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Original Article

Classifying Carnivore Tracks Using Dimensions That Control for Snow Conditions

NICHOLAS P. McCANN,[1,2] *Department of Forestry and Natural Resources, Purdue University, West Lafayette, IN 47907, USA*
PATRICK A. ZOLLNER, *Department of Forestry and Natural Resources, Purdue University, West Lafayette, IN 47907, USA*
JONATHAN H. GILBERT, *Great Lakes Indian Fish and Wildlife Commission, P.O. Box 9, Odanah, WI 54861, USA*

ABSTRACT Snow-tracking is important for elucidating patterns of carnivore behavior, but misclassifying tracks reduces the accuracy of snow-tracking studies. Quantitative methods improve accuracy by distinguishing between similar tracks left by different carnivores. American marten (*Martes americana*) and fisher (*Pekania pennanti*) tracks are difficult to distinguish. We studied martens and fishers in northern Wisconsin, USA, during winter 2008–2010, to determine whether dimensions of tracks left in snow differed by snow conditions, and if marten and fisher tracks could be accurately classified by analyzing track dimensions that controlled for snow conditions. Snow depth, snow compaction, and crust depth correlated strongly with fisher step depth. Classification trees accurately classified marten and fisher tracks, and were 5–14% more accurate when track dimensions controlled for snow conditions. Species-only classifications were 91–96% accurate. Trees that classified sex and species were 75–89% accurate, indicating that snow-tracking can be used to estimate sex-specific marten and fisher habitat selection, distribution, and abundance. Controlling for snow conditions improves track classification accuracy for martens and fishers, and would likely improve classification accuracy for other carnivores. © 2017 The Wildlife Society.

KEY WORDS American marten, classification tree, fisher, *Martes americana*, *Pekania pennanti*, snow-tracking, tracking, Wisconsin.

Noninvasive methods are important for studying carnivores. Common noninvasive methods include recording photographs using camera traps, collecting genetics from hair snares and scat, and conducting track surveys (McKelvey et al. 2006, Funston et al. 2010, Long et al. 2011, Kiseleva and Sorokin 2013). Track surveys require minimal equipment and result in a greater probability of detection for some carnivores when compared with camera traps and molecular techniques (Gese 2001, Choate et al. 2006, Gompper et al. 2006, Barea-Azcón et al. 2007, Pirie et al. 2016). Carnivores active during winter are studied by classifying tracks in snow (snow-tracking; Crowley et al. 2012, Proulx 2014), enabling estimates of abundance, habitat selection, and distribution (Squires et al. 2004, Hebblewhite et al. 2014, Kojola et al. 2014).

Investigators use snow-tracking to categorize groups of tracks by gait type and measure track dimensions (Zalewski 1999, Gu et al. 2014). The pattern left by groups of tracks corresponds with movements made by the animal while traveling (its gait; Elbroch 2003). Walking, galloping, bounding, and loping are common gaits (Halfpenny et al. 1995). The 2× lope occurs when patterns from 2 prints repeat, hind prints are not parallel, and hind prints register at or behind front prints (Halfpenny et al. 1995, Elbroch 2003). Members of Mustelidae, Cricetidae, and Soricidae use the 2× lope when traveling in snow (Halfpenny et al. 1995, Elbroch 2003). Track dimensions include straddle width (distance between the lateral outside edges of a pair of footprints), step depth (distance from the snow surface to the deepest point in the footprint), and stride length (distance between tracks made by the same foot during 1 cycle of locomotion; Halfpenny et al. 1995). These dimensions and others can be measured for tracks left by any gait.

Track identification is difficult when track dimensions are similar for >1 carnivore found in the same area. Geographic ranges and track dimensions of Canada lynx (*Lynx canadensis*) and mountain lions (*Puma concolor*) overlap, for example, making their tracks difficult to distinguish (Halfpenny et al. 1995). Tracks left by invasive mink (*Neovison vison*) and protected polecat (*Mustela putorius*) are also difficult to distinguish (Harrington et al. 2008). Qualitative methods used to distinguish tracks can be inaccurate (De Angelo et al. 2010). Quantitative methods are more accurate and can be used to distinguish among similar tracks left by different carnivores (Halfpenny et al. 1995, De Angelo et al. 2010). When tracks

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[1] *E-mail: nmccann@glifwc.org*

[2] *Present address: Great Lakes Indian Fish and Wildlife Commission, P.O. Box 9, Odanah, WI 54861, USA.*

are correctly identified, snow-tracking results in greater detection rates than track plates and remote cameras for some carnivores and eliminates potential bias from using bait and lure at camera-trap stations and at hair snares (Gompper et al. 2006, Proulx and O'Doherty 2006).

