern interior of B.C., local concerns were raised by trappers by 1991 because of extensive clearcutting to attempt to either control Mountain Pine Beetle (*Dendroctonus ponderosae*) infestations of lodgepole pine or to salvage stands with extensive beetle-killed trees (B. Harris, pers. comm. 1991 to L. Gyug). Those concerns led to the work described in this paper and the exploration of possible measures to mitigate the effects of clearcutting on marten habitat. In particular, marten have been found to den in logging debris piles (Bull & Heater, 2000; Raphael & Jones, 1997) including woody debris piles at the edges of clearcuts even when they did not generally use the recent clearcuts (Steventon & Major, 1982). Retention of woody debris piles in clearcuts may, therefore, be immediately beneficial to marten populations. This can be as resting or denning sites (Wilk & Raphael, 2018), as foraging sites for small mammal prey (Sullivan et al., 2017, 2021; Sullivan & Sullivan, 2023), or as paths to cross clearcuts (Seip et al., 2018).

While the project described here was conducted from 1991-1994, since that time, the problem has remained relevant. Other authors have continued to investigate methods to mitigate the effect of extensive clearcutting in general (e.g., Payer & Harrison, 2003) or due to Mountain Pine Beetle infestations marten in B.C. in particular. For example, Proulx (2009) identified forest habitats that should be prioritized for conservation rather than clearcutting. Steventon and Daust (2009) modelled effects of various timber harvesting scenarios on marten populations. They based connectivity on their habitat quality rating and dispersal rates at a landscape-level based on genetic isolation (e.g., Broquet et al., 2006). Studies have looked at landscape-level connectivity

at multiple scales related to clearcutting (e.g., Cushman et al., 2011; Planckaert & Desrochers, 2012), and at dispersal risk in relation to clearcuts (Johnson et al., 2009). More specifically, others have continued to examine woody debris piles as possible mitigation of the effects of clearcutting on marten (e.g., Sullivan et al., 2017, 2021; Seip et al., 2018; Wilk & Raphael, 2018; Sullivan & Sullivan, 2023).

I used snow-tracking up to five years post-harvest to assess whether retaining woody debris piles in clearcuts could, at least partially, mitigate the loss of forest habitat for marten in the southern interior of B.C. The first question of interest was whether marten relative use (the track index) differed between surrounding forests and cutblocks with or without retained woody debris spot piles and windrow piles. The second question was whether the amount of pile retention affected marten use within cutblocks. The third question was how marten used the various retained structural elements within the cutblocks, e.g., retained mature or understory trees in upland areas or along streams in addition to woody debris piles, by following marten trails within the cutblocks and tabulating the piles or other elements encountered in cutblocks.

Methods and Materials

Study area

The study area was in the southern interior of B.C. (Figure 1) across an area of about 20,000 km^2. Within the study area, study sites were chosen between 1300 m and 1650 m elevation in areas where marten were either previously known to be common (Gyug, unpublished data) or likely to be common in the Montane Spruce (MS), Engelmann Spruce-Subalpine Fir (ESSF) and Interior Cedar-Hemlock (ICH) Biogeoclimatic Zones (Pojar et al., 1987). These higher elevation plateaus and foothills in the southern interior of B.C. are dissected by low elevation dry valleys in which marten only rarely occur (Gyug, personal observations). This marten distribution is different from that in the Cascade Mountains to the west (Gyug, unpublished data) and in the Columbia Mountains to the east (e.g., Van Tighem & Gyug, 1984; Mowat, 2006) where marten are relatively common from valley bottoms up to subalpine parkland.

