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# **Ecology of Fishers in the Sub-boreal Forests of North-central British Columbia**

## **Final Report**

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Richard D. Weir and Fraser B. Corbould  
June 2008

PWFWCP Report No. 315

The Peace/Williston Fish & Wildlife Compensation Program is a cooperative venture of BC Hydro and the provincial fish and wildlife management agencies, supported by funding from BC Hydro. The Program was established to enhance and protect fish and wildlife resources affected by the construction of the W.A.C. Bennett and Peace Canyon dams on the Peace River, and the subsequent creation of the Williston and Dinosaur Reservoirs.

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## EXECUTIVE SUMMARY

Fishers (*Martes pennanti*) are medium-sized carnivores of the Mustelidae (weasel family) that are uncommon predators in the forests of central British Columbia. Although much of British Columbia's landscape historically supported viable populations of fishers, it is believed that the distribution and abundance of the species has declined over the past several decades. Fishers are classified as Identified Wildlife under the Forest and Range Practices Act in British Columbia because they are vulnerable to human activities, particularly vegetation change from forest practices and over-harvest by trapping. At the onset of this study, much of our understanding of fisher ecology was based on work completed in the hardwood-dominated forests of northeastern United States and the boreal forest of central Canada. Substantial gaps in our understanding of fisher ecology in western North America existed.

To facilitate the improved management of fishers and their habitat in north-central British Columbia, we examined the habitat relationships, spatial organization, and behaviour of fishers in an industrial forest landscape of the Sub-Boreal Spruce (SBS) biogeoclimatic zone by monitoring radio-tagged fishers between 1996 and 2000. Within the 1,830-km<sup>2</sup> study area in the Williston region, we captured 21 fishers (6 males, 15 females) in 9,616 trap-nights between October 1996 and March 2000 (0.69 fishers/100 trap-nights). We followed 7 to 12 radio-tagged fishers per year, with an average of 298 radio-days of monitoring per fisher (SD = 317 days,  $n = 20$ ).

The fisher population in the Williston region appeared to be relatively stable and possibly near its carrying capacity. We observed average adult and low juvenile survival of fishers, with infrequent recruitment into the population. Nine of 16 fishers died while being monitored: 3 were killed by trappers, 2 died from interspecific conflict, 1 died of starvation, 1 died in a live-trap accident, 1 died when the tree she was in blew down, and 1 cause of death was undetermined. The mean annual survival of fishers  $\geq 1$  year old was 0.71% (SD = 0.35,  $n = 3$  years). We monitored 8 female fishers  $\geq 2$  years old over 18 potential individual whelping seasons. Five females produced 12 litters, with a mean annual whelping rate of 69% (SD = 22%). We could not conclusively identify the presence of young with any females that whelped during our study but, based on ancillary information, the estimated minimum proportion of litters having  $\geq 1$  young survive to 40 days was 42% and to the fall period (i.e., livetrapping period) was 25%. Although the population appeared to be stable, the average density of fishers in the study area was very low: 11.2 fishers/1,000 km<sup>2</sup> at 31 October and 8.6 fishers/1,000 km<sup>2</sup> at 31 March, which were among the lowest densities documented for fishers. Although the Williston fisher population sustained a harvest rate of at least 9% (1 fisher/1,000 km<sup>2</sup>), it is unknown if a higher level of harvest would be sustainable without experimental testing. Because of the low density and relatively dispersed

nature of females, a broader-scale approach than currently employed by management agencies, including managing for sex ratios closer to 1:1, is needed to maintain viable and resilient fisher populations in northern SBS forests.

The spatial organization of fishers in north-central British Columbia was similar to that exhibited by the species in other areas, although home ranges of radio-tagged fishers were larger than elsewhere. Aggregate 95% fixed kernel estimates of home ranges were 49 km<sup>2</sup> (SD = 16, n = 6) for female fishers and 219 km<sup>2</sup> for males (n = 2). Home ranges of females were smaller than males and tended to be relatively exclusive of other females, whereas males overlapped extensively with females. Home ranges were generally larger during winter than non-winter. Large areas of the landscape were unoccupied by resident fishers and may have been unsuitable for supporting this species. Thus, dispersing individuals may have remained transient for up to 2 years until suitable unoccupied habitat became available through the death of conspecifics. At least 6 of 11 transient fishers that we monitored died before establishing home ranges and only 1 of 6 juvenile fishers successfully established a home range while being monitored. Fishers moved widely throughout the landscape while transient (e.g., crossing larger rivers), but potentially at great peril; 1 juvenile female died 77 km away from her capture location after moving at least 135 km in 45 days. The distances between natal and established home ranges were up to 41 km apart, which was consistent with other studies. Our spatial organization data suggest that the quality of the landscape for fishers in the Williston region was poor, and not uniformly distributed, relative to other regions of North America.

Both short- and long-terms factors affected the behaviour of fishers. Fishers were active throughout the diurnal period, with some minor peaks in activity around mid-day and early evening. During non-winter, the likelihood of fishers being active increased with ambient temperature. The diurnal activity of males increased during the mating season, compared to non-mating periods, whereas activity decreased during the mating season for females without young. Females with young were less likely to be active than females without young. Identifying these factors provides a better understanding of how rates of activity, and thus energy expenditure, change through time. In addition to diurnal activity patterns, we assessed the effect of ambient temperature, season, sex, body mass, and location within their home range on the type of rest structure selected by radio-tagged fishers. We located fishers using 54 different rest sites on 60 occasions. Fishers rested most frequently on branch rest structures (57%), followed by CWD (22%), cavity (17%), and ground (5%) rest structures. Fishers were more likely to use cavity rest sites than branch sites near the centre of their home ranges. When the ambient temperature was colder than -11°C, fishers were most likely to select a CWD structure for resting. Thermal attributes of the 4 types of rest sites, although

not the only factor that affected selection of rest sites, likely affected the structures that fishers selected and helped explain the patterns that we observed.

Female fishers followed a consistent pattern of reproduction each spring. Females did not produce offspring each year, but litters were born during a small time period each spring, with a mean parturition date of 4 April ( $SD = 4$  d,  $n = 12$ ). Females used between 1 and 3 trees as reproductive dens during the rearing period, which generally lasted between early April and late May. Natal dens (i.e., whelping sites) were used for between 30 and 49 d ( $\bar{x} = 41$  d,  $SD = 7$ ,  $n = 9$ ). We observed females switching to maternal dens (i.e., secondary reproductive dens) on 5 occasions. Parturient fishers spent, on average, 11 h each day (range: 3.9 – 24 h,  $n = 50$  monitoring-days) at their reproductive dens while being monitored. The total time spent at the den each day generally diminished as the denning period progressed. Our data supported the hypothesis that females timed the start of excursions away from their reproductive dens to coincide with peak daily temperatures.

Black cottonwood trees were the only feature used as reproductive dens ( $\bar{x} = 109$  cm dbh,  $SD = 25$ ,  $n = 13$ ) and cavities in large-diameter cottonwood trees appeared to be critical habitat elements for fishers in the SBS. However, very little is known about the rates and characteristics of cavity formation within this tree species. To address this knowledge gap, we conducted 2 trials that investigated large-diameter cottonwood trees ( $>50$  cm dbh) and their cavities. Female fishers used large-diameter black cottonwood trees that had larger stem diameter, fewer large branches in the top quarter of the main bole, less bark remaining, and the presence of a major fork in bole than other large cottonwood trees available within the study area. Despite these differences, the inherent morphology of den trees had a large influence on characteristics we used to describe potential fisher den trees. We concluded that cavities in large-diameter cottonwood trees provided features and conditions that are beneficial to denning female fishers and their young: protection from weather, thermally advantageous microenvironment (i.e., greater opportunities for heat absorption), protection and concealment from potential hazards, and elevated vantage points.

To assess the functional aspects of cavities in large-diameter cottonwood trees, we monitored 2 natural cavities (1 large, 1 small) on the same tree to assess if entrance, chamber, and bole characteristics affected the thermal properties of a potential den cavity.

Temperatures inside the 2 cavities were more stable than external ambient temperatures. The temperature inside the larger cavity was typically warmer than the mean daily ambient temperature for the entire day. Chamber height, thickness of holding wood for greater insulating value, southern-facing entrance to allow solar radiation to enter the cavity, and smaller entrance opening to reduce opportunities for convective heat loss appeared to contribute to the overall stability of the temperature inside the tree cavity.

Almost all activities of fishers occur in forested environments and forest harvesting is capable of having widespread effects on their populations in the province. Because of the apparent association of fishers with features of late-successional forests, forest-harvesting activities that focus on these forest age classes may detrimentally affect fisher populations by altering and degrading the abundance and distribution of the resources that they require. By monitoring radio-tagged fishers, we attempted to identify the habitat features upon which radio-tagged fishers made resource selection decisions when selecting home ranges, stands, patches, and individual habitat elements.

At the landscape scale, the probability of a home range area being occupied by a resident fisher decreased with the increasing amounts of open area (i.e., wetland ecosystems and recently logged areas). Our data suggested that a 5% increase in the percentage of a potential home range in open areas (e.g., logging 245 ha in a female's home range over a 12-year period) decreased the probability of occupancy by 50%. From this, it is clear that the rate of forest harvesting can have profound effects on the ability of the landscape to support sustainable populations of fishers.

Within their home ranges, fishers were selective in the stands that they used in their day-to-day life. We identified 2 models that best explained the selection of stands by radio-tagged fishers. According to the first model, which was based upon site series, the odds of fishers selecting Spruce-Dry stands (SBSmk1/04, SBSmk1/05, or SBSmk2/03 site series) were 3.5 times lower than stands classified as Spruce-Zonal (SBSmk1/01, SBSmk2/01, or SBSwk2/03 site series) and 5.4 times greater for Spruce-Wet (SBSmk1/09, SBSmk2/06, or SBSwk2/06 site series) stands than Spruce-Zonal stands. The second model, based upon structural features found in each stand, predicted that the probability of use of a stand was positively related to the percent of high-shrub cover and volume of large (>20 cm diameter) elevated coarse woody debris (CWD), but negatively related to the percent of coniferous tree cover, deciduous tree cover, and density of trees with rust brooms. These 2 models were good predictors of the selection of stands within the home range by fishers and are useful for predicting the effects of habitat alterations on the utility of stands for fishers.

Fishers were highly selective for the patches they used for resting, often selecting patches of habitat that were substantially different than typical sites within each stand. Fishers selected patches of habitat with higher densities of trees with rust brooms; they were 2.4 times more likely to select a patch with 25 stems/ha of trees with rust brooms (i.e., 1 tree in a 400-m<sup>2</sup> patch) than one with no rust brooms. Fishers also selected patches with more elevated large logs that provided winter resting sites; the probability of a patch being selected for resting was 1.34 times higher in patches with 16 m of estimated rest-site potential than one with no rest-site potential. We did not detect selection for patches when fishers were active, or those in which females situated reproductive dens.

Fishers seemed to fulfil their most stringent habitat requirements by selecting specific trees and other elements for denning and resting. We identified fishers using specific elements at 55 rest sites and 13 reproductive dens (8 natal, 5 maternal). Rest sites included 39 arboreal (9 cavities and 30 branch or rust brooms), 11 CWD (single piece), 2 CWD piles, and 3 ground sites. Radio-tagged fishers showed high levels of selectivity for trees that they used for resting, being more likely to select a tree if it was either a large-diameter aspen or cottonwood tree with decay, large-diameter spruce tree with rust brooms, or a spruce or subalpine fir tree with rust brooms. At CWD rest sites, fishers rested inside hollow pieces of CWD ( $n = 2$ ) or in subnivean sites underneath CWD ( $n = 9$ ). Probability of use was positively related to CWD piece size, length, and elevation above the ground. Female fishers reared offspring exclusively in old, large-diameter ( $\bar{x} = 109.5$  cm, SD = 24.7 cm,  $n = 13$ ), black cottonwood trees that were alive (but declining) or dead.

Most habitat features for which fishers showed high specificity were the result of the natural processes of disease, death, and decay of trees typically found in late-successional forests. These habitat attributes consistently occurred in a very restricted range of sites (e.g., a single tree species), which suggests that only a narrow range of habitat conditions meet these requisites. Although these habitat attributes were rare in the landscape, they were also targeted during forest-harvesting activities. This highlights the need to ensure an adequate supply of these features are maintained and promoted, both spatially and temporally, in managed forests.

Habitat considerations for fishers can be included in management decisions throughout all phases of forest planning and application. Providing quantified measures of the importance of identified habitat features is useful for habitat conservation because it provides managers with a prioritized, target-based focus for management guidelines. It also gives managers a better method to predict the impacts of their decisions on identified habitats for fishers. Habitat conservation can best be achieved by considering the distribution and abundance of habitats required by fishers throughout the landscape, within the home range, and in residual and managed stands.

The Williston study was the first study of fishers conducted in north-central British Columbia and has greatly advanced our understanding of fisher ecology in the sub-boreal forests of British Columbia. Information on the fundamental characteristics of fisher populations and habitats will help managers and trappers to better manage fisher populations. If the conservation of fisher populations is a concern, land managers need to consider the rate and extent of forest harvesting when developing forest management plans; this is particularly important when large tracts of land are harvested or impacted (e.g., mountain pine beetle infestation). Reliance upon habitat conservation measures in the Forest and Range Practices Act may not achieve an adequate distribution and abundance of these important habitats for

fishers in the Williston region. To ensure habitat is maintained for fishers in the short- and long-term, forest-harvesting prescriptions must be developed to provide sufficient retention and recruitment of important structural attributes during all stages of forest development. Habitat considerations to benefit fishers can be included in management decisions throughout all phases of forest planning and management. A multi-scaled approach to habitat management is recommended. Our work also suggests several opportunities for the enhancement of degraded habitats for fishers.

As of June 2008, 3 peer-reviewed publications have been produced from this project:

- Weir, R., F. Corbould, and A. Harestad. 2004. Chapter 9 - Effect of ambient temperature on the selection of rest structures by fishers. Pages 187-197 in D. J. Harrison, A. K. Fuller, and G. Proulx, Editors. Martens and Fishers (*Martes*) in Human-altered Environments: An International Perspective. Springer Science+Business Media, New York, New York, USA.
- Weir, R. D., and F. B. Corbould. 2006. Density of fishers in the Sub-boreal Spruce biogeoclimatic zone of British Columbia. Northwestern Naturalist 87:118-127.
- Weir, R. D., and F. B. Corbould. 2007. Factors affecting diurnal activity of fishers in north-central British Columbia. Journal of Mammalogy 88:1508-1514.

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## 1.0 INTRODUCTION

Fishers (*Martes pennanti*) are medium-sized carnivores of the Mustelidae (weasel family) that occur in the temperate and boreal forests of North America. Fishers are associated with forested ecosystems, from the hardwood forests in the east to the montane coniferous forests in the west (Powell 1993). Fishers are uncommon, but important, predators in the forests that they occupy. Within British Columbia, fishers occur throughout much of the lowland forested areas in the interior of the province and in the Peace River and Fort Nelson Lowland areas east of the Rocky Mountains (Weir 2003). Although much of British Columbia's landscape historically supported viable populations of fishers, populations in the province appear to have declined over the past several decades, with populations possibly disappearing from some southern areas of the province (Weir 2003).

Although their contribution is small, fishers are a valued component of the fur harvest in British Columbia. Fisher pelts are moderately valuable relative to other furbearers, ranking between 6th and 8th in average value per pelt since 1993-94 in the province (Weir 2003). Between 1994 and 2002, fishers accounted for an average of about \$12,000, or 0.9% of the total value of furs harvested in British Columbia (Weir 2003). Fishers can be trapped by qualified trappers on traplines and private lands in the central and northern portions of the province; no hunting season exists for fishers.

Much of our understanding of fisher ecology is based on work completed in the hardwood-dominated forests of north-eastern United States and the boreal forest of central Canada. In these areas, fishers appear to be habitat generalists, using a wide variety of forest types to acquire their resources, but generally avoid habitats that lack overhead cover (Kelly 1977, Douglas and Strickland 1987, Arthur and Krohn 1991, Powell 1993). Fishers in eastern North America have small intrasexually exclusive home ranges averaging 14 km<sup>2</sup> and 34 km<sup>2</sup> for adult females and males, respectively (Powell 1994a). Density estimates in these areas range from 50 to 385 fishers per 1,000 km<sup>2</sup> (Powell and Zielinski 1994, Fuller et al. 2001).

Although a considerable amount of work has been completed on fishers in eastern portions of their range, substantial gaps in our understanding of fisher ecology in western North America still exist. In the coniferous-dominated forests of western North America, the composition of forest types, climatic conditions, and prey communities are different than in eastern North America and likely result in different patterns of resource use and behaviour by fishers. Indeed, studies recently completed in Oregon, California, and British Columbia suggest that several aspects of fisher ecology in western North America are considerably different than elsewhere (Weir 1995a, Aubry et al. 2002, Zielinski et al. 2004a). Fisher diets in British Columbia (Weir et al. 2005) and California (Zielinski et al. 1999) appear to be substantially more diverse than those of fishers in eastern North America (Martin 1994).

Unlike their eastern counterparts, fishers inhabiting western forests appear to be habitat specialists and require late-successional seral stages or structural features for foraging, resting, and whelping (Jones 1991, Seglund 1995, Weir 1995a). An early conservation assessment suggested that fishers in the Pacific Northwest region of the United States were dependent upon late-successional forests to provide adequate resources and so may be more sensitive to habitat alterations than their eastern conspecifics (Ruggiero et al. 1994). The spatial organization may also be considerably variable as the size of fisher home ranges of some western North American populations have been found to be 2 to 3 times larger than those of eastern North American populations (Jones 1991, Heinemeyer 1993, Dark 1997); a study in south-central BC, that monitored primarily translocated animals, also observed these disparate home range sizes (Weir 1995a). These potential differences in resource use and behaviour among fishers in different portions of their range need to be clarified to improve understanding of fisher ecology in British Columbia.

Special management regulations were instituted in British Columbia after fishers were listed as vulnerable in 1992 (BC Conservation Data Centre, unpublished data); this included a 2-year closure of trapping in the province. Fishers are classified as Identified Wildlife under the Forest and Range Practices Act in British Columbia because they are vulnerable to human activities, particularly habitat change via forest practices. Fishers are blue-listed by the British Columbia Conservation Data Centre because of this and their vulnerability to over-harvest by trapping (Lofroth 2004). Regulatory measures, however, have potentially provided little benefit because they have had little effect on fisher populations (e.g., fishers were often incidentally trapped during the closed seasons) or because regulations (i.e., habitat and population management decisions) are based on fisher ecology in eastern North America that may be inappropriate. As such, forest management prescriptions that are more detailed and BC-specific are required to ensure the maintenance of fisher habitat in British Columbia's industrialised forests. Fishers, which are reported to be easily trapped, are sensitive to trapping pressures (Powell 1993, Banci and Proulx 1999) and the assumption that trapped fisher populations in western North America behave similarly to those in eastern areas may result in inappropriate management of this resource (Powell and Zielinski 1994).

The broad goal of this study was to collect information on the ecology of fishers in an industrial forest landscape of north-central British Columbia. Our intent was to examine habitat relationships, spatial organization, and behaviour of fishers to improve their management in the province. Of particular emphasis was the identification of limiting factors for fisher habitats and populations that might facilitate habitat conservation and population persistence.

We prepared this report to document all data collected during the term of the project. Sections with few data were included because those data may be important to future

researchers even though their value cannot be assessed fully at this point. Chapters 7 and 8 and part of Chapter 9 have previously been published in peer-reviewed journals (Weir et al. 2004, Weir and Corbould 2006, Weir and Corbould 2007). The remainder of Chapters 6 through 11 may be submitted for publication in peer-reviewed journals in the future.

This project was funded by the Peace/Williston Fish and Wildlife Compensation Program (PWFWCP) – a joint venture between BC Hydro and the provincial fish and wildlife agencies, and Forest Renewal British Columbia (FRBC). Partners in the project were the PWFWCP, the British Columbia Ministry of Water, Land and Air Protection (WLAP), Slocan Group Mackenzie Operations, Abitibi Consolidated Ltd., and the British Columbia Trapper's Association. A. Bowser, G. Carlson, H. Davis, A. Hahn, V. Hawkes, J. McCormick, J. Perreault, and D. Wellwood tirelessly monitored traps, radio-tagged fishers, collected radiolocations, measured habitat, entered data, and were key to the success of this project. Thanks to Tony and James for working hard to get good data and always making fieldwork fun. The project was conducted co-operatively with the FRBC-funded Northern Wolverine Study, whose personnel generously assisted in the live capture and aerial monitoring of fishers for this study: many thanks to E. Lofroth, D. Reid, W. Harrower, V. Hawkes, C. Hoodicoff, V. Larsen, M. Leung, J. Proche, E. Refuse, D. Wellwood and the reams of volunteers from this project. M. McAdie, DVM, performed surgeries in the field to tag fishers with intraperitoneal transmitters, and willingly helped monitor live traps. H. Schwantje, DVM, conducted post-mortems on many of the radio-tagged fishers that died during this study. L. Frey and E. Stier safely piloted us during many aerial telemetry flights. C. Kyle completed genetic analyses to assess relatedness among our fishers. J. Campbell, R. Critchlow, W. Harrower, and J. McCormick fearlessly scaled and measured the den trees and other large-diameter cottonwood trees. Special thanks to Pacific Arborists (Vancouver, BC) for donating some of the tree-scaling equipment. S. Barry assisted with the generation of the randomly situated home ranges for the landscape analysis. Conversations with W. Harrower greatly facilitated the habitat analyses. We would also like to express our gratitude to Slocan Group Mackenzie Operations and Abitibi Consolidated Ltd. for providing us with living facilities, access to their power utilities, and “camp privileges” at their Munro and Mesilinka Logging Camps. H. Davis deserves undying gratitude for tolerating long field absences and endless days fixated on writing; her patience and understanding cannot be fully thanked. H. Davis, D. Heard, and E. Lofroth provided helpful comments on earlier drafts of this report.

## 2.0 STUDY AREA

Our study area covered approximately 1,830 km<sup>2</sup>, was centred 70 km north-west of Mackenzie, British Columbia (55° 19'N, 123° 6'W), and was entirely within the Williston Reservoir watershed (upper Peace River drainage; Fig. 2-1). The topography in the area was characterized by a gently rolling plateau rising from the Rocky Mountain Trench (Williston Reservoir, full pool 672 m ASL) in the east to the slopes of the Wolverine and Swannell Range mountains in the west. The plateau was drained by a series of small creeks with poorly developed or non-existent floodplains. Floodplains with extensive riparian zones only occurred along portions of the Manson and Mesilinka Rivers.

The study area was within the Sub-Boreal Interior ecoprovince (Omineca Mountains ecoregion, including the Parsnip Trench, Southern Omineca Mountains, and Manson Plateau ecosections; Demarchi 1995). The study area was all within and the Sub-Boreal Spruce (SBS) biogeoclimatic zone (Meidinger and Pojar 1991).

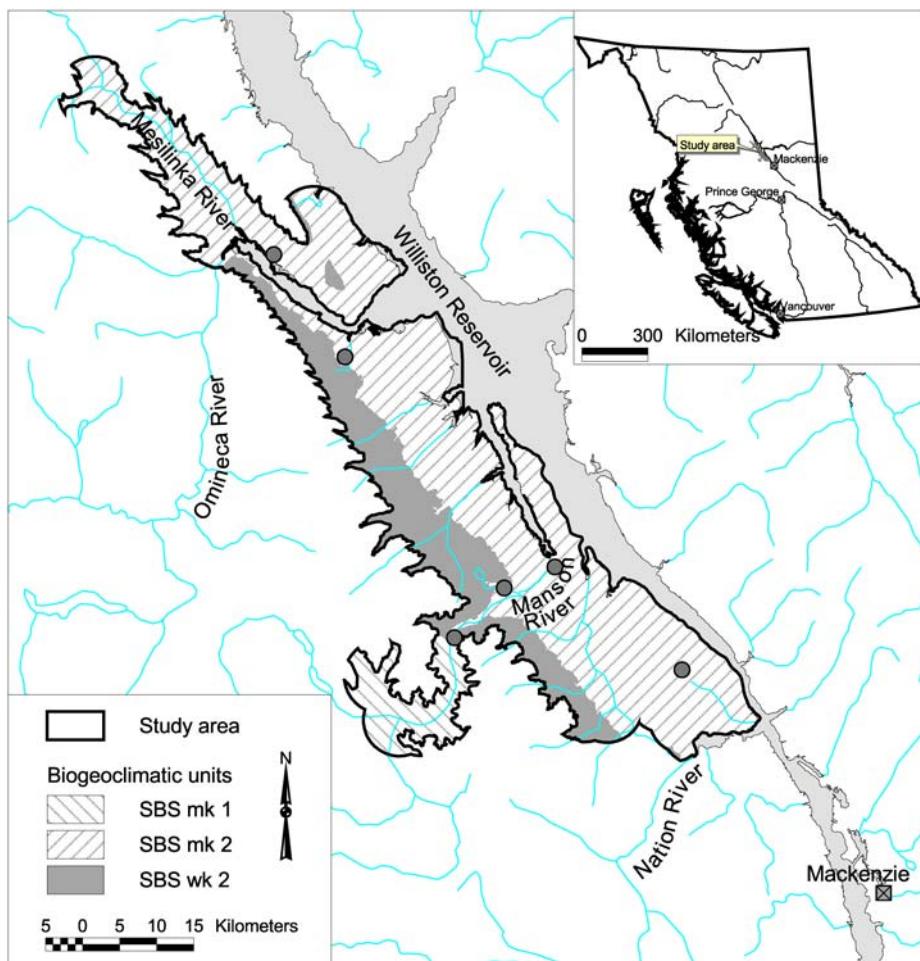


Figure 2-1. Location and biogeoclimatic zones of the Williston study area in north-central British Columbia. Climate stations are identified by grey circles.

The boundary of the study area was defined by the extent of the SBS zone within our live trapping and animal monitoring activities. The 2 SBS subzones (moist-cool [SBSmk1 and SBSmk2] and wet-cool [SBSwk2]) within the study area were the most northerly SBS subzones in the province, although the SBSmk subzone is identified as the “typical” SBS subzone (Meidinger et al. 1991). The SBSmk covered 80% of the study area, and was situated at elevations below 800 m, whereas the SBSwk occurred between 800 and 1,100 m (MacKinnon et al. 1990). Annual precipitation averages 690 mm in the SBSmk and 905 mm in the SBSwk, and snowfall averages 335 cm/year and 1,075 cm/year in the SBSmk and SBSwk respectively (MacKinnon et al. 1990). Snow cover in the study area generally lasted from mid-November until mid-April. Peak snow depths averaged 91 cm ( $SD = 30$  cm,  $n = 4$ ) and typically occurred in mid-March. The mean annual temperature during the study was 2°C, with temperatures ranging between -47°C and +36°C.

Forests in the SBSmk were dominated by hybrid spruce (*Picea glauca* x *engelmannii*), lodgepole pine (*Pinus contorta*), black spruce (*Picea mariana*), and subalpine fir (*Abies lasiocarpa*), with deciduous components of trembling aspen (*Populus tremuloides*) and paper birch (*Betula papyrifera*). Black cottonwoods (*Populus balsamifera* spp. *trichocarpa*) occurred as a minor element in riparian-type ecosystems and occasionally in other areas with sub-hygric or wetter ecological moisture regimes. The composition of forests in the SBSwk was similar to the SBSmk, but hybrid spruce and subalpine fir were more prevalent in the SBSwk. Common understory shrubs were prickly rose (*Rosa acicularis*), black huckleberry (*Vaccinium membranaceum*), black twinberry (*Lonicera involucrata*), kinnikinnick (*Arctostaphylos uva-ursi*), and black gooseberry (*Ribes lacustre*).

Forest succession following natural disturbances in the SBSmk and SBSwk are comprised primarily of lodgepole pine, while later successional stands are dominated by spruce and subalpine fir. The moist cool subzone typically had a natural disturbance regime of frequent, large-scale fires with a mean return interval of about 127 years, whereas the wet cool subzone had a mean fire return interval of 270 years (DeLong 1998). Insect outbreaks may also be an important natural disturbance factor in these areas (Wong et al. 2004).

Human-caused habitat disturbances in or immediately adjacent to the study area were fairly recent and large. With the flooding of the Rocky Mountain Trench by the Williston Reservoir in 1968, all lands below 672 m elevation were submerged; much of this were riparian forests along the lower Omineca, Manson, and Parsnip Rivers. Forest harvesting had occurred extensively throughout the study area over the past 30 years; 532 km<sup>2</sup> had been logged since 1970, representing 29% of the total study area. Forest harvesting and natural disturbances have resulted in a mosaic of seral stages throughout the study area.

The study area encompassed portions of 5 registered fur-harvesting traplines ( $\bar{x} = 1,039$  km<sup>2</sup>,  $SD = 347$ ). These traplines were active to varying degrees, as evidenced by the total

harvest of between 28 and 154 American martens (*M. americana*) per trapline during the 4-year study period ( $\bar{x} = 70$  martens/trapline, SE = 49; MWLAP, unpublished data).

### 3.0 GENERAL METHODS

#### 3.1 Capture and Handling

##### 3.1.1 Live Trapping

We used several different types of live-traps to capture fishers during the autumn and winter months between October 1996 and March 2000. We primarily used Havahart wire-cage traps (Models 1081 and 1089; approximately 24.5 cm by 31 cm by 81 cm). We placed traps in areas that appeared to be suitable habitat for fishers, or where we observed recent fisher tracks. We also used several log-cabin and barrel traps that were intended primarily to capture wolverines (*Gulo gulo*). The log-cabin sets were made of intermeshing logs with a trigger mechanism that released a log-pole door when bait was pulled from inside the trap (Copeland et al. 1995). Barrel traps consisted of a 45-gallon drum with a sliding door cut into one end (Banci 1987), similar in design to culvert traps used to capture bears. Log-cabin traps were permanent, while barrel traps could be moved to a preferred trap site, but with much more difficulty than wire-cage traps.

We selected trap locations within patches of habitat that had microsite attributes reported to be used by fishers (Weir 1995a). Traps were often set under or beside elevated pieces of coarse woody debris (CWD) or beneath the boughs of a group of regenerating conifers. Each wire-cage trap was set to ensure that trapped animals remained dry, insulated, and had a supply of food. We placed traps on beds of spruce or subalpine fir boughs and covered the top and sides of the traps with wax-coated cardboard boxes (i.e., tree seedling boxes). Traps were also lined inside with hay and covered with more boughs so that snow and wind would not penetrate the trap. Log-cabin and barrel traps did not require special insulation techniques for wind, but hay or straw was placed inside the barrel traps to insulate the animal from the metal structure. We baited each wire-cage trap with approximately 500 g of moose, grouse, salmon or duck meat. Log-cabin and barrel traps were baited with pieces of moose carcass (1.5 - 3 kg) or whole salmon (1 - 4 kg).

We took several actions to enhance the efficacy of the traps. Prior to setting the trap for the first time, the pan, cable, and door of each trap were lubricated with petroleum jelly and tested to ensure that the trap functioned properly. Vegetation near each trap site was scented with a combination of commercial fisher, marten and beaver lure and skunk oil. Scent was re-applied every 3-5 days. We checked traps once or twice daily and assessed the functioning of each trap every 2-3 days. When we captured non-target species in the traps (usually American martens), we fed them a small amount of strawberry jam to reduce the likelihood of hypoglycaemia and released them immediately. We closed and removed traps at locations where we captured American martens for more than 5 consecutive nights. For each trap that captured a fisher, we calculated the latency to first detection (LFD; Zielinski

and Stauffer 1996) as the number of nights that the trap was operational until the fisher was captured.

### 3.1.2 Immobilization and Tagging

Prior to immobilization, we estimated the body weight of each fisher to ensure that animals were administered appropriate dosages of anaesthetic. For fishers captured in Havahart traps, we used a handling cone to restrain the animal and administered drugs with a hand-held syringe. We injected fishers captured in log-cabin traps with anaesthetic using a pole syringe.

We used several anaesthetics to immobilize fishers. Fishers were immobilized using either a 10:1 mixture of ketamine hydrochloride:xylazine hydrochloride, a 5:1 mixture of ketamine hydrochloride:medetomidine hydrochloride, or a 1:1 mixture of tiletamine hydrochloride:zolazepam hydrochloride (Telazol®). To affix radiocollars, we administered 22 mg/kg of ketamine:xylazine, 10 mg/kg of ketamine: medetomidine, or 8 mg/kg of Telazol® to fishers. Before anaesthetising fishers for implant surgery, we administered Telazol® at 5 mg/kg to induce anaesthesia. Then, to maintain anaesthesia, we placed a mask over the animal's face and a mixture of isoflurane (Aerrane®) and oxygen was administered, delivered by a portable vaporiser. The concentration of isoflurane was initially 3% for induction and 1-2% for the maintenance of anaesthesia. Because of dramatic decreases in body temperature we observed during some immobilizations, we placed immobilized fishers in a sternal position over warm hot-water bottles while the animals were anaesthetised.

We measured, monitored, and marked fishers while they were immobilized. Sex, body weight, and cranial and skeletal measurements were documented. We also collected hair-root samples for genetic analysis and a premolar (PM1) tooth for cementum annuli analysis (Strickland et al. 1982); tooth samples were sent to Matson's Laboratory, Milltown MT, for aging. For individuals from which we could not extract a tooth, we classed fishers as adults or juveniles by palpating the sagittal crest and examining the level of tooth wear (Powell 1993). For morphometric comparisons, we classified individuals as either adult (>18 months old) or juvenile (5.5-7.5 months old) due to the timing of our captures and because skeletal metrics for fishers should not change once they are >1 year of age (Douglas and Strickland 1987; Powell 1993). For individuals that were >18 months old and measured on more than one occasion, an average value for their skeletal metrics was used to represent the individual. All other metrics were based on the first measurement for each individual. Respiration and cardiac rates, body temperature, and capillary refill time were recorded at regular intervals while the fishers were immobilized. We tattooed each fisher with a permanent identification number in their inguinal region. During the first trapping session, we also marked each fisher with a 3.4 cm x 1.0 cm nylon livestock tag (Nasco Farm and Ranch) in the pinnae of at

least one ear. Photographs were taken of the head, dorsal, and ventral regions of each fisher to assist in future identification.

We used 2 methods to radio-tag fishers: radiocollars and intraperitoneal implant transmitters. During the first 2 years of the study, we tagged fishers with external radiocollars (Holohil MI-2M [1996-97] or Telonics MOD-080 [1997-98]). In subsequent years, we tagged the fishers with intraperitoneal implant transmitters (Telonics IMP/300/L), which involved surgery conducted by a veterinarian in the field. Radiotransmitters were equipped with motion sensors (4-hour delay) to indicate mortality or a discarded transmitter.

Radiocollars were affixed to immobilized fishers following standard collaring procedures (Anderka 1987). We fitted radiocollars so that the collar circumference was about 3-4 cm greater than the circumference of the neck of the individual, and slightly less than the skull circumference. With each radiocollar that we attached in 1997-98, we inserted a spacer of 2 layers of cotton fire hose so that the spacer would rot and the collars would drop off after 12-18 months (Hellgren et al. 1988).

To implant intraperitoneal transmitters, a licensed veterinarian made a routine surgical preparation of the ventral midline was performed following hair removal. Hair removal was limited to an approximately 3 cm by 5 cm area to minimise heat loss subsequent to release. A skin incision was made caudal to the umbilicus. Subcutaneous tissue was bluntly dissected and the incision continued through the linea alba. The sterilised implant transmitter was then inserted into the abdominal cavity and tucked around the body wall, adjacent to the right kidney, dorsal to the intestines. The abdomen was closed with 3-0 absorbable suture materials. The incision was sealed with skin glue (Vetbond®).

Following our handling activities, we wrapped the fisher in a blanket to reduce the likelihood of hypothermia and placed them in the live trap to recover from anaesthesia. We released them from the live trap when they were fully recovered from the effects of the anaesthetic.

### 3.2 Radiotelemetry Monitoring

We located fishers using standard ground and aerial telemetry procedures (White and Garrott 1990). From the ground, we collected directional bearings from ground locations to the fisher with the use of a 3-element, collapsible Yagi antenna. We estimated actual locations and 95% error polygons from ground telemetry using Locate II software (Nams 1990). Fishers were located from the air using Cessna 182 aircraft with 2 bi-directional H-antennae mounted on the wing struts. For each aerial telemetry location, we recorded geocoordinates, time, site characteristics, overstory vegetation composition, and estimated precision of the location. We estimated the precision of each location using the 95% error polygons for ground locations and subjectively for aerial locations. We then classified each location into 1 of 6 precision categories for use in scale-based (i.e., habitat and home range)

analyses:  $\pm < 1$  m,  $\pm 1\text{-}30$  m,  $\pm 31\text{-}50$  m,  $\pm 51\text{-}100$  m,  $\pm 101\text{-}250$  m, and  $\pm 251\text{-}500$  m (Table 3-1). We assigned capture locations to the least precise category because of the potential bias (i.e., attracting fishers into habitats that otherwise may not have been used) of these data. We did not use radiolocations with error estimates  $> 78.5$  ha (i.e., 500 m radius) for habitat or home range analyses.

### 3.3 Weather Measurements

We recorded temperatures and snow depths at 5 climate stations located throughout the study area (Fig. 2-1). We collected daily maximum and minimum temperatures, total snow depth, and total fresh snowfall during the previous 24 hours at these stations. We added remote temperature data loggers (Optic Stowaway®) to record hourly temperatures at all climate stations from October 1998 onwards. Climate stations were established under typical forest canopy at least 10 m from the forest edge in well-ventilated, shaded locations; temperature devices were placed approximately 2 m above the ground. In December 1998, we also began to collect data using a remote weather station comprised of a sonic ranger sensor, temperature probe and remote datalogger (Campbell Scientific Canada, Edmonton, AB) to record snow depth and ambient temperature every 2 hours (*sensu* Sagar and Corbould 2004). The remote weather station was located on level ground at the edge of a regenerating cutblock in the Manson River area.

Table 3-1. Suitability of radiolocations for habitat analyses at different spatial scales. A “\*“ denotes scale for which the location is appropriate for analysis.

Precision of radiolocation	Error polygon area	Spatial scale			
		Element	Patch	Within-home range	Landscape
$\pm < 1$ m	None	*	*	*	*
$\pm 1\text{-}30$ m	< 0.3 ha		*	*	*
$\pm 31\text{-}50$ m	0.3 - 0.8 ha			*	*
$\pm 51\text{-}100$ m	0.8 - 3.0 ha			*	*
$\pm 101\text{-}250$ m	3.0 -19.6 ha				*
$\pm 251\text{-}500$ m	19.6 – 78.5 ha				*

## 4.0 GENERAL RESULTS

### 4.1 Capture

We had 281 different trap sites operational for 9,616 trap-nights between October 1996 and March 2000. On average, sites were active for 42 trap-nights during 1996-97 (range: 3 – 98,  $n = 77$ ), 26 trap-nights during 1997-98 (range: 1 – 75,  $n = 110$ ), 21 trap-nights during 1998-99 (range: 4 – 45,  $n = 101$ ), and 17 trap-nights during 1999-2000 (range: 2 – 37,  $n = 79$ ). Traps were usually set continuously for 15- to 21-day periods, with traps being operational most often during the October-November and February-March time periods (Fig. 4-1). We sampled a larger area in the early stages of the project and focussed sampling efforts in later years. Trap-night density was higher in the first 2 capture seasons (2.87 and 2.84 trap-nights/km<sup>2</sup>, respectively) than in the 1998-99 and 1999-2000 seasons (1.98 and 1.54 trap-nights/km<sup>2</sup>, respectively). Traps were set 1.0 km apart on average (range = 0.1 to 6.1 km,  $n = 281$ ).

We captured 21 fishers<sup>1</sup> (6 males, 15 females) on 66 occasions during the 4 trapping seasons, for an overall capture rate of 0.69 fishers/100 trap-nights. One adult female died in a log-cabin trap when first captured and was thus not included in subsequent analyses. Two

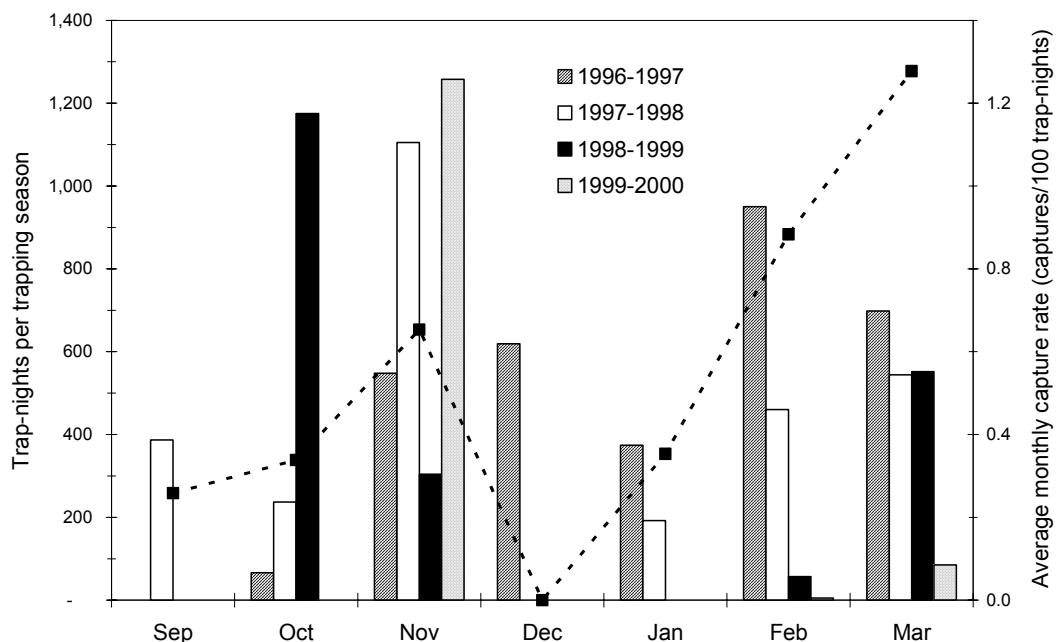


Figure 4-1. Monthly trapping effort per trapping season (bars) and average monthly fisher capture rate (dashed line) in the Williston region of north-central British Columbia, October 1996 to March 2000.

<sup>1</sup> We captured 3 fishers that had not been previously caught, but escaped prior to immobilization. However, fishers that met the initial description were later caught at the same respective traps within the same trapping season and were therefore not considered new fishers.

additional fishers (1 male, 1 female) were captured and radio-tagged adjacent to the study area but were excluded from all analyses except for morphological and genetic metrics. We recorded the highest capture rates during February (0.88 fishers/100 trap-nights) and March (1.28 fishers/100 trap-nights), and no captures occurred during December despite a notable effort in the first trapping season (Fig. 4-1).

Latency to first detection was 13.7 days for resident fishers ( $SD = 12.3$  days until capture,  $n = 18$  fishers). We did not include captures of 3 fishers in our LFD calculation because these animals later proved to be transient and may not have been exposed to live traps as consistently as fishers that were or became established in the study area.

At first capture, 7 fishers were adults ( $\geq 2$  years; 2 males, 5 females), 8 were subadults (1-2 years old; 2 males, 6 females), and 6 were juveniles ( $< 1$  year old; 2 males, 4 females). On 11 occasions we captured individual fishers more than once in the same trapping season, with 3 individuals being captured 6 to 7 times each. Sub-adult female F15 was caught 7 times in a 12-day period just prior to her death due to starvation. Adult female F04 was captured 6 times within 114 days in her first capture season. Adult male M01 was captured 6 times in 65 days in his second capture season. Female F04 was the most frequently captured fisher during the course of our study: 11 captures in 3.3 years.

We had 897 captures of non-target species. We captured American martens on 793 occasions (8.2 captures/100 trap-nights) and also caught wolverines ( $n = 21$ , log-cabin traps only), minks ( $n = 27$ ), red squirrels (*Tamiasciurus hudsonicus*,  $n = 34$ ), red foxes (*Vulpes vulpes*,  $n = 10$ ), snowshoe hares ( $n = 3$ ), gray jays (*Perisoreus canadensis*,  $n = 2$ ), and northern flying squirrels (*Glaucomys sabrinus*,  $n = 1$ ). We also incidentally captured a wolf (*Canis lupus*), a lynx (*Lynx canadensis*), a raven (*Corvus corax*), and a grizzly bear (*Ursus arctos*) cub in log-cabin traps. Ermine (*Mustela erminea*) and their tracks were observed going in and out of several sprung traps.

## 4.2 Immobilization

We conducted 36 immobilizations on 20 fishers, with each fisher being immobilized between 1 and 5 times to either attach or replace radiocollars, remove radiocollars, or in preparation for further anaesthesia prior to implant surgery. Fishers were released without immobilization when there was no need to attach or replace a radio transmitter. Telazol® was used most often as the anaesthetic for immobilizations (30 of 36 occasions), with ketamine:meditomidine (4 times) and ketamine:xylazine (2 times) being used for the remainder. For immobilizations that involved radio-collaring (i.e., a deeper plane of anaesthesia was required than needed prior to surgical anaesthesia), we administered Telazol® at between 5.5 and 22.5 mg/kg ( $\bar{x} = 11.7$  mg/kg,  $SD = 5.2$ ,  $n = 19$ ), which produced anaesthesia lasting between 25 and 130 minutes ( $\bar{x} = 59$  minutes,  $SD = 32.2$ ,  $n = 11$ ).

Table 4-1. Body measurements for 22 fishers captured and radio-tagged between November 1996 and March 2000 in the Williston region of north-central British Columbia. Significant differences between an age-sex category for a metric are indicated with the same letter (*t*-test, P<0.05).

Metric	Age <sup>a</sup>	Sex	n	Mean	SD	
Weight (kg)	>18 months	Male	6	5.1	0.94	A
		Female	11	2.7	0.40	A
	Juvenile	Male	2	4.3	0.78	B
		Female	4	2.4	0.30	B
Neck girth (cm)	>18 months	Male	6	23.3	2.71	A
		Female	10	17.0	1.13	A
	Juvenile	Male	2	20.7	2.12	B
		Female	4	16.3	0.65	B
Chest girth (cm)	>18 months	Male	6	30.0	2.98	A
		Female	11	23.2	2.11	A
	Juvenile	Male	2	28.7	3.61	B
		Female	4	21.8	0.35	B
Body length (cm)	>18 months	Male <sup>b</sup>	6	68.5	5.22	A
		Female <sup>b</sup>	10	57.0	2.07	A,C
	Juvenile	Male	2	64.8	0.71	B
		Female	4	54.2	2.22	B,C
Tail length (cm)	>18 months	Male <sup>b</sup>	6	37.8	0.99	A
		Female <sup>b</sup>	11	34.6	2.64	A
	Juvenile	Male	2	38.1	1.91	B
		Female	4	33.5	1.47	B
Total length (cm)	>18 months	Male <sup>b</sup>	6	106.3	5.51	A
		Female <sup>b</sup>	10	91.4	4.39	A
	Juvenile	Male	2	102.9	2.62	B
		Female	4	87.7	3.62	B
Head width (cm)	>18 months	Male	5	7.8	1.10	A
		Female	9	6.2	0.39	A,C
	Juvenile	Male	1	6.6		
		Female	4	5.7	0.17	C
Head depth (cm)	>18 months	Male	5	7.6	2.49	A
		Female	9	5.0	0.62	A
	Juvenile	Male	1	5.2		
		Female	4	4.6	0.13	
Head circumference (cm)	>18 months	Male	6	26.9	2.88	A
		Female	10	19.9	1.53	A
	Juvenile	Male	1	22.0		
		Female	4	18.3	1.01	

<sup>a</sup> Measurements were taken when individuals were adults (>18 months old) or juvenile (5.5 and 7.5 months old).

<sup>b</sup> For adults that had their skeletal features measured on more than one occasion, an average value represented the individual.

### 4.3 Morphology and Physical Condition

We recorded measurements for 22 fishers: 6 males and 11 females >18 months old and 2 males and 4 females as juveniles. Male M20 was measured at both age categories. Males >18 months old were substantially larger than females for all metrics, as were juvenile males compared to juvenile females (Table 4-1, Appendix 4-1). These data are consistent with fishers elsewhere in North America (Douglas and Strickland 1987, Powell 1993). Body weight did not change by more than 14% between successive years for 7 fishers weighed on more than one occasion, except for an adult male that weighed 22% more between 2 consecutive years (4.7 kg to 5.7 kg; Figure 4-2). On 2 occasions, both in winter 1998-99, we measured females >18 months old twice during the same trapping season: 1 female weighed 4% less (2.7 kg to 2.6 kg) after 5 months and the other female weighed 17% less (3.0 kg to 2.5 kg) after 4 months (Fig. 4-2). Also, we collected post-mortem weights of 2 female fishers that died of starvation in December. Both females (1 juvenile, 1 >18 months old) weighed 1.6 kg post-mortem, down 27% from their 2.2-kg weight when captured approximately 30-40 days earlier. These weight discrepancies may, at least in part, be attributable to differences in the amount of food consumed immediately prior to their handling, in particular bait consumed in the trap.

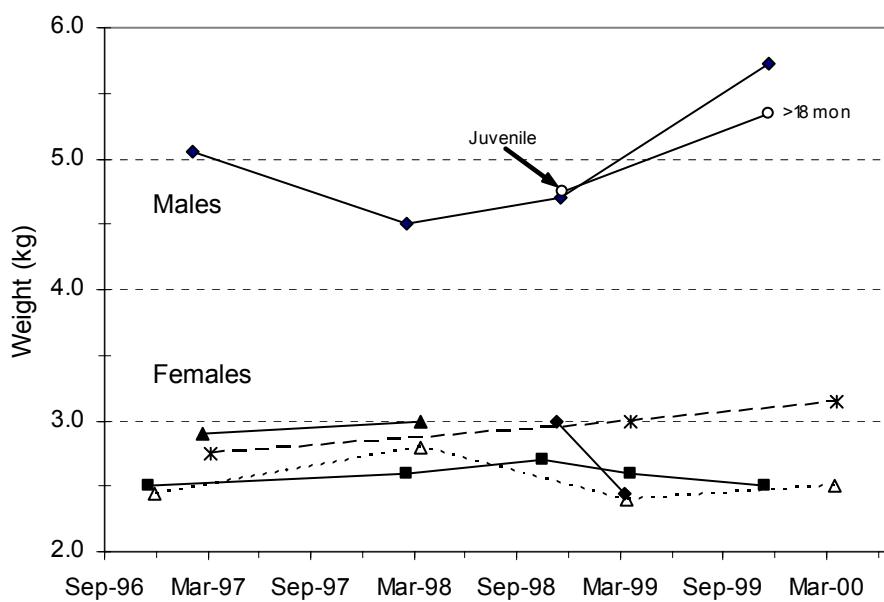


Figure 4-2. Body weights of 7 adult fishers (>18 months old; 2 males and 5 females) that were examined on more than one occasion between November 1996 and March 2000 in the Williston region of north-central British Columbia.

Upon external examination, fishers appeared to be in relatively good health at time of capture. Only 1 individual, a 2-year-old male, showed any sign of serious injury due to natural causes. This fisher had a crescent-shaped open wound, about 2.5 cm long by 0.2 cm wide, that was situated near the dorsal midline of his pelvis. The infected area had granulated tissue that was cleaned with antiseptic (Betadine) swabs prior to his release. Less serious injuries that we observed involved worn and damaged teeth and/or claws (particularly on adults) and the presence of porcupine quills in the head and ventral region of an adult male. No adverse reaction to the quills was observed (i.e., no infection or swelling present), therefore the quills were not pulled out prior to his release. No obvious external parasites were apparent on any captured fisher.

#### 4.4 Radio-tagging and Marking Effects

We assessed the physical effects of radiocollars on 6 fishers that were radio-collared and subsequently recaptured. Four of the 6 fishers had no evidence of damage to their fur or tissues by the radiocollar. Two fishers had sustained damage to tissue underlying their radiocollar (2 cm wide). Chronic abrasion from the collar had resulted in marked necrosis of the skin and subcutaneous tissues. The resulting defect caused extensive formation of granulation tissue and proliferation of bacteria within the superficial necrotic debris. The viable skin margins on either side of the defect had become thickened and had partially overgrown the surface of the collar, embedding the collar in the tissues of the neck. In both these cases, the veterinarian present in the field removed the radiocollar, debrided any necrotic or thickened tissue, flushed the site with antibiotics (Penicillin G sodium), trimmed the skin edges, partially sutured the wound<sup>2</sup>, administered a broad-spectrum antibiotic (enrofloxacin), and released the fishers uncollared. Given the amount of tissue loss, the associated wound contamination and the secondary tissue changes that were observed, it was anticipated that the wound would result in some areas of permanent hair loss, some areas of thickening or fibrosis, and some superficial areas of ongoing epithelial loss (M. McAdie, DVM, personal communication). When these animals were recaptured 8-12 months later, however, both showed no residual effects of the previous injury: complete and normal hair cover was present on the entire neck region, and palpation and manipulation of the skin did not reveal any obvious thickening or scar tissue (M. McAdie, DVM, personal observation).

Four (1 male, 3 females) of 7 fishers that received IP transmitters were reassessed approximately 1 year later, and none showed any adverse effects as all appeared healthy and the suture location from surgery was almost indistinguishable. Despite deliberate dorsal placement of the transmitters, they moved ventrally within the abdominal cavities and had

<sup>2</sup> An opening was left at the ventral aspect of the neck through which a temporary drain (gauze soaked in Betadine solution) exited in order to allow some short-term drainage of the contaminated wound.

relocated between the 2 sheets of greater omentum. There was no evidence of adhesions or any other indication of acute or chronic reaction to the transmitter (M. McAdie, DVM, personal observation). Four females that carried IP transmitters; they appeared to reproduce normally in 5 of 7 potential parturition episodes (i.e., found in reproductive den the following April). The 2 non-reproductive occasions involved an 8-year-old female that did not have a foetus present when examined in March and a female that had a foetus present in March but it was her first reproductive year (i.e., 2 years old). Females are in their reproductive prime between 4 and 7 years of age (Douglas and Strickland 1987, Paragi 1990, this study [Section 5]).

We assessed retention of nylon livestock tags placed in both ears of 6 fishers during the first trapping season. At least 1 eartag was lost within a year of placement for 4 fishers, and as early as 30 days for 1 fisher. Fishers lost both eartags as quickly as 64 days and all but 1 fisher had lost both eartags by 3.5 years; 1 fisher still retained an eartag after 3.7 years. Most ears were injured from tag loss (e.g., periphery of ear notched or jagged), but all ears had healed over completely by the first examination after the loss of a tag. Due to their poor retention and the cancellation of the scheduled photographic mark-recapture project, eartags were not used after the first trapping year.

## 5.0 POPULATION ECOLOGY

Fisher populations have been a management concern in British Columbia since a considerable decline in their harvest was observed in the late 1980s (Weir 2003). As a result, fishers were identified as a species of “special concern” in the province due to their vulnerability to fur harvesting and habitat alteration (Banci 1989, BCCDC 1992) and fur-harvest seasons were closed in 1991-1992. However, the closure did not meet its desired outcome and was discontinued after the 1992-1993 season because of a high incidental catch of fishers where martens were trapped (BCMELP 1993).

Monitoring the demographic parameters of a population provides insight into what factors limit its growth (e.g., high mortality, poor recruitment) and how quickly a population can respond to possible changes in prey resources or to potential adverse impacts (e.g., overharvesting). Our understanding of fisher demographics in British Columbia has been limited to fur-harvest statistics (Banci 1989, Weir 2003). Harvest data, however, may not accurately reflect a population’s true size, composition, or status because harvest rates are influenced by such factors as pelt price and trapper effort (Strickland 1994). As such, this type of analysis may not reflect actual population processes.

Much of the information on the population ecology and reproductive biology of fishers have been gleaned from studies conducted in eastern North America (Powell 1979a, Douglas and Strickland 1987, Arthur and Krohn 1991, Krohn et al. 1994, Koen et al. 2007a). Populations in western North America have been studied much less (Powell and Zielinski 1994) and many of these western studies (Roy 1991, Heinemeyer 1993, Proulx et al. 1994), including the lone British Columbia study (Weir 1995a), have involved transplanted animals. These later studies, therefore, may not accurately reflect population characteristics of native fisher populations.

Fisher densities are greatest in eastern North America (Banci 1989, Powell and Zielinski 1994). Mortalities are mainly due to human-related causes (primarily fur trapping; Powell 1993, Krohn et al. 1994, Powell and Zielinski 1994). Few populations are lightly harvested and adult males and juveniles are most susceptible to trapping and other mortality agents, therefore these populations are primarily biased towards adult females (Douglas and Strickland 1987, Powell 1994a).

Reliable survival estimates, particularly estimates for different seasons and age/sex classes, are few for fisher studies due to characteristically small sample sizes (e.g., usually <10 fishers monitored each year). Annual survival rates for fishers  $\geq 1$  year old range from 0.45 to 0.90 (Krohn et al. 1994, Krohn et al. 1994, York 1996, Koen et al. 2007a), although these estimates generally have poor precision. Survival rates for young are largely based on captive animals (Frost and Krohn 1997, Fontana et al. 1999).

Both sexes are sexually mature and can breed at 1 year of age but, due to delayed implantation, cannot produce their first offspring until 2 years of age (Powell 1993). Females whelp in spring (Feb-Apr), breed approximately 1-2 weeks later, and raise their young alone (Douglas and Strickland 1987, Powell 1993). Annual parturition rates are variable (0-100%) within and among study areas (Arthur and Krohn 1991, Powell 1993, Frost and Krohn 1997, Fontana et al. 1999). Litters average 2-3 young (Douglas and Strickland 1987, Frost et al. 1997).

Geographic variation in population and reproductive data exist (Powell and Zielinski 1994). In British Columbia, data is very limited. Weir (1995a) examined mortality and reproduction in a cursory way and Hall's (1942) breeding and parturition data were from fur farms. Identifying factors that affect fisher survivorship and reproduction are fundamental to understanding population dynamics, and may provide insight into life-history stages that have greatest influence on population viability. Our objective was to examine the population ecology and reproductive biology of fishers in the Williston region, north-central British Columbia. This would provide empirical data for British Columbia and improve the knowledge base for fisher populations in western North America. Age and sex composition, mortality, and reproductive characteristics are presented here. A density estimate for our study area is reported in *Section 7*.

## 5.1 Methods

We captured fishers using wire-cage, log-cabin, and metal-barrel livetraps during fall-winter periods between November 1996 and March 2000. For a detailed description of capture and handling methodologies see *Section 3*.

### 5.1.1 Age and Genetic Relatedness

To determine the year of birth for study animals, we extracted teeth (PM1) during handling and from mortalities. These were sent to Matson's Laboratory, Milltown MT, for cementum annuli analysis (Poole et al. 1994). We classified fishers as juvenile (<1 year old), subadult (1-2 years old), or adult ( $\geq 2$  years old). However, for survival estimates, we classified individuals as either <1 or  $\geq 1$  year old to allow comparison with other studies.

To evaluate fisher dispersal, we assessed the relatedness of monitored fishers by conducting microsatellite genetic fingerprinting of individuals using hair and muscle tissue samples. Analyses were performed by C. J. Kyle of the University of Alberta, Edmonton (*sensu* Kyle et al. 2001). He extracted DNA from all hair and tissue samples using a QIAamp® Tissue Extraction Kit. (QIAGEN). He used 13 microsatellite primer sets developed by Davis and Strobeck (1998) for badgers (*Taxidea taxus*; BA-1), American martens (MA-1, MA-2, MA-19) and wolverines (GG-7, GG-14); by Duffy et al. (1998) for wolverines (Ggu 101, Ggu 216); by Flemming et al. (1999) for minks (*Mustela vison*) and ermines (*M. erminea*; Mvis-072, Mvis002, Mer095, Mer082); and by Dallas and Pierney

(1998) for Eurasian otters (*Lutra lutra*; L-604). Polymerase chain reaction (PCR) amplification was performed as in Davis and Strobeck (1998), and DNA fragments were visualized using an ABI Prism™ 377 DNA sequencer. The programs GENESCAN™ ANALYSIS 2.02 and GENOTYPER® 2.0 were used to analyse DNA fragments.

We assessed all putative relationships by exclusion. If individuals shared an allele at 13 of 13 markers, we assigned parentage as *likely*. Since some hair samples did not replicate well for all markers, we considered individuals that shared 12 markers and had 1 “blank” marker (i.e., poor loci amplification) as a *possible* match. Where parentages were assigned, we cross-referenced genetic and cementum annuli results, along with whelping data, to substantiate relationship possibilities.

To make inferences regarding the characteristics and timing of fisher dispersal, we assessed the likelihood of genetic relatedness amongst fishers that were monitored within our study area, including 2 individuals (1 adult male and 1 adult female) that we captured adjacent to our study area.

### 5.1.2 Mortality

During the first 2 years of the study, we radio-tagged fishers with neck collars. In subsequent years, we radio-tagged fishers with intraperitoneal transmitters. These were surgically implanted by a veterinarian in the field. In both cases, radiotransmitters were equipped with motion sensors (4-hour delay) to indicate mortality or a discarded transmitter.

We monitored radio-tagged fishers via ground and aerial telemetry (see *Section 3*), and attempted to obtain at least 1 radiolocation for each tagged animal every 2 weeks during winter and once every 4 weeks during summer. Radiolocations were obtained almost exclusively during daylight hours. We monitored fishers until the animal died, we lost contact (e.g., transmitter malfunctioned, battery expired, or the animal dispersed outside the study area), or until monitoring activities ceased at the end of the project.

We conducted site investigations as soon as possible after a mortality signal was detected, usually within 36 h. Cause of mortality was determined based on evidence found at the site and upon physical examination of the carcass. Where possible, necropsies were conducted by the provincial wildlife veterinarian. If the exact date for the mortality or disappearance of an animal was unknown (i.e., transmitter failure or animal emigration), we used the day after the last known “alive” record as the change date for calculating monitoring duration and survival analyses.

We calculated survival estimates, at 1 month intervals, for fishers >1 year old using a staggered entry design for the Kaplan-Meier estimator (Pollock et al. 1989). We censored fishers that had lost their radio collar, had their radio collar removed, or whose transmitter battery expired. If these individuals were recaptured, they were added to the sample as a new record (McLellan et al. 1999).

### 5.1.3 Reproduction

When a veterinarian was present during livetrapping activities, we assessed adult females captured in February and March for presence of foetuses by palpating the abdomen or internal investigation prior to IP transmitter placement.

We considered females to have produced young (whelped) when they were located  $\geq 3$  times using the same structural element (reproductive den) in the March to May period. We considered the origin of the rearing period to be the first day the female was located in a reproductive den (*sensu* Paragi et al. 1996, Powell et al. 1997). To identify whelping dates, we attempted to locate female fishers at least once every 3 days during late March and early April. Once reproductive dens were identified, we attempted to monitor females at least every 7 days. For some denning females, we established remote monitoring systems (radiotelemetry data logger, video camera, or 35-mm remote camera) at the den site; see *Section 9* for further details.

We assumed that females had successfully reared a litter if they denned for  $\geq 8$  weeks. At 8 weeks of age, fisher young have opened their eyes, have started to eat solid food, and become more mobile (Powell 1993, Fontana et al. 1999, Frost and Krohn 2004).

Observational studies of females with young indicate that females use dens for 58 to 80 days (Leonard 1980, Powell 1993, Paragi et al. 1996).

We estimated fall recruitment rates (juveniles per adult female) based on our best estimate of the number of individuals in each age/sex class potentially present in the study area on 31 October each year using radiotelemetry and live-capture data (see *Section 7*). We included all juveniles that were captured (live or kill trapped) during the subsequent fall/winter period and, based on aging data, all other juveniles that were assigned to the given cohort year. Similarly, we included all radio-tagged adult females that were alive on 31 October and all adult females captured (live or kill trapped) during the following fall/winter period in the estimate.

## 5.2 Results

### 5.2.1 Age, Sex and Genetic Relatedness

We captured 21 fishers (66 total captures) within the study area during 4 fall/winter trapping seasons, November 1996 to March 2000. All fishers, but 1, were radio-tagged for monitoring. Fisher age classes at first capture were 6 juveniles (2 males, 4 females), 8 subadults (2 males, 6 females), and 7 adults (2 males, 5 females). The year-specific age of 18 of the 20 radio-tagged fishers (Fig. 5-1) ranged from 0.5 years at first capture (female F13) to 8.7 years at time of death (female F07). The oldest male monitored was 5.0 years (male M01).

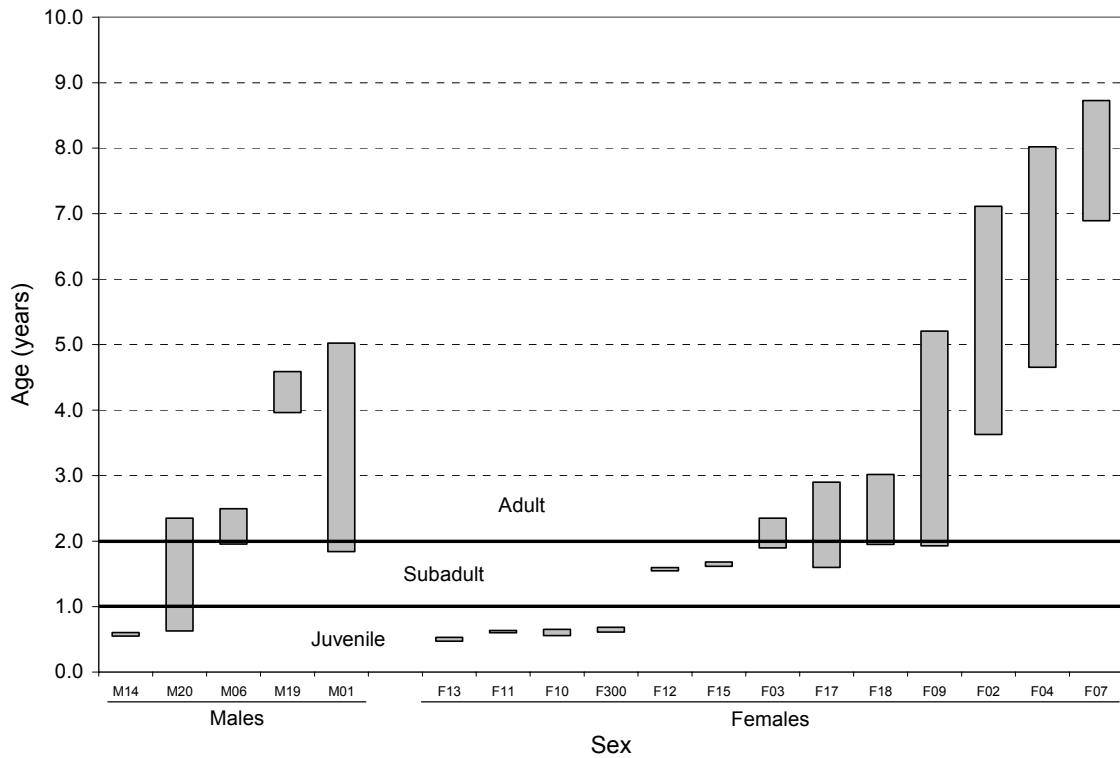


Figure 5-1. Age distribution of 18 known-age radio-tagged fishers in the Williston region of north-central British Columbia, between November 1996 and November 2000. Bar indicates age at first capture to age at last monitoring record.