Snow conditions influence track dimensions, which in turn influences classification accuracy (Halfpenny et al. 1995). Track depth increases when moving across deep, soft snow that lacks a crust. Coyotes (*Canis latrans*) and Canada lynx, for example, had greater step depths when using soft snow (Murray and Boutin 1991, Crête and Larivière 2003); coyotes had greater step depths when snow was deep (Murray and Boutin 1991); and red foxes (*Vulpes vulpes*) had greater step depths when a crust was absent (Halpin and Bissonette 1988). The surface area of tracks is also influenced by snow conditions. Deep tracks that show disturbance from the legs and body are wider than shallow tracks that do not show disturbance and stride lengths can be longer on compact snow (Raine 1983, Halfpenny et al. 1995).

Track classification accuracy might be improved by controlling for snow conditions. Dimensions of tracks left by an animal while traveling on level surfaces approximate the animal's body dimensions (Halfpenny et al. 1995). Step depth, straddle width, and stride length approximate the foot-loading, body width, and length of the animal that left the track. Variation in snow conditions that reduces the correlation between track dimensions and body dimensions would reduce the accuracy of track classifications made from measuring track dimensions. Controlling for snow conditions would be most important when classifying tracks left by similarly sized animals that use the same gait and occupy the same areas as snow conditions may alter track dimensions, resulting in tracks that are otherwise indistinguishable.

American marten (*Martes americana*) and fisher (*Pekania pennanti*) are carnivores that are active year-round and distributed where snow is present in winter (Powell et al. 2003). Martens have fur-covered feet that are large relative to their size and mass. Fisher feet are not fur-covered or as large relative to their size and mass. As a result, fisher foot-loading is $\geq$2 times greater than for martens (Krohn et al. 2005, Renard et al. 2008). Adult females are smaller than adult males in both species; both sexes of adult marten are smaller than both sexes of adult fisher (Powell et al. 2003). Fishers and martens reach adult length by their first autumn (Powell et al. 2003, Frost and Krohn 2005). Male and female fishers reach 75% and $\geq$90% of adult mass and male and female martens reach >80% and >90% of adult mass by their first autumn (Frost and Krohn 2005, Krohn et al. 2005). The resulting ordering (smallest to largest) of mean size, mass, and foot-loading during winter is female marten, male marten, female fisher, and male fisher (Powell et al. 2003, Frost and Krohn 2005, Krohn et al. 2005).

Tracks left by martens and fishers in snow are difficult to distinguish (Halfpenny et al. 1995). Martens and fishers usually use a 2× lope during winter (99% of marten tracks and 79% of fisher tracks in midwinter; Raine 1983). Resulting straddle widths, step depths, and stride lengths frequently overlap (Raine 1983, Halfpenny et al. 1995). Fisher tracks may show toe pads (marten tracks do not) in dense snow, and leave a trough and a foot and tail drag in deep snow (marten tracks do not; Halfpenny et al. 1995, Proulx 2011). Toe pads are absent, however, when snow is soft, and >80% of tracks do not have troughs and drags because fishers avoid deep snow, which is energetically expensive to move in (Raine 1983, Krohn et al. 2005). Habitat associations are not useful for distinguishing tracks because martens and fishers have similar diets, select similar habitat, and are found in the same areas (Powell et al. 2003, McCann et al. 2014). Snow-tracking is used to study martens and fishers, including in areas where both species occur (Erb 2014, Woodford and Lapin 2015). Study results would be improved by increasing the accuracy of track classifications.