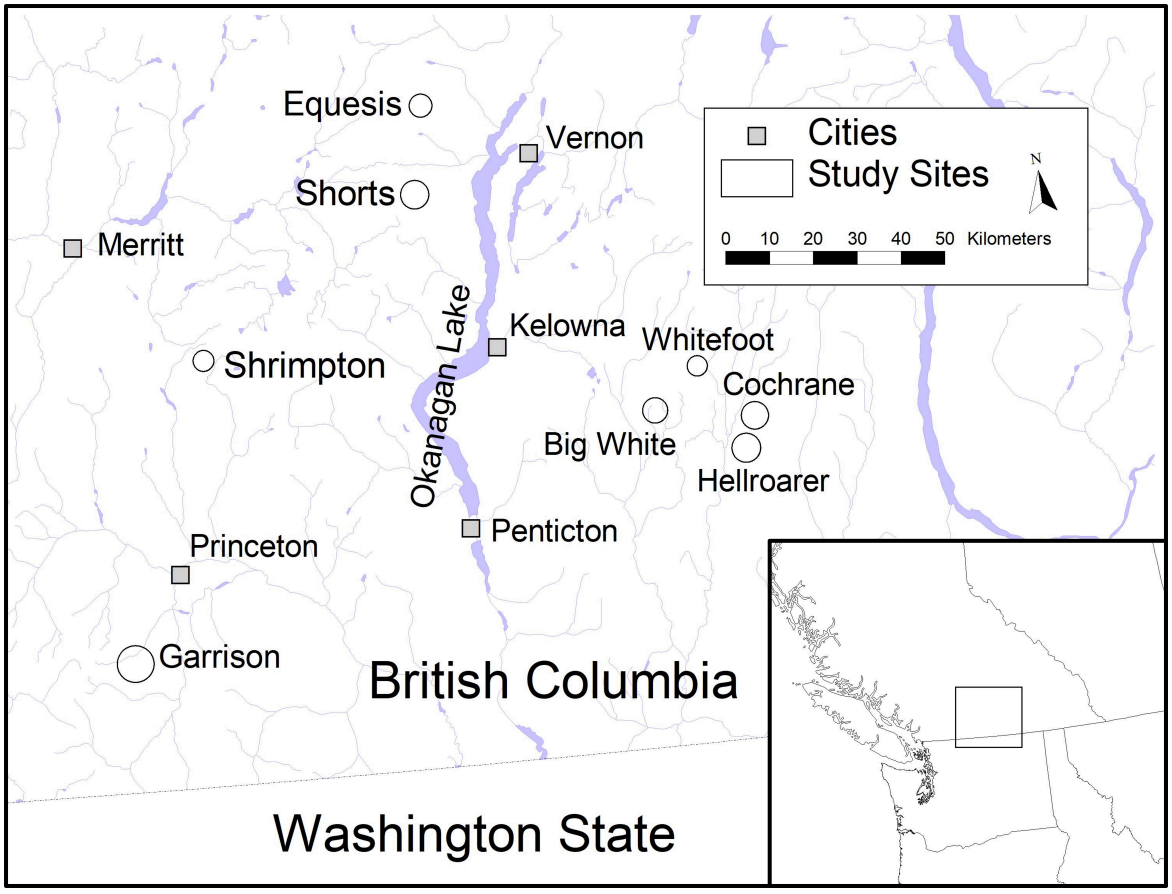


Figure 1. *The study area in the interior of southern British Columbia showing sites with groups of cutblocks, with inset map showing general location of study area.*

Lodgepole pine predominates in young upland stands in the MS zone which generally proceed to an Engelmann spruce and subalpine fir climax after about 250 years in the absence of fire (Gyug, 2000). Spruce and subalpine fir are common at all stages of regeneration in the ESSF. The particular areas and elevations of the ICH zone within the study area were very similar ecologically to the MS zone, i.e., were dominated by successional lodgepole pine, but also contained some western larch in upland areas, and western redcedar in wetter sites.

Post hoc, the study area was divided into two regions, one west of Okanagan Lake and one east of Okanagan Lake. This was based on the relative marten abundance found during the study in forests in each region based on the snow track indices, but mainly on the different marten use of cutblocks in the two areas, i.e., no use at all west of

Okanagan Lake. This changed the study design to an examination of marten use of piles in cutblocks only east of Okanagan Lake

At the time of this study (1991-1994), American Marten was considered one species (*Martes americana*) but the Pacific Marten (*M. caurina*) was split from American Marten in 2017 (Dawson et al., 2017). American Marten is found in the Columbia Mountains east of the study area (Lucid et al., 2020), while both American and Pacific marten, or even potential hybrids, may be found in the Cascade Mountains west of the study area (Colella et al., 2018). East of Okanagan Lake, which was the only region where I found marten using cutblocks, the species is almost certainly American Marten, however, without knowing exactly where the fracture, or potential hybrid, zone is between the two species, I refer to marten generically throughout this paper.

Field methods

I used marten track crossing frequency of snow-track transects as the basic measure of marten habitat use, which is also a measure of relative abundance. Snow tracking has been used in many other marten studies (e.g., Thompson et al., 1989; Mowat, 2006; Proulx, 2009). Where snowmobile travel was unlimited by topography or other features in a stand that had been clearcut, i.e., in a cutblock, a transect 50m from adjacent forest was used as the track transect with an additional transect across the center of the cutblock, as long as the center transect was at least 150m from the outer transects. Where there were debris piles near a cutblock edge, I always placed transects between the forest and the piles to detect any marten use of the piles. This method allowed almost all marten trails within cutblocks to be found with the exception of trails that travelled only a few meters into a cutblock and did not contact any debris piles. After preliminary tracking in one cutblock in the winter of 1991-92, tracking of all cutblocks commenced in early December and ended by mid-February of the winters of 1992-93 and 1993-94. To assess marten use of surrounding forests, transects were travelled by snowmobile on snow-bound forestry roads at each of the sites.

For marten, the track index for each cutblock was expressed as tracks/km-day, which was the number of tracks crossing the transect divided by the product of transect length and total accumulated days since snowfall (estimated to the nearest 0.5 day). The target sampling level was 15 tracking days for each cutblock in each winter of 1992-93 and of 1993-94, which took between 1 and 4 visits each winter to each cutblock. This target was chosen because it would be expected to yield non-zero marten track densities in low-quality habitat or in areas of low

marten densities where the expected value would be around 0.20 tracks/km-day (Gyug and Van Tighem 1984, Gyug unpublished data).

I followed individual marten trails whenever tracks were seen in cutblocks, even if those tracks did not cross the particular transect in the cutblock. All trails were followed to where the trail both entered and exited the cutblock. Behaviour was recorded as hunting (investigating holes in snow or meandering), or traveling (straight-line travel). Total distance travelled in the cutblock, maximum distance from the surrounding forest, and all major structural elements encountered were recorded. These elements within clearcuts were later grouped into the following categories: 1) woody debris piles that were the focus of this study, 2) dense cover retained after clearcutting consisting of approximately 1000 understory stems/ha or >200 stems >10m tall/ha, 3) sparse cover that included retained mature trees at densities of <5/ha, undersized non-merchantable trees at densities of <50/ha, mechanically created 3-m tall stubs at densities of <10/ha, or open parts of a cutblock with no trees retained, and 4) riparian zones along streams where a no-machine buffer zone had been established typically 5-m to each side of stream bank with either sparse or dense cover retained as above.

Marten trails were considered to be crossing cutblocks in two instances: firstly, when there were no forest connections between the forest stands the marten left and then traveled to, and secondly, when marten crossed a portion of a cutblock, but the distance the marten would have had to travel in continuous forest to reach from the entrance point to the exit point was at least 5 times greater than the distance travelled across the cutblock. Other marten trails within cutblocks were interpreted only as forays into the cutblock, rather than crossings.

Woody debris piles

Retained woody debris piles were either spot piles or windrow piles. Spot piles were either made at landings from tree tops, limbs and defective stems, or by “rough-bunching” woody debris with an excavator over the entire cutblock after timber harvest. A spot pile is a single pile, often broadly conical in shape. Rough-bunched piles and landing piles were sometimes long and narrow rather than circular in footprint, but these were very minor in occurrence and were grouped in with the spot piles because they were not in a configuration that joined piles together in any logical connection.

