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SNOW-TRACKING TO DETERMINE *MARTES* WINTER DISTRIBUTION AND HABITAT USE

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Abstract: – In the past, biologists have examined animal tracks in the snow as a means of studying foraging habits and movements. With the advent of more advanced technology, some scientists replaced snow-tracking with more sophisticated techniques (radio-telemetry, photographic stations etc.) to study animal movements and habitat use. Others declined using snow-tracking methods, because of their concerns regarding non-independence of tracks and potential problems with spatial autocorrelation in the data. In the midst of the technological and statistical debate, there is a lack of consideration of the unbiased aspect of tracking data, their accuracy, and their biological significance. Snow-tracking may provide researchers with unique insight into the ecology of martens (*Martes* spp.), fishers (*Martes pennanti*), and sympatric wildlife species, yield behavioural and habitat information that may be unavailable or only inferred using the more technologically-advanced techniques, and be used to validate habitat models. Here we give examples of such insights, and provide suggestions on avoiding some analytical pitfalls associated with tracking data.

Introduction

Many species of the genus *Martes* are found north of 35° latitude, where annual snow cover may last several months (Proulx et al. 2004). In the past, scientists have followed and recorded the tracks of martens (*Martes* spp.) and fishers (*Martes pennanti*) to confirm their presence in diverse habitats (Thompson et al. 1989), identify behaviours (Pulliainen 1981), and monitor population trends (Raphael 1994). However, snow-tracking has been criticized, either because of the difficulty in differentiating tracks among individuals (Zalewski 1999) or species (Halfpenny et al. 1995), or because of a potential pseudoreplication problem through a lack of independence among track records (e.g. Hurlbert 1984). Also, with the advent of more technology-intensive methods, snow-tracking has been employed less often by scientists (Beauvais and Buskirk 1999).

Snow-tracking allows one to establish the distribution of species across landscapes (Thompson et al. 1989), with precise information about the location and trajectories of the animals relative to particular micro-environments and habitat edges (Pulliainen

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1981, Heinemeyer 2002), and to assess the ability of stands to meet the winter ecological needs of species (Proulx et al. 2006). In the last decade, in western North America, snow-tracking has been used repeatedly to validate habitat models and assess use of various successional stages by *Martes* (O'Doherty et al. 2000, Proulx et al. 2006). Snow-tracking has long been used to study habitats of mammals other than martens and fishers. For example, Parker (1981) used it for lynx (*Lynx canadensis*), Litvaitis et al. (1985) for snowshoe hares (*Lepus americanus*), D'Eon (2001) for mule deer (*Odocoileus hemionus*), Proulx (2005) for long-tailed weasel (*Mustela frenata*), and Proulx and Kariz (2005) for moose (*Alces alces*). The technique can provide valuable information about stand use by animals (O'Doherty et al. 2000, Proulx et al. 2006), particularly in the case of species such as the American marten (*Martes americana*), which, in western North America, appears to be highly discriminate in the selection of environmental conditions in winter (Buskirk and Powell 1994).

We believe that, in the midst of the technological and statistical debate about snow-tracking, there is a lack of consideration of the unbiased aspect of snow-tracking data vs. other techniques, and their biological significance. In this paper, we argue that snow-tracking may be a valuable tool to determine the winter distribution of martens and fishers, and it allows us to better understand their habitat use. We review the advantages of snow-tracking, provide suggestions on avoiding some analytical pitfalls, and recommend standard operating procedures.

Definition and use of snow-tracking in habitat studies

Although large-scale aerial surveys of animal tracks have been conducted in the past (St-Georges et al. 1995), they are less informative over closed-canopy coniferous forests where data sets become fragmented due to invisibility of animal tracks. In this paper, snow-tracking involves recording animal tracks in snow, at ground level with snowmachines, skis, or snowshoes. Animal tracks are usually recorded along transects crossing various habitats.