We studied martens and fishers in winter to determine if tracks left in snow could be distinguished by measuring track dimensions and snow conditions. We hypothesized that track dimensions would be larger in soft and deep snow that had a deep crust (present far below the snow surface) and fisher track dimensions would be more strongly influenced by snow conditions than marten track dimensions. We also hypothesized that track dimensions that control for snow conditions would improve classification accuracy, resulting in accurate sex-specific track classifications.

STUDY AREA

We studied martens and fishers on and near the Great Divide District of the Chequamegon–Nicolet National Forest in northern Wisconsin, USA (described by McCann et al. 2010; Fig. 1). The region has long winters. The mean temperature was −10° C in January and February during this study, with mean monthly liquid equivalent precipitation of 4 mm resulting in a mean snow depth of 35 cm (National Centers for Environmental Information, www.ncdc.noaa.gov, accessed 7 Dec 2010).

The study area was dominated by northern mesic forests containing sugar maple (*Acer saccharum*) and quaking aspen

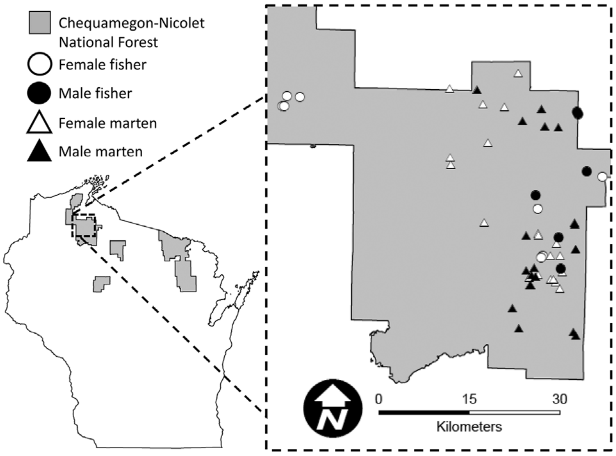

Figure 1. Study area where tracks left in snow by American martens and fishers were measured on and near the Chequamegon–Nicolet National Forest in northern Wisconsin, USA, during winter 2008–2010.

(*Populus tremuloides*; Epstein et al. 2002). Sugar maple stands often included yellow birch (*Betula alleghaniensis*) and basswood (*Tilia americana*). Lowlands often had white cedar (*Thuja occidentalis*), black spruce (*Picea mariana*), tamarack (*Larix laricina*), red maple (*A. rubrum*), and black ash (*Fraxinus nigra*). Hemlock (*Tsuga canadensis*) was often found near cedar where land graded toward uplands. Hardwood understories often contained scattered balsam fir (*Abies balsamea*). Hazelnut (*Corylus* spp.) and alder (*Alnus* spp.) were common shrubs.

METHODS

Capture and Handling of Martens and Fishers

We captured martens and fishers between October and February during 2008–2009 and 2009–2010 with single-door Tomahawk box-traps (Tomahawk Live Trap Co., Hazelhurst, WI, USA; models 106 and 108). Traps were placed where sign of martens and fishers was observed. We fitted a very-high-frequency (VHF) transmitter collar containing an activity switch (Gilbert et al. 2009) to each captured adult marten (model 080, 40 g; Telonics, Inc., Mesa, AZ, USA) and fisher (model 125, 55 g; Telonics, Inc.). Adult martens were identifiable by well-developed sagittal crests and mass >680 g (F; $\bar{x} = 896$ g) or >900 g (M; $\bar{x} = 1,128$ g; J. H. Gilbert, unpublished data). Adult fishers had well-developed sagittal crests and weights $\geq$2,500 g (F; $\bar{x} = 2,688$ g) or >4,000 g (M; $\bar{x} = 5,594$ gL; J. H. Gilbert, unpublished data). Our capture and handling procedures followed American Society of Mammalogists (Sikes et al. 2016) and Purdue University (Purdue Animal Care and Use Committee Protocol 07-032) guidelines.

We also studied juvenile and adult martens outfitted with VHF transmitter collars and translocated to the study area from northeastern Minnesota, USA, in September of 2008 and 2009 as part of a supplementation project (Woodford et al. 2013). Translocated martens had collars without activity switches (model MI-2M, 32 g, Holohil Systems, Carp, ON, Canada; model 080, 48 g, Telonics, Inc.; and model LPM-2700M, 28 g, Wildlife Materials, Inc., Murphysboro, IL, USA; Woodford et al. 2013).

