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Note

Integrating Motion-Detection Cameras and Hair Snags for Wolverine Identification

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ABSTRACT We developed an integrated system for photographing a wolverine's (*Gulo gulo*) ventral pattern while concurrently collecting hair for microsatellite DNA genotyping. Our objectives were to 1) test the system on a wild population of wolverines using an array of camera and hair-snag (C&H) stations in forested habitat where wolverines were known to occur, 2) validate our ability to determine identity (ID) and sex from photographs by comparing photographic data with that from DNA, and 3) encourage researchers and managers to test the system in different wolverine populations and habitats and improve the system design. Of the 18 individuals (10 M, 8 F) for which we obtained genotypes over the 2 years of our study, there was a 100% match between photographs and DNA for both ID and sex. The integrated system made it possible to reduce cost of DNA analysis by >74%. Integrating motion-detection cameras and hair snags provides a cost-effective technique for wildlife managers to monitor wolverine populations in remote habitats and obtain information on important population parameters such as density, survival, productivity, and effective population size. © 2011 The Wildlife Society.

KEY WORDS DNA, *Gulo gulo*, hair snagging, identification, microsatellite genotyping, motion-detection cameras, photographs, Southeast Alaska, wolverine.

Wolverines (*Gulo gulo*) range widely, occur at low densities, and occupy habitats that are remote and often difficult to access (Copeland and Whitman 2003). For these reasons, ecological studies of wolverines have been expensive and labor intensive, relying primarily on radiotelemetry for much of current knowledge of wolverine spacing patterns and population parameters (Persson et al. 2009). Use of motion-detection cameras and microsatellite genotyping to monitor wolverines and other cryptic carnivores is becoming increasingly common with recent advances in these detection techniques (Lofroth and Krebs 2007, Koen et al. 2008, Balme et al. 2009, Fisher et al. 2009). Published evaluations of non-invasive techniques for monitoring wildlife focus on effectiveness and cost comparisons among methodologies, and recommendations for integrating methods emphasize multi-species monitoring (Koen et al. 2008, Long et al. 2008, Balme et al. 2009). Wolverines have a pattern of light-colored pelage on their throat and chest (ventral pattern) that is unique among individuals (Fig. 1) and does not change appreciably over time (Magoun et al. 2011). Photographs of the ventral surface of a wolverine can be used to identify not only the individual but also its sex (Fig. 2).

We developed an integrated system of cameras and hair snags, targeted specifically to wolverines, to maximize the amount of information about wolverine populations that can be gained from using a combination of non-invasive techniques. Our integrated system photographed the ventral pattern and the abdominal area of captive wolverines while concurrently collecting hair from the animals (Magoun et al. 2011). We sought to test the system on a wild population of wolverines. Specifically, our objectives were to 1) test the system on a wild population of wolverines using an array of camera and hair-snag (C&H) stations in forested habitat where wolverines were known to occur, 2) validate our ability to determine identity (ID) and sex from photographs by comparing photographic data with that from DNA, and 3) encourage researchers and managers to test the system in different wolverine populations and habitats and improve the system design.

STUDY AREA

Our study area comprised 2,140 km^2 of coastal tidelands, temperate rainforest, muskeg, alpine habitat, and glaciers in the Tongass National Forest on the mainland of Southeast Alaska near Petersburg (56° 48.67602′ N, −132° 57.07452′ W). Boundaries of the study area were Port Houghton on the north, LeConte Bay on the south, Frederick Sound on the