Roadside-logging windrow piles were made in cutblocks where there were no landings, i.e., trees were processed and then loaded directly

onto trucks parked on either permanent or temporary roads with the woody debris piled in windrows beside the road. The length of roadside-logging windrow piles depended on the actual area harvested, i.e., number of trees brought to the roadside. Where this harvested area was large, debris piles were continuous but breaks were made mechanically at least every 100m made to reduce the potential for fire to propagate along continuous piles. Where the area served by the roadside loading site was smaller or more topographically restricted, windrow piles were more discontinuous. Some cutblocks that had both windrow piles and rough-bunched spot piles were classified with the windrow pile cutblocks.

Height, width and length of each pile were measured in the snow-free season to estimate volume of woody debris. A conical shape was assumed for piles with circular footprints, and a triangular vertical cross-section for windrow piles. The volume of woody debris within piles was assumed to account for one-third of the gross volume of the pile with the other two-thirds being air spaces. Logging debris piles were typically 1.5 to 3-m high and always showed some access points to the interior of the pile from the snow surface, even in the deepest winter snows. Typical spot pile size was 6-m diameter circular footprint. For all cutblocks, piles were counted to calculate pile density but given the long nature of windrow piles, piled woody debris volume per cutblock was the metric used in the analysis, rather than density.

In two cutblocks, the conditions changed between the first and second winters of the study. Cutblock 114-3 (Cochrane site) had extensive windrow piles in 1992/93 but these were burned in fall 1993. Because of this change from one winter to the next, the two winters of sampling on this cutblock were treated as separate samples. In 1992-93, cutblock 128-8 (Hellroarer site) was two separate cutblocks (Upper and Lower) separated by a band of forest 420-520 m long and between 100 and 250-m wide. That forest band was logged and replaced by a series of windrow debris piles before the winter of 1993-94, which provided an opportunity to compare marten crossing of the cutblock via a forest corridor in one year vs no forest but with windrow piles the next year.

Study design and analyses

The first winter of the study (1991-92) was a preliminary examination of one cutblock with windrow debris piles to see if there was any use of debris piles at all by marten. Over the summer and fall of 1992, 8 sites were chosen each with at least two cutblocks where forest licensees were willing to delay burning the debris piles in the cutblocks for two years. Piles were made by licensees in the regular course of business, with no

direction given as to location or types of piles. Between two and eight study cutblocks with debris piles were chosen at each site (Figure 1). An experimental design was chosen that looked at entire cutblocks rather than at individual debris piles because a) debris piles were very numerous (n = 924), and b) piles were of greatly varying sizes and configurations making statistical comparisons problematic. A completely balanced study design with each type of debris pile at each site was not achievable. Control cutblocks with no (or very few) retained debris piles were only available in 7 of 8 sites. Cutblocks with spot piles were available in 7 of the 8 sites. Windrow debris piles were only available in 3 of the 8 sites, all of which were east of Okanagan Lake. In each of the 8 sites there was surrounding forest that served as a control to determine levels of marten use in the intact forests around the cutblocks.

The numbers of rough-bunched spot piles retained throughout a cutblock depended both on the amount of woody debris on site, and the levels that B.C. Forest Service personnel in four different forest districts deemed acceptable to retain without unduly increasing short-term fire hazard. In addition, some cutblocks originally chosen as controls, i.e., no piles, during fall 1992 turned out to have unburned piles not visible from any roads remaining in corners of the cutblocks when examined on snowmobiles during the first winter.

The first question of interest was whether marten relative use (the track index) differed between surrounding forests and cutblocks with or without retained woody debris piles. I used a single-factor ANOVA study design with categorical factors of forest, controls, windrow piles and spot piles. Post-hoc comparisons among categories were made using Tukey's Honestly Significant Difference test. The second question was whether the amount of pile retention affected marten use within cutblocks, which I addressed by regressing marten relative use against cutblock woody debris volume as a continuous variable. Throughout, whenever I present a mean, I also present the standard error (SE) and the sample size. The third question was how marten used the various retained structural elements within the cutblocks. I tabulated the piles or other retained forest elements encountered in cutblocks in relation to 1) total distance of each trail within the cutblock, 2) maximum distance from forest edge and 3) distance of cutblock crossed.

Results

In the winters of 1992-93 and 1993-94, I sampled 1410 km-days in 41 cutblocks where 96 marten tracks crossed the transects. This included

26.6 actual km of cutblock transects in 1992-93 visited twice each, and 54.4 km in 1993-94 that were visited, on average, 3.2 times each. A total of 106 marten trails were followed including 9 trails followed during the preliminary sampling winter of 1991-92 when only one cutblock was sampled. The 106 marten trails totaled 29.153 km distance followed within the cutblocks. In 495 km-days sampling in surrounding forests that averaged 2.5 km of transect per site, I counted 403 marten tracks crossing the transects. Mean cutblock size was 37 ha (range 3.5 - 240 ha).

Cutblock and forest use

Marten use of forests west of Okanagan Lake (mean 0.328 tracks/km-day, SE 0.238, n = 4 sites) was significantly lower ($F_{1,6}$ = 10.9, p = 0.02) than of forests east of Okanagan Lake (mean 1.821 tracks/km-day, SE 0.384, n = 4 sites). Marten use in forests was higher at all of the sites east of Okanagan Lake than at any of the sites west of Okanagan Lake. Consequently, further analysis of marten cutblock use only considered sites east of Okanagan Lake because marten made no use of any cutblocks west of Okanagan Lake. It appeared that where marten were relatively less common, there may have been little incentive to use suboptimal habitat in clearcuts, whether there were woody debris piles there, or not.