Snow-Tracking

We followed trails left in snow by collared martens and fishers between December and March of 2008–2009 and 2009–2010 (described by McCann et al. 2014). In 2008–2009, we selected individual martens and fishers to track using a random-stratified design (strata were species and sex) without replacement until all individuals were sampled. We randomly sampled individuals to track each day (without respect to species or sex) and without replacement in 2009–2010.

We navigated to rest sites used by inactive individuals (determined by VHF transmitter signal characteristics) and backtracked the trail left in snow by the marten or fisher during its previous activity bout for $\geq$500 m. When a focal animal became active while we navigated to it, we determined the direction it was traveling using signal characteristics and navigated to a location behind its direction of travel to locate its trail. We then followed the trail backward >100 m before recording data for $\geq$500 m.

We measured track dimensions at fixed intervals (25-m intervals in 2008–2009 and 100-m intervals in 2009–2010) along each marten and fisher trail. Tracks were from straight trails left in level snow by 2× lopes (the most commonly observed gait). We measured stride length, step depth, and straddle width. We used the minimum outline method to measure straddle width, which measures the track left by the feet but not disturbance caused by the body (Fjelline and Mansfield 1989). We did not measure tracks obscured by wind-blown snow or distorted by snow-melt.

We measured snow compaction, snow depth, and crust depth (when a crust was present) between successive sets of tracks. We measured snow compaction by measuring the sinking depth of a penetrometer (scaled to the forefoot-loading of a female marten on the study area—24 g/cm^2; J. H. Gilbert, unpublished data) dropped from 10 cm above the snow surface. We measured the distance from the snow surface to the first crust and ground with a tape measure.

Statistical Analysis

We used simple linear regressions (Program R version 3.3.1, www.r-project.org, accessed 23 Jul 2016) to determine whether marten and fisher track dimensions were correlated with snow conditions. Snow depth, penetrometer sinking depth, and crust depth were predictor variables. Step depth, stride length, and straddle width were dependent variables. We used a median value for each variable (calculated for each $\geq$500 m snow-track) to reduce pseudoreplication (Hurlbert 1984). We developed linear regressions for martens and fishers separately, resulting in 9 total regression analyses for each species. We set $\alpha = 0.05$ and corrected for the experiment-wise Type I error rate for each set of 9 regression analyses with Bonferroni adjustments (Ott and Longnecker 2001; $\alpha/9 = 0.006$). We considered a track measurement to be strongly correlated with a snow condition when a linear regression was significant and corresponding coefficient of determination was $\geq$0.60.

We used classification trees to identify track measurements and snow conditions that accurately categorized female and male marten and fisher tracks. Classification trees are useful for ecological studies because they are nonparametric, robust to outliers and missing data, identify nonlinear relationships well, and variable selection is intrinsic, which differs from other methods such as discriminant analysis (De'ath and Fabricius 2000, Feldesman 2002, Swihart et al. 2007). Trees are developed by recursively dividing data sets into homogeneous groupings of response variables. Undivided data are at the top of a tree. Binary splits of the predictor variable data (branches) end at nodes (leaves). V-fold cross-validation identifies the optimal tree size (one that reduces model overfitting). The change in tree accuracy is assessed when a new predictor variable is added by calculating a misclassification cost, which is similar to use of Akaike's Information Criterion for model selection (Burnham and Anderson 2002, Swihart et al. 2007). Tree branch length is proportional to the relative increase in homogeneity that results from use of a predictor variable.