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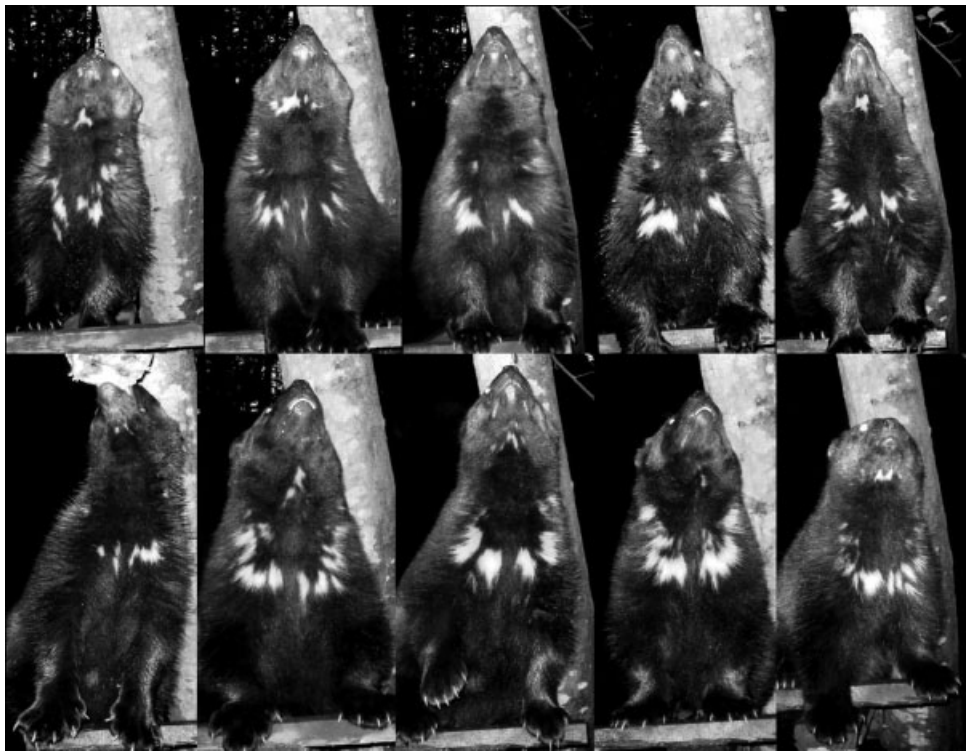

Figure 1. Ventral patterns of 10 unique captive wolverines we photographed on 15 November 2008 in western Washington, USA, using a motion-detection camera with an incandescent flash. All wolverines in the photographs are males except the female in the lower right-hand corner, and most of the wolverines are genetically related.

west, and the Stikine Icefield on the east. Elevations ranged from sea level to 2,164 m. Most forested habitat occurred within 20–50 km of the coast and comprised Sitka spruce (*Picea sitchensis*) and western hemlock (*Tsuga heterophylla*) on productive forest sites and mountain hemlock (*Tsuga mertensiana*) and Alaska-yellow cedar (*Chamaecyparis nootkatensis*) on poorly drained sites. Temperatures at sea level during the study ranged from −4°C to 7°C but were considerably colder at higher elevations, although rarely falling below −23°C. Snowfall during the study was very heavy, reaching depths >4 m at higher elevations. Human inhabitants and developments were clustered near Point Agassiz where there was a local network of old logging roads. Access for trappers was either along this road system with snowmachines and 4-wheelers or along the coast with boats. Average annual harvest of wolverines in the study area in 2000–2009 was 2 (range 1–6) with males comprising 67% of the total harvest for those years. Trappers limited their efforts to take wolverines in 2007–2009 in cooperation with our study.

METHODS

From February to June 2009, we set up 29 C&H stations in forest stands from sea level to 670 m above sea level. We selected sites for C&H stations based on radiotracking and photographic data from 2008 (A. J. Magoun, Alaska Department of Fish and Game, unpublished report) and knowledge of wolverine home range size from other wolverine studies (Persson et al. 2009). We distributed our C&H stations to access known or potential wolverine home ranges and to maximize the number of individuals that might be documented at our stations while minimizing cost of deployment (i.e., maximizing C&H stations accessible by boat or road and minimizing C&H stations accessible only by helicopter). A minimum convex polygon encompassing the C&H stations in 2009 was 1,707 km^2 and distances between cameras ranged from 0.6 km (separated by a 250-m-wide ocean channel) to 30 km.

