Conserving American Marten *Martes americana* winter habitat in sub-boreal spruce forests affected by Mountain Pine Beetle *Dendroctonus ponderosae* infestations and logging in British Columbia, Canada

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Abstract

Current management plans to clear cut large forest stands of Mountain Pine Beetle *Dendroctonus ponderosae*-infested Lodgepole Pine *Pinus contorta* could adversely affect American Marten *Martes americana* winter habitat. I assessed and predicted winter distribution of American Marten in the Sub-boreal Spruce Biogeoclimatic Zone of central interior British Columbia to estimate the impact of Lodgepole Pine harvesting on this species. I predicted that American Marten would be present in excellent- and high- quality polygons that corresponded to ≥80 years old, undisturbed, conifer-dominated stands with ≥30% canopy closure, ≥20 m²/ha basal area, and circum-mesic soils. Martens would be absent from immature and young forests, and from late-successional pure deciduous, Lodgepole Pine, and Black Spruce *Picea mariana* stands. Habitat use by American Marten was assessed by traversing about 170 km of transects from December to February 2005–2008. A total of 108 American Marten tracks were recorded: 106 in excellent- and high-quality polygons with mature and old mixed coniferous and conifer-dominated mixed stands, and two in low-quality polygons with mature Lodgepole Pine stands. The observed frequency of tracks per habitat type differed ($P < 0.05$) from expected. American Marten tracks were found in stands that were, on average, 156.6 years old with 52.3% canopy closure, and 39.9 m²/ha basal area. Most stands (92.6%) had 20–49 cm dbh trees, and <20% shrub cover. Lodgepole Pine was present, and often was the dominant species in most mixed coniferous stands used by American Martens. The extensive logging of stands where Lodgepole Pine is mixed with other conifers would undoubtedly have a negative effect on American Marten winter habitat. For effective conservation of American Martens, forest management plans must be based on spatially-explicit data that relate to specific habitat requirements. I demonstrated the ability to predict winter distribution of American Marten in landscapes infested by Mountain Pine Beetle, and to identify stands that should be protected for conservation.

Keywords: Habitat conservation, Lodgepole Pine, Sub-boreal Spruce forest

Conservando el hábitat de invierno de la Marta Americana *Martes americana* en los bosques de abetos sub-boreales, afectados por la infestación del escarabajo de pino *Dendroctonus ponderosae* y la tala extensiva en Columbia Británica, Canadá

Resumen

Los actuales planes de manejo forestal que incluyen la tala de grandes extensiones de bosques para la producción del pino *Pinus contorta* infestado del escarabajo de pino *Dendroctonus ponderosae* pueden impactar de manera negativa el hábitat de invierno de la marta americana *Martes americana*. El objetivo del presente estudio fue el de evaluar y predecir la distribución en invierno de la marta americana en la zona biogeoclimática de los abetos sub-boreales del interior central de la Columbia Británica, con el fin de determinar el impacto de la producción del *Pinus contorta* sobre esta especie. Se predijo que la marta americana estaría presente en polígonos de alta y excelente calidad, que correspondan a sitios no perturbados por ≥ de 80 años dominados por confieras con ≥ 30% de densidad de dosel, ≥ 20 m²/ha de área basal y suelos de tipo medio con un buen nivel de drenaje. Las martas estarían ausentes en bosques inmaduros o jóvenes y en bosques deciduos puros en estados sucesionales tardíos de *Pinus contorta* y *Picea mariana*. El uso de hábitat por la marta americana fue evaluado en campo y aproximadamente 170 Km de transectos fueron realizados, con seguimiento de rastros en la nieve, desde diciembre hasta febrero entre el 2005 y el 2008. Un total de 108 indicios de la marta americana fueron registrados: 106 en polígonos de alta-excelente calidad en bosques maduros y mixtos viejos de coníferas o bosques mixtos dominados por coníferas, y 2 indicios en polígonos de baja calidad con bosques de *Pinus contorta* maduros. La frecuencia observada de rastros por tipo de hábitat fue significativamente diferente ($P < 0.05$) de lo esperado. Los rastros de la marta americana fueron encontrados en bosques que tienen en promedio 156.6 años de antigüedad, con 52.3% de densidad del dosel y 39.9 m²/ha de área basal. La mayoría de los bosques (92.6%) tienen árboles entre 20 y 49 cm de DAP y < 20% de cobertura de arbustos. *Pinus contorta* estuvo presente y a menudo fue la especie dominante, en la mayoría de los bosques coníferos mixtos utilizados por la marta americana. La tala extensiva de bosques donde *Pinus contorta* está mezclado con otras coníferas tendría sin duda un efecto negativo en el hábitat de invierno de la marta americana. Para que un plan de manejo forestal sea efectivo en cuanto a la conservación de la marta americana, debe estar basado en fuentes de información espacialmente explicitas que relacionen los requerimientos de hábitat de manera específica. Este estudio mostró que es posible predecir la distribución del hábitat de invierno de la marta americana en paisajes infestados por el pino escarabajo de montaña, e identificar bosques que deben ser protegidos para la conservación de la biodiversidad.