Snow-tracking usually involves backtracking where one follows the trail of an animal in the direction opposite to that of the animal's movement. Distance and directional changes within various habitats may be recorded to better understand habitat use (Heinemeyer 2002), and a series of behaviours such as foraging (Powell 1978, Andruskiw 2003) and scent-marking (Pulliainen 1982). This is a form of focal animal sampling where the continuous actions of an individual are recorded over time and space. Such measurements allow for the calculation of path metrics such as tortuosity and fractal dimension (Heinemeyer 2002), which can help assess behaviour relative to landscape features.

Snow-tracking is also used in surveys to determine a species' winter distribution and habitat selection (D'Eon 2001, Proulx et al. 2006).

Advantages and limitations

Independently of the method used in the field, snow-tracking has many advantages that set it apart from other research techniques.

Non-invasive information

Wiens and Milne (1989) and Turchin (1991) have elaborated on the benefits of knowing the trajectories of animal movements, especially in terms of behavioural responses to habitat edges. To gather such information, researchers have devised methods of marking mammals that normally do not leave tracks visible to humans, for example the use of tracking spools on squirrels (Baker and van Vuren 2004) or fluorescent powders on small mammals (Proulx et al. 1995, Keinath 2000), but that do require animals' manipulation. In contrast, researchers of *Martes* in snowy environments are afforded a non-invasive means of examining movements without having to capture, restrain, anaesthetize, radio-collar, or otherwise mark animals. Snow-tracking allows one to observe aspects of an animal's behaviour without disturbing it (Pulliainen 1982, Heinemeyer 2002). Backtracking and transect inventories using snow-tracking have no known impacts on the behaviour or well-being of animals. Forward tracking, however, could push an animal to change behaviour, direction or habitat, if conducted shortly after the tracks were laid.

Unbiased information

Non-invasive techniques such as the use of hair snares, track plates, and photographic stations (Zielinski and Kucera 1995) are valuable alternatives to live-trapping because they are not likely to incur stress. However, as is the case with trapping, their efficacy depends on the use of baits and lures, which attract animals to specific sites. Baiting animals is a source of error, as animals may temporarily leave their habitats to investigate a source of food (Raphael 1994, Powell and Proulx 2003). Depending on the scale and nature of the question being addressed, such a bias could be misleading in a heterogeneous environment. We do not believe that snow-tracking has an impact on the distribution of animals because their movements are not altered by the presence of baits and lures. Of course, where fur-trapping activities are underway, animals may be attracted to trappers' baits, and this could have an impact on animals' track distribution. Investigators must be aware of this bias when assessing the movements of individuals across landscapes. Also, a researcher's personal scent could push an animal to change behaviour, direction or habitat, particularly if forward tracking is used.

Precise information

Contrary to any other technique, snow-tracking provides researchers with precise information about the location and path of an animal at scales from the landscape to the microhabitat level (e.g. Heinemeyer 2002, Andruskiw 2003). When habitat data are collected at the track site, analysis is not dependent on habitat maps and their associated spatial error. This feature is especially important in highly heterogeneous landscapes. Backtracking is more informative than capture-recapture, because it allows one to collect continuous information on the trajectories of paths and use of various habitats by animals without biases incurred by the use of baits and lures.

Track surveys also provide more microhabitat-specific information than radio-telemetry. The magnitude of telemetry locational error depends on the experience of the investigator, the quality of the equipment, the location of the animal (e.g. mountainous areas, deep cover etc.), and environmental conditions (e.g. windy conditions and twisting of the antennas, landscape heterogeneity) (Bissonette et al. 1994). In addition, unless radio-collared animals are stationary when radio-located, a lack of precise synchrony of the telemetry recordings introduces more spatial error (Kauhala and Tiilikanen 2002). The size of radio-telemetry error polygons may be in the hectare range (e.g. Payer and Harrison 2004, E. O'Doherty, unpublished data), and this is a critical bias in highly fragmented areas where patches may be, on average, smaller than telemetry error.