Mean annual fall recruitment was 0.58 juveniles per adult female ( $SD = 0.55, n = 4$  years, range 0 – 1.33). Adult sex ratios averaged 0.39 males per adult female ( $SD = 0.16, n = 4$  years, range = 0.17 – 0.50). Based on our annual fall density estimates (see *Section 7*), the average annual growth rate for the Williston region was 1.02 ( $SD = 0.32, n = 3$ ) for the study period.

Study animals were born in 7 of the 10 years (1990 to 1999) prior to the end of the project (Fig. 5-2). Eight (44%) individuals, all female, were from the 1997 cohort year. Only 2 study animals were born in the last 2 years of the study.

We identified full parental relationships for 2 individuals and maternal relationships for 2 others (Table 5-1). We also identified one possible maternal relationship (juvenile F12 to F07), but evidence for this was not as definitive. We observed a relatively high homozygosity of alleles and, due to DNA amplification problems with some hair samples, a high frequency of “blank” alleles occurred in some samples. This may have limited our ability to discern other possible relationships among fishers in our study.

All captures of juvenile fishers occurred during fall trapping sessions. Female F13 was the only juvenile related to the adult female residing where the juvenile was captured (Table 5-2). Thus, given that resident females exhibited typical exclusivity of intrasexual territories

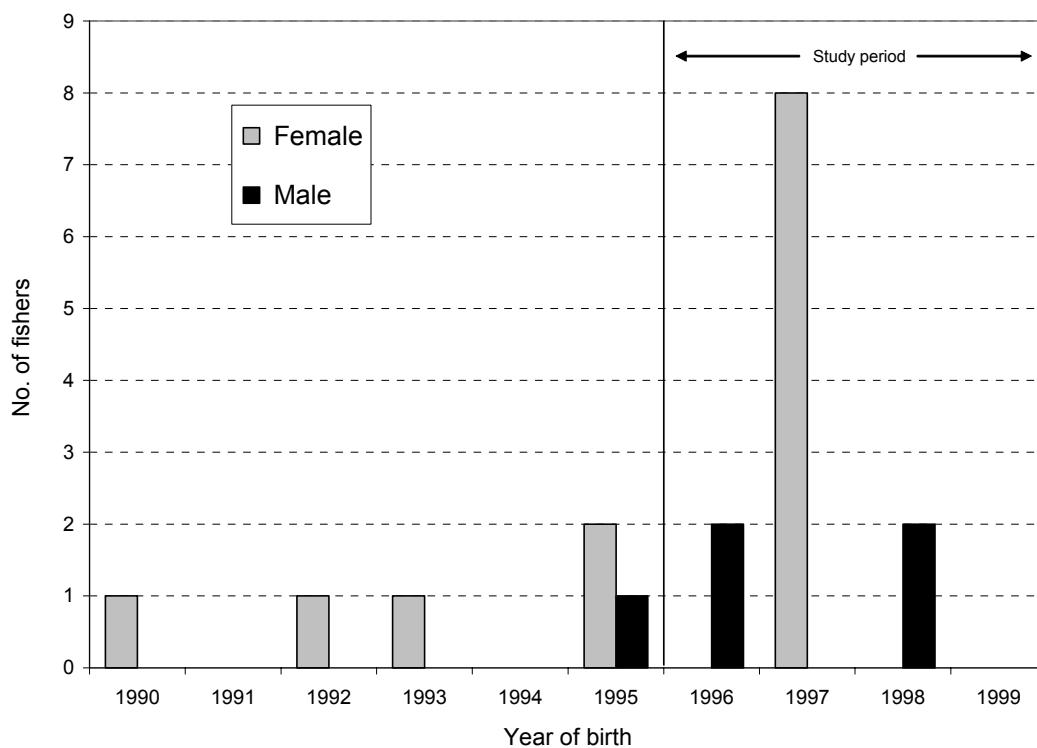


Figure 5-2. Year of birth for 18 known-age radio-tagged fishers in the Williston region of north-central British Columbia, 1996 to 2000.

Table 5-1. Genetic relatedness of radio-tagged fishers in the Williston region of north-central British Columbia, 1996 to 2000.

Offspring	Year of birth	Likely <sup>a</sup>		Possible <sup>b</sup>	
		Maternal	Paternal	Maternal	Paternal
F09	1995	F07			
F12	1997			F07	
F13	1997	F03	M30		
F17	1997	F07			
M20	1998	F09	M01		

<sup>a</sup> Relatedness likely: 13 of 13 alleles match (13, 0, 0).

<sup>b</sup> Relatedness possible: 12 of 13 alleles match, 1 allele "blank" (12, 1, 0).

(see *Section 6*), these data indicate that juveniles of both sexes had commenced dispersal activities from their maternal home range by late October to mid-November (i.e., as early as 6.6 months old for males and 7.2 months old for females).

### 5.2.2 Mortality

Radio-tagged fishers were monitored between 18 November 1996 and 4 November 2000, with an average of 298 "on air" monitoring days per individual ( $SD = 317$  d,  $n = 20$ ). We monitored 7 to 12 fishers per year (1 Apr – 31 Mar; Fig. 5-3). We observed no evidence that survivorship of radio-tagged fishers was affected by capture and handling activities, or by either type of radiotransmitter.

Table 5-2. First capture locations for juveniles relative to resident adult females in the Williston region of north-central British Columbia, 1996 to 2000.

Juvenile	Sex	Date of first capture	Offspring of resident adult female where captured	Proximity to maternal home range
F13	Female	23-Sep-97	Yes <sup>a</sup>	0 km
F11	Female	9-Nov-97	No	Unknown
F300	Female	13-Nov-97	No	Unknown
F10	Female	25-Nov-97	Inconclusive <sup>b</sup>	
M14	Male	22-Oct-98	No	Unknown
M20	Male	20-Nov-98	Not applicable <sup>c</sup>	11 km

<sup>a</sup> Capture location was within the 96% isopleth of the utilisation distribution for F03.

<sup>b</sup> Genetic relatedness to resident female was inconclusive: 10 matching and 3 "blank" alleles.

<sup>c</sup> Not captured within the home range of an adult female.

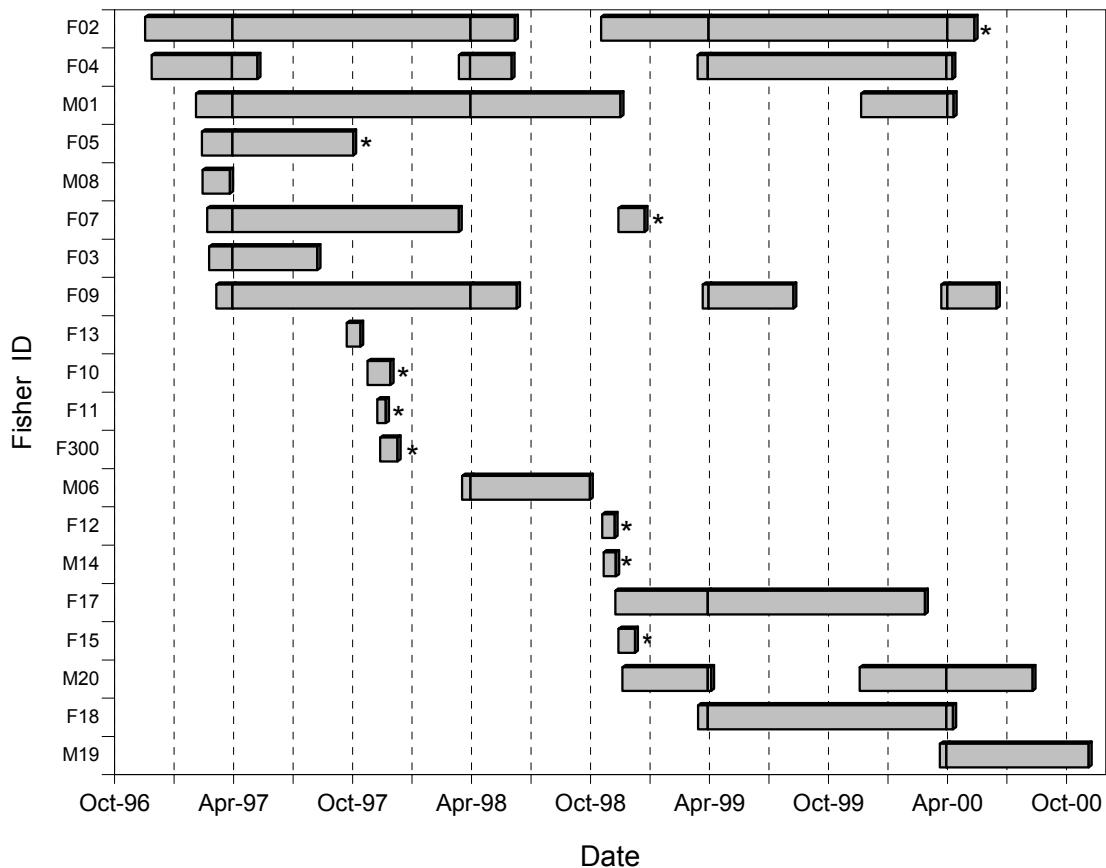


Figure 5-3. Monitoring history for 20 radio-tagged fishers in the Williston region of north-central British Columbia, November 1996 to November 2000. A monitoring year was defined as 1 April to 31 March. Gaps in bars indicate that the fisher was not radio-tagged for the intervening period. An asterisk indicates mortality for the last radiolocation record.

Table 5-3. Fate, at last record, of 20 fishers radio-tagged and monitored in the Williston region of north-central British Columbia, November 1996 - November 2000.

Age class <sup>a</sup>	Sex	Alive	Mortalities						Fate unknown	Total		
			Human-caused		Natural							
			Harvest	Accident <sup>b</sup>	Starvation	Conflict <sup>c</sup>	Fall	Unknown				
Adult	male	3							2	5		
	female	4				1	1	1	1	8		
Subadult	male									0		
	female		1		1					2		
Juvenile	male			1						1		
	female		2			1			1	4		
	Total	7	3	1	1	2	1	1	4	20		

<sup>a</sup> Age class of animal at their last record (i.e., at mortality, when lost contact, or when stopped monitoring): adult ( $\geq 2$  years old), subadult (1-2 years old), and juvenile (<1 year old).

<sup>b</sup> Mortality attributed to research capture activities; data not used in survivorship analyses.

<sup>c</sup> Mortality attributed to interspecific conflict: non-consumptive attack or injury resulting from foraging altercation.

We determined the fates of 16 of the 20 radio-tagged fishers during the study. Nine animals died while being monitored (Table 5-3). On average, mortality investigations occurred 10 days ( $SD = 6$ ,  $n = 9$ ) after the last radiolocation that the animal was determined to be alive. Seven mortalities occurred in winter; 3 individuals were killed by trappers (2 juvenile and 1 subadult female), 2 individuals died from interspecific conflict (1 juvenile and 1 adult female), a subadult female died of starvation, and a juvenile male died in a live-trap accident. All radio-tagged animals that were kill-trapped (2 in 1997 and 1 in 1998) were killed between mid-November and mid-December in marten or otter (*Lutra canadensis*) trap sets. Another kill-trapping mortality occurred to an untagged male in November 1998.

We observed 2 mortalities from interspecific conflict: an 8.7-year-old female fisher (F07) and an 8-month-old female (F10). The adult female's intact carcass was found on top of the snow within a mature coniferous stand. She had a broken spine, severe trauma to the shoulder and chest regions, and multiple puncture wounds. Based on puncture markings, her mortality was consistent with a lynx conflict. The juvenile mortality was caused by a porcupine (*Erethizon dorsatum*) quill becoming lodged in her throat causing a large abscess to form. She eventually succumbed to starvation. She died 77 km from where she was captured 35 days earlier and her weight had dropped from 2.2 kg at capture to 1.6 kg at the time of death. The other starvation death (subadult female F15) also occurred in December and this fisher had lost the same amount of body mass: from 2.2 kg when captured to 1.6 kg at time of death, a month later. Prior to her death, F15 was captured 7 times before we ceased our livetrapping activities in the area. The live-trap accident (juvenile male M14) occurred when a log-cabin trap door did not fully release until the fisher was attempting to leave the trap.

Two mortalities of resident adult female fishers (F02 and F05) were recorded outside the winter season. Fisher F02 was found in mid-May near a recently fallen large-diameter cottonwood tree. F02 had multiple skeletal fractures and severe haemorrhaging and organ damage. We suspect that she received her fatal injuries as a result of the tree falling while she was either inside or exiting the nest cavity of a goldeneye (*Bucephala* sp.). Fisher F05's transmitter was identified on mortality during a mid-October aerial-telemetry flight but, during subsequent intensive ground searching and further aerial telemetry, she could not be located. No fishers were captured and no fisher tracks were observed in the area until subadult female F18 was captured over a year later. F18 established a home range in the area soon thereafter (see *Section 6*).

In addition to the study-area animals, an adult male (M30) and an adult female (F16) that we captured, tagged, and periodically monitored outside of the study area died while being monitored. M30 was eaten by a wolverine. Fresh wolverine scat and tracks were present at the site, along with hair and skeletal fragments (part of mandible and fractured ribs). F16, a reproductive female, was recovered in late April from a site within a regenerating 20-year-old cutblock, 3.8 km from her reproductive den. We found F16 curled up with her head down in a small ground depression under a patch of regenerating subalpine fir trees. Her carcass was intact and covered with ground litter. A necropsy discerned that death was caused by trauma to the occipital region of the skull. We also discovered a moderate amount of haemorrhaging on the ventral region of her throat. Puncture holes on the dorsal and lateral portions of the occipital region were consistent with the canine spacing of a male fisher. The timing of the mortality was consistent with the fisher-mating season (6 to 27 Apr in British Columbia; Hall 1942). F16 was confirmed to be raising young when her den cavity was investigated in the summer and at least 1 decomposing neonate was found.

The fates of 4 individuals were unknown. Adult female F03 presumably slipped her radio collar in August as it was found on a branch, 12 m up a mature spruce tree. A site investigation and the collar condition revealed no indications that death had occurred. A large adult male (M08) was captured in mid-February near the south-western periphery of our study area. He was monitored until late March after which he was no longer radiolocated, even though multiple aerial-telemetry flights were conducted over a large area. We suspect his collar failed and he was not recaptured within our study area. Juvenile female F13 was captured in late September and was consistently radiolocated in her maternal home range for the following month. Subsequent extensive aerial-telemetry flights failed to locate her. We suspect her radio collar malfunctioned or she dispersed, as she was not observed again although intensive trapping occurred within this area and frequent aerial telemetry flights were conducted over a large area. The transmitter of subadult male M06 was last heard on mortality in mid-October but the detection distance for his transmitter had

declined substantially in previous months and the battery life was reaching its expected lifespan. Therefore, an expired or malfunctioned transmitter was the likely cause of losing contact.

For the period November 1996 to March 2000, the probability of survival for fishers  $\geq 1$  year in age was 0.27 (95% CI = 0.08-0.45; Fig. 5-4). Survival estimates varied widely among years but, on average, annual and winter survival estimates were similar (Table 5-4). Although 7 females  $\geq 1$  year old were monitored in 1998-1999, no annual estimate was calculated because no females were radio-tagged for the July to October period. No adult males died while radiotagged.

For 4 known-fate juveniles, 3 females captured in 1997 died within 35 days of their initial capture date (October or November). The lone juvenile male, captured in 1998, survived until we stopped monitoring him at the end of the study, 2 years later. No survival rates were calculated for juveniles.

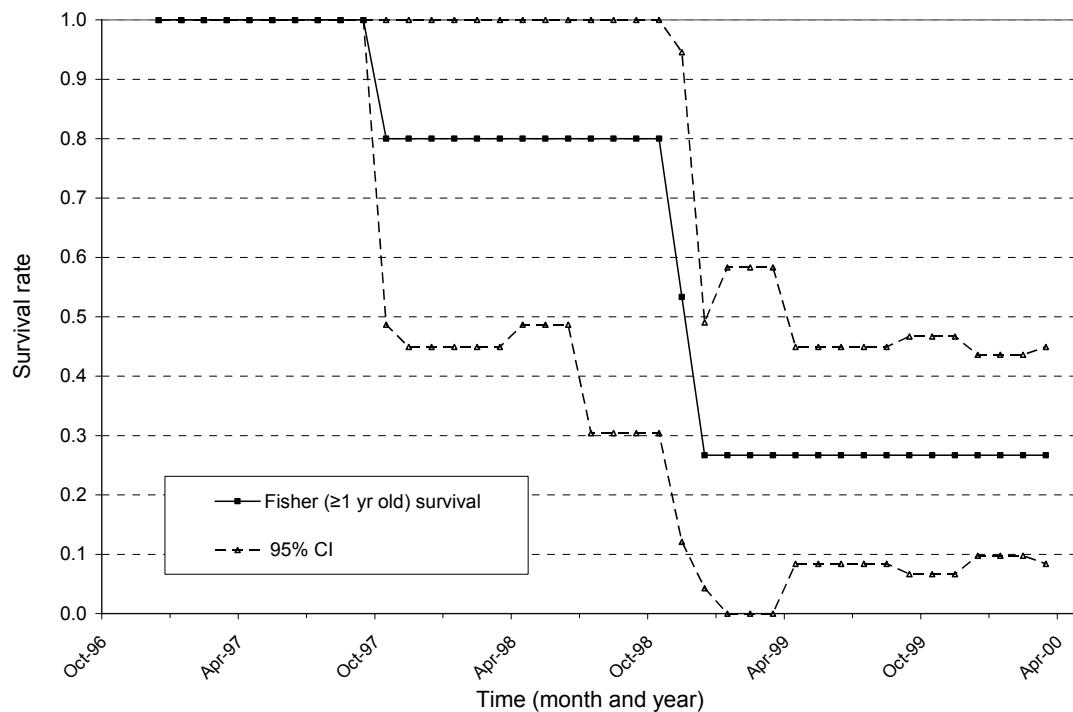


Figure 5-4. Kaplan-Meier survival estimate, at 1-month intervals, for 14 radio-tagged fishers  $\geq 1$  year of age in the Williston region of north-central British Columbia, November 1996 to March 2000.

Table 5-4. Annual (Apr-Mar) and winter (Nov-Mar) Kaplan-Meier survival estimates, based on 1-month intervals, for 14 radio-tagged fishers  $\geq 1$  year of age in the Williston region of north-central British Columbia, November 1996 to March 2000.

Category & Year	No. monitored	No. died	Survival estimate	95% CI	
<b>Annual fisher survival</b>					
1997-1998	8	1	0.80	0.45	1.00
1998-1999	9	3	0.33	0.00	0.71
1999-2000	8	0	1.00	1.00	1.00
Mean (SE)			0.71 (0.20)		
<b>Annual female survival</b>					
1997-1998	6	1	0.75	0.33	1.00
1998-1999					
1999-2000	5	0	1.00	1.00	1.00
Mean (SE)			0.88 (0.13)		
<b>Winter female survival</b>					
1997-1998	3	0	1.00	1.00	1.00
1998-1999	5	3	0.25	0.00	0.55
1999-2000	4	0	1.00	1.00	1.00
Mean (SE)			0.75 (0.25)		

### 5.2.3 Reproduction

During our study, we monitored 8 radio-tagged female fishers  $\geq 2$  years old over 18 potential whelping seasons (Fig. 5-5). We documented 5 females whelping 12 times during this period, with a mean annual whelping rate of 69% ( $SD = 22\%$ ). Although sample sizes were different among years, this did not affect the estimated whelping rate.

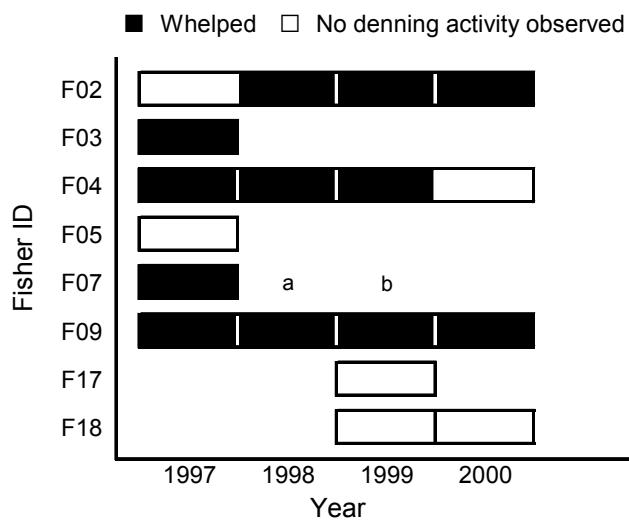


Figure 5-5. Yearly whelping status of 8 adult ( $\geq 2$  years old) female fishers monitored in the Williston region of north-central British Columbia, 1997 to 2000. Whelping status was based on spring behavioural characteristics (sensu Paragi 1990, Powell et al. 1997). Female F07 was (a) pregnant in mid-March but was not radio-tagged in the spring denning period, and (b) pregnant in late December at time of mortality.

To corroborate determination of reproductive status based on behavioural characteristics, adult females captured in the February-March period were classified as pregnant or non-pregnant on 7 occasions by a veterinarian. For all but 1 female, behavioural characteristics observed in April were consistent with their earlier assessment. Three females deemed pregnant whelped and 3 females deemed barren did not whelp. The lone exception involved a female that had a foetus present in March but did not show any whelping behaviour in April. It was her first reproductive year (i.e., 2 years old).

Transmitters did not appear to affect whether a female was capable of bearing young. Females successfully whelped on 5 of 8 occasions when IP transmitters were present and 7 of 10 occasions when a radio collar was affixed. These were similar to or higher than rates reported for other studies (Paragi 1990, York 1996).

We observed parturient fishers initiating use of reproductive dens between 30 March and 12 April. Mean date of parturition was 4 April (median = 3 Apr, SD = 4 days,  $n = 12$ ). The parturition date of 3 females monitored over multiple reproductive seasons varied by 3 to 14 days. Female F02 whelped between 30 March and 12 April ( $n = 3$  years), F04 whelped between 2 and 4 April ( $n = 3$ ), and F09 whelped between 1 and 5 April ( $n = 4$ ).

Females were parturient between 2 and 7 years of age (Fig. 5-6). Females 5 to 7 years old ( $n = 4$ ) whelped in all 8 reproductive seasons monitored. Females between 2 and 4 years old ( $n = 5$ ) whelped 50% of the time (4 of 8 reproductive seasons). We also monitored 2 females at 8 years of age: F04 did not whelp, whereas F07 was observed to be pregnant in mid-March but her subsequent whelping status could not be determined because she was not radio-tagged for the following period. When F07 died in late December at 8.7 years of age, she

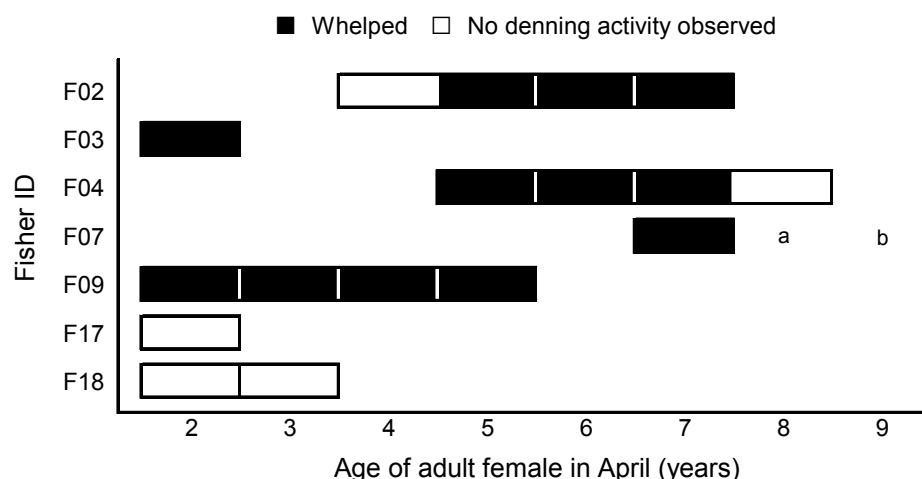


Figure 5-6. Whelping status in relation to age of 7 female fishers monitored in the Williston region of north-central British Columbia, 1997 to 2000. Female F07 was (a) pregnant in mid-March but was not radio-tagged in the spring denning period, and (b) pregnant in late December at time of mortality.

was again pregnant. Two females (F05 and F18) accounted for 3 of 6 occasions that adult females did not whelp. These 2 fishers had home ranges in the same geographic area, though at different times during the study.

Using radiotelemetry and remote-camera monitoring at den sites, we could not conclusively identify the presence of young with females that whelped during our study (*Section 9*). No dens were investigated during the denning season due to the potential for young and den abandonment (Paragi 1990, York 1996). However, on 3 occasions, young production within the study period was confirmed based on genetic and aging data from captured individuals. Also, an offspring (F13) from female F03 in 1997 indicated that this individual successfully bred when 1 year old and subsequently whelped and reared at least 1 young at 2 years of age. In addition, anecdotal data indicated that young production likely occurred on 2 other occasions. Small teeth marks were found on the collar strapping of 2 slipped radio collars, suggesting that young were reared until tooth eruption (i.e., ~40 days; Frost and Krohn 2004, Fontana et al. 1999). Consequently, the estimated proportion of litters having  $\geq 1$  young survive to 40 days was a minimum of 42% (5 litters from 12 occasions) and to the fall period (i.e., livetrapping period) was a minimum of 25% (3 litters from 12 occasions).

### 5.3 Discussion

The population of fishers that we studied in the Williston region of north-central British Columbia was characterized by average adult survival, low juvenile survival, low recruitment, and a growth rate (*lambda*) near 1. These features and observed behavioural characteristics were consistent with a stable population near carrying capacity (*K*), albeit at exceptionally low densities (see *Section 7*).

Survival data suggested that opportunities for recruitment of new individuals into the population were rare. Most of the mortality that we observed occurred in the juvenile and subadult age classes, which are typically most vulnerable to mortality agents (Douglas and Strickland 1987, Powell 1993, Krohn et al. 1994, Strickland 1994), with humans causing about half of the mortality. The few cases of adult mortality resulted from natural events. The low turn-over of adult resident animals resulted in few suitable areas being available to juvenile fishers, unlike that observed by Arthur et al. (1989a) in Maine and Koen et al. (2007b) in Ontario. Because few unoccupied suitable habitats occurred within the landscape, some fishers were probably forced to be transient up to 2 years of age, which was substantially longer than observed elsewhere (Arthur et al. 1993, Powell 1993). It was during these periods of protracted transiency that juvenile and subadult fishers may have been exposed to high mortality risk. This likely contributed to the low rate of recruitment (0.58 juveniles per adult female) that we observed within the population.

Several population characteristics indicated that the fisher population in the Williston region was stable and at or near its carrying capacity. The late-winter density changed very little over the 4-year term of the study (<19% or  $\leq 1.5$  fishers/1,000 km $^2$ ; see *Section 7*), which was negligible compared to some *Martes* populations that exhibit fluctuations up to an order of magnitude during similar time periods (Powell 1994a). Our observations of limited population growth and low recruitment were consistent with a population near its carrying capacity. Population-level behaviours also suggested that the landscape could not support higher densities of fishers: protracted transiency of young fishers, quick assumption of open territories, no notable changes to home range sizes, and no changes in geographic areas used even though transients were present (*Section 6*). Given these indicators and our data, we believe the fall carrying capacity in our study area was 11.2 fishers/1,000 km $^2$  for the study period.

The low rate of fur harvest of fishers by trappers in the Williston region did not appear to strongly affect population composition and was likely to be sustainable at this level. Annual harvests of fishers on the 5 traplines that encompassed the study area were similar between our study period (0.85 fishers/1,000 km $^2$ ) and the previous 10 years (1.06 fishers/1,000 km $^2$ ) (Provincial Wild Fur Harvest, Ministry of Environment, unpublished data). When pooled, this equated to an annual harvest averaging 1.00 fishers/1,000 km $^2$ , or approximately 8.9% of our average annual fall population density (*Section 7*). This harvest rate was probably sustainable considering the population was stable. Furthermore, this level of trapping did not appear to reduce the population notably from its carrying capacity or affect its age composition, which is characteristic of an unharvested *Martes* population (Powell 1994a).

Fluctuating prey availability did not appear to affect the number of fishers that occurred each year in our study area. The primary prey for fishers in British Columbia is snowshoe hare (Weir et al. 2005). The peak of the hare cycle for central British Columbia (180 km south of our study area) was reported to be at the start of each decade (Sullivan and Sullivan 1988, Sullivan 1994) and, based on population responses to the hare cycle (Bowman et al. 2006), we expected to see increased survival of juvenile and adult fishers for the last 2 years of our study. However, we captured fewer juveniles and observed no apparent change in adult survival during this period. Therefore, either there was no notable fluctuation in hare abundance during the term of our study (contrary to anecdotal field observations), fishers in our study area did not respond strongly to the hare population, or mortality factors other than starvation overwhelmed any effect of increased prey resources, particularly for juveniles.

The distribution of mates may have affected the population characteristics that we observed. Female fishers in the Williston region had the largest home ranges were up to 2 to 4 times larger than documented elsewhere and home ranges were often not adjacent to those of other females (*Section 6*). Due to these large, widely dispersed female home ranges, males

may not have been able to access multiple females during the brief mating period, in which case their mating opportunities may have been limited to only 1 or 2 females. Consequently, if an adult male died, females that were in more “isolated” areas may not be bred, which may have been the case for 2 radio-tagged females that we monitored. Alternatively, these 2 females may have resided in areas that were suboptimal for winter food resources, thus poor nutrition may have affected their reproductive output in spring (Frost and Krohn 1997).

Given that the annual parturition rate for females  $\geq 2$  years old in our study averaged 69%, we expected more juveniles in our sample of radio-tagged animals. This parturition rate was similar to the average annual rate of 68% reported in Massachusetts (York 1996) and greater than the 54% observed in Maine (Paragi 1990). We also observed similar age-specific parturition rates as other researchers (Paragi 1990, Douglas and Strickland 1987). Although we did not observe young during the denning period, extended den use and other data (genetic relatedness, teeth marks of young on radio collars) indicated that in 9 of 12 occasions at least 1 young was likely reared to the end of the denning period. Survival to the post-denning period is reported to be high for litters (92-100%) and for individual young (89-96%; Frost and Krohn 1997, Fontana et al. 1999). Based on these data and an average of 2 young per litter, we estimated 14 juveniles may have survived to the post-denning period. Since we captured only 3 offspring that were born during our study period and related to resident females, we estimated a minimum young survival rate of 0.21 for the post-denning to fall-trapping period. For essentially the same period, Paragi et al. (1994) reported a minimum young survival rate of 0.60. Poor capture success, poor survival, and early dispersal were possible causes for our low observance. Juvenile fishers are widely reported to be the most susceptible age class to various trapping methods (e.g., Douglas and Strickland 1987, Powell 1993, Krohn et al. 1994) and therefore would be expected to be the easiest individuals to capture. Starvation was not a likely causal factor during summer because it has not been noted as a factor in the literature and 2 prey species (snowshoe hares and ruffed grouse [*Bonasa umbellus*]; Weir et al. 2005) were expected and appeared to be at or nearing their cyclic peak in the last 2 years of the study (Hodges 1999, Sullivan 1994, Davies and Bergerud 1988, R. Weir and F. Corbould personal observations). Although early dispersal from their maternal home range was possible, dispersal from the entire study area was much less likely. The lack of juveniles live- or kill-trapped in the January to March period, when fishers are most vulnerable to trapping (Douglas and Strickland 1987), would suggest that very few or no juveniles were present in the study area at that time. The most plausible causes of low juvenile numbers were therefore summer mortality due to predation or conflict.

Parturition dates observed were consistent with those reported elsewhere (Hall 1942, Douglas and Strickland 1987, Powell 1993, Fontana et al. 1999). Powell (1993) proposed

that latitude may account for the variance in parturition dates throughout fisher range, as implantation to initiate gestation is stimulated by photoperiod. This hypothesis was supported by our data as our animals were the most northerly fisher population studied ( $55.3^{\circ}$  latitude) and they had the latest parturition date ( $\bar{x} = 4$  Apr, median = 3 Apr) reported in the literature. Powell (1993) further suggested that the variation in birthing dates within a population was likely due to differences between individual females, rather than annual differences for individuals. This pattern was consistent for 2 of 3 female fishers monitored for 3-4 years. Both whelped within 3-5 days of previous whelping dates. The third female whelped over a 13-day period over her 3 reproductive seasons.

We believe that the composition of our sample of radio-tagged fishers represented the true population structure during our study. It was unlikely that untagged resident fishers were present within the study area because of our extensive livetrapping efforts and successful capture of adult females (hardest component to capture; Douglas and Strickland 1987, Krohn et al. 1994). No tracks were observed outside areas used by tagged animals and, although trappers continued to trap, no untagged fishers were trapped in the study area after the first trapping season (local trappers, personal communication).

#### 5.4 Management Implications

Our study area appeared to have a relatively stable, low-density population of fishers during the study period. Strickland (1994: 151) noted that “Low-density populations are the least resilient and the most difficult to assess, and only well-established populations should be harvested”. Fishers were harvested sustainably at a harvest rate of 9% for the past 15 years, and it did not appear that fur-harvest notably affected the population. It is unknown what level of harvest can be sustained without experimentally testing the system; Caughey and Sinclair (1994) recommend, though, that any prescribed harvest be at least 25% below the estimated maximum sustained yield. Because of the low density and relatively dispersed nature of females across our study area, the impacts of potential component Allee effects (Stephens et al. 1999), such as insufficient males to breed, should be taken into account.

Restricting both the fisher- and marten-trapping season to the November-January period may reduce any potential impact of fur harvesting on the reproductive component of the fisher population. This change would reduce the overall occurrence of targeted and incidental trapping when fishers are most vulnerable (i.e., when food resources are least available; Powell and Zielinski 1994). Limiting the harvest to juveniles would not inordinately affect the income to trappers (Douglas and Strickland 1987), particularly when one takes into account the long-term productivity of the population (e.g., more individuals may be harvested). Additionally, this early-season period is when fisher and marten pelts are of highest value (Douglas and Strickland 1987, Strickland and Douglas 1987), thus ensuring that trappers take all animals when their pelts are prime.

Management decisions to maintain viable and resilient fisher populations in north-central British Columbia should consider a broader-scale approach than is likely currently employed by management agencies. Because of the larger and more dispersed spatial arrangement of female home ranges in SBS forests (this study [*Section 7*], Weir 1995) compared to other fisher populations, adult sex ratios in these and similar areas should be managed closer to 1:1 as it would be physically (i.e., energetically and temporally) more difficult for males to be polygamous over such wide areas. The low density of fishers we observed and the increased habitat alteration that is occurring in north-central British Columbia due to logging resulting from the mountain pine beetle epidemic will likely require that for the intermediate term (10-20 years) fewer fishers be harvested in this and other similar regions of the SBS zone to ensure their longer term conservation. Due to the high diversity of landscapes within British Columbia and the likely disparate factors (e.g., mortality causes, prey populations, dispersal ability) that affect their population and reproductive parameters in these different regions, it would be prudent to collect data from representative ecosystems to better understand fisher requirements and constraints across British Columbia.

## 6.0 SPATIAL ORGANIZATION AND DISPERSAL

Fishers are solitary carnivores and, other than mothers raising young, usually interact with conspecifics only during mating and territorial defence (Powell 1993). Fishers are aggressive towards each other and conspecific interactions often lead to fights that are occasionally fatal. This asociality is also exhibited in their spatial organization, whereby members of the same sex do not have overlapping home ranges (Powell 1993).

Differential selection pressures between sexes in Mustelidae have resulted in different strategies of space use for each sex and, consequently, the spatial organization of the population. Fishers tend to exhibit intrasexually exclusive home ranges (Kelly 1977, Arthur et al. 1989a), which is a common spacing pattern among Mustelidae (Powell 1979b). Moors (1980) hypothesized that male mustelids are larger than females so that they can cover large areas more quickly, and therefore encounter more females as potential mates. The smaller size of females may optimize capture of prey during rearing of the young (Powell 1993). Males have larger home ranges than females to sequester sufficient mating opportunities and meet the greater energy demands of a larger body size. This spatial organization, in combination with size of home ranges, has implications for the density of fishers that occupy a landscape.

Powell (1994a) summarized the reported sizes of home ranges of fishers from across North America and derived a mean of 38 km<sup>2</sup> for males and 15 km<sup>2</sup> for females. Estimates from Idaho and Montana suggest that home ranges of fishers are larger in western regions than in eastern and southern areas, possibly due to lower prey densities (Jones 1991, Heinemeyer 1993). Badry et al. (1997), however, found that translocated fishers in Alberta had home ranges of 24.3 km<sup>2</sup> and 14.9 km<sup>2</sup> for males and females respectively, which were similar to home range sizes of fishers in eastern North America. Zielinski et al. (2004a) noted that fishers in California, at the southwest portion of their range, had home ranges similar to those found in eastern landscapes.

Another important component of spatial organization in fishers is the dispersal and home range establishment of juveniles. Very little is known about dispersal and home range establishment because few studies have documented this process. In eastern North America, fishers disperse from their natal ranges during their first winter and establish home ranges in unoccupied habitats soon afterward (Arthur et al. 1993, Powell 1993). Arthur et al. (1993) observed that dispersing juveniles in Maine established home ranges 11 km, on average, from their natal ranges. The low degree of relatedness among fisher populations across Canada and even between adjacent areas such as the Cariboo and Omineca regions of British Columbia (Kyle et al. 2001) supports the hypothesis of low dispersal. Effective dispersal by fishers is dependent upon many factors: the ability to move through the landscape, suitable cover, prey resources, mortality risk, and presence of conspecifics.

Few studies have examined the spatial organization of fishers near the northern limit of their distribution. The objectives of our study were to describe the spatial organization and dispersal characteristics of fishers and to examine the effects of season and sex on space use in north-central British Columbia. We expect that the spatial organization and home range size of fishers in British Columbia might be different than elsewhere in their range because of differences in densities of resources (Banci 1989).

## 6.1 Methods

We live-trapped, radio-tagged, and collected point radiolocations of fishers as outlined in *Section 3*. For home range analysis, we included only those ground telemetry locations that had 95% error polygons smaller than 0.75 km<sup>2</sup> and aerial telemetry locations with estimated error <500 m. We selected 0.75 km<sup>2</sup> because it was equivalent to approximately 2% of the area of an average annual home range for a female fisher (Weir 1995a), which we considered to be an acceptable level of precision.

We estimated the size and location of the home range of each resident fisher using two estimators. For fishers with  $\geq 30$  radiolocations, we estimated home ranges using the 95% isopleth of the utilisation distribution (UD) generated from the fixed kernel method with the smoothing parameter selected by least-squares cross-validation (Worton 1989, Seaman et al. 1999). For fishers with repeated observations at one location (e.g., reproductive den, rest site), we initially estimated the smoothing parameter for the fixed kernel for a dataset without repeat observations. Using the value of the smoothing parameter generated from this technique, we re-ran the fixed kernel on the complete dataset. We calculated the core area of each home range using the 50% isopleth of the same distribution. To allow comparison with other studies, we also calculated aggregate home ranges using the minimum convex polygon (MCP) created from 100% of the locations obtained for each fisher with  $\geq 25$  radiolocations. We used the Animal Movement extension to ArcView (Hooge and Eichenlaub 1999) for all home range calculations.

We observed average maximum movement rates of 0.66 km/h for females (SD = 0.90 km/h,  $n = 10$ ) and 0.76 km/h for males (SD = 0.56 km/h,  $n = 3$ ) for sequential radiolocations separated by <43 h during our study period. Based upon this and approximate home range sizes of 35 km<sup>2</sup> for females and 160 km<sup>2</sup> for males, we estimated that a female fisher could reach any point within her home range within 10.1 h and males could do so within 18.8 h. Thus, to be conservative, we considered radiolocations to be temporally independent if separated by >20 h for either sex. This measure of temporal independence is 4 h longer than that derived for radio-tagged fishers in Maine (Arthur et al. 1989a).

We calculated aggregate and seasonal home ranges for each fisher. Aggregate home ranges were based upon all radiolocations collected for the individual during the course of monitoring (i.e., up to 4 consecutive years), with a minimum period of 10 months. We

estimated seasonal home ranges from data collected within one season but pooled across multiple years for each fisher. We examined space-use during 2 seasons that roughly coincided with the presence or absence of snow cover: winter (15 Nov – 31 Mar) and non-winter (1 Apr – 14 Nov).

We measured spatial overlap of the home ranges and core areas among radio-tagged fishers using a coefficient of overlap (Walls and Kenward 2001). This measure allowed us to assess the overlap between 2 home ranges with a single measurement:

$$\text{coefficient of overlap} = 2 \times (\text{overlap}_1 \times \text{area}_1) / (\text{area}_1 + \text{area}_2)$$

where the home range area<sub>x</sub> of fisher<sub>x</sub> had a coefficient of overlap<sub>x</sub>.

We assessed the dispersal patterns of transient fishers by capturing juveniles in their natal ranges (i.e., their mother's home range) during trapping sessions in September, October, and November. We radio-tagged each transient (juvenile or subadult) fisher that we captured and collected point radiolocations until they had established a home range. We calculated the minimum net distance dispersed while transient by determining the distance between the centre of their natal range and that of their established home range or their last radiolocation.

## 6.2 Results

We collected 686 radiolocations of 20 fishers between 18 November 1996 and 10 August 2000. We collected sufficient data to estimate aggregate and seasonal (non-winter and winter) home ranges and core areas for 10 adult fishers (8 F, 2 M; Table 6-1). Because of data constraints, different individuals were used for the calculation of aggregate and seasonal home ranges.

### 6.2.1 Home Range Sizes

Aggregate 95% UD home ranges of female fishers were smaller than those of males (Table 6-2, Fig. 6-1). Estimates of the aggregate MCP home ranges were also smaller for females than males. Aggregate core areas of females were smaller than those of males. The average size of the winter home range was 65 km<sup>2</sup> for females and 190 km<sup>2</sup> for one male (Table 6-2, Fig. 6-2). The mean size of non-winter home ranges was 41 km<sup>2</sup> for females and 200 km<sup>2</sup> for males (Table 6-2, Fig. 6-3).

We investigated seasonal changes in home range size and spatial configuration for 4 fishers (Table 6-3). Two female fishers had home ranges that were at least 2 times larger during winter than during the non-winter period. Home range sizes for the other 2 fishers (1 male, 1 female) increased less than 10% from winter to non-winter. Coefficient of overlap between winter and non-winter home ranges of individual fishers ranged from 0.34 to 0.72. Non-winter home ranges of adult females were generally constrictions of their winter home ranges (Fig. 6-4).

Table 6-1. Sizes ( $\text{km}^2$ ) of home ranges of radio-tagged fishers in the Williston region of north-central British Columbia, 1997-2000, as determined using the minimum convex polygon and fixed kernel (utilisation distribution; UD) methods.

Fisher ID	n <sup>a</sup>	Minimum convex polygon			95% UD			50% UD		
		Aggregate	Non-winter	Winter	Aggregate	Non-winter	Winter	Aggregate	Non-winter	Winter
F02	121	105.8	65.6	96.5	39.7	26.7	61.3	4.4	2.7	10.8
F03	41		22.6			27.3			3.0	
F04	82	79.7	23.6	78.9	48.9	17.8	87.8	5.2	2.9	13.5
F05	38		52.2			59.7			8.9	
F07	53	35.7	30.4	25.3	46.9	34.0		3.9	3.7	
F09	103	77.5	70.2	49.2	81.2	78.2	71.4	13.7	10.8	7.6
F17	43	24.4	13.9	20.3	38.2			9.7		
F18	56	30.6	15.8	24.7	39.5		39.7	5.9		8.2
M01	71	177.8	153.6	107.6	212.5	200.5	189.7	29.9	24.9	30.4
M20	49	177.2	116.5	141.9	225.2	198.4		63.9	55.9	

<sup>a</sup> number of radiolocations used to estimate aggregate home range

Table 6-2. Summary of aggregate and seasonal home range and core area sizes ( $\text{km}^2$ ) of radio-tagged fishers in the Williston region of north-central British Columbia, 1996 to 2000.

	Male			Female		
	$\bar{x}$	SD	n	$\bar{x}$	SD	n
Aggregate						
95% UD <sup>a</sup>	219		2	49	16	6
MCP <sup>b</sup>	178		2	59	33	6
Core area <sup>c</sup>	47		2	7	4	6
Non-winter						
95% UD	200		2	41	23	6
Core area	40		2	5	4	6
Winter						
95% UD	190		1	65	20	4
Core area	30		1	10	3	4

<sup>a</sup> 95% fixed kernel utilisation distribution

<sup>b</sup> minimum convex polygon method

<sup>c</sup> 50% fixed kernel utilisation distribution

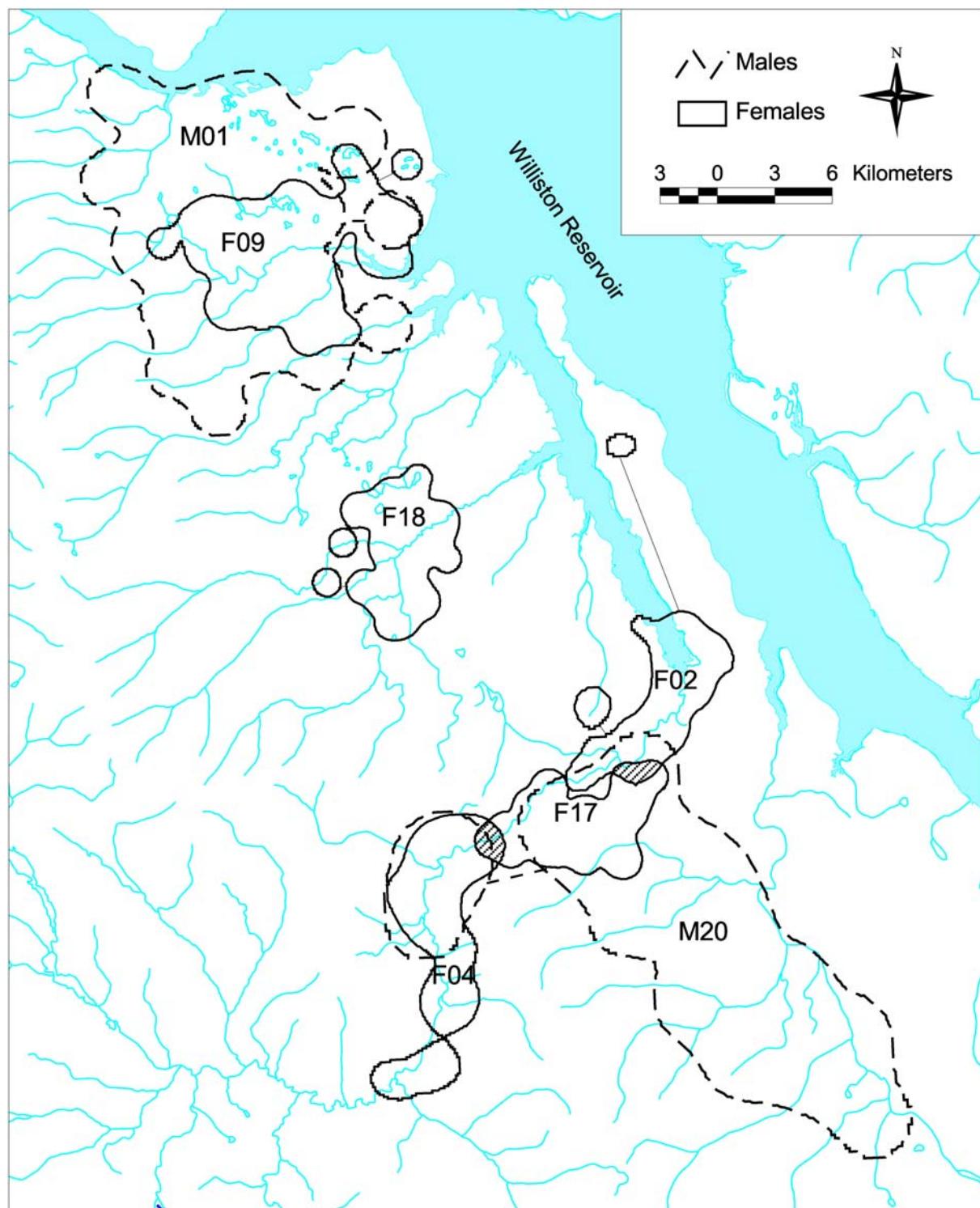


Figure 6-1. Aggregate home ranges (95% UD) of radio-tagged fishers in the Williston region of north-central British Columbia during 1996 to 2000. Cross-hatched areas represent intrasexual overlap of home ranges. F07 (dead female) is not shown.

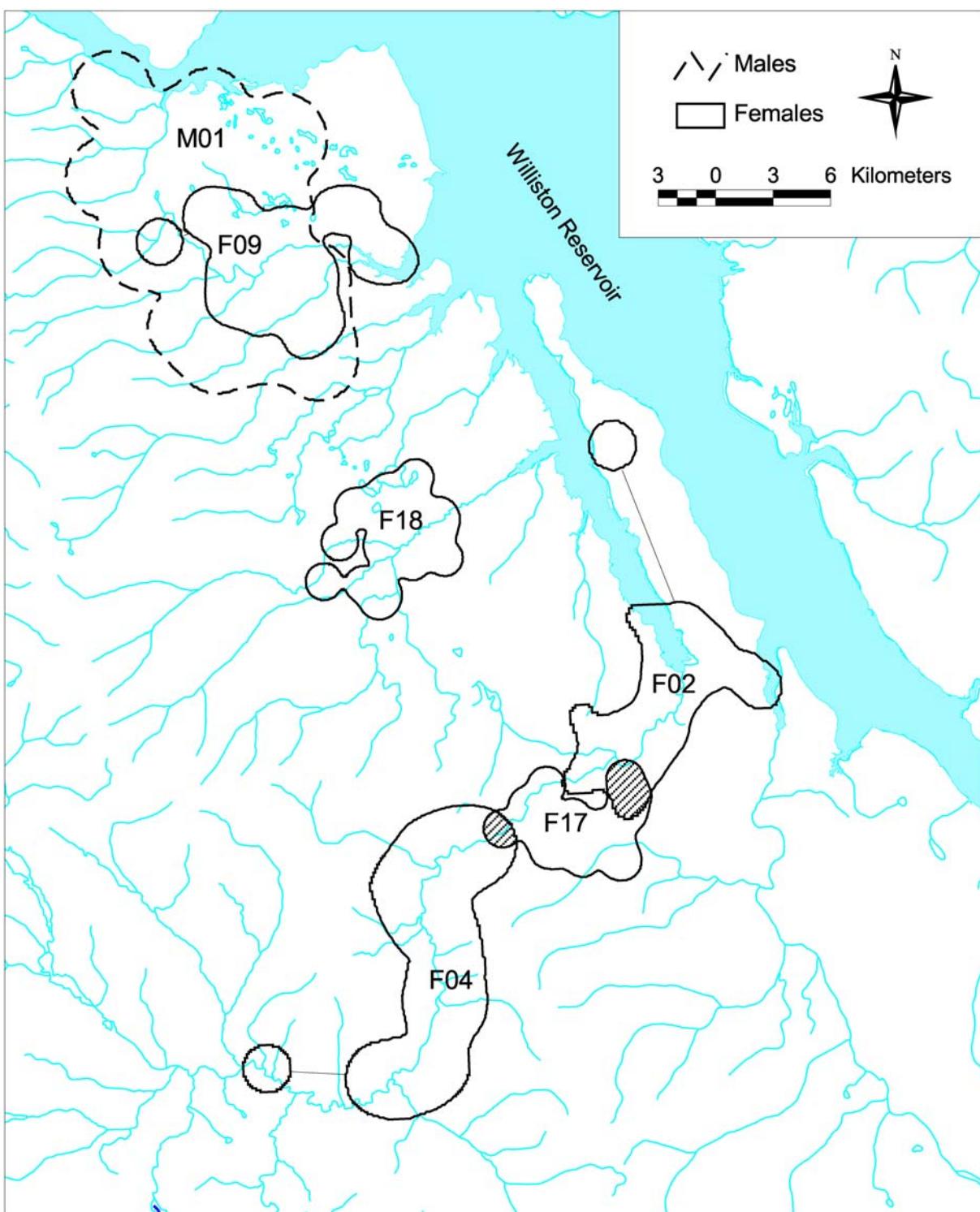


Figure 6-2. Winter home ranges (95% UD) of radio-tagged fishers in the Williston region of north-central British Columbia during 1996 to 2000. Cross-hatched areas represent intrasexual overlap of winter home ranges among females.

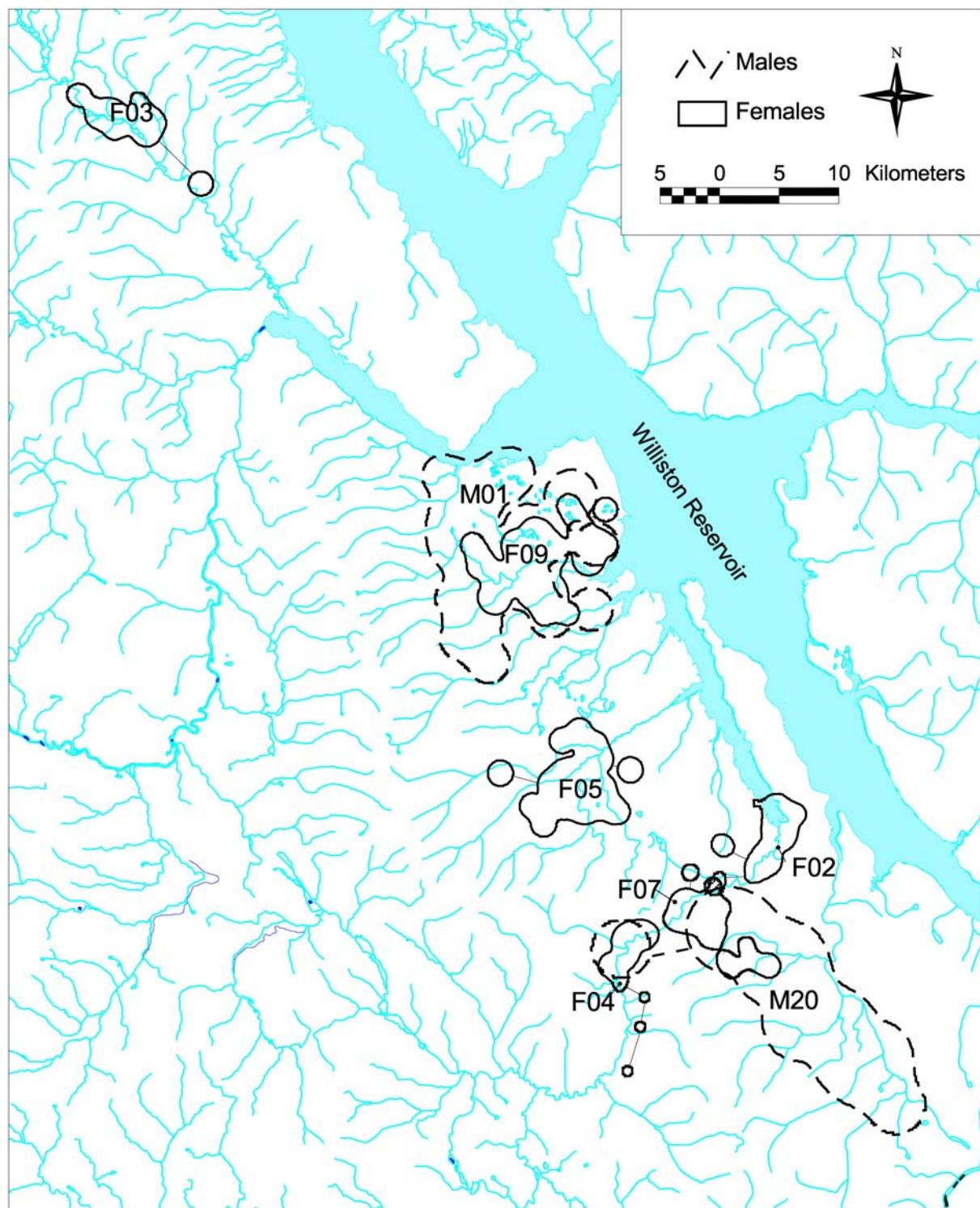


Figure 6-3. Non-winter home ranges (95% UD) of radio-tagged fishers in the Williston region of north-central British Columbia during 1996 to 2000. Cross-hatched areas represent intrasexual overlap of non-winter home ranges.

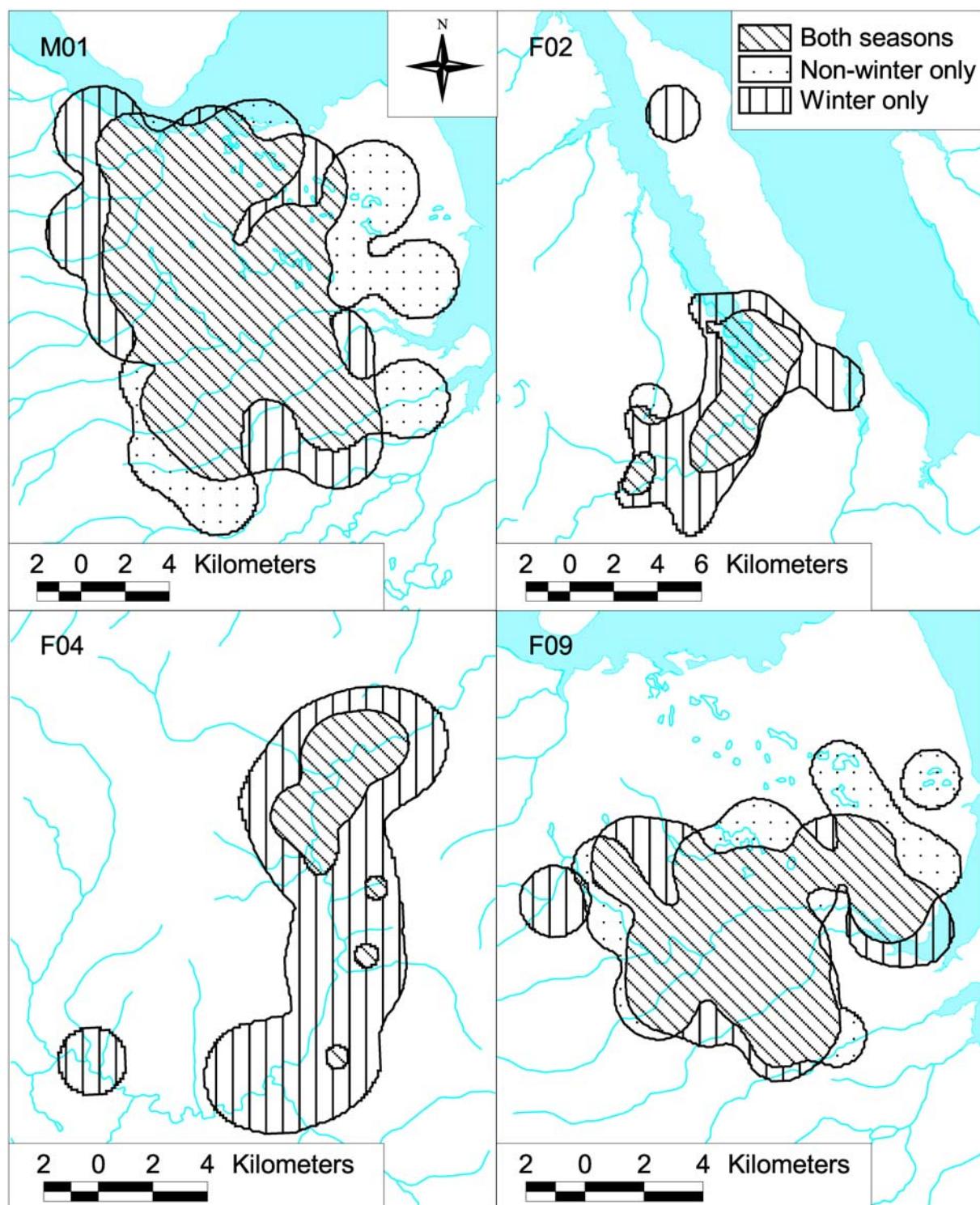


Figure 6-4. Changes in home ranges of radio-tagged fishers between winter and non-winter in the Williston region of north-central British Columbia during 1996 to 2000. All females (F02, F04, F09) showed signs of whelping and rearing young during the non-winter period (except for F02 during 1997 and F04 in 2000).

Table 6-3. Changes in seasonal home ranges (95% utilisation distribution) among adult fishers in the Williston region of north-central British Columbia, 1996 to 2000. Each of the females reared offspring during the non-winter period (except for F02 during 1997 and F04 in 2000).

Fisher	95% UD area (km <sup>2</sup> ) Winter	95% UD area (km <sup>2</sup> ) Non-winter	Coefficient of overlap
M01	190	200	0.72
F02	61	27	0.56
F04	88	18	0.34
F09	71	78	0.72

### 6.2.2 Distribution of Home Ranges

Fishers had 95% UD home ranges with considerable intersexual and little intrasexual overlap (Figs. 6-1 to 6-3, Appendices 6-1 to 6-3). We observed 3 cases of intrasexual overlap among aggregate home ranges of living fishers. In these cases, the coefficient of overlap varied between 0.05 and 0.06. The 2 male fishers that we monitored had no overlap as they were situated near the northern and southern extremes of the study area. The coefficients of overlap for the aggregate home ranges of females were  $\leq 0.06$ , even though 3 females resided in close proximity along the Manson River floodplain (Fig. 6-1). We also observed minimal intrasexual overlap during the winter and non-winter seasons. Overlap of female winter home ranges was limited to one female (F17) slightly overlapping the home ranges of 2 adjacent females. Overlap coefficients for F17 were 0.04 with F04 and 0.11 with F02. During the non-winter period, we observed 1 minor overlap among female home ranges; the coefficient of overlap between F02 and F07 was 0.04. We did not observe intrasexual overlap of 50% UD core areas. We did, however, document overlap between male and female core areas among aggregate (2 cases; coefficient of overlap = 0.19, 0.12), winter (1 instance; coefficient of overlap = 0.21), and non-winter (1 instance: coefficient of overlap = 0.05) core areas.

We observed 2 incidences where home range areas that became available due to the death of the resident fisher were incorporated into another fisher's home range (Fig. 6-5). Following female F07's death in early 1999, female F17 assumed a considerable portion of the area previously used by F07. F17 was confirmed through genetic and tooth-cementum analyses to be an offspring of F07, born in 1997. We tagged F17 in late 1998 and her movements up to the time of F07's death were around the periphery of F07's home range. Following the death of F07, F17 shifted space use to include much of her mother's home range (coefficient of overlap = 0.53) and core area (coefficient of overlap = 0.23). Female fisher F18 used a portion of the area previously occupied by female F05. The coefficient of overlap of F18's aggregate home range and F05's non-winter home range was 0.46. Unfortunately, we could not confirm the death of F05 (transmitter died prior to retrieval) and did not tag F18 until 1.5 years after the disappearance of F05. We were unable to determine if F18 and F05 were related.

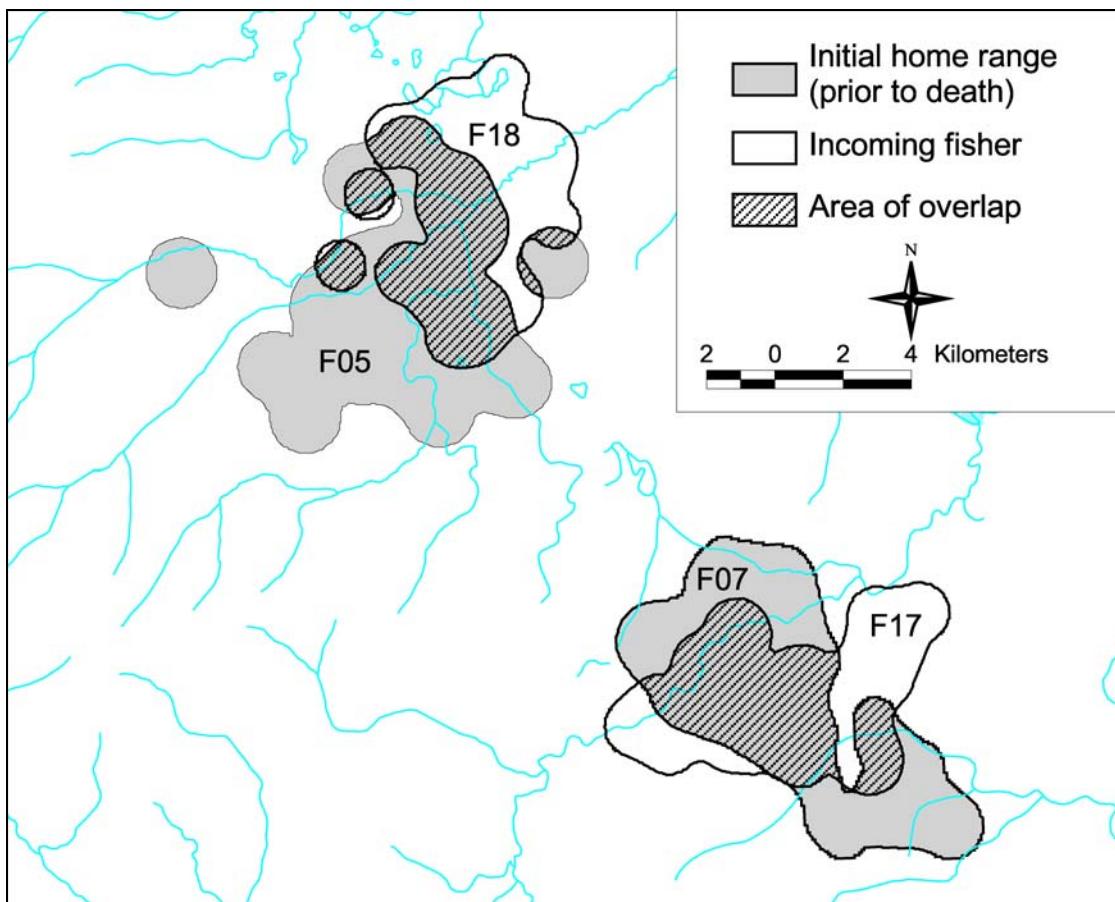


Figure 6-5. Occupation of previously occupied home ranges of dead resident fishers by subadult fishers in the Williston region of north-central British Columbia, 1997 to 2000.