Palabras clave: conservación de hábitat, bosques de abetos sub-boreales, hábitat de invierno

Introduction

In central British Columbia (BC), Canada, recent epidemics of Mountain Pine Beetle *Dendroctonus ponderosae* have resulted in the infestation of at least 4.2 million hectares of mature (≥81 years) and old (≥140 years; DeLong *et al*. 2003, Morgantini & Kansas 2003) Lodgepole Pine *Pinus contorta* stands (Readshaw 2003). Using clear cuts (40–60 ha or larger in landscapes damaged by fire, insects or wind; BC Forest Practices Code 2006), government and industry plan salvage harvesting of beetle-infested trees in much of the Central Interior to extract as much timber value as possible before the wood deteriorates. Because Mountain Pine Beetles prefer large diameter trees (Safranyik 2004), harvesting beetle-infested trees adversely affects the distribution and structure of late-successional forests (Safranyik *et al*. 1974). This would be likely to have a negative effect on American Marten *Martes americana*, a forest specialist that is associated with late-successional, circum-mesic coniferous or conifer-dominated mixed forests in western North America (Proulx *et al*. 2004). Considering that the American Marten is an economically important species (Proulx 2000) associated with numerous species in late-successional forests (Gyug 1996, Lawlor 2003), extensive clear cutting is a source of concern to wildlife managers (Proulx *et al*. 2004).

To estimate the effect of extensive Lodgepole Pine logging on American Marten winter habitat in the Central Interior, I investigated the species's habitat requirements in winter when harsh environmental conditions increase the animals' requirements for energy, nutrients, shelter and security (Proulx *et al*. 2004). My objective was to assess and predict late-winter distribution of American Marten in the BC Sub-boreal Spruce Biogeoclimatic Zone by: 1) rating the potential of forest stands according to their composition and structural characteristics and 2) verifying habitat use by Marten using snowtracking.

Study Area

The study was conducted in central interior BC, in four supply blocks of Canadian Forest Products Ltd in the Prince George Forest District (53°55′N, 122°44′W). Field investigations occurred in Supply Block F (700,000 ha of forests) in the southwest portion of the district, and in Supply Block E (905,000 ha) in the north (Fig. 1). In Fort St. James District (54°27′N, 124°15′W), the study was conducted in Supply Block C (638,000 ha of forests) in the southern portion of the district, and the southern portion of Supply Block B (70,000 ha) in the north (Fig. 1). All study areas were located within the Sub-boreal Spruce Biogeoclimatic Zone where hybrid White Spruce *Picea engelmanii* x *glauca* and Subalpine Fir *Abies lasiocarpa* were the dominant climax tree species (Meidinger *et al*. 1991). Lodgepole Pine occurred in mature forests in the drier parts of the zone, and both Lodgepole Pine and Trembling Aspen *Populus tremuloides* were pioneer species in many early-successional stands. Lodgepole Pine represented >35% of the merchantable wood in Supply Block E, and >50% in other supply blocks. Douglas-fir *Pseudotsuga menziesii* was at the northernmost border of its natural range and sporadically occurred on dry, warm and rich soils at lower elevations. Black Spruce *Picea mariana* was occasionally found in climax upland forests (Meidinger *et al*. 1991).