We developed 4 ordinal classification trees (Program R package rpartScore, http://CRAN.R-project.org/package=rpartScore, accessed 23 Jul 2016). The first 2 trees used predictor variables (medians calculated from each ≥500-m snow-track) to classify tracks for 4 ordinal sex–species combinations: female marten, male marten, female fisher, and male fisher. The first of these 2 trees had predictor variables for track dimensions: step depth, stride length, and straddle width. The second tree had predictor variables for track dimensions and predictor variables for snow conditions: step depth, stride length, straddle width, snow depth, penetrometer sinking depth, and crust depth. The second tree also had predictor variables for step depth, straddle width, and stride length that controlled for snow conditions by dividing each step depth, straddle width, and stride length measurement by penetrometer sinking depth, snow depth, and crust depth at the same location. We controlled for variation in snow conditions to increase the correlation between track dimensions and body dimensions. A marten with lower foot-loading, for example, would take shallower steps than a marten with greater foot-loading when snow is soft, but would take steps of similar depths when snow is highly compacted (e.g., on a game trail). The third and fourth classification trees classified tracks for 2 ordinal species-only combinations: marten and fisher (Powell et al. 2003, Krohn et al. 2005). The third tree included predictor variables for track dimensions (but not snow conditions). The fourth tree included variables for track dimensions, snow conditions, and track dimensions that controlled for snow conditions.

Methods for classification were identical between trees. We used 10-fold cross-validation and total misclassification cost to identify optimally sized trees. We quantified classification tree accuracy using confusion matrices that compared tree predictions to observed species and sex–species classifications. We also calculated the mean correct classification rate for each tree.

RESULTS

We recorded 1,658 track and 1,738 snow conditions measurements from 56 trails, including 33 trails (26 marten, 7 fisher) in 2008–2009 and 23 (16 marten, 7 fisher) trails in 2009–2010. Trails were from 15 individual martens (8 F, 7 M) and 2 fishers (1 F and 1 M) in 2008–2009, and 16 martens (8 F, 8 M) and 6 fishers (3 F, 3 M) in 2009–2010. We collected a mean of 10 (SD = 7) stride, 10 (SD = 7) straddle, 10 (SD = 7) step depth, 11 (SD = 7) penetrometer, 11 (SD = 7) snow depth, and 10 (SD = 7) crust depth measurements on each of the 56 trails.

Influence of Snow Conditions on Track Dimensions

Fisher step depth was strongly correlated ($r^2 > 0.60$ for significant regressions) with snow conditions. Fisher step depths were deep when crusts were deep ($r^2 = 0.82$, $F_{1,10} = 47.1$, $P < 0.001$, $Y = 3.9 + 0.52X$; Fig. 2), penetrometer sinking depths were deep ($r^2 = 0.65$, $F_{1,10} = 16.2$, $P = 0.002$, $Y = 6.0 + 0.25X$), and snow was deep ($r^2 = 0.62$, $F_{1,10} = 18.6$, $P = 0.002$, $Y = -5.2 + 0.40X$). All other regressions for fishers were nonsignificant ($r^2 \leq 0.23$ and $P \geq 0.12$).