Before beginning field work, we assembled materials for each C&H station and constructed run poles that would fit inside a helicopter to shorten helicopter standby time during set up of the stations. At some stations accessed by boat or road, we used a log (approx. 15 cm diameter) found on site. For the prefabricated run poles, we used 120-cm-long pieces of 2 × 4 lumber (38 mm × 89 mm) with a 20-cm-long block of 4 × 4 lumber (89 mm × 89 mm) attached with 4 screws to the underside of one end of the run pole. At each station, we attached the run pole horizontally to a tree using 3–4 lag bolts through the block of 4 × 4 lumber. We positioned run poles ≥1 m above bare ground or snow (Fig. 3a). The distal end of a run pole pointed toward another tree approximately 3–4 m away and was usually supported by a small pole (approx. 5–10 cm diameter) cut on site, positioned vertically under the run pole, and secured in place with a screw (Fig. 3). This additional pole was not necessary to support wolverines, but it provided extra stability when heavier animals visited the site or when researchers stood on the run pole to hang the bait.

To attach the support structure (described below) to the run pole, we used 2 short pieces of 2 × 4 lumber, one that

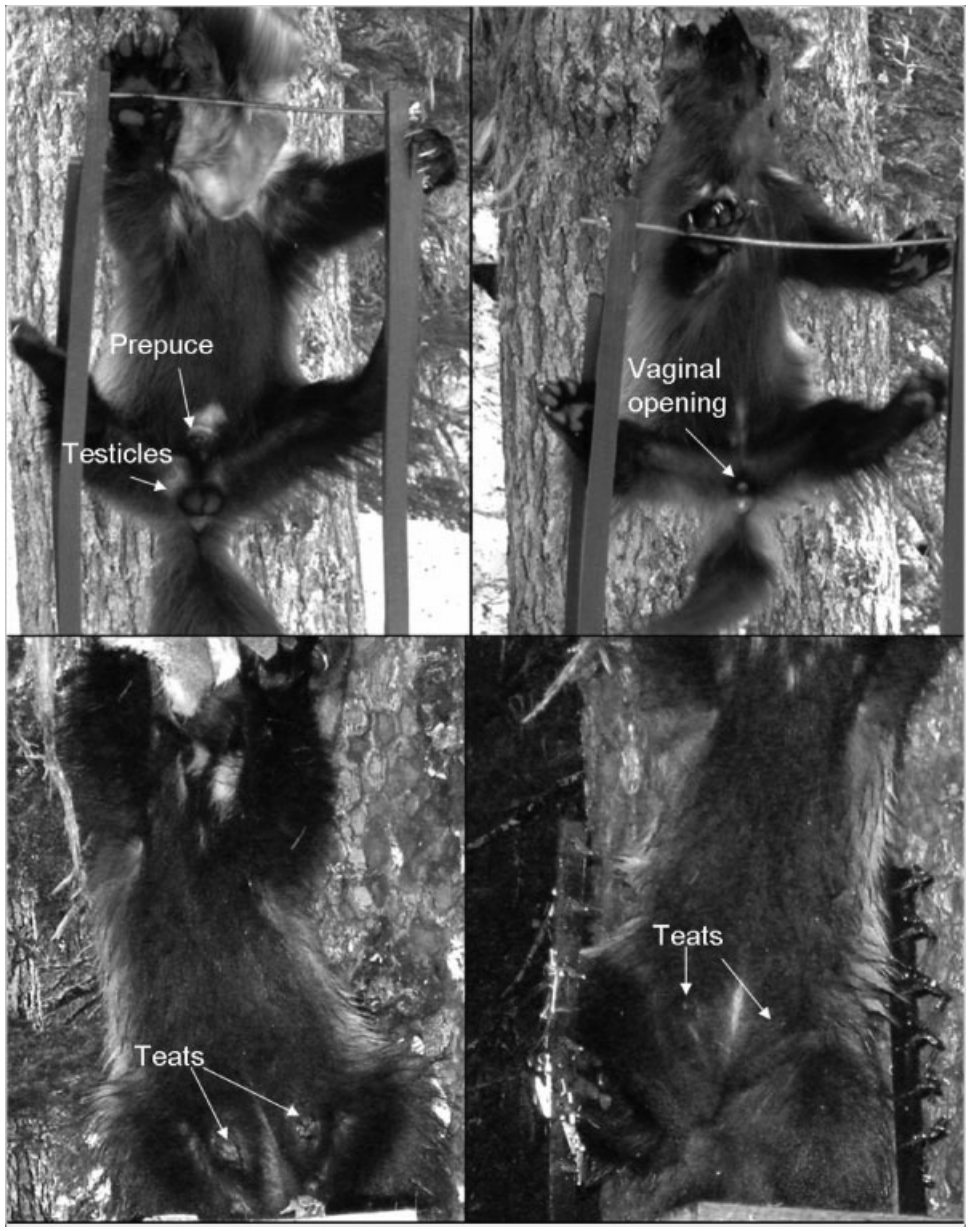

Figure 2. Photographs of 3 unique wolverines taken with motion-detection cameras at sites in Southeast Alaska, USA, showing the abdominal area with evidence of sex for a male ≥2 years old photographed on 11 May 2009 (top left), a non-lactating female photographed on 12 May 2009 (top right), and a lactating female photographed on 13 May 2009 (lower left) and again on 26 June 2009 (lower right). The 2 lower photographs show regression of teat size after weaning.