Methods

Rating forest stands and polygons

I used the variables of Proulx *et al.* (2006) to identify forest stands that usually have coarse woody debris and a developed understory (Table 1). Minimum levels of canopy closure and basal area allowed me to reject stands with too much disturbance. I subjectively allocated weight values to selected variables based on my

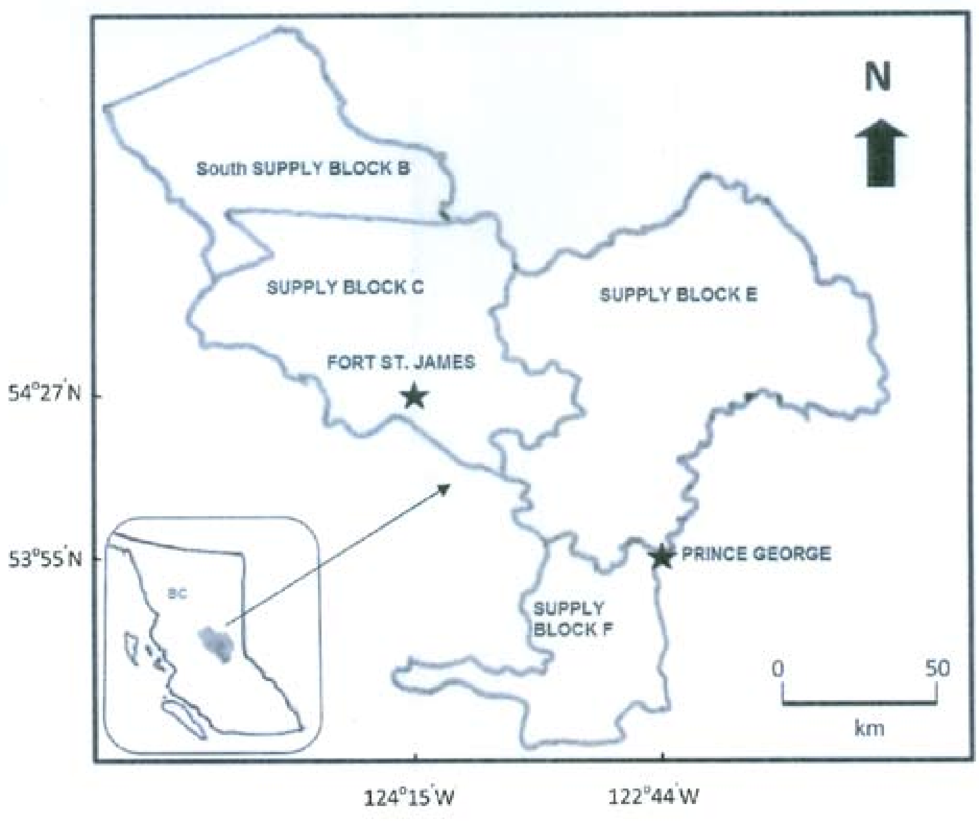

Fig. 1. Location of study areas in central interior British Columbia (BC), Canada.

Table 1. Habitat variables used to rate polygons for American Marten in Sub-boreal Spruce forests of British Columbia (Proulx et al. *2006).*

Criterion	Weight given	
	1	0
Forest type	Pure or mixed coniferous (spruce, fir) or conifer-dominated mixed stands	Pure deciduous, Black Spruce or Lodgepole Pine stands.
Age (years)	≥80	<80
Crown closure	≥30%	<30%
Basal area	≥20 m²/ha	<20 m²/ha
Soil	Circum-mesic	Hygric or xeric
Disturbance	Cutblock (except partial logging <1970) or road—Rejected.	

evaluation of their importance to American Marten (Proulx *et al.* 2006). The sum of weights allowed the classification of vector map polygons (i.e. homogenous areas with similar forest stand characteristics) into four categories of potential winter habitat: (1) excellent, 5 points; (2) high, 4 points; (3) medium, 3 points; and (4) low, ≤2 points.