### 6.2.3 Dispersal and Transient Movements

We monitored 14 fishers that were  $<2$  years of age, of which 11 appeared to be transient (Table 6-4). That is, their initial capture locations were either  $>3$  km from their eventual home ranges or, for a period after their capture, they moved throughout the landscape showing little evidence of area fidelity. Six (4 female, 2 male) of the transient fishers were juveniles and 5 (3 female, 2 male) were between 17 and 22 months of age. The 3 individuals that were  $<2$  years old and not transient were 23 months old and female. The mean distance between successive radiolocations for transient fishers was 7.0 km ( $SD = 5.5$  km,  $n = 11$ ), which was farther than distances moved by resident fishers ( $\bar{x} = 3.4$  km,  $SD = 1.6$ ,  $n = 10$ ). However, when the movements were scaled for time lapsed between radiolocations, this difference diminished considerably (transients:  $\bar{x} = 72$  m/h,  $SD = 45$ ,  $n = 11$ ; residents:  $\bar{x} = 61$  m/h,  $SD = 42$ ,  $n = 10$ ).

Table 6-4. Movements and fates of transient radio-tagged fishers in the Williston region of north-central British Columbia, 1997 to 2000.

Fisher ID	Age at first capture (months)	Transient period			Fate
		Minimum distance travelled (km)	Duration (days) (# radiolocations)		
F13	6	20.7	21 (3)	Unknown <sup>a</sup>	
F10	7	135.6	45 (6)	Dead - starvation	
F300	7	31.9	26 (7)	Dead - trapped	
F11	8	17.8	15 (4)	Dead - trapped	
F12	17	16.7	25 (3)	Dead - trapped	
F15	18	31	38 (10)	Dead - starvation	
F17	18	31.2	143 (9)	Established home range	
M14	7	7.5	19 (3)	Dead - livetrap accident	
M20	7	172.2	137 (19)	Established home range	
M06	21	34.6	73 (4)	Unknown <sup>a</sup>	
M01	22	64	63 (8)	Established home range	

<sup>a</sup> suspected radiotransmitter failure

At least 6 of 11 transient fishers died while being monitored, with only 1 of 6 juvenile fishers successfully establish a home range. We documented home range establishment for 2 of 5 transients that were 1-year old. All 3 fishers that established home ranges began to show long-term site fidelity between 31 March and 5 April.

Using DNA fingerprinting and parentage analysis (*Section 5.2.1*), we identified the natal ranges of 4 fishers (3 F, 1M) and measured net dispersal distance for these individuals. Two fishers successfully established home ranges while monitored, one established a home range at or before monitoring began, and we could not monitor the remaining fisher because of transmitter malfunction. Distances between the centres of the natal and established home ranges were 0.7 km (F17), 32.7 km (F09), and 41.3 km (M20). Movement distances and directions from natal ranges were varied and included periods of sporadic site fidelity (Fig. 6-6).

Transient fishers were initially captured at various locations across the study area. At least 3 transients were captured within home ranges of adult females that were not likely their mothers (i.e., shared less than 13 of 13 alleles). Two transient fishers were captured within their natal range, one 6-months old and the other 18-months old at the time of capture. The minimum distance travelled while monitored varied greatly among individuals and was likely influenced by sampling intensity (Table 6-4). Notably, 1 juvenile female moved at least 135 km in 45 days. She covered an area of 1,237 km<sup>2</sup>, crossed large rivers, and used typically less-optimal habitats (e.g., relatively open-canopied subalpine forests) before succumbing to starvation.

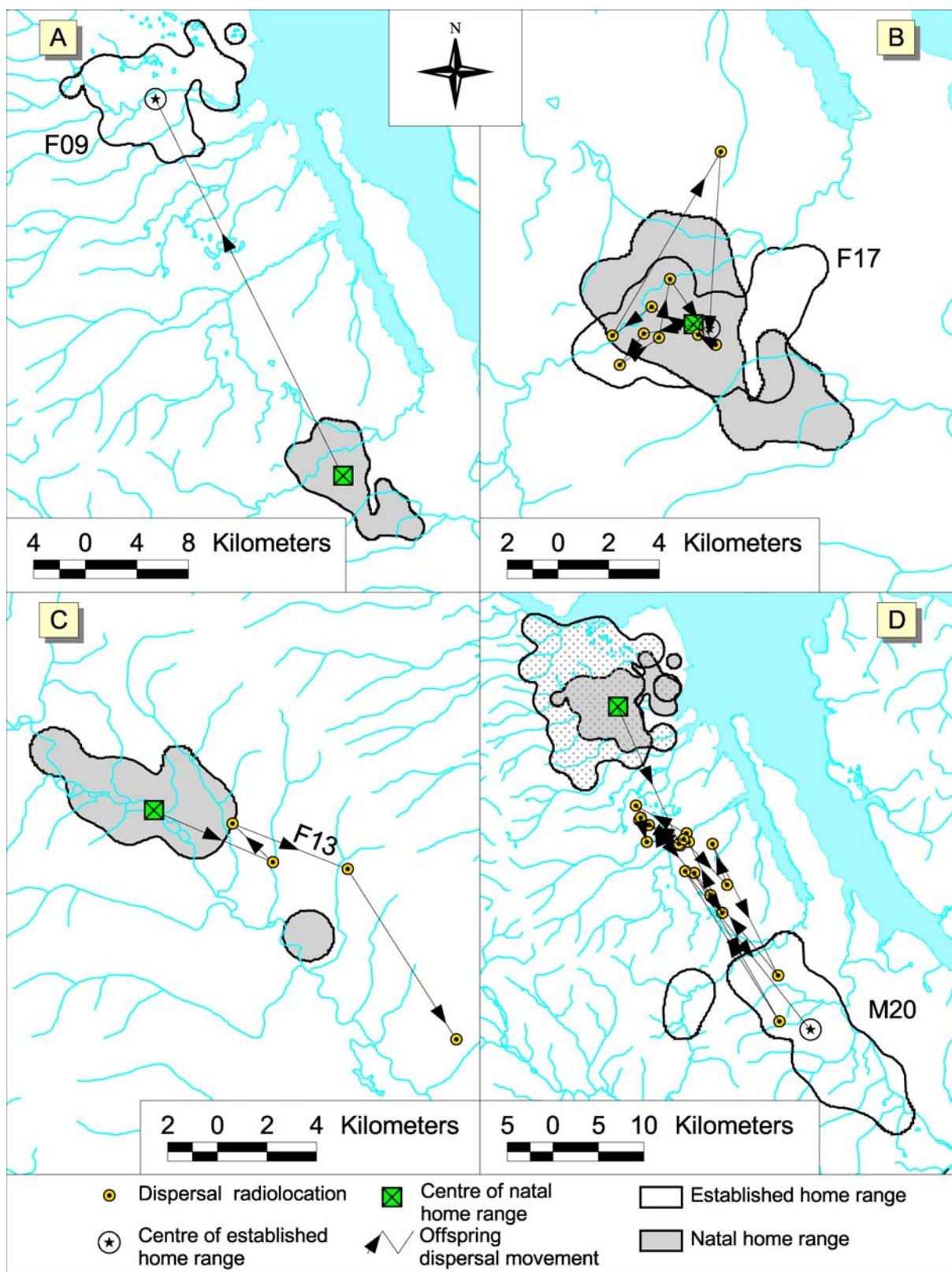


Figure 6-6. Dispersal of fishers from natal ranges determined through genetic analysis of radio-tagged fishers in the Williston region of north-central British Columbia, 1997 to 2000. A: F09 dispersal from F07; B: F17 from F07; C: F13 from F03; D: M20 dispersal from F09 and M01.

### 6.3 Discussion

Generally, fishers in north-central British Columbia exhibited similar spatial organization to that of fishers elsewhere in North America. Home ranges of males overlapped extensively with females and those of females tended to be relatively exclusive of other females. However, the home range sizes and their spatial distribution within the landscape of our study were substantially different than reported elsewhere.

The 10 aggregate home ranges in our study were considerably larger than those reported by other researchers. Aggregate MCP home ranges of our 2 male fishers were up to 15 times larger than any other estimate found in the literature (e.g., 9.2 km<sup>2</sup>, Québec, Garant and Crête 1997; 30.9 km<sup>2</sup>, Maine, Arthur et al. 1989a). Female home ranges were at least 2-4 times larger than those reported elsewhere (e.g., 3.6 km<sup>2</sup>, Ontario, Koen et al. 2007b; 5.4 km<sup>2</sup>, Québec, Garant and Crête 1997; 16.3 km<sup>2</sup>, Maine, Arthur et al. (1989a).

Large home range sizes may be related to the density and distribution of resources available to fishers. In areas with a paucity of prey, we would expect home ranges to be generally larger than in those areas with abundant prey (Harestad and Bunnell 1979). Thompson and Colgan 1987) found that home ranges of American martens in Ontario increased in size as the density of prey declined. Jones (1991) speculated that male fishers in Idaho had large home ranges because of low prey density. Similarly, Garant and Crête (1997) hypothesized that the home ranges of fishers in western Québec were very small because of abundant prey. It is also possible that the availability of prey for fishers diminishes with latitude, thus potentially affecting the size of the home range. Although proposed for American martens, no relationship between home-range size and latitude was found (Buskirk and McDonald 1989). We did not assess prey availability so we did not examine the relationship between home range size and prey.

Prey may not be the only resource that affected the size of the home ranges of fishers in our study. The landscape has been subjected to considerable habitat modification through hydroelectric development, timber harvesting, silvicultural practices, and road and power-line establishment. Consequently, the abundance and distribution of habitats that provide important thermal and security cover may have been diminished. Habitat alterations have probably changed the distribution and abundance of both prey and important habitat components across the landscape, and their effects have likely been cumulative. These changes to the primary resources used by fishers undoubtedly contributed to the spatial organization that we observed. Nonetheless, we observed fishers maintaining intrasexually exclusive home ranges, suggesting that the density of resources was sufficient to support this form of spatial organization (Powell 1994a).

For sexually dimorphic carnivores such as fishers, differences in sizes of home ranges between sexes should be similar to differences in body mass, especially at high densities

(Garant and Crête 1997). Aggregate home ranges of male fishers in our study were 4.5 times the size of those of females, whereas the body mass of male fishers in British Columbia are only 1.7-1.9 times that of females (Weir 2003, this study [*Section 4*]). This discrepancy in home range size to body mass ratio was substantially greater in our study than for fishers in other areas (1.5, New Hampshire, Kelly 1977; 1.9, Maine, Arthur et al. 1989a; 1.8, Québec, Garant and Crête 1997).

This large discrepancy may reflect the composition of the landscape. Many studies on the ecology of fishers typically occur in areas with relatively high densities of fishers (e.g., Arthur et al. 1989a, Garant and Crête 1997). In areas where home ranges of females are densely packed and resources are distributed uniformly across the landscape, the ratio of home range size between the sexes appears to be closer to that predicted by body mass ratios (e.g., Garant and Crête 1997). However, where resources (e.g., prey, habitat, female fishers) are more scarce and the distribution of areas suitable for establishing home ranges are not uniform across the landscape, the resultant spatial organization would be large home ranges with unoccupied areas amongst them, such as the pattern observed in this study.

In addition to body-size effects, home ranges of male fishers are larger than females because males space themselves to sequester mating opportunities with several females (Powell 1994a). Thus, male home ranges must be larger to find the females as well as sufficient food. Wider distribution of females and food results in larger home ranges of males.

We assume that, for an animal with intrasexually exclusive home ranges such as fishers, the increase in the discrepancy between the body mass ratio and home range size ratio between the sexes is indicative of landscape quality. Thus, our spatial organization data suggest that the quality of the landscape for fishers in our study area was poor relative to other regions of North America. Fisher densities of 6 to 49 times less dense than populations in eastern North America support this hypothesis (*Section 7*).

Although our sample size was small, the movement and dispersal patterns of transient fishers may help further explain the spatial organization of fishers in our study area. Fishers often spent >1 year as transients and did not appear to establish a home range until almost 2 years of age. Fishers in eastern portions of their range disperse from their natal ranges during their first winter and establish home ranges in unoccupied habitats soon afterward (Arthur et al. 1993, Powell 1993). Dispersing juvenile females that successfully established home ranges in Maine did so within 2 months of the onset of dispersal, whereas males take up to 9 months to establish home ranges (Arthur et al. 1993).

Several factors contributed to the long transiency period of young fishers in our study area. Much of the landscape appeared to be unoccupied and may have been unsuitable for supporting fishers. Dispersing individuals may have had to remain transient until suitable,

occupied habitat became available through the death of conspecifics. This hypothesis is supported by 2 instances of previously occupied home ranges being assumed by 23-month old fishers. Hence, dispersing fishers may be transient for longer periods because the landscape suitability (*Section 10*), population density (*Section 7*), and adult survival rate (*Section 5*) resulted in few opportunities in time and space in which to establish home ranges. The high rate of mortality for transient fishers suggests that few individuals successfully disperse to establish home ranges, perhaps because individuals are forced to persevere for longer periods of transience, which are characterized by higher mortality risk.

The net distance between natal and established home ranges of transient fishers was typical of that reported by other researchers. Dispersing juveniles in Maine typically established home ranges less than 11 km from their natal ranges and that there was no apparent difference among sexes in net dispersal distance (Arthur et al. 1993). Juvenile fishers typically disperse a distance equal to 1-3 times the mean length of an adult home range (Arthur et al. 1993). Our data support this dispersal relationship. Although many transient fishers made large-scale movements across the landscape, 2 fishers that we documented dispersing out of their natal ranges moved approximately 3 times the length of their mother's home range.

Despite these relatively short dispersal distances, fishers appear to be capable of moving widely throughout the landscape. One juvenile fisher that we monitored travelled at least 132 km and covered over 1,200 km<sup>2</sup> before it died 77 km from where it was first captured. Weir and Harestad (1997) noted that translocated fishers in central British Columbia wandered widely following their release and covered areas of more than 700 km<sup>2</sup> while transient. Also, a radio-collared fisher was photographed using a wildlife overpass in Banff National Park, over 200 km from the nearest radiotelemetry study (T. Clevenger, personal communication). It is unclear if wide-ranging dispersers are as successful as those that establish home ranges closer to their natal range. Our anecdotal observations suggest that long-range movements may exacerbate the risks associated with being transient.

#### 6.4 Management Implications

Fishers in our study area, a segment of the SBS biogeoclimatic zone, had notably larger home ranges and correspondingly lower densities than elsewhere within their range in North America even though this zone is considered one of the most productive zones for fishers in the province (Banci 1989, Weir 2003).

Our data suggest that fishers are not distributed uniformly across the landscape and that home ranges may be large in this area because of the distribution and abundance of mates, prey, and suitable habitat. Landscape alterations that influence the resources needed by female fishers will affect the density of the fisher population. Human activities that further disperse, alter or remove these resources will likely have the net effect of increasing the area

needed by females to sequester sufficient resources. Similarly, the intensity of fur harvest in an area can have implications to the successful establishment of future home ranges and recolonization.

## 7.0 DENSITY<sup>3</sup>

Whether for conservation of vulnerable species or management of harvested wildlife, population management often necessitates an approximation of the density at which the species of interest occurs. Density estimates and vital rate data are necessary information for modelling population changes under various management scenarios. Density estimates are also useful to wildlife and habitat managers because they provide benchmarks from which habitats can be ranked at both regional and landscape scales. Additionally, habitat-based density estimates and their resultant population estimates for identified areas are often integral inputs for population viability analyses.

Fishers are medium-sized carnivores of the Mustelidae family that are found in boreal and temperate coniferous and deciduous-coniferous forests across North America (Proulx et al. 2004). Fishers are difficult to inventory because effective methods are generally labour-intensive and costly (Powell 1993). As a result, no universal method exists for estimating the density of fisher populations. In the past, fisher densities have been estimated using snow-track counts (de Vos 1952), fur-harvest returns (Douglas and Strickland 1987), live-capture and radiotelemetry data (Kelly 1977, Arthur et al. 1989a), and track plate surveys (Zielinski and Kucera 1995). Recently, Fuller and others (2001) estimated the density of fishers in Massachusetts by using mark-recapture information and territory mapping.

Fisher density estimates for eastern North America range from 50 to 385 fishers/1000 km<sup>2</sup> (Powell and Zielinski 1994, Fuller et al. 2001), but Banci (1989) suggested that fisher densities were considerably lower in western North America. In her analysis, she cited only 2 studies that had quantitative data for this portion of the species' range; both provided rough estimates of less than 5 fishers/1000 km<sup>2</sup>. One of these estimates was from northeastern British Columbia where, due to differential habitat quality across the landscape, substantial areas of land were not thought to be occupied by fishers (Quick 1953). Similarly, Jones (1991) surmised that the low densities of fishers in the west were the result of generally poorer quality habitats.

Fishers in British Columbia are currently managed as a furbearer that can be legally harvested by trappers on registered traplines between 1 November and 15 February. However, harvests of fishers have declined considerably in British Columbia over the past 30 years, which has contributed to its current status as "vulnerable" in the province (Weir 2003). Due to the lack of relevant density estimates for western North American fisher populations, and particularly north-central British Columbia, harvest management may be incorrectly based on estimates from other jurisdictions. We estimated the density of fishers in an

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<sup>3</sup> This section published as Weir, R. D., and F. B. Corbould. 2006. Density of fishers in the Sub-boreal Spruce biogeoclimatic zone of British Columbia. Northwestern Naturalist 87:118-127.

industrial forest landscape in north-central British Columbia to help wildlife managers and trappers to better regulate harvest levels and help facilitate population persistence.

## 7.1 Methods

### 7.1.1 Livetrapping and Tagging

We captured and radiotagged fishers during the fall and winter (*Section 3*) to determine the minimum number of fishers that were alive in the study area by the end of winter (late March) each year. We attempted to capture and radio-tag fishers in 4 annual intensive capture sessions conducted during the late-fall and winters of 1996-1997, 1997-1998, 1998-1999, and 1999-2000. We set live traps so that they were continuously operational for between 12 to 22 days for 2 to 6 time-periods during each of these annual capture sessions.

### 7.1.2 Density Estimate

We calculated the density of fishers twice during the year: the start and end of each annual capture session. We estimated a late-winter (31 March) density by dividing the area that was effectively sampled during the annual capture session (see below) by the number of fishers known to be alive at the end of that capture session (minimum number alive, MNA; Krebs 1966). We also estimated a fall (31 October) density using the same effectively sampled area and the fall MNA, which was derived by tallying all of the fishers known to be alive at the start of each annual capture session. This latter number included animals captured during the subsequent capture session plus those fishers that were previously tagged and still alive based on radio-telemetry data. Thus, the late-winter estimate was based on the fall estimate minus known mortalities.

The fall density estimate relied upon the assumption that juvenile and subadult fishers that were caught during the subsequent capture session were present in the sampled area on 31 October. Although juvenile and subadult fishers are generally believed to be transient (Powell 1993), our data for transient radio-tagged individuals (2F, 1M) showed that the net dispersal distance (that is, between the centres of each fisher's maternal home range and their respective established home ranges) was between 0.7 km and 41.3 km ( $\bar{x} = 20.2$  km, SD = 20.4 km,  $n = 3$ ). Based on this low dispersal distance and the very low suitability of habitats surrounding the study area (alpine tundra to the west, large reservoir to the east), it is unlikely that many animals dispersed into or out of the project area. Also, our data and that of Weir (1995a) suggested that fishers establish their home ranges, and thus become resident, by the end of March, so we likely would have captured transient individuals within the study area by the end of the capture session (that is, 31 March).

We estimated the area that we sampled during each capture session by considering the "effective area" that each live trap sampled. As a first step in delineating the sampled area, we identified live traps that were operational for a sufficient time to capture a fisher based on

the latency to first detection (LFD; Zielinski and Stauffer 1996). Derived from empirical data, the LFD was 13.7 days for resident fishers that we captured ( $SD = 12.3$  days until capture,  $n = 18$  fishers). We did not include captures of 3 fishers in our LFD calculation because these animals later proved to be transient and may not have been exposed to live traps as consistently as fishers with established home ranges. For our estimate of area sampled, we only included live traps that were operational for at least 16 days during each capture session to ensure that only traps that had surpassed the LFD criteria were used.

Second, we determined the effective area sampled by each live trap. We assumed that a fisher would have a reasonable likelihood of encountering traps on its day-to-day travels throughout its home range. We considered the 75% isopleth of the animal's utilisation distribution (UD) during the winter (that is, a capture session) as the smallest area that a fisher was likely to use consistently during our sampling. Based on our calculated 75% isopleths (range = 18.8 to 34.9 km<sup>2</sup>,  $n = 5$  female fishers), we selected the smallest 75% isopleth (18.8 km<sup>2</sup>) to represent the area that was effectively livetrapped. Consequently, a 4.89-km buffer, which circumscribed an area that was equivalent to our smallest 75% isopleth, was placed around each live trap that was active during the capture session. Portions of the buffer that overlapped the inundation area of the Williston Reservoir were excluded from the area sampled. In addition, because we were attempting to produce a density estimate for the SBS zone and we livetrapped exclusively within this zone, we excluded any areas that fell outside this zone, including other forested areas. We felt confident in excluding these other areas because  $\leq 7\%$  of the amalgamated home ranges of all fishers included these outlying areas.

Lastly, to delineate the entire area that we effectively sampled, we also included all portions within the SBS of the home ranges (that is, 95% isopleths of the annual UD) for radio-tagged fishers that were alive during the annual capture session that fell outside of the livetrapped area as defined above. This resulted in small areas outside the livetrapped area (6% and 8% of the total area) being included in the effective area that, although unlikely, may have included portions of the home ranges of untagged resident animals.

## 7.2 Results

We had 281 different live trap sets operational for 9724 trap-nights (that is, 1 trap operational for 1 24-hour period) over the 4 annual capture sessions (Table 7-1). On average, sites were active for 42 trap-nights during 1996-97 (range: 3 – 98,  $n = 77$ ), 28 trap-nights during 1997-98 (range: 1 – 75,  $n = 110$ ), 21 trap-nights during 1998-99 (range: 4 – 45,  $n = 101$ ), and 17 trap-nights during 1999-2000 (range: 2 – 37,  $n = 79$ ). Most trap sites were operational for at least 16 days during each capture session (Fig. 7-1). We sampled a larger area in the early stages of the project and focussed sampling efforts in later years (Table 7-1, Fig. 7-2). Trap-night density was higher in the first 2 capture sessions (2.87 and 2.84 trap-

Table 7-1. Fall (31 October) and late-winter (31 March) density estimates derived from the minimum number alive (MNA) estimate for areas sampled during each annual capture session in the Williston region of north-central British Columbia, 1996–2000.

Capture session <sup>a</sup>	Trap-nights <sup>b</sup>	# of traps	MNA				Area sampled <sup>c</sup> (km <sup>2</sup> )	Density (fishers/1000 km <sup>2</sup> )					
			31 October					31 Oct					
			ad	sub	juv	Σ		31 Mar					
1996-1997	3255	77	7	3	1	11	5	3	1	9	1135	9.7	7.9
1997-1998	3033	110	5	1	8	14	5	1	4	10	1069	13.1	9.4
1998-1999	2088	101	7	4	2	13	5	2	1	8	1009	12.9	7.9
1999-2000	1348	79	7	1	0	8	7	1	0	8	873	9.2	9.2

a November to March, but including September and October in 1997–98.

b 1 trap-night = 1 live trap set for one 24-h period.

c Estimated using a 4.89-km diameter buffer around each live trap that was operational for ≥16 trap-nights and the 95% isopleths of resident tagged animals that were alive during the capture session, excluding the Williston Reservoir and areas outside the Sub-Boreal Spruce biogeoclimatic zone.

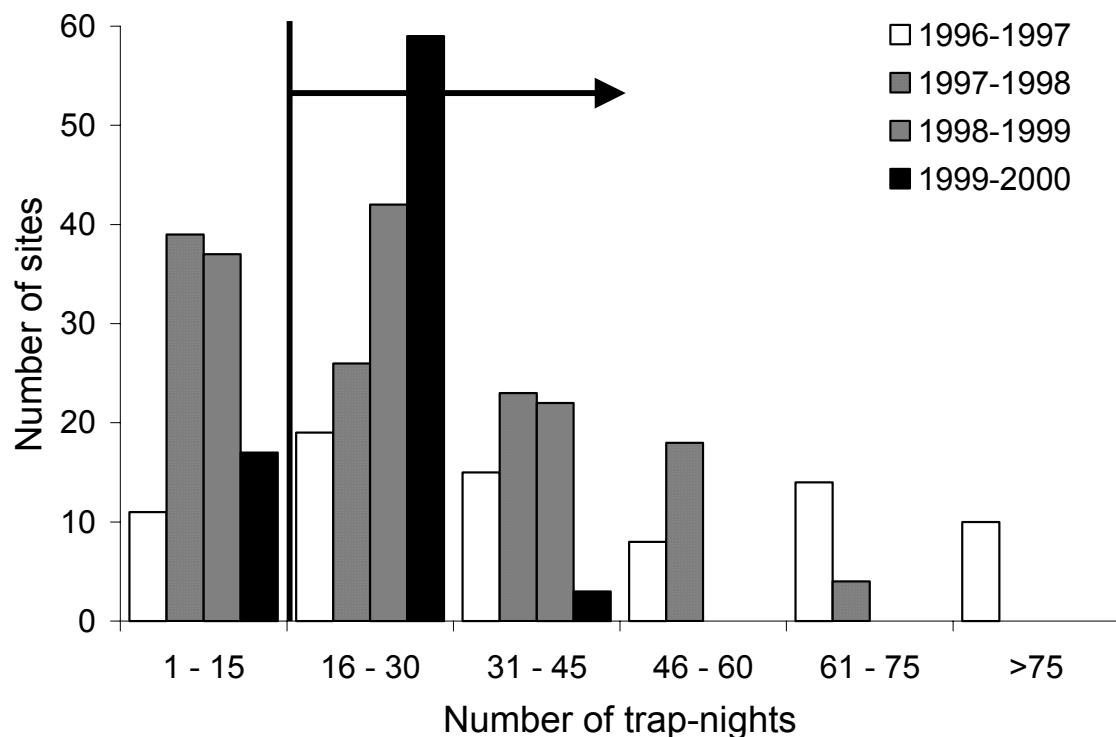


Figure 7-1. Intensity of live-trapping effort (trap-nights per site) for fishers during each capture session in the Williston region of north-central British Columbia, 1996–2000. Sites for which ≥16 trap-nights were conducted per session (to right of vertical line) were included in the calculation of sampled area. n = 9,724 trap-nights.

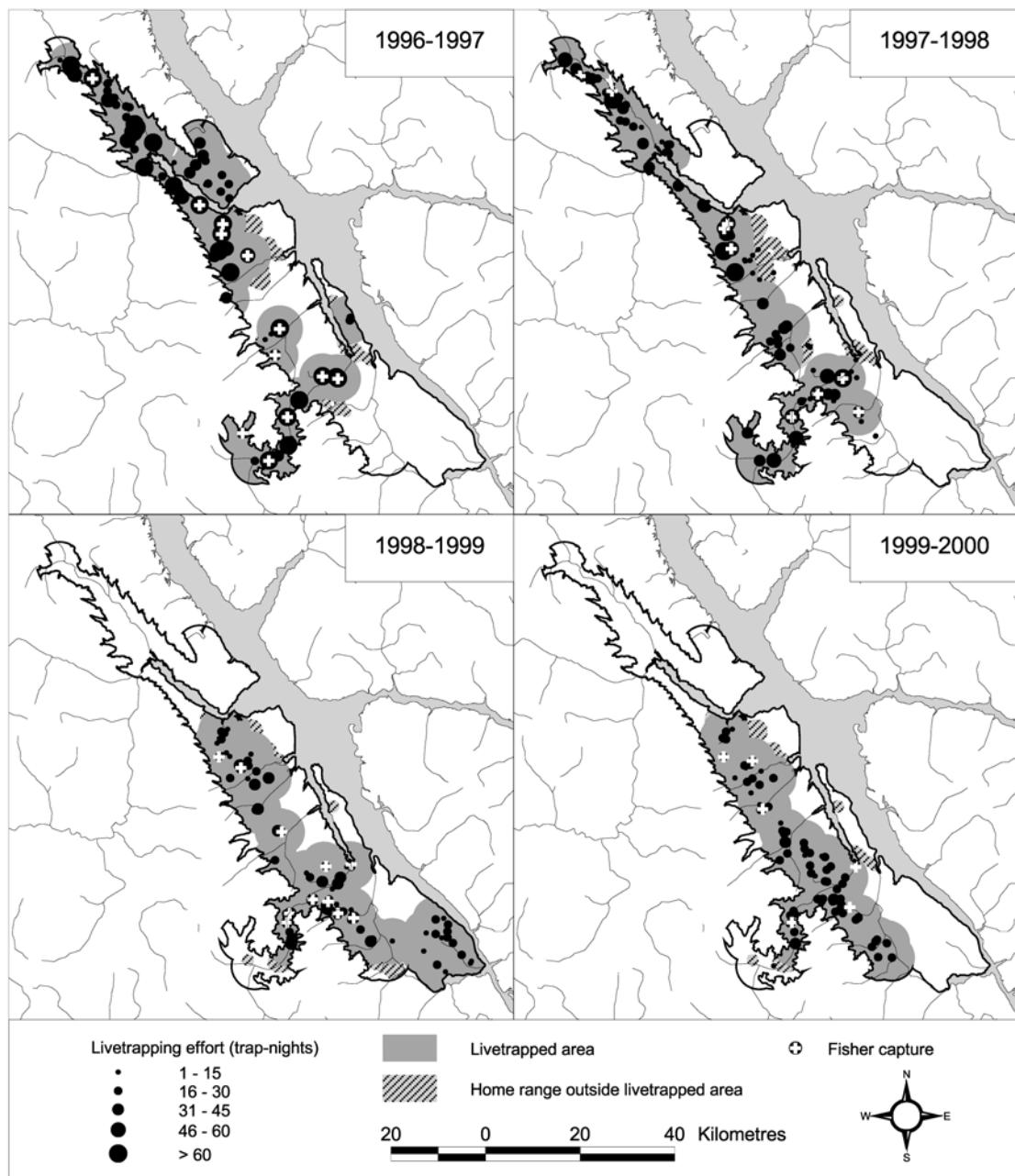


Figure 7-2. Spatial distribution of live-trapping effort and effective area sampled for fishers during each of 4 capture sessions conducted in the Williston region of north-central British Columbia, 1996–2000. Grey shading represents portions of the effective area that were livetrapped; cross-hatched shading were portions of home ranges of resident fishers that occurred outside of the livetrapped areas.

nights/km<sup>2</sup>, respectively) than in the 1998-99 and 1999-2000 sessions (2.07 and 1.54 trap-nights/km<sup>2</sup>, respectively).

We captured 21 fishers (15 F, 6 M) during the 4 annual capture sessions. At first capture, 7 were adults, 8 were subadults, and 6 were juveniles. Additionally, 1 untagged adult male

fisher was kill-trapped by a trapper within our sampling area during the 1996-1997 capture session.

We assumed that we either captured or had previously tagged all of the fishers within our sampled areas by the end of each capture session. Many areas that we livetrapped appeared to be unoccupied by fishers. Conversely, small portions of several fisher home ranges occurred outside of the livetrapped area. In only one instance after the first capture session did we capture a previously untagged adult fisher (3 year-old male) in the study area (2000). Data from 3 other males that we radiotagged suggested that subadult males were transient until at least 2 years of age. Thus, we assumed that this male was present in the sampled area during the 1998-99 capture session (that is, as an adult), but not prior to this.

The average density at 31 October for the 4 years of sampling was 11.2 fishers/1,000 km<sup>2</sup> ( $SD = 2.1$  fishers/1,000 km<sup>2</sup>,  $n = 4$  capture sessions) and 8.6 fishers/1,000 km<sup>2</sup> ( $SD = 0.8$  fishers/1,000 km<sup>2</sup>,  $n = 4$  capture sessions) at 31 March (Table 7-1). The estimated density varied among years, ranging from 7.9 to 13.1 fishers/1,000 km<sup>2</sup>.

### 7.3 Discussion

Although our estimates were greater than the only other reported density estimate for British Columbia (4.8 fishers/1000 km<sup>2</sup>; Quick 1953), the density of fishers in our study area was still substantially lower than that reported from elsewhere within the species' range. By comparison, populations from eastern North America were 6 to 49 times denser than our study area (Douglas and Strickland 1987, Powell and Zielinski 1994, Garant and Crête 1997, Fuller et al. 2001, Koen et al. 2007b). In fact, the densities that we calculated were among the lowest that we encountered in the literature.

For species that have intrasexually exclusive home ranges and polygamous males, such as fishers (Powell 1994a), density will largely be dependent upon the home range sizes of each sex and the distances among home ranges. The magnitude of both these variables is likely a function of the quality and spatial distribution of habitats. Given similar mortality parameters among areas, areas with homogeneous, high-quality habitat, which supplies all of an animal's life requisites in a small space, will generally have smaller, closer-spaced home ranges (Harestad and Bunnell 1979), and thus a higher density of individuals, than areas with patchy, high-quality habitat.

Indeed, the low density that we observed may be related to the home range size and spacing of individuals within our study area. Powell (1994a) summarized the size of fisher home ranges from across North America and derived a mean home range size of 38 km<sup>2</sup> for males and 15 km<sup>2</sup> for females. In comparison, fishers in our study area and a site elsewhere in the SBS zone of central British Columbia had home ranges that averaged 162 km<sup>2</sup> for males ( $SD = 105$  km<sup>2</sup>,  $n = 3$ ) and 38 km<sup>2</sup> for females ( $SD = 18.6$  km<sup>2</sup>,  $n = 11$ ; Weir 1995a, Peace/Williston Fish and Wildlife Compensation Program, unpublished data). Consequently,

based on home range size alone, we would expect that fishers in the SBS zone would occur at one-half to one-third of the density of other fisher populations. In addition, our livetrapping results and radio-telemetry data indicated that not all of the sampled area was inhabited by fishers (Peace/Williston Fish and Wildlife Compensation Program, unpublished data), likely causing greater disparity with other fisher populations where the habitat is more spatially uniform and of higher quality (Arthur et al. 1989a, Garant and Crête 1997, Fuller et al. 2001).

Fisher densities fluctuate temporally, sometimes in excess of an order of magnitude (Powell 1994a), as a population responds to various factors. Changes in prey abundance and vulnerability, such as that caused by the 10-year snowshoe hare (*Lepus americanus*) cycle, can have a dramatic effect on fisher populations (Powell 1993, Powell and Zielinski 1994), although Bulmer (1974) did not detect significant cycling of fisher populations in British Columbia. Kill-trapping for fur harvest can also affect the local density and spatial organization of fisher populations (Arthur et al. 1989a) because harvest pressure is usually spatially and temporally uneven (Powell and Zielinski 1994). Although fur harvesting affected the density of fishers in our study area (5 of the 22 fishers that were detected in our sampled area were later killed by trappers) and this was included in our density estimates, we do not feel that it overtly affected our estimate compared to other trapped populations that did not account for losses due to kill-trapped animals. Our data indicated that density varied during our 4-year monitoring period, but the confounding factors of different sampling areas, fur harvest, unknown prey abundance, and low sample size limited what we could conclude about these differences.

Enumeration indices that rely on capturing individuals, such as our MNA technique, produce an underestimate of the population or density (Jolly and Dickson 1983, Tuyttens 2000, McKelvey and Pearson 2001). An alternative to the enumeration approach is to use estimators that involve marking captured individuals and evaluating proportions of marked to unmarked individuals in subsequent sampling (mark-recapture; Krebs 1989:15). Mark-recapture estimates have been shown to have low bias and relatively high precision in their estimates of population size and are often preferred to enumeration techniques (Jolly and Dickson 1983, Tuyttens 2000). However, mark-recapture estimators were not appropriate for our data because 2 assumptions required for these methods were violated: not every individual had the same probability of being caught and it was unlikely that marked individuals in our population had the same probability of survival among sampling periods.

We chose to use MNA enumeration methods to estimate population size in our study area for 2 additional reasons. In their review of population estimators, McKelvey and Pearson (2001) suggested that, for populations of <50 individuals, the number of unique individuals captured (that is, MNA) was the population measure with the lowest variance and sensitivity to sources of variation. Also, they found that the MNA performed better than estimators,

such as mark-recapture methods, when population attributes (for example, capture probabilities that vary across time, individuals and capture history) were unknown and the variation in capture probabilities was very different from null expectations. In light of these factors, we chose the known negatively biased MNA technique to best estimate our population size.

Several aspects of our sampling regime likely minimized the negative bias of our population and density estimate. Adult male and juvenile fishers are reported to be the most susceptible segments of the population to capture, whereas adult female fishers are believed to be the most difficult to catch (Douglas and Strickland 1987, Powell 1994a). Therefore in a biased sample, one would expect juveniles and adult males to dominate captures, and adult females to be much less common. However, 46% of our captures (29 of 63) were of adult female fishers, whereas we captured adult males 11 times and juvenile fishers 7 times during the term of the project. Animals that are in poor body condition may also be more susceptible to capture because they would likely be more desperate for food (that is, trap bait) than healthy animals. Although we had no quantitative measure of health (for example, fat levels), all adult fishers that we caught appeared to be in good physical health based on external and, where possible, internal examination (M. McAdie, DVM, and R. Weir, personal observation). Thus, the intensive effort expended to capture fishers in the study area, the relatively high frequency with which we caught adult females relative to other age-sex classes, the apparent good health of fishers and, as well, the anecdotal observation that fisher tracks were not observed during the winter period in any area that did not have a captured animal, suggests that the negative bias in our estimate was likely minimal.

Although the MNA estimate may have been slightly negatively biased, the area effectively sampled was also, if anything, negatively biased. This is because our estimate of the area that an individual trap was assumed to sample was based on the 75% UD of the smallest winter home range for our adult females. We occasionally caught radiotagged fishers at traps outside of their winter 75% UD, which suggests that the effective area sampled by each trap may have been larger than the 4.89 km buffer that we used. Consequently, the negative bias of the sampled area may have somewhat ameliorated the MNA bias.

Minimum number alive estimates, even though they are negatively biased to some extent and require an intensive capture effort to get a reasonably accurate population indices, were likely the most appropriate method to census the small population of fishers in our study area. Lower-intensity capture methods, such as non-invasive molecular tagging (Mowat and Paetkau 2002), may be a more cost-effective way of estimating population size and density of fishers in north-central British Columbia.

## 7.4 Management Implications

Although our study area has undergone intensive forest harvesting since 1972, we believe it is representative of the current state of the SBS zone because of similarities in forest harvesting and fur-trapping pressure among areas. Because the SBS zone is typically comprised of productive conifer-dominated forests located on rolling terrain at lower elevations of British Columbia's interior region (Meidinger and Pojar 1991), this area is a large and integral component of the forest-harvesting landbase and has among the most suitable habitat for fishers in the province (Weir 2003). Thus, our density estimate should be representative of similar landscapes elsewhere in the SBS zone.

Until new data demonstrates otherwise, wildlife managers in British Columbia can use the density of between 7.9 and 13.1 fishers/1000 km<sup>2</sup> to help them manage populations of fishers in the SBS zone and possibly elsewhere in the province. Specifically, wildlife managers and trappers may use these data to estimate sustainable harvest rates on traplines of interest within the SBS. This density estimate may also be applied to habitat suitability data to estimate population sizes in other areas of British Columbia. Further studies are required to expand on our results and describe fisher population demographics in other biogeoclimatic zones in British Columbia and other western landscapes. Information is also needed on the relationships among densities, population dynamics, habitat, and prey to help guide the management and conservation of fisher populations in the dynamic and industrialized forest landscapes of British Columbia.

The ability of the fisher population in the Williston region to support fur-harvest may be low. Previous analyses of several fisher populations in eastern North America suggested that populations would decline if harvest levels were >20-25% of the pre-trapping population (Douglas and Strickland 1987, Paragi et al. 1994). Based on our average pre-trapping (31 Oct) estimate of approximately 20 fishers in the 1,830 km<sup>2</sup> study area (Table 7-1), the project area would be expected to support an annual harvest of 4-5 animals. This rate of harvest, however, assumes that fecundity and juvenile recruitment rates are similar to eastern studies, a situation that was unlikely in our case. Therefore, harvesting at these rates could severely impact the reproductive component of the population. York (1996) modelled a closed, hypothetical population with literature-generated demographic parameters. All parameters were derived from harvested populations. He found that only under the best-case scenario (i.e., highest values for fertility, litter size, female birth composition, and survival) did the population show growth, and only marginally so. Consequently, he suggested that most harvested populations rely on immigration to remain viable over the long term.

## 8.0 ACTIVITY PATTERNS<sup>4</sup>

Members of the Mustelidae family generally have long, thin bodies with high surface-to-volume ratios, which result in higher energetic costs for day-to-day life relative to many other mammals (Brown and Lasiewski 1972). Because of these morphometric characteristics, which also constrain energy storage, energy balances are very tenuous for these species (Harlow 1994). In addition, because many mustelids live in cold environments that pose further energetic challenges, rates of activity likely play an important role in their overall energy budget. Examining the activity patterns of fishers provides us with an opportunity to evaluate the factors that may affect decisions regarding activity, and hence optimization of the fitness, of a typical cold-environment mustelid.

Fishers exhibit a variety of complex behaviours in the acquisition of resources needed for their survival and reproduction (Powell 1993) and many factors have been reported to affect the timing and rates of their activity. Although initially believed to be primarily nocturnal (de Vos 1952, Coulter 1966), more recent studies have reported that fishers tend to be crepuscular (i.e., most active at sunrise and sunset; Kelly 1977, Johnson 1984, Arthur and Krohn 1991, Powell 1993). Periods of activity are generally 2 to 5 hours long and are often separated by longer stretches (>10 h) of inactivity (Powell 1993).

Intrinsic factors may play an important role in affecting activity patterns of fishers. During spring, denning (i.e., parturient) female fishers are reported to be more active than non-denning females as expected, given energy demands for nursing (Arthur and Krohn 1991). Also, Kelly (1977) and Arthur and Krohn (1991) both reported that fishers were more active in summer than winter. Male fishers may be more active than female fishers (Kelly 1977), especially during the breeding season when they are attempting to locate mates (Arthur and Krohn 1991).

Extrinsic factors may also affect activity rates of fishers. Deep, soft snow can inhibit movement during winter and, because of this, fishers are reported to modify their small-scale movements to avoid areas with less-supportive snow (Leonard 1980, Raine 1983). Fishers may also modify their behaviour during periods of extreme cold (Weir et al. 2004).

Identifying the primary factors that affect activity patterns of fishers will provide us with insight into the limitations within which fishers expend energy and acquire resources. Understanding the basis of this relationship will help us to predict the effects of changes in the distribution and abundance of resources (e.g., alteration of habitat, effects of global warming) on the ability of the landscape to support fishers.

We expect activity rates of fishers to be affected by both extrinsic and intrinsic factors, as identified by previous researchers: temporal proximity to twilight, season, abiotic factors

<sup>4</sup> This section published as Weir, R. D., and F. B. Corbould. 2007. Factors affecting diurnal activity of fishers in north-central British Columbia. *Journal of Mammalogy*:88 1509-1514.

(e.g., snow conditions, ambient temperature), reproductive status, and sex of the animal. In this study, we used radiotelemetry data collected from fishers in the sub-boreal forests of north-central British Columbia to examine these hypotheses.

### 8.1 Methods

We estimated the activity of free-ranging radio-tagged fishers based on the strength and consistency of their respective radio signals from ground telemetry (Arthur and Krohn 1991, Drew and Bissonette 1997). Radio signals from resting fishers were usually strong and consistent, whereas fishers that were active usually produced signals that fluctuated greatly in both strength and consistency. We classified each radiolocation as "active", "not active", or "unknown". "Not active" radiolocations were those where the signal was strong, the strength did not fluctuate noticeably, and the transmitter location did not change within the monitoring period. "Active" radiolocations were those where the signal fluctuated greatly and the transmitter location changed during monitoring. "Unknown" occurred when the radio signal was neither clearly constant nor fluctuating. We did not observe substantial differences in the characteristics of signal attenuation between collar and implant transmitters.

We attempted to collect 4-8 radiolocations per fisher for each month during our monitoring periods. For each radiolocation, we collected data on temporal proximity to twilight (i.e., hours from sunrise or sunset), season (winter [16 November – 15 April] or snow-free [16 April – 15 November]), concurrent local ambient temperature, snow conditions (total depth of snow, depth of new snow in past 24 hours), reproductive condition, and sex of the individual. Temperature and snow data were recorded at 5 climate stations throughout the study area (see *Section 3*).

We classified the timing of reproductive behaviour differently among age and reproductive classes. We classified radiolocations from female fishers with young as being from the rearing period if they occurred from 2 days before the observed whelping date and 30 June. For males, we considered radiolocations to be from the mating period if they occurred between 1 March and 15 May (Powell 1993). We considered radiolocations from females without young to be from the mating period if they were collected between 1 April and 15 May. All other radiolocations were considered to be from the non-reproductive period.

We assessed the effect of temporal proximity to twilight, season, total snow depth, presence of  $\geq 5$  cm of snow fallen during past 24 hours, ambient temperature, reproductive status, and sex on the likelihood of activity of fishers by considering these factors in several competing models using an information-theoretic approach (Burnham and Anderson 1998). We used information from previous studies of fisher ecology and suspected ecological relationships to develop 17 a priori models (i.e., hypotheses) that we tested. We examined

the support by the data for each of the models composed of arrangements of these variables, with the global model including all 7 variables. We considered activity as a binary response variable (i.e., active or not active) and used logistic regression methods to parameterize each of the models. We assessed multicollinearity among variables with ordinary least squares regression. In cases with correlation coefficients  $\geq 0.4$ , we excluded 1 set of the correlated variables from the model on the basis of a priori knowledge. We included only those radiolocations where the fisher was classified as "active" or "not active" in our analyses.

Because we collected multiple observations from a fixed number of fishers, we expected that data points would not be independent. To account for the longitudinality of these data, we employed generalized estimating equations (GEEs) to derive a population-averaged model (Hosmer and Lemeshow 2000:311), which predicted the proportion of radiolocations when fishers were active.

We used an information-theoretic approach (Burnham and Anderson 1998) to identify the most parsimonious model to predict activity among radio-tagged fishers. However, since GEEs are not likelihood-based, we used a modification to the Akaike Information Criterion to produce a quasi-likelihood information criterion ( $QIC_u$ ; Pan 2001). We assumed that correlation of data only occurred within individuals, which allowed us to select exchangeable correlation as our working correlation structure. We calculated the  $QIC_u$  score for each model and ranked the relative support for each by comparing this score among the competing models. We identified the "best" model from our candidate set by selecting the model with the lowest  $QIC_u$  score. We used multi-model inference (Burnham and Anderson 1998) to estimate model-averaged parameters and unconditional 95% confidence intervals for each of the variables in the production of a best predictive model.

## 8.2 Results

We collected 368 radiolocations of 13 radio-tagged fishers between 7 December 1996 and 18 July 2000 that we could classify as either "active" or "not active" ( $\bar{x} = 28$  radiolocations/fisher,  $SD = 25$ ,  $n = 13$ ; Table 8-1). During this period, we identified fishers as being active on 170 occasions (46%) and not active 198 times (54%). Fishers were active at 45% of radiolocations during non-winter and 47% during winter.

Males were active for 59% of their locations, whereas females were active for 43% of their locations (Table 8-1), and males appeared to maintain this higher diurnal activity rate throughout much of the year, with the exception being in the June-July period (Fig. 8-1). Fishers were active throughout the diurnal period (Fig. 8-2), with some minor peaks in activity around noon and early evening. These slight peaks were also somewhat reflected in the proportion of radiolocations that were active related to sunrise or sunset; fishers were most active at 3 to 4 hr and >6 hr from these twilight periods (Fig. 8-3).

Table 8-1. Activity patterns of radio-tagged fishers in the Williston region of north-central British Columbia, 1996-2000. Number of radiolocations for each category and season are shown.

Sex	ID	Non-winter		Winter		Total	Monitoring period	
		Not active	Active	Not active	Active		7-Dec-96	21-May-00
Female	F02	21	8	17	8	54	7-Dec-96	21-May-00
	F03	7	7		2	16	29-Mar-97	25-Jun-97
	F04	27	13	21	3	64	17-Mar-97	9-Apr-00
	F05	1	3			4	3-Apr-97	24-Jun-97
	F07	6	3	1	1	11	2-Apr-97	20-Nov-98
	F09	25	13	6	5	49	2-Apr-97	16-Jun-00
	F15			2		2	16-Nov-98	17-Nov-98
	F17	6	12	7	14	39	14-Nov-98	26-Feb-00
	F18	9	16	11	18	54	19-Mar-99	10-Apr-00
	M01	4	2	6	3	15	25-Jun-97	13-Mar-00
Male	M06	1	1			2	11-Jun-98	14-Jun-98
	M19				1	1	29-Mar-00	29-Mar-00
	M20	7	18	13	19	57	19-Jan-99	18-Jul-00
	Total	114	96	84	74	368		

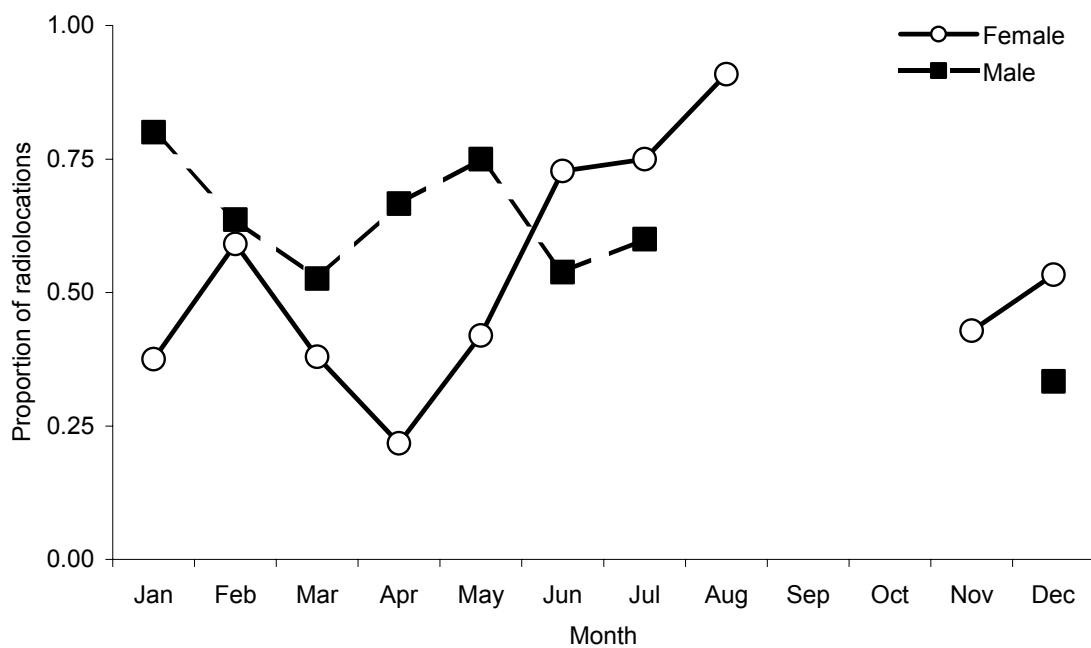


Figure 8-1. Monthly mean rates of diurnal activity of radio-tagged fishers in the Williston region of north-central British Columbia, 1996-2000.

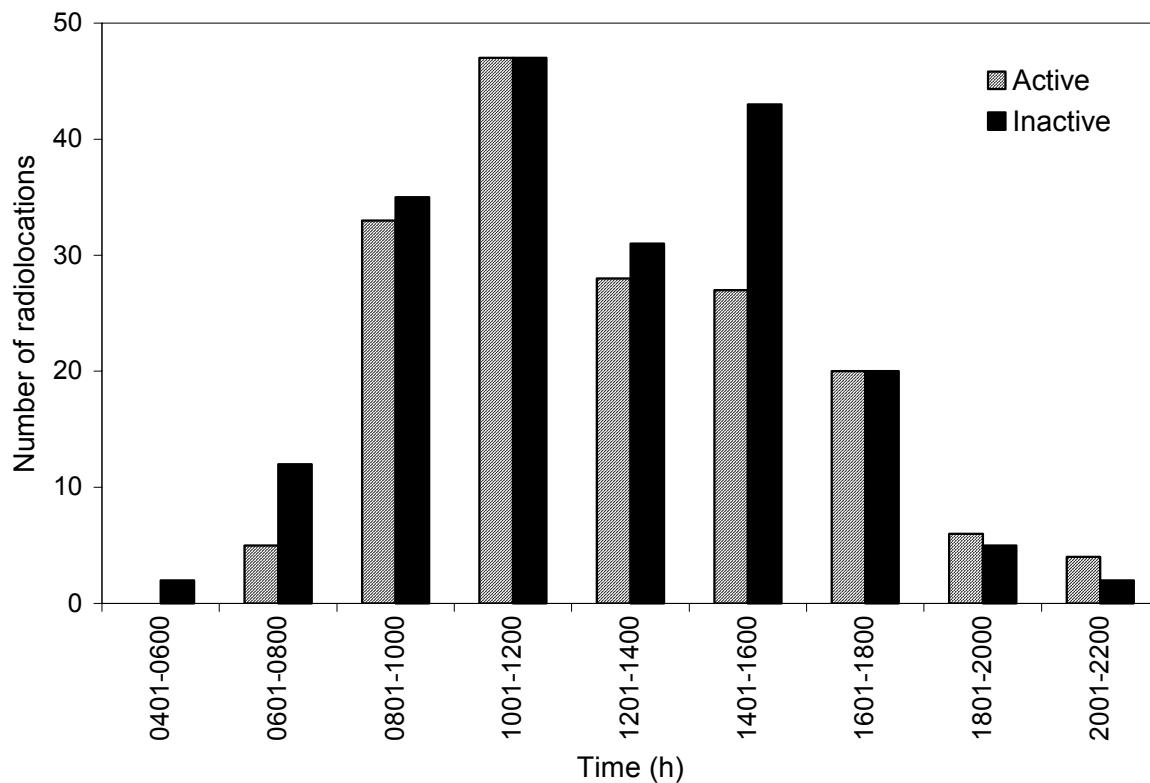


Figure 8-2. Effect of time-of-day on diurnal activity of radio-tagged fishers in the Williston region of north-central British Columbia, 1996-2000.

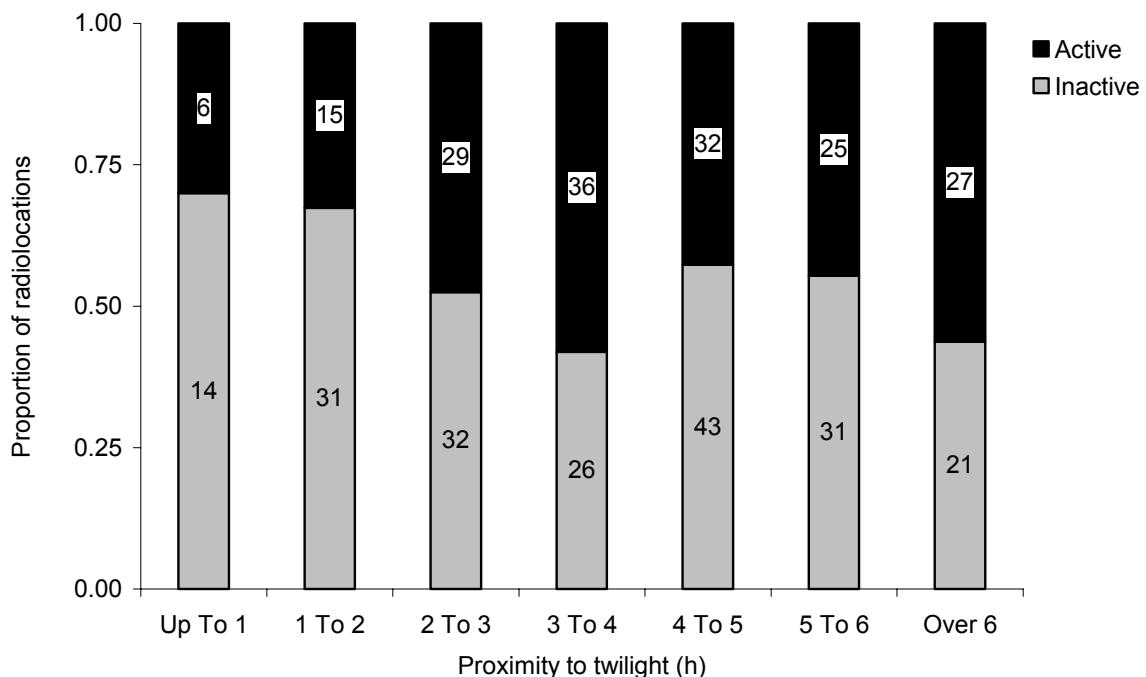


Figure 8-3. Effect of proximity to twilight on the diurnal activity rates of radio-tagged fishers in the Williston region of north-central British Columbia, 1996-2000.

The data had almost equal support for 2 models as being the best from our candidate set (Table 8-2). The model that explained diurnal activity as being affected by ambient temperature during the snow-free season and reproductive condition depending upon sex ranked 0.6 QIC<sub>u</sub> units lower than the second-best model, which was a slightly expanded version of the best model. This second-best model included 1 additional variable: presence of  $\geq 5$  cm new snow during the past 24 hr during winter. These 2 top models were almost equally supported by the data; the best model was only 38% more likely to be the actual best model than the second-best model in the candidate set (Burnham and Anderson 1998). The 95% confidence set of models was rounded out with a third model that included total snow depth during winter, ambient temperature during the snow-free season, and reproductive condition depending upon sex.

The multi-model parameterization of the 2 equivocal top models (Table 8-3) suggested that diurnal activity in fishers increased during days with  $\geq 5$  cm of new snow during winter, as ambient temperature increased during the snow-free season, during the mating period for

Table 8-2. Candidate models used to examine factors that affected the likelihood of diurnal activity of radio-tagged fishers in the Williston region of north-central British Columbia, 1996 to 2000. A “\*\*” demarks 95% confidence set of best models.  $n = 368$  radiolocations of 13 fishers.

Model description	K <sup>a</sup>	QIC <sub>u</sub> <sup>b</sup>	$\Delta_i^c$	w <sub>i</sub> <sup>d</sup>
* T <sub>a</sub> <sup>e</sup> during the snow-free season, reproductive condition depending upon sex	5	457.8	0	0.451
* Presence of $\geq 5$ cm new snow during winter, T <sub>a</sub> during the snow-free season, reproductive condition depending on sex	6	458.4	0.6	0.326
* Total snow depth during winter, T <sub>a</sub> during the snow-free season, reproductive condition depending on sex	6	459.7	1.9	0.175
New snow depth during winter, proximity to twilight during the snow-free season, reproductive condition depending on sex	5	463.7	5.9	0.023
new snow during winter, T <sub>a</sub> during winter, proximity to twilight	6	464.5	6.7	0.016
Global model	10	465.6	7.8	0.009
T <sub>a</sub> during winter, proximity to twilight, reproductive condition depending on sex	5	478.0	20.2	<0.001
Reproductive condition [Arthur and Krohn 1991]	3	486.6	28.8	<0.001
Reproductive condition depending on sex	4	487.4	29.7	<0.001
Snow depth during winter, T <sub>a</sub> during the snow-free season	3	487.9	30.1	<0.001
T <sub>a</sub> during the snow-free season	2	490.0	32.2	<0.001
Proximity to twilight, season, sex [Kelly 1977]	4	499.3	41.5	<0.001
Season	2	502.6	44.8	<0.001
New snow, T <sub>a</sub> [Leonard 1980 Raine 1983, Weir 1995]	3	504.8	47.0	<0.001
Sex [Kelly 1977, Johnson 1984]	2	506.1	48.3	<0.001
Proximity to twilight [Kelly 1977, Johnson 1984, Arthur and Krohn 1991, Powell 1993]	2	507.5	49.7	<0.001
Null model	1	510.0	52.2	<0.001

<sup>a</sup> number of estimated parameters in associated model

<sup>b</sup> quasi-likelihood information criterion (Pan 2001)

<sup>c</sup> difference in QIC<sub>u</sub> scores between model and best selected model

<sup>d</sup> Akaike weight (Burnham and Anderson 1998)

<sup>e</sup> ambient temperature (°C)

Table 8-3. Parameterization of equivocal best models from candidate set to explain the factors affecting the likelihood of diurnal activity of radio-tagged fishers in the Williston region of north-central British Columbia, 1996 to 2000.

Parameter	Composite coefficient	Odds ratio	Unconditional 95% CI	
			Lower	Upper
Intercept	-0.011	0.99	0.96	1.02
Presence of $\geq 5$ cm new snow during winter <sup>a</sup>	0.614	1.85	1.00	3.42
T <sub>a</sub> <sup>b</sup> during the snow-free season	0.088	1.09	1.03	1.15
Mating reproductive condition for males <sup>c</sup>	0.467	1.60	0.91	2.79
Mating reproductive condition for females <sup>c</sup>	-0.161	0.85	0.44	1.66
Rearing young <sup>c</sup> (females only)	-1.375	0.25	0.14	0.46

<sup>a</sup> during previous 24-h period

<sup>b</sup> ambient temperature (°C)

<sup>c</sup> compared to reference value of "non-reproductive"

males, when non-reproductive for females without young, and when rearing young compared to non-reproductive periods. However, the 95% confidence intervals around the odds ratio for mating compared to non-reproductive for both males and females encompassed 1, so we could not determine with confidence whether the effect of these variables was positive or negative. The parameterized best model suggested that the presence of  $\geq 5$  cm of new snow during winter increased the likelihood of activity by 85% and that an increase of 5°C increased the likelihood of activity by 55%. It also predicted that males during reproductive periods were 60% more likely to be active than during non-reproductive periods, mating females were 15% less likely to be active than non-mating females, and females with young were 75% less likely to be active than females without young.

### 8.3 Discussion

Our data suggested that factors that affected the likelihood of diurnal activity by radio-tagged fishers were not necessarily those that fluctuated over short time scales, as had been documented in other studies (e.g., Kelly 1977, Johnson 1984). Rather, activity seemed to be related to extrinsic and intrinsic factors that changed over both long and short time periods. The important variables of reproductive condition changed over months, whereas ambient temperature and snowfalls varied daily.

Our observation that the likelihood of diurnal activity was affected by ambient temperature during the snow-free season has not been reported in the literature. Faccio (1992) did not detect any substantial effect of temperature on activity rates, although he did note that activity seemed to be related to concurrent cloud cover and precipitation values. From an energetic perspective, all of the ambient temperatures that we encountered during the snow-free season (range: -8.9°C to 29.4) were well above the lower critical temperature estimated for active fishers (-20°C for females, -30°C for males; Powell 1993) and thus, we did not expect a behavioural response to ambient temperature during this period.

Fishers may have increased their activity with ambient temperature because foraging opportunities were better at warmer temperatures during the snow-free season. The activity of prey may be greatest during warmer temperatures (red squirrels, Obbard 1987; snowshoe hares, Theau and Ferron 2001) and fishers may have synchronized periods of activity with their prey to increase the probability of successful foraging. It is unclear as to why the relationship between ambient temperature and diurnal activity was not evident during the winter period.

Diurnal activity was also affected by the reproductive status of the fishers. This factor was mediated by sex, which was not unexpected. Male fishers are expected to be more active during the breeding season while searching for mates (March – May; Arthur and Krohn 1991), which we observed. Contrary to our results, however, Arthur and Krohn (1991) and Leonard (1980) observed that female fishers with young were more active than females without young, presumably because females needed to spend more time foraging during this period. Yet, our observations that females with young spent much of their time during the reproductive period in their respective reproductive dens suggest that other factors affected their activity rate while rearing young. Perhaps females needed to spend more time nursing their young or providing thermal or security protection, or prey was sufficiently abundant that they did not have to forage for extended periods of time to sequester adequate food. Alternatively, we collected more radiolocations on females with young during the first month following whelping than later during the rearing period (56 radiolocations during April, compared to 22 and 18 radiolocations in May and June, respectively). This may have weighted our observations to periods when females needed to spend more time with their young.

Our observation that the likelihood of activity of fishers increased with fresh snowfalls of  $\geq 5$  cm during winter is contrary to many other findings. Specifically, both Leonard (1980) and Raine (1983) observed that fishers reduced their movements during periods of deep snow. However, it is likely that the characteristics of the snow in our study area were substantially different than those found in the more continental boreal forest in which Leonard (1980) and Raine (1983) studies occurred. In our study area, snowfalls were often followed by thaws and subsequent freezing temperatures that produced snowpacks with numerous snow layers that had variable densities (R. Weir, unpublished data). Once snow settled during these thaw-freeze events, the base upon which new snow fell may have been substantially firmer than other areas. Thus, new snow may not be a substantial impediment to movement for fishers. Perhaps there is a predatory benefit to new snow or it is easier to capture small prey in soft snow. Conversely, fishers may have to move more widely because prey is more difficult to locate. This relationship is counterintuitive and requires further examination.

The models in the candidate set that were least supported by our data were simple models that included 1 or 2 variables. The fishers that we had radio-tagged did not appear to be consistently crepuscular, as reported by Kelly (1977) and Johnson (1984). Models that included proximity to twilight were not well supported by our data, although most radiolocations were collected during daylight hours, which may have biased our data. Models that were based on the simplistic categories of season or sex (Kelly 1977, Johnson 1984) were also least-supported by our data. Instead, our analysis suggested that an array of factors affected the diurnal activity of fishers.

It is possible that the motivation behind the activity patterns that we observed were the result of other intrinsic factors affecting fishers, rather than the extrinsic abiotic or biotic factors that we measured. Factors such as time since last meal or hormone levels may more closely affect activity by fishers. Also we did not examine, nor have data for, habitat-related factors or other spatial factors that may have affected the likelihood of activity of an individual, such as habitat quality or prey catchability.

Unfortunately, our data on activity rates were limited to diurnal time periods, primarily on the daytime side of twilight. It is possible that activity patterns during other portions of the circadian period are substantially different. Consequently, activities that occurred during our monitoring periods may have been influenced by activities that were primarily nocturnal. Unless activity rates are consistent between the nocturnal and diurnal periods, one period will undoubtedly have an influence on the other. Additional research is required to describe the nocturnal activity patterns of fishers, and thus provide a more complete understanding of their diel activity rates.

#### 8.4 Management Implications

Because of their long, thin bodies and poor fat storage capabilities, energy balances of fishers are more critical for this species than others (Harlow 1994). Altering either the spatial or temporal factors that affect the ability of fishers to acquire resources may negatively affect energy balances. Consequently, human activities that affect the distribution and abundance of the resources required by fishers can ultimately affect the ability of individuals to occupy an area. Given a better understanding of the temporal factors that affect activity rates of fishers, we can better speculate on the effects of changes to the distribution and abundance of resources on the energy balance of this species.

Our data provide a better understanding of the temporal patterns within which fishers acquire resources. Activity rates provide a glimpse into the day-to-day factors that appeared to affect decisions that fishers made regarding the allocation of time and resources. These budgets may constrain other facets of the ecology of fishers, such as responses to habitat change or population perturbation. Understanding the temporal patterns of activity also

provides us with better conceptualization of behavioural patterns, such as foraging and movements.