There were significant differences in marten use of forests and the three categories of cutblocks east of Okanagan Lake ($F_{3,19}$ = 26.17, p <0.001; Figure 2). However, there were no significant differences between the three categories of cutblocks (controls, spot piles and windrow piles) using Tukey's HSD test (p ranged from 0.77 to 0.99), but all were significantly lower than forest use (p <0.001 in every comparison). While the ANOVA did not show any difference between cutblocks, marten use of cutblocks was significantly linearly correlated with piled volume of woody debris ($F_{1,17}$ = 6.70, p = 0.02, Figure 3). Even with relatively high volumes of woody debris in piles (>20 m^3/ha), marten use of cutblocks still only averaged 0.266 tracks/km-day (SE 0.071, n = 8) , or 15% of that in surrounding forests. Marten use of these cutblocks was not correlated with size of the cutblock ($F_{1,17}$ = 0.16, p = 0.70).

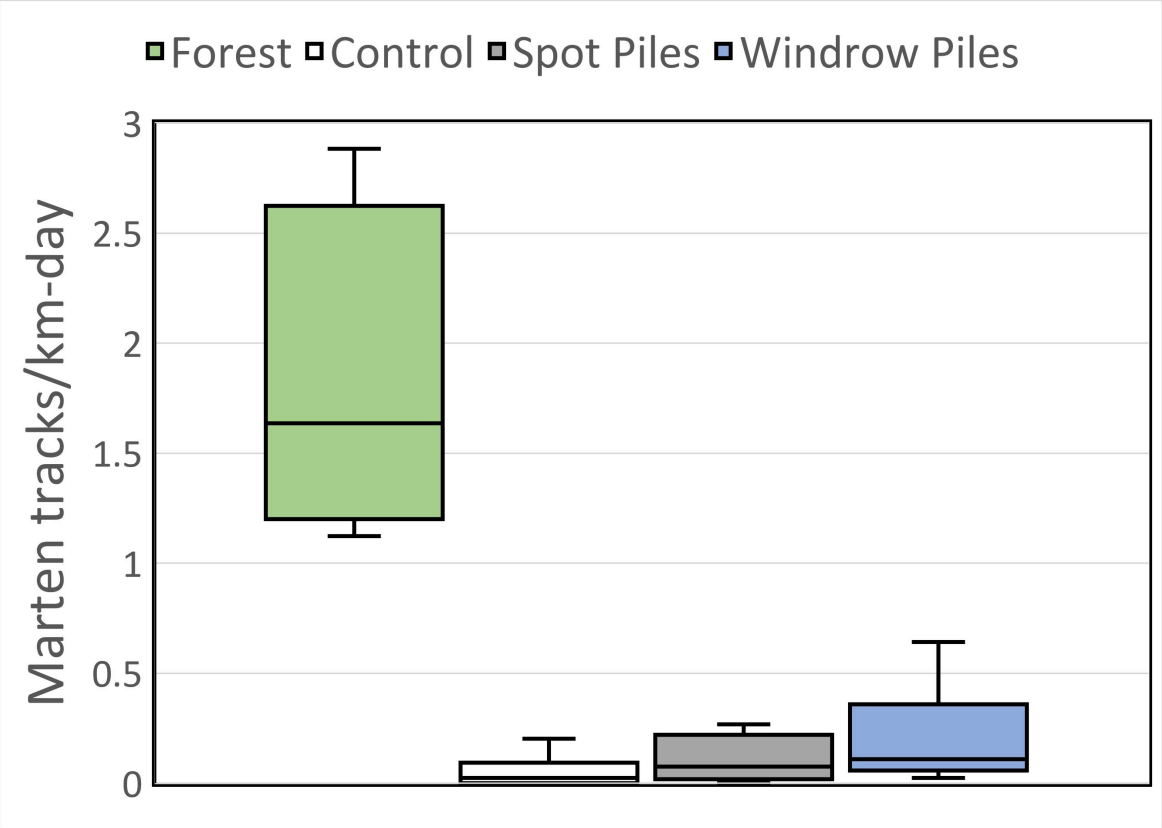


Figure 2. *Box-and-whisker plot of relative marten use (tracks/km-day) of forests and cutblocks with different pile treatments east of Okanagan Lake. Horizontal bar is mean, box is 25th to 75th percentile, and ends of whiskers are extreme values.*