Field assessment of potential American Marten habitats

Because of the size of areas surveyed, field assessments were conducted over two winters in Supply Blocks F (43 transects), E (32 transects), and C (54 transects). Surveys in Supply Block B (17 transects) were conducted during one winter only in the southern portion of the block that was contiguous with Supply Block C. A random stratified approach (Krebs 1978) was used to locate transects averaging ≥1- km long on a yearly basis, and ≥1-km apart that crossed all polygon types. Transects were plotted on predictive maps, and starting points were located using compass bearings and distance to distinct topographic features. Transects were inventoried (snowshoed) (snow depths: 45–180 cm; temperatures: -25 °C to 2 °C) using a compass, 1:50,000 scale maps, and a hip chain (device with filament used to record linear distances). Forest composition was recorded along survey transects: coniferous (coniferous species >75%; pure if only one species), deciduous (deciduous species >75%), or mixed (neither type >75%). Successional stages corresponded to immature-pole (open areas and new stands; pole corresponded to 7.5–12.4 cm dbh trees; about 0–40 years), young (achievement of dominance by some trees and death of others, uneven dbh, multi-storied canopy; about >40–80 years), mature (even canopy of trees, developed understory as the canopy opens up; about >80–140 years), and old (structurally complex, established shade-tolerant species, mortality of tall and large canopy trees, canopy gaps, large down woody material; about >140 years but variable with species) (Proulx & Kariz 2005). Only fresh tracks (i.e. ≤48 hours old from most recent snowfall) crossing transects were recorded. Due to the similarity between Fisher *Martes pennanti* and American Marten footprints (Halfpenny *et al.* 1995), when mustelid tracks were encountered, they were investigated on both sides of transects and within forest stands to find the best tracks available. The combination of footprint (pattern and size, presence/absence of toe pad prints) and trail (gait, distance between jumps, and dragging of the feet) characteristics was used to identify all tracks (see Murie 1975, Rezendes 1992, Halfpenny *et al.* 1995). American Marten tracks are usually smaller, although the footprints of female Fishers and male American Martens may be of similar size. In winter, the undersurface of American Marten's feet is heavily covered with hair and toe pads do not show (Murie 1975, Rezendes 1992). The undersurface of Fisher's feet has sparse hair, and pads show well in clear prints (Halfpenny *et al.* 1995). Approximate locations along transects were determined using hip chain distances and forestry maps. Track locations were entered into the Vegetation Resources Inventory (VRI) database to identify site attributes. VRI is the standard for assessing the quantity and quality of timber and other vegetation resources in BC. It uses photo interpretation and detailed ground sampling to estimate timber volume and other vegetation resources within a predefined unit (BC Forest Investment Account 2009). The VRI information was compared to field observations to ensure that polygon classification was appropriate.

Data analyses

The proportion of inventory transects within each polygon type or habitat type was used to determine the expected frequency of tracks per polygon or habitat type. Chi-square statistics with Yates's correction and the Fisher Exact Probability Test (Zar 1999) were used to compare observed to expected frequencies of track intersects per polygon or habitat type (Proulx *et al.* 2006, Proulx & O'Doherty 2006). Probability values ≤ 0.05 were considered statistically significant.

Autocorrelation is often present in ecological data and may not be totally avoidable (Legendre 1993, Bowman & Robitaille 1997). It potentially occurs during analysis of track survey data because of the uncertainty in whether one or more animals have made the tracks being counted. Although some investigators (e.g. Thompson 1949, de Vos 1952) recommended not counting repeated crossings by the same animals, it is sometimes difficult to confirm that a series of tracks along a transect belong to the same animal (de Vos 1951) because home ranges overlap (Buskirk & Ruggiero 1994) and winter dispersal movements can occur (Clark & Campbell 1976). Because of rugged environmental conditions, we did not follow tracks that crossed close together to learn whether the same animal made them. However, based on track characteristics, we deduced that two different animals could be as close as 100 m apart along the same transect. To minimize spatial autocorrelation, only tracks ≥100 m apart within the same forest stand were recorded (Bowman & Robitaille 1997).

Results

Field assessment of polygons

Approximately 20 km of transects were inventoried every year in each Supply Block, for a total of 170,264 m (Table 2). The observed distribution of tracks per polygon type differed ($P < 0.05$) from expected. In Supply Block F, 30 (93.8%) of 32 tracks were located in excellent- and high- quality polygons; two were found in low-quality polygons. In other Supply Blocks, all tracks (n = 76) were in excellent- and high- quality polygons (Table 2).