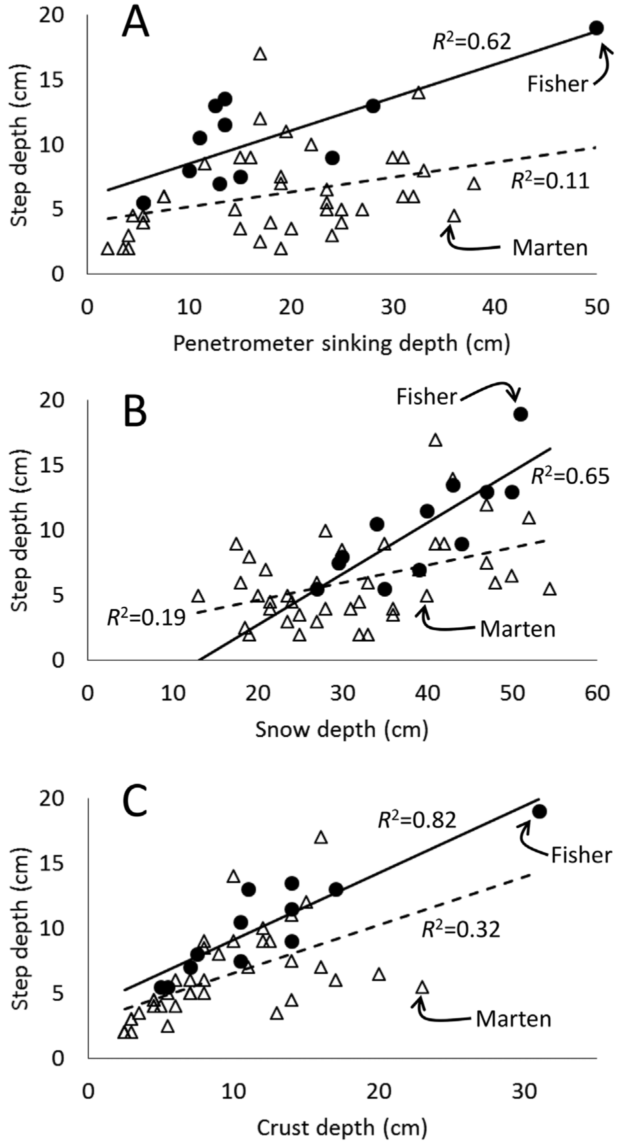

Figure 2. Relationships between the depth of tracks left by American martens (empty triangles and hatched linear regression trend-line) and fishers (filled circles and solid regression trend-line) in snow with penetrometer sinking depth (A), snow depth (B), and crust depth (C) in northern Wisconsin, USA, during winter 2008–2010. Correlation between marten step depth and penetrometer sinking depth in Panel A was nonsignificant and depicted for comparison only. Coefficient of determination between step depth and penetrometer sinking depth and step depth and crust depth was $r^2 = 0.27$ and $r^2 = 0.70$ for fishers when the point with the largest values was removed from analysis, but r^2 was not reduced for the correlation between step depth and snow depth when the point with the largest values was removed ($r^2 = 0.65$).

Marten track dimensions were not strongly correlated with snow conditions. Less than 35% of variation in step depth for martens was explained by crust depth ($r^2 = 0.32$, $F_{1,38} = 18.1$, $P < 0.001$, $Y = 2.9 + 0.37X$; Fig. 2) and snow depth ($r^2 = 0.19$, $F_{1,38} = 8.9$, $P = 0.005$, $Y = 1.9 + 0.13X$), and <25% of variation in stride length was explained by penetrometer sinking depth ($r^2 = 0.23$, $F_{1,38} = 11.4$, $P = 0.002$, $Y = 77.6 - 0.90X$).

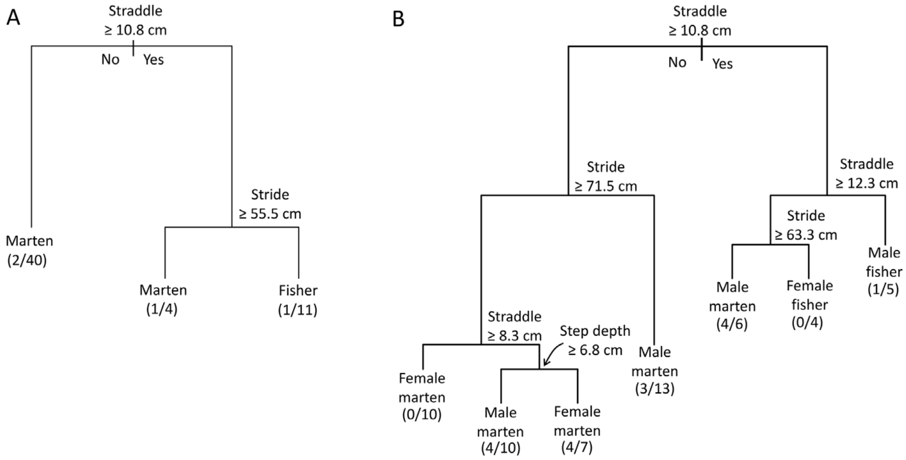

Figure 3. Classification trees for classifying American marten and fisher tracks in snow in northern Wisconsin, USA, during winter 2008–2010. The level of a predictor variable that defined a split was labeled at each split. Marten and fisher classifications were at terminal nodes along with the proportion of misclassifications (no. misclassified/no. of classifications). Both panels were developed using track measurements, but not snow conditions. Panel A classified species. Panel B classified sex and species. Tracking data can be compared to splits in each tree. Answering yes at a split leads to the right branch, while answering no leads to the left.

All other marten regressions had low coefficients of determination ($r^2 \leq 0.11$) and were nonsignificant ($P \geq 0.03$).