Our findings that diurnal activity rates were related to both biotic and abiotic factors provides us with a framework through which we may better predict changes to the energy balance of fishers in British Columbia. This is particularly important given the ongoing anthropogenic changes to the distribution and abundance of resources used by fishers. Understanding the factors that affect the decisions regarding energy expenditure by fishers also has implications for understanding energy budgets of other cold-environment mustelids, such as American martens.

## 9.0 DEN ATTENTIVENESS

In fishers, females invest considerable time and resources to raising young; they have been estimated to expend approximately 33% of their annual energy budget during the 2 months rearing and caring for their young, which is approximately double that used by females without young during the same time period (Powell and Leonard 1983). Despite this apparent high investment, the factors that affect reproduction by female fishers during the rearing period are poorly understood.

Maternal care influences the success of reproduction in fishers (Frost and Krohn 1997). Between March and June each year, female fishers rear 1 to 4 young in reproductive dens for about 2 months, after which the young are weaned (Powell 1993). During early stages of young development, females must provide milk and keep the young warm (Frost and Krohn 1997). As young develop, they rely on the female to provide adequate food supplies until they leave the den and learn to hunt. The frequency and timing of visits by female fishers to reproductive dens provides an estimate of maternal care and an indication of factors that may affect reproductive success.

Many factors probably affect den attentiveness by females. Individual behaviour, size and positioning of foraging areas relative to the den location, synchronization of absences with peaks in prey activity, and thermal properties of the den all likely put constraints on the timing and duration of absences from the den by females (Henry et al. 1997). Also, sometime 3-9 days following parturition, female fishers will need to be away from their dens for at least 1-8 hours to breed (Powell 1993). Females with large litters may also have to spend more time away from their dens to sequester sufficient resources to provide milk and food for their young (Paragi et al. 1994).

Females with young have quite variable rates and timing of activity. Leonard (1980) monitored a single denning female and found that proportion of time away from the den increased with time since parturition. He also noted that the female left her young unattended in the den during the warmest part of the day. Paragi et al. (1994) determined that, although there may have been some effects of the stage of young development and litter size on activity rates of the female, individual variation had the greatest single effect on their respective activity patterns. Female fishers may spend more time in their dens attending to young during early stages of development to provide warmth, milk, and urogenital stimulation to facilitate urination and defecation (Paragi 1990). The proportion of time that females spent in their dens declined as the young developed (Paragi 1990), a pattern that Henry et al. (1997) also noted for the ecologically similar American marten.

Our objectives were to describe the patterns of attendance by female fishers at reproductive dens in the Williston region of north-central British Columbia and assess the influence of several factors on the likelihood of a female being present at her den. These

results may help identify factors that affect the survivorship of young, which ultimately affect the recruitment into the population. This information will also help identify time constraints during which females can be away from their dens while mating and sequestering food.

### 9.1 Methods

We intensively monitored activity patterns of radio-tagged female fishers that gave birth to young during April to June of 1997 to 2000. We considered females to have whelped when we repeatedly located them using the same structural element over several weeks, with the origin of the rearing period as the first day that the female was located in the den (Paragi 1990, Powell et al. 1997). We considered natal dens to be the first den used (i.e., where young were born) and maternal dens to be subsequent structures used consistently until mid-June (i.e., end of the rearing season).

We used several techniques to monitor den attentiveness. We monitored radio-tagged females continuously for periods of up to 10 hours on several occasions using normal ground telemetry methods. We also established remote radiotelemetry stations that continuously monitored radiotagged female fishers at their den. Stations consisted of a Lotek SRX\_400 receiver/datalogger system (W21 option) powered by an external deep-cycle 12V battery. The datalogger was placed in a plywood enclosure that was attached (>2 m above ground) to a large tree trunk within 50 m of the den tree. The gain on the receiver was adjusted so that the radiotransmitter was detected within a 50-m radius of the den tree. Consequently, a “den-tending” episode consisted of a radio-tagged female being in the den or within 50 m of the den tree. The datalogger scanned for the radiotransmitter at 15-min intervals for 30 sec.

We also used 2 non-telemetry methods to assess den attentiveness and productivity of female fishers. In 1998, we used a remote-sensing video camera with 3 active infra-red sensors (Compu-Tech Systems® RM-680) or a 35-mm instamatic camera (TrailMaster® TM35) with either a single passive (TM1500) or active (TM500) infra-red sensor. We trained the infra-red sensors on the bole of the den tree, about 2.5 m above ground level, so that movement on the bole (i.e., animal ascending or descending tree) would activate the cameras. Date and time of activation were recorded on the respective media. To assess the timing of den-tending and -excursion episodes, we divided the daily monitoring period into 4 6-hour intervals and used the monitoring data to determine which activity (i.e., den-tending or excursion) occurred for the majority of each interval for each fisher. We then tallied the number of intervals for the entire monitoring period by activity.

### 9.2 Results

We had 8 adult ( $\geq 1$  year old) female fishers radiotagged during 18 potential reproductive seasons between 1997 and 2000 (Table 9-1). We documented 5 female fishers whelping 12 times during this period. Females whelped at ages ranging between 2 and 7 years, with all females between 5 and 7 years of age whelping successfully each year (8 whelping seasons,

$n = 4$  females). We monitored 3 adult females for 4 consecutive reproductive seasons. Two of the females whelped in 3 consecutive years and 1 whelped in all 4 years. See *Section 5* for complete reproduction details.

Parturient fishers began using natal dens between 30 March and 12 April over the 4 reproductive seasons (Table 9-1). The mean date of parturition for 12 litters, as determined from initiation of use of the natal den, was 4 April (median = 3 Apr, SD = 4 d). The parturition dates of 3 females monitored over multiple reproductive seasons varied by 3 to 14 days (Table 9-1). We documented females using natal dens for 30 to 49 d ( $\bar{x} = 41$  d, SD = 7,  $n = 9$ ). One female (F02 in 2000) died while away from her den on a foraging excursion, so her 43-d rearing period was not included in any analyses. A 2-y old female (F09) abandoned her natal den 19 days after whelping and was not subsequently observed using another site repeatedly; we suspect that she lost or abandoned her litter for the season.

Table 9-1. Reproduction of adult female fishers in the Williston region of north-central British Columbia, 1997-2000.

Year	Fisher ID	Whelp	Age (year)	Natal Den			Maternal Den			Minimum denning duration <sup>a</sup> (days)
				Whelp date	End date	Duration (days)	Start date	End date	Duration (days)	
1997	F02	No	4							
	F03	Yes	2	11 Apr	11 May	30	11 May	28 May	17	47
	F04	Yes	5	02 Apr	04 May	32				32
	F05	No	2+							
	F07	Yes	7	02 Apr	09 May	37	09 May			37
	F09	Yes	2	02 Apr	21 Apr	19 <sup>b</sup>				19
1998	F02	Yes	5	30 Mar	13 May	44	13 May	06 May	24	76 <sup>c</sup>
	F04	Yes	6	04 Apr	21 May	47				47
	F09	Yes	3	01 Apr	20 May	49				49
1999	F02	Yes	6	12 Apr	22 May	40				40
	F04	Yes	7	03 Apr	17 May	44	17 May	07 Jun	21	65
	F09	Yes	4	05 Apr	20 May	46	20 May			46
	F17	No	2							
	F18	No	2							
2000	F02	Yes	7	08 Apr	21 May	43 <sup>d</sup>				43 d
	F04	No	8							
	F09	Yes	5	05 Apr						
	F18	No	3							

<sup>a</sup> confirmed number of days of den use

<sup>b</sup> suspected abandonment of natal den

<sup>c</sup> use of second maternal den occurred from 07 Jun to at least 13 Jun (not shown)

<sup>d</sup> den use ended due to mortality of adult female

We observed females switching to maternal dens on 5 occasions, although we determined duration of maternal den use on only 3 occasions. These 3 females used maternal dens for 17 to 24 d ( $\bar{x} = 21$  d, SD = 4; Table 9-1). One female used a second maternal den in a season. We observed females using their reproductive dens for up to 76 d in a single season. The latest that we recorded a female using a den was 13 June. All reproductive dens were situated in large-diameter, declining black cottonwood trees; see *Section 12* for details on characteristics of den trees.

We collected 1327.4 h of continuous monitoring information at natal dens of 2 radio-tagged female fishers (F02 and F04) during 4 reproductive seasons (Figs. 9-1 to 9-4). Continuous monitoring data were derived solely from remote telemetry stations. Monitoring periods ( $n = 5$ ) lasted between 2.5 and 23.6 d. Parturient fishers spent, on average, 11 h each day (range: 3.9 – 24 h,  $n = 50$  monitoring-days) at their natal dens while being monitored. During the 2-week period following whelping, we documented a single prolonged excursion (>8 h) by each female fisher: at 13 days post-whelping, F02 left her natal den for 9 hours, whereas F04 left her den for 8 hours at 7 days after parturition (Fig. 9-1 and 9-4, respectively). The total time spent at the den each day diminished as the denning period progressed (Fig. 9-5).

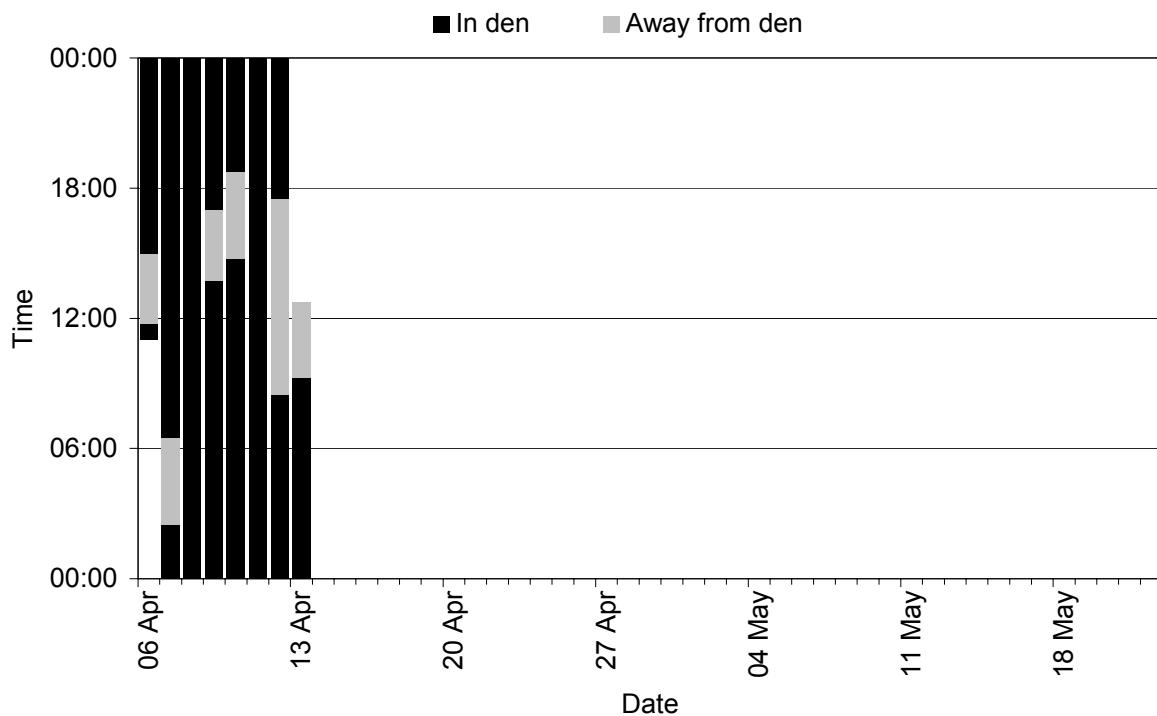


Figure 9-1. Attentiveness patterns of F02 at her natal den during April 1998, Williston region of north-central British Columbia. Estimated parturition date was 30 March.

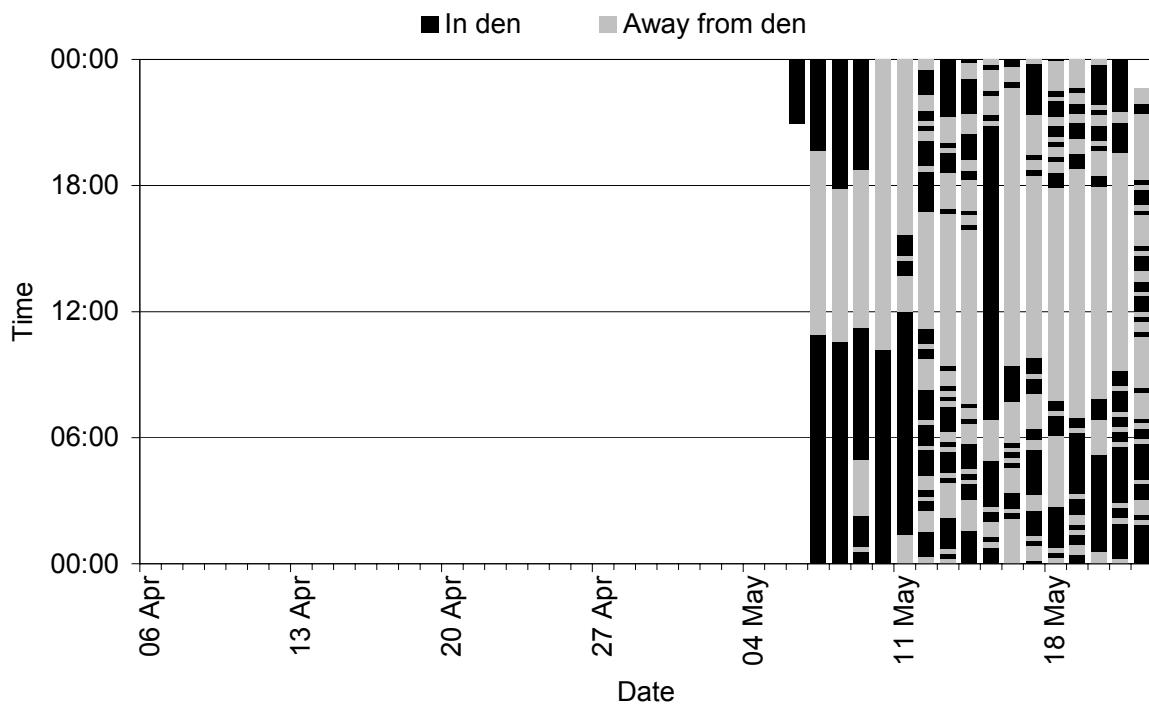


Figure 9-2. Attentiveness patterns of F02 at her natal den during May 1999, Williston region of north-central British Columbia. Estimated parturition date was 12 April.

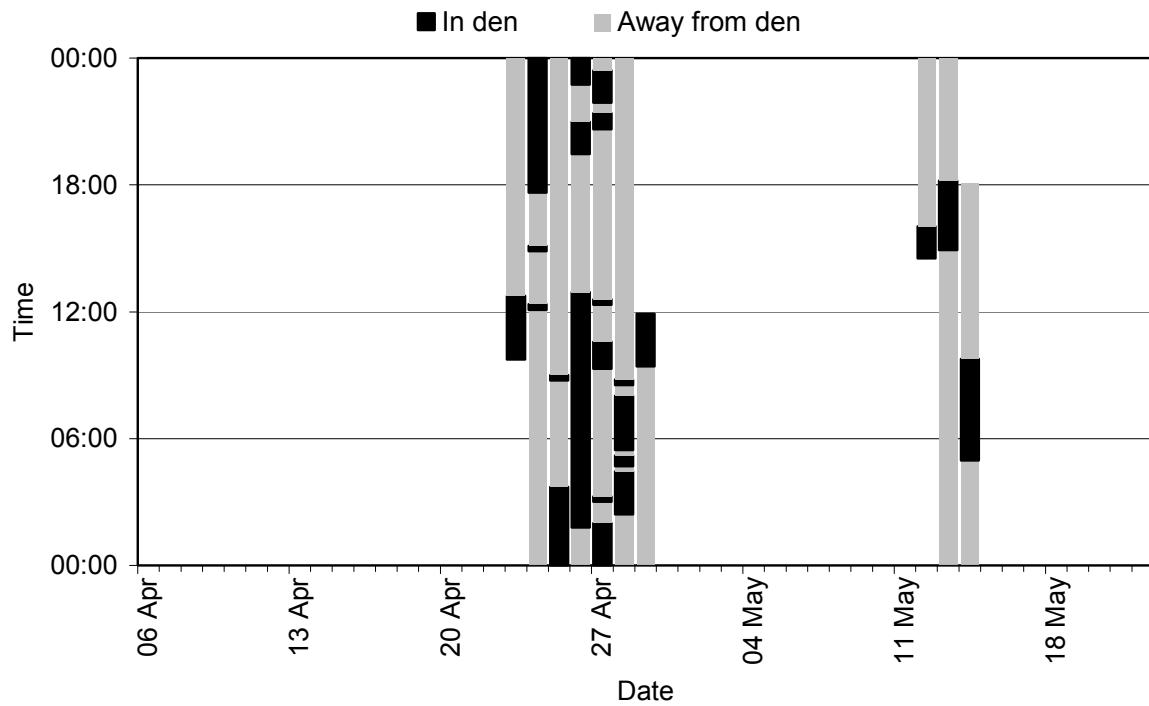


Figure 9-3. Attentiveness patterns of F04 at her natal den during April and May 1998. Estimated parturition date was 4 April.

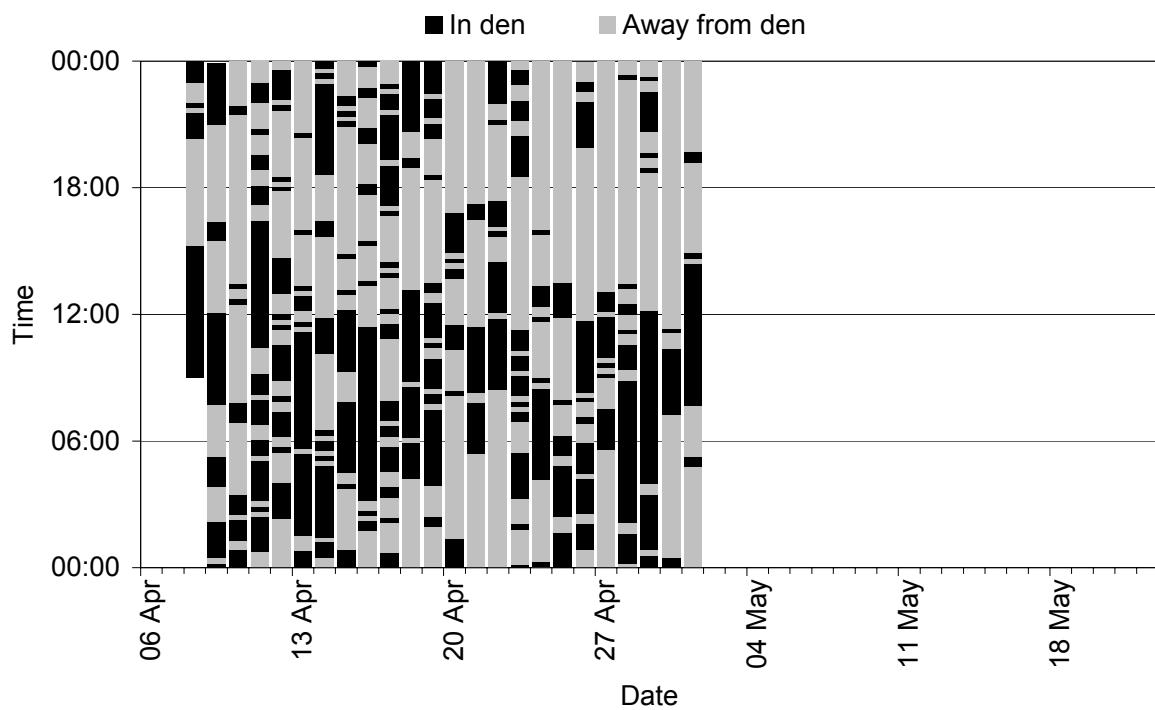


Figure 9-4. Attentiveness patterns of F04 at natal den during April and May 1999. Estimated parturition date was 3 April.

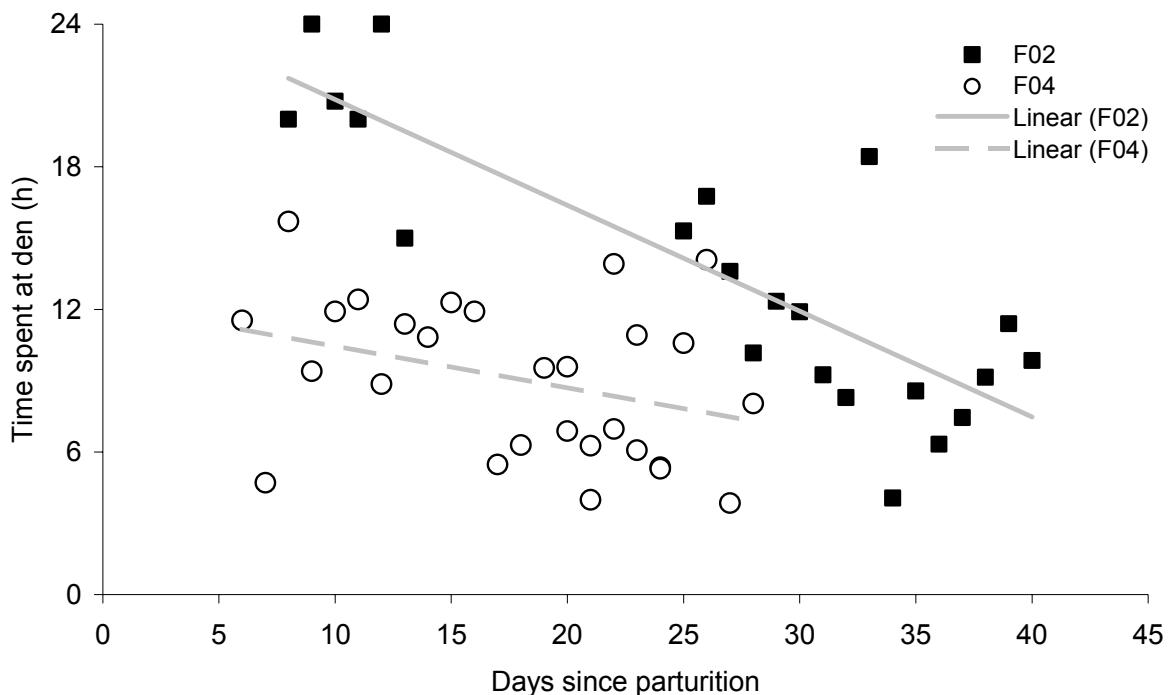


Figure 9-5. Relationship between days since parturition and time spent in natal dens each day for 2 radiotagged female fishers in the Williston region of north-central British Columbia, 1998 and 1999. Lines show predicted linear relationships for each fisher based upon this autocorrelated data.

The duration and frequency that the 2 females left their natal dens varied by individual fisher (Figs. 9-1 – 9-4, 9-6). As the rearing period progressed, F02 made excursions more frequently, whereas F04 appeared to make fewer, longer ones. Excursions lasted between 0.25 and 24.75 h ( $\bar{x} = 2.5$  h,  $n = 318$ ), whereas den-tending episodes lasted between 0.25 and 55.25 h ( $\bar{x} = 1.8$  h,  $n = 317$ ). Females left the natal den, on average, 6 times each day (range 0 – 16,  $n = 50$  monitoring-days) and most excursions (191 of 318, 60%) lasted less than 1 hour (Fig. 9-7).

Female fishers most frequently at the natal den between midnight and noon and were most frequently away from the den during the afternoon (Fig. 9-8). The duration of time spent at the den may have been positively related to the duration of the previous excursion (Fig. 9-9). We detected no trends in the duration of either den-tending or -excursion episodes with time since parturition, ambient temperature, or proximity to twilight. The majority of excursions, however, seemed to begin during the warmest part of the day and den tending seemed to start more frequently during the coldest periods of each day (Fig. 9-10).

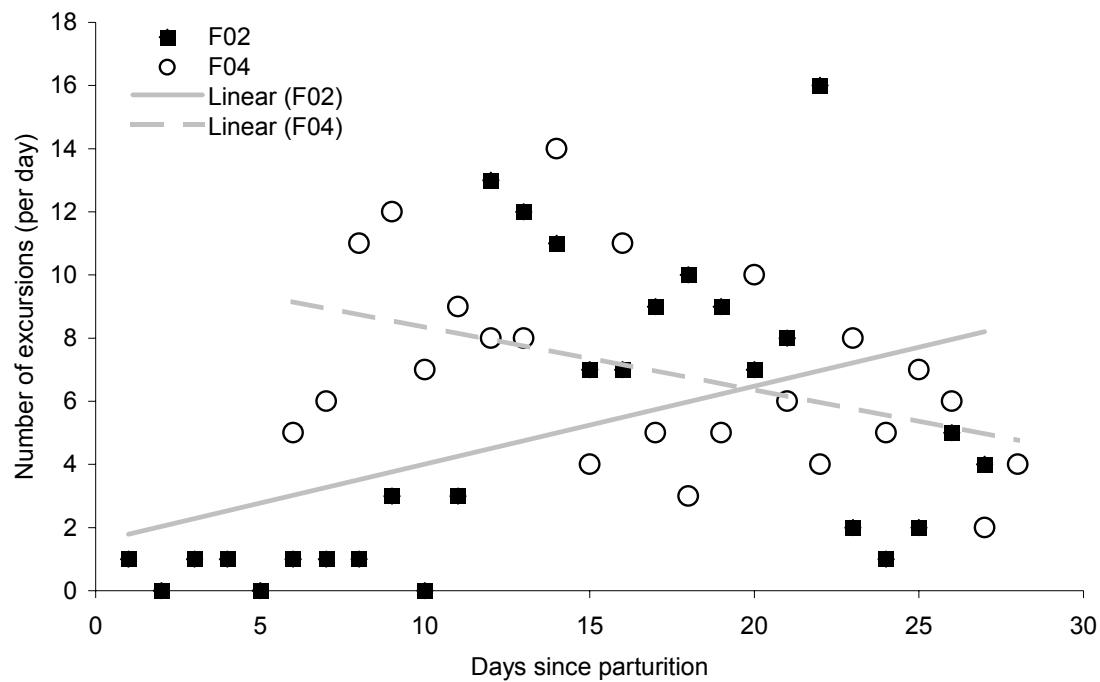


Figure 9-6. Relationship between days since parturition and number of excursions that 2 females made from their natal den each day in April and May 1998 and 1999, Williston region of north-central British Columbia. Lines show predicted linear relationships for each fisher based upon this autocorrelated data.

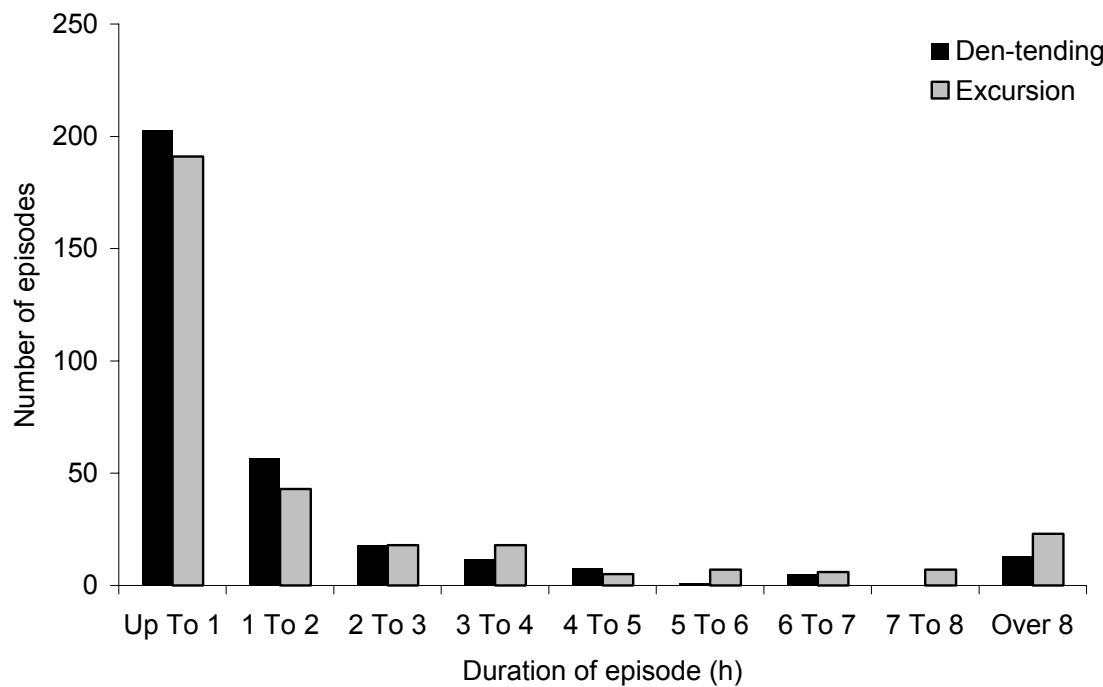


Figure 9-7. Frequency of occurrence of excursion and den-tending episodes of 2 parturient fishers during April and May 1998 and 1999, Williston region of north-central British Columbia.

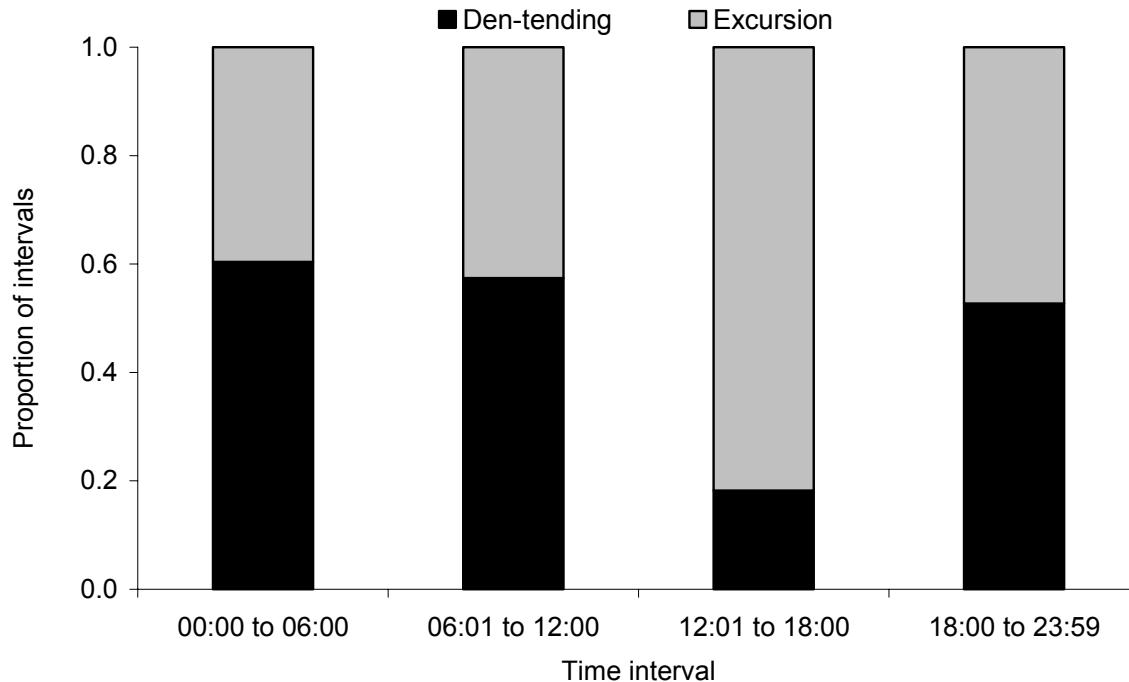


Figure 9-8. Proportion of 6-hour time intervals dominated by each activity type (den-tending or excursion) for 2 parturient fishers in April and May 1998 and 1999, Williston region of north-central British Columbia.

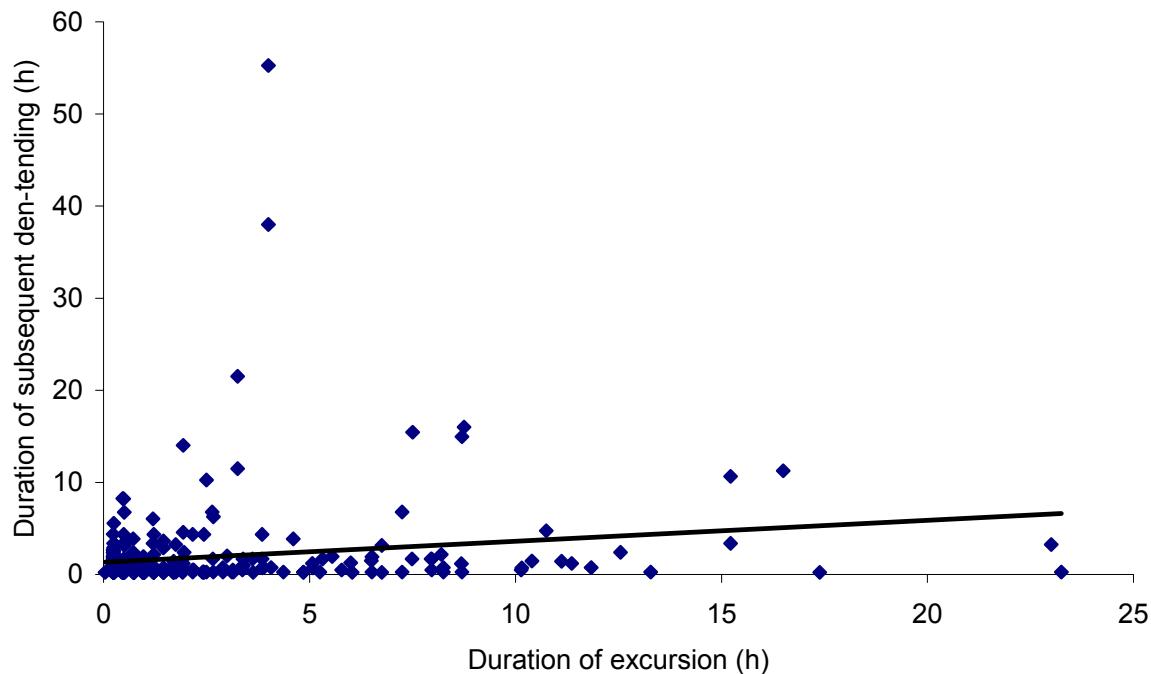


Figure 9-9. Relationship between duration of excursion and the subsequent natal den-tending episode for 2 radiotagged female fishers in the Williston region of north-central British Columbia, April and May 1998 and 1999. Dark line shows predicted linear relationship based upon this autocorrelated data.

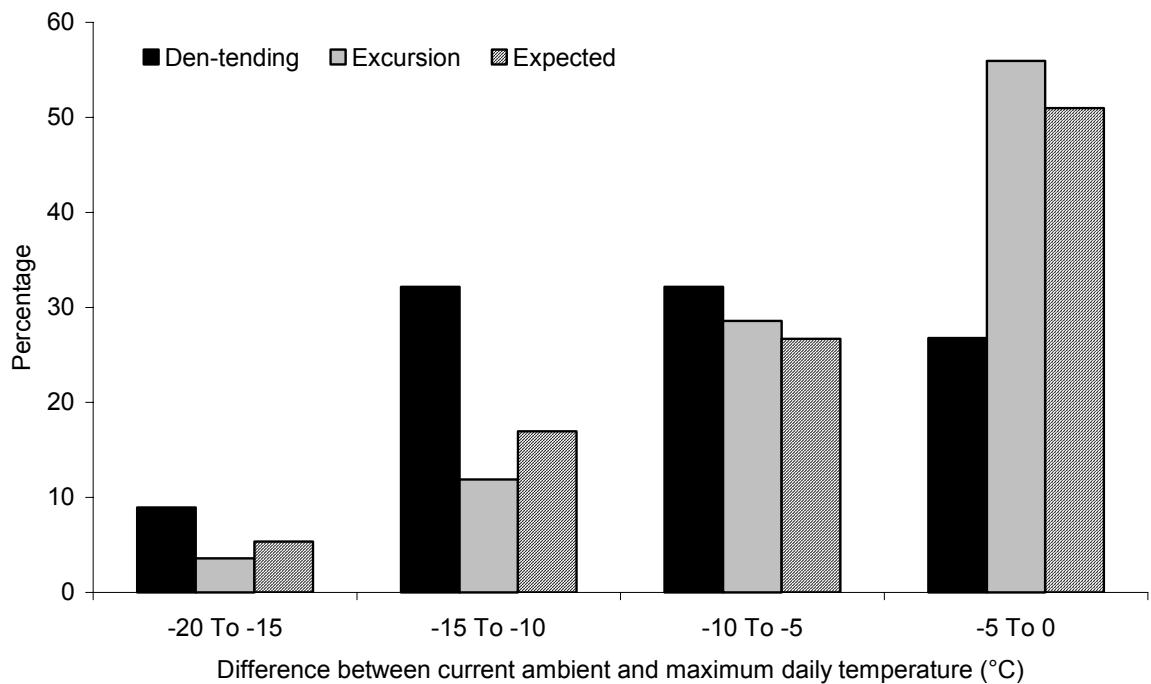


Figure 9-10. Difference between ambient temperature at the start of den-tending or excursion episodes that lasted  $\geq 2$  h and the maximum daily temperature for 2 radiotagged fishers in the Williston region of north-central British Columbia, April and May 1998 and 1999. Expected values are based upon hourly readings at automated climate stations within the study area during the monitoring periods.

We could not determine litter sizes because our camera equipment did not record evidence of the presence of young at the den trees<sup>5</sup>.

### 9.3 Discussion

The timing of whelping was consistent each spring and similar to that reported in the elsewhere. The date of parturition varies throughout the range of fishers, but generally occurs between February and early April (Douglas and Strickland 1987). Reported parturition dates for fishers in British Columbia were between 23 March and 10 April (Hall 1942, Weir 2003). Captive fishers in the East Kootenay region, south-eastern British Columbia, gave birth to litters between 17 March and 4 April (Fontana et al. 1999).

The northerly extent of our study area may have contributed to the late parturition dates that we observed relative to studies in eastern regions (e.g., mean date: 21-22 Mar, Maine, Paragi 1990, Frost and Krohn 1997). Powell (1993) proposed that latitude may account for the variance in parturition dates throughout fisher range, as implantation to initiate gestation is likely stimulated by photoperiod (Mead 1994). This hypothesis was supported by our data as our animals were the most northerly fisher population studied ( $55.3^{\circ}$  latitude) and they had the latest parturition date ( $\bar{x} = 4$  Apr, median = 3 Apr) reported in the literature. Powell (1993) further suggested that the variation in birthing dates within a population was likely due to differences between individual females, rather than annual differences for individuals. This pattern was consistent for 2 of 3 female fishers monitored for 3-4 years. Both whelped within 3-5 days of previous whelping dates. The third female whelped over a 13-day period over her 3 reproductive seasons.

Although den attentiveness observations were limited to 2 fishers over 2 reproductive seasons each, we observed several patterns in the timing and duration of den-tending and excursion activities. Generally, females spent most of the days immediately following parturition in their dens but, as the young developed, the females began to spend more time away from their dens. This trend was similarly reported by Leonard (1980), and Powell and Leonard (1983) suggested that this relationship was related to the increased energetic demands of nursing or acquiring food for their young. Arthur and Krohn (1991) found that activity rates of females with young increased throughout the rearing period, thus spending more time away from the den to acquire sufficient resources for their developing young. We also noted that the timing of excursions away from dens seemed to occur primarily in late afternoon. These patterns in den attentiveness over both short and long time periods were likely related to several ecological and developmental factors.

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<sup>5</sup> Although no physical evidence of young was found, 1 female fisher (F16) that we monitored adjacent to the study area was determined to have whelped based on the same criteria and, upon investigating her natal den 1 month after her mid-May death, the remains of at least 1 young was found in her den.

Interestingly, both females that we monitored during early April had extended absences from their dens at 7 or 13 days following parturition, possibly for breeding. Approximately 3-9 days following parturition, female fishers come into oestrus for a period of 6-8 days (Mead 1994). During this time, the female will leave the den to mate (Powell 1993), presumably far enough away from the den to reduce the risk of infanticide by the male (Leonard 1980). Although we did not follow the females during these extended excursions, the timing of their absences coincided with predicted oestrus and mating activities.

The timing of excursions from the dens each day was not closely linked to the ambient temperature. However, both females appeared to time longer absences from the den during the afternoon (12:00 – 18:00). Leonard (1980) noted that a female he monitored usually left her young during the warmest part of the day and usually returned when the ambient temperature dropped below 0°C. Our data supports the hypothesis that females timed the start of their excursion to coincide with peak daily temperatures.

The 2 fishers we monitored had different strategies for tending their litters. F02 appeared to make few, longer duration excursions early in the rearing period, whereas F04 spent more time away from the den and had shorter periods of den tending. This variability between individuals was also observed by Paragi et al. (1994) in Maine, who noted that the individual was the best predictor of the probability of being away from the den, more so than the time of day or time since parturition.

Differences in den attentiveness may have been a function of litter size. Paragi et al. (1994) speculated that the length of time away from the den appeared to be linked to the number of young that the female was rearing. Presumably, more young require additional food resources (Powell and Leonard 1983), so more frequent or longer excursions would result.

It is unclear why we observed a high number of single 15-min episodes (i.e., a lone 30-sec period when the radiotransmitter was detected or not). These frequent short episodes may reflect den attentiveness activities, but also could reflect foraging activity in the area surrounding the den tree (i.e., signal detected, or not, due to presence or absence of signal obstructions); a quick “check-in” to see if hazards existed near the den or to deliver food items; or brief periods away from the den to use a latrine. Video monitoring of the den would aid in assessing the accuracy of the dataloggers in capturing den-tending and excursion episodes.

The camera techniques used to monitor the dens were fraught with logistical challenges and hampered our ability to collect complete and comprehensive attentiveness data. Both the remote-sensing camera and video camera relied upon infrared motion detectors to be triggered by the fisher passing through their beam on its way up or down the den tree. However, the active infrared sensors (TM500 and video system) were very sensitive to

moving vegetation (from wind) and sunshine (direct and sun incidence on the tree bole), and thus were consistently triggered by these “non-events”. Also, it was difficult to determine the path the animal would take to ascend or descend the tree for the passive sensor (TM1500) with a single beam. Thus, these systems repeatedly failed to detect fishers ascending or descending the tree. Consequently, we suggest that a single camera or single sensor system is not a reliable method to monitor den attentiveness. The height of the entrance to the den cavity (up to 25 m above ground) prevented us from using the den entrance as the trigger point.

The remote telemetry stations produced more reliable results, although this equipment also proved to be difficult to deploy under field conditions. We collected data on 5 of 9 occasions during which we deployed dataloggers at natal dens. We encountered difficulties with power supply, accessing stored data, and damage to the antenna coaxial cable (e.g., squirrels chewing cables). Since we did not want to displace any denning females, we attempted to minimize the human disturbance in and around the den sites by not establishing the station right at the den tree and by visiting our stations only once or twice during the monitoring period. However, to garner the greatest resolution for data interpretation and to ensure that systems work adequately and data is not lost, we recommend that stations be established as close as possible to the den entrance (i.e., at same height as den entrance on an adjacent tree) and that more frequent maintenance visits are warranted.

## 10.0 HABITAT RELATIONSHIPS OF FISHERS

Fishers inhabit a broad range of environments across their geographic distribution, from deciduous forests of New Hampshire to coniferous forests of the Western Cordillera (Powell 1993). In these environments, fishers rely on many aspects of forested ecosystems to fulfil their life requirements. Fishers use a range of structures that provide thermally beneficial and predator-secure sites for rearing young (Paragi et al. 1996, Gilbert et al. 1997, Weir and Harestad 2003) and resting (Raine 1983, Arthur et al. 1989b, Powell 1993, Weir 1995a, Zielinski et al. 2004b). Fishers also tend to use structurally diverse forested habitats that provide catchable prey (Powell and Zielinski 1994), such as snowshoe hares, squirrels, and voles.

Despite needing similar resources, the habitats that fishers use to acquire them vary considerably across North America. In eastern deciduous forests, fishers appear to be habitat generalists, acquiring their necessary resources in a variety of stand types and structural stages (Kelly 1977, Arthur et al. 1989b, Powell 1993). In western coniferous-dominated forests, fishers have closer ties to specific habitat features, many of which develop in late-successional structural stages (Jones and Garton 1994, Weir 1995a).

These differences in patterns of habitat selection make application of results from one study area to another difficult. For example, fishers in eastern North America often select for habitats with a coniferous component (Arthur et al. 1989b, Powell 1993), whereas they do not typically show strong selectivity for coniferous forests in western North America, except during winter (Weir and Harestad 2003).

These discrepancies may occur in large part, not because of differences in the behaviours of fishers, but because the resources fishers need are distributed at different spatial scales among regions. Studies conducted primarily in eastern North America indicate that fishers avoid stands with little or no tree cover (Powell 1993). However, fishers in British Columbia occasionally use stands without consistent overhead cover, but when doing so, they select patches within these stands that provide this attribute (Weir and Harestad 2003). In this case, fishers select for areas that provide the same resource (overhead cover), only at a different spatial scale. The inconsistency in the observed selection patterns by fishers may be related to the scale at which the researchers examined selection.

Thus, to extend our understanding of the habitat ecology of fishers, we need to examine the relationships between fishers and their habitat from a scale-based context. Because fishers can fulfil different resource needs at several different spatial scales (Weir and Harestad 2003), habitat analyses need to be considered at different spatial scales (Fig. 10-1). By doing this, researchers can better understand the linkages between fishers and their habitat.

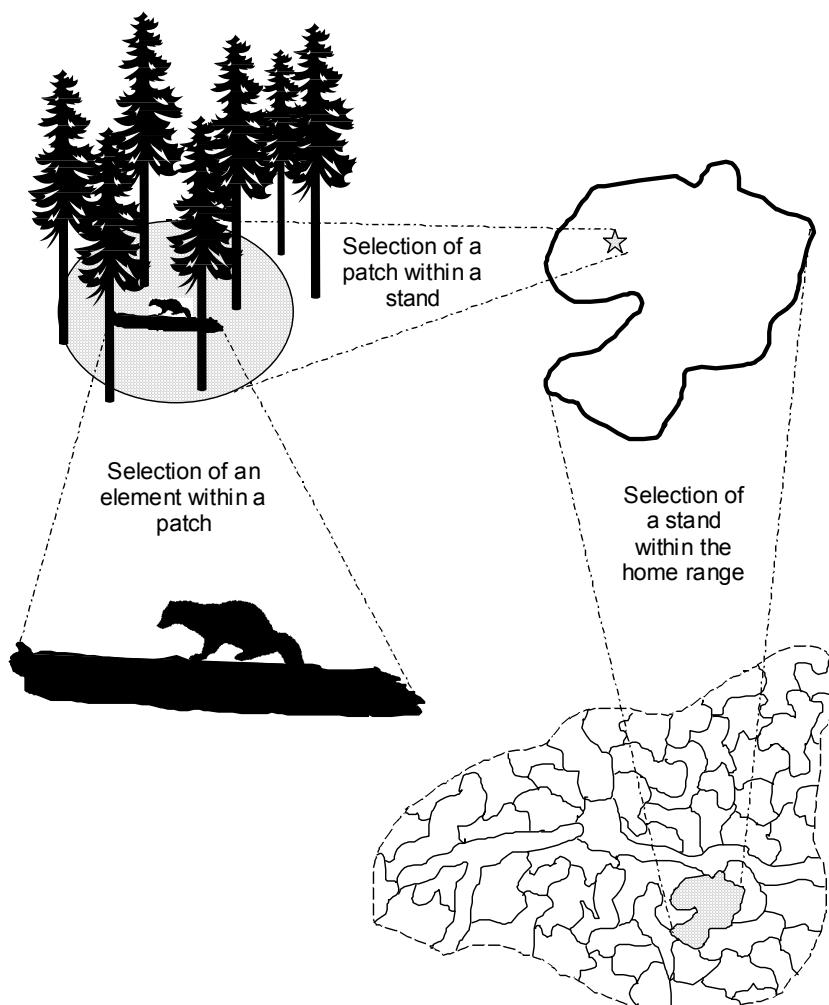


Figure 10-1. Fishers select resources at multiple spatial scales (from Weir and Harestad 2003).

Almost all activities of fishers occur in forested environments. In an extensive review of the distribution of the species, Proulx et al. (2004) identified loss of forested habitat from human development as the main long-term threat to fisher populations throughout their range. In fact, the close association of fishers in the western United States with late-successional forests prompted the US Forest Service to consider specific conservation measures for fishers as a result of widespread changes in their forested landbase (Powell and Zielinski 1994).

Forest harvesting occurs in all areas inhabited by fishers in British Columbia and thus has the capability to have widespread effects on their populations in the province. Because of the apparent association of fishers with features of late-successional forests, forest-harvesting activities that focus on these forest age classes may detrimentally affect fisher populations by altering and degrading the abundance and distribution of the resources they require (Weir 2003). The direct impacts of forestry activities on the habitat relationships of fishers have not been well documented; depending on the temporal and spatial extent of disturbances,

impacts could affect the relative “health” of fisher populations by decreasing individual survivorship, fecundity, and dispersal ability (Weir 2003).

Our objectives were to identify the habitat features upon which radio-tagged fishers made resource selection decisions. Furthermore, we attempt to develop predictive relationships between the probability of use by the species and identified habitat features. Identifying the features that affect habitat selection by fishers will help managers predict the effects that forest development and other disturbance factors will have on fishers. We modeled factors that affected resource selection at 4 spatial scales: selection of elements within patches, patches within stands, stands within the home range, and home ranges within the landscape.

Because previous work has shown that different factors likely affect the resources that fishers select at fine versus broad spatial scales (Weir and Harestad 2003), we divided this section into 2 parts. In the first part, we examine fine-scale selection of habitat by assessing the selection of elements and patches used by fishers for resting, denning, and while active. In the second part, we examine habitat relationships at broader spatial scales by examining the selection of stands used by fishers, and where fishers occur within the landscape. We conclude this section by summarizing the habitat relationships of fishers among the various spatial scales and the implications of the results on our understanding of the habitat ecology of fishers in British Columbia.

## 10.1 Fine Spatial Scale

Fishers occupy a wide variety of forest types and are often considered habitat generalists in their day-to-day life (Powell 1993). However, several aspects of their natural history are associated with fine-scale habitat components. Fishers use a wide variety of fine-scale habitats for rest sites, including tree nests and cavities, logs, root wads, willow (*Salix* spp.) thickets, ground burrows, and rock aggregations (Raine 1981, Arthur et al. 1989b, Jones 1991, Powell 1993, Kilpatrick and Rego 1994, Gilbert et al. 1997, Mazzoni 2002, Zielinski et al. 2004b, Yaeger 2005). For reproductive dens, female fishers primarily use cavities in standing live and dead trees, with *Populus* spp. providing the majority of the sites (Leonard 1980, Weir 1995a, Paragi et al. 1996, Gilbert et al. 1997, Powell et al. 1997, Yaeger 2005). When hunting, fishers focus their activities on patches of habitat that have higher densities of prey (Powell 1994b).

Fishers require different resources for different behaviours. Features of resting sites are different than those of reproductive dens. Fishers rely on rest sites to confer many benefits, including refuge from potential predators and thermoregulatory cover (Kilpatrick and Rego 1994). Reproductive dens must also be of sufficient size to house up to 4 young (Powell 1993). Successful foraging habitat must have suitable levels of catchable prey (Powell and Zielinski 1994) combined with suitable cover to avoid predation (Powell 1993). As behaviours of fishers change, so do the habitat features that can be used effectively, and thus, the habitats that they select.

Whether the attributes that fishers need for each behaviour consistently occur in only 1 type of site (e.g., a single tree species), or a wide diversity of habitats, provides insight into the strength of the linkages between the behaviours and identified habitats. The strength of these linkages have implications for habitat conservation if, for example, forest harvesting alters the distribution or abundance of 1 of the habitat features for which fishers have high specificity.

We explored fine-scale habitat selection by radio-tagged fishers in the Williston region of north-central British Columbia by examining selection of elements and patches used by fishers for resting, denning, and while active. Our objectives were to 1) identify fine-scale habitat features that fishers exploit for these behaviours, 2) develop parsimonious models that predict the probability of selecting identified habitat features for each behaviour, and 3) assess the specificity that fishers have for each feature. To achieve this, we posed several questions:

- 1) are fishers selective for the elements or patches that they use for resting, denning, or while active?
- 2) if so, what features affect the probability of selection?

- 3) how strong is the relationship between behaviour and the selection of fine-scale habitat features?

Understanding the linkages between fishers, their behaviours, and the supply of identified fine-scale habitats will allow us to predict the effects that habitat alteration may have on the ability of habitats to support sustainable populations of fishers.

#### 10.1.1 Hypothesis (Model) Evaluation

Past research on fine-scale selection of habitat by fishers has identified many environmental variables that may affect which habitats are selected for resting, denning, and while active (Tables 10-1, 10-2). Many of the models we examined were based on observations from elsewhere, especially from Weir and Harestad's (2003) study of fishers in the southern portion of the SBS zone. Several models were new hypotheses we thought might better explain selection than previously identified models. Since we believed that the motivation of fishers for selecting fine-scale habitat varied with behaviour, we examined selection separately for resting, denning, and active/unknown behaviours. For each behaviour, we compared the support by the radiotelemetry data for several hypothetical models and assessed the probability of each model in the candidate set being closest to "reality". We also included a null model to determine if selection actually occurred.

Selection for fine-scale habitat can be detected at 2 spatial scales; fishers may select for specific habitat structures (elements) or they may select for atypical patches that are different from the surrounding stand. Elements are discrete structures that, in forest environments, are often single trees (Weir and Harestad 2003). Patches are a slightly coarser scale and include multiple elements that function collectively (from the perspective of the animal). For example, a group of 25 small spruce saplings in a stand of mature lodgepole pine trees may function as foraging habitat for a fisher, because snowshoe hares may be associated with this area.

We evaluated 3 different sets of models that predicted selection of elements within patches for 2 types of resting behaviours (arboreal and coarse woody debris [CWD] resting) and for reproductive dens (Table 10-1). At the patch scale, we examined models for 3 behaviours: resting, denning, and active (Table 10-2). Radiolocations that were categorized as "active" included some that could not be positively identified as inactive (e.g., resting).

Table 10-1. Candidate models used to examine selection of elements within patches by radio-tagged fishers in the Williston region of north-central British Columbia, 1997-2000. Model categories summarize the hypothesized relationships between probability of use and generalized habitat features. References refer to the previous study that identified the respective model as a plausible hypothesis to explain selection at this scale. Variable definitions provided in Appendix 10-1.

Model ID	Model category	Number of variables	Probability of use of element related to:	Reference
<u>Resting - Arboreal sites</u>				
E-AR1	Tree size	1	DBH	Yaeger 2005
E-AR2	Tree species	3	Species	Mazzoni 2002
E-AR3	Tree crown	3	Crown class	
E-AR4	Pathogens	1	Presence of rust brooms	Weir and Harestad 2003
E-AR5		1	Presence of pathogens	Variation of Kilpatrick and Rego 1994
E-AR6		2	Tree status	Yaeger 2005
E-AR7	Tree size & species	3	DBH depending upon species	
E-AR8	Tree size & pathogens	2	DBH and presence of pathogens	
E-AR9		2	Presence of rust brooms in spruce trees and DBH of <i>Populus</i> species with pathogens	
E-AR10		2	DBH of spruce trees with rust brooms and DBH of <i>Populus</i> species with pathogens	
<u>Resting - CWD sites</u>				
E-CWD1	Piece characteristics	1	Diameter	Weir and Harestad 2003
E-CWD2		1	Length	
E-CWD3		1	Decay class	
E-CWD4		1	Coniferous piece	
E-CWD5	Cavity under/in logs	1	Estimated rest-site potential (length of potential resting area provided by interstitial space)	
E-CWD6		1	Height above ground	
<u>Denning sites</u>				
E-DEN1	Tree species	1	Species	Paragi et al. 1996, Weir and Harestad 2003
E-DEN2	Tree size	1	DBH	Weir and Harestad 2003
E-DEN3	Tree status	1	Tree status	Paragi et al. 1996, Weir and Harestad 2003
E-DEN4	Tree size & status	1	DBH depending upon tree status	
E-DEN5	Tree size & patch cover	1	DBH depending upon high-shrub cover in patch	
E-DEN6		1	DBH depending upon leaf-on cover in patch	
E-DEN7		1	DBH depending upon tree cover in patch	

Table 10-2. Candidate models used to examine selection of patches within stands by radio-tagged fishers in the Williston region of north-central British Columbia, 1997-2000. Model categories summarize the hypothesized relationships between probability of use and generalized habitat features. References refer to the previous study that identified the respective model as a plausible hypothesis to explain selection at this scale. Variable definitions provided in Appendix 10-2.

Model ID	Model category	Number of variables	Probability of use of patch related to:	Reference
<u>Resting</u>				
P-R1	Tree density	1	Density of trees with rust brooms	Weir and Harestad 2003
P-R2		1	Density of trees with cavities	Kilpatrick and Rego 1994
P-R3	Tree density & CWD	2	Density of trees with rust brooms and estimated rest-site potential	
P-R4		2	Density of trees with rust brooms and volume of elevated large CWD	Weir and Harestad 2003
P-R5		3	Volume of elevated large CWD, density of trees >35 cm dbh, and density of trees with rust brooms	Weir and Harestad 2003
P-R6	Tree density, CWD, & abiotic conditions	2	Density of trees with rust brooms when ambient temperature > 0°C and estimated rest-site potential when snow $\geq$ 15 cm deep	
P-R7		2	Density of trees with rust brooms when ambient temperature > 0°C and volume of elevated large CWD when snow $\geq$ 15 cm deep	Weir and Harestad 2003
P-R8		2	Density of trees with rust brooms interacting with ambient temperature and estimated rest-site potential when snow $\geq$ 15 cm deep	
P-R9	Cross-scale factors	1	Coniferous tree cover compensatory with stand-averaged coniferous tree cover	Weir and Harestad 2003
P-R10	CWD	1	Estimated rest-site potential	
P-R11	CWD & cover	5	Volume of CWD, coniferous tree cover, deciduous tree cover, high-shrub cover, and low-shrub cover	Weir and Harestad 2003
P-R12	Foraging	1	Coniferous shrub cover	Powell 1994b
P-R13	General	3	Presence of water within 100 m, number of tree layers, and number of deciduous tree species	Seglund 1995
P-R14		4	Leaf-off cover during winter, leaf-on cover during non-winter, maximum dbh of tree in patch, and slope	Zielinski et al. 2004b
<u>Denning</u>				
P-W1	Den opportunities	1	Density of den-sized black cottonwood trees	Weir and Harestad 2003
P-W2		1	Deciduous tree cover	
P-W3		1	Density of trees with cavities	Paragi et al. 1996
P-W4		1	Number of deciduous tree species in patch	
P-W5		1	Largest dbh of tree in patch	

Table 10-2. Con't.

Model ID	Model category	Number of variables	Probability of use of patch related to:	Reference
<u>Active</u>				
P-A1	Cover	2	Leaf-off cover during winter and leaf-on cover during non-winter	Powell 1993
P-A2		1	Coniferous shrub cover	Powell 1994a
P-A3		2	Coniferous shrub cover and density of trees with rust brooms	
P-A4		3	Coniferous shrub cover, volume of elevated CWD, and density of trees with rust brooms	
P-A5	Foraging & cover	2	Volume of elevated CWD and low-shrub cover	
P-A6	Cover & travel	2	Coniferous shrub cover and estimated length of logs suitable for travelling	
P-A7	Combination of patch and stand scale structure	6	Volume of CWD depending upon stand-averaged volume of CWD, coniferous tree cover depending upon stand-averaged coniferous tree cover, deciduous tree cover depending upon stand-averaged deciduous tree cover, high-shrub cover depending upon stand-averaged high-shrub cover, low-shrub cover depending upon stand-averaged low-shrub cover	Weir and Harestad 2003
P-A8	General	1	Volume of CWD	Weir and Harestad 2003

## 10.1.2 Methods

### 10.1.2.1 Experimental design

We used similar designs at both the element and patch scales to examine the effects that various factors had on the probability of use of an element or patch. At the element scale, we compared the element used by a fisher (e.g., a tree used for a reproductive den) to simultaneously unused elements found within the same patch. At the patch scale, we compared a patch of habitat used by a fisher (e.g., a clump of sapling conifers) to a simultaneously unused patch within the same stand. We considered a radiolocation to be the currency of use (i.e., index of time spent at a specific element or patch; Buskirk and Millspaugh 2006).

We used the broader scale of examination to identify the boundaries of “choice sets” (Buskirk and Millspaugh 2006) for each selection event. That is, we identified features available to a fisher within the broader scale of examination. For example, we considered use of a specific element, such as a reproductive den tree, relative to the numerous elements available within that patch. Likewise, selection of a patch occurred when individuals selected from a choice of patches within a stand.

We restricted choice sets to radiolocations that were temporally independent at each scale. We defined temporal independence as the time needed for an individual to access any other element or patch within the same spatial scale. That is, the time needed for a fisher to select any other element within a patch, or patch within a stand. We observed average maximum movement rates of 0.66 km/h for females ( $SD = 0.90$  km/h,  $n = 10$ ) and 0.76 km/h for males ( $SD = 0.56$  km/h,  $n = 3$ ) for sequential radiolocations separated by  $<2$  d. Based upon this and the maximum sizes of patches ( $400$  m $^2$ ) and stands ( $<12.0$  km $^2$ ), we determined that fishers could reach any patch within a stand within 12 hours, and any element within a patch within 15 minutes. We used these estimated travel times as the basis for determining temporal independence of radiolocations.

### 10.1.2.2 Fisher radiolocations

We captured, radio-tagged, and radio-located fishers as described in *Sections 3 and 4* and categorized each radiolocation into 1 of 5 precision categories to determine the spatial scales at which each radiolocation was suitable for analysis (see *Section 4*). For element scale analyses, suitable radiolocations included those where we visually identified the structure used by the fisher (i.e., error  $\leq 1$  m): we either saw the fisher using the element or had other definitive information (e.g., tracks leading to some CWD). For patch scale analyses, all element-scale and any other radiolocations that had error polygons  $<0.3$  ha were considered suitable.

### 10.1.2.3 Habitat measurement

We measured structural and vegetative attributes for used and unused elements and patches. We paired each used element or patch (i.e., radiolocation point) with a simultaneously unused element or patch elsewhere within the same scale. This does not mean that the fisher never used the simultaneously unused element or patch; only that it was not used at the exact moment that the fisher was at its radiolocation point. This temporal stratification was key to our analytical design; it allowed us to compare used and unused elements or patches within the temporal stratum.

Data were collected at 2 types of 400-m<sup>2</sup> plots using standardized measurement techniques: *fisher-patch plots* and *patch-comparison plots*. At fisher-patch plots (i.e., all radiolocation points with precision estimates <0.3 ha), we measured physical, structural, and vegetative characteristics of the patch and, where we identified the element used by the fisher, we measured the element used and all other unused elements within the plot. At the patch-comparison plots, we measured the same characteristics, plus site and stand descriptors (BCMELP and BCMOF 1998a). Patch-comparison plots were used to characterize a patch that was simultaneously not used by the fisher within the same stand. For our analyses, a stand was a contiguous area (i.e., a mapped polygon) that had the same site series and structural stage, as defined by 1:20,000-scale predictive ecosystem mapping (PEM; Atticus Resource Consulting Ltd. 2002, Timberline Forest Inventory Consultants Ltd. 2004). Fisher-patch plots were centred on the element used by the fisher or the geocoordinates of the estimated radiolocation. Patch-comparison plots were centred on random geocoordinates within their respective stand polygons. All plot data were collected between June and September of 1999 and 2000.

We assessed physical, vegetative, and structural characteristics at both plot types using standard methods (BCMELP and BCMOF 1998b). We recorded aspect, elevation, slope, and mesoslope position. We assessed vegetation composition at each plot using ocular cover estimates for tree (stems > 10 m tall), high-shrub (2-10 m), low-shrub (0.15-2 m), herbaceous, and moss layers (BCMELP and BCMOF 1998c). We estimated the percent cover of trees, high shrubs (2-10 m high, both coniferous and deciduous species), low shrubs (0.15-2 m high), and coniferous shrubs, and estimated the total percent of overhead cover (tree and shrub layers) during summer (leaf-on) and winter (leaf-off). We measured stocking densities of trees ≥ 15 cm dbh using variable-radius prism plots (7 to 11 trees per plot; Resources Information Standards Committee 2004). We recorded species, dbh, appearance code, crown code, presence of rust brooms, and presence of pathogens for each tree (BCMELP and BCMOF 1998d) and estimated the age of identified trees using an increment borer. We measured CWD ≥ 7.5 cm diameter encountered along two 24-m transects emanating at perpendicular angles on a random azimuth from the plot centre. For each piece

of CWD, we recorded its distance along the transect, species, diameter at the intercept point, decay class, tilt angle, and height above ground (BCMELP and BCMOF 1998e).

To better assess aspects of CWD that might provide foraging and resting habitat for fishers, we 1) estimated the length of potential resting habitat (i.e., sheltered interstitial space) provided by each piece of CWD, and 2) determined if pieces would provide an elevated travel route (run-log) for a fisher. We assumed that resting habitat was provided by CWD when either of 2 situations occurred: the piece was  $\geq 7.5$  m long,  $>35$  cm in diameter somewhere along its length, and its lower surface was 25-50 cm above the ground; or the piece was  $\geq 75$  cm in diameter, hollow, and  $\geq 4$  m long. We considered a piece to be suitable as a run-log if it was  $\geq 7.5$  m long,  $\geq 25$  cm in diameter, decay class 2 or 3 (BCMELP and BCMOF 1998e), had its upper surface  $>50$  cm above the ground, and had no notable obstructions that would impede a fisher moving along its upper surface (e.g., branches, shrub growth, other pieces of debris).

We used plot data to quantify characteristics of used and unused patches. We calculated stem density (stems/ha) for declining or dead trees (i.e., appearance code 2-9), trees  $\geq 35$  cm dbh, black cottonwood trees suitable for reproductive dens (i.e., stem  $\geq 88.6$  cm dbh and appearance code 2-4; Weir 1995a), trees with spruce broom rust (*Chrysomyxa arctostaphyli*) or fir broom rust (*Melampsorella caryophyllacearum*), and deciduous trees  $\geq 40$  cm dbh with visible signs of decay. In addition to calculating the total volume of CWD per plot (Van Wagner 1968, Brown and Roussopoulos 1974), we estimated the volume that was suspended off the ground, total volume of pieces  $\geq 20$  cm diameter, and total volume of pieces  $\geq 20$  cm diameter and suspended off the ground. We calculated an index of aggregation ( $R$ ; Krebs 1989:126) and the density of pieces along the 2 transects as metrics of CWD structural complexity.

### 10.1.3 Analysis

We analysed the factors that affected selection by radio-tagged fishers at the element and patch spatial scales separately. We considered selection as a binary process and modelled it as a logistic function. Because we used temporal stratification to identify used and unused elements and patches, the derived function was a resource selection probability function (RSPF, Manly et al. 2002).