When following fishers, Powell (1994) noted that tracks changed within metres from travelling in near straight lines to zigzagging upon entering a dense, lowland habitat from an open, upland habitat. Thus, behavioural responses of fishers to habitats and their prey in these habitats were made on a far finer scale than could be measured with radio-telemetry with errors in location estimates (Powell 1994). O'Doherty et al. (2000) conducted snow-track surveys amongst 240 small clearcuts in a forest matrix. Snow-tracking showed that while marten movements occurred in proximity to these clearcuts, very few tracks entered cut blocks. Such precise information could not be obtained from radio-collared animals in the same study area, because the average telemetry error was similar in magnitude to the clearcut width and spacing (E. O'Doherty, unpublished data). With snow-tracking, researchers can measure characteristics of animal pathways such as tortuosity or fractal dimension (Heinemeyer 2002) as a function of variables such as habitat type or weather. Not only will snow-tracking allow one to identify stands used by animals, but also to locate specific sites used at the arboreal and subnivean levels (de Vos 1951, Andruskiw 2003).

Relevant to specific behavioural activities

Without having to capture and mark animals, snow-tracking allows one to record specific activities such as scenting (Pulliainen 1982, Snyder and Bissonette 1987), hunting (Powell 1978, Arthur et al. 1989, Heinemeyer 2002, Andruskiw 2003), and encounters with other carnivores (G. Proulx, unpublished data). Contrary to most other inventory methods, it allows one to establish relationships between specific behavioural activities and environmental conditions with the spatial accuracy needed in predictive models. It also allows researchers to recognize habitat features (e.g. subnivean dens - Raine 1983; squirrel (*Tamiasciurus* spp.) middens - Sherburne and Bissonette 1993) that may be overlooked at a coarser scale resolution, yet that may warrant further investigations.

Concerns

Issues associated with habitat studies are numerous and extend beyond the scope of this review. Garshelis (2000) discussed these issues in detail. Nevertheless, habitat study methods involving locations of animals (capture-recapture, radio-telemetry) or their signs (snow-tracking) have several problems in common. For example, independently of the method used, habitat use-availability studies inherently assume that animals have free and equal access to all habitats considered to be available (Garshelis 2000). Also, sample bias is an obvious potential problem in measuring habitat use. Interpretations of habitat use from observations of animals or their signs can vary among observers (Schooley and McLaughlin 1992) and detectability can vary among types of habitats (Powell 1994, Halfpenny et al. 1995), both of which can introduce biases in the data. We believe that snow-tracking is superior to many other methods in identifying habitats selected by animals, because the technique records specific locations without interpretations or assumptions from the observers, and it has no impact on animal movements.

Because mustelids use scent-marked routes, which depict their familiarity with their surroundings (Pulliainen 1982), and frequently change direction and zigzag throughout their home range (Powell 1978), mustelids' movements are not independent of each other in time and space. One zigzag leads to another zigzag, and one series of tracks in one habitat type may explain the use of an adjacent habitat type. Thus, spatial autocorrelation may occur in tracking data, and lead to pseudoreplication when replicated information on individuals is used to answer population-level questions (Hurlbert 1984). This problem is not limited to snow-tracking data. In telemetry studies where relocations are used as the sample unit rather than the individual animal, pseudoreplication is the most common problem (Bissonette et al. 1994). However, when there is little variation among animals, groups and populations, questions can sometimes be answered with a small number of individuals (Still 1982). For example, Proulx et al. (2006) tracked an unknown number of animals during 2 winters over a large landscape. They recognized that tracks may not have been strictly independent, since the identity of the individuals making each track was unknown. On the other hand, there was so little variation in their data from transects dispersed over space and time, that the information gathered on a limited number of animals was representative of the population, given the assumption that the number of animals followed was most likely greater than one. Nonetheless, there are many ways to increase independence of samples and to lessen the effect of autocorrelated data on the assessment of habitats used by a species:

1. *Individual identification* – Obviously, if track distribution can be associated with an individual, as determined through capture-recapture or radio-telemetry, one may differentiate between animals and use the individual as the unit of replication. Identifying sex and identity of individuals using snow track measurements is possible, but the technique is not always reliable (Zalewski 1999).