was 35.6 cm (14 in.) long and one that was 40.6 cm (16 in.) long, and attached the shorter piece with screws to the run pole so that it was perpendicular to the pole, flush with the distal end of the pole, and centered on the pole. We positioned the longer crosspiece similarly but 22 cm from the distal end of the run pole (Fig. 3b).

To construct the support structures, which we mounted at the distal end of the run poles, we used square rods (approx. 2.5 cm) of ultra high molecular weight (UHMW) polyethylene plastic (Plastic Supply, Inc., Tacoma, Washington) and steel alligator clips with 7.9-mm jaw opening (Mueller Electric Company, Akron, OH; Fig. 3). The support structure consisted of 3 parts: 1) 2 vertical, 76-cm-long pieces of UHMW plastic (uprights), each screwed at their base to opposite ends of the shorter crosspiece on the run pole; 2) 2 similar pieces of UHMW mounted diagonally for bracing the 2 uprights (braces) with one end of each piece bolted to the top of the UHMW uprights and the other screwed into the end of the longer wooden crosspiece on the run pole; and 3) a 46-cm-long, 6.4-mm diameter (0.25 in.) threaded steel rod that spanned the distance between the uprights approximately 2.5 cm from the top of the structure (crossbar).

Behind the support structure, we added 2 additional pieces of UHMW plastic approximately 30–40 cm long (snag posts) on which we mounted 6–8 alligator clips (Model #BU-60PR2; Mueller Electric Company; Figs. 3b and 4). We inserted the base ends of these clips into 6.4-mm-diameter holes drilled into the snag posts, tapping lightly on the tip of the jaw with a hammer, and firmly seating the base clips into the holes. The clips were held in by friction