We developed different sets of candidate models to evaluate hypothesized relationships between habitat factors and element or patch selection for each behaviour at each spatial scale (Tables 10-1 and 10-2). We used information from previous studies of fisher ecology and suspected ecological relationships to develop *a priori* models that we tested using information-theoretic inference (Burnham and Anderson 1998), in which several competing hypotheses (models) were simultaneously confronted with data (Johnson and Omland 2004). We limited the minimum events per variable for our model building to 10 (Peduzzi et al.

1996). We assessed multicollinearity among variables at each scale by ordinary least-squares regression; we considered combinations of variables with  $r^2 \geq 0.4$  sufficiently correlated to exclude them from the same model (Ballinger 2004). Many models that were based on previously published literature included correlated variables. To evaluate these models, we excluded the variable of each correlated pair that we believed to have the least ecological relevance to the selection process.

Some models included 2 variables that interacted; using this approach we modelled the effect on the probability of use of one factor being mediated by (or compensatory to) another. For example, model E-AR10 (Table 10-1) includes the variable interaction “DBH depending upon presence of rust brooms in spruce trees”. Our interpretation of this interaction is that fishers will be more likely to use a large diameter spruce tree with rust brooms than either 1) a small diameter spruce tree with rust brooms, or 2) a large diameter tree that does not have rust brooms. In this instance, the variables function collectively to influence selection. This is slightly different than model E-AR8, which predicts that the probability of use of a tree is affected by either tree diameter *or* presence of pathogens in the tree. In this case, the 2 variables affect selection independent of each other (i.e., additively).

We used an information-theoretic approach to identify the most parsimonious models (Burnham and Anderson 1998) that predicted selection by radio-tagged fishers at each spatial scale. Information-theoretic inference allowed us to compare the support by the data among several hypothetical models and determine the probability of each model in the candidate set being closest to the underlying process that affected selection (i.e., selection decisions by the animal).

We dealt with the longitudinal nature of repeated observations on a fixed number of radio-tagged fishers by employing generalized estimating equations to generate a population-averaged model (Hu et al. 1998). Because generalized estimating equations are not likelihood-based, we used a modification to the Akaike Information Criterion to produce a quasi-likelihood information criterion ( $QIC_u$ ) to identify the most parsimonious model (Pan 2001). We assumed that correlation among data points occurred within individuals, which necessitated the use of exchangeable correlation (Ballinger 2004) as our working correlation structure. The number of estimated parameters in each model ( $K$ ) equalled the number of variables in the model plus 2 (for estimated parameters: model intercept and working correlation matrix). We calculated the  $QIC_u$  score for each model and ranked the relative support for each model by comparing the scores among competing models. We then identified the “best” model from this candidate set by selecting the model with the lowest  $QIC_u$  score. We assessed whether selection occurred by comparing the  $QIC_u$  scores of models in the candidate set to a null model that predicted no selection. We considered

selection to have occurred if the null model was outside the 95% confidence set of best models.

We used Akaike weights ( $w_i$ ) to quantify strength of evidence for candidate models (Burnham and Anderson 1998). The 95% confidence set of best models was identified using the fewest top models where  $\sum w_i$  was  $\geq 0.95$ . We used multi-model inference to estimate model-averaged parameters and unconditional 95% confidence intervals for each of the variables in the production of a best predictive model (Burnham and Anderson 1998). Odds ratios  $>1$  indicated increasing probability of use with increasing values of the variable, whereas odds ratios  $<1$  indicated decreasing probability of use. This inferential process allowed us to determine if selection occurred, and if so, to estimate the changes in probability of use of an element or patch based upon increases or decreases of identified habitat features.

Because our modelling approach employed a used-unused design, we evaluated performance of the each model by estimating the area under its receiver-operating characteristic (ROC) curve (Hosmer and Lemeshow 2000). The area under this curve provides a measure of discrimination of the model. That is, it helps us quantify the likelihood predicted by the model of a site used by a fisher was higher than non-use. Following guidance provided by Hosmer and Lemeshow (2000:160), areas under the ROC curve have the following discriminatory powers:  $\leq 0.5$  (none), 0.5-0.7 (poor), 0.7-0.8 (acceptable), 0.8-0.9 (excellent), and  $>0.9$  (outstanding).

#### 10.1.4 Fine-scale Results

##### 10.1.4.1 Element scale

We collected 92 radiolocations of 11 fishers between 17 March 1997 and 10 April 2000 that were suitable for element-scale analyses. We identified fishers using specific elements at 13 reproductive dens (8 natal, 5 maternal), and 55 rest sites<sup>6</sup>. Rest sites included 39 arboreal (9 cavities and 30 branch or rust brooms), 11 CWD, 2 CWD piles, and 3 ground sites. The remaining 24 radiolocations were collected at tracks in snow and, thus, were not associated with any identifiable habitat element.

When using arboreal rest sites, fishers rested most frequently in hybrid spruce trees (Fig. 10-2), and in dominant, live trees (Figs. 10-3 and 10-4). Trees used by resting fishers were somewhat larger than those not used within the same patch ( $\bar{x}_{\text{used}} = 57.3$  cm dbh, SD = 24.1,  $n = 39$ ;  $\bar{x}_{\text{unused}} = 44.4$  cm dbh, SD = 22.5,  $n = 208$ ). The estimated age of trees used for resting and the largest temporally unused tree within the patch were similar ( $\bar{x}_{\text{used}} = 129$  y, SD = 41,  $n = 30$ ;  $\bar{x}_{\text{unused}} = 130$  y, SD = 42,  $n = 15$ ).

Radio-tagged fishers strongly selected for trees used for arboreal rest sites (Table 10-3), with the 95% confidence set of best models scoring  $\geq 51$  QIC<sub>u</sub> units better than the null model

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<sup>6</sup> For additional descriptions of structures used for resting and whelping, see sections 11 and 12.

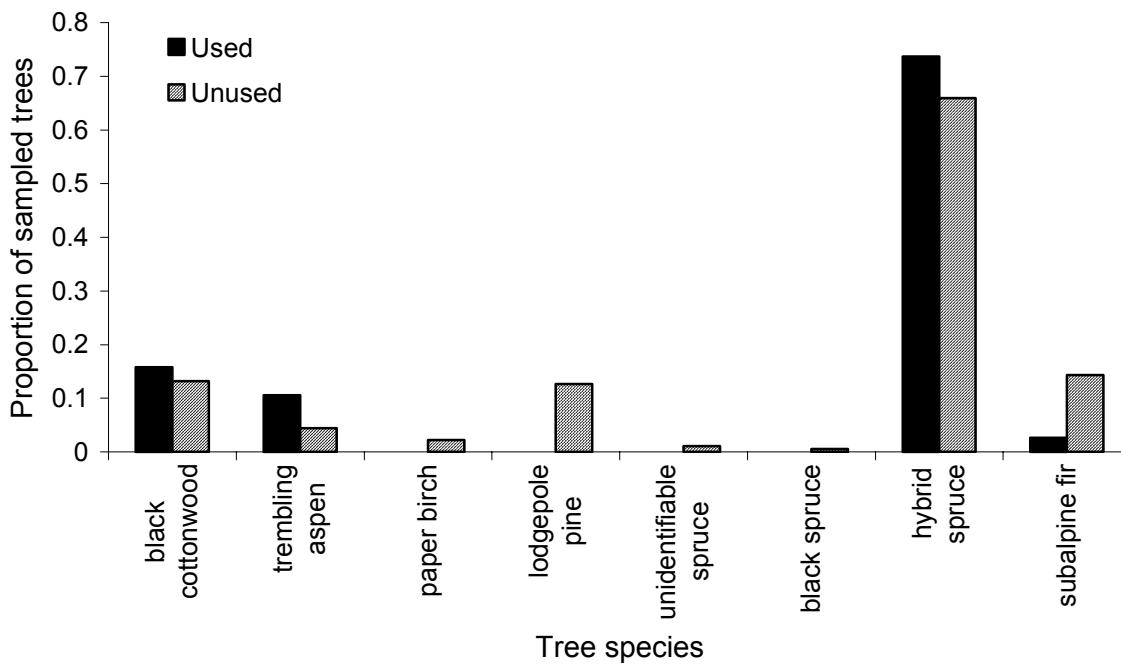


Figure 10-2. Species of trees used by fishers for resting and temporally unused trees within the same patch (i.e., variable-radius cruise plot) in the Williston region of north-central British Columbia, 1997-2000.  $n = 39$  used and 208 unused trees.

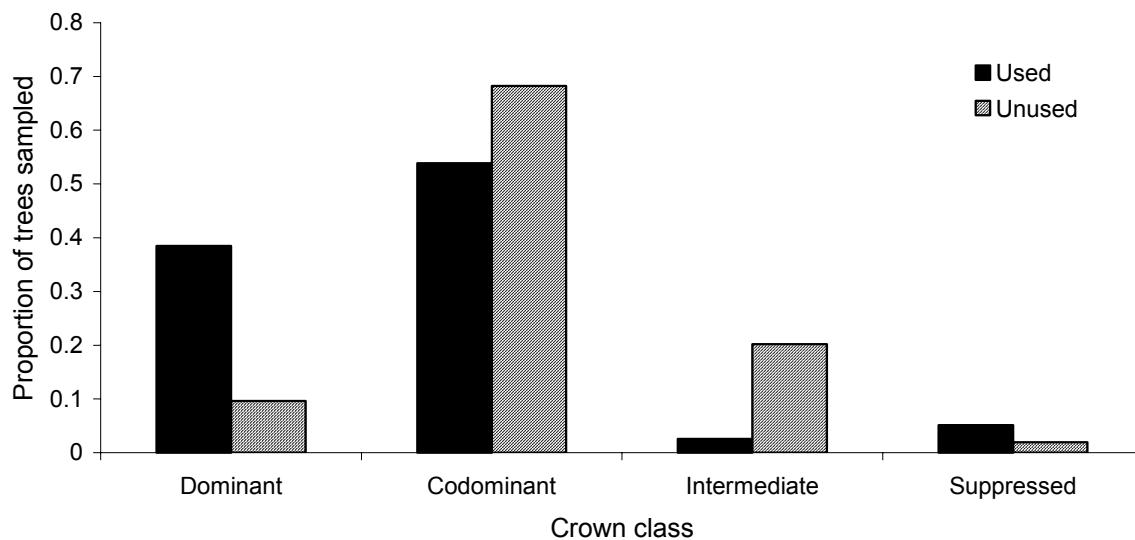


Figure 10-3. Crown class of trees used by fishers for resting and temporally unused trees within the same patch (i.e., variable-radius cruise plot) in the Williston region of north-central British Columbia, 1997-2000.  $n = 39$  used and 208 unused trees.

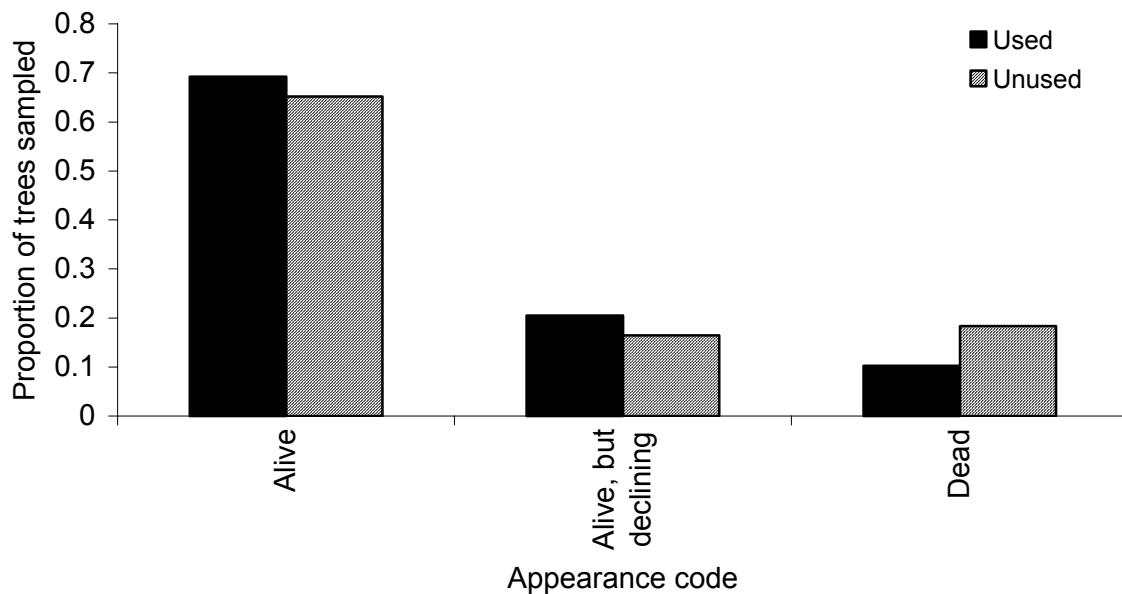


Figure 10-4. Appearance codes of trees used by fishers for resting and temporally unused trees within the same patch (i.e., variable-radius cruise plot) in the Williston region of north-central British Columbia, 1997-2000.  $n = 39$  used and 207 unused trees.

Table 10-3. Ninety-five percent confidence set of models to explain selection of trees within patches for arboreal rest sites in the Williston region of north-central British Columbia, 1997-2000.  $n = 39$  used and 207 unused trees. See Appendix 10-3 for QIC<sub>u</sub> scores for all models in the candidate set.

Model ID	Model category	Probability of use of tree for resting related to:	K <sup>a</sup>	QIC <sub>u</sub> <sup>b</sup>	$\Delta_i^c$	w <sub>i</sub> <sup>d</sup>	Area under ROC curve
E-AR9	Tree size, pathogens	Presence of rust brooms in spruce trees and DBH of <i>Populus</i> species with pathogens	4	164.329	0	0.796	0.80
E-AR10	Tree size, pathogens	DBH of spruce trees with rust brooms and DBH of <i>Populus</i> species with pathogens	4	168.209	3.881	0.114	0.80
E-AR4	Pathogens	Presence of rust brooms	3	168.701	4.372	0.089	0.74

<sup>a</sup> number of estimated parameters in associated model

<sup>b</sup> Quasi-likelihood Information Criterion for small samples (Pan 2001)

<sup>c</sup> difference in QIC<sub>u</sub> scores between model and best-selected model

<sup>d</sup> relative likelihood of model; Akaike weight (Burnham and Anderson 1998)

(Appendix 10-3). The model most supported by the data predicted probability of use based on the presence of rust brooms in spruce trees and the dbh of *Populus* species with pathogens. This model had good discriminatory power (ROC curve area = 0.80). Multi-model parameterization indicated that the probability of using a specific tree for resting was positively associated with all 4 factors in the 95% confidence set of best models (Table 10-4). Fishers were more likely to select a tree for resting if it was either a large-diameter aspen or cottonwood tree with decay, large-diameter spruce tree with rust brooms, a spruce tree with rust brooms, or any spruce or subalpine fir tree with rust brooms. Parameterization of the best model suggested that fishers were 2.5 times more likely to select a spruce tree with a rust broom (probability of use = 0.62) than a 100 cm dbh aspen or cottonwood tree with signs of decay (probability of use = 0.25; Fig. 10-5).

At CWD rest sites, fishers rested inside hollow pieces of CWD ( $n = 2$ ) or in subnivean sites underneath CWD ( $n = 9$ ). One subnivean CWD site involved the use of 2 pieces of debris. We only detected fishers using CWD of decay classes 1 – 3 (Fig. 10-6). Pieces of CWD used by fishers were typically longer, larger diameter, higher off the ground, and had more rest-site (interstitial) space than unused pieces within the patch (Table 10-5).

Table 10-4. Multi-model parameterization of factors affecting selection of arboreal rest sites within patches by radio-tagged fishers in the Williston region of north-central British Columbia, 1997-2000. Odds ratios >1 indicates increasing probability of use with increasing values of the variable; ratios <1 indicate an inverse relationship.

Variable	Model-averaged estimate	Unconditional SE	Odds ratio (95% CI)	Relationship
Intercept	-2.683	0.239		
DBH (cm) of <i>Populus</i> species with pathogens	0.016	0.005	1.017 (1.007 - 1.026)	Positive
Presence of spruce trees with rust brooms	3.180	0.577	24.047 (7.585 - 76.239)	Positive
DBH (cm) of spruce trees with rust brooms	0.063	0.015	1.065 (1.033 - 1.098)	Positive
Presence of rust brooms	2.890	0.539	17.997 (6.119 - 52.935)	Positive

Table 10-5. Characteristics of coarse woody debris (CWD) used by fishers at rest sites compared to temporally unused pieces encountered along two 24-m transects within the same patch in the Williston region of north-central British Columbia, 1997-2000.  $n = 12$  used and 202 unused pieces of CWD.

Variable	Used		Unused	
	Mean	SD	Mean	SD
Piece diameter (cm)	41	25	23	16
Piece height above ground (cm)	42	52	13	20
Piece length (m)	13	9	8	7
Length of potential resting space (m)	4	3	1	2

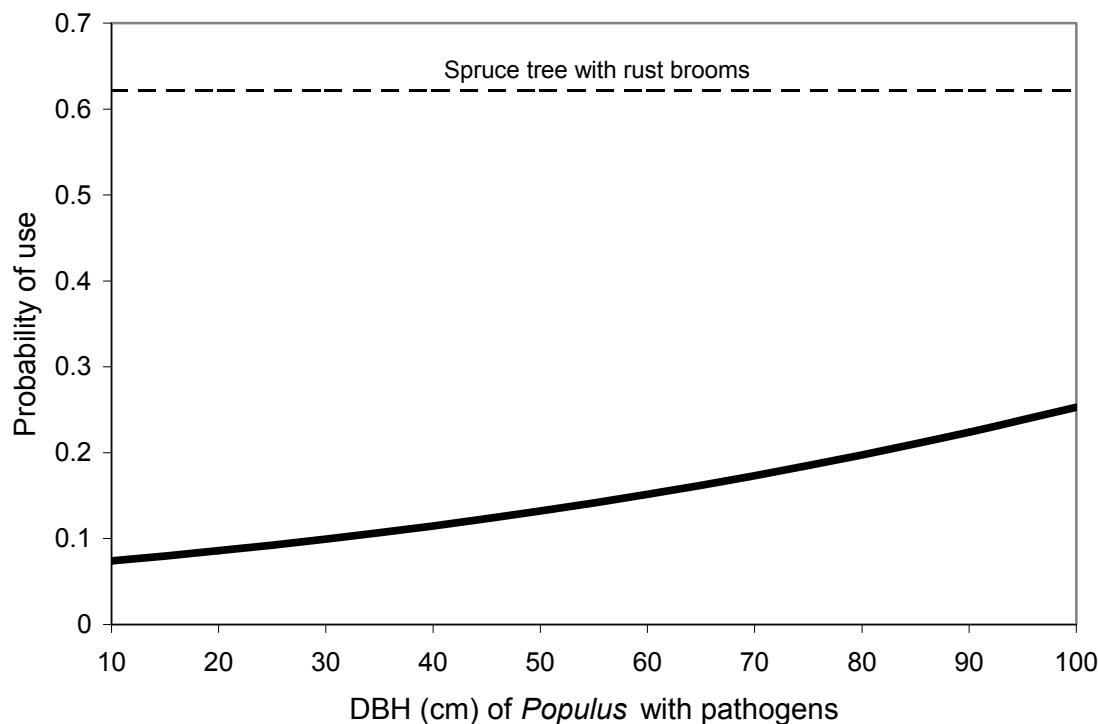


Figure 10-5. Effect of dbh of *Populus* (aspen or cottonwood) with pathogens on the probability of a tree being used by a fisher for resting (solid line), relative to the probability of a spruce tree with rust brooms being used (dashed line), in the Williston region of north-central British Columbia, 1997-2000. Ranges of independent variables were based upon the 95<sup>th</sup> percentile of values recorded during habitat evaluations.

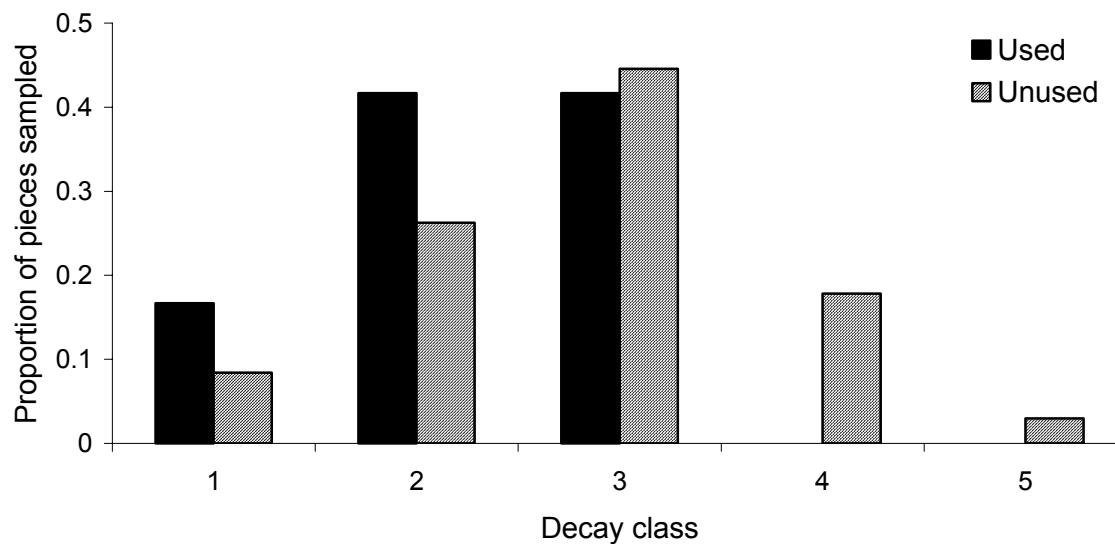


Figure 10-6. Decay classes of coarse woody debris pieces used by resting fishers and temporally unused pieces found along two 24-m transects within the same patch in the Williston region of north-central British Columbia, 1997-2000.  $n = 12$  used and 202 unused pieces of CWD.

Radio-tagged fishers were selective in the pieces of CWD they used for resting (Table 10-6), with the best model scoring  $>8$  QIC<sub>u</sub> units better than the null model (Appendix 10-4). The best model in our candidate set predicted probability of use based on our estimated rest-site potential. All but the piece-length model had acceptable levels of discriminatory power (i.e., ROC scores  $>0.7$ ). Multi-model parameterization of the variables in the 95% confidence set suggested that the probability of use of a piece of CWD for resting was positively related to all 4 variables that were identified in the 95% confidence set of models (Table 10-7, Fig. 10-7). That is, a piece that was  $>35$  cm in diameter somewhere along its length and had its lower surface 25–50 cm above the ground increased the probability of use by 24% for each 1-m increase in its length. Our parameterization also predicted that an increase of 10 cm in the elevation of a piece off of the ground increased the probability of use by 29%, and an increase in diameter of 5 cm increased the probability of use by 23%. Finally, our data suggested that the probability of use increased by 8% with a 1-m increase in length of piece.

Table 10-6. Ninety-five percent confidence set of best models to explain selection of pieces of CWD within patches (i.e., two 24-m transects) used by radio-tagged fishers for resting in the Williston region of north-central British Columbia, 1997–2000.  $n = 12$  used and 202 unused pieces of CWD. See Appendix 10-4 for QIC<sub>u</sub> scores for all models in the candidate set.

Model ID	Model category	Probability of use of CWD piece for resting related to:	K <sup>a</sup>	QIC <sub>u</sub> <sup>b</sup>	$\Delta$ <sup>c</sup>	w <sup>d</sup>	Area under ROC curve
E-CWD5	Cavity under logs	Length of potential resting space	3	88.003	0	0.535	0.77
E-CWD6	Cavity under logs	Height above ground	3	89.177	1.174	0.297	0.73
E-CWD1	Piece characteristics	Diameter	3	91.154	3.151	0.111	0.79
E-CWD2	Piece characteristics	Length	3	94.255	6.252	0.023	0.65

<sup>a</sup> number of estimated parameters in associated model

<sup>b</sup> Quasi-likelihood Information Criterion for small samples (Pan 2001)

<sup>c</sup> difference in QIC<sub>u</sub> scores between model and best-selected model

<sup>d</sup> relative likelihood of model; Akaike weight (Burnham and Anderson 1998)

Table 10-7. Multi-model parameterization of factors affecting selection of pieces of CWD within patches for resting by radio-tagged fishers in the Williston region of north-central British Columbia, 1997–2000. Odds ratios  $>1$  indicates increasing probability of use with increasing values of the variable; ratios  $<1$  indicate an inverse relationship.

Variable	Model-averaged estimate	Unconditional SE	Odds ratio (95% CI)	Relationship
Intercept	-4.325	0.646		
Length of potential resting space (m)	0.215	0.086	1.240 (1.045 - 1.472)	Positive
Height above ground (cm)	0.026	0.006	1.026 (1.014 - 1.038)	Positive
Diameter (cm)	0.041	0.012	1.042 (1.017 - 1.068)	Positive
Length (m)	0.075	0.024	1.078 (1.028 - 1.130)	Positive

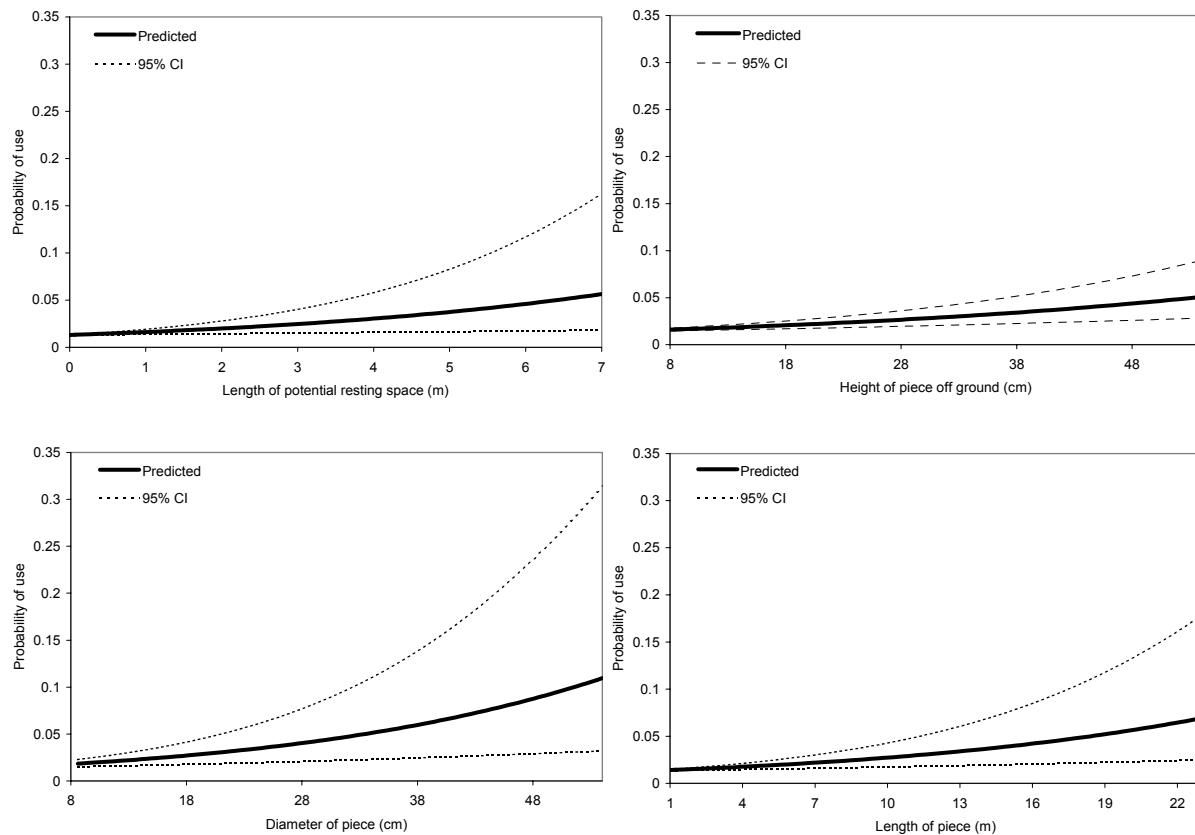


Figure 10-7. Relationship between features of coarse woody debris and probability of use for resting by radio-tagged fishers in the Williston region of north-central British Columbia, 1997-2000. Ranges of independent variables were based upon the 95<sup>th</sup> percentile of values recorded during habitat evaluations.

Female fishers reared offspring exclusively in old, large-diameter black cottonwood trees that were alive (but declining) or dead stems (Fig. 10-8). The average dbh of trees used for denning was substantially larger than unused trees within the same patches ( $\bar{x}_{\text{dens}} = 109.5 \text{ cm}$ ,  $SD = 24.7 \text{ cm}$ ,  $n = 13$ ;  $\bar{x}_{\text{unused}} = 63.0 \text{ cm}$ ,  $SD = 30.0 \text{ cm}$ ,  $n = 59$ ). However, if only black cottonwood trees were considered, the difference was notably less ( $\bar{x}_{\text{unused}} = 100.1 \text{ cm}$ ,  $SD = 22.5 \text{ cm}$ ,  $n = 17$ ). Because all reproductive dens were located in black cottonwood trees, we had complete separation of the data and could not compare the model that included species as a variable to other models in the candidate set. An *a posteriori* analysis of the remaining models, considering only cottonwood trees found within the patches, showed that none of the remaining models were substantially more likely to predict use than the null model of no-selection (Table 10-8).

#### 10.1.4.2 Patch scale

We collected 141 radiolocations of 12 fishers that were suitable for patch-scale habitat analyses; 92 of which were used for the element-scale analysis. Between 1 and 24 patch-scale radiolocations were collected for each fisher ( $\bar{x} = 11.8$ ,  $SD = 8.4$ ). We collected

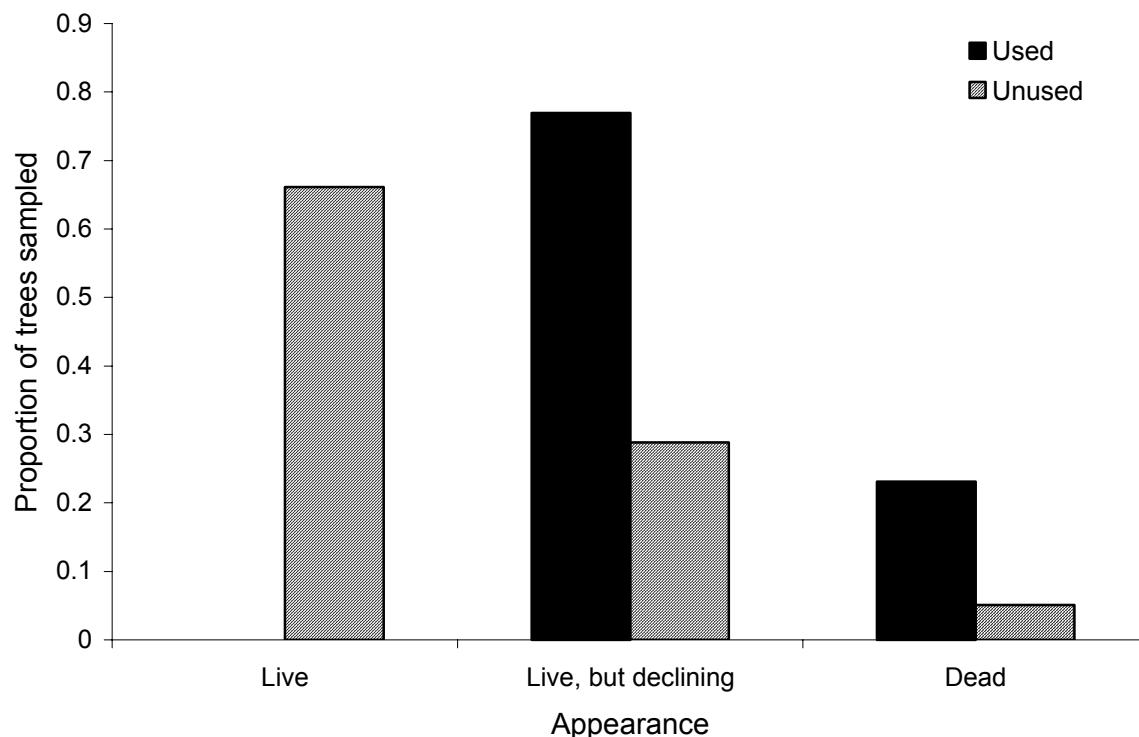


Figure 10-8. Appearance classes of trees used by female fishers for reproductive dens and unused trees within the same patch in the Williston region of north-central British Columbia, 1997-2000.  $n = 13$  den trees and 59 unused trees.

Table 10-8. *A posteriori* comparison of set of candidate models that predicted use of cottonwood trees for denning within patches in the Williston region of north-central British Columbia, 1997-2000.  $n = 13$  den and 17 unused cottonwood trees.

Model ID	Model category	Probability of use of cottonwood tree for denning related to:	K <sup>a</sup>	QIC <sub>u</sub> <sup>b</sup>	$\Delta_i^c$	$w_i^d$
E-DEN4	Tree size & status	DBH depending upon tree status	3	44.773	0	0.246
E-DEN-null		Null model (no selection)	2	45.054	0.281	0.214
E-DEN2	Tree size	DBH	3	45.846	1.073	0.144
E-DEN3	Tree status	Tree status	3	46.388	1.615	0.11
E-DEN5	Tree size & patch cover	DBH depending upon high shrub cover in patch	3	46.539	1.766	0.102
E-DEN6	Tree size & patch cover	DBH depending upon leaf-on cover in patch	3	46.622	1.849	0.098
E-DEN7	Tree size & patch cover	DBH depending upon tree cover in patch	3	46.859	2.085	0.087

<sup>a</sup> number of estimated parameters in associated model

<sup>b</sup> Quasi-likelihood Information Criterion for small samples (Pan 2001)

<sup>c</sup> difference in QIC<sub>u</sub> scores between model and best-selected model

<sup>d</sup> relative likelihood of model; Akaike weight (Burnham and Anderson 1998)

information on habitat patches used at 62 resting, 13 reproductive den, and 66 active or unknown activity radiolocations. These patches occurred in 24 different combinations of ecosystem association and structural stage. Average values of structural attributes at used and temporally unused patches were not substantially different (Appendix 10-5), although not stratified by behaviour, ecosystem association or structural stage.

We detected pronounced selection for habitat patches used by fishers for resting. The null model was essentially implausible, scoring >25 QIC<sub>u</sub> units away from the best model (Appendix 10-6). The 95% confidence set of best models included only 2 of 14 models from the candidate set. The most-likely model predicted the use of patches for resting based on the density of trees with rust brooms and the total length of logs with estimated rest-site potential (Table 10-9). The next-best model, which scored 5.632 QIC<sub>u</sub> units worse than the best model, also included density of trees with rust brooms, but the second variable was volume of elevated large CWD. The area under the ROC curve indicated the best model had acceptable discriminatory power. Parameterization of variables in the 95% confidence set of models (Table 10-10) suggested probability of use was positively related to values of all 3 variables (Table 10-11). According to our parameterized best model (Fig. 10-9), fishers were 2.4 times more likely to select a patch with 25 stems/ha of trees with rust brooms (i.e., 1 tree in a 400-m<sup>2</sup> patch) than one with no rust brooms. The estimated probability of a patch being

Table 10-9. Ninety-five percent confidence set of best models to explain use of patches within stands by radio-tagged fishers for resting in the Williston region of north-central British Columbia, 1997-2000. *n* = 62 used and unused patches. See Appendix 10-6 for QIC<sub>u</sub> scores for all models in candidate set.

Model ID	Model category	Probability of use of patch for resting related to:	K <sup>a</sup>	QIC <sub>u</sub> <sup>b</sup>	Δ <sub>i</sub> <sup>c</sup>	w <sub>i</sub> <sup>d</sup>	Area under ROC curve
P-R3	Tree density, CWD	Density of trees with rust brooms, estimated rest-site potential	4	150.780	0	0.921	0.75
P-R4	Tree density, CWD	Density of trees with rust brooms, volume of elevated large CWD	4	156.412	5.632	0.055	0.69

<sup>a</sup> number of estimated parameters in associated model

<sup>b</sup> Quasi-likelihood Information Criterion for small samples (Pan 2001)

<sup>c</sup> difference in QIC<sub>u</sub> scores between model and best-selected model

<sup>d</sup> relative likelihood of model; Akaike weight (Burnham and Anderson 1998)

Table 10-10. Multi-model parameterization of factors affecting selection of patches within stands used by radio-tagged fishers for resting the Williston region of north-central British Columbia, 1997-2000. Odds ratios >1 indicates increasing probability of use with increasing values of the variable; ratios <1 indicate an inverse relationship.

Variable	Model-averaged estimate	Unconditional SE	Odds ratio (95% CI)	Relationship
Intercept	-0.677	0.146		
Density of trees with rust brooms (stems/ha)	0.030	0.009	1.030 (1.013 - 1.048)	Positive
Estimated rest-site potential (m)	0.085	0.026	1.089 (1.034 - 1.147)	Positive
Volume of elevated large CWD (m <sup>3</sup> /ha)	0.005	0.002	1.005 (1.001 - 1.009)	Positive

Table 10-11. Characteristics of patches used by fishers for resting compared to temporally unused patches in the Williston region of north-central British Columbia, 1997-2000.  $n = 62$  radiolocations.

Variable	Used		Unused	
	Mean	SD	Mean	SD
Density of trees with rust brooms (stems/ha)	24.8	41.5	3.1	13.4
Estimated rest-site potential (m)	5.0	10.9	1.0	3.1
Volume of elevated large CWD ( $m^3/ha$ )	80.2	182.3	35.3	46.2

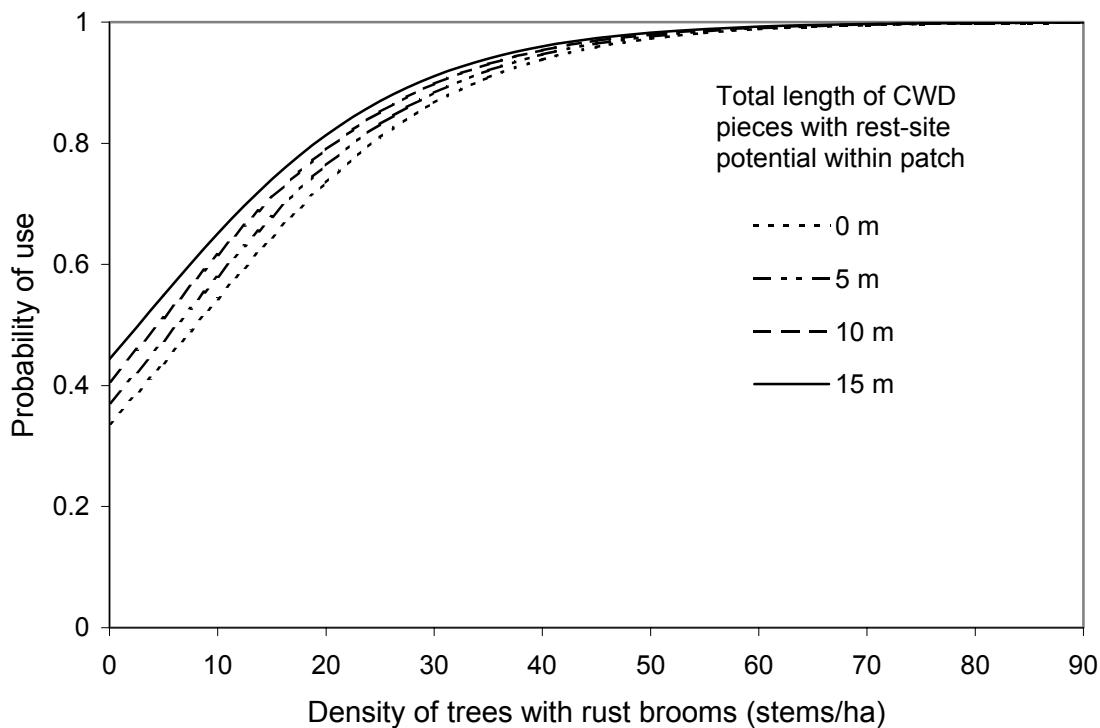


Figure 10-9. Predicted relationship among density of trees with rust brooms, length of pieces of CWD with rest-site potential, and the probability of a patch being used by a fisher for resting in the Williston region of north-central British Columbia, 1997-2000. Ranges of independent variables were based upon the 95<sup>th</sup> percentile of values recorded during habitat evaluations. Fishers were least likely to select a patch with no rust brooms and no rest-site potential.

selected for resting was 1.34 times higher in a patch that had 16 m of estimated rest-site potential than one with no rest-site potential. Our parameterized model predicted that the probability of use exceeded 95% for patches that had >40 stems/ha of trees with rust brooms and >8 m of rest-site potential, or for patches with >45 stems/ha of trees with rust brooms.

We observed modest selection of patches for reproductive dens; the best model was 30 times more likely than the null model, scoring 6.77 QIC<sub>u</sub> units better than it. However, the 95% confidence set of best models included the null model (Table 10-12), so we could not definitively exclude “no selection” as a plausible explanation for the data. All of the models in the 95% confidence set showed poor or no discriminatory power, so we did not develop

Table 10-12. Ninety-five percent confidence set of best models that explained selection of patches within stands used for whelping by radio-tagged fishers in the Williston region of north-central British Columbia, 1997-2000.  $n = 13$  used and 13 unused patches. See Appendix 10-7 for QIC<sub>u</sub> scores for all models in candidate set.

Model ID	Model category	Probability of use of patch for whelping within stand related to:	K <sup>a</sup>	QIC <sub>u</sub> <sup>b</sup>	$\Delta_i^c$	W <sub>i</sub> <sup>d</sup>	Area under ROC curve
P-W5	Den opportunities	Largest dbh of trees in patch	3	33.27	0	0.870	0.65
P-W2		Deciduous tree cover (%)	3	39.514	6.244	0.038	0.58
Null		Null model (no selection)	2	40.044	6.774	0.029	0.50
P-W3		Density of cavity trees in patch	3	40.367	7.097	0.025	0.58

predictive models for these selection functions. Although we observed selectivity, the patches of habitat in which female fishers whelped were not consistently different from unused patches within the same stand (Table 10-13).

Models that predicted the selection of patches in which radio-tagged fishers were active were not substantially better than the null model and all models in the 95% confidence set showed poor or no discriminatory power (Table 10-14).

#### 10.1.5 Fine-scale Discussion

We identified several functional relationships between the behaviour of radio-tagged fishers and the fine-scale habitats they selected in our study area. We showed that fishers were selective for structural elements and patches of habitat used for resting and denning. We did not, however, observe consistent selection of patches when fishers were active. The probability of use of identified elements or patches was strongly tied to either the presence or abundance of several key parameters. For many behaviours, fishers were highly specific in the habitat features that they exploited. These relationships have implications for the maintenance of sustainable fisher populations.

##### 10.1.5.1 Resting

Fishers used a variety of elements and patches for resting. Similar to the observations of Arthur et al. (1989b) in Maine, Raine (1983) in Manitoba, and Weir and Harestad (2003) in south-central British Columbia, we found fishers resting in cavities in deciduous trees, on rust brooms of coniferous trees, and in or under CWD. Selection for resting habitat occurred at both spatial scales. This is consistent with other research that reported fishers selecting atypical patches in which to rest (Jones 1991, Weir and Harestad 2003, Zielinski et al. 2004b). The habitat elements and patches used by fishers for resting were different from unused habitats, suggesting these sites confer some advantage to fishers.

When fishers chose arboreal rest sites, the probability of selecting an element or patch was dependent upon the presence or abundance of habitat characteristics specific to that site. Usually the probability of use was strongly related to the species of tree, the presence of

Table 10-13. Characteristics of patches used by radio-tagged fishers for whelping compared to unused patches in the same stand in the Williston region of north-central British Columbia, 1997-2000.  $n = 13$  radiolocations.

Variable	Used		Unused	
	Mean	SD	Mean	SD
Largest dbh of tree in patch (cm)	113	24	78	34
Deciduous tree cover (%)	13	12	6	11
Density of trees with cavities (stems/ha)	20	16	11	19

Table 10-14. Ninety-five percent confidence set of models explaining the factors that affected selection of patches by radio-tagged fishers while active in the Williston Region of north-central British Columbia, 1996-2000.  $n = 66$  radiolocations. See Appendix 10-8 for QIC<sub>u</sub> scores for all models in the candidate set.

Model ID	Model category	Probability of use of patch while active or when behaviour unknown related to:	K <sup>a</sup>	QIC <sub>u</sub> <sup>b</sup>	$\Delta_i^c$	$w_i^d$	Area under ROC curve
P-A8	General	Volume of CWD	3	186.128	0	0.294	0.58
Null		Null model (no selection)	2	186.991	0.863	0.191	0.50
P-A6	Cover, travel	Coniferous shrub cover, estimated length of logs suitable for travelling	4	187.413	1.285	0.155	0.55
P-A5	Foraging, cover	Volume of elevated CWD, low-shrub cover	4	187.768	1.641	0.13	0.57
P-A1	Cover	Leaf-off cover during winter, leaf-on cover during non-winter	4	188.658	2.53	0.083	0.59
P-A2	Foraging	Coniferous shrub cover	3	188.956	2.829	0.072	0.53
P-A4	Foraging	Coniferous shrub cover, volume of elevated CWD, density of trees with rust brooms	5	190.621	4.493	0.031	0.58

<sup>a</sup> number of estimated parameters in associated model

<sup>b</sup> Quasi-likelihood Information Criterion for small samples (Pan 2001)

<sup>c</sup> difference in QIC<sub>u</sub> scores between model and best-selected model

<sup>d</sup> relative likelihood of model; Akaike weight (Burnham and Anderson 1998)

decay or disease characteristics, and often the tree size. Rarely did fisher rest in live trees that had no sign of pathogens, and fishers never used lodgepole pine trees (the most abundant species in the landscape) for resting.

Trees with rust brooms were clearly an important feature of resting habitat for fishers in our study area; fishers were highly selective for this feature at both the element and patch spatial scales. In fact, the estimated probability of a fisher selecting such a tree as a rest site was approximately 17 times that of selecting one without a rust broom. Rust brooms generally form in the crown of infected trees (Ziller 1974) and fishers likely selected rust brooms because these sites were elevated above the ground and provided secure platforms on which to rest. Other researchers have reported fishers using “witches brooms” for resting (e.g., Arthur et al. 1989b, Kilpatrick and Rego 1994), and Weir and Harestad (2003) reported high use of rust brooms by fishers in south-central British Columbia.

Trees that were likely to have cavities were also more likely to be used as rest sites. Although we observed less use of cavities than rust brooms, fishers were quite selective in

the species, size and condition of trees that they selected. A 10-cm increase in the dbh of a trembling aspen or black cottonwood tree that had decay present increased its probability of use within a patch by 18%. Fishers elsewhere commonly use cavities in trees for resting (Arthur et al. 1989b, Kilpatrick and Rego 1994, Zielinski et al. 2004b). Zielinski et al. (2004b) attributed this to females having a greater need for protection from thermal and moisture extremes and predators. They also suggested that females may have a predisposition to choose structures that are similar to reproductive dens.

Coarse woody debris was used for resting only when snow was present. When using subnivean rest sites, fishers selected CWD based on the size of potential subnivean cavities. Subnivean interstitial spaces likely provided beneficial thermal environments (Taylor and Buskirk 1994). These results are broadly consistent with research conducted on fishers in cold environments. In Idaho, Jones (1991) reported patch-scale selection by fishers for CWD pieces >47 cm diameter during winter. Weir and Harestad (2003) observed that fishers only selected subnivean cavities associated with large pieces of CWD and only when temperatures were <-20°C in south-central British Columbia. Fishers in California rarely used CWD sites for resting (Zielinski et al. 2004b), which may be related to the relative rarity of extreme cold in this region.

Fishers likely selected elements and patches for resting to meet 2 different needs. When temperatures were sufficiently warm (e.g., >-15°C; *Section 11*), they selected elements or patches that may have provided the greatest protection from predators and benefits for detecting prey. Because arboreal rest sites provide an elevated position, these sites probably afforded earlier visual, auditory and olfactory detection of approaching predators. Similarly, these sites may provide greater detection of potential prey. When temperatures were colder and snow depths were sufficient to cover pieces of elevated CWD, fishers may have selected sites that were thermally most advantageous and yet still provided some predator-avoidance benefits.

#### 10.1.5.2 Denning

Female fishers in our study area were highly selective for the tree species in which they whelped and reared offspring, exclusively using large-diameter black cottonwood trees. Aside from selecting this species, no other factor that we measured appeared to affect den selection at the element or patch scale. This may be because the selection for den sites was based on other characteristics that we did not measure (e.g., presence and size of cavities), or because our sample size was limited. Black cottonwood trees have a high incidence of internal decay (Maini 1968), which potentially results in the formation of many cavities. Tree cavities may be better than other potential dens in our study area, such as brooms or hollow logs (Aubry et al. 2001), because these other structures may not provide suitable environments (e.g., adequate protection or thermal benefits) during the rearing period in the

Williston region (see *Section 12*). Although other tree species in our study area form cavities (i.e., trembling aspen and paper birch), cavities in these species may not attain sufficient size to adequately house an adult female and her young, or may not provide other features that make them suitable or advantageous as reproductive dens.

Although we could not evaluate selectivity of den trees, female fishers appeared to preferentially use certain den trees. Three females that we observed denning for more than one year re-used 1 of their previously natal dens and 1 individual used the same natal den for 3 consecutive years. This female also used her subsequent maternal den for 2 consecutive years (*Section 5* and *Section 9*). Certain characteristics of these den cavities, trees, or sites must have provided greater benefits to young-rearing or survival than other available structures or sites within their home range, such as better thermoregulatory properties, better protection from adverse conflict or weather conditions, closer proximity to available prey resources, or proven reproductive success.

The use of large-diameter black cottonwood trees as reproductive dens by female fishers in our study was consistent with Weir's (1995a) study. In eastern and southern portions of their range, however, fishers whelp in a variety of generally smaller hardwood trees (Paragi et al. 1996, Powell et al. 1997, Gilbert et al. 1997). Although we did not detect selection for tree size, large cottonwood trees were rare across the landscape. Trees that fishers used for dens were larger than the 75<sup>th</sup> percentile of all cottonwood trees measured at randomly located habitat plots.

#### 10.1.5.3 Active Behaviour

We failed to detect patch-scale habitat selection by active fishers and the performance of the estimated models was very poor. Our candidate set was comprised of generic, simple models that relied on ecological correlates to represent resources that fishers were thought to be sequestering while active. The best linkages between selection and habitat occur when researchers can quantify the actual resource the animal is selecting (e.g., prey) and not ecological correlates that do not provide the resource needed (Morrison 2001). Multiple behaviours (e.g., foraging for hares, foraging for squirrels, travelling) may have been influenced the selection process for active radiolocations, further confounding our analysis. Until resource-specific motivations are determined, it will be difficult to parameterize an effective model for active fishers. Having larger sample sizes, though, would enhance the power of the model-selection process. Alternatively, fishers may not select resources for these behaviours at the patch spatial scale, although this is unlikely given previous research findings (e.g., Powell 1994b).

## 10.2 Broad Spatial Scale

Fishers make many resource selection decisions throughout their life. Upon leaving their natal home range, fishers must decide where in the landscape to establish a home range. This is a critical decision; it is within this home range that they must find sufficient resources to survive and reproduce and all future resource selection decisions are dependent on the suite of habitats within this selected area. Despite the importance of this, very little is known about the factors that influence home range establishment by fishers.

Fishers successfully establish home ranges only where there is a sufficient concentration of suitable habitat (Powell 1994a). Overhead cover appears to be a basic habitat requirement for the species (Powell 1993), and fishers may select home ranges to meet this basic need. Other factors that may affect where fishers occur include tree canopy closure, tree size class, percent conifer, and annual precipitation (California; Carroll et al. 1999). In Ontario, snow depth and proportion of coniferous forest were the best predictors of landscape habitat suitability (Carr et al. 2007). In Nova Scotia, fisher presence in the harvest was positively associated with presence of agricultural land, number of merchantable tree species, mature forest, and presence of streams but negatively associated with number of wetlands present and areas with no variation in topography (Potter 2002). Detecting landscape-scale selection may be difficult; Weir and Harestad (1997) did not detect consistent selection for the composition of the home ranges of 9 fishers in the SBS of south-central British Columbia, although they speculated that landscape granularity affected this result.

Once fishers have established a home range, further day-to-day resource selection decisions must be made. Fishers must acquire sufficient food, avoid predation, and find mates within their home range. Many factors can affect the ease with which fishers acquire resources necessary to survive and reproduce and the stands that fishers select are key components to this process.

Much of the past research on the habitat relationships of fishers has focussed on examining the day-to-day selection of stands within the home range. Fishers have been variously reported to select coniferous stands in Maine (Arthur et al. 1989b), deciduous stands in Alberta (Badry et al. 1997), and mixed coniferous-deciduous stands in Ontario (de Vos 1952). Fishers may also select stands on the basis of structural stage (Jones and Garton 1994) or snow conditions (Raine 1983). Weir and Harestad (2003) noted that fishers selected stands with more overhead cover, better foraging habitat, better snow interception, and more resting habitat. Elsewhere in British Columbia, Proulx (2006) reported that fisher tracks in snow were more common in structurally complex coniferous stands.

Understanding how fishers select a home range, then make decisions about where within their home range to extract resources will help guide habitat management that affects both populations and individual fishers. These examinations are particularly relevant given the

close association of fishers with features of late-successional forests, which are targeted during forest harvesting activities.

We explored broad-scale habitat selection by radio-tagged fishers in the Williston region of north-central British Columbia by examining the selection of stands and home ranges by fishers. Our objectives at these scales were to 1) identify the features of habitat that fishers select, 2) develop parsimonious models that predict the probability of selection and 3) assess the specificity that fishers have for each factors. To achieve this, we ask several questions:

- 1) Do fishers select areas in the landscape for home ranges?
- 2) Do fishers select for stands within their home ranges?
- 3) If so, what features affect the probability of selection?
- 4) How strong is the relationship between identified features and the selection of identified broad-scale habitat features?

#### 10.2.1 Hypothesis (Model) Evaluation

Past research has identified several key habitat relationships that may affect where fishers will establish home ranges and which stands they will use within this home range (Tables 10-15, 10-16). We evaluated the habitat relationships of fishers at broad scales by examining several hypothetical models that predicted the relationship between these variables and probability of use. Many of the models were based on research from elsewhere, especially from Weir and Harestad's (2003) study of fishers in the southern portion of the Sub-Boreal Spruce biogeoclimatic zone. Several models were unique hypotheses that we developed by combining variables that might better explain selection. For each scale of analysis, we compared the support, by the radiotelemetry data, among several hypothetical models and assessed the probability of each model in the candidate set being closest to "reality". At the landscape spatial scale, we considered 3 categories of models: those that predicted selection of home ranges on the basis of avoidance of stands, inclusion of stands, and general features (Table 10-15). At the within-home range scale, we examined 14 candidate models (Table 10-16) from 5 broad categories: those that predicted selection of stands within the home range on the basis of resource requirements for resting, cover, foraging, denning, and non-specific entities. Definitions of the variables found in each model are listed in Appendix 10-9 and 10-10.

#### 10.2.2 Methods

##### 10.2.2.1 Experimental Design

We examined several models by comparing stands or home ranges used by radio-tagged fishers to those available within the scale of examination. At the within-home range scale, we compared the features of stands used by fishers to those available within their respective home ranges and considered the radiolocation to be the measured currency of use (Buskirk

Table 10-15. Set of candidate models used to examine selection of home ranges within the landscape by radio-tagged fishers in the Williston region of north-central British Columbia, 1996–2000. Categories summarize the hypothesized relationships between probability of use and generalized habitat features in the model. Descriptions of constituent variables are listed in Appendix 10-9.

Model ID	Model category	Probability of occupancy related to:	Reference
L-1	Inclusion	Complex structural stages	Jones and Garton 1994
L-2	Inclusion	Forested ecosystem associations	Unique hypothesis
L-3	Inclusion	Habitat suitability index	Allen 1983, Tully 2006
L-4	Inclusion	Mature and old structural stage productive ecosystems	Unique hypothesis
L-5	Inclusion	Mature and old structural stage riparian	Unique hypothesis
L-6	Inclusion	Stands $\geq$ 30% cover	Arthur et al. 1989b
L-7	Non-specific	Granularity	Weir and Harestad 1997
L-8	Avoidance	Non-forested ecosystem associations	Unique hypothesis
L-9	Avoidance	Open areas	Powell 1993
L-10	Avoidance	Recent logging	Buck et al. 1994

and Millspaugh 2006; i.e., an index of time spent at a specific site). For the landscape analysis, we used the home range as the currency of use and compared the features of the home ranges selected by radio-tagged fishers to potential home ranges that could occur within the landscape (i.e., available home ranges).

Boundaries for “choice sets” (Buskirk and Millspaugh 2006) available to each individual were based on the scale at which selection was evaluated. We considered use of a stand to have occurred as selection of one of numerous stands available within the home range. Likewise, home ranges were selected among potential home ranges within the landscape. We defined temporal independence as the time needed for a fisher to access any other stand within its home range. We observed average maximum movement rates of 0.66 km/h for females ( $SD = 0.90$  km/h,  $n = 10$ ) and 0.76 km/h for males ( $SD = 0.56$  km/h,  $n = 3$ ). Based upon this data and the maximum sizes of stands ( $0.64 – 12.0$  km $^2$ , depending on individual), and home ranges ( $27.3 – 225$  km $^2$ , depending on individual), we determined that fishers could reach any stand within their home range within 20 hours (see *Section 6*). We used this estimated time of travel to independent points as the basis for temporal independence of radiolocations. For landscape-scale analysis, we assumed that each fisher could access any potential home range within the landscape while dispersing from their natal home range.

#### 10.2.2.2 Fisher radiolocations

We captured, radio-tagged, and radio-located fishers as described in *Section 3* and *Section 4*. We categorized each radiolocation into 1 of 5 precision categories and used these measures of precision to determine the spatial scales for which each radiolocation was suitable for analysis (see *Section 4*).

Table 10-16. Set of 14 candidate models predicting selection of stands within home ranges by radio-tagged fishers in the Williston region of north-central British Columbia, 1996-2000. Categories summarize the hypothesized relationships between probability of use and generalized habitat features in the model. Descriptions of constituent variables are listed in Appendix 10-10.

Model ID	Model category	Number of variables	Probability of use of stand within home range related to:	Reference
S-1	Cover	4	Coniferous tree cover, volume of hard CWD, deciduous tree cover, high-shrub cover	Weir 1995a
S-2	Cover	2	Coniferous tree cover during winter, deciduous tree cover	Arthur et al. 1989b
S-3	Cover	1	Overhead cover	Arthur et al. 1989b, Powell 1993
S-4	Cover	2	Seasonal cover	Powell 1993
S-5	Denning, cover	2	Density of den-sized black cottonwood trees while whelping, leaf-on cover while whelping	Unique hypothesis
S-6	Foraging	3	Cover of coniferous shrubs while active, volume of elevated large CWD while active, overhead cover	Unique hypothesis
S-7	Foraging, cover	3	Volume of CWD, density of all trees, deciduous tree cover	Weir and Harestad 2003
S-8	Resting	2	Volume of elevated large CWD, density of trees with rust brooms	Weir and Harestad 2003
S-9	Resting	2	Density of trees with rust brooms while resting, estimated CWD rest site length while resting	Unique hypothesis
S-10	Resting, cover	5	Coniferous tree cover, deciduous tree cover, high-shrub cover, density of trees with rust brooms, volume of elevated large CWD	Weir and Harestad 2003
S-11	Resting, foraging, cover	4	Density of trees with rust brooms while resting, estimated CWD rest site length while resting, density of dead trees while resting, overhead cover	Unique hypothesis
S-12	Resting, foraging, cover	6	Density of trees with rust brooms while resting, estimated CWD rest site length while resting, density of dead trees while resting, cover of coniferous shrubs while active, volume of elevated large CWD while active, overhead cover	Unique hypothesis
S-13	Non-specific	8	Ecosystem association	Unique hypothesis
S-14	Non-specific	7	Structural stage	Jones and Garton 1994

### 10.2.2.3 Habitat measurement

We used map-based data derived largely from photo-interpretation to examine habitat relationships at the within-home range and landscape scales. At the within-home range scale, we compared features of stands used by radio-tagged fishers to those that were available within their respective home ranges. We also compared features of the home ranges of resident fishers with potential home ranges situated throughout the landscape. We used the same map-based data for analysis at both scales.

We used predictive ecosystem maps (PEM) to estimate the abundance and distribution of stands within the home ranges and landscape of the study area. We used 1:20,000-scale PEM (Atticus Resource Consulting Ltd. 2002, Timberline Forest Inventory Consultants Ltd. 2004) to identify polygons (i.e., stands  $> 2.0$  ha) that had the same site series and structural stage (Resources Information Standards Committee 1999). Sub-polygon variability in site series was captured by complex polygons, whereby the proportions of up to 3 site series were identified within each polygon (Resources Information Standards Committee 1998). Each polygon was assigned 1 of 8 structural stages. Because of broad structural and floristic similarities among site series in the 3 biogeoclimatic variants (SBSmk1, SBSmk2, SBSwk2) of our study area, we amalgamated 31 site series into 9 ecosystem associations (Fig. 10-10, Appendix 10-11). We used the combination of ecosystem association and structural stage to classify stands, which we considered to be relatively homogeneous assemblages of habitat  $\geq 2$  ha (i.e., they were similar with respect to CWD, closure of vegetation strata, and other structural attributes).

Complex polygons were common in the PEM data. Therefore, for each observation (i.e., single radiolocation or randomly located point in a stand), we estimated its composition by assigning proportions equal to the decile (Resources Information Standards Committee 1998) of each ecosystem association that occurred in the polygon. To further capture the uncertainty associated with imprecise radiolocations, we assigned an area-based weight for error polygons that encompassed  $>1$  PEM polygon.

We also used the information from randomly located plots to predict typical structural conditions for each ecosystem association and structural stage. We used data from both patch-comparison plots and randomly located *stand-description plots* (SDP) to calculate mean values for structural variables for each combination (Appendix 10-12). We used  $\geq 3$  replicates of each ecosystem association and structural stage combinations in these calculations. We did not include data from patch-comparison plots that fell in atypical sites (e.g., roads, landings, creeks) in the calculation of stand-averaged structural values.

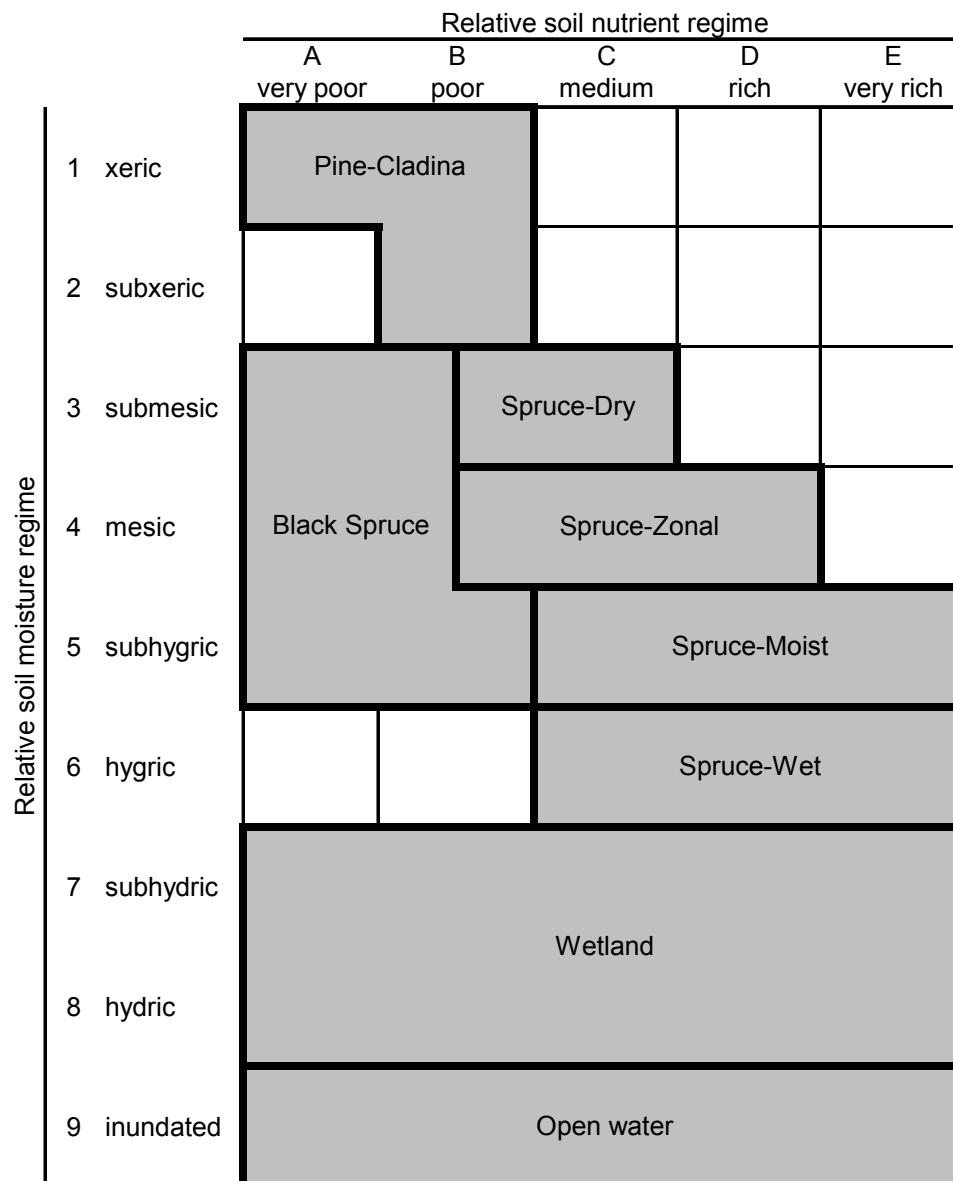


Figure 10-10. Edaphic grid of ecosystem associations used in the analysis of habitat selection by fishers in the moist-cool and wet-cool subzones of the Sub-Boreal Spruce biogeoclimatic zone (SBSmk and SBSwk). Some overlap of the Spruce-Moist and mesic-medium nutrient sites occurred in the wet-cool subzone. The non-vegetated ecosystem association (not illustrated) occurred when bedrock or unmodified soil was exposed.

### 10.2.3 Analysis

We completed separate analyses of the models that predicted selection by radio-tagged fishers at the within-home range and landscape spatial scales. We considered selection as a binary process and modelled it as a logistic function. Because we compared use to availability, we estimated a resource selection function (RSF, Manly et al. 2002) for selection at each spatial scale.

### 10.2.3.1 Within-Home Range Scale

We examined the support by the data for several competing models that predicted the probability of using stands to those available within the home range of resident fishers (Type 3 design, Thomas and Taylor 2006). We used radiolocations of resident fishers with error polygons < 3 ha (i.e., 50% larger than the minimum mappable unit in the PEM) to quantify use of stands within the home range. We estimated the home range of each resident fisher using the aggregate 95% UD isopleth (see *Section 7*). For each suitably precise radiolocation, we quantified the availability of stands by identifying the stands at 200 randomly located points within the home range of each fisher.