2. *Minimum spacing of survey transects* – Maintaining a minimum distance between survey transects, corresponding to at least the minimum diameter or the length of the largest axis of an average home range, may minimize autocorrelation of individual tracks. For example, knowing that the minimum diameter of the home range of female martens is approximately 1 km^2 (Strickland et al. 1982), a minimum distance of at least 1 km

between survey transects should be maintained (Proulx et al. 2006).

3. *Minimum spacing of tracks* – To minimize spatial autocorrelation, only 1 track intercept is sampled when tracks are clustered within a pre-defined distance. Proulx et al. (2006) recorded only track intercepts that were ≥ 100 m apart within the same stand; however, two tracks < 100 m apart were recorded if they were found in two different stand types. Because this minimum spacing of track intercepts may be inadequate, as some martens may range widely (Bowman and Robitaille 1997), Proulx et al. (2006) also analysed data using only tracks that were ≥ 1000 m apart within the same stand. Data analyses carried out with different in-between track distances should be compared to assess the effect of a possible spatial autocorrelation of tracks on conclusions. Minimum spacing of tracks may, however, result in a loss of data. For example, Proulx et al. (2006) concluded that 2 track sets that were 100 m apart along a transect belonged to 2 different animals. Using a minimum distance between track records of more than 100 m would have resulted in the loss of information. De Solla et al. (1999) also expressed their concern about destroying biologically relevant information when trying to eliminate autocorrelation. They considered that, because few animals move in a random or temporally-independent fashion, autocorrelated data are required to model animal movement and space use sufficiently.

Biological significance and ethical considerations

In eastern Canada, snow-tracking studies showed that American martens used late-successional coniferous-deciduous and coniferous forests (Bateman 1968, Snyder and Bissonette 1987). Similar findings were reported in radio-telemetry (Drew 1995) and capture-recapture (Snyder and Bissonette 1987) studies. In western Canada, snow-tracking studies showed that martens avoided areas lacking cover and preferred areas with overhead canopy cover (Campbell 1979, Hargis and McCullough 1984); marten tracks were found in late-successional coniferous stands with 30-50% canopy closure and ≥ 20 m^2/ha in mature trees (Proulx et al. 2006). Radio-telemetry studies showed also that martens avoided open areas and preferred late-successional stands with 20-60% canopy closure and > 20 m^2/ha in mature trees (Campbell 1979, Spencer et al. 1983, Koehler et al. 1990, Flynn 1991, Lofroth 1993). Campbell (1979) also reported a markedly lower capture rate in harvested areas than in undisturbed sites. In Europe, snow-tracking studies showed that pine martens (*Martes martes*) preferred spruce and mixed forests, avoiding areas without overhead cover (Pulliainen 1981). Identical findings were found with radio-telemetry (Marchesi 1989, Brainerd et al. 1994). Although non-exhaustive, this comparison of winter habitat studies for *Martes americana* and *M. martes* shows that conclusions reached with snow-tracking data are similar to those reached with radio-telemetry and capture-recapture. This alone suggests that concerns raised by some scientists about the ability of snow-tracking data to identify habitat use by martens are unfounded.