Habitats with American Marten tracks

Most (98.2%) American Marten tracks were found in circum-mesic, mature, and old mixed coniferous and conifer-dominated mixed stands (Table 2). Only two tracks were found in pure mature Lodgepole Pine stands (Table 2). The observed frequency of tracks per habitat type differed from expected ($P < 0.05$), with 94

Table 2. Winter distribution of American Marten tracks according to polygon and habitat types, central interior British Columbia.

Unit	Supply blocks							
	F (2005–2007)		E (2006–2008)		C & B (2006–2008)		All (2005–2008)	
	Total transect length – m (%)	Number of American Marten tracks (%)	Total transect length – m (%)	Number of American Marten tracks (%)	Total transect length – m (%)	Number of American Marten tracks (%)	Total transect length – m (%)	Number of American Marten tracks (%)
Polygon type								
Low	13,887 (34.2)	2 (6.3)	16,837 (39.5)	0 (0)	29,968 (34.4)	0 (0)	60,692 (35.7)	2 (1.9)
Medium	2,265 (5.6)	0 (0)	2,700 (6.3)	0 (0)	12,930 (14.9)	0 (0)	17,895 (10.5)	0 (0)
High	5,391 (13.3)	5 (15.6)	13,711 (32.2)	12 (80)	21,441 (24.6)	27 (44.3)	40,543 (23.8)	44 (40.7)
Excellent	19,017 (46.9)	25 (78.1)	9,373 (22)	3 (20)	22,744 (26.1)	34 (55.7)	51,134 (30)	62 (57.4)
Total	40,560 (100)	32 (100)*	42,621 (100)	15 (100)*	87,083 (100)	61 (100)*	170,264 (100)	108 (100)*
Habitat type								
Immature-pole	9,322 (23)	0 (0)	13,021 (30.6)	0 (0)	25,784 (29.6)	0 (0)	48,127 (28.3)	0 (0)
Young	3,770 (9.3)	0 (0)	2,368 (5.6)	0 (0)	12,685 (14.6)	0 (0)	18,823 (11.1)	0 (0)
Mature + old pure Lodgepole Pine or Black Spruce	2,974 (7.3)	2 (6.3)	2,510 (5.9)	0 (0)	1,674 (1.9)	0 (0)	7,158 (4.2)	2 (1.9)
Mature + old mixed coniferous + conifer-dominated mixed stands	24,494 (60.4)	30 (93.7)	24,722 (58)	15 (100)	46,940 (53.9)	61 (100)	96,156 (56.5)	106 (98.1)
Total	40,560 (100)	32 (100)*	42,621 (100)	15 (100)*	87,083 (100)	61 (100)*	170,264 (100)	108 (100)*

*Observed American Marten track distribution significantly different from expected ($P < 0.05$).

(87%) tracks recorded in mixed coniferous stands (Fig. 2). Lodgepole Pine was present in 64 (68%) of these stands, and was the dominant species in 26 (27.7%) of them.

American Marten tracks were found in stands that were, on average, 156.6 years old (n = 107, SD = 44.7; median = 150.5 years), with a 52.3% (± 10.4%; range = 30–75%) canopy closure, and a 39.9 m²/ha (± 12.4 m²/ha) basal area (Fig. 2). Most stands (92.6%) had 20–49 cm dbh trees, and <20% shrub cover (Fig. 2).

Discussion

In this study, American Martens in the Sub-boreal Spruce Biogeoclimatic Zone used late-successional conifer-dominated stands in winter, as was previously found (Lofroth 1993, Proulx *et al*. 2006). Martens selected mixed-coniferous stands with well-developed ground structure (i.e. accumulations of coarse woody debris, including large logs and decaying stumps, shrubs and shade-tolerant