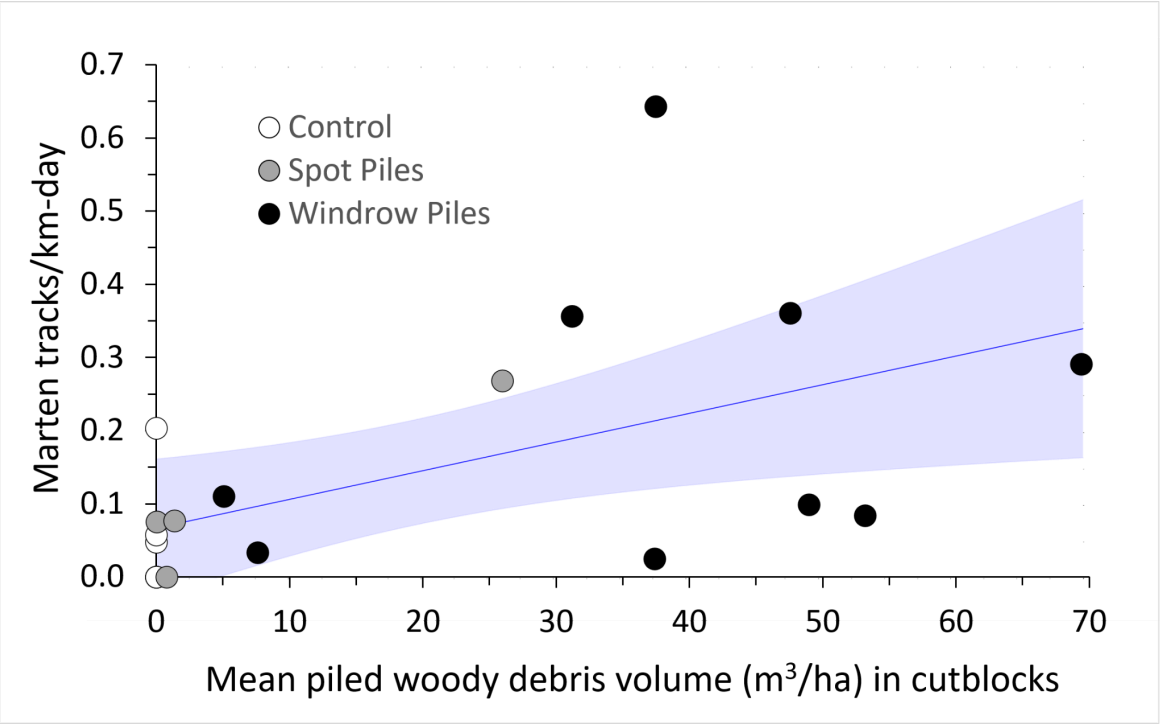


Figure 3. *Linear regression of marten use of cutblocks against the mean volume of woody debris retained in piles east of Okanagan Lake. Regression line of all cutblocks is y = 0.0687+0.0039x (r2 = 0.28) with 95% confidence band of the regression shown.*

Marten trails in cutblocks

Analysis of 106 marten trails within cutblocks (all of which were east of Okanagan Lake) showed that 72% of the trails used debris piles (Figure 4, Figure 5). A further 7% travelled within 30m of a pile, veering towards the pile, but did not actually contact the pile. Dense cover was used by 11% of trails and 10% of the trails used only sparse cover within cutblocks. The trails using sparse cover were never longer than 400m total length within the cutblocks and never ventured more than 140m from forest cover. Of the trails using piles or dense cover, 30% travelled more than 400m within the cutblock and 26% ventured more than 130m from forest cover. The longest observed distance travelled within a cutblock was 1800 m with that marten travelling along and hunting within a riparian corridor that had dense understory retention.

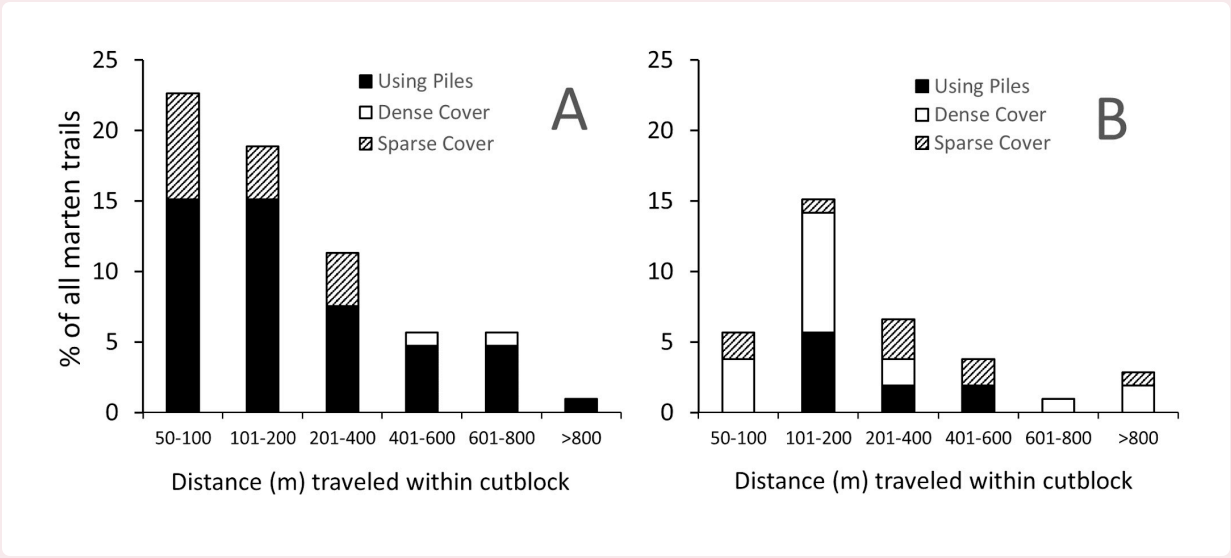


Figure 4. *Percentage of marten trails traveling different distances within cutblocks in relation to features encountered within cutblocks. (A) trails in upland areas not encountering any riparian area (n = 69); (B) trails that encountered riparian areas (n = 37).*

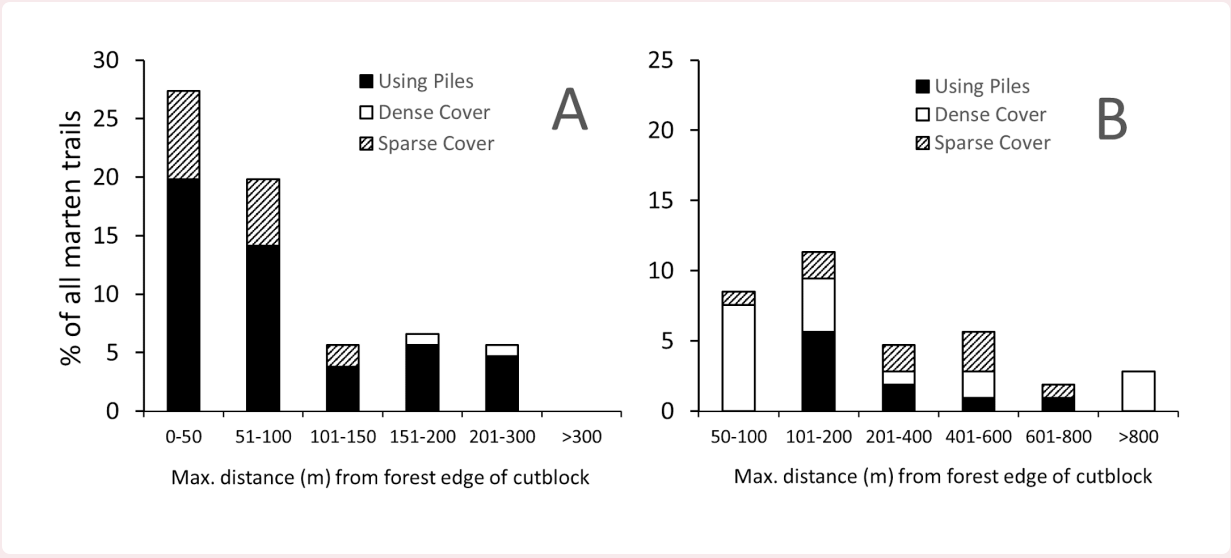


Figure 5. *Percentage of marten trails (n = 106) that reached different maximum distances from forests at cutblock edges in relation to features encountered within cutblocks. (A) trails in upland areas not encountering any riparian area (n = 69); (B) trails that encountered riparian areas (n = 37).*