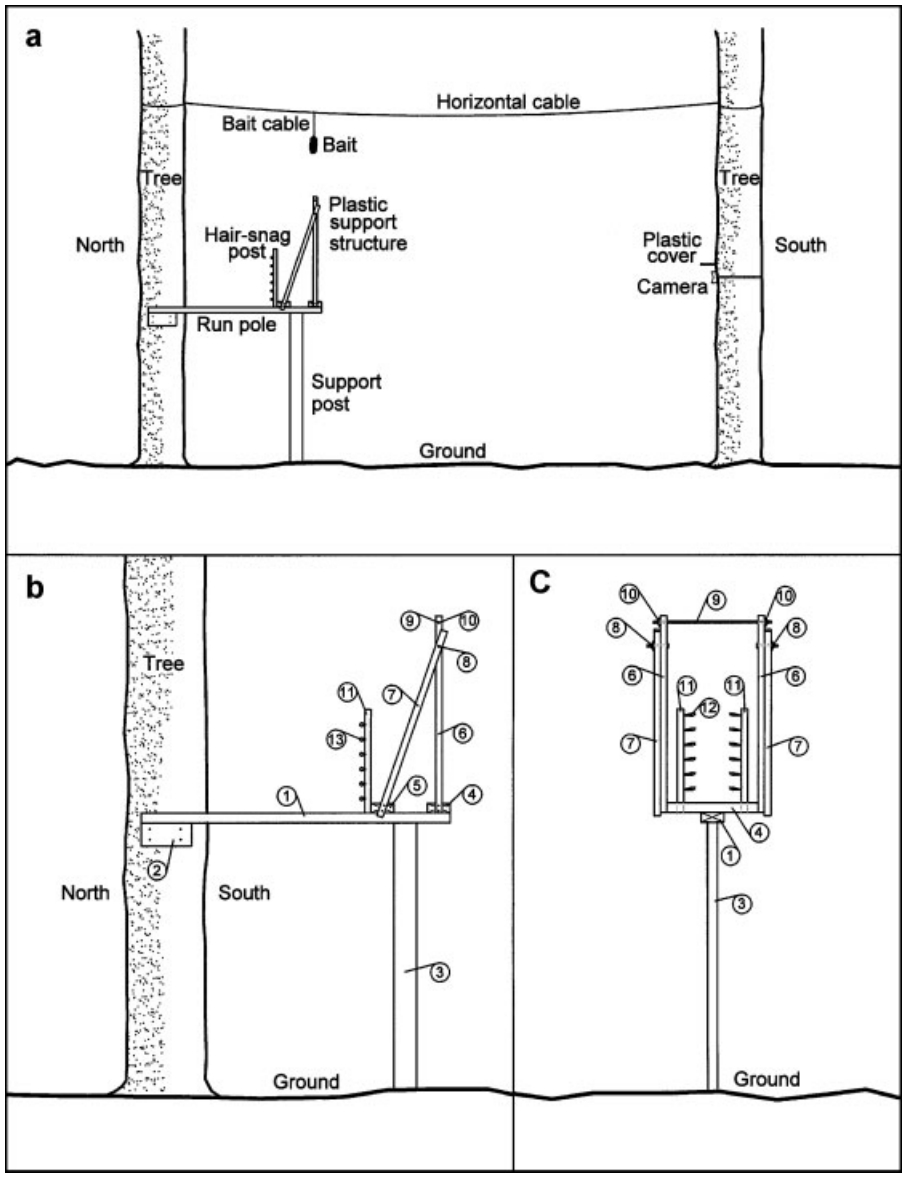

Figure 3. Three views of an of an integrated system of motion-detection camera and hair-snag devices used in Southeast Alaska, USA, in 2009 and 2010 showing (a) the complete system, (b) a side view of the run pole, support structure, and snag posts, and (c) the distal end of the run pole showing the support structure and the hair-snag posts as viewed from the camera. Numbers refer to the following elements of the run pole and hair-snag structure: 1) run pole, 2) wooden block with lag screws, 3) vertical support post, 4) short crosspiece, 5) long crosspiece, 6) ultra high molecular weight (UHMW) plastic upright, 7) UHMW plastic diagonal brace, 8) bolt, washer, and lock nut, 9) threaded steel crossbar, 10) washer and lock nut, 11) UHMW plastic snag post, 12) base clips and trigger clips, and 13) eye screws.

and rarely fell out even with vigorous activity by animals on the run poles. We screwed the snag posts vertically into the proximal edge of the longer crosspiece, one on each side of the run pole separated by approximately 25 cm so that they were visible in photographs.