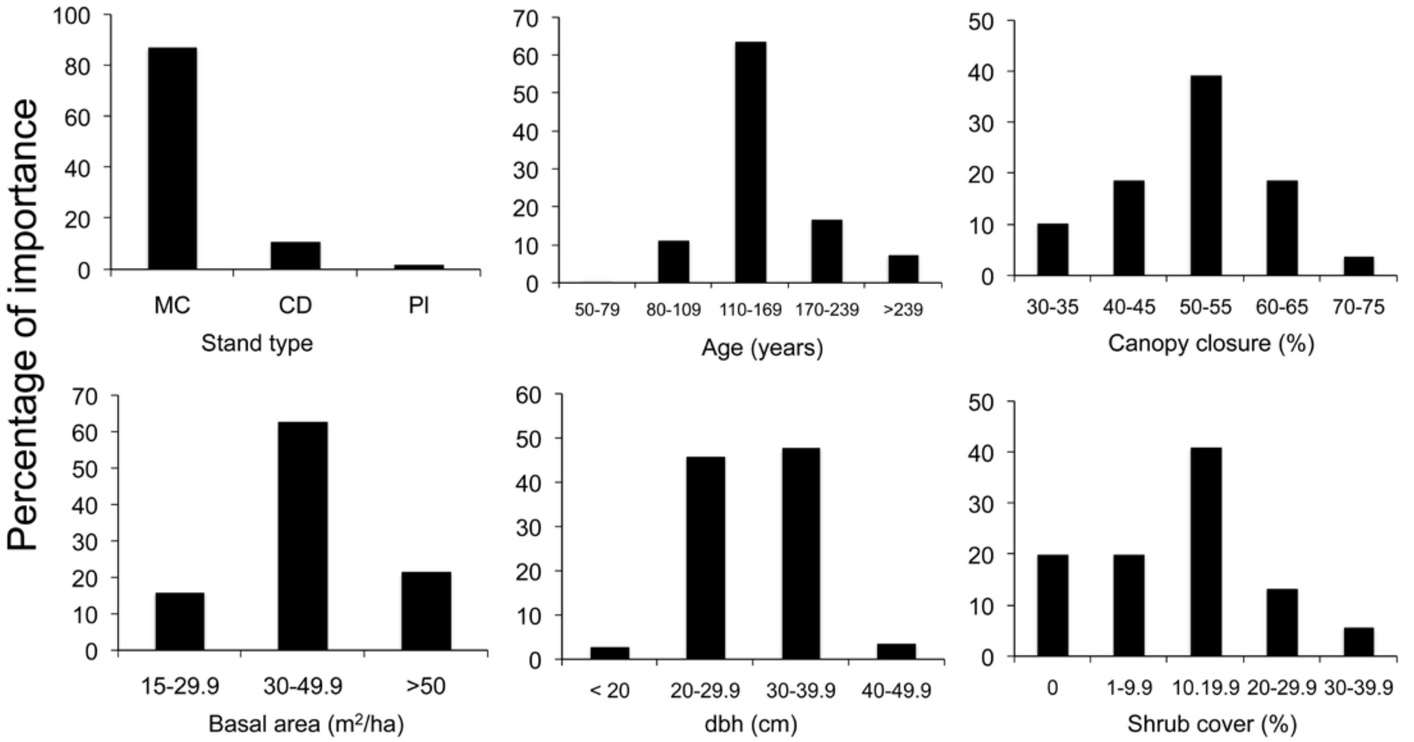

Fig. 2. Characteristics of stands used by American Marten in winter in Sub-boreal Spruce forests of British Columbia, December to February 2005–2008 (MC – mixed coniferous; CD – coniferous–deciduous; Pl – Lodgepole Pine).

seedlings), and a multi-storied canopy over pure Lodgepole Pine stands that have little ground structure (open grounds with poor coarse woody debris and scattered shrubs) and a single-storied canopy (Burnett 1981, Buskirk *et al*. 1989, Fager 1991, Wilbert 1992).