We used the predictive ecosystem map to identify the ecosystem association and structural stage of each radiolocation and random point. We used stand-averaged means for vegetative and structural characteristics for each combination of ecosystem association and structural stage to further evaluate their effects on selection within the home range.

We considered use as a binary response variable and used conditional logistic regression (Hosmer and Lemeshow 2000:243) to parameterize each candidate model (see below), with the individual fisher as the stratification variable. Using this approach, we compared 1 “used” stand to 200 “available” stands within the home range for each radiolocation to generate a RSF to explain selection of stands within the home range.

### 10.2.3.2 Landscape Scale

To examine factors affecting selection of home ranges within the landscape, we compared the composition of the aggregate 95% UD isopleth for each fisher to that available in the landscape. We defined our landscape as the extent of the SBS that was “effectively” live-trapped during the study (see *Section 6.1.3*). We described the distribution and abundance (i.e., availability) of stands within the landscape (Wilson et al. 1998) by generating 162 pseudo-home ranges for each fisher. The size and shape of the individual’s observed home range was used to generate their respective pseudo-home ranges. Each pseudo-home range replicate was positioned at a random geocoordinate within the landscape and then rotated to a random angle. We set 2 criteria for the placement of pseudo-home ranges within the landscape: no part of the pseudo-home range could extend > 100 m into the draw-down zone of the Williston Reservoir, and at least 50% of it had to lie within the extent of the landscape as we defined it. We allowed overlap to occur between pseudo-home ranges and the observed home range. This allowed us to compare “used” to “available” home ranges in the landscape for each individual and generate a resource selection function (RSF; Manly et al. 2002). To allow equivalent comparisons for measurements between used and pseudo-home ranges, we scaled all measurements to total area within the home range that occurred within the SBS (e.g., proportion of home range logged since 1988).

We measured 10 variables that were constituents of the hypothetical models that we considered. Within each used and pseudo-home ranges, we measured the length of “definite” creeks and rivers by overlaying the home range with Terrain Resource Inventory Modelling data (TRIM; BCMSRM 2000). We determined the proportion of each home range with at least 30% tree cover using Forest Inventory Planning data (FIP; BCMOF 2002). The FIP data was also used to assess the proportion of each home range that had undergone timber harvest since 1988. Estimates of the area-averaged habitat suitability index (HSI) developed for fishers by Allen (1983) were calculated for each home range based on canopy closure, mean dbh, overstory composition, and layer count information in the FIP data. We assessed the percentage of each home range in each ecosystem association and structural stage using PEM data and used PEM polygons to calculate the number of stands found in each home range. We also combined the PEM and TRIM data to determine the length of creeks and rivers in mature and old forest structural stages in each home range. Each of these measures was scaled to home range area for each stratum (i.e., an individual fisher).

We determined the effect that variables had on the likelihood of a potential home range area being occupied by a resident fisher (i.e., landscape-scale selection). We considered home range occupancy as a binary response variable and used 1-*M* conditional logistic regression (Hosmer and Lemeshow 2000:243) to parameterize each candidate model. Using this approach, we compared 1 “used” home range to 162 pseudo-home ranges for each resident fisher to generate a RSF to explain selection of home ranges within the landscape.

#### 10.2.3.4 Model selection

We used an information-theoretic approach to identify the most parsimonious models (Burnham and Anderson 1998) to predict selection by radio-tagged fishers at each spatial scale. We calculated the Akaike Information Criteria score modified for small sample sizes ( $AIC_c$ ; Burnham and Anderson 1998) for each model and ranked the relative support for each by comparing the scores among competing models at each scale. We then identified the “best” model from this candidate set by selecting the model with the lowest  $AIC_c$  score. We used Akaike weights ( $w_i$ ; Burnham and Anderson 1998) to quantify strength of evidence among the candidate set of models. The 95% confidence set of best models was identified using the fewest top models whereby the  $\sum w_i$  was  $\geq 0.95$ . We used multi-model inference to estimate model-averaged parameters and unconditional 95% confidence intervals for each variable in a best predictive model (Burnham and Anderson 1998). We used odds ratios from model-averaged parameters to quantify the effect of each variable on the probability of use by radio-tagged fishers. Odds ratios  $>1$  indicated increasing probability of use with increasing values of the variable; ratios  $<1$  indicated decreasing probability of use. Essentially, this inferential process allowed us to estimate the change in probability of use of a stand or home range based upon increases or decreases of identified habitat features.

### 10.2.3.5 Evaluation of model performance

To assess model prediction at the within-home range spatial scale, we divided the data set into model-training and model-testing partitions. We used a systematic selection of 80% of the observations to identify and parameterize the best model and used the remaining 20% to test the predicted best model (Johnson et al. 2006:352). We applied the best model to the PEM data and estimated RSF scores for all polygons in the home ranges of each of the 10 radio-tagged fishers. We took the maximum and minimum estimated RSF scores and divided the range into 20 equal-width bins. We further reduced these bins into 8 bins with more-or-less equal numbers of polygons in each bin. We applied the best model to the model-testing partition and assigned the estimated outcome of each application to the appropriate bin, depending upon its score. For each fisher, we regressed the number of observations in each bin with the expected number, based upon polygons in the home range. We compared the AIC<sub>c</sub> score for this regression to one with no slope (i.e., a null model). We also compared the AIC<sub>c</sub> score to a regression with a slope of 1 to determine if our best model was substantially different. Because of small sample size, we did not evaluate model performance for the analysis of landscape-scale selection.

### 10.2.4 Broad-scale Results

#### 10.2.4.1 Within-home range (stand) scale

Between 1996 and 2000, we collected 389 radiolocations of 10 resident fishers that were suitable for analyses at the within-home range spatial scale ( $\bar{x} = 39$  radiolocations per individual, SD = 22). Radiolocations were collected throughout the year for each individual. We parsed the dataset into model-training and model-testing partitions of 311 and 78 radiolocations, respectively.

The data provided plausible support for only 2 of 14 models that predicted selection of stands within the home range (Table 10-17). The best-supported model predicted that the probability of use of a stand within the home range was based on ecosystem association (ecosystem-association model). The second-best model predicted that the probability of a use of a stand was based on several structural features (structural-features model): deciduous tree cover, coniferous tree cover, high-shrub cover, density of trees with rust brooms, and volume of large elevated CWD. Both models were nearly equally supported by the data, being separated by 1.514 AIC<sub>c</sub> units (Table 10-17).

Both models were good predictors of the selection of stands within the home range by fishers. The slope of the regression between observed and expected frequencies in each RSF bin was substantially different from 0, but not from 1 for both models ( $r^2 = 0.51$  for ecosystem-association model;  $r^2 = 0.30$  for structural-features model). However, in 1 bin of the ecosystem-association model and 2 bins of the structural-features model, the predicted

Table 10-17. Ninety-five percent confidence set of models that explained the selection of stands within the home range of radio-tagged fishers in the Williston region of north-central British Columbia, 1996-2000.  $n = 389$  radiolocations of 10 fishers. See Appendix 10-13 for  $AIC_c$  scores for all models in candidate set.

Model ID	Model category	Probability of use of stand within home range related to:	K <sup>a</sup>	$\log \mathcal{L}$	$AIC_c$ <sup>b</sup>	$\Delta_i^c$	$w_i^d$
S-13	General	Ecosystem association	8	-1883.46	3782.913	0	0.681
S-10	Resting, cover	Volume of elevated large CWD, density of trees with rust brooms, coniferous tree cover, deciduous tree cover, high-shrub cover	5	-1887.21	3784.426	1.514	0.319

<sup>a</sup> number of estimated parameters in associated model

<sup>b</sup> Akaike Information Criterion for small samples (Burnham and Anderson 1998)

<sup>c</sup> difference in  $AIC_c$  scores between model and best-selected model

<sup>d</sup> relative likelihood of model; Akaike weight (Burnham and Anderson 1998)

frequency was lower than observed, which suggests that different factors, other than those in the models, may have contributed to the selection of stands within the home range.

Interpretation of the parameterized ecosystem-association model was not straightforward. Because the model included a categorical variable (ecosystem association), the odds ratios derived for the parameters estimated the probability in selecting each specific ecosystem association relative to the reference ecosystem association (Spruce-Zonal; Table 10-18).

Table 10-18. Parameterization of best models that predicted selection of stands within the home range of radio-tagged fishers in the Williston region of north-central British Columbia, 1996-2000. Odds ratios for the ecosystem-association model are the odds of selecting the identified ecosystem association relative to the odds of selecting the Spruce-Zonal ecosystem association. Odds ratios >1 indicate increasing probability of use with increasing values of the variable; ratios <1 indicate decreasing probability of use.

	Model-averaged parameter estimate	Unconditional SE	Odds ratio (95% CI)	Relationship
<u>Ecosystem-association model</u>				
Black-Spruce	-0.543	0.279	0.581 (0.333 - 1.016)	
Non-vegetated	0.087	2.027	1.091 (0.019 - 62.885)	
Open water	-0.682	0.484	0.505 (0.192 - 1.331)	
Pine-Cladina	0.206	0.375	1.229 (0.581 - 2.599)	
Spruce-Dry	-1.262	0.410	0.283 (0.125 - 0.642)	Negative
Spruce-Moist	-0.340	0.245	0.711 (0.436 - 1.161)	
Spruce-Wet	1.691	0.213	5.423 (3.543 - 8.301)	Positive
Wetland	-0.444	0.459	0.642 (0.256 - 1.606)	
<u>Structural-features model</u>				
Coniferous tree cover (%)	-0.013	0.008	0.988 (0.972 - 1.003)	
Deciduous tree cover (%)	-0.105	0.032	0.900 (0.845 - 0.959)	Negative
High-shrub (2-10 m) cover (%)	0.017	0.008	1.017 (1.001 - 1.034)	Positive
Density of trees with rust brooms (stems/ha)	-0.047	0.023	0.954 (0.912 - 0.998)	Negative
Volume of large (>20 cm) elevated CWD (m <sup>3</sup> /ha)	0.030	0.004	1.031 (1.023 - 1.038)	Positive

The best model predicted that odds of radio-tagged fishers selecting Spruce-Dry stands were 3.5 times less than the Spruce-Zonal ecosystem associations and 5.4 times greater for the Spruce-Wet than the Spruce-Zonal ecosystem associations.

The structural-features model predicted that the probability of use of a stand was positively related to the percent of high-shrub cover and volume of large ( $>20$  cm diameter) elevated CWD, and negatively related to percent of deciduous tree cover and density of trees with rust brooms (Fig. 10-11). Although the model also included coniferous tree cover as a

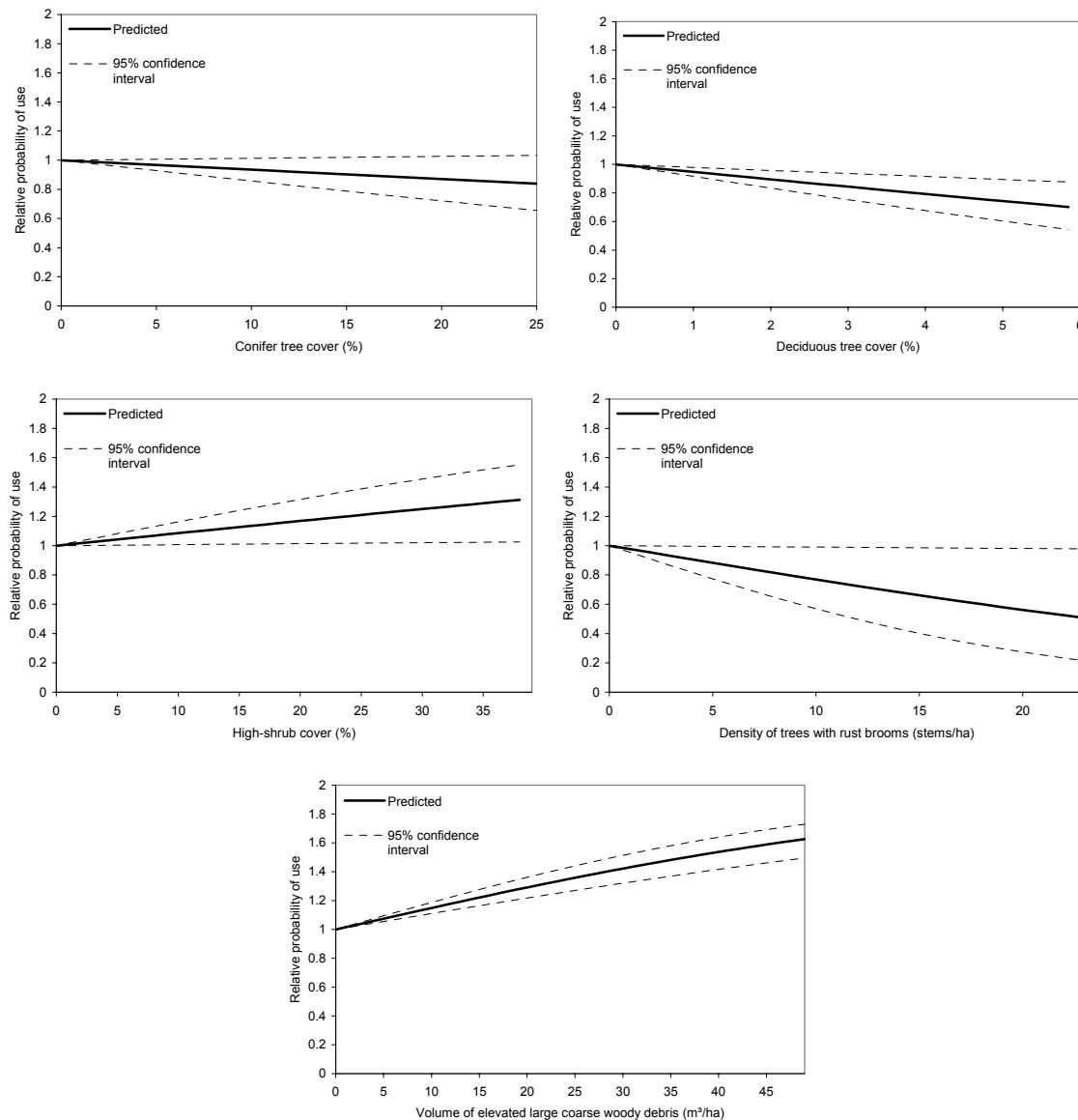


Figure 10-11. Predicted relationships between structural features and relative probability of use of stands within the home range by radio-tagged fishers in the Williston region of north-central British Columbia, 1996-2000. The displayed range of each structural variable was based upon the 95<sup>th</sup> percentile of observed data for that variable.

variable, the effect of this variable was neither definitively positive nor negative because the 95% CI of the odds ratio encompassed 1. Odds ratios predicted that an increase of 5% in cover of the high-shrub layer (i.e., 2-10 m tall shrubs and trees) increased the probability of use of a stand by 17%. It also predicted that an increase of 20 m<sup>3</sup>/ha of large elevated CWD increased the probability of use by 29%. The model predicted that a 1.5% increase in cover of deciduous trees decreased the probability of use by 7.8% and an increase of 13 stems/ha of trees with rust brooms (i.e., minimum detectable change) decreased probability of use by 30%.

#### 10.2.4.2 Landscape scale

We collected sufficient data to estimate their respective home range sizes and shapes on 10 resident fishers (2 M, 8 F; see *Section 7*). Overlap of used and pseudo-home ranges varied among individuals ( $\bar{x} = 5\%$  of used home range area, SD = 12%, n = 1620 replicates), but was as high as 24% for one male fisher that had a large, elongated home range (M20; Appendix 10-14). Metrics for the 10 variables found in the candidate models were similar between used and pseudo-home ranges (Appendix 10-15).

The model best supported by the data to predict the likelihood of occupancy by each fisher contained a single variable – the percent of home range in open areas (i.e., areas classified as wetland ecosystems and recently logged; Table 10-19). This model ranked 6.382 AIC<sub>c</sub> units better, and was 24 times more likely, than the next-best model (percent of home range in non-forested ecosystem associations). The 95% confidence set of best models included 5 other models.

Table 10-19. Ninety-five percent confidence set of models that explained selection of home ranges across the landscape by 10 radio-tagged fishers in the Williston region of north-central British Columbia, 1996 to 2000. See Appendix 10-16 for AIC<sub>c</sub> scores for all models in candidate set.

Model		Probability of occupancy related to:	K <sup>a</sup>	logL	AIC <sub>c</sub> <sup>b</sup>	$\Delta_i^c$	w <sub>i</sub> <sup>d</sup>
Model ID	category						
L-9	Avoidance	Open areas	1	-46.293	94.589	0	0.806
L-8	Avoidance	Non-forested ecosystem associations	1	-49.484	100.971	6.382	0.033
L-2	Inclusion	Forested ecosystem associations	1	-49.508	101.018	6.430	0.032
L-10	Avoidance	Recent logging	1	-49.613	101.229	6.640	0.029
L-6	Inclusion	Stands $\geq 30\%$ cover	1	-49.923	101.849	7.260	0.021
L-5	Inclusion	Mature and old structural stage riparian	1	-49.941	101.885	7.296	0.021
L-3	Inclusion	Habitat suitability index	1	-49.981	101.964	7.375	0.020

<sup>a</sup> number of estimated parameters in associated model

<sup>b</sup> Akaike Information Criterion for small samples (Burnham and Anderson 1998)

<sup>c</sup> difference in AIC<sub>c</sub> scores between model and best-selected model

<sup>d</sup> relative likelihood of model; Akaike weight (Burnham and Anderson 1998)

Multi-model parameterization of the best model predicted that the probability of a home range area being selected by a resident fisher decreased with the increasing amounts of wetland ecosystem association and recent logging present in the area (Table 10-20).

Parameterization of this model suggested that a 5% increase in open areas within a potential home range decreased the probability of occupancy by 50% (Fig. 10-12). A 25%-increase in open areas reduced the probability of occupancy to essentially nil.

### 10.2.5 Broad-scale Discussion

We detected resource selection by fishers at both the stand and landscape spatial scales. Fishers selected home ranges with fewer open areas and, once a home range was selected, fishers selected stands on the basis of either ecosystem association or several key structural variables.

#### 10.2.5.1 Within-home range (stand) scale

Radiotelemetry data provided overwhelming support for 2 models that predicted the selection of stands within the home range. Both of these models were at least 6900 times more likely, given the data, to be closer to the underlying selection process than other models within the candidate set. We could not definitively exclude no-selection as an explanation because we could not examine a no-selection (null) model due to analytical limitations of conditional logistic regression. We feel that no-selection was highly improbable, given the large differences in relative likelihood between the top 2 models and the rest of the candidate set.

The most plausible models explaining selection of stands within the home range were the ecosystem-association and structural-features models. These models were complimentary and useful for both application and interpretation of the broad-scale habitat relationships.

Table 10-20. Multi-model parameterization of variables in the 95% confidence set of best models to explain selection of home ranges within the landscape by radio-tagged fishers in the Williston region of north-central British Columbia, 1996-2000.

Variable	Model-averaged parameter estimate	Unconditional SE	Odds ratio (95% CI)	Relationship
Open areas	-0.219	0.096	0.803 (0.663 - 0.973)	Negative
Non-forested ecosystem associations	-0.084	0.061	0.919 (0.813 - 1.039)	
Forested ecosystem associations	0.084	0.061	1.088 (0.962 - 1.229)	
Recent logging	-0.241	0.167	0.786 (0.563 - 1.097)	
Stands $\geq$ 30% cover	0.045	0.034	1.046 (0.978 - 1.119)	
Mature and old structural stage riparian	0.734	0.495	2.084 (0.775 - 5.606)	
Habitat suitability index	7.689	5.653	>1000 (0.027- >1000)	

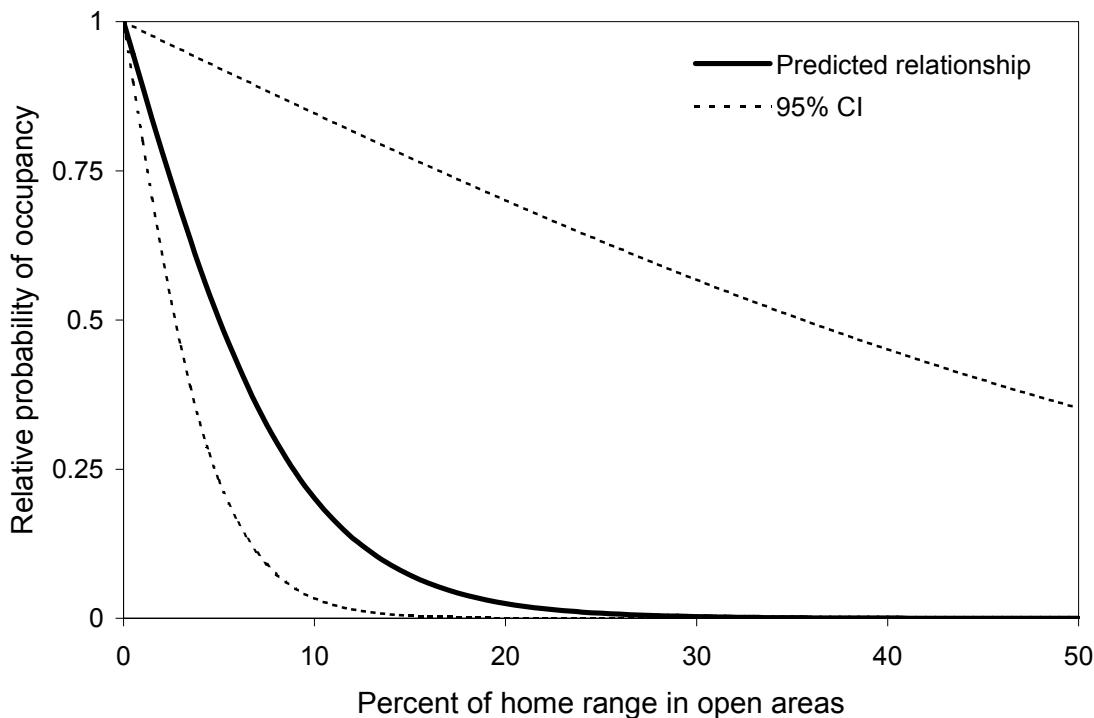


Figure 10-12. Effect of open areas (recent logging and wetlands) on the relative probability of a home range being occupied by resident radio-tagged fishers in the Williston region of north-central British Columbia, 1996-2000.

The ecosystem-association model predicted use of stands by fishers based on site series, which are the basic units of forest management in British Columbia. Application of this model by forest practitioners is straightforward, as it can be reliably applied to existing map-based data (see Fig. 10-13a for example). Although based on coarse management units, the reliability of the model was high and thus may be useful for management. The structural-features model predicted the probability of use nearly as well, but was much easier to interpret ecologically and had higher resolution (Fig. 10-13b).

Several aspects of categorizing habitats by ecosystem association likely resulted in our observation that fishers selected for specific associations within their home ranges. The density of many structural attributes for which fishers selected, such as coarse woody debris and vegetation cover, were relatively high in the Spruce-Wet ecosystem association. This ecosystem association was a typical riparian forest with sub-hygric or hygric moisture and medium to rich nutrient regimes. Fishers in south-central British Columbia commonly used forested riparian ecosystems (Weir 1995b) and similar observations have also been reported in California (Seglund 1995, Zielinski et al. 2004b), Idaho (Jones 1991) and Montana (Heinemeyer 1993). These stands were at least 5 times more likely to be used than the most

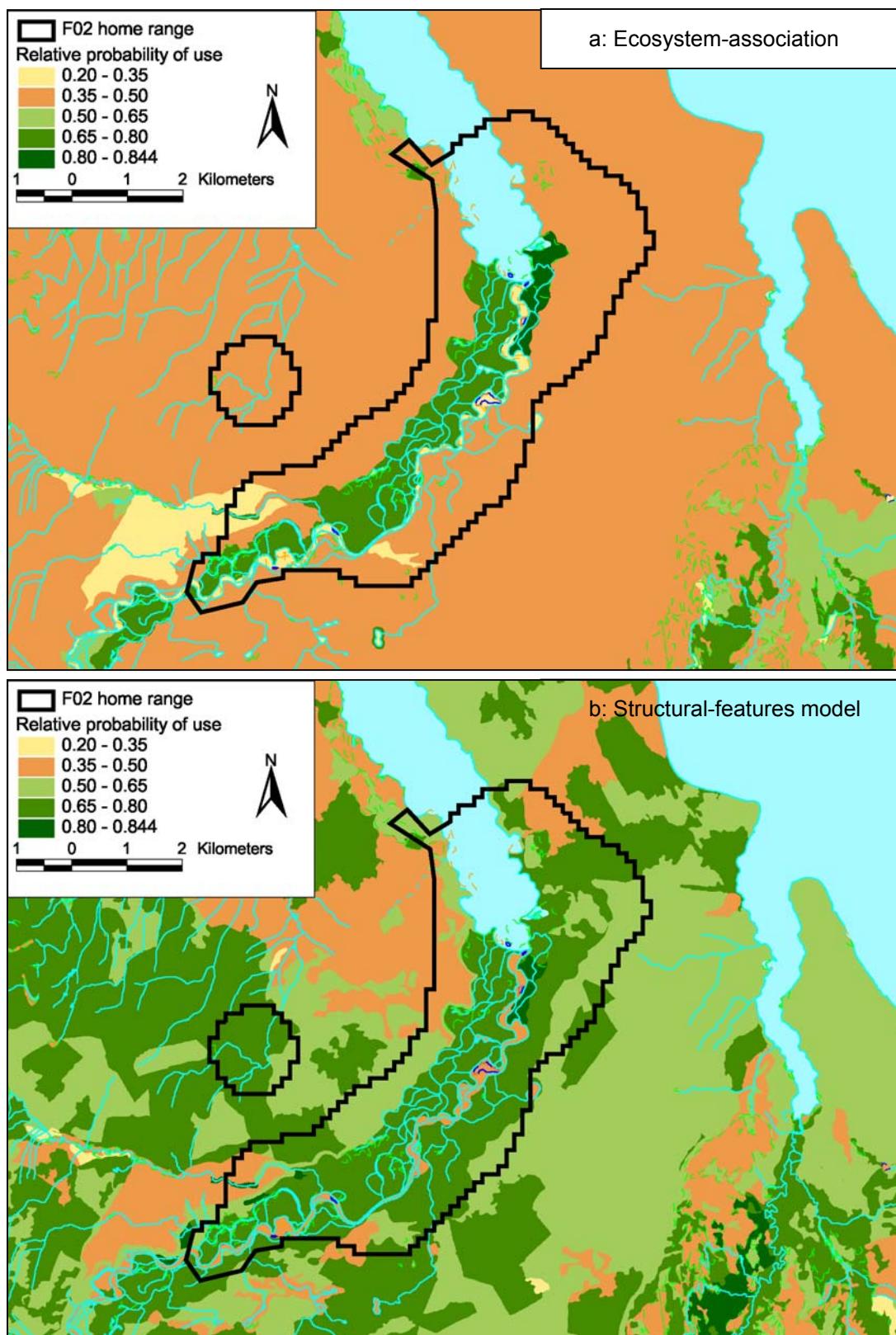


Figure 10-13. Application of ecosystem-association (a) and structural-features (b) models to predictive ecosystem map of the lower Manson River, including the home range of adult female F02.

common stands (Spruce-Zonal). It is likely that unmeasured features, such as prey density, would have added to or interacted with the measured features to better describe resources available to fishers within the Spruce-Wet ecosystem association. Likewise, avoidance of the Spruce-Dry ecosystem association may be related to the relative paucity of prey and habitat structure in that association.

The other plausible model indicated that fishers selected stands on the basis of several structural variables. Fishers showed strong selectivity for stands that had higher structural diversity of the forest floor (i.e., more elevated large CWD and high-shrub cover). The model also predicted that fishers were less likely to use stands with deciduous tree cover, high densities of trees with rust brooms, and possibly coniferous tree cover.

Fishers were more likely to use stands with considerable structural diversity, likely because these stands provided 2 necessary resources: foraging habitats and rest sites. Forested habitats with elevated large CWD and high-shrub cover are structurally diverse and tend to have higher densities of catchable prey (Powell and Zielinski 1994), such as snowshoe hares, squirrels, and voles. Stands with elevated large CWD also provide opportunities for resting, particularly during winter (see *Section 11*). Our observation that fishers selected stands with increased structure was consistent with Weir and Harestad (2003) and Proulx (2006), who also attributed their findings to fishers selecting foraging and resting habitat. Our analyses suggested that these habitat factors had very strong effects on selection of stands, indicating that they were important habitat features upon which fishers made stand-scale decisions.

The likelihood of a fisher selecting a stand within its home range was negatively related to the cover of deciduous trees in the stand. Deciduous trees have no foliage during winter and thus do not provide substantial overhead cover for half the year. During winter, snow interception would be less in stands with more deciduous trees and may impede fisher movements (Raine 1983). Prey may not have been as abundant or available in these stands (R. Weir, unpublished data). Because deciduous stands may be more open (especially during winter), they may not meet the requirement of fishers for overhead cover (Powell 1993). Avoidance of deciduous stands has been observed by other researchers (Maine, Arthur et al. 1989b; California, Buck 1982; Connecticut, Kilpatrick and Rego 1994). These observations are somewhat contrary to Weir and Harestad's (2003) findings in south-central British Columbia, where fishers selected stands with 21-40% deciduous cover during summer.

Stands with coniferous tree cover are favoured by fishers in Manitoba (Raine 1983) and Maine (Arthur et al. 1989b). Coniferous forests provide both consistent overhead cover and snow interception that are important to fishers (Powell 1993). Although an important component of our predictive model, we could not reliably identify this relationship since the 95% confidence interval of the odds ratio for this variable encompassed 1.

It is unclear why fishers were less likely to select stands with higher densities of trees with rust brooms, especially when they showed high selectivity for this habitat feature at the patch and element scales (Weir and Harestad 2003, this study). Densities of trees with rust brooms may have been correlated with another, unmeasured, habitat feature upon which fishers made selection decisions. The cone crop for trees with rust brooms may be less than those without, and thus densities of red squirrels and voles may be lower in these stands. Alternatively, fishers may meet the requirement for arboreal resting sites at element or patch spatial scales only, and avoid stands with this feature at broader scales. This relationship requires further examination.

Conversion of mature- or old-forest structural stages to early successional forests through logging generally reduced the value to fishers (Figure 10-14). This is consistent with other research that has identified disturbed (logged) forests as often having lower habitat value for fishers (e.g., Buck et al. 1994, Jones and Garton 1994). However, the utility of one of the ecosystem associations increased when these stands were harvested (Spruce-Dry ecosystem association). Herb- and shrub-structural stage forests of this type had higher relative probabilities of use than older forests. Young- and mature-forest structural stages in this ecosystem association had depauperate levels of the structure upon which fishers selected stands (i.e., high-shrub cover and elevated large CWD; Appendix 10-12). These features were more abundant in younger structural stages. However, forest harvesting lowered the predicted probability of use for all other ecosystem associations. The relative probability of use reached lowest during the pole-sapling structural stage (Fig. 10-14). Thus, temporal effect of succession need to be incorporated into forest management plans when considering the effects of forest harvesting on fishers. These results suggest that structural features define the suitability of stands for fishers, rather than simple characteristics such as overstory closure or tree species (Powell and Zielinski 1994).

#### 10.2.5.2 Landscape Scale

Fishers selected home ranges based on avoidance, rather than the inclusion, of specific features in the landscape, avoiding establishing home ranges in areas with high densities of open areas. Fishers successfully establish home ranges only where there is a sufficient concentration of suitable habitat (Powell 1994a), thus exclusion of wetland ecosystems and recently logged stands from their home range may be linked to the densities of specific resources found in these areas. Wetlands likely have lower prey densities (snowshoe hares, squirrels, and voles) than other areas (R. Weir, unpublished data). Potter (2002) also noted that fisher captures were negatively related to the presence of wetlands. Wetlands and recently logged areas typically have little overhead cover, thus fishers may be exposed to greater risk from aerial predators in these areas (Powell and Zielinski 1994). In Ontario, fishers did not colonize areas without overhead cover (Powell 1993).

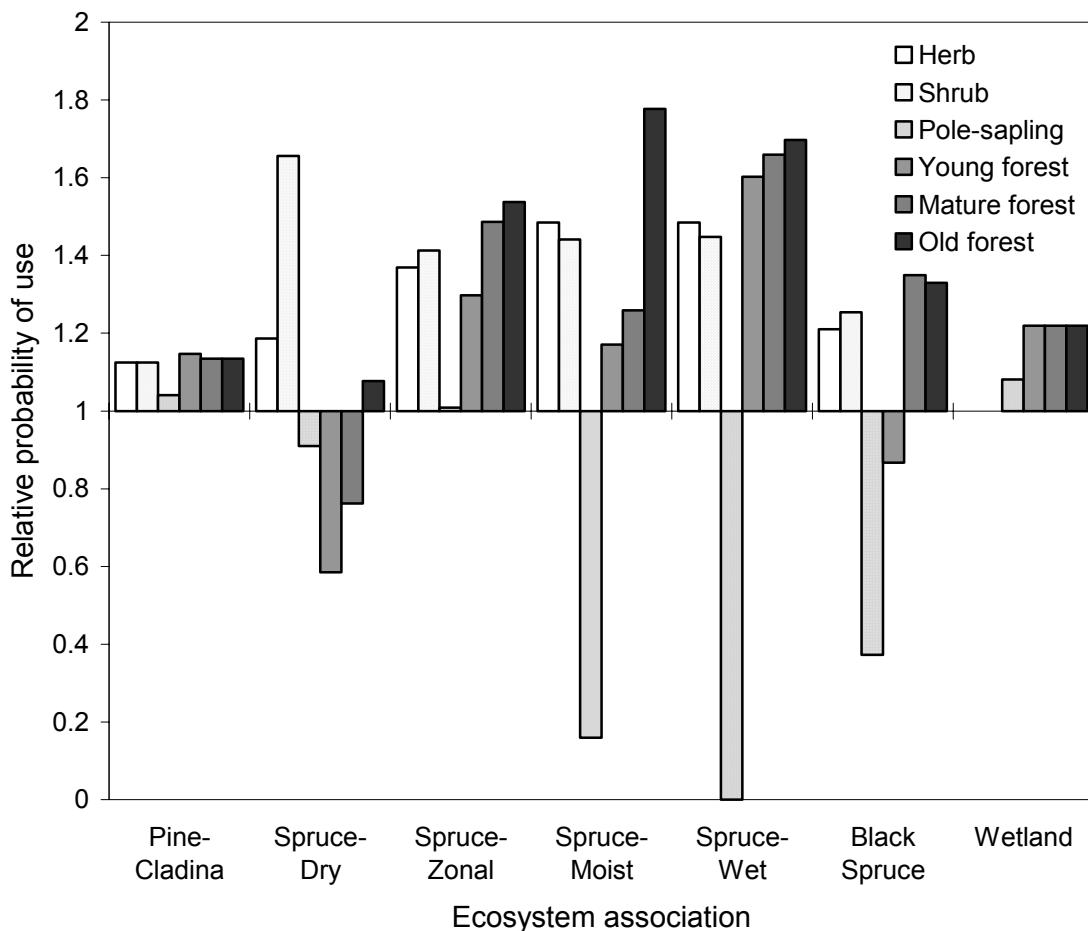


Figure 10-14. Relative probability of use by fishers of different combinations of ecosystem association and structural stage as predicted by the structural-features model. Values < 1 indicated negative association with selection; those >1 indicated positive association. Fishers were most likely to use old-forest Spruce-Moist stands and least likely to use pole-sapling Spruce-Wet stands.

The percentage of the home range in either wetlands or recently logged areas had strong effects on the probability of home range occupancy. For an average female fisher in the Williston region (mean home range size = 49 km<sup>2</sup>; this study [Section 6]), a 5% increase in open area would represent 245 ha of forest harvested within her home range during the past 12 years. Forest-harvest units (i.e., cutblocks) in our study area averaged 16.7 ha (SD = 25.4 ha, n = 937) and ranged up to 225 ha. As such, a 5% increase in open areas would be roughly equivalent to 15 cutblocks. Accelerated rates of forest harvest in areas affected by mountain pine beetle (*Dendroctonus ponderosae*) may have serious implications for the ability of the landscape to support sustainable populations of fishers.

We assumed that fishers were capable of selecting any area in the landscape to establish a home range and that the entire landscape was available. However, fishers are territorial (Powell 1994a) and the presence of conspecifics likely constrained the areas that were

available in which to establish a home range. This could have several implications for our results, including apparent avoidance of areas already occupied and attraction to areas with residents of the opposite sex, both of which could confound the results that we observed.

### 10.3 Conclusions and Management Implications

We identified habitat relationships that further our understanding of the habitat ecology of fishers in the northern portion of their range. We have identified several differences between habitat selection in northern areas compared to southern and eastern areas. It builds on the work done by Weir and Harestad (2003) by confirming and expanding several of their habitat models developed for fishers in southern portions of the SBS biogeoclimatic zone. It also improves the efficacy of habitat management because we have developed data-driven models that help resource managers estimate the effect of habitat changes by forest management or other means on the distribution and habitat selection of fishers in the SBS of north-central British Columbia.

Fishers made habitat selection decisions for many life requisites at a variety of spatial scales; a summary of pertinent relationships and their estimated effects are provided in Table 10-21. Fishers avoided including open areas within their home range, and once they had selected a home range, selected stands on the basis of either ecosystem association or several structural features. Fishers were also selective when using patches within stands; fishers selected patches of habitat based on the density of features used for resting. At the finest scale, fishers were highly selective for the specific tree used for reproductive dens, and the tree or log used for resting.

Patterns of resource selection varied considerably and were scale- and behaviour-specific. The selection function that best predicted resting patches was very different than that for reproductive dens. This is not unexpected, as resource requirements differ among behaviours. Differential resource selection was strongest at fine (i.e., patch and element) spatial scales, concurring with Weir and Harestad's (2003) conclusion that the most specific resource selection occurs at the finest spatial scales.

Our fine-scale results improve our functional understanding of the habitat ecology of fishers in the sub-boreal forests of north-central British Columbia, as we showed that fishers had high specificity for certain habitat components when resting and denning. This specificity suggests that we have identified (or more closely identified) the functional component of the habitat upon which fishers make their decisions for these behaviours (*sensu* Morrison 2001). For the most part, fishers were more likely to select these habitat features based on increasing size of their values, suggesting that larger trees were more likely to be used than smaller ones. Our analyses showed that these habitat variables were good predictors of where fishers would rest and den, so they may be useful for application elsewhere.

Table 10-21. Summary of reliable relationships between habitat features and probability of use by radio-tagged fishers at the element, patch, within-home range, and landscape spatial scales in the Williston region of north-central British Columbia, 1996-2000. The estimated effect of changes in values of the feature on the relative probability of use is listed for each parameter.

Scale	Habitat feature	Relationship with probability of use	Estimated effect	
			Change in parameter value	Change in probability of use (%)
<u>Element</u>				
Arboreal resting	DBH of aspen or black cottonwoods with decay (cm)	+ weak	10	18
	Presence of spruce with rust brooms	+ v. strong	1	2305
	DBH of spruce trees with rust brooms (cm)	+ strong	10	88
	Presence of rust brooms	+ v. strong	1	1700
CWD resting	Height above ground of piece (cm)	+ moderate	10	29
	Diameter of piece (cm)	+ weak	5	20
	Length of potential resting space (m)	+ moderate	1	24
Denning	Presence of black cottonwood trees	+ v. strong	n/a	n/a <sup>a</sup>
<u>Patch</u>				
Resting	Density of trees with rust brooms (stems/ha)	+ strong	13	60
	Estimated rest-site potential in patch (m)	+ weak	1	15
	Volume of elevated large CWD (m <sup>3</sup> /ha)	+ moderate	25	22
<u>Within-home range</u>				
	Spruce-Dry, relative to the Spruce-Zonal ecosystem association	- v. strong	1	-253
	Spruce-Wet, relative to the Spruce-Zonal ecosystem association	+ v. strong	1	442
	Coniferous tree cover			
	Deciduous tree cover			
	High-shrub cover			
	Density of trees with rust brooms			
	Volume of elevated large CWD			
<u>Landscape</u>				
	Potential home range recently logged or in wetland ecosystem association (%)	- v. strong	5	-50

<sup>a</sup> Likely highly significant, but not estimatable because of complete separation of data.

Most habitat features for which fishers showed high specificity were the result of the natural processes of disease, death, and decay of trees typically found in late-successional forests. These habitat attributes consistently occurred in a very restricted range of conditions (e.g., a single tree species). These habitat attributes were either rare in the landscape or targeted during forest-harvesting activities. This highlights the need to ensure that an adequate supply of these features is maintained and promoted, both spatially and temporally, in managed forests.

The specificity of selection appeared to be linked to the scale of examination. At broad scales, the resource requirements of fishers were met in a variety of habitat conditions and as

such, fishers selected home ranges with a wide variety of habitat conditions. At finer scales, the resources upon which fishers made decisions were constrained to a narrow range of habitat conditions. This suggests that fishers have a high specificity for fine-scale habitat features and that other habitats cannot, or do not, supply the requisite features.

Although our study occurred in a different subzone of the SBS than Weir's (1995a) study, the scales at which we detected selection were very similar. The scale at which selection is detected is dependent not only on the underlying selection mechanism, but also the distribution and abundance of necessary resources. The selection mechanism likely remains relatively similar among individual fishers and populations, but the distribution and abundance of resources likely change considerably both within and across different environments. Thus, selection patterns observed in one area may not be broadly transferable to another where the resource distribution and abundance patterns may be different. However, by identifying the scale at which each of these processes occur, we can better manage habitat to supply the requirements of both individuals and populations of fishers.

We identified important habitats and provided an indication of their importance using of logistic regression modelling. Estimated odds ratios provided insight into both the linkages to and relative value of features for fishers. This analysis approach allowed an approximation of the potential effect of changing values of features due to habitat change and better prediction of the outcomes of forest management or other habitat changes on individual fishers and their populations.

Quantifying the importance of habitat features is useful for habitat conservation because it provides managers with a prioritized, target-based focus for management guidelines. It also gives managers a better method to predict the impacts of their decisions on the utility of habitats to support fishers. For example, elevated pieces of CWD >20 cm diameter affect the utility of a stand for fishers. During site preparation following forest-harvesting operations, logging residue is often yarded into piles and burned. This leaves few pieces of CWD and those left are invariably lying directly on the ground. If instead, a minimum of 25 m<sup>3</sup>/ha of elevated large CWD was left behind it would increase the probability of use of the area for fishers by 35%. Similarly, the conversion of a mature Spruce-Moist forest (averaging 49 m<sup>3</sup>/ha of elevated large CWD) to a cutblock with no elevated large CWD would reduce its value to fishers by 39%.

Our results help direct potential restoration of degraded fisher habitat. Recruitment of important habitat components will help restore areas that have been degraded. For example, black cottonwood trees appear to be the only tree species that are large enough to form cavities suitable for reproductive dens. This species is limited to sites where roots have continuous access to moisture (i.e., sub-hygric or wetter ecological moisture regimes; Maini 1968), which are primarily floodplains along large rivers. Planting and management

programs that promote the recruitment and growth of these rare elements will help ensure a sustainable supply of reproductive dens for fishers into the future. Other important habitat components that may be appropriate for restoration include rust brooms in spruce trees, creation of elevated CWD, and protection of advanced regeneration in harvested stands.

Identification of the factors that affect the occurrence of fishers in the landscape is useful for predicting the effects of landscape alteration on populations of fishers. Modelling the probability of occupancy of the landscape, particularly under varying landscape-change scenarios, will be critical to the evaluation of effects of resource development on populations of fishers. Identification of factors that affect selection of stands within the home range during the day-to-day activities of fishers are critical to understanding the direct effects of habitat alterations on an individual fisher's ability to survive and reproduce.

## 11.0 REST SITE SELECTION<sup>7</sup>

Fishers rely on rest sites for refuge from potential predators and thermoregulatory cover (Kilpatrick and Rego 1994). Fishers use a wide variety of structures for their rest sites, including tree nests and cavities, logs (hollow or solid), root wads, willow (*Salix* spp.) thickets, ground burrows, and rock aggregations (Raine 1981, Arthur et al. 1989b, Jones 1991, Powell 1993, Kilpatrick and Rego 1994, Gilbert et al. 1997, Zielinski et al. 2004b). Although the types of structures used by fishers for resting has been well documented, the motivation for selecting specific rest structures is still largely unexamined.

American martens are ecologically similar to fishers and use many of the same types of structures for resting (e.g., Buskirk et al. 1989, Martin and Barrett 1991, Gilbert et al. 1997, Raphael and Jones 1997). Much of the selection for rest sites by American martens has been attributed to ambient temperature and wind as they tend to select subnivean rest sites during periods of windy cold weather (e.g., Buskirk et al. 1989, Martin and Barrett 1991). The lower critical temperature (i.e., the lowest ambient temperature at which an animal can passively maintain body temperature, Harlow 1994) of American martens at rest is relatively high at 16°C (Buskirk et al. 1988). Therefore, American martens select microenvironments that are energetically favourable for resting during periods of low temperature (Buskirk et al. 1989, Taylor and Buskirk 1994).

Because fishers have a greater body mass than American martens, Buskirk and Powell (1994) hypothesized that thermal losses while resting are probably not as important. Fishers are not exposed to temperatures within their distribution that approach their lower critical temperature while resting (-60°C for females and -120°C for males; Powell 1979a). However, evidence suggests that fishers do modify their selection of resting structures in response to ambient temperature. Fishers tend to use subnivean rest sites more frequently during winter and arboreal rest structures (e.g., tree nest and cavity sites) more frequently during spring (Raine 1981, Arthur et al. 1989b, Jones 1991, Kilpatrick and Rego 1994).

Across the range of fishers in Canada, arctic high-pressure weather systems can persist for several weeks during winter, where ambient temperatures are consistently below -25°C. Fishers in these areas are exposed to temperatures close to their lower critical temperature that may cause them to modify their behaviour. Because of this, we predict that ambient temperature and body mass may play a role in the selection of resting structures. Furthermore, the need to find thermally beneficial rest structures vary seasonally because fishers may be constrained to specific rest sites only during specific seasons (Arthur et al.

<sup>7</sup> Portions of this section published as Weir, R., F. Corbould, and A. Harestad. 2004. Chapter 9 - Effect of ambient temperature on the selection of rest structures by fishers. Pages 187-197 in D. J. Harrison, A. K. Fuller, and G. Proulx, Editors. Martens and Fishers (*Martes*) in Human-altered Environments: An International Perspective. Springer Science+Business Media, New York, New York, USA.

1989b). Rest sites likely do not have the same thermal properties throughout the year (e.g., coarse woody debris (CWD) are not thermally advantageous unless they are completely covered in snow; Taylor and Buskirk 1994).

Other factors can also affect the selection of rest structures by fishers. Fishers may rest near foraging or travelling (de Vos 1952). Thus, we would expect that fishers would be more likely to rest in highly used areas of their home range (i.e., core areas). Male fishers are not as adept at climbing trees as females (Powell 1977, Pittaway 1978, Leonard 1980), so males may be less likely to select arboreal rest structures than females. Due to their sexual dimorphism, male fishers also lose thermal energy more slowly than females (Powell 1977) and, therefore, their need to select thermally beneficial rest structures during cold temperatures may not be as important as it may be for females.

The objective of our research was to determine if ambient temperature, season, snow depth, sex, body mass, and location within their home range affected the type of rest structure selected by fishers in the Williston study area. Findings will guide the retention of structures that are important to fishers during forest management decisions. We did not consider the availability of the different types of structure as a variable; this relationship was examined in *Section 10*.

## 11.1 Methods

We classified the activity of fishers at each location following methods in *Section 8*. For most radiolocations of resting (i.e., not active) fishers, we attempted to “home-in” (White and Garrott 1990) on the fisher and identify the rest structure that the individual was using. Within 0.5 hr of identifying each rest structure, we recorded the ambient temperature at automated recording stations within 20 km of each resting site. We also recorded the season (winter or non-winter, as defined in *Section 6*) and the sex and body mass (at last handling) of the individual fisher.

We determined the relative spatial location of each structure used for resting within the home range of each fisher. We estimated the “non-resting” utilisation distribution (UD) to represent areas used for foraging and travelling for each fisher that we collected at least 30 non-resting locations. We identified the isopleth (UD score) of the non-resting UD in which each rest site occurred for each animal. For example, a radiolocation near the edge of the UD would have a “high” score (e.g., 81%, point A in Fig. 11-1), whereas a radiolocation near the centre of the home range would have a “low” score (e.g., 13%, point B in Fig. 11-1). The UD score for a location was inversely related to its proximity to the centre (core) of the non-resting component of the animal’s home range.

We assessed the effect of UD score, season, body mass, sex, and ambient temperature on the type of rest structure selected by radio-tagged fishers in several competing models using an information-theoretic approach (Burnham and Anderson 1998). We did not include snow

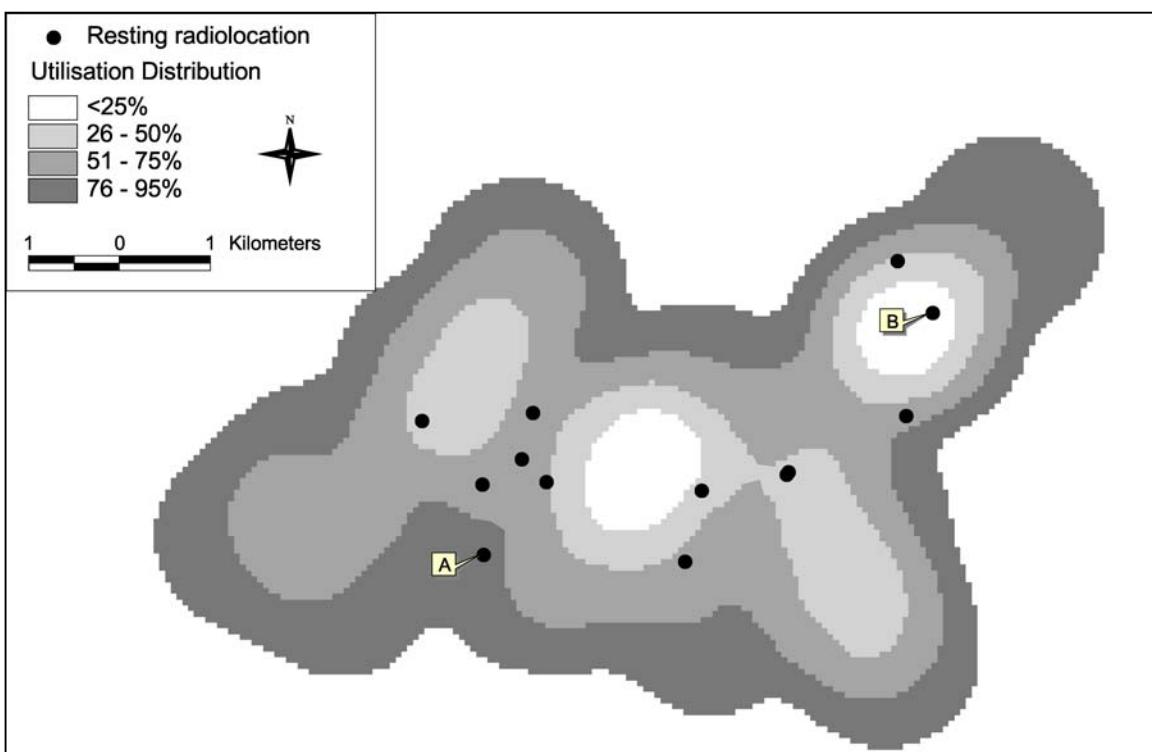


Figure 11-1. Example of the method used to determine UD score (percentage of the non-resting UD volume) for resting locations used by fishers, 1997 to 2000, in the Williston region of north-central British Columbia. For example, point A had a UD score of 81% (i.e., 81% of the UD volume), whereas point B had a UD score of 13%.

depth as a variable because of its high correlation with season and ambient temperature, which we thought were more important explanatory variables. We examined the support by the data for each of 10 *a priori* models composed of arrangements of these variables (see Table 11-3). These models were based on hypothesized ecological relationships or observed relationships identified in published literature. Because some variables were highly correlated (i.e., sex and body mass, ambient temperature and season), we constructed models that did not include both of these variables. Instead, we created models with either 1 of the correlated variables or an interaction term of the 2 variables (i.e., sex\*body mass). Because of this multicollinearity, we did not include a “global” model (all variables included) in our candidate set. We considered the type of structure used as a categorical response variable and used multinomial logistic regression methods to parameterize model. We included only those telemetry locations for which we determined the exact structure used by fishers for resting.

We calculated the AIC<sub>c</sub> score for each model and ranked the relative support for each model by comparing the scores among competing models. We identified the “best” model from the candidate set as the model with the lowest AIC<sub>c</sub> score. We used Akaike weights ( $w_i$ ; Burnham and Anderson 1998) to quantify strength of evidence among the candidate set of models. We used multi-model inference (Burnham and Anderson 1998) to estimate

model-averaged parameters and unconditional 95% confidence intervals for each variable to develop a best predictive model. Because the relationship between ambient temperature and structure selection may be important in sub-boreal forests, we developed specific logistic regression models for each type of rest structure to estimate the probability of use in relation to ambient temperature.

## 11.2 Results

We identified fishers using 4 distinct structures for resting: branch, cavity, CWD, and ground. Branch rest structures were arboreal sites that typically involved abnormal growths (i.e., brooms) caused by spruce broom rust (*Chrysomyxa arctostaphyli*) or fir broom rust (*Melampsorella caryophyllacearum*). We occasionally observed branch rest sites associated with exposed large limbs of black cottonwood and hybrid spruce trees. Cavity rest structures were chambers in decayed heartwood of the main bole of black cottonwood or aspen trees. Fishers accessed cavities through branch-hole entrances into heart-rot (black cottonwood and aspen trees) or excavations made by primary cavity-nesting birds (aspen trees only). Coarse woody debris rest structures were located inside, among, or under pieces of downed woody debris resulting from natural tree mortality or logging residue. Coarse woody debris rest structures were usually comprised of a single large (>35 cm diameter) piece of debris, but on 2 occasions CWD involved several pieces of smaller diameter logging residue. Coarse woody debris sites were only used when snow depths were >27 cm. Ground rest structures were large pieces of loosely arranged colluvium (e.g., rock piles), animal burrows, or sites on the surface of the snow.

We located 11 radio-tagged fishers (2 M, 9 F) using 54 rest sites on 60 occasions between 5 April 1997 and 7 April 2000. We recorded fishers using branch rest structures most frequently (57%), followed by CWD (22%), cavity (17%), and ground (5%) rest structures (Table 11-1). Rust brooms were the most frequently used structure. We documented most (90%) rest structures being used only once, however, we observed fishers re-using 4 rest structures twice and 1 structure 3 times. One of the structures used twice (a large spruce rust broom) was used by different fishers (1 M, 1 F) in 2 different years. We did not observe any obvious differences in rest structure use between the sexes, though we likely had insufficient data to adequately make such a comparison.

Most structures (48 of 54) used by fishers were associated with a single stem that was either standing (i.e., live trees or snags) or had fallen (i.e., CWD). Fishers used single trees or logs ranging in size from 13.6 cm to 139.4 cm in diameter (Table 11-2). Black cottonwood stems were the largest diameter of all 3 types. Two rest sites were associated with accumulations of CWD: 1 from logging debris and the other from natural tree mortality.

Table 11-1. Rest structures used by 11 radio-tagged fishers between 1997 and 2000 in the Williston region of north-central British Columbia.  $n = 60$  radiolocations.

Fisher ID	Branch	Cavity	CWD <sup>a</sup>	Ground	Total
F02	5	4	3		12
F03	1				1
F04	9	1	2	2	14
F05	1				1
F07				1	1
F09	2				2
F15		1	1		2
F17	3	1	4		8
F18	6	3	1		10
M01	3				3
M20	4		1	1	6
<b>Total</b>	<b>34</b>	<b>10</b>	<b>12</b>	<b>4</b>	<b>60</b>

<sup>a</sup> CWD sites were always associated with snow cover (i.e., subnivean sites)

Table 11-2. Characteristics of single-stem woody structures (i.e., trees and coarse woody debris; CWD) used by radio-tagged fishers for resting between 1997 and 2000 in the Williston region of north-central British Columbia.  $n = 48$  structures.

Element type	Tree Species	Diameter <sup>a</sup> (cm)		Number of uses	
		$\bar{x}$	SD	n	
Branch	Hybrid spruce	48.4	13.6	28	32
	Black cottonwood	112.0		1	1
	Subalpine fir	37.0		1	1
Cavity	Black cottonwood	95.5	27.8	5	6
	Trembling aspen	62.6	18.5	4	4
CWD <sup>b</sup>	Trembling aspen	33.0		2	2
	Hybrid spruce	42.1	10.4	3	4
	Lodgepole pine	23.8		2	2
	Black cottonwood <sup>c</sup>	82.5		2	2

<sup>a</sup> diameter-at-breast-height of main tree bole associated with arboreal (branch and cavity) sites, and diameter at point of use for CWD sites

<sup>b</sup> CWD sites were always associated with snow cover (i.e., subnivean sites)

<sup>c</sup> semi-collapsed hollow log

The average diameter of pieces in the logging pile was 18.7 cm ( $SD = 11.0$ ,  $n = 36$ ). The other CWD site was 2 elevated logs of hybrid spruce (16.4 and 24.5 cm diameter, respectively). Four rest sites were ground resting sites that included sites under rocks (2), in a previously excavated burrow (1), and on the surface of the snow (1). The simultaneous ambient temperature near the rest sites ranged between -29.4 and 21.1°C, with only CWD resting sites being used at ambient temperatures  $<-15^{\circ}\text{C}$  (Fig. 11-2).

We used 44 of 60 rest sites for information-theoretic inference because parameter values were not available for all of the rest sites. We used the branch type of rest structure as the

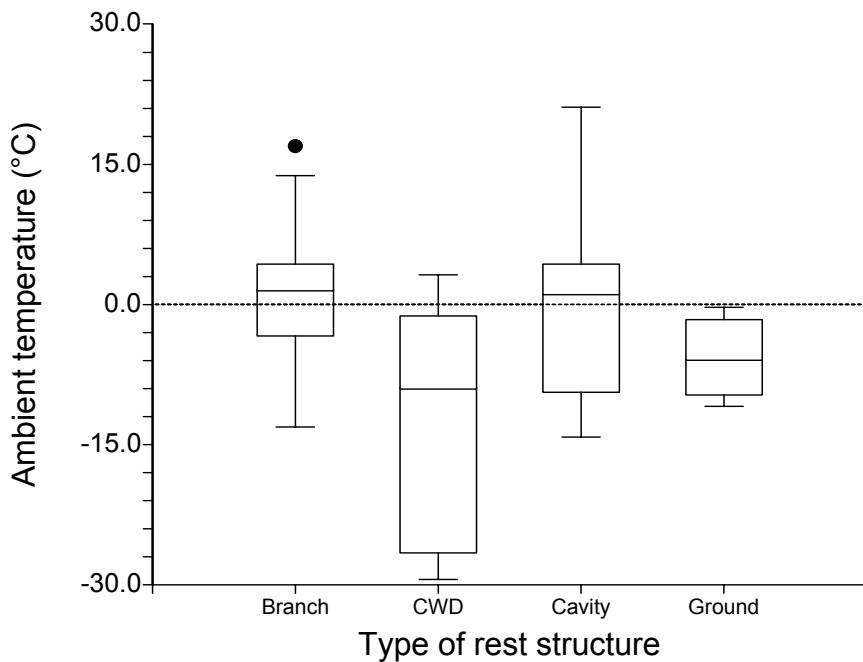


Figure 11-2. Box-and-whisker plot of simultaneous ambient temperatures when each type of rest structure was used by radio-tagged fishers in the Williston region of north-central British Columbia, 1997-2000. Median [horizontal line within box], interquartile (25-75%) range [box], range of values within 1.5 times the interquartile range [whiskers], and values >1.5 times outside the interquartile range [solid dot] are presented.  $n = 60$  locations.

reference value for multinomial logistic regression because it was the most commonly used structure. This allowed us to compare the odds of radio-tagged fishers selecting other types of structure (i.e., cavity, CWD, or ground structures) relative to selecting a branch structure. Thus, our interpretations were limited to the comparison of the probability of use of rest structures *in comparison* to the probability of use of branch rest structures.

The data provided support for 5 models that explained the selection of rest structures by radiotagged fishers. The model that included ambient temperature, UD score, and body mass was best supported by the data (Table 11-3). Two of the next-nearest models included ambient temperature, UD score, and either sex or the interaction of sex and body mass. Models that included ambient temperature and body mass or ambient temperature as a single variable comprised the remaining models in the 95% confidence set. We observed considerable width in the 95% confidence intervals of the odds ratio for each parameter in the best model and most intervals encompassed 1, indicating no predictable effect. The only factor that reliably predicted selection of cavity rest sites over branch sites was the UD score of the radiolocation (Table 11-4). Our results suggest that a 5% decrease in the UD score (i.e., a location closer to the core of the home range) increased the likelihood that fishers would use a cavity rest structure over branch sites by 18%. The only factor that

Table 11-3. Candidate models for the examination of factors that affected the selection of rest structures by radio-tagged fishers in the Williston region of north-central British Columbia, 1997 to 2000.  $n = 44$  locations of 8 fishers. A “\*\*” denotes 95% confidence set of best models.

Variables	Reference	$\log(\mathcal{L})$	K <sup>a</sup>	AIC <sub>c</sub>	$\Delta^b$	$w_i^c$
* T <sub>a</sub> <sup>d</sup> , UD score <sup>e</sup> , body mass		-32.750	4	74.525	0	0.512
* T <sub>a</sub> , UD score, sex		-33.839	4	76.703	2.178	0.172
* T <sub>a</sub> , UD score, sex*body mass		-34.039	4	77.103	2.578	0.141
* T <sub>a</sub> , body mass	Buskirk and Powell 1994	-35.549	3	77.699	3.174	0.105
* T <sub>a</sub>	Raine 1981, Arthur et al. 1989b, Jones 1991, and Kilpatrick and Rego 1994	-37.115	2	78.523	3.998	0.069
UD score, season		-40.931	3	88.462	13.937	<0.0001
UD score	de Vos 1952, Coulter 1966	-42.399	2	89.091	14.566	<0.0001
Season	Arthur et al. 1989b, Jones 1991, and Kilpatrick and Rego 1994	-43.413	2	91.119	16.594	<0.0001
All constant		-45.147	1	92.388	17.864	<0.0001
Sex	Powell 1977, Pittaway 1978, Leonard 1980	-44.292	2	92.876	18.351	<0.0001

a number of estimated parameters in associated model

b difference in AIC<sub>c</sub> scores between model and best-selected model

c Akaike weight (Burnham and Anderson 1998)

d ambient temperature (°C)

e percentage of the non-resting utilisation distribution in which the resting site was located

Table 11-4. Multi-model parameterization of factors affecting the likelihood of selecting cavity, CWD, and ground structures instead of branch structures for resting by radio-tagged fishers in the Williston region of north-central British Columbia, 1996 to 2000. Odds ratios represent the change in probability of using specific structures rather than branch structures for resting, given a 5-unit increase in the variable of interest, except for body mass (1-unit).

Parameter	Reference value	Composite coefficient	Odds ratio	Unconditional 95% CI	
				Lower	Upper
<u>Cavity vs. Branch</u>					
intercept		2.58			
ambient temperature (°C)		0.04	1.04	0.94	1.16
UD score (%)		-0.04	0.82	0.68	0.99
body mass		-0.30	0.74	0.04	12.67
sex	male	9.18	>1000	0	>1000
<u>CWD vs. Branch</u>					
intercept		-2.08			
ambient temperature (°C)		-0.15	0.48	0.28	0.81
UD score (%)		-0.003	0.98	0.82	1.18
body mass		0.19	2.57	0.02	292.58
sex	male	0.33	5.06	0	>1000
<u>Ground vs. Branch</u>					
intercept		-3.24			
ambient temperature (°C)		-0.09	0.65	0.23	1.81
UD score (%)		-0.001	0.99	0.72	1.38
body mass		-0.78	0.02	0	>1000
sex	male	1.77	>1000	0	>1000

affected selection of CWD over branch sites was ambient temperature. A decrease in ambient temperature of 5°C increased the likelihood that a fisher rested in a CWD site compared to a branch site by 52%.

Logistic regression of ambient temperature on the probability of selecting each type of resting structure yielded several prominent relationships (Fig. 11-3). When the ambient temperature was colder than -11°C, fishers were most likely to select CWD structures for resting. Above this ambient temperature, branch structures were most likely to be selected. The probability of selecting a cavity rest structure also increased with ambient temperature, whereas ground sites showed a slight decrease in probability of use with increasing temperature.

### 11.3 Discussion

The types and characteristics of structures that fishers used for rest sites were similar to that reported elsewhere in their distribution (Arthur et al. 1989b, Kilpatrick and Rego 1994, Zielinski et al. 2004b). In the dry-warm SBS of central British Columbia, Weir and Harestad (2003) reported fishers primarily using branches and rust brooms in hybrid spruce trees.

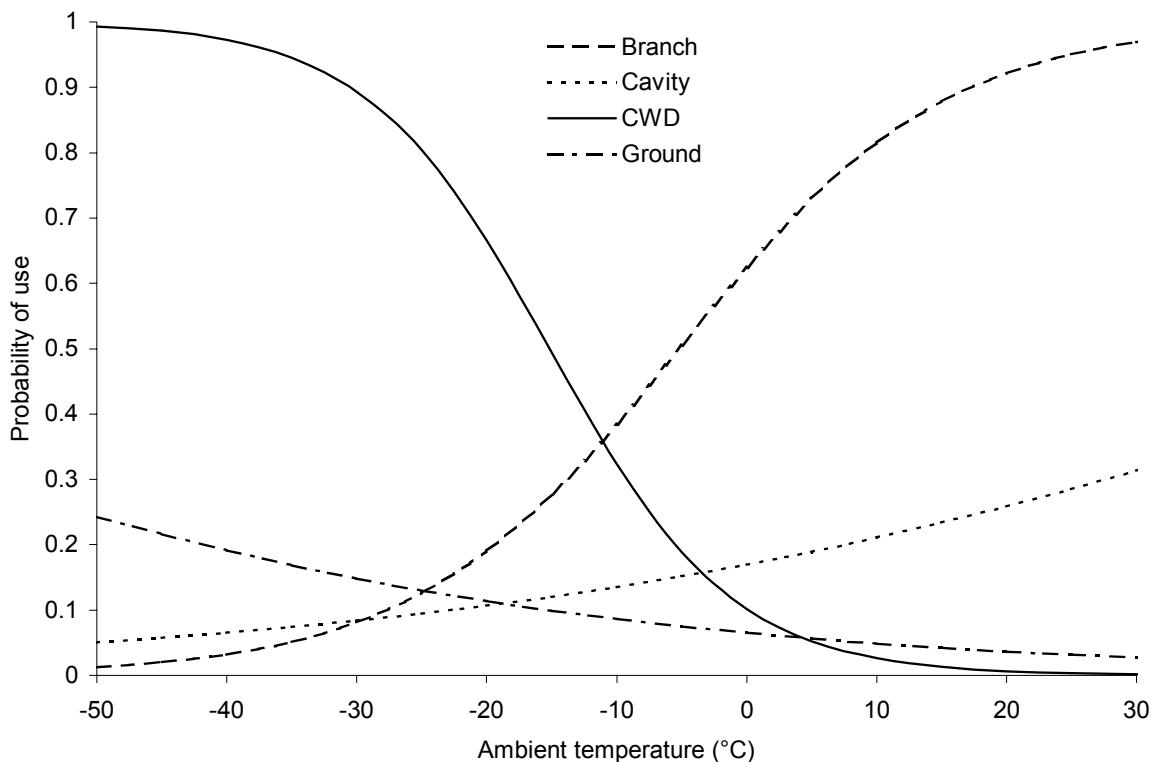


Figure 11-3. Predicted influence of ambient temperature on the probability of use of each type of rest structure by radio-tagged fishers in the Williston region of north-central British Columbia, 1997 to 2000.