When setting the alligator clips, we opened each base clip and inserted another alligator clip (Model #BU-60; Mueller Electric Company) so that the base clip held this trigger clip open. We attached each trigger clip to a simplex snap (AISI 304-stainless steel; Henssgen Hardware Corporation, Glens Falls, NY) using a 7- to 8-cm-long lanyard that we made from Steelon® nylon-coated wire (BD45BL; Berkley®, Spirit Lake, IA) and Berkley connector sleeves (B3) with a #5 standard gauge split ring (Worth Company, Stevens Point, WI) at the opposite end, which we threaded through the barrel end of the trigger clip (Fig. 5). We secured the trigger clips to the snag posts by attaching the simplex snaps to small eye screws inserted into the back of the snag posts (Fig. 3b). The springs in the base clips were at least as strong as those in the trigger clips so that the base clips held the trigger clips open to the widest extent possible. When dislodged by an animal, trigger clips would dangle at the end of the lanyards, preventing another animal from depositing hair in the clips (Fig. 6).

We ran a cable (2-mm-thick wire rope) horizontally between the 2 trees and high enough that the bottom of the bait was approximately 30–40 cm above the crossbar (Fig. 3). Larger pieces of bait required a higher horizontal

Figure 4. Photograph of a wolverine taken with a motion-detection camera at a camera and hair-snag station in Southeast Alaska, USA, in 2010 showing the ultra high molecular weight (UHMW) plastic uprights and steel crossbar and 2 UHMW plastic hair-snag posts with 7 base clips and trigger clips per post.

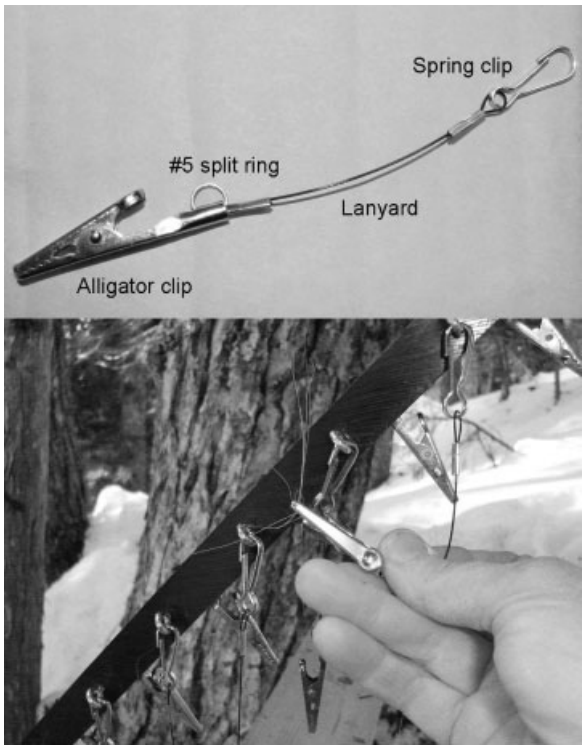

Figure 5. Trigger clip attached to a spring snap by a nylon-coated wire lanyard before it is clipped to an eye screw in a hair-snag post (upper photograph) and a trigger clip with wolverine hair collected at a camera and hair-snag station in Southeast Alaska, USA, in 2009 (lower photograph). All other trigger clips are dangling by lanyards from the eye screws in the hair-snag posts.