Unfortunately, in the midst of technological and statistical debates, there is a lack of consideration of the biological significance of snow-tracking data. In an attempt to remove all spatial dependency among observations so that usual statistical tests can be used, expensive and sometimes unique information may be lost. For example, on a survey transect, a researcher may record within a few hundred metres tracks of the same animal zigzagging among stands in order to take advantage of low overhead cover, and crossing a cut block using the cover of scattered trees (as in Hargis and McCullough 1984). A decision to eliminate tracks to accommodate some statistical concern would then mean losing biologically significant information about an animal's habitat use. Pulliainen (1981) followed marten tracks for 4 successive winters. Although tracks were temporally and spatially autocorrelated, and concerns about use-availability assumptions were not discussed, Pulliainen (1981) rightfully concluded that pine martens clearly preferred spruce and mixed forests, and avoided openings. Animals establish and maintain home ranges because doing so provides long term benefits (food, access to mates, rest sites, escape chances etc.) that exceed the costs (energy requirements, risk of predation, competition etc.) (Powell 2000). Probably all martens have cognitive maps of where they live (Peters 1978, Powell 2004). Snow-tracking, because of the quality of the information that it provides, can effectively help researchers to describe such cognitive maps.

Ethical considerations must also be taken into consideration when investigating *Martes* habitats. Many populations are endangered (Proulx et al. 2004) and should not be put at risk through live-trapping, marking, and radio-collaring. As noted by Powell and Proulx (2003), researchers must always work to improve research methods and to decrease the effects on research animals, if for no other reason than to minimize the chances of affecting the animals' behaviour in ways that ultimately influence research results. Researchers must use common sense about trapping mammals, which implies that they will judge appropriately the methods required for a study. When appropriate data can be collected more easily and inexpensively without trapping, common sense maintains that trapping should be avoided (Bekoff and Jamieson 1996). While snow-tracking involves considerable time facing rugged field conditions, it allows wildlife professionals to gather significant information on habitats without ever interfering with martens' and fishers' lives.

Standard operating procedures

Snow-tracking can provide valuable information about *Martes* winter habitat (Snyder and Bissonette 1987, O'Doherty et al. 2000, Proulx et al. 2006), particularly when species like the American marten are highly discriminate in the selection of environmental conditions (Buskirk and Powell 1994). However, effective snow-tracking requires experienced trackers, and the inventory protocol must be correctly designed and implemented. The following stepwise procedures should be considered in future studies.

Survey transects

The following is largely based on RIC (1998), Thompson et al. (1989), and Proulx et al. (2006). Surveys may be conducted in early winter (before mid-December) to reduce variance from over-winter mortality factors among years, or from reduced activity during extreme cold. Surveys in deep snow and in extreme cold may be useful, however, to identify habitats that are best suited to enable martens to fend against harsh environmental conditions.

1. Locate transects at random, in areas that are accessible. Transects should be ≥ 1 km apart. Transects may be permanent, and used from year to year, or new ones may be used during each sampling period. Transects may vary in length but should cover habitat types in proportion to their occurrence. Because of a faster rate of degradation in trail visibility in open sites, trackers can use models to estimate the additional sampling effort necessary to apply to exposed sites to ensure that the probability of detecting the target species is the same as in protected sites (Beauvais and Buskirk 1999). If the objective is to assess the ability of various habitats to meet *Martes* needs, these habitats should be surveyed under similar environmental conditions, during the same time period. Even if weather conditions are not optimal for snow-tracking, the assumptions are made that animal behaviour and signs are affected the same way in all areas, and the observer's ability to identify tracks is the same in all areas.
2. Plot transects on 1:20,000 (or larger scale) maps; tie starting points by compass bearings and distance to distinctive topographic features. If possible, do not locate transects along or < 100 m from active roads, which may impact on habitat use by martens (Robitaille and Aubry 2000).
3. Transects may be surveyed using snowshoes, skis or snowmobiles (speed < 10 km/h) if terrain and cover allow it. They should be carried out at least 12 h after, but within 72 h of, snowfall, when temperatures are ≤ 20°C. Light is an important factor in seeing and identifying tracks. Dawn and dusk should be avoided. Tracking should not be conducted when general flat light conditions (when it is snowing) occur.
4. Because it is sometimes difficult to confirm that a series of tracks along a transect belong to the same animal (de Vos 1951), as home ranges overlap (Buskirk and Ruggiero 1994) and winter dispersal movements are known to occur (Clark and Campbell 1976), record all fresh tracks (i.e. not melted, deformed or filled with crusty snow) crossing the survey transects, and their distance along transects using a hip chain and/or a GPS receiver. Exact location can also be determined with compass bearings, topographic maps and air photos. Establishing sex and individual identities of animals may be facilitated with track measurements (see Zalewski 1999). Due to the similarity between mustelid prints, when tracks are encountered, they should be investigated on both sides of transects and within forest stands to find the best tracks available (often on the lee side of fallen trees), and confirm their identification. The combination of footprint (size, presence/absence of toe pad prints) and trail (gait, distance between jumps, and dragging of the feet or belly) characteristics should be used to identify tracks.
5. Changes in habitat types and structures along transects should be recorded