These trees averaged 46 cm dbh, which was comparable to our observed average of 48 cm dbh. Similarly, black cottonwood trees that were used were approximately the same size in both study areas (~100 cm dbh). Weir and Harestad (2003), however, documented fishers using CWD structures with a mean diameter twice our observed average (39 cm). This discrepancy may be due to differences in tree species (i.e., absence of Douglas-fir [*Pseudotsuga menziesii*] in our study area) and forest disturbance histories. Forest disturbances were quite different in the 2 areas as selective high-grade logging dominated Weir and Harestad's (2003) study area, whereas the Williston study area primarily had fire and clearcut-logging disturbances. The size of the CWD may not be as critical as its functionality (i.e., its arrangement and structural integrity provide sufficient interstitial space for a fisher to rest).

The low rate of re-use of resting structures (10%) was consistent with that documented in other studies of fisher ecology (16%, Kilpatrick and Rego 1994; 3%, Seglund 1995; 11%, Zielinski et al. 2004b). Zielinski et al. (2004b) suspected that the low rate of re-use was affected by the proximity to kill sites. Kilpatrick and Rego (1994) noted that many re-used sites were associated with scavenged carcasses or porcupine dens, which suggests that availability of abundant, predictable food sources may mediate re-use of rest structures.

It was apparent that ambient temperature, sex, body mass, and location within the non-resting home range had some effect on the type of rest structure that was selected by fishers. However, our results indicated that only 2 of these 4 factors had a clearly predictable relationship with rest structure selection: ambient temperature affected the probability of selecting CWD structures, whereas the location within the non-resting home range seemed to affect selection of cavity rest structures.

With respect to ambient temperature, fishers in our study used structures for resting in a pattern similar to that reported elsewhere. Fishers used arboreal branch and cavity sites most frequently throughout the year but switched to CWD sites when the temperature was colder. In Maine (Arthur et al. 1989b), Idaho (Jones 1991), and Connecticut (Kilpatrick and Rego 1994), fishers also used arboreal sites most frequently and CWD or subnivean sites only on very cold days. These data support the hypothesis that fishers mediate their selection of CWD rest structures depending on ambient temperature.

The thermal attributes of the 4 types of rest sites likely affected the structures that fishers selected and helps explain the patterns that we observed. Taylor and Buskirk (1994) measured and calculated the thermal properties of branch, cavity, and CWD sites in high-elevation forests of southern Wyoming. They found that CWD sites provided the warmest microenvironments only during periods of cold temperatures (<-5°C), deep snow pack (>15 cm), and high wind speed. Branch or cavity sites were warmer during all other combinations of ambient temperature, snow pack, and wind. In Manitoba, Raine (1981) measured the

ambient temperature at 1 subnivean rest site of a fisher. He found that, while the ambient temperature was  $-26^{\circ}\text{C}$ , the temperature inside the subnivean cavity was  $-11^{\circ}\text{C}$ . Although fishers in our study areas did not encounter temperatures that were near their estimated lower critical temperature for resting, we expect that they select rest structures that were the most energetically favourable to help maximize fitness. The exclusive use of subnivean CWD structures for resting during cold temperatures ( $<-15^{\circ}\text{C}$ ) suggests that fishers select this type of rest structure for the energetic benefits relative to other structures.

Thermoregulation did not appear to be the only factor that affected the selection of rest sites by fishers. Our finding that fishers selected cavity versus branch rest structures based upon where they were within their home range was somewhat unexpected. Several authors have suggested that fishers rest close to food sources (de Vos 1952, Coulter 1966, Powell 1993), so perhaps fishers use these structures in areas in which they forage on a regular basis. Cavity rest structures are very likely more rare than branch structures (i.e., rust brooms and large branches; Kilpatrick and Rego 1994, this study [*Section 10*]), so individuals may need to spend more time investigating an area before they identify suitable cavities. Consequently, individuals may have greater knowledge of potential suitable rest sites closer to the core areas of their home range. Alternatively, suitable branch sites may be sufficiently conspicuous that they are easily discernable by travelling fishers, thus their selection may occur often in areas that are less known by the individual (e.g., outside their core areas).

Raphael and Jones (1997) speculated that arboreal structures offer greater protection from predators than do ground sites. Because of their elevated position, the detection of potential predators would probably be enhanced in tree sites that afford earlier visual, auditory and olfactory discovery of approaching predators. Similarly, elevated sites may provide greater detection of potential prey. In the absence of restrictive thermoregulatory demands, we expect that fishers would select structures based upon these other factors.

One important factor that we did not include in this analysis, which undoubtedly plays a substantial role in selection, is the availability of each type of structure at various spatial scales. It is unclear how important the factors of ambient temperature, sex and body mass of the individual, and location within the non-resting home range were relative to availability, but we suspect that it may have an over-riding influence on selection. The number of resting sites in trees is generally greater than that for ground sites (Martin and Barrett 1991), hence, fishers may select tree sites opportunistically. This may partially explain why branch sites were the most commonly used structure.

We located all our fisher rest sites during daylight conditions. Although some of these resting periods were likely initiated during the preceding nocturnal period, differences in rest site use may exist between daylight and nocturnal periods. Therefore, determining the types

of rest sites used by fishers during all portions of the 24-h day should be investigated to further identify the importance of each of these rest site types.

## 12.0 CAVITY PREVALENCE, POSITION, AND TEMPERATURE

The reproductive contribution of female fishers is dependent upon the success of whelping and rearing young, and the structures that are used for these activities are important to this process. Reproductive dens of fishers are primarily situated in cavities of standing, live and dead deciduous trees (Leonard 1980, Weir 1995a, Paragi et al. 1996, Gilbert et al. 1997, Powell et al. 1997, this study [*Section 10*]). Den cavities occur less frequently in coniferous trees, hollow logs, and ground sites (Roy 1991, Buck et al. 1994, Yaeger 2005, Aubry et al. 2002). In British Columbia, fishers were found denning only in cavities of living and dead large-diameter cottonwood trees (Weir 1995a, this study [*Section 10*]).

Trees likely need several characteristics to provide sites that are suitable for reproduction. Leonard (1980) speculated that female fishers select elevated sites to avoid predators and interspecific conflict. Leonard (1980) and Paragi et al. (1996) further suggested that elevated south-facing entrances would confer thermal advantages because these sites would be warmer than ground sites due to increased solar radiation. Most importantly, trees need to be large enough to have a cavity of sufficient size to house an adult female and her litter (Powell 1993). In the Sub-boreal Spruce (SBS) forests of north-central British Columbia, black cottonwood trees are the only species that routinely grow sufficiently large to house a female and her litter (i.e.,  $\geq 50$  cm in diameter), and have decay characteristics that are conducive for forming fisher-sized cavities (Allen et al. 1996). Trembling aspen and paper birch trees, which are the only other species that often form cavities, rarely exceed 40 cm diameter within SBS forests of north-central British Columbia (K. Simonar, Ministry of Forests, Prince George). Given these relationships, it is not unexpected that female fishers use cottonwood stems exclusively in northern SBS forests for reproductive dens. If large-diameter cottonwood trees are advantageous to fisher reproduction in these forests, their abundance and spatial distribution may have a large influence on where female fishers establish home ranges and may influence where populations of fishers exist on the landscape.

The properties of cottonwood trees that make them suitable for reproductive dens are largely unknown. The characteristics of den cavities may be a product of tree morphology or the agents that initiate cavity formation (e.g., primary cavity nesters, prevailing wind directions, typical locations of decay). Because denning female fishers prefer cavities in large-diameter cottonwood trees and the lack of knowledge concerning the morphology and characteristics of these cottonwood stems, we investigated cavity abundance and position, and evaluated the thermal properties of cavity chambers.

### 12.1 Methods

#### 12.1.1 Cavity Abundance and Position

To determine the abundance of den-sized cavities and trees for fishers, we estimated the minimum size that a cavity in a black cottonwood tree needed to be for a reproductive den

for a female fisher. Based on body metrics, we predicted that the floor of a cavity chamber needed to be  $\geq 30$  cm in diameter ( $\sim 700 \text{ cm}^2$ ) to hold an adult female fisher and 2-3 young. We further estimated that, to remain standing, a tree needed an outer shell of holding wood and tree bark  $\geq 10$ -cm thick. Thus, we predicted that tree boles needed to be  $\geq 50$  cm in diameter to have the potential for a cavity that could be used by a fisher as a reproductive den. Therefore, we limited our assessments to living and dead black cottonwood stems that had a diameter-at-breast height (dbh) of  $\geq 50$  cm; collectively referred to as “suitable trees”.

We compared the features of trees used as reproductive dens (natal and maternal) identified through telemetry of radio-tagged female fishers (see *Section 9*) to a sample of suitable trees not used for denning within their respective home ranges. We randomly selected  $\leq 4$  suitable trees within 30 m of den trees. We also identified other patches of suitable trees based on forest-cover maps, airphotos, and from observer knowledge of the study area. At these non-den sites, we chose 1 suitable tree as the centre point of a 30-m radius plot. We measured that tree and  $\leq 4$  other randomly selected suitable trees within the plot.

We measured 15 attributes on each sampled stem. These included tree class (WTCBC 2000), amount of bark present on the main bole (BCMELP and BCMOF 1998d), stem dbh and height, and length of usable stem (distance from the ground to where the bole was no longer  $\geq 50$  cm diameter). For some den trees, tree class, dbh, and height were based on measurements collected during fisher-patch plots conducted in 1999 and 2000. We recorded several characteristics of tree limbs; the bark and anchoring characteristics of limbs were used to discriminate between branches and suckers<sup>8</sup>. We measured the number, location, length ( $\leq 0.5$  m, 0.6-2.0 m,  $> 2.0$  m), vigour (healthy, unhealthy, dead), and general angle from vertical ( $\leq 30^\circ$ ,  $31\text{-}60^\circ$ ,  $61\text{-}90^\circ$ ) of all large ( $\geq 10$  cm diameter) branches on the portion of the stem  $\geq 50$  cm diameter. We recorded the number and location of large ( $\geq 10$  cm diameter) suckering limbs, the relative abundance (none, low, medium, high) of small ( $< 10$  cm diameter) suckering limbs, and the presence of burls and major forks in the main bole.

We visually assessed the usable length of each tree bole to determine if a cavity was present. If a cavity was present, or we could not fully assess the tree visually, we assessed the stem’s hazard rating to determine if it was safe to climb (WTCBC 2000). We climbed only safe trees using rappelling gear. We conducted the assessments in spring, before full leaf-out had occurred, to ensure greatest visibility of tree features.

<sup>8</sup> Branches typically had furrowed bark and were assumed to have cores (anchor points) that extended into the heartwood of the stem, whereas suckering limbs were assumed to be vegetative outgrowths from the main bole that had less furrowed bark and rudimentary anchor points that did not penetrate farther into the stem than the sapwood, and likely only to the outer xylem.

We considered a cavity as any opening on the usable portion of the bole that extended into the sapwood and had some decay present. We considered a suitable cavity as an opening with the following characteristics:

1. an entrance hole sufficiently large to allow an adult female fisher passage: axes  $\geq 4$  cm by  $\geq 5$  cm (lower 95% CI values for a female fisher's cranium size in British Columbia; R. Weir, unpublished data),
2. a chamber of sufficient depth ( $\geq 30$  cm) to provide protection from the external environment, and
3. an internal chamber with a floor of sufficient area ( $\geq 700$  cm<sup>2</sup>) to house a female fisher with young. We assumed that the chamber dimensions of the cavity just inside the entrance were similar to dimensions at the chamber floor.

We assessed each cavity for 7 attributes that characterized the entrance, chamber, and tree bole. We recorded entrance orientation, opening width and height, height above ground, and origin. We also measured chamber height (entrance to chamber floor) and diameter of the bole at the cavity entrance. All fisher den cavities were not assessed during this trial, so we supplemented data for some attributes with data collected during preliminary den assessments conducted in 1998 and 1999.

We calculated densities of suitable trees within different stand types (combinations of ecosystem association and structural stage) and within the study area from variable-radius plots conducted at patch-comparison and stand-description plots within the study area (see *Section 10*). The number of cavities within female home ranges were estimated based on the average number of cavities per suitable tree, density of suitable trees per stand type (*Section 10*), stand composition of the home range, and home range size (i.e., 95% UD; *Section 6*). We assumed the number of cavities on each individual tree did not change among stand types.

Statistical analyses were conducted using Statistica 7.0, with level of significance set at  $\alpha = 0.05$ . We used  $t$  and  $\chi^2$  tests for most comparisons, but a Mann-Whitney U-test was used to compare the size of entrance openings. We estimated a mean angle ( $\bar{a}$ ) for the orientation of cavity entrances and calculated the dispersion ( $r$ ) of the data (Zar 1996). We used Rayleigh's test to determine if the mean angle was significantly different from random (Zar 1996).

### 12.1.2 Cavity Temperature

We monitored 2 natural cavities on a single large-diameter cottonwood tree to investigate thermal properties of cavities. The tree was situated on the floodplain of the Willow River, 25 km northeast of Prince George, BC; tree coordinates: 54° 3.8' N, 122° 25.5' W. Although the site was not located in our radiotelemetry study area, it was within the same subzone (SBSmk) that dominated the study area.

Table 12-1. Characteristics of the cavity entrances and chambers, and temperature-sensor positions for cavities monitored on a 118-cm dbh cottonwood tree in the Sub-Boreal Spruce moist-cool biogeoclimatic subzone near Prince George, British Columbia, 9 May – 31 July 2001.

Cavity no.	Cavity entrance						Cavity chamber			Sensor <sup>a</sup> position			General comments	
	Origin	Height (m)	Aspect (°)	DEH (cm)	Length (cm)	Width (cm)	Insulating potential (cm) <sup>b</sup>	Inside diameter (cm)	Chamber height (cm)	Shape	T <sub>a</sub> sensor	T <sub>i</sub> sensor depth (cm)		
											Aspect (°)	Height (m)		
1	Broken limb	19.9	35	76	13	11	30	15	62	Irregular	310	19.9 (same as entrance)	30-35 (~30 cm above chamber floor)	Entrance slightly above major fork and relatively void of surrounding limbs due to broken top.
2	Broken limb	14.8	220	90	8	6.5	35	20	3	Round - irregular	300	14.8 (same as entrance)	3 (on chamber floor)	Entrance mid-way between large lateral branch and fork, therefore somewhat protected by surrounding limb growth.

<sup>a</sup> Ambient (T<sub>a</sub>) and internal chamber (at or near chamber floor; T<sub>i</sub>) temperatures.

<sup>b</sup> An estimate of the insulating potential for the cavity (i.e., amount of holding wood) was calculated based upon the bole and inside cavity diameter. The wall thickness (excluding the bark) for the bole was also measured at the entrance of each cavity (Cavity #1 – 11 cm; Cavity #2 – 6 cm) but we believe the former value was a better measure of the cavity's insulating potential.



Figure 12-1. Photographs of (a) the microsite around the study tree (looking north) and (b) the entrance locations to the 2 natural cavities (looking northwest) on the 118-cm dbh cottonwood tree studied in the Sub-Boreal Spruce moist-cool biogeoclimatic subzone near Prince George, British Columbia. Photographs taken on 9 May 2001.

The study tree was 30 m tall, 118 cm dbh, and estimated to be 110 years old. The tree was alive but unhealthy due to obvious structural defects (tree class 2; Fig. 12-1). The main bole had a fork at 19 m above ground. The entrance to Cavity #1 was situated about 1 m above the fork on the north side of the northern fork, whereas the entrance to Cavity #2 was located on the southern side of the main bole, mid-way between 2 sizable lateral branches and the fork (Table 12-1, Fig. 12-1). Although both forks had broken off, large live branches were growing from their tops.

We used HOBO® H8 Pro Series Temp/Ext Temp (Onset Computer Corporation) measuring devices to record external ambient temperature ( $T_a$ ) on the north side of the tree bole and the internal cavity temperature ( $T_i$ ) (Table 12-1). The  $T_i$  sensor for Cavity #1 was on the chamber floor. The sensor for Cavity #2 was about 30 cm above the chamber floor due to the location of the main unit.

Paired-temperature readings were recorded every 10 min. Mean daily temperatures were calculated based on all 10-min readings for the day (00:10 to 24:00). We used the Wilcoxon paired-sample test to compare the mean  $T_a$  outside the 2 cavities and between the  $T_i$  readings inside the 2 cavities. We used a correlation test to determine relationships between their respective  $T_a$  and  $T_i$ . Since  $T_i$  was potentially dependent on  $T_a$ , single linear regression was used for  $T_a$ - $T_i$  relationships. Analyses were conducted using Statistica 7.0, with level of significance set at  $\alpha = 0.05$ .

To obtain indices of the insolative and conductive heating potential available, we estimated the hourly and daily solar radiation at the site and calculated the daily accumulated  $T_a$  outside each cavity. The hourly solar radiation at the site was estimated using hourly  $K_{down}$  values (amount of direct and diffuse solar radiation;  $\text{Wm}^{-2}$ ) derived from 2 weather monitoring stations about 26 km and 31 km southwest of the study tree (unpublished data, Ministry of Environment, Prince George, British Columbia). We calculated the daily accumulated  $T_a$  outside each cavity by summing their respective 10-min  $T_a$  readings.

## 12.2 Results

### 12.2.1 Cavity Abundance and Position

Between 19 May and 17 June 2000, we assessed 61 suitable trees at 19 sites: 31 trees at 9 den sites and 30 trees at 10 non-den sites. The number of suitable trees at den sites ( $\bar{x}_{den} = 22$  trees/ha,  $SD = 23.3$ ,  $n = 9$  sites) was not different from non-den sites ( $\bar{x}_{nd} = 17$  trees/ha,  $SD = 18.0$ ,  $n = 10$  sites;  $P = 0.606$ ).

We detected suitable trees in young-forest to old-forest structural stages of the Spruce-Moist and Spruce-Wet ecosystem associations, where they ranged from 4-31 stems/ha. These habitat types represented 8% of the study area.

Most (47 of the 61) suitable stems needed to be climbed to conduct a complete assessment. However, 21 stems were unsafe to climb, including 3 of the 9 stems used by fishers as reproductive dens. Many of the unsafe stems appeared to have a cavity present. Due to this sampling bias, we calculated minimum estimates of the number of cavities and suitable cavities on den and non-den trees. Den trees had at least 4.2 cavities/stem ( $SD = 2.5$ ,  $n = 6$ ) and 1.3 suitable cavities/stem ( $SD = 0.52$ ,  $n = 6$ ). Non-den trees had a minimum of 0.7 cavities/stem ( $SD = 1.0$ ,  $n = 34$ ) and 0.2 suitable cavities/stem ( $SD = 0.5$ ,  $n = 34$ ). Based on non-den trees, we estimated that at least 800 to 2,400 suitable cavities were present in female home ranges within the study area.

The majority of den and non-den trees were live with some visible sign of external decay (Figure 12-2; Table 12-2). Three of the 9 den trees were forked mid-way up the bole, whereas only 1 of the 52 non-den trees had a fork present ( $P = 0.0008$ ). Den trees ( $\bar{x} = 109$  cm,  $SD = 25$ ,  $n = 13$ ) were larger than non-den trees ( $\bar{x} = 85$  cm,  $SD = 23$ ,  $n = 52$ ;  $t = 3.354$ ,  $df = 63$ ,  $P_{dbh} = 0.006$ ; Table 12-3). Stem height ( $t = 0.933$ ,  $df = 54$ ,  $P_{ht} = 0.355$ ) and number of large branches on a bole  $\geq 50$  cm in diameter ( $t = 0.502$ ,  $df = 50$ ,  $P_{lbr} = 0.618$ ) were not significantly different for den and non-den trees (Table 12-3). Den trees had more bark missing on the main bole than non-den trees ( $\chi^2 = 12.578$ ,  $df = 2$ ,  $P_{bk} < 0.002$ ).

Den trees had fewer large branches in the top quarter of the main bole than non-den trees ( $\chi^2 = 13.861$ ,  $df = 3$ ,  $P < 0.003$ ; Table 12-4). However, both tree types had  $>95\%$  of their large branches in the upper half of the stem and none in the bottom quarter of the stem. Other

Table 12-2. Characteristics of cottonwood trees and den cavities used by 5 female fishers for their reproductive dens in the Williston region of north-central British Columbia, 1997-2000. Data were based on measurements made during the May-June 2000 assessments and during preliminary den assessments conducted in 1998 and 1999.

Fisher ID	Den type & year	Stem					Den entrance						Den chamber <sup>a</sup>			
		Tree sp. <sup>b</sup>	Tree class <sup>c</sup>	Bark code <sup>d</sup>	DBH (cm)	Tree height (m)	Origin	DEH <sup>e</sup> (cm)	Ht. above ground (m)	Opening height (cm)	Opening width (cm)	Area <sup>f</sup> (cm <sup>2</sup> )	Aspect (°)	Height (cm)	Width (cm)	Depth (cm)
F02	Natal - 98 to 00	Act	2	2	132	45	limb	66	19	9	8	57	250	290	10	10
	Maternal - 98 (1)	Act	2	2	154	39	limb	84	18	7	9	49	167	90	9	9
	Maternal - 98 (2)	Act	5	5	142	10	crack	130	3	74	5	291	205	50	70	10
F03	Natal - 97	Act	3		118	26	limb									
	Maternal - 97	Act	2		138	42	limb	79	20	20	19	298	140	10	40	20
F04	Natal - 97	Act	2		88	36	limb	89	6	5	4	16	183	90		
	Natal - 98 & 99	Act	2	1	88	27	limb	50	21	9	5	35	2	440	16	20
	Maternal - 99	Act	2	2	80	23	limb									
	Natal - 97	Act	2	3	104	26	limb	67	17	7	8	44	110	203	38	38
F07	Natal - 97	Act	3	4	84	25	limb	54	20	13	10	102	210	335	10	30
	Maternal - 97	Act	2		105	35	limb	70	16	10	13	102	135	190	20	20
F09	Natal - 97	Act	2		96	33	limb	56	26	8	8	50	337	280	35	35
	Natal - 99 & 00	Act	2	1	93	24	crack	68	3	22	7	121		114		

<sup>a</sup> Width and depth measurements made just inside the cavity entrance. Height measurements made from bottom of entrance hole down to chamber floor.

<sup>b</sup> Tree species: Act - black cottonwood (*Populus balsamifera trichocarpa*).

<sup>c</sup> Tree classes 1 (live, stem intact) to 6 (dead, limited stem standing; WTCBC 2000). Tree class 2 is a live tree but has visual evidence of some decay being present (e.g., broken or dead limbs).

<sup>d</sup> Bark retention code on main bole (BCMELP and BCMOF 1998d): 1 (all bark present) to 7 (no bark present). For analyses, codes were grouped to represent ≤5% (codes 1-2), 6-50% (codes 3-4), and >50% (codes 5-7) bark missing.

<sup>e</sup> Diameter at entrance height (DEH).

<sup>f</sup> Entrance opening area approximated using formula for an ellipse.

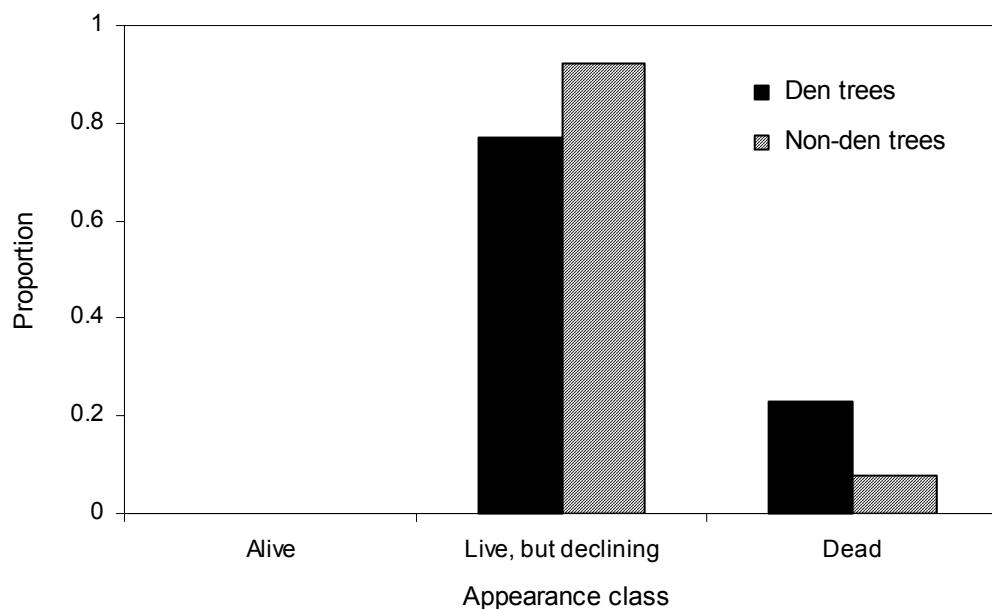


Figure 12-2. Appearance classes of large-diameter ( $\geq 50$  cm dbh) cottonwood trees in the Williston region of north-central British Columbia, May-June 2000. N = 13 den trees and 52 non-den trees.

Table 12-3. Characteristics of large-diameter ( $\geq 50$  cm dbh) cottonwood trees in the Williston region, north-central British Columbia, May-June 2000. Similar letters denote means that were significantly different ( $P < 0.05$ ).

Metric and strata (units)	n	Mean	SD	Min	Max
Dbh (cm)					
Non-den trees	52	85	23.0	51	148 A
Den trees	13	109	24.8	80	154 A
Height (m) <sup>a</sup>					
Non-den trees	44	33.4	4.87	21	46
Den trees	12	31.8	7.59	23	45
Number of large branches per stem <sup>a,b</sup>					
Non-den trees	45	4.2	3.51	0	16
Den trees	7	4.9	2.9	0	8

<sup>a</sup> Excludes stems with broken tops.

<sup>b</sup> Number of large ( $\geq 10$  cm diameter) branches attached to the usable portion ( $\geq 50$  cm diameter) of the bole.

Table 12-4. Characteristics of large ( $\geq 10$  cm diameter) branches on the usable<sup>a</sup> portion of large-diameter ( $\geq 50$  cm dbh) cottonwood trees in the Williston region of north-central British Columbia, May-June 2000.

Metric & categories	Large branches on den trees (n)	Large branches on non-den trees (n)
Location	(24)	(101)
Top quarter	38%	71%
Upper-mid quarter	58%	26%
Lower-mid quarter	4%	3%
Bottom quarter	0%	0%
Length $\geq 10$ cm in diameter	(34)	(187)
$\leq 0.5$ m	3%	2%
0.6-2.0 m	9%	14%
$> 2.0$ m	88%	84%
Angle <sup>b</sup>	(34)	(187)
0-30°	41%	24%
31-60°	21%	27%
61-90°	38%	49%
Vigour	(34)	(187)
Healthy	18%	13%
Unhealthy	65%	67%
Dead	18%	20%

<sup>a</sup> Portion of tree bole  $\geq 50$  cm in diameter.

<sup>b</sup> Predominant angle of large branches from vertical plane (horizontal = 90°).

characteristics of large branches were not different between den and non-den trees: length ( $\chi^2 = 1.195$ , df = 2,  $P_l < 0.550$ ), angle ( $\chi^2 = 5.454$ , df = 2,  $P_a < 0.065$ ), and vigour ( $\chi^2 = 0.567$ , df = 2,  $P_v < 0.753$ ) (Table 12-4).

For live trees, the number of large and small suckers was not different between den and non-den trees ( $\chi^2 = 1.96$ , df = 3,  $P_{ls} < 0.581$ ;  $\chi^2 = 2.42$ , df = 3,  $P_{ss} < 0.491$ ; Appendix 12-1). Both types of trees had a majority ( $\geq 80\%$ ) of their stems with few to no suckers present on the main bole. When large suckers were present, they occurred mostly in the upper half of the stem; this was similar to the distribution of large branches.

The length of stem estimated as usable to a denning female fisher (bole diameter  $\geq 50$  cm) ranged from 6 to 27 m per tree (Fig. 12-3). The usable length did not appear to be different between the 2 stem types.

Since we could not fully assess all stems for cavities due to safety concerns, we assumed that cavity characteristics were not different between climbed and unclimbed trees. Cavity entrances originated primarily from broken branches on den and non-den trees, except for suitable cavities on non-den trees that were varied (Table 12-5). Cavity entrances due to

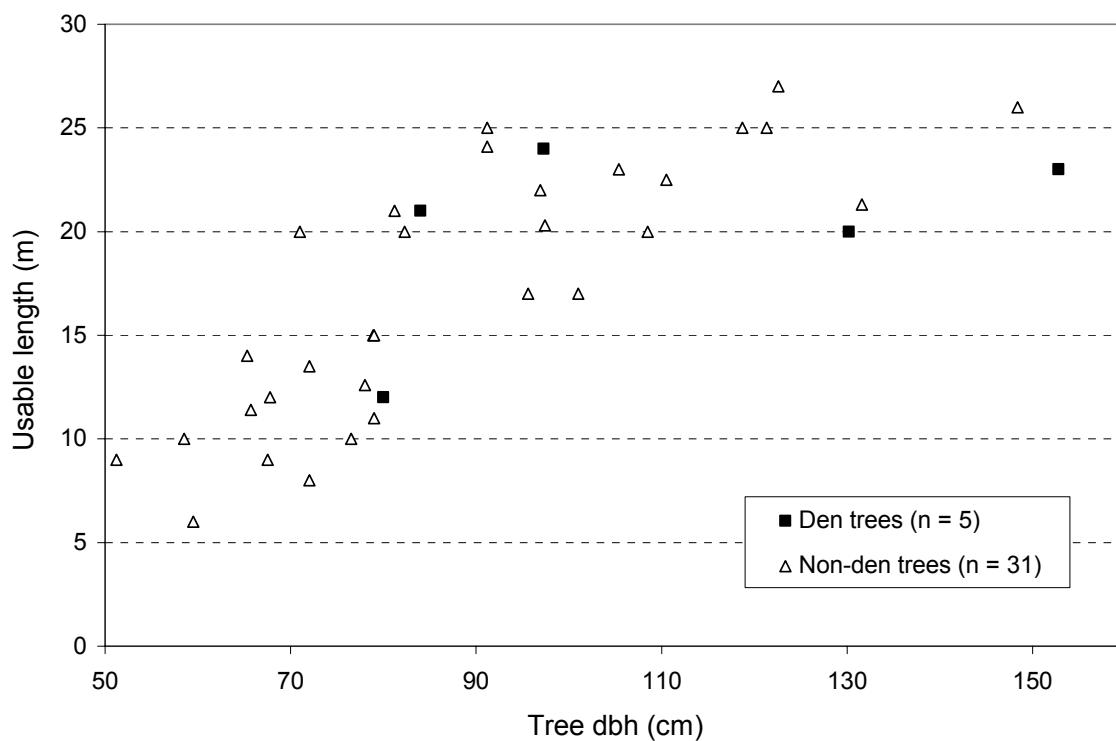


Figure 12-3. Usable length of the bole ( $\geq 50$  cm diameter) on large-diameter ( $\geq 50$  cm dbh) cottonwood trees in the Williston region of north-central British Columbia, May-June 2000.

Table 12-5. Origin of entrances to cavities on large-diameter ( $\geq 50$  cm dbh) cottonwood trees in the Williston region of north-central British Columbia, May-June 2000.

Damage agent	Den trees		Non-den trees	
	All cavities (n = 26)	Den cavities (n = 13)	All cavities (n = 26)	Suitable cavities (n = 6)
Broken limb	77%	85%	77%	33%
Broken top	4%		4%	17%
Burl	8%			
Frost/stress crack	4%	15%		
Scar			8%	17%
Unknown	8%		12%	33%

frost/stress cracks or burls were only observed on den trees. We observed no cavity entrances originating from primary cavity nesting birds (e.g., woodpeckers).

We observed no obvious differences in bole size at the cavity entrance or in entrance height for cavities on den and non-den trees (Table 12-6). When pooled, cavity entrance heights averaged 18.1 m ( $SD = 5.73$  m,  $n = 53$ ). Three (2 natal, 1 maternal) of the 13 fisher dens had entrances  $<10$  m in height (Table 12-2), whereas 8% of all cavities and no suitable cavities on non-den trees had entrance heights  $<10$  m.

Median opening size for cavity entrances was not different between fisher dens and suitable cavities on non-den trees ( $Z = 0.20$ ,  $P = 0.841$ ; Table 12-6). Entrance openings for fisher dens ranged from  $16\text{ cm}^2$  to  $299\text{ cm}^2$  (Table 12-2). The mean aspect of all cavity entrances on den trees was  $109^\circ$  ( $SD_{d,ac} = 74^\circ$ ,  $r_{d,ac} = 0.1676$ ,  $n_{d,ac} = 23$ ), and was  $168^\circ$  for fisher dens ( $SD_{d,d} = 68^\circ$ ,  $r_{d,d} = 0.2862$ ,  $n_{d,d} = 11$ ). Mean aspect for all cavity entrances on non-den trees was  $134^\circ$  ( $SD_{nd,ac} = 77^\circ$ ,  $r_{nd,ac} = 0.0887$ ,  $n_{nd,ac} = 29$ ), and  $89^\circ$  for suitable cavities ( $SD_{nd,s} = 61^\circ$ ,  $r_{nd,s} = 0.4273$ ,  $n_{nd,s} = 5$ ). The aspects of cavity entrances were not significantly different from random (Rayleigh's  $z_{d,ac} = 0.6457$ ,  $P_{d,ac} = 0.529$ ; Rayleigh's  $z_{d,d} = 1.3755$ ,  $P_{d,d} = 0.257$ ; Rayleigh's  $z_{nd,ac} = 0.2283$ ,  $P_{nd,ac} = 0.800$ ; Rayleigh's  $z_{nd,s} = 0.9131$ ,  $P_{nd,s} = 0.42$ ).

We observed no difference in chamber heights between fisher den cavities and suitable cavities on non-den trees ( $Z = 1.529$ ,  $P_{cht} = 0.135$ ). Yet, 4 of 11 fisher dens were considerably (80-240 cm) deeper than the deepest suitable cavity on non-den trees and all but 1 fisher den had a chamber height  $\geq 50$  cm (Table 12-2 and 12-5). The lone shallow fisher den was a maternal den.

### 12.2.2 Cavity Temperature

We collected  $T_a$  and  $T_i$  temperatures for 2 natural cavities on the same tree from 9 May to 31 July 2001 (Table 12-7). On several occasions in May successive 10-min readings for  $T_i$  in Cavity #2 were unusual (up to  $10^\circ\text{C}$  different) for short sporadic periods throughout the 24-hr day. This was likely due to the cavity being used by an animal (e.g., a squirrel). Data were corrected by interpolation based on the  $T_i$  readings before and after each event.

The average daily  $T_a$  for the monitoring period, based on Cavity #2 data (i.e., 15 m above ground), was  $12.6^\circ\text{C}$  and the temperature varied on average  $13.2^\circ\text{C}$  each day (Table 12-7). The extreme minimum and maximum  $T_a$  recorded for the monitoring period were  $-2.0^\circ\text{C}$  and  $29.5^\circ\text{C}$  respectively.

The  $T_a$  readings outside Cavity #1 were  $0.50^\circ\text{C}$  colder than Cavity #2 (Table 12-7). The difference between paired- $T_a$  readings were  $\leq 1.0^\circ\text{C}$  apart for 88% of their 10-min readings and for all of their daily means.

Table 12-6. Characteristics of cavities on large-diameter ( $\geq 50$  cm dbh) cottonwood trees in the Williston region of north-central British Columbia, May-June 2000. All cavities included any site that had an opening through the stem exterior and had decay present that created an internal chamber of any size. A suitable cavity was a cavity with minimum dimensions for its access point and chamber parameters. A den cavity was a cavity that was used for a natal or maternal den by a female fisher.

Metric and strata (units)	n	Mean	Median	SD	Min	Max
Bole diameter at cavity entrance (cm)						
All cavities - non-den trees	26	50	49	11.8	28	80
All cavities - den trees	26	57	55	16.9	22	90
Suitable cavities - non-den trees	6	57	54	15.3	38	80
Den cavities - den trees	11	74	68	22.3	50	130
Cavity entrance height (m)						
All cavities - non-den trees	26	19	21	5.6	6	29
All cavities - den trees	27	17	17	5.7	4	27
Suitable cavities - non-den trees	6	21	21	2.7	18	25
Den cavities - den trees	11	15	18	7.8	3	26
Entrance opening size ( $\text{cm}^2$ )						
Suitable cavities - non-den trees	6	480	51	885	19	2,144
Den cavities - den trees	11	110	57	99	16	299
Chamber height (cm)						
Suitable cavities - non-den trees	5	88	60	70	32	200
Den cavities - den trees	11	190	190	134	10	440

The  $T_i$  readings inside Cavity #1 were  $0.60^\circ\text{C}$  warmer on average than in Cavity #2 (Table 12-7). The  $T_i$  readings in Cavity #1 were typically (71 of 82 days) at or above its respective mean daily  $T_a$  throughout all parts of the day, whereas the temperature in Cavity #2 was rarely (7 of 82) above its mean daily  $T_a$  for the entire day (Fig. 12-4). Furthermore, when short ( $\leq 2$  days) cooling trends occurred in the ambient temperature,  $T_i$  readings in Cavity #1 remained higher than the maximum daily  $T_a$  for the entire day.

Cavity #2 had greater range in daily  $T_i$  readings than in Cavity #1 as it fluctuated on average  $4.16^\circ\text{C}$  more than inside Cavity #1 (Table 12-7). Also, temperatures changed in shorter time intervals in Cavity #2 than in Cavity #1. Temperatures inside Cavity #1 never varied by more than  $0.41^\circ\text{C}$  (i.e., the smallest measurable temperature interval) between 10-min and 1-hr time intervals, whereas Cavity #2 varied by up to  $1.58$  and  $2.01^\circ\text{C}$  during the same intervals respectively. Cavity #1 did not change by more than  $0.41^\circ\text{C}$  on 38% of the monitoring days, and it remained the same temperature all day on 5 occasions.

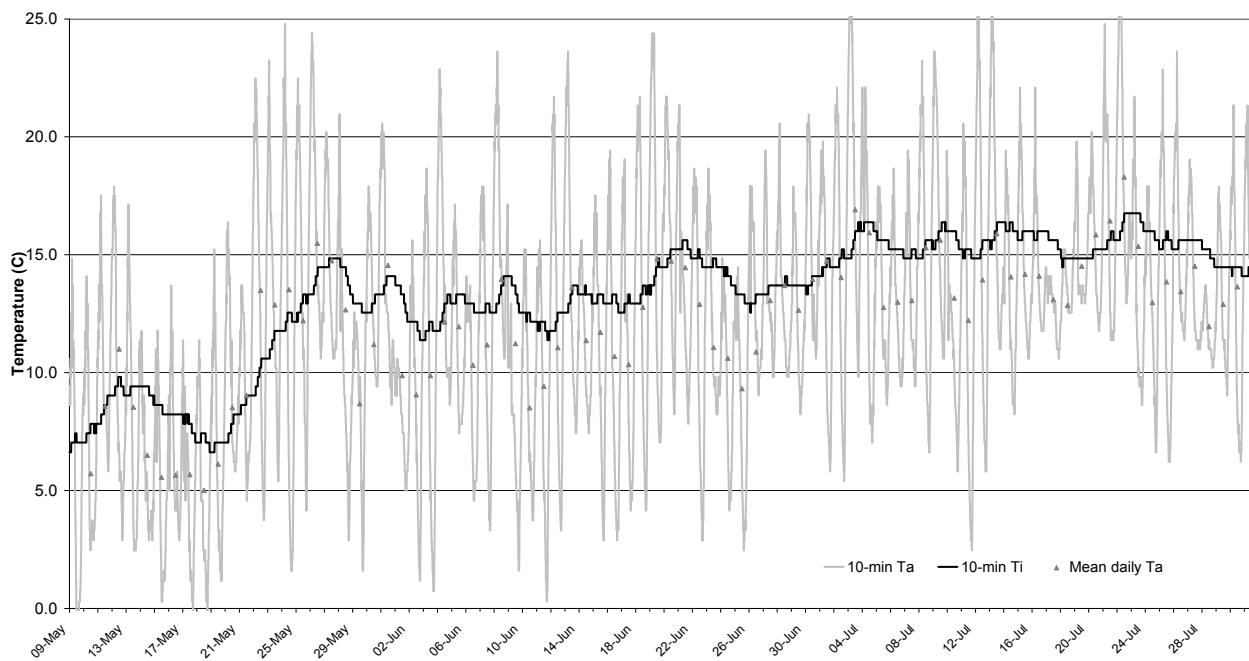
The minimum daily temperature inside Cavity #2 lagged behind the minimum ambient temperature, but the pattern was not so clear for Cavity #1. With few exceptions (<5%), the minimum daily  $T_a$  outside both cavities occurred between 23:10 and 06:00, with 61% occurring between 04:10 to 06:00. Similarly, Cavity #2 had its minimum daily  $T_i$  readings occur primarily (85%) between 04:10 and 07:00 (Appendix 12-2). The majority (79%) of the minimum daily  $T_i$  readings for Cavity #2 occurred just prior to or shortly after the minimum

Table 12-7. Ambient<sup>a</sup> ( $T_a$ ) and internal chamber ( $T_i$ ) temperatures (°C) for 2 natural cavities in a cottonwood tree (tree class 2, dbh = 118 cm) near Prince George, British Columbia, May-July 2001. Cavity #1 had a northeast entrance aspect at 20 m above ground and a chamber height of 62 cm. Cavity #2 had a southwest entrance aspect at 15 m above ground and a chamber height of 3 cm.

Metric	n	Mean	SD	Min	Max
<b>10-min temperature data</b>					
<i>Summary statistics for locations</i>					
$T_{a1}$	12,005	12.12	5.178	-1.97	29.50
$T_{a2}$	12,005	12.62	5.097	-1.06	29.50
$T_{i1}$	12,005	13.231	2.5717	6.62	16.76
$T_{i2}$	12,005	12.636	3.2257	3.31	19.42
<i>Differences between paired-temperature readings</i>					
$T_{a1} - T_{a2}$	12,005	-0.497	0.5473	-6.20	4.60
$T_{i1} - T_{i2}$	12,005	0.595	1.9441	-4.61	6.62
$T_{i1} - T_{a1}$	12,005	1.11	4.722	-13.50	12.39
$T_{i2} - T_{a2}$	12,005	0.015	3.1976	-14.27	5.77
<i>Change in 10-min readings</i>					
$T_{a1}$	12,004	0.001	0.3899	-3.46	3.05
$T_{a2}$	12,004	0.001	0.4315	-3.46	5.38
$T_{i1}$	12,004	0.0007	0.05775	-0.41	0.41
$T_{i2}$	12,004	0.0008	0.17641	-1.58	1.15
<i>Change in 1-hr readings</i>					
$T_{a1}$	2,000	0.00	1.374	-6.55	4.38
$T_{a2}$	2,000	0.00	1.431	-6.10	6.31
$T_{i1}$	2,000	0.0039	0.12827	-0.41	0.41
$T_{i2}$	2,000	0.005	0.5001	-2.01	1.63
<b>Daily temperature data</b>					
<i>Daily mean</i>					
$T_{a1}$	82	12.1	2.90	5.01	18.30
$T_{a2}$	82	12.6	2.95	5.24	18.78
$T_{i1}$	82	13.26	2.549	6.93	16.76
$T_{i2}$	82	12.7	2.79	5.78	17.32
<i>Daily range</i>					
$T_{a1}$	82	13.1	4.70	2.70	23.88
$T_{a2}$	82	13.2	4.61	2.71	25.76
$T_{i1}$	82	0.71	0.365	0.00	1.56
$T_{i2}$	82	4.87	1.660	1.91	8.53
<i>Daily accumulated</i>					
$T_{a1,sum}$	82	1,750	417	721	2,635
$T_{a2,sum}$	82	1,820	425	754	2,704

<sup>a</sup> Ambient temperatures were measured on the northern side of the tree bole at the same height as the cavity entrance.

a) Cavity #1 (*entrance: northeast aspect, 20 m height; chamber: 62 cm deep*)



b) Cavity #2 (*entrance: southwest aspect, 15 m height; chamber: 3 cm deep*)

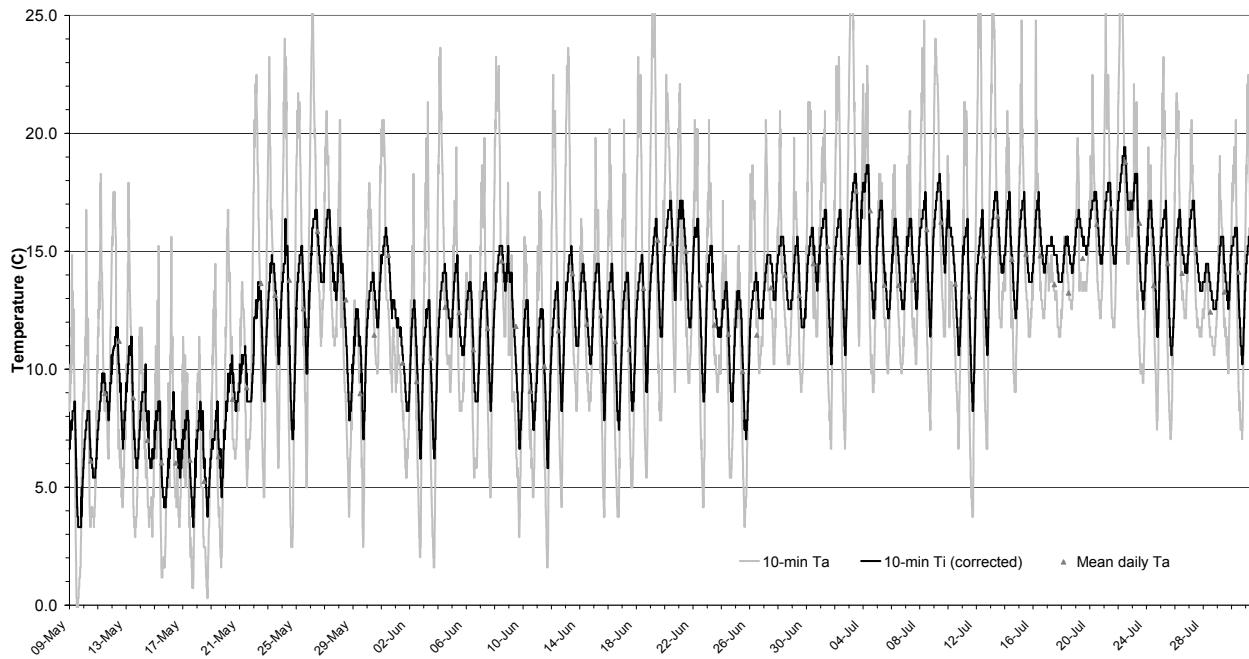


Figure 12-4. Ambient ( $T_a$ ) and internal chamber ( $T_i$ ) temperatures, based on readings every 10 min, for 2 natural cavities on a large-diameter (118 cm dbh) cottonwood tree near Prince George, British Columbia, 9 May – 31 July 2001. The mean daily  $T_a$ , from outside the respective cavity, is also presented. Chamber temperature for Cavity #2 was corrected for some time periods because temporary use of the cavity by an animal.

daily  $T_a$  (-0.9 to 2.0 hrs). Cavity #1 had minimum daily  $T_i$  readings that were widely dispersed (00:10 to 16:00), but most commonly occurred just after midnight (37% between 00:10 and 01:00; Appendix 12-2). Minimum daily  $T_i$  readings in relation to the minimum daily  $T_a$  outside Cavity #1 was also widely dispersed, occurring primarily from 5.9 hrs before to 13.0 hrs after the minimum daily  $T_a$ .

As with minimum temperatures, the timing of maximum daily  $T_i$  readings for Cavity #2 lagged behind the maximum  $T_a$  whereas maximum temperatures inside Cavity #1 did not. Over 90% of the maximum daily  $T_a$  readings outside both cavities occurred between 12:10 and 19:00, with >73% occurring between 14:10 and 18:00. The maximum daily  $T_i$  for Cavity #2 occurred between 17:10 to 22:00 for 78% of the monitoring days (Appendix 12-3a). Relative to the maximum  $T_a$  for the day, the maximum  $T_i$  reading for Cavity #2 lagged by  $\leq 6$  hrs on 75% of the monitoring days (Appendix 12-3b). For Cavity #1, the maximum daily  $T_i$  occurred predominantly (88%) between 21:10 and 01:00, with 60% of these maximum readings occurring just after midnight (00:10 to 01:00; Appendix 12-3a). The maximum daily  $T_i$  relative to the maximum daily  $T_a$  for Cavity #1 was distributed bimodally: 51% of  $T_i$  readings occurred at 14.0 to 17.9 hrs before the maximum daily  $T_a$  and 33% occurred 4.1 to 9.0 hrs after the maximum daily  $T_a$  (Appendix 12-3b).

In general,  $K_{down}$  values peaked between 10:00 and 13:00 during the monitoring period, and had medians of 12:00. Cavity #1 had a bimodal relationship and Cavity #2 had a simple lag effect between their maximum daily  $T_i$  and the estimated maximum daily  $K_{down}$ , (Appendix 12-4). The peaks for Cavity #1 and the lag time for Cavity #2 occurred 3-4 hrs later in the day for the  $K_{down}$  relationships than for the maximum  $T_a$ - $T_i$  relationships. Linear relationships for the 2 cavities were significant for comparisons between daily  $T_i$  range and daily accumulated  $K_{down}$ , but daily accumulated  $K_{down}$  accounted for little of the variation in daily  $T_i$  range at either cavity:  $r^2_{cav1} < 0.107$ ,  $P_{cav1} < 0.003$ ;  $r^2_{cav2} < 0.531$ ,  $P_{cav2} < 0.001$ . No relationships were observed between maximum  $T_i$  and daily accumulated  $K_{down}$  for a given day (Appendix 12-5). Also, no relationships were observed between daily  $T_i$  and daily accumulated  $T_a$  for the 2 cavities.

### **12.3 Discussion**

Compared to non-den trees, those used by fishers had several features that made them more suitable as dens. Den trees had a larger dbh, fewer large branches in the top quarter of the main bole, less bark remaining, and were more likely to have a fork in the bole. Denning females may have selected stems with larger diameters than non-den trees because these larger trees had better-suited cavities for rearing young. Powell et al. (1997) postulated that the absolute size of a stem may be less important than its size relative to other available stems. If a female is to use a stem for denning, though, the cavity (and therefore the stem) must be at least a minimum size to allow the female and young to fit inside. Fewer large branches in the

top quarter of the main bole may reflect the fewer, but not statistically different, number of large branches we observed growing in a horizontal direction on den trees than on non-den trees. That is, horizontal branches in the upper canopy are probably most susceptible to breakage because of physical stresses caused by the weight of the limb, wind action, and snow loading. Consequently, the loss of these branches may indicate greater decay is present, thus den-sized cavities would possibly be more likely to be present on these stems. More decay may similarly correlate with more bark sloughing from the bole, a condition that was more prevalent on den trees. When branches are lost, there is also a greater chance that bark will be removed when the breakage occurs. Lastly, we found that stems used by denning fishers were more likely to have a fork present in their main bole. A stem with 2 leaders early on in life may indicate that an injury had occurred, thus decay vectors may have been able to establish earlier in these stems. These features may be variables that depict which stems have the greatest chance to have a cavity suitable for a denning female fisher.

The regular stem features of large-diameter cottonwood trees dictated the characteristics of 9 variables we used to compare between the 2 tree types. Suitable trees that we assessed were predominantly alive, but declining; this included stems that were unsafe to climb. Elsewhere in their range, however, fishers often used cavities in dead trees for their reproductive dens (Paragi et al. 1996, Powell et al. 1997). This difference was likely a result of the specific decay characteristics of available tree species: decadent trembling aspen trees were abundant in Maine (Paragi et al. 1996), and most den sites were situated in softwood stems in New England (Powell et al. 1997). Due to the decay processes exhibited by softwood stems in British Columbia, such stems do not have sizable cavities until the tree is usually dead (WTCBC 2000). Both Powell et al. (1997) and Paragi et al. (1996) found no selection in the species used by denning fishers, unlike our study that found all dens in cottonwood stems.

Although fishers selected atypical cottonwood trees as reproductive dens for some stem characteristics, we did not detect any differences in the cavity characteristics between den and non-den trees. Cavities on both den and non-den trees had entrances derived primarily from branches breaking off the main bole. Large branches were found almost exclusively in the upper half of the main bole and, as such, cavity entrances would be expected to occur predominantly in the upper portion of the bole (i.e., above 10 m). Because of this, entrances are rare on the lower portion of the boles, even though internal chambers created by heartrot may already be present (F. Corbould, personal observation). None of the cavities that we assessed were created by primary cavity-nesting birds. Therefore, fishers in our study area likely have to rely on tree-decay processes for the creation of cavities.

Female fishers may select elevated and south-facing den sites to gain thermoregulatory benefits and avoid adverse conflict (Leonard 1980, Paragi et al. 1996). For dens in large-diameter cottonwood trees, it appears that these potential benefits are coincidental with where

cavities are available on these stems. Furthermore, based on our cavity temperature trial, the thermal properties of these cavities were likely unaffected by the entrance aspect. This relationship, though, may only hold true for cavities in large stems (e.g., >75 cm diameter).

Female fishers also did not appear to select den entrances to exclude potentially antagonistic male fishers. Contrary to Leonard's (1980) suggestion, entrance openings were almost always large enough to allow passage of adult males (i.e., head size ~25-40 cm<sup>2</sup>; this study [Section 4], Paragi et al. 1996, Powell et al. 1997). As well, adult males were observed easily ascending and descending den-sized trees (R. Weir, F. Corbould, J. McCormick, personal observations).

The cavity temperature trial was intended to give preliminary insight into the thermal benefits that cavities in large-diameter cottonwood trees provided relative to ambient temperatures. Both cavities we monitored provided a more stable thermal regime than the ambient temperature. Cavity #1, which was most similar to den sites used by female fishers in our study area, provided a more stable and, on average, warmer temperature regime than Cavity #2. The temperature inside Cavity #1 was typically warmer than the mean daily T<sub>a</sub> for the entire day, and on a few occasions was warmer than the maximum T<sub>a</sub> for the entire day; these situations rarely occurred for Cavity #2. The stable temperature regime of Cavity #1 was exemplified by the extremely limited variability in its T<sub>i</sub> readings.

Chamber height was the primary difference between the more thermally stable and warmer cavity (Cavity #1) and Cavity #2 (62 cm vs. 3 cm), which had a larger bole diameter, a southerly entrance aspect, thicker holding wood, a larger cavity diameter, and a smaller entrance opening. Our observations are somewhat contrary to findings for northern flickers (*Colaptes auratus*) in that cavities with southern entrances and larger bole diameters were warmer and had more stable thermal properties (Wiebe 2001). However, using Wiebe's data (Fig. 5, p. 417), the limited temperature variation (<1.6°C) exhibited each day by Cavity #1 would not be unexpected based on its bole diameter and tree status. We assume the same did not hold true for Cavity #2 due to its limited chamber height; all cavities monitored by Wiebe had a chamber height ≥13 cm. This does not mean that deeper chambers would have warmer and more stable temperatures under all conditions as we realize that our trial had significant limitations, with sample size being foremost. A much more extensive investigation into cavities with different characteristics and more elaborate monitoring would be needed to elucidate which factors generally provide more beneficial thermoregulatory properties over others.

The conductivity of the bole surrounding each cavity may have affected the timing of changes in cavity temperature and may explain why temperature maxima and minima did not exactly match or consistently lag behind ambient temperature or solar radiation. Unlike Sedgeley (2001) and Wiebe (2001), who both reported a simple lag in cavity temperatures

from ambient temperatures, we observed considerable variability in the timing of maxima and minima within Cavity #1 relative to ambient temperatures and solar radiation indices. The rate and amount of heat transferred through the bole may be different at different times of the day, or from one day to another, due to variances in its heat conductivity. Water content in *Populus* is typically greatest at night and lowest during mid-day (Blake et al. 1996). Because more water is in the bole at night, the cavity would be better insulated from external temperatures. Characteristics of the woody matter surrounding the cavity, such as the thickness, composition (e.g., percent sound and rotten wood), moisture content, and moisture state (e.g., frozen), may play a significant role in the rate and extent that heat is transferred to the internal chamber. These factors may have such an overriding effect that the daily warming from increased ambient temperatures and solar radiation do not have a notable affect on temperatures inside cavities of large-diameter cottonwood trees. For cavities that provide such a stable microenvironment, we expect any heat emitted by an animal to elevate the chamber temperature and stay that way for extended periods of time. These conditions would be advantageous to a denning female fisher as it would allow her to safely leave her young in the den at any time to capitalize on other favourable situations or conditions that benefit her fitness (e.g., crust on snow for more efficient locomotion for foraging or finding a mate).

Denning female fishers in our study used larger diameter stems, re-used the same dens from year-to-year, and moved den sites fewer times each year (*Sections 9 and 10*) than reported elsewhere (Paragi et al. 1996, Powell et al. 1997). These observations indicate that den cavities in large-diameter cottonwood stems likely provide suitable thermoregulatory properties and sufficient space for a female fisher and her young for most of the rearing period. The need to move litters to new dens may still be required to maintain quick access to food resources, avoid potential predators, or to leave the cavity due to parasites or dead litter mates (Powell et al. 1997).

Our estimate of the number of suitable cavities for denning fishers suggested that this factor was not limiting in our study area (>800 suitable cavities potentially available within each female's home range). However, not all cavities, even with supposedly similar structural characteristics, afford the same microclimate characteristics (Sedgeley 2001). So, the number of cavities that are actually suitable (i.e., suitable entrance size, chamber size, and thermal properties) for denning fishers in home ranges of the Williston study area is likely less than we estimated based solely on the cavity's structural features. All females that whelped more than once during our study re-used den sites (*Section 9*); re-use of dens by fishers has not been previously reported in the literature. Therefore, certain characteristics of these den cavities, trees, or sites must provide greater benefits to female fishers than other structures or sites within their home range (e.g., better thermoregulatory properties, better protection from

adverse conflict or weather conditions, closer proximity to available prey resources, proven reproductive success).

Female fishers selected cavities exclusively in large-diameter cottonwood trees but several stem and cavity attributes thought to be preferred by denning fishers, due to perceived benefits, appear to be intrinsic features of the morphology of large-diameter cottonwood trees. Although it is unknown if cavities in these stems confer the optimal reproductive success, it is obvious that these stems and their cavities provide several features and conditions that can be beneficial to denning female fishers and their young within the Williston region: protection from weather and ground-water conditions; thermally advantageous microenvironments; protection and concealment from potential predators; vantage points for observing predators or prey; elevated sites for greater solar radiation (e.g., while resting on a limb); and sites that are adjacent but external to the den cavity for resting, depositing fecal/urine waste, and avoiding attack (i.e., alternative escape routes).

## **12.4 Management Implications**

Due to the many large-diameter cottonwood trees observed along the floodplains of the major watercourses in our study area and the necessity of riparian areas to be managed with greater consciousness for wildlife habitat (e.g., riparian management zones, wildlife corridors; Mackenzie LRMP 2000, MOFR 2005), trees suitable for reproductive dens may not be limiting in these riparian areas. However, in areas where logging and silviculture practices are more intensive or where cottonwood trees are less common, the identification, maintenance, and continued recruitment of these stems could be an important factor in maintaining reproductive habitat for female fishers in north-central British Columbia.

In the short term (e.g., <20 yrs), current forest-harvesting practices (e.g., single-stem retention, wildlife tree patches) can retain mature cottonwood trees in logged areas to some extent. Retained single stems may even be more prone to limb breakage and the creation of cavity access points because their limbs are more likely subjected to extreme wind events due to their increased exposure. However, females that choose to den in these trees may be at greater risk to predation or attack because of their increased visibility. The thermal properties of cleared and regenerating areas are also different from more mature stands (Brownlee et al. 1988, Sagar et al. 2001), which may further affect the utility of retained trees. Thus, the full utility and benefit of retained stems in logged areas for fishers may not be recognized until after the area has regenerated to a height that would ameliorate these potential disadvantages.

Development of a model that predicts the likelihood of a stem being useful as a fisher reproductive den would be helpful to field personnel that are tasked with identifying stems for retention and conservation. For this model to be applied in an operational setting, it would be most practical to base the metrics on stem characteristics derived from a ground-based assessment. Based on the literature (Paragi et al. 1996, Powell et al. 1997) and features of

cottonwood trees in our study area, female fishers can probably den in boles as small as 40 cm diameter.

The recruitment of cottonwood stems also needs to be addressed in forest management plans to provide adequate sites for the long term. Like other deciduous species, cottonwood stems that out-compete favoured coniferous stems in reforestation efforts are actively targeted during silviculture activities (e.g., removal, herbiciding). In some landscapes, riparian areas (i.e., those managed under more strict forest harvesting guidelines) may not exist over large expanses of the forest land-base so intensive logging and stand-management activities may limit the supply of cottonwood stems. For these areas to provide future denning opportunities for fishers, cottonwood stems should be proactively maintained or recruited in suitable areas (e.g., wetter microsites). Furthermore, beneficial characteristics provided by these cottonwood stems likely do not occur until the stem has reached at least 40-50 cm in diameter, when the tree is probably at least 70 yrs of age (Peterson et al. 1996).

Because these stems provide cavities and other structural features that address the habitat requirements of a diverse and abundant group of wildlife species (WTCBC 2000), these initiatives would also benefit many other wildlife species.

### **13.0 SUMMARY AND MANAGEMENT IMPLICATIONS**

This study was the first conducted on fishers in north-central British Columbia. It has greatly furthered our understanding of fisher ecology in sub-boreal forests and has improved the knowledge base for fishers in British Columbia. Valuable information on the fundamental characteristics of this population will help managers and trappers to better manage sustainable populations of fishers. Detailed habitat examinations provide habitat managers with information needed to evaluate and minimize the impacts of land management on the utility of forests and landscapes to support fishers.

The fisher population in the Williston region was influenced by the ability of the landscape to support fishers and the intrinsic dynamics of the population. Like other populations, fishers in the Williston region sequestered the resources necessary to survive and reproduce by defending intrasexual home ranges. These home ranges ( $>38 \text{ km}^2$  for females,  $>212 \text{ km}^2$  for males) were the largest reported anywhere for fishers. Few areas within the landscape supported home ranges and older-aged animals with high survival held occupied home ranges. These factors resulted in a stable, low-density population characterized by low turnover.

The low density makes the population vulnerable to over-harvest. The October (i.e., pre-trapping) density in our study area averaged 11.2 fishers/1,000 km<sup>2</sup>, which was 3-21% of densities reported elsewhere. At this density, the removal of only a few adult females could greatly diminish the reproductive component of the population. Thus, the population would be unlikely to rebound quickly from harvest. Due to this vulnerability, connectivity to other fisher populations within the region must be maintained to ensure emigration. Although the Williston fisher population sustained a harvest rate of at least 9% (1 fisher/1,000 km<sup>2</sup>), it is unknown if a higher level of harvest would be sustainable without experimental testing. Because of the low density and relatively dispersed nature of females, a broader-scale approach than currently employed by management agencies, including managing for sex ratios closer to 1:1, is needed to maintain viable and resilient fisher populations in northern SBS forests.

Habitats must provide fishers with security from predators, shelter from environmental conditions, and available food sources. We examined the habitat relationships of fishers in the Williston region by evaluating selection at several spatial scales, ranging from the landscape to individual trees. The need for security cover appeared to be a primary motivation for fishers when establishing a home range. In the Williston region, the temporal and spatial distribution of open areas (i.e., wetlands and areas recently logged) affected where fishers occurred in the landscape. Because of this, forest harvesting can strongly affect the ability of the landscape to support fisher home ranges. Our data predicts that logging 245 ha (e.g., 5% of a typical female home range) reduces the relative probability of occupancy for the surrounding area by 50%. If conservation of fisher populations is an objective, land managers need to consider the rate and

extent of forest harvesting when developing forest management plans; this is particularly important when large tracts of land are concurrently harvested, such as that which occurs during salvage harvest of trees killed by mountain-pine beetles.

Once fishers establish a home range, they must find sufficient foraging and resting opportunities to survive and, for females, suitable den sites to rear young. Habitat structures used by fishers for resting and denning resulted from the natural processes of growth, disease, death, and decay of trees. Fishers selected rust brooms in coniferous trees, cavities in large deciduous trees, and, during winter, hollows under large pieces of downed woody debris. Sites under downed woody debris may be critical for the survival of fishers during periods of extreme cold (e.g., <-15°C). Female fishers exclusively used cavities in large-diameter black cottonwood trees for whelping and rearing young. All these habitat structures accumulate over time and reach their greatest densities in mature and late-successional forests. Management practices that suppress disease, death, and decay of trees or remove older-aged forests will have a detrimental affect on the supply of these vital resources.

Reliance upon habitat conservation measures in the Forest and Range Practices Act may not support an adequate distribution and abundance of important habitats for fishers. Fishers are an Identified Wildlife species, which allows for the delineation of Wildlife Habitat Areas up to 100 ha. Special management prescriptions for fishers can be applied in these areas, but they represent <3% of a typical home range in the Williston region, so they likely do not provide sufficient conservation of all habitats needed by fishers to survive and reproduce. Wildlife Tree Patches, another management strategy for conserving wildlife habitat, are identified in or around harvest units. If identified properly, they can include sites that have higher densities of suitable habitats, but these too are limited in size relative to a fisher home range. Similarly, Riparian Management Areas, which include forested areas immediately adjacent to defined watercourses, will include some of the habitats needed by fishers, but not all of them. In those areas of the landscape that are outside of these special management areas, the supply of fisher habitats should be considered to ensure persistence of fisher populations.