Windrow debris piles that were placed in series and provided logical travel connections between them were used more often than spot piles. The windrows were relatively continuous but were broken at frequent intervals even to the point of being 50% pile and 50% open ground in one cutblock. Marten regularly (15% of all trails) used these series of windrow piles to travel distances of greater than 400m within cutblocks.

Spot piles by themselves were not used by marten except when they were placed adjacent to creeks or on the shortest paths of 135m or less across open ground from one piece of forest to another. Marten were tracked adjacent to two cutblocks where local densities of spot piles were high (4-6/ha) but marten did not venture even 20m out from the forest to these piles. By contrast, virtually all windrow piles near forest showed some use by marten. However, spot piles beside or near creeks seemed to provide the connectivity that marten found in windrow piles with the combination of riparian understory reserves and spot piles used as travel corridors and hunting areas in four cutblocks.

For marten trails that crossed cutblocks (n = 58, Figure 6), trails only rarely crossed more than 100 m of open ground with sparse cover in cutblocks, instead using riparian travel corridors or windrow piles. Only 1 trail (160 m) that crossed and did not use either riparian areas or piles (n = 9) exceeded 85 m crossing distance. Even when using spot piles, marten never crossed open ground with sparse cover of more than 135m. Mean distance of cutblocks crossed was 188 m (SE 22m, n = 48 crossings), while mean distance travelled within cutblocks was 275 m (SE 27, n = 106 trails). All crossings of distances >400 m used windrow piles.

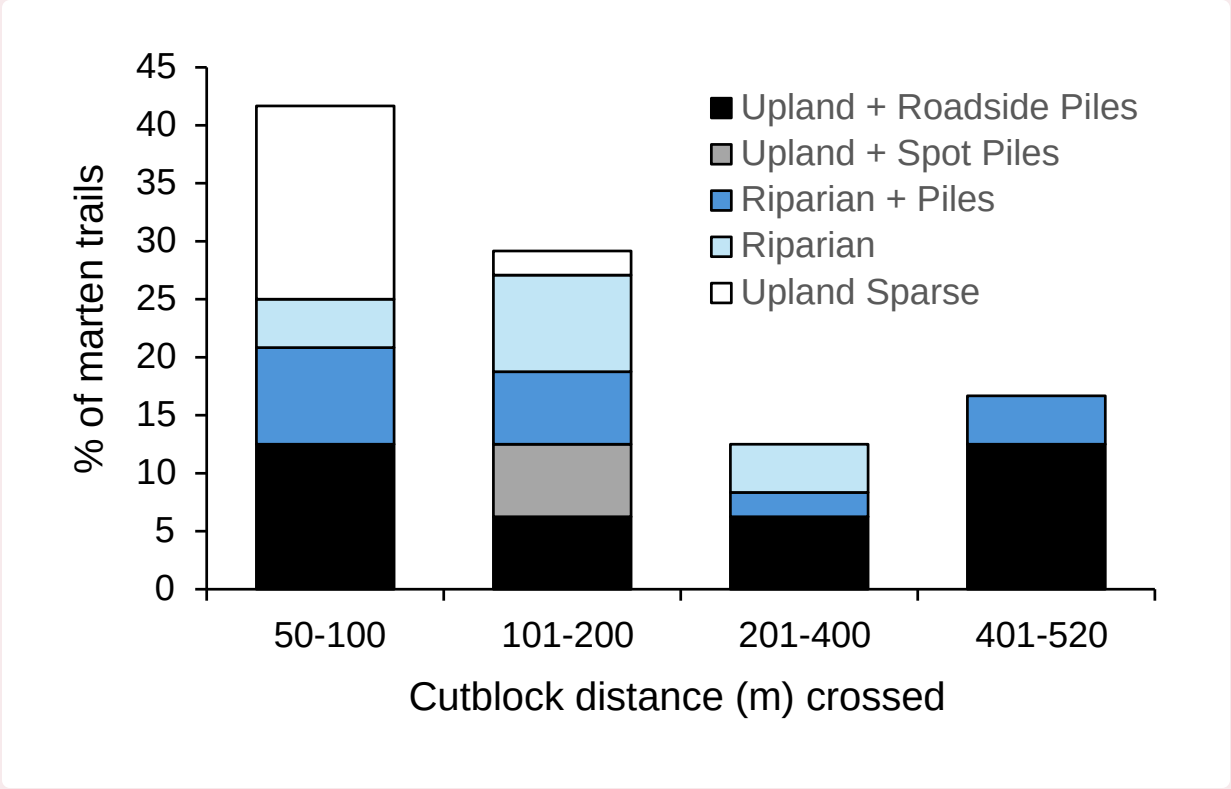


Figure 6. *Percentages of marten trails (n = 58) crossing different distances in cutblocks and the features used while crossing.*

Almost all marten trails made use of whatever cover or other features were available rather than straight line behaviour. For example, one marten trail crossed an open section of cutblock 128-2U between piles and creek buffer zones where there were five 3-m high-cut stumps (specifically retained for cavity-nesting birds). This 100 m section of trail zigzagged within 1m of each of the five high-cut stumps while still using the straightest line possible across this open area. The only straight-line travel exhibited by marten was for very short (but not specifically quantified) distances in between these sorts of features within the cutblocks. Other features besides stubs and piles consisted of mature trees that had been retained after timber harvest but then blown over, tipped-up root wads, standing retained mature trees, and young retained conifers with branches that drooped to snow level.