Classification Without Snow Conditions Predictor Variables

The tree that classified marten and fisher tracks without respect to sex using step depth, stride length, and straddle width (but not snow conditions and track dimensions that controlled for snow conditions) identified straddle width and stride length as influential for classifying tracks (Fig. 3A). This tree correctly classified 98% of marten tracks and 83% of fisher tracks (Table 1). Mean classification accuracy was 91% (SD = 11%, $n = 2$ classifications).

The tree that used step depth, stride length, and straddle width (but not snow conditions) to classify sex-specific marten and fisher tracks identified all 3 of these predictor variables as influential for classifying tracks (Fig. 3B). Classification accuracy for female marten tracks was 68%, whereas classification of male marten tracks was 95% accurate (Table 2). Female and male fisher track-classification accuracy was 57% and 80%, respectively. Mean classification accuracy was 75% (SD = 16%, $n = 4$ classifications).

Table 1. Confusion matrices from 2 classification trees that identified marten and fisher tracks left in snow in northern Wisconsin, USA, during winter 2008–2010. The left matrix was developed by only including track measurements. The right matrix included track measurements, snow conditions measurements, and track measurements that were standardized by snow conditions. Fewer predictions were made for each matrix than in each corresponding classification tree because predictions were made using only complete data sets.

	Predicted without snow conditions		Predicted with snow conditions	
	Marten	**Fisher**	**Marten**	**Fisher**
Observed				
Marten	41	1	42	0
Fisher	2	10	1	11

Classification With Snow Conditions Predictor Variables

Marten and fisher track classifications were more accurate when snow conditions were included in analysis. The tree that classified marten and fisher tracks without respect to sex identified straddle width and step depth that controlled for penetrometer sinking depth as influential for classifying tracks (Fig. 4A). This tree correctly classified 100% (42 of 42) of marten tracks and 92% (11 of 12) of fisher tracks (Table 1). Mean classification accuracy was 96% (SD = 6%, $n = 2$ classifications).

The tree that classified tracks from marten and fishers and their sexes identified straddle width, stride length, step depth that controlled for penetrometer sinking depth, straddle width that controlled for crust depth, and snow depth as influential variables (Fig. 4B). Stride length influenced correctly distinguishing female and male marten tracks. Step depth that controlled for penetrometer sinking depth influenced correctly distinguishing between male marten tracks with larger straddle widths from tracks left by fishers. This tree correctly classified 91% of female marten and 95% of male marten tracks (Table 2). Female fisher classifications were 71% accurate and male fisher track classifications were 100% accurate. Mean classification accuracy was 89% (SD = 13%, $n = 4$ classifications).

DISCUSSION

We accurately identified marten and fisher tracks by quantifying dimensions of tracks left in snow. Sooted track plates also classify marten and fisher tracks accurately and are important for studying carnivores (Zielinski and Truex 1995, Zielinski et al. 2013). Snow-tracking, however, may be preferred for studying martens and fishers when snow cover is present in accessible areas. Detection probability is greater for some carnivores when using snow-tracking than when using track plates, including >3 times greater for fishers (Gompper et al. 2006).

Table 2. Confusion matrices from 2 classification trees that identified female and male American marten and fisher tracks left in snow in northern Wisconsin, USA, during winter 2008–2010. The left matrix was developed by only including track measurements. The right matrix included track measurements, snow conditions measurements, and track measurements that were standardized by snow conditions. Fewer predictions were made for each matrix than in corresponding classification trees because predictions were made using only complete data sets.

	Predicted without snow conditions				Predicted with snow conditions			
	F marten	M marten	F fisher	M fisher	F marten	M marten	F fisher	M fisher
Observed								
F marten	15	7	0	0	20	2	0	0
M marten	1	19	0	0	1	19	0	0
F fisher	0	2	4	1	0	1	5	1
M fisher	0	1	0	4	0	0	0	5

Controlling for snow conditions improved track classification accuracy. Different foot-loadings would explain why step depth that controlled for penetrometer sinking depth helped to distinguish fisher tracks from tracks with large straddle widths left by martens. Foot-loading is greater for fishers than for martens and step depth approximates foot-loading (Krohn et al. 2005). Controlling for snow compaction helped to distinguish fisher and marten tracks by improving the relationship between step depth and foot-loading.