To ensure habitat is maintained for fishers in the short and long-term, forest-harvesting prescriptions must provide sufficient retention and recruitment of structural attributes from all stages of forest development, including a range of stem sizes and decay and the ecological processes that create them. Silvicultural prescriptions that ensure a variety of forest characteristics are retained and recruited in managed forests will be an important component of forest management plans that encourage the persistence of fisher populations.

Habitat considerations to benefit fishers can be included in management decisions in all phases of forest planning and application. Habitat conservation can be achieved by considering the distribution and abundance of habitats required by fishers throughout the landscape, within the home range, and in residual and managed stands.

Specifically, decisions to benefit fishers can be made as part of the following planning processes and operational activities:

1. Sustainable Forest Management plans:
  - Determining harvest areas within Landscape Unit
  - Timing, rate, and rotation of harvesting
2. Silvicultural Prescriptions for specified cutting permit areas:
  - Identifying Wildlife Tree Patches to maximize inclusion of preferred tree species and stems with important structural features (e.g., large DBH, cavity or rust broom present)
  - Setting retention targets for structural attributes (e.g., CWD, stem density); achieved through different harvesting methods, salvage options, and site preparations.
3. Harvesting and site preparation, through operator-based decisions:
  - Single tree retention (wildlife trees or potential recruitment)
  - Woody debris waste pile amounts and configurations
  - Retention of patches of structure (e.g., shrubby areas or advanced regeneration)
  - Process-at-stump options

An extension program that includes a pictorial habitat handbook would be one extension tool to help planners, foresters, and operators to incorporate fisher habitat considerations into forest management.

This multi-scaled approach to habitat management, although flexible, must be applied prudently. It is unlikely that the cumulative degradation of larger scale habitats (e.g., landscapes, stands) can be totally compensated by prescriptions at smaller scales. Therefore, habitat management initiatives conducted at smaller spatial scales must not preclude appropriate management considerations at higher levels.

To facilitate the incorporation of best management practices for fishers into forest planning activities, it would be advantageous for forest inventory data to include structural habitat variables that are important to fishers. Without this data, managers will not be as effective in managing for fisher habitat. To help forestry workers implement habitat measures for fishers in the field, ground-based assessment tools need to be developed that easily identify the most appropriate trees for retention (e.g., trees with cavities present or with the greatest potential for future cavity creation). The inclusion of fisher-related variables in forest inventories and the development of a ground-based assessment will not only benefit fishers but will also benefit the management of many other wildlife (e.g., American marten, secondary cavity nesters).

Our work suggests many opportunities for the enhancement of degraded habitats for fishers. These would create or facilitate the natural processes of growth, disease, death, and decay of

trees that are important to fishers. Potential habitat enhancement options include the following activities:

- Inoculate spruce trees with broom rusts (or plant kinnikinnick, the telial host of *Chrysomyxa arctostaphyli*) to facilitate the formation of rust brooms,
- Inoculate cottonwood trees with heart-rot fungus to promote cavity formation (reproductive dens and rest sites),
- Damage large deciduous trees to facilitate cavity creation (e.g., mechanically remove limbs, drill holes into tree bole),
- Plant important tree species in strategic locations (e.g., cottonwood trees in appropriate non-riparian microsites),
- Create CWD sites, and
- Develop artificial den sites that mimic the functioning of reproductive dens.

Few related management prescriptions or enhancement trials have been conducted, so any such initiatives should be carried out using an adaptive management framework.

The most important outcome of this project will be the application of our better understanding of fisher ecology to the landbase. As such, we recommend that targeted extension initiatives be developed and implemented to ensure this information is conveyed to agencies and organizations that affect fisher conservation in the province. Potential extension targets include:

- Forest licencees with operations in the SBSmk and SBSwk biogeoclimatic subzones, including Canadian Forest Products Ltd., Abitibi Consolidated, and BC Timber Sales.
- Regulatory agencies whose jurisdictions affect fisher populations and their habitat, including the Ministry of Environment and Ministry of Forests and Range.
- Local trappers and the British Columbia Trappers Association,
- Organizations, such as BC Hydro, whose developments affect populations of fishers, and
- Other members of the scientific community who may apply these results elsewhere in the range of fishers.

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## 15.0 APPENDICES

Appendix 4-1. Morphological metrics for 22 fishers captured in or adjacent to the Williston study area of north-central British Columbia, November 1996 to March 2000.

Fisher ID	Age <sup>a</sup>	Sex	Weight (kg)	Neck girth (cm)	Chest girth (cm)	Body length (cm)	Tail length (cm)	Total length (cm)	Head width (cm)	Head depth (cm)	Head circumference (cm)
M01	>18 months	Male	5.0	23.0	31.0	65.6 <sup>b</sup>	37.3 <sup>b</sup>	102.9 <sup>b</sup>	6.6	7.3	26.5
F02	>18 months	Female	2.5	16.5	25.0	56.6 <sup>b</sup>	34.2 <sup>b</sup>	90.9 <sup>b</sup>	6.2	4.8	22.0
F03	>18 months	Female	3.0	17.0	22.0	58.0	32.0	90.0	6.1	5.3	19.1
F04	>18 months	Female	2.4	15.0	21.0	57.5 <sup>b</sup>	35.2 <sup>b</sup>	92.7 <sup>b</sup>	7.0	6.0	19.5
F05	>18 months	Female	3.5	17.8	25.5		36.5				19.5
M06	>18 months	Male	3.6	18.5	25.0	60.5	37.0	97.5	7.1	5.2	22.5
F07	>18 months	Female	2.9	17.8	23.5	60.6 <sup>b</sup>	39.1 <sup>b</sup>	99.8 <sup>b</sup>	6.1	5.0	20.9
M08	>18 months	Male	5.8	24.2	30.5	70.8	38.4	109.2	9.0	11.8	30.1
F09	>18 months	Female	2.8	17.0	21.3	59.6 <sup>b</sup>	35.4 <sup>b</sup>	94.9 <sup>b</sup>	5.7	4.5	22.0
F10	Juvenile	Female	2.2	15.5	22.0	53.0	33.0	86.0	5.5	4.5	18.0
F11	Juvenile	Female	2.8	17.0	22.0	57.5	35.5	93.0	5.9	4.7	19.0
F12	>18 months	Female	2.3	16.0	22.0	57.4	36.0	93.4	6.1	4.2	18.0
F13	Juvenile	Female	2.2	16.0	21.3	53.2	33.5	86.7	5.7	4.6	19.2
M14	Juvenile	Male	3.7	19.2	26.1	65.3	39.4	104.7	6.6	5.2	22.0
F15	>18 months	Female	2.2	16.0	20.0	54.0	31.0	85.0	5.8	4.6	18.0
F16	>18 months	Female	2.8	18.0	24.3	55.7	35.9	91.6	6.5	5.9	21.0
F17	>18 months	Female	3.0	18.7	26.8	55.4 <sup>b</sup>	35.0 <sup>b</sup>	90.5 <sup>b</sup>			18.5
F18	>18 months	Female	2.3		23.5	55.0	30.0	85.0	5.9	4.7	
M19	>18 months	Male	6.2	26.8	34.2	76.0	37.5	113.5			30.0
M20 (juv)	Juvenile	Male	4.8	22.2	31.2	64.3	36.7	101.0			
M20 (>18)	>18 months	Male	5.4	23.0	29.2	68.3	39.5	107.8	7.3	7.3	25.5
M30	>18 months	Male	4.5	24.0	30.0	70.0	37.0	107.0	8.9	6.5	27.0
F300	Juvenile	Female	2.2	16.5	22.0	53.0	32.0	85.0	5.6	4.4	17.0

<sup>a</sup> Measurements for adults were taken when individuals were >18 months old or between 5.5 and 7.5 months old (juvenile).

<sup>b</sup> Skeletal metrics should not change once a fisher is >1 yr of age (Douglas and Strickland 1987, Powell 1993). Therefore, for individuals that were >18 months old and had their skeletal features measured on more than one occasion, an average value was calculated and used to represent the individual.

Appendix 6-1. Coefficient of overlap among aggregate home ranges and core areas of radio-tagged fishers in the Williston region, 1996 to 2000. Lower diagonal is the overlap among 95% UD home ranges. Upper diagonal is overlap among 50% UD core areas. The overlap between F07 and F17 (in italics) resulted from the incorporation of F07's home range by F17 following the death of F07.

Fisher ID	F02	F04	F07	F09	F17	F18	M01	M20
F02		0	0	0	0	0	0	0
F04	0		0	0	0	0	0	0
F07	0.06	0		0	0.23	0	0	
F09	0	0	0		0	0	0.47	0
F17	0.05	0.05	<i>0.53</i>	0		0	0	0.12
F18	0	0	0	0	0		0	0
M01	0	0	0	0.19	0	0		0
M20	0.07	0.19		0	0.24	0	0	

Appendix 6-2. Coefficient of overlap among winter home ranges and core areas of radio-tagged fishers in the Williston region, 1996 to 2000. Lower diagonal is the overlap among 95% UD home ranges. Upper diagonal is overlap among 50% UD core areas.

Fisher ID	M01	F02	F04	F09	F17	F18
M01		0	0	0.21	0	0
F02	0		0	0	0	0
F04	0	0		0	0	0
F09	0.42	0	0		0	0
F17	0	0.11	0.04	0		0
F18	0	0	0	0	0	

Appendix 6-3. Coefficient of overlap among non-winter home ranges and core areas of radio-tagged fishers in the Williston region, 1996 to 2000. Lower diagonal is the overlap among 95% UD home ranges. Upper diagonal is overlap among 50% UD core areas. F07 and F20 were not concurrently alive, so no overlap occurred.

Fisher ID	M01	F02	F03	F04	F05	F07	F09	M20
M01		0	0	0	0	0	0.05	0
F02	0		0	0	0	0	0	0
F03	0	0		0	0	0	0	0
F04	0	0	0		0	0	0	0
F05	0	0	0	0		0	0	0
F07	0	0.04	0	0	0		0	0
F09	0.49	0	0	0	0	0		0
M20	0	0.01	0	0.11	0	0	0	

Appendix 10-1. Variables used in models that predicted the selection of elements used by radio-tagged fishers in the Williston region of north-central British Columbia, 1997-2000. Type of data or unit for each variable is listed in parentheses.

Variable	Description
<b>Arboreal rest sites</b>	
Tree species	Species of tree (8 categories: black cottonwood, paper birch, trembling aspen, lodgepole pine, black spruce, hybrid spruce, subalpine fir)
DBH	Diameter-at-breast height (cm)
Crown class	Position of crown within canopy of stand (4 categories: dominant, codominant, intermediate, suppressed)
Tree status	Relative health of tree (3 categories: alive, declining, dead)
Presence of rust brooms	Whether tree had rust brooms (binary)
Presence of pathogens	Whether tree stem had visible signs of pathogens (binary)
Presence of spruce	Whether tree stem was a black spruce or hybrid spruce (binary)
Presence of <i>Populus</i>	Whether tree stem was a black cottonwood or trembling aspen (binary)
<b>CWD rest sites</b>	
Coniferous piece	Whether piece was coniferous species (binary)
Diameter	Diameter (cm) of piece at transect crossing point
Decay class	Decay of piece based upon wood texture, portion of piece on ground, presence of twigs, and loss of bark (5 categories)
Length	Total length of piece (m)
Height above ground	Height above ground (cm) of piece at transect encounter point
Length of potential resting space	Length of piece with the following criteria that provided sheltered interstitial space for resting either in or under the piece (m): ≥7.5 m long, >35 cm in diameter somewhere along its length, and its lower surface was 25-50 cm above the ground; or ≥75 cm in diameter, hollow, and ≥4 m long
<b>Reproductive dens</b>	
Tree species	Species of tree (2 categories: black cottonwood, other species)
DBH	Diameter-at-breast height (cm)
Tree status	Relative health of tree (3 categories: alive, declining, dead)
Tree cover in patch	Cover of trees >10 m tall within 400-m <sup>2</sup> plot (%)
High-shrub cover in patch	Cover of shrubs 2-10 m tall within 400-m <sup>2</sup> plot (%)
Leaf-on cover in patch	Maximum cover of all plants within 400-m <sup>2</sup> plot (%)

Appendix 10-2. Variables used in models that predicted selection of 400 m<sup>2</sup>-patches used by radio-tagged fishers in the Williston region of north-central British Columbia, 1997-2000. Variables used to assess selection of patches for denning are not listed. Type of data or unit for each variable is listed in parentheses.

Variable	Description
<u>Resting</u>	
Coniferous tree cover	Cover of coniferous species in the shrub and tree layers (%)
Deciduous tree cover	Cover of deciduous species in the shrub and tree layers (%)
High-shrub cover	Cover of all plants in the high-shrub layer (2-10 m; %)
Low-shrub cover	Cover of all woody plants in the low-shrub layer (0.15-2 m; %)
Leaf-off cover during winter	Cover of all plant species during winter (%)
Leaf-on cover during non-winter	Cover of all plant species during non-winter (%)
Number of deciduous tree species	Number of deciduous tree species in 400-m <sup>2</sup> patch (continuous)
Density of trees >35 cm dbh	Density of trees that were >35 cm dbh (stems/ha)
Density of trees with rust brooms	Density of trees with rust brooms (stems/ha)
Density of trees with cavities	Density of trees with cavities or visible signs of internal decay (stems/ha)
Maximum dbh of tree in patch	Diameter-at-breast height of largest tree in 400-m <sup>2</sup> patch (cm)
Volume of elevated large CWD	Volume of pieces ≥20 cm diameter and suspended off the ground at transect crossing point (m <sup>3</sup> /ha)
Estimated rest-site potential	Total length of pieces that provided suitable cavities for resting either in or under piece (m)
Ambient temperature >0°C	Whether ambient temperature at time of radiolocation was above freezing (binary)
Snow ≥ 15 cm deep	Whether snow depth at time of radiolocation was ≥ 15 cm (binary)
Presence of water within 100 m	Presence of creeks, river, lakes, or marshes within 100 m (binary)
Slope	Slope of plot (%)
<u>Active/unknown behaviour</u>	
Leaf-off cover during winter	Cover of all plant species during winter (%)
Leaf-on cover during non-winter	Cover of all plant species during non-winter (%)
Coniferous shrub cover	Cover of coniferous species in the high- or low-shrub layers (0.15-10 m; %)
Coniferous tree cover interacting with stand-averaged coniferous tree cover	Cover of coniferous trees in 400-m <sup>2</sup> plot multiplied by the average cover of coniferous trees in that combination of ecosystem association and structural stage (% <sup>2</sup> )
Deciduous tree cover interacting with stand-averaged deciduous tree cover	Cover of deciduous trees in 400-m <sup>2</sup> plot multiplied by the average cover of deciduous trees in that combination of ecosystem association and structural stage (% <sup>2</sup> )
High-shrub cover interacting with stand-averaged high-shrub cover	Cover of high shrubs (2-10 m) in 400-m <sup>2</sup> plot multiplied by the average cover of coniferous trees in that combination of ecosystem association and structural stage (% <sup>2</sup> )
Low-shrub cover interacting with stand-averaged low-shrub cover	Cover of low shrubs (0.15-2 m) in 400-m <sup>2</sup> plot multiplied by the average cover of low shrubs in that combination of ecosystem association and structural stage (% <sup>2</sup> )
Density of trees with rust brooms	Density of trees with rust brooms (stems/ha)
Density of trees with cavities	Density of trees with cavities (stems/ha)
Volume of CWD	Total volume of CWD (m <sup>3</sup> /ha)
Volume of elevated CWD	Total volume of CWD elevated above ground on transects (m <sup>2</sup> /ha)
Volume of CWD interacting with stand-averaged volume of CWD	Total volume of CWD in plot multiplied by the average volume of CWD for that combination of ecosystem association and structural stage ([m <sup>3</sup> /ha] <sup>2</sup> )
Estimated length of logs suitable for travelling	Total length of logs ≥7.5 m long, ≥25 cm in diameter, decay class 2 or 3, with upper surface >50 cm above the ground, and no obstructions that would impede movement (m)

Appendix 10-3. Information-theoretic analysis of factors affecting selection of trees within patches in which fishers rested in the Williston region of north-central British Columbia, 1997-2000. A “\*\*” marks 95% confidence set of best models.  $n = 39$  used, 207 unused elements.

Model ID	Model category	Probability of use of tree for resting related to:	$K^a$	$QIC_u^b$	$\Delta_I^c$	$w_i^d$	Area under ROC curve
E-AR9	Tree size, pathogens	* Presence of rust brooms in spruce trees and DBH of <i>Populus</i> species with pathogens	4	164.329	0	0.796	0.80
E-AR10	Tree size, pathogens	* DBH of spruce trees with rust brooms and DBH of <i>Populus</i> species with pathogens	4	168.209	3.881	0.114	0.80
E-AR4	Pathogens	* Presence of rust brooms	3	168.701	4.372	0.089	0.74
E-AR3	Crown	Crown class	5	200.178	35.85	0	0.71
E-AR7	Tree size & species	DBH interacting with species	5	205.593	41.265	0	0.71
E-AR2	Tree species	Species	4	207.747	43.419	0	0.64
E-AR1	Tree size	DBH	3	212.679	48.351	0	0.68
E-AR8	Tree size, pathogens	DBH, presence of pathogens	4	214.672	50.344	0	0.64
Null		Null model (no selection)	2	219.464	55.136	0	0.50
E-AR5	Pathogens	Presence of pathogens	3	220.192	55.863	0	0.46
E-AR6	Pathogens	Tree health [alive/declining/dead]	4	223.234	58.905	0	0.52

<sup>a</sup> number of estimated parameters in associated model

<sup>b</sup> Quasi-likelihood Information Criterion for small samples (Pan 2001)

<sup>c</sup> difference in  $QIC_u$  scores between model and best-selected model

<sup>d</sup> relative likelihood of model; Akaike weight (Burnham and Anderson 1998)

Appendix 10-4. Information-theoretic analysis of models to explain selection of pieces of CWD within patches (i.e., two 24-m transects) used by radio-tagged fishers for resting in the Williston region of north-central British Columbia, 1997-2000.  $n = 12$  used, 202 unused elements. A “\*\*” marks 95% confidence set of best models.

Model ID	Model category	Probability of use of CWD piece for resting related to:	K <sup>a</sup>	QIC <sub>u</sub> <sup>b</sup>	$\Delta_i^c$	w <sub>i</sub> <sup>d</sup>	Area under ROC curve
E-CWD5	Cavity under logs	* Estimated rest-site potential	3	88.003	0	0.535	0.77
E-CWD6	Cavity under logs	* Height above ground	3	89.177	1.174	0.297	0.73
E-CWD1	Piece characteristics	* Diameter	3	91.154	3.151	0.111	0.79
E-CWD2	Piece characteristics	* Length	3	94.255	6.252	0.023	0.65
E-CWD3	Piece characteristics	Decay class	3	94.255	6.252	0.023	0.65
Null		Null model (no selection)	2	96.46	8.457	0.008	0.50
E-CWD4	Piece characteristics	Coniferous piece	3	98.423	10.42	0.003	0.49

<sup>a</sup> number of estimated parameters in associated model

<sup>b</sup> Quasi-likelihood Information Criterion for small samples (Pan 2001)

<sup>c</sup> difference in QIC<sub>u</sub> scores between model and best-selected model

<sup>d</sup> relative likelihood of model; Akaike weight (Burnham and Anderson 1998)

Appendix 10-5. Average values of structural attributes at patches used by fishers and comparison points within the same stand in the Williston region of north-central British Columbia. Average patch values were not stratified by ecosystem association or structural stage.  $n = 141$  radiolocations and 141 plots located at a randomly located site elsewhere within the same stand.

Variable	Used		Unused	
	Mean	Std Dev	Mean	Std Dev
<u>Vegetation cover (%)</u>				
Tree cover	15.3	13.0	13.1	12.2
Coniferous tree cover	12.2	11.9	10.7	10.7
Deciduous tree cover	3.9	7.3	3.2	7.3
High-shrub cover	23.2	15.3	23.3	17.1
Coniferous shrub cover	8.1	10.9	8.4	12.4
Low-shrub cover	27.0	18.6	27.9	21.9
Leaf-off cover <sup>a</sup>	20.7	11.4	19.6	13.4
Leaf-on cover <sup>a</sup>	58.5	22.5	57.8	24.8
<u>Tree density (stems/ha)</u>				
All trees	374.0	350.8	358.0	401.8
Trees > 35 cm dbh	80.3	96.9	65.2	96.4
Trees with cavities	3.9	11.3	6.0	36.9
Potential den trees	2.0	6.4	1.5	6.6
Trees with rust brooms	13.5	36.5	3.9	17.7
Declining or dead trees <sup>b</sup>	44.0	95.4	43.1	97.1
<u>Coarse woody debris</u>				
Number of pieces/transect	14.8	9.5	13.2	9.3
Density (pieces/m)	0.4	0.6	0.3	0.2
Index of aggregation	2.1	1.2	2.0	1.3
Mean piece length (m)	7.4	3.6	8.1	3.9
Total volume (m <sup>3</sup> /ha)	173.5	182.9	127.1	105.2
Hard <sup>c</sup> volume (m <sup>3</sup> /ha)	119.5	170.0	83.9	82.8
Elevated <sup>d</sup> volume (m <sup>3</sup> /ha)	80.7	135.7	55.2	63.9
Elevated large <sup>e</sup> volume (m <sup>3</sup> /ha)	54.1	127.0	32.0	50.2
Total length with rest-site potential (m)	2.9	7.8	1.2	4.2
Total length suitable for travel (m)	1.4	2.1	1.1	1.8

<sup>a</sup> cover provided by trees and shrubs

<sup>b</sup> appearance codes 2-9 ([BCMELP and BCMOF] 1998d)

<sup>c</sup> decay classes 1-3 ([BCMELP and BCMOF] 1998e)

<sup>d</sup> piece suspended above ground at survey point

<sup>e</sup> pieces > 20 cm diameter and suspended above ground

Appendix 10-6. Information-theoretic analysis of models to explain selection of patches within stands used by radio-tagged fishers for resting in the Williston region of north-central British Columbia, 1997-2000.  $n = 62$  radiolocations. A “\*\*” demarks 95% confidence set of best models.

Model ID	Model category	Probability of use of patch for resting within stand related to:	K <sup>a</sup>	QIC <sub>U</sub> <sup>b</sup>	$\Delta_i^c$	W <sub>i</sub> <sup>d</sup>	Area under ROC curve
P-R3	Tree density, CWD	* Density of trees with rust brooms, estimated rest-site potential	4	150.78	0	0.921	0.75
P-R4	Tree density, CWD	* Density of trees with rust brooms, volume of elevated large CWD	4	156.412	5.632	0.055	0.68
P-R1	Tree density	Density of trees with rust brooms	3	160.012	9.232	0.009	0.66
P-R5	Tree density, CWD	Volume of elevated large CWD, density of trees >35 cm dbh, density of trees with rust brooms	5	160.177	9.397	0.008	0.66
P-R6	Tree density, CWD, abiotic conditions	Density of trees with rust brooms when ambient temperature > 0°C, estimated rest-site potential when snow ≥ 15 cm deep	4	160.902	10.121	0.006	0.68
P-R7	Tree density, CWD, & abiotic conditions	Density of trees with rust brooms when ambient temperature > 0°C, volume of elevated large CWD when snow ≥ 15 cm deep	4	166.041	15.261	0	0.62
P-R10	CWD	Estimated rest-site potential	3	167.585	16.805	0	0.61
P-R8	Tree density, CWD, & abiotic conditions	Density of trees with rust brooms interacting with ambient temperature, estimated rest-site potential when snow ≥ 15 cm deep	4	172.581	21.801	0	0.64
P-R13	General	Presence of water within 100 m, number of tree layers, number of deciduous tree species	5	173.338	22.558	0	0.66
P-R14	General	Leaf-off cover during winter, leaf-on cover during non-winter, maximum dbh of tree in patch, slope	6	174.256	23.476	0	0.65
Null	Null						
P-R11	CWD & cover	Volume of CWD, coniferous tree cover, deciduous tree cover, high-shrub cover, low-shrub cover	7	175.901	25.12	0	0.50
				176.273	25.492	0	0.64
P-R9	Cross-scale factors	Coniferous tree cover interacting with stand-averaged coniferous tree cover	3	176.439	25.658	0	0.56
P-R2	Tree density	Density of trees with cavities	3	177.033	26.252	0	0.49
P-R12	Foraging	Coniferous shrub cover	3	177.057	26.277	0	0.53

<sup>a</sup> number of estimated parameters in associated model

<sup>b</sup> Quasi-likelihood Information Criterion for small samples (Pan 2001)

<sup>c</sup> difference in QIC<sub>U</sub> scores between model and best-selected model

<sup>d</sup> relative likelihood of model; Akaike weight (Burnham and Anderson 1998)

Appendix 10-7. Information-theoretic inference of candidate models examining the factors that affected selection of patches used for whelping by radio-tagged fishers in the Williston Region of north-central British Columbia, 1996-2000. A “\*\*” demarks 95% confidence set of best models.  $n = 13$  radiolocations.

Model ID	Probability of use of patch for whelping within stand related to:	K <sup>a</sup>	QIC <sub>U</sub> <sup>b</sup>	$\Delta_i^c$	w <sub>i</sub> <sup>d</sup>	Area under ROC curve
P-W5	* Maximum dbh of trees in patch	3	33.27	0	0.870	0.65
P-W2	* Deciduous tree cover (%)	3	39.514	6.244	0.038	0.58
Null	* Null model (no selection)	2	40.044	6.774	0.029	0.50
P-W3	* Density of cavity trees in patch Number of deciduous species	3	40.367	7.097	0.025	0.58
P-W4	in patch Density of den-sized	3	40.367	7.097	0.025	0.58
P-W1	cottonwood trees (stems/ha)	3	41.88	8.609	0.012	0.46

<sup>a</sup> number of estimated parameters in associated model

<sup>b</sup> Quasi-likelihood Information Criterion for small samples (Pan 2001)

<sup>c</sup> difference in QIC<sub>U</sub> scores between model and best-selected model

<sup>d</sup> relative likelihood of model; Akaike weight (Burnham and Anderson 1998)

Appendix 10-8. Information-theoretic inference of candidate models examining the factors that affected selection of patches by radio-tagged fishers while either active or for which the behaviour was unknown in the Williston Region of north-central British Columbia, 1996-2000. A “\*\*” marks 95% confidence set of best models.  $n = 66$  radiolocations.

Model ID	Model category	Probability of use of patch while active or when behaviour unknown related to:	K <sup>a</sup>	QIC <sub>u</sub> <sup>b</sup>	$\Delta_i^c$	w <sub>i</sub> <sup>d</sup>	Area under ROC curve
P-A8	General	* Volume of CWD	3	186.128	0	0.294	0.58
Null		* Null model (no selection)	2	186.991	0.863	0.191	0.50
P-A6	Cover, travel	* Coniferous shrub cover, estimated length of logs suitable for travelling	4	187.413	1.285	0.155	0.55
P-A5	Foraging, cover	* Volume of elevated CWD, low-shrub cover	4	187.768	1.641	0.13	0.57
P-A1	Cover	* Leaf-off cover during winter, leaf-on cover during non-winter	4	188.658	2.53	0.083	0.59
P-A2	Foraging	* Coniferous shrub cover	3	188.956	2.829	0.072	0.53
P-A4	Foraging	* Coniferous shrub cover, volume of elevated CWD, density of trees with rust brooms	5	190.621	4.493	0.031	0.58
P-A3	Foraging	Coniferous shrub cover, density of trees with rust brooms	4	190.855	4.727	0.028	0.53
P-A7	Cross-scale	Volume of CWD depending upon stand-averaged volume of CWD, coniferous tree cover depending upon stand-averaged coniferous tree cover, deciduous tree cover depending upon stand-averaged deciduous tree cover, high-shrub cover depending upon stand-averaged high-shrub cover, low-shrub cover depending upon stand-averaged low-shrub cover	7	191.855	5.728	0.017	0.60

<sup>a</sup> number of estimated parameters in associated model

<sup>b</sup> Quasi-likelihood Information Criterion for small samples (Pan 2001)

<sup>c</sup> difference in QIC<sub>u</sub> scores between model and best-selected model

<sup>d</sup> relative likelihood of model; Akaike weight (Burnham and Anderson 1998)

Appendix 10-9. Description of variables used in candidate models that predicted the selection of home ranges within the landscape by radio-tagged fishers in the Williston region of north-central British Columbia, 1996-2000.

Variable	Description
Recent logging	Percentage of home range logged since 1988
Stands $\geq$ 30% cover	Percentage of home range in stands with $\geq 30\%$ tree cover
Habitat suitability index	Area-weighted average of Allen's (1983) habitat suitability index
Granularity	Number of stands/km <sup>2</sup> in home range
Complex structural stages	Percentage of home range in young forest, mature forest, and old forest structural stages
Forested ecosystem associations	Percentage of home range in Pine-Cladina, Spruce-Dry, Black Spruce, Spruce-Zonal, Spruce-Moist, or Spruce-Wet ecosystem associations
Non-forested ecosystem associations	Percentage of home range in non-vegetated, wetland, or open water ecosystem associations
Mature and old structural stage riparian	Length of creeks and rivers in mature and old forest structural stages in each home range (km/km <sup>2</sup> )
Mature and old structural stage productive ecosystems	Percentage of home range in mature and old forest structural stages of the Spruce-Zonal, Spruce-Moist, or Spruce-Wet ecosystem associations
Open areas	Percentage of home range logged since 1988 or in wetland ecosystem association

Appendix 10-10. Description of variables used in candidate model that predicted the selection of stands within home ranges of radio-tagged fishers in the Williston region of north-central British Columbia, 1996-2000. Estimates of cover, density, and CWD for each stand were derived from mean values found at randomly located plots within the specific combination of ecosystem association and structural stage.

Variable	Description
<b>General</b>	
Ecosystem association	9 ecosystem associations derived from amalgamation of 31 site series in SBSmk1, SBSmk2, and SBSwk2 variants
Structural stage	8 structural stages ranging from non-vegetated to old forest
<b>Vegetation cover (%)</b>	
Coniferous tree cover	Cover of coniferous trees $\geq 10$ m tall
Coniferous tree cover during winter	Cover of coniferous trees $\geq 10$ m tall for radiolocations collected during winter
Coniferous shrub cover while active	Cover of coniferous shrubs 0.15 – 10 m tall at active radiolocations
Deciduous tree cover	Cover of deciduous trees $\geq 10$ m tall
High-shrub cover	Cover of shrubs 2 – 10 m tall at peak cover
Leaf-on cover while whelping	Cover provided by all plants at peak cover for radiolocations collected during the whelping period
Overhead cover	Total cover provided by trees and shrubs
Seasonal cover	Leaf-on cover during non-winter, leaf-off cover during winter
<b>Tree density (stems/ha)</b>	
Density of all trees	Density of all stems $\geq 15$ cm dbh
Density of dead trees while resting	Density of all dead stems $\geq 15$ cm dbh
Density of den-sized black cottonwood trees while whelping	Density of black cottonwood trees $\geq 88.6$ cm dbh with appearance code 2 <sup>a</sup> (declining) during whelping period
Density of trees with rust brooms	Density of trees $\geq 15$ cm dbh with rust brooms
Density of trees with rust brooms while resting	Density of trees $\geq 15$ cm dbh with rust brooms at resting radiolocations
<b>Coarse woody debris</b>	
Volume of CWD	Volume of CWD $\geq 7.5$ cm diameter ( $m^3/ha$ )
Volume of hard CWD	Volume of CWD $\geq 7.5$ cm diameter in decay class 1, 2 or 3 <sup>b</sup> ( $m^3/ha$ )
Volume of elevated large CWD	Volume of CWD $\geq 20$ cm diameter no resting on ground ( $m^3/ha$ )
Volume of elevated large CWD while active	Volume of CWD $\geq 20$ cm diameter no resting on ground at active radiolocations ( $m^3/ha$ )
Estimated CWD rest site length while resting	Total length of pieces that provided suitable cavities for resting either in or under piece (m) at resting radiolocations

<sup>a</sup> [BCMELP and BCMOF] 1998d

<sup>b</sup> [BCMELP and BCMOF] 1998e

Appendix 10-11. Lookup table for site series (digits; MacKinnon et al. 1990) or map codes (letters; Resources Information Standards Committee 1998) grouped into 9 ecosystem associations for habitat analysis in the Williston region of north-central British Columbia.

Ecosystem association	Biogeoclimatic variant	SBSmk1	SBSmk2	SBSwk2
	Any			
Non-vegetated	CB, GP, IN, RO, RZ			
Pine - Cladina		02, 03	02	02
Spruce - Dry		04, 05	03	
Spruce - Zonal		01	01	03
Black Spruce		06	04	04
Spruce - Moist		07, 08	05	01, 05
Spruce - Wet		09	06	06
Wetland	OF, FE, OS, WS, LO, LU, WE	10		
Open water	LA, OW, PD, RI			

Appendix 10-12. Average values (SD) of structural variables for each combination of ecosystem association and structural stage found at 95 random patch-comparison and 42 stand-description plots in the Williston region of north-central British Columbia.

Structural stage	N	Cover (%)										
		All trees	High shrub (2-10 m)	Low shrub (0.15-2 m)	Leaf-on <sup>a</sup>	Leaf-off <sup>b</sup>	Coniferous trees	Deciduous trees	Coniferous shrubs			
Pine-Cladina	3	4	0	0	15	12	17	13	29	7	22	10
	4	4	14	10	11	10	8	5	31	10	21	9
	5	3	15	10	18	16	19	10	48	13	18	16
	6	1	25		35		2		61		35	25
Spruce-Dry	2	1	0		1		2		3		3	0
	3	7	1	1	28	11	15	7	38	13	18	11
	4	3	23	11	7	3	17	3	44	11	25	8
	5	5	20	10	8	6	16	12	42	7	21	13
	6	2	25	7	6	6	17	10	45	0	25	10
Spruce-Zonal	3	10	0	0	34	17	31	34	59	21	20	12
	4	5	20	14	34	20	16	11	62	22	25	20
	5	5	23	10	28	21	15	10	60	16	19	9
	6	10	22	8	16	10	22	12	54	15	26	12
Spruce-Moist	3	10	0	1	26	19	26	20	42	27	11	9
	4	3	17	9	19	7	21	21	53	24	26	20
	5	3	25	9	25	22	54	32	83	33	27	11
	6	13	19	10	17	11	51	20	81	25	17	10
	7	7	20	16	16	9	56	18	85	20	20	14
Spruce-Wet	3	4	5	10	9	11	28	15	36	27	9	8
	4	1	20		30		15		60		20	
	5	2	16	13	29	5	47	4	76	13	5	7
	6	7	16	12	20	14	43	27	72	27	11	10
	7	3	12	7	24	12	21	15	49	12	18	9
Black Spruce	3	4	0	0	9	5	18	8	24	4	14	11
	4	4	19	14	14	15	12	5	42	6	35	3
	5	4	16	6	8	5	14	6	37	10	20	3
	6	3	21	5	25	10	28	19	64	27	45	5
Wetlands	2	2	0	0	0	0	5	2	5	2	0	0
	3	1	0		0		15		15		4	
	4	3	1	1	10	3	20	6	28	8	15	5
	5	3	7	3	21	21	10	6	36	17	12	6

<sup>a</sup> includes all deciduous and coniferous plants in the shrub and tree layers

<sup>b</sup> includes all coniferous plants in the shrub and tree layers

Structural stage	N	Stem density (stems/ha)							
						Black cottonwood trees >88.6 cm dbh, declining		Trees with rust brooms	
		All trees	Dead trees	DBH>35 cm				Trees with cavities	
Pine-Cladina	3	4	0	0	0	0	0	0	0
	4	4	131	151	0	0	0	0	0
	5	3	948	598	62	107	0	0	0
	6	1	381	0	0	0	0	0	0
Spruce-Dry	2	1	0	0	0	0	0	0	0
	3	7	78	100	10	25	0	0	0
	4	3	352	321	0	0	0	0	0
	5	5	500	272	96	214	68	96	0
Spruce-Zonal	6	2	792	414	0	0	111	45	0
	3	10	24	77	0	0	0	0	0
	4	5	365	628	14	19	14	19	0
	5	5	718	497	6	14	15	21	0
Spruce-Moist	6	10	770	484	117	174	118	131	0
	3	10	37	90	0	0	0	0	0
	4	3	773	190	98	169	17	29	0
	5	3	613	75	119	165	184	247	0
Spruce-Wet	6	13	360	236	42	81	145	60	10
	7	7	276	131	57	56	172	58	17
	3	4	23	45	0	0	23	45	7
	4	1	613	0	0	0	0	0	3
Black Spruce	5	2	322	429	0	0	65	66	0
	6	7	158	198	13	34	63	31	8
	7	3	653	455	176	277	149	197	0
	3	4	0	0	0	0	0	0	0
Wetlands	4	4	642	787	159	318	11	22	0
	5	4	908	455	17	34	0	0	28
	6	3	869	615	189	90	65	59	55
	2	2	0	0	0	0	0	0	0
	3	1	0	0	0	0	0	0	0
	4	3	73	126	0	0	0	0	0
	5	3	503	587	83	144	0	0	0
									0

		Volume of CWD (m³/ha)								
	Structural Stage	N	Total	Elevated	Elevated large volume		Hard			
Pine-Cladina	3	4	61.00	21.17	15.50	14.34	0.00	0.00	59.75	22.14
	4	4	40.00	52.67	7.50	9.26	0.00	0.00	10.50	12.12
	5	3	88.67	103.47	54.67	80.09	7.00	12.12	77.00	98.47
	6	1	64.00		39.00		0.00		46.00	
Spruce-Dry	2	1	40.00		12.00		12.00		40.00	
	3	7	183.57	157.64	80.29	103.67	37.14	71.94	147.71	160.47
	4	3	133.00	47.47	14.00	12.12	0.00	0.00	18.00	19.05
	5	5	131.60	88.78	31.60	19.68	7.60	16.99	60.80	28.33
Spruce-Zonal	6	2	31.50	36.06	12.50	13.44	0.00	0.00	19.00	22.63
	3	10	65.10	50.96	17.60	19.19	10.30	12.86	44.00	50.32
	4	5	126.80	126.21	46.00	81.31	26.60	59.48	83.60	99.18
	5	5	154.80	160.43	61.20	70.49	37.80	50.69	57.00	63.34
Spruce-Moist	6	10	151.10	103.93	102.10	75.95	40.70	49.01	117.90	85.83
	3	10	115.00	63.22	26.40	19.83	17.00	17.04	76.00	56.59
	4	3	120.67	113.14	34.00	28.62	8.33	7.37	33.33	18.72
	5	3	112.00	40.34	65.33	55.87	36.67	63.51	88.67	47.52
	6	13	163.54	111.82	65.77	69.41	49.00	56.90	102.00	87.44
Spruce-Wet	7	7	168.14	72.80	100.57	65.75	76.71	70.99	138.43	72.12
	3	4	108.00	75.29	45.25	64.11	29.50	51.31	67.00	74.09
	4	1	8.00		0.00		0.00		2.00	
	5	2	243.50	19.09	84.50	112.43	60.50	85.56	103.50	133.64
	6	7	164.57	152.30	85.57	108.62	77.86	98.90	111.14	116.69
Black Spruce	7	3	203.33	138.23	70.33	49.03	49.00	46.29	161.00	102.06
	3	4	107.75	35.65	31.75	9.54	12.50	14.53	86.25	22.05
	4	4	91.50	68.92	29.00	16.83	0.00	0.00	30.75	10.69
	5	4	88.50	56.01	38.50	29.73	2.50	5.00	52.50	43.05
Wetlands	6	3	101.00	92.31	48.33	50.85	20.00	22.27	78.00	93.58
	2	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	3	1	0.00		0.00		0.00		0.00	
	4	3	10.00	16.46	4.67	7.23	0.00	0.00	10.00	16.46
	5	3	30.33	27.47	26.00	22.34	7.33	6.43	28.67	24.68

CWD measures												
	Structural stage	N	Pieces/transect	Piece length (m)		Total rest potential (m)	Index of aggregation		Travel logs			
Pine-Cladina	3	4	14.75	8.06	4.73	3.64	0.00	0.00	2.46	1.01	0.00	0.00
	4	4	8.25	10.21	4.15	0.02	0.00	0.00	2.11	0.09	0.00	0.00
	5	3	14.67	12.50	10.22	3.39	0.00	0.00	1.59	1.56	0.33	0.58
	6	1	22.00		8.14		0.00		2.28		0.00	
Spruce-Dry	2	1	5.00		6.20		0.00		2.52		0.00	
	3	7	22.29	14.64	6.01	3.67	0.43	1.13	2.23	2.38	1.00	2.24
	4	3	20.67	6.51	5.28	1.26	0.00	0.00	1.37	0.21	0.00	0.00
	5	5	16.20	6.30	8.90	2.76	1.20	2.68	2.00	0.98	0.40	0.89
Spruce-Zonal	6	2	8.50	9.19	5.95	2.05	0.00	0.00	0.88	1.25	0.00	0.00
	3	10	10.10	9.09	6.40	5.13	0.10	0.32	1.64	1.11	0.50	0.71
	4	5	13.60	11.06	8.81	7.39	0.00	0.00	1.70	1.15	1.60	3.05
	5	5	17.40	12.18	8.96	2.86	0.00	0.00	1.31	0.81	1.40	2.19
Spruce-Moist	6	10	21.70	11.47	10.18	2.83	1.30	4.11	1.48	0.42	2.00	1.83
	3	10	11.50	6.82	4.56	2.47	0.00	0.00	2.22	1.13	0.30	0.67
	4	3	20.00	14.11	5.61	1.66	0.00	0.00	2.24	1.46	0.33	0.58
	5	3	16.67	6.35	9.57	2.90	5.33	9.24	2.24	1.17	0.33	0.58
	6	13	9.31	8.69	10.20	3.07	2.54	5.58	2.14	1.41	1.85	1.86
Spruce-Wet	7	7	13.71	6.16	11.76	3.36	5.71	12.50	2.06	0.70	2.00	2.08
	3	4	8.75	5.74	4.55	1.46	0.00	0.00	2.60	2.02	0.00	0.00
	4	1	3.00		3.00		0.00		0.23		0.00	
	5	2	15.00	12.73	11.85	6.33	2.00	2.83	3.34	2.98	4.00	5.66
	6	7	6.86	6.74	10.04	3.94	2.29	2.43	1.75	1.46	1.43	1.81
Black Spruce	7	3	13.00	4.58	11.05	3.62	10.33	9.29	1.95	0.58	2.00	1.00
	3	4	21.00	2.16	4.45	2.59	0.00	0.00	1.47	0.40	0.50	1.00
	4	4	18.25	8.46	5.32	1.21	0.00	0.00	2.14	0.81	0.00	0.00
	5	4	17.00	10.65	8.92	3.80	0.00	0.00	1.60	0.63	0.50	1.00
Wetlands	6	3	15.33	13.05	9.68	2.48	0.00	0.00	1.47	1.20	0.33	0.58
	2	2	0.00	0.00			0.00	0.00			0.00	0.00
	3	1	0.00				0.00				0.00	
	4	3	3.33	4.93	2.28	1.81	0.00	0.00	1.33	1.88	0.00	0.00
	5	3	6.33	7.57	11.04	2.93	0.00	0.00	1.06	0.92	0.00	0.00

Appendix 10-13. Information-theoretic inference of candidate models to explain the selection of stands within the home range of radio-tagged fishers in the Williston region of north-central British Columbia, 1996-2000. A “\*\*” demarks 95% confidence set of best models.

Model ID	Model category	Model components	K <sup>a</sup>	log $\mathcal{L}$	AIC <sub>c</sub> <sup>b</sup>	$\Delta_i^c$	w <sub>i</sub> <sup>d</sup>
S-13	General	* Ecosystem association	8	-1883.46	3782.913	0	0.681
S-10	Resting, cover	* Volume of elevated large CWD, density of trees with rust brooms, coniferous tree cover, deciduous tree cover, high-shrub cover	5	-1887.21	3784.426	1.514	0.319
S-1	Cover	Coniferous tree cover, volume of hard CWD, deciduous tree cover, high-shrub cover	4	-1897.06	3802.123	19.21	0
S-7	Foraging, cover	Volume of CWD, density of all trees, deciduous tree cover	3	-1900.95	3807.901	24.989	0
S-14	General	Structural stage	5	-1902.29	3814.583	31.67	0
S-8	Resting	Volume of elevated large CWD, density of trees with rust brooms	2	-1917.22	3838.44	55.528	0
S-9	Resting	Density of trees with rust brooms while resting, estimated CWD rest site length while resting	2	-1919.07	3842.146	59.233	0
S-11	Resting, foraging, cover	Density of trees with rust brooms while resting, estimated CWD rest site length while resting, density of dead trees while resting, overhead cover	4	-1917.88	3843.766	60.853	0
S-12	Resting, foraging, cover	Density of trees with rust brooms while resting, estimated CWD rest site length while resting, density of dead trees while resting, cover of coniferous shrubs while active, volume of elevated large CWD while active, overhead cover	6	-1917.23	3846.468	63.556	0
S-3	Cover	Overhead cover	1	-1933.05	3868.099	85.186	0
S-2	Cover	Coniferous tree cover during winter, deciduous tree cover (Arthur et al. 1989b)	2	-1932.5	3869.001	86.089	0
S-5	Denning, cover	Density of den-sized black cottonwood trees while whelping, leaf-on cover while whelping	2	-1933.39	3870.78	87.868	0
S-6	Foraging	Cover of coniferous shrubs while active, volume of elevated large CWD while active, overhead cover	3	-1932.44	3870.889	87.976	0
S-4	Cover	Seasonal cover	2	-1933.66	3871.314	88.402	0

<sup>a</sup> number of estimated parameters in associated model

<sup>b</sup> Akaike Information Criterion for small samples (Burnham and Anderson 1998)

<sup>c</sup> difference in AIC<sub>c</sub> scores between model and best-selected model

<sup>d</sup> Akaike weight (Burnham and Anderson 1998)

Appendix 10-14. Mean overlap rates between used and 162 pseudo-home ranges for each of 10 radio-tagged fishers monitored in the Williston region of northcentral British Columbia, 1996-2000.

Fisher ID	Overlap (%)	
	Mean	SD
M01	6	16
F02	1	4
F03	2	8
F04	3	9
F05	3	11
F07	3	7
F09	2	7
F17	2	6
F18	3	9
M20	24	19

Appendix 10-15. Descriptive statistics of used and pseudo-home ranges for 10 radio-tagged fishers monitored in the Williston region of northcentral British Columbia, 1996-2000.

Variable	Metric	Used home ranges (n = 10)		Pseudo-home ranges (n = 1620)	
		Mean	SD	Mean	SD
Recent logging	% of HR <sup>a</sup> logged since 1988	2.85	1.57	4.11	2.74
Stands ≥ 30% cover	% of HR with >=30% canopy closure	74.07	4.86	69.24	11.30
Habitat suitability index	area-averaged HSI score	0.15	0.03	0.12	0.06
Granularity	stands/km <sup>2</sup> of HR	13.36	8.99	13.51	14.50
Complex structural stages	% of HR in young-forest or older structural stages	60.19	7.52	55.32	12.45
Forested ecosystem associations	% of HR in Pine-Cladina, Spruce-Dry, Black Spruce, Spruce-Zonal, Spruce-Moist, or Spruce-Wet ecosystem associations	93.30	2.76	88.99	9.63
Non-forested ecosystem associations	% of HR in non-vegetated, wetland, or open water ecosystem associations	6.56	2.74	10.92	9.67
Mature and old structural stage riparian	km of stream in mature-old forest/km <sup>2</sup> of HR	1.15	0.53	0.90	0.54
Mature and old structural stage	% of HR in mature and old forest structural stages of the Spruce-Zonal, Spruce-Moist, or Spruce-Wet ecosystem associations	26.78	9.82	23.49	11.37
Open areas	% of HR logged since 1988 or in wetland ecosystem association	6.57	3.23	13.42	10.24

<sup>a</sup> HR: home range

Appendix 10-16. Information-theoretic inference of candidate models that explained the selection of home ranges across the landscape by 10 radio-tagged fishers in the Williston region of north-central British Columbia, 1996 to 2000. A “\*\*” demarks 95% confidence set of best models.

Model ID	Model category	Model description	K <sup>a</sup>	logL	AIC <sub>c</sub> <sup>b</sup>	Δ <sub>i</sub> <sup>c</sup>	w <sub>i</sub> <sup>d</sup>
L-9	Avoidance	* Open areas	1	-46.293	94.589	0	0.806
L-8	Avoidance	* Non-forested ecosystem associations	1	-49.484	100.971	6.382	0.033
L-2	Inclusion	* Forested ecosystem associations	1	-49.508	101.018	6.430	0.032
L-10	Avoidance	* Recent logging	1	-49.613	101.229	6.640	0.029
L-6	Inclusion	* Stands ≥ 30% cover	1	-49.923	101.849	7.260	0.021
L-5	Inclusion	* Mature and old structural stage riparian	1	-49.941	101.885	7.296	0.021
L-3	Inclusion	* Habitat suitability index	1	-49.981	101.964	7.375	0.020
L-1	Inclusion	Complex structural stages	1	-50.149	102.300	7.711	0.017
L-4	Inclusion	Mature and old structural stage productive ecosystems	1	-50.522	103.046	8.457	0.012
L-7	General	Granularity	1	-50.937	103.876	9.288	0.008

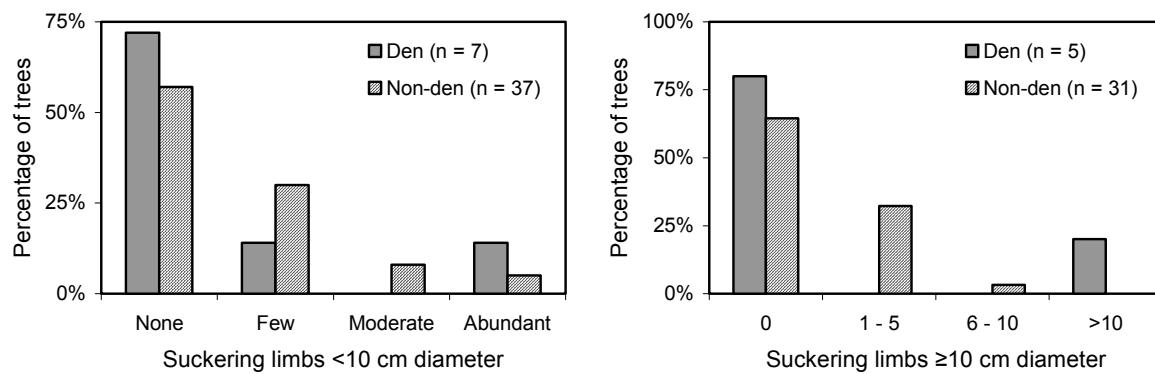
<sup>a</sup> number of estimated parameters in associated model

<sup>b</sup> Akaike Information Criterion for small samples (Burnham and Anderson 1998)

<sup>c</sup> difference in AIC<sub>c</sub> scores between model and best-selected model

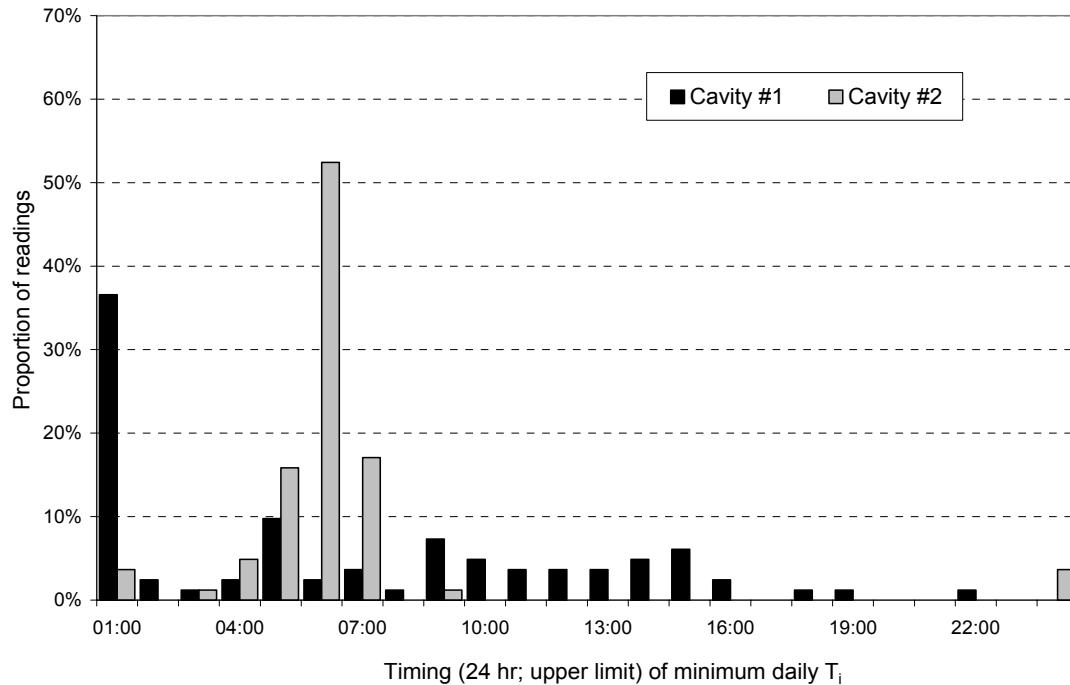
<sup>d</sup> relative likelihood of model; Akaike weight (Burnham and Anderson 1998)

Appendix 12-1. Prevalence of suckering limbs on large-diameter ( $\geq 50$  cm dbh) cottonwood trees in the Williston region of north-central British Columbia, May-June 2000.

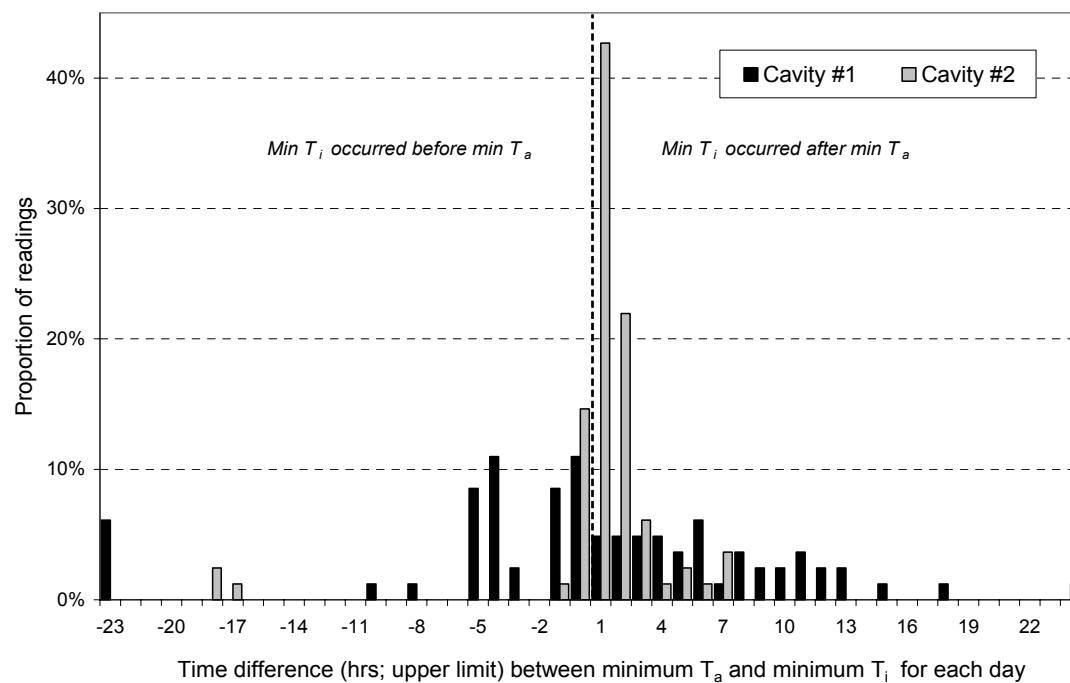


Appendix 12-2. Timing of minimum daily temperatures inside ( $T_i$ ) 2 natural cavities monitored in a cottonwood tree (tree class 2, dbh = 118 cm) located near Prince George, British Columbia, May-July 2001. For all samples,  $n = 82$  daily readings. Cavity #1 had a northeast entrance aspect at 20 m above ground and a chamber height of 62 cm. Cavity #2 had a southwest entrance aspect at 15 m above ground and a chamber height of 3 cm.

- a) Timing of minimum daily  $T_i$  in relation to 24-hr clock.

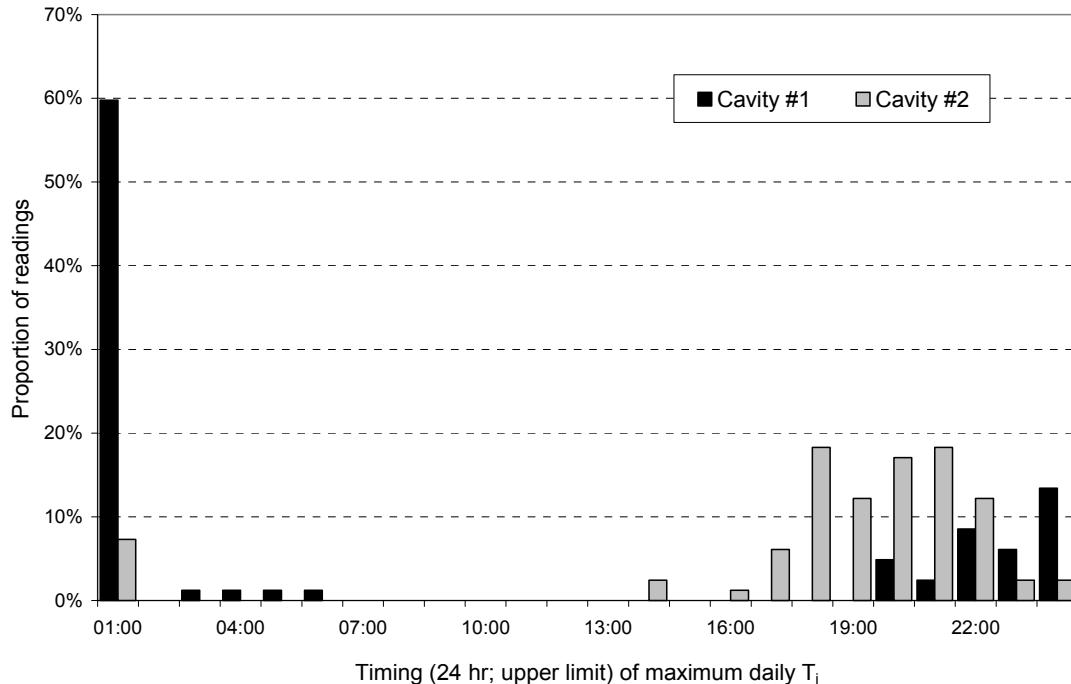


- b) Timing of minimum daily  $T_i$  in relation to minimum daily  $T_a$ .

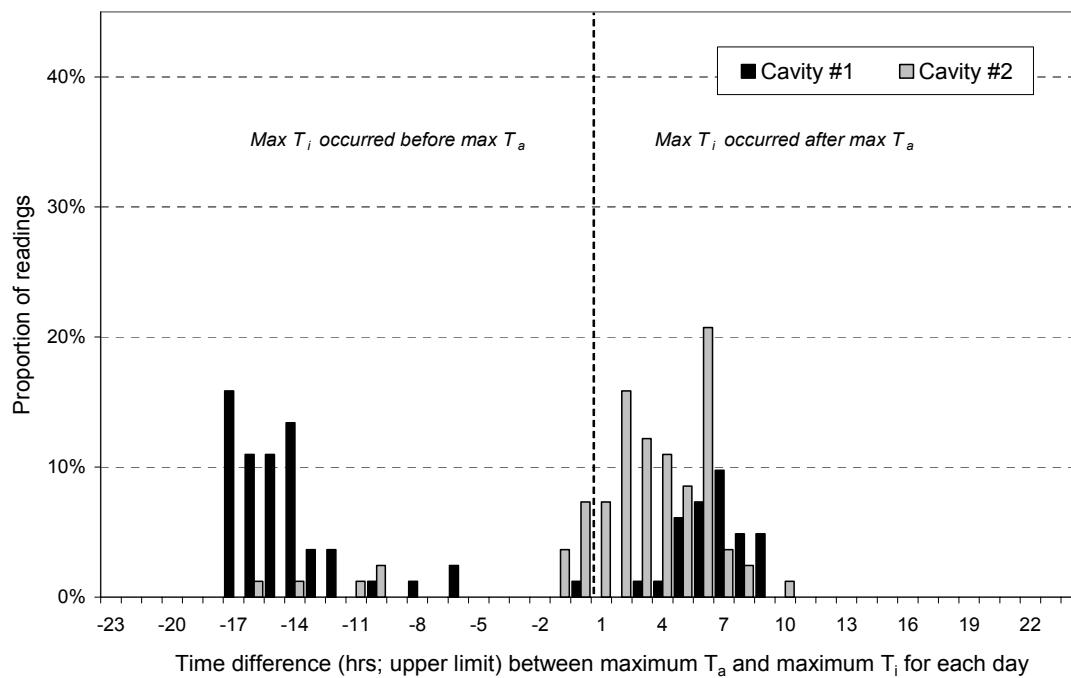


Appendix 12-3. Timing of maximum daily temperatures inside ( $T_i$ ) 2 natural cavities monitored in a cottonwood tree (tree class 2, dbh = 118 cm) located near Prince George, British Columbia, May-July 2001. For all samples,  $n = 82$  daily readings. Cavity #1 had a northeast entrance aspect at 20 m above ground and a chamber height of 62 cm. Cavity #2 had a southwest entrance aspect at 15 m above ground and a chamber height of 3 cm.

a) Timing of maximum daily  $T_i$  in relation to 24-hr clock.

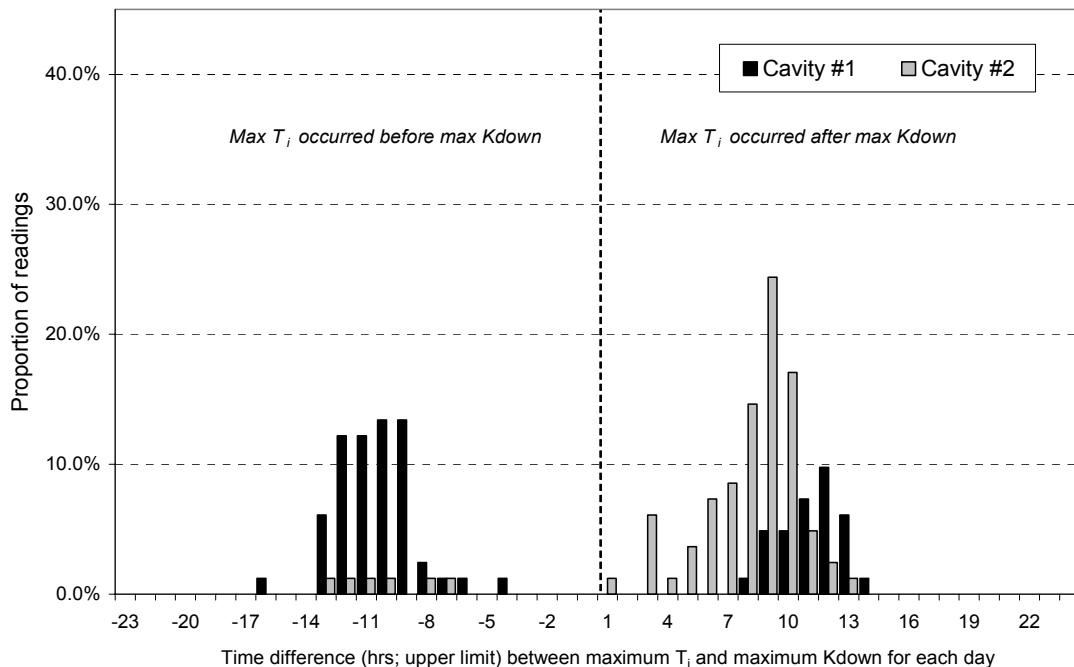


b) Timing of maximum daily  $T_i$  in relation to maximum daily  $T_a$ .

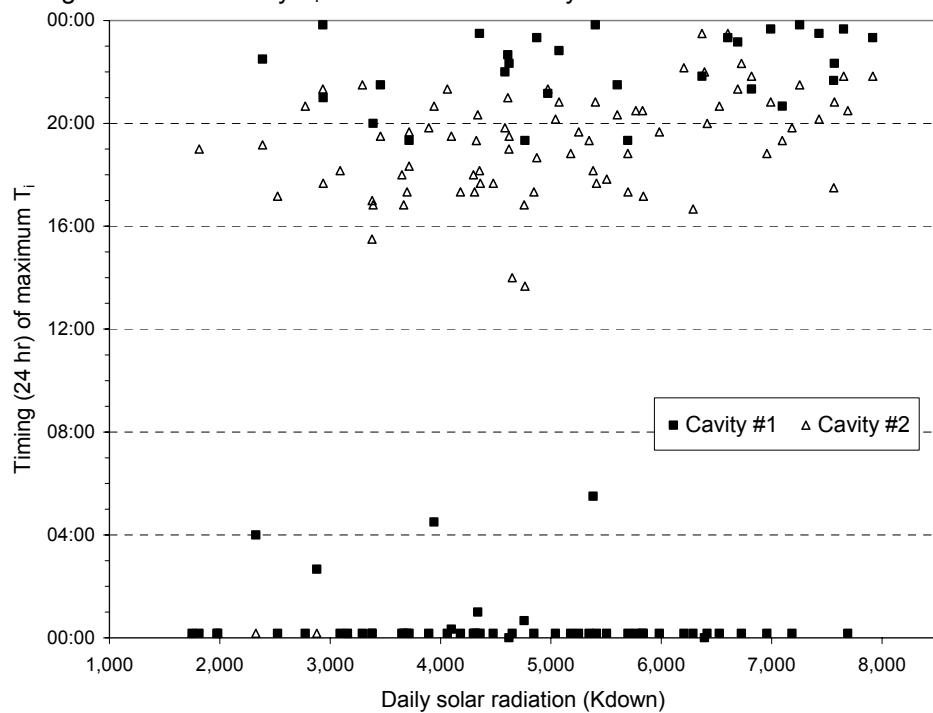


Appendix 12-4. Timing of maximum daily chamber temperatures ( $T_i$ ) for 2 natural cavities in a cottonwood tree (tree class 2, dbh = 118 cm) in relation to solar radiation values ( $K_{down}$ ) recorded at Prince George, British Columbia, May-July 2001. For all samples,  $n = 82$  readings.

a) Timing of maximum daily  $T_i$  in relation to the maximum hourly solar radiation.



b) Timing of maximum daily  $T_i$  in relation to the daily accumulated solar radiation.



Appendix 12-5. Daily range in chamber temperatures ( $T_i$ ) in relation to the daily accumulated ambient temperature ( $T_a$ ) for 2 natural cavities in a cottonwood tree (tree class 2, dbh = 118 cm) located near Prince George, British Columbia, May-July 2001. For both samples,  $n = 82$  readings.