Lodgepole Pine was present, and often was the dominant species, in mixed coniferous stands used by American Martens. The extensive logging of stands where Lodgepole Pine occurred with other conifers would be likely to affect American Marten winter habitat adversely. In the last decade, based on various guidelines, discussion papers, and an intent to emulate natural disturbance events such as fire (BC Environment and Forests 1995, DeLong & Tanner 1996, MSRM 2004), forestry companies have harvested large tracts of land in central British Columbia, often leaving only small, disconnected patches of late-successional coniferous forests. Habitat fragmentation (often measured by the percentage of the landscape that is unforested) even at low levels (i.e. 20–30%) of a Marten's home range, and the loss of forest interior (sheltered, secluded environment away from the influence of forest edges and open habitats) have negative effects on American Martens (Thompson & Harestad 1994, Hargis & Bissonette 1997, Chapin *et al*. 1998, Potvin *et al*. 2000). The loss of contiguous late-successional forests may result in local extirpation of American Martens (Bissonette *et al*. 1997). Because habitat loss alters landscape connectivity, Martens may be unable to disperse in fragmented habitats. In Supply Block F, Proulx (2007) reported a drastic landscape change due to extensive logging of Lodgepole Pine in spruce- and Douglas-fir-dominated stands. He noted that forests valuable for American Martens were getting smaller in size and more disconnected from each other. While in the winter of 2005–-2006 he recorded one American Marten track per 518 m of snowtracking in late-successional forest stands, in the winter of 2006–2007, when timber harvesting was more extensive and removed long-established connectivity corridors (Proulx 1999), he recorded one American Marten track per 1,045 m of snowtracking. Proulx (2008) surveyed American Marten tracks in three 250-m-wide corridors comprised of late-successional mixed coniferous stands. He also inventoried furbearer tracks in immature and young stands located immediately adjacent to the corridors. Proulx (2008) found American Marten tracks only in the corridors. Martens did not use immature and young forests to travel across fragmented landscapes. The extensive harvesting of habitats suitable to American Martens may isolate animals into metapopulations (Dykstra 2004) or force them to use less ecologically valuable younger forests (Proulx 2006a), and ultimately impact on the species's persistence in managed landscapes (Dykstra 2004).

Current forestry practices in this study area appear incompatible with the conservation of American Marten winter habitat. American Marten tracks were most numerous in ≥110 year-old stands. Sustainable management plans in the Central Interior are generally based on 80-year rotations; therefore, stands that are beginning to provide Martens with mature habitat characteristics are harvested. There are no minimum requirements for canopy closure or basal area in stands left as reserves in managed landscapes (BC Environment and Forests 1995). There is little concern about the size and spatial distribution of stands that are adjacent to extensive clear cut blocks (Proulx in press).

More importantly, American Martens select resources at different spatial scales, including region, home range, stands within home range, and particular sites within stands (Johnson 1980, Lofroth 1993). Marten home ranges consist of a series of late-successional stands that are either contiguous or connected by adequate natural corridors. Like most carnivores, American Martens have cognitive maps (Peters 1978, Powell 2000, Proulx 2005) of where they live, in that they do not use space within their home range randomly. Today, forestry companies use quasi-spatial forest management models that retain discrete 'representative' ecosystems independent of specific habitat requirements (e.g. Bunnell *et al*. 2003, Huggard 2004, MSRM 2004), and focus on the conservation of a few stand elements (e.g. Bunnell *et al*. 1999), that do not incorporate multi-scale habitat requirements of animals. For a forest management plan to be effective for the conservation of American Marten, it must be based on spatially-explicit data that relate to specific habitat requirements. Winter habitat requirements of American Marten are well known, and with the use of forest inventory datasets such as VRI, winter distribution across landscapes can be predicted. Forests used by American Martens in winter are also preferred by Fisher (Proulx 2006b), a species at risk in BC; Mule Deer *Odocoileus hemionus* (Proulx in press); woodpeckers and other birds associated with late-successional forests (Davis *et al*. 1999, Gyug 1996, Proulx 2006c). Conserving American Marten winter habitat is also, therefore, conserving a wealth of sympatric species across landscapes.

American Martens are easily trapped and susceptible to overharvest because of their relatively low natality and large home ranges (Banci & Proulx 1999). When subjected to both habitat degradation and intense trapping pressure, species's resilience may decrease and populations may be compromised (Banci & Proulx 1999). This is particularly true in managed forests where expanding road networks associated with timber harvesting increase trapper access (Soukkala 1983, Hodgman *et al*. 1994, Thompson 1994). Knowing that winter habitat of American Marten may be compromised in central interior British Columbia, conservation efforts should focus on the development of sound forest management plans to ensure that this species does not join the provincial list of species at risk.

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