Marten entered the subnivean layer, or an area beneath the snow surface, at piles, tree wells, upturned stumps, large boulder piles, or along creek banks. In 106 marten trails, only one descended to the subnivean layer directly through the snowpack, and it was within 30 m of

a windrow pile. Windrow piles were used for both travel and hunting. In many cases, particularly when the pile was on a roadside within 20 m of a forest, marten entered piles at one or more places, then exited the pile at the same or a different place, and returned to the same forest. This was interpreted as hunting behaviour and, in one case, the trail heading back to the forest showed the drag marks of prey the marten had captured. In other cases, marten travelled on top of or immediately beside windrow piles, only occasionally entering the pile.

Cutblock 114-3 provided the only comparison of a single site with, and then without, debris piles. In winter 1992-93, the first winter after timber harvest, this was the only cutblock in which marten trails exhibited hunting behaviour well removed from piles among retained mature trees with density <5/ha and in understory reserves with <20 small trees/ha. In winter 1993-94, marten showed no use whatsoever of this same cutblock after the piles had been burned in the fall of 1993 even though tracks were frequently seen in the forest immediately adjacent to the cutblock; all such tracks stopped at the forest edge.

Windrow piles across cutblocks were used by marten to cross cutblocks but strips of forest cover seemed to be more effective based on a single case in this study. In cutblock 128-2, a forested corridor in the first winter was replaced by windrow piles in the second winter. Marten use dropped from 1.79 tracks/km-day to 0.47 tracks/km-day at that particular location, with the 4 marten trails crossing that 420-520 m section in the second year all using the windrow piles.

Discussion

At least in the short term as studied here, marten will make use of windrow piles in cutblocks in the winter. The series of windrow piles created by roadside logging can create opportunities for marten hunting as well as for crossing cutblocks that they might otherwise not attempt to cross or even enter. The low use of cutblocks without slash piles is presumably because of high predation risk in areas without tree cover and/or because of low prey availability (Moriarty et al., 2015). Retention of woody debris piles would be just one tool for managing marten populations in fragmented forest landscapes. However, no matter what the level of woody debris piles is retained, recently-harvested cutblocks had far lower marten use than surrounding forests, i.e., the windrow piles could mitigate some of the effect of clearcutting on marten habitat in terms of crossing or using the clearcuts, but the clearcuts could not be

made into high-quality marten habitat that would be used equivalently to forests.

Other studies have found similar results for marten use of cutblocks in winter. Cushman et al. (2011) found marten in winter would not travel more than 17 m into clearcuts. Other marten crossings of cutblocks in winter have been reported as no more than 200 m (Soutiere, 1979) or 600 m (Snyder & Bissonette, 1987). Mean distances crossed in cutblocks, where reported, were fairly similar to the 188 m found in this study, i.e., 197 m (Volkmann & Hodges, 2021) and 150 m (Snyder & Bissonette, 1987), as were longest maximum cutblock distances crossed: 520 m (this study), 595 m (Volkmann & Hodges, 2021) and 600 m (Snyder & Bissonette, 1987). These longest crossings were associated with remnant trees, some understorey retention or with slash piles (this study, Volkmann and Hodges 2021) or en-route to residual stands in cutblocks (Snyder & Bissionette, 1987). Marten use of windrow piles and other retained forest features to cross cutblocks resulted in some of the longest recorded winter crossings of cutblocks.

Windrow piles would be best retained throughout a cutblock. Of the 7 cutblocks where virtually all piles were kept, total retained volumes were estimated at greater than 30 m^3/ha. When most windrow piles were burned, and overall volume fell below 10 m^3/ha (only 1 cutblock), very little use was observed. Piles near forest were used for hunting (presumably on the voles present in the piles, e.g., Sullivan and Sullivan 2023), while piles further away were used as travel routes as well as for hunting.

Isolated spot piles received very little marten use. If they are to be a useful mitigation method, the data here suggests they should be placed in or near travel routes that are likely to be used for other reasons. These likely travel routes included distances of <150 m across large clearcuts or to forested habitat-islands within cutblocks, and along creeks of any size within cutblocks. Based on the findings here, spot pile density along, or within 50 m of, creeks should be greater than 25 m^3/ha, or 4 piles/ha (based on an average pile being 6-m diameter and 1.75-m high). This application would be limited to areas that are rough-bunched since landing piles will never approach this density along creeks. Sullivan et al. (2021) made a similar recommendation suggesting piles should be at least 2-m height and 5-7 m width or diameter and arranged as continuous windrows, or in a linear array of spot piles, and that these should particularly be placed connecting forest patches or reserves or along riparian areas.

Marten populations west of Okanagan Lake were lower than east of Okanagan Lake with no observed cutblock use at all by marten west of Okanagan Lake, no matter how many woody debris piles were retained. At low population levels, marten may not use sub-optimal habitat in clearcuts at all. This limited the interpretations of woody debris pile use in cutblocks to those situations where marten populations may be relatively high. As such there may be limits to how successful woody debris piles may be as a mitigation strategy where marten populations are low.

Retention of woody debris piles was one method to mitigate clearcutting effects on marten as shown by this study, by Seip et al. (2018), and as summarized for other studies by Sullivan et al. (2021). Retention of debris piles allowed marten to cross clearcuts that they would not otherwise have crossed, especially when in conjunction with retention of forest or understory reserves as found here, and also found by Sullivan and Sullivan (2021). For winter movement across clearcuts, woody debris piles are recommended for retention as a mitigation strategy for marten, but preferably combined with other methods including forest corridors or including streamside reserves of either mature trees or understory trees as shown here, and as recommended by Seip et al. (2018).