Sex-specific marten and fisher habitat selection, distribution, and abundance would be assessed more accurately using snow-tracking protocols that include measurement of snow conditions. Sex classifications were 14% more accurate when measurements of track dimensions controlled for snow conditions than when measurements did not. Our results compliment studies that found stride length and footprint width from tracks left in snow distinguished between sexes of pine martens with 85% accuracy (*Martes martes*; Zalewski 1999) and tracks left on sooted plates could distinguish sexes of martens and fishers with >90% and 99% accuracy when species was known beforehand (Slauson et al. 2008).

Step depth measurements we collected on fisher trails were consistent with findings from another study that concluded fishers had deeper step depths during midwinter than during late winter when a crust had formed (Raine 1983). Snow was measured at snow monitoring stations each 2 weeks (not on fisher tracks) and track age was unknown in that study (Raine 1983). Snow conditions can differ over short distances (e.g., meters) and time periods (e.g., hours). Measuring snow conditions on trails shortly after use enabled us to quantify the relationship between step depth and snow conditions because our measurements reflected the conditions experienced by fishers and martens.

Consistent straddle widths across variable snow conditions indicate that using the minimum outline method is effective for reducing the influence of snow conditions on straddle width measurements (Fjelline and Mansfield 1989). Consistent stride lengths suggest that 2× loping velocity is not influenced by the range of snow conditions used by martens and fishers. Longer stride lengths on compacted snowshoe hare (*Lepus americanus*) trails may have reflected increased velocity while chasing hares in another study (Raine 1983).

Different regional marten and fisher morphologies can influence the accuracy of track classifications. A discriminant function for classifying male and female marten tracks left on sooted plates that was developed in Ontario, Canada (Routledge 2000), for example, inaccurately distinguished tracks left by martens in California, USA, where martens were smaller (Slauson et al. 2008). The accuracy of track classifications made using our trees could also be influenced by different regional morphologies. The straddle width split on our classification trees, for example, might be reduced from 10.8 cm to a smaller value in areas where martens are

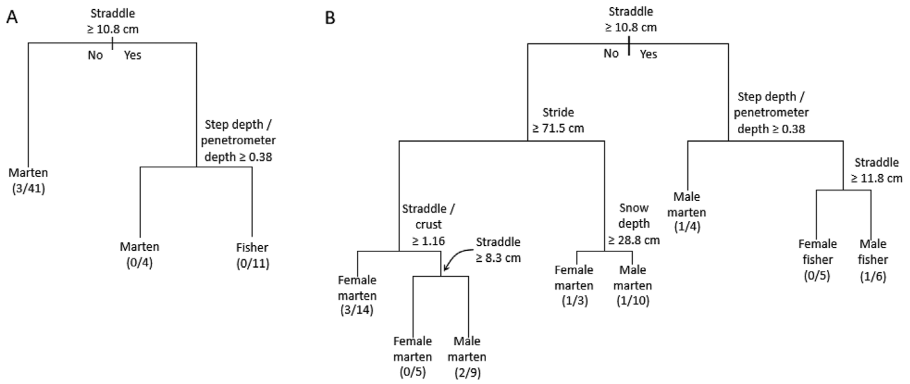

Figure 4. Classification trees for classifying female and male American marten and fisher tracks in snow in northern Wisconsin, USA, during winter 2008–2010. The level of a predictor variable that defined a split was labeled at each split. Female and male marten and fisher classifications were at terminal nodes along with the proportion of misclassifications (no. misclassified/no. of classifications). Both panels were developed using track measurements and snow conditions. Panel A classified species. Panel B classified sex and species. Tracking data can be compared to splits in each tree. Answering yes at a split leads to the right branch, while answering no leads to the left. Figure 4 has 1 more classification than Figure 3 because of missing data.

smaller but fishers are the same size as those in our study (e.g., in ME, USA; Krohn et al. 2005). Martens and fishers on our study area are at the upper end of mass ranges reported by Powell et al. (2003). The mass of adult fishers is relatively consistent throughout the fisher range (Powell 1982), but mass of martens varies widely (Hagmeier 1961), suggesting that variation in mass of martens will influence whether trees we developed accurately classify marten and fisher tracks in other regions.

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