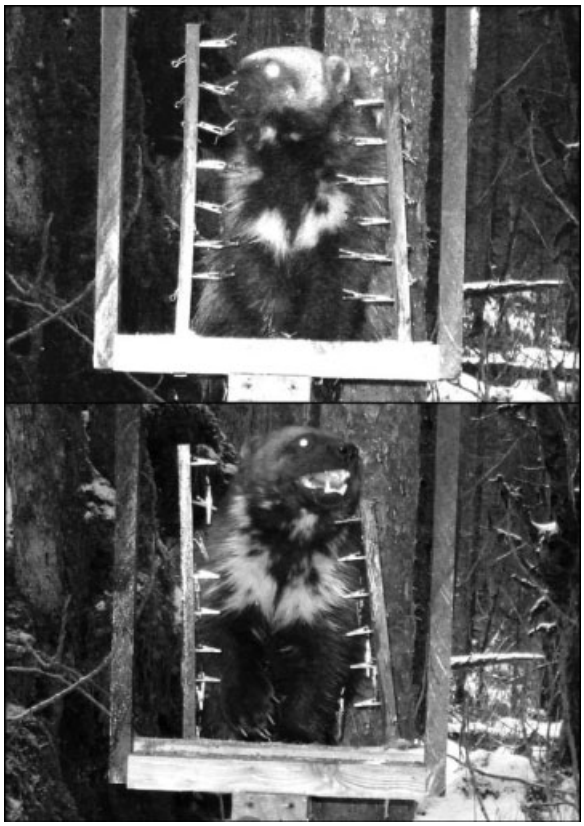

Figure 6. A wolverine on a run pole at a camera and hair-snag station in Southeast Alaska, USA, in 2009 before any of the trigger clips were dislodged (upper photograph) and a different wolverine on the run pole after all the trigger clips were dislodged (bottom photograph).

cable. For bait, we used locally available animals that wolverines would be familiar with, including parts of deer (*Odocoileus hemionus*), moose (*Alces alces*), black bear (*Ursus americanus*), and beaver (*Castor canadensis*) that were from road-killed animals or were remnants of animals taken by hunters or trappers. We threaded a piece of cable through a hole drilled through a major bone in the bait and, using a cable clamp, attached the bait cable to the horizontal cable and adjusted the height and location of the bait above the distal end of the run pole before tightening the cable clamp.

We attached a Trail Watcher® motion-detection camera (Trail Watcher, Monticello, GA) to the tree opposite the run pole so that the camera faced the distal end of the run pole (Fig. 3a). We set the camera to take photos with the incandescent flash on both day and night to provide sharp photographs with no shadows. The camera triggered every time an animal moved in front of the camera, resulting in photos taken approximately 4 s apart and yielding 500–700 photos on a 2-gigabyte memory card. For back-up in case of malfunction, battery depletion, or a full memory card, we also attached another Trail Watcher camera or a Reconyx® infrared camera (Reconyx, Inc., Holmen, WI) to the tree and set this second camera to take photos over a longer period of time. The Reconyx camera had no incandescent flash and generally produced poorer quality photos but would operate over a longer period of time and at

temperatures below −23°C. We adjusted the height and position of the cameras so that the identification placard on the end of the run pole was centered near the bottom of the photographs (Fig. 4).

When we visited the C&H stations to collect hair, which we did each time we checked cameras to change batteries and memory cards at 1- to 4-week intervals, we placed the hair from each trigger clip (Fig. 5) into a separate small envelope and labeled the envelope with a collection and trigger clip number that included the date, camera site, and clip position on the snag post (e.g., C10-041809-R7 indicated a sample of hairs collected at C&H station C10 on 18 Apr 2009 from the seventh clip from the top on the right snag post). Therefore, each hair sample envelope contained ≥1 hair that we knew came from the same animal. Hereafter, we refer to the contents of these envelopes as a hair sample (or sample) regardless of the number of hairs in the envelope. We then placed these sample envelopes into a larger envelope labeled with the collection identification number for that station and date (e.g., C10-041809) and referred to these envelopes as a collection. Because we had mounted the trigger clips so they could be seen on the photographs, we could tell which clips were set and which ones were triggered, both before and after a visit by a wolverine (Fig. 6), thereby allowing us to determine which individual wolverine was associated with each triggered clip. This integrated method of photographing and collecting hair from wolverines made it possible to link genotypes with the unique ventral patterns of the wolverines photographed at the stations.