While optimal forest corridor width was not studied here, Gyug (2000) found that streamside forest corridors as narrow as 20 m were used by marten in proportion to their width. Partial-harvest within those corridors that retained at least 200 trees/ha still allowed for marten use (Gyug, 2000) but this may also have depended on levels of downed woody debris and retained understory within the partially-harvested forest. Wilk and Raphael (2018) found that the primary marten uses of woody debris piles were as denning and resting sites throughout the year rather than just for hunting small mammals.

Retaining woody debris piles is a recommended method for mitigating some of the effects of clearcutting on marten, whether that be to facilitate winter movement across clearcuts by reducing predation risk, providing additional and diverse small mammal prey (e.g., species listed within Martin et al. 2025), or as resting or denning sites (e.g., Wilk et al., 2018). Retention of slash piles may be especially useful in conjunction with other mitigation strategies including retention of some mature and understorey trees, especially along stream corridors, because slash piles on their own are unlikely to be of sufficiently high density or dispersion across a block to facilitate movements on their own.

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Author Contributions

There was a sole author who completed all phases of the work.

Data Availability

Data is available from the author upon request.

Transparent Peer Review

Results from the Transparent Peer Review can be found here.

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Conflicts of Interest

The author has no conflicts of interest to declare.

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AI Use Statement

No AI tools were used in the preparation of this manuscript.

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Supplementary Information

Table S1. *Attributes of cutblocks used in the study including snow tracking effort (km-days) and marten relative abundance.*

Region	Site	Block Number	Block size (ha)	Type of debris piles	Est. piled debris volume (m^3/ha)	Pile density (/ha)	Km-days	Marten tracks/ km-day
East	BigWhite	14D	51	None	0	0	30.7	0.195
East	BigWhite	14B	240	Spot	0.05	0.01	52.2	0.077
East	BigWhite	999-92	22	Spot	26.0	1.73	37.3	0.268
East	Cochrane	114-2	65	None	0	0	28.0	0.643
East	Cochrane	114-3 (93-94)	42	None	0	0	42.0	0.048
East	Cochrane	114-4	30	None	0	0	40.0	0
East	Cochrane	114-3(92-93)	42	Windrow	37.5	0.33	35.0	0.057
East	Cochrane	146-1	28	Windrow	53.2	0.55	35.7	0.084
East	Cochrane	146-3	38	Windrow	47.6	0.49	52.7	0.361
East	Cochrane	114-8A	62	Spot	1.4	0.15	26.0	0.077
East	Cochrane	146-2	3.5	Windrow	5.1	0.29	9.1	0.110
East	Cochrane	146-4	32	Windrow	31.2	0.34	39.3	0.356
East	Hellroarer	115-3	20	None	0	0	41.5	0
East	Hellroarer	128-2L	25	None	0	0	31.8	0
East	Hellroarer	115-1	63	Windrow	69.4	0.79	46.1	0.174
East	Hellroarer	128-2U	103	Windrow	49.0	0.54	98.9	0.142
East	Hellroarer	128-8	55	Windrow	7.6	0.06	60.7	0.033
East	Whitefoot	4-7	42	Windrow	37.4	1.31	40.6	0.025
East	Whitefoot	4-2	44	Spot	0.8	0.11	42.9	0
West	Equesis	274-3	4.4	None	1.6	0.23	9.0	0

Region	Site	Block Number	Block size (ha)	Type of debris piles	Est. piled debris volume (m^3/ha)	Pile density (/ha)	Km-days	Marten tracks/ km-day
West	Equesis	274-1	14	Spot	27.7	3.57	38.4	0
West	Equesis	274-2	26	Spot	4.8	1.19	30.4	0
West	Equesis	903-7	13	Spot	3.2	1.08	19.4	0
West	Equesis	202-3	6.3	Spot	1.1	0.16	18.1	0
West	Garrison	594-5	37	None	0	0	19.0	0
West	Garrison	595-2	10	None	0	6.36	10.7	0
West	Garrison	589-1	20	Spot	3.1	0.10	27.7	0
West	Garrison	589-2	5	Spot	9.8	1.40	18.0	0
West	Garrison	589-3	12	Spot	4.5	0.75	28.8	0
West	Garrison	594-2	42	Spot	2.5	0.03	35.6	0
West	Garrison	594-4	30	Spot	1.8	0.36	24.9	0
West	Garrison	595-1	30	Spot	0.2	0.03	19.0	0
West	Garrison	595-4	11	Spot	44.5	0	24.9	0
West	Garrison	595-5	12	Spot	14.6	2.08	14.6	0
West	Shorts	837-5	80	None	0	0	60.0	0
West	Shorts	837-1	13	Spot	56.0	8.00	24.0	0
West	Shorts	837-3	37	Spot	1.9	0.87	61.5	0
West	Shorts	837-6	44	Spot	43.8	6.18	52.5	0
West	Shrimpton	88-480	25	None	0	0	11.7	0
West	Shrimpton	88-481	22	Spot	1.5	0.18	14.7	0
West	Shrimpton	88-482	35	Spot	3.6	0.51	31.0	0
West	Shrimpton	88-485	27	Spot	0.7	0.07	28.8	0

Table S2. *Marten snow tracking relative abundance in forests adjacent to, or nearby, cutblocks at each study site. Region refers to east or west of Okanagan Lake.*

Region	Site	Effort (km-days)		Marten tracks/km-day		
		1992/93	1993/94	1992/93	1993/94	Mean
East	BigWhite	8.60	21.30	1.784	0.465	1.125
East	Cochrane	15.40	29.82	2.582	1.104	1.843
East	Hellroarer	32.20	19.73	1.774	1.087	1.431
East	Whitefoot	20.48	26.56	1.619	4.150	2.885
West	Equesis	27.27	28.64	0.314	0.147	0.231
West	Garrison	38.52	45.03	0.000	0.000	0.000
West	Shorts	78.52	54.75	0.110	0.000	0.055
West	Shrimpton	25.02	23.36	0.813	1.239	1.026

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