using the hip chain and/or GPS receiver.

Snow-tracking

The following is largely based on Hargis and McCullough (1984), Arthur et al. (1989), Heinemeyer (2002), and Proulx et al. (2006).

1. Locate trail 12-72 hours after a snowfall. Ideally the sample unit should be the individual to assure independence of samples. Where tracks cannot be attributed to known individuals, selecting trails that are far apart across the landscape may increase the likelihood of sampling the movements of different animals.
2. Follow trail in either direction; however, if trail appears very fresh, follow track backwards to avoid disturbing the animal.
3. Record habitat type and structure along trail according to a pre-determined classification system.
4. Measure distance travelled along trail in each habitat by pacing, or using a hip chain or a GPS receiver.
5. Determine habitat availability by using, for instance, a series of randomly placed transects, each consisting of 3 1-km lines oriented in a triangle; it would also correspond to the proportion of habitat types along track survey transects. If specific habitat variables are collected along trail, e.g. at specific activities (scenting, killing etc.) or sites (snag with cavity, coarse woody debris at subnivean entry points), such variables should also be inventoried along control transects. We stress the importance of collecting habitat data on the ground instead of simply superimposing GPS-derived track data upon habitat maps. Few maps have the spatial accuracy necessary to distinguish between habitat types within a few metres and we have observed numerous tracks very close to habitat boundaries. If good habitat maps are available relative to the scale of the question, spatial autocorrelation errors can be reduced by adapting the method (from time intervals to space intervals) of Arthur et al. (1996) for assessing habitat use when availability changes.

Conclusions

Where snow falls frequently year after year, snow-tracking is a valuable tool to detect the presence of *Martes* and assess the ability of landscapes and stands to meet their environmental needs. Snow-tracking provides researchers and managers with site-specific information about the location of animals without impacting on the animals' behaviour and well-being, and without altering their natural environment. Although snow-tracking is a traditional technique, it is also specialized work and must be used with a scientifically sound protocol to record tracks and analyse data properly.

As with all methodologies, snow-tracking has limitations. To answer specific questions about the ecology of a species, it may be necessary to use it in conjunction with other survey methods. In highly fragmented areas where patches may be, on average, smaller than radio-telemetry error, radio-tracking would provide little useful information regarding habitat choice without snow-tracking information. Conversely, it is virtually impossible to backtrack all the movements of an animal within its home range. Radio-telemetry provides researchers with valuable waypoints to assess the extent of animal movements and determine home range boundaries. Focusing on these waypoints, researchers may find exact locations where radio-collared animals have travelled. Using backtracking, researchers can determine the trajectory of movements and investigate at a fine resolution scale exactly what habitat characteristics are being used without spatial error. Hair snaring (Mowat and Paetkau 2002), and photographic (Zielinski and Kucera 1995) or remote video cameras (Aubry et al. 1997) may be used along backtracked trails to detect non-collared individuals, which may use the same area, and other carnivores. The combined use of snow-tracking and other investigative field techniques would be a powerful research approach indeed.

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