To reduce the cost of DNA analysis, we subsampled from among collections and from among samples within collections so that every wolverine identified by its ventral pattern that left hair at a C&H station was selected for genotyping at least once. We selected collections for analysis based on photographic evidence that only 1 wolverine had visited the site before we collected the hair or, in the case of a visit by >1 individual, we could see from the photos which wolverines had triggered which clips. We tried to sample from ≥2 collections for each wolverine identified by its ventral pattern, although sometimes individuals were represented in only one collection.

We extracted genomic DNA from hair samples using standard protocols for tissues (Dneasy Tissue kit; Qiagen Inc., Hilden, Germany), with overnight incubation in lysis buffer and Proteinase K on a rocker at 60°C. We examined hair samples at 9 microsatellite loci used previously with wolverine samples in other studies: *Gg4*, *Gg7*, *Ma2*, *Ma8*, *Tt4* (Davis and Strobeck 1998); *Ggu101*, *Ggu216*, *Ggu234*, and *Ggu238* (Duffy et al. 1998). We amplified microsatellites using protocols detailed in the respective sources, except we amplified these microsatellites using 0.8 units of Taq polymerase and 45 polymerase chain reaction (PCR) cycles. We visualized the resulting products on a LI-COR DNA analyzer (LI-COR Biotechnology, Lincoln, Nebraska). We accepted data from hair samples as error-free only if the microsatellites produced consistent scores in 3 separate PCR reactions. In addition, we used an SRX–SRY region to determine sex (Hedmark et al. 2004).

To validate the accuracy of ID and sex determined from photographs of wolverines, we compared results from photographs with that from DNA using the following blind protocol to eliminate observer bias. A. Magoun determined ID of wolverines using photographs of ventral patterns, assigned a name to each unique individual, identified sex of individuals using photographs of wolverines in a bipedal stance, and determined which individuals had triggered the hair-snag clips. Without knowledge of ID and sex of wolverines identified from photographs, M. Schwartz and K. Pilgrim extracted DNA from hairs and identified genotype and sex of individuals in hair samples. They assigned a code number to each genotype and provided a list of genotype ID codes, sex, and associated collection and trigger clip numbers to A. Magoun and C. Long, who independently compared the DNA data to the photographic data.

To test our ability to identify the same individuals in consecutive years and detect any new individuals, we repeated our sampling in March–June 2010 at 12 stations where we detected wolverines in 2009. Using the 2010 photographs, we identified ID and sex of wolverines previously verified by DNA in 2009 and assigned a name and sex to new individuals. We then verified ID and sex using DNA from hairs collected at C&H stations in 2010.

RESULTS

Over the 2 years of our study, we photographed 21 wolverines (10 M, 11 F) and collected 374 hair samples in 72 collections. We analyzed 99 samples and identified 18 unique genotypes (10 M, 8 F) for wolverines previously identified by ventral patterns (86%). In addition to the 18 genotyped individuals, photographs provided ID and sex for 1 additional female and ID for 2 other wolverines of unknown sex. There were no wolverines genotyped from hair samples for which we had not previously established ID and sex from photos. In other words, if a wolverine deposited hair in trigger clips, it also provided enough photographs to establish ID and sex from photographs. From genetic data we calculated a probability of identity of 1.5×10^{-7} for the 18 individuals we genotyped and 6 others captured in the study area from 2007 to 2010 as part of another study (A. J. Magoun, unpublished report), suggesting we had adequate power to discriminate among individuals using microsatellite DNA.

In the first year of our study, we obtained photographs of wolverine ventral patterns at 22 of 29 (76%) C&H stations and collected 188 hair samples in 34 collections from 18 of the 29 (62%) stations. From the photographs, we identified 14 unique wolverines (8 M, 6 F). Using photographs of dislodged clips, we were able to link each of these individuals to ≥1 hair sample. After performing DNA extractions on 74 of the 188 samples (39%), we obtained sufficient DNA for genotyping 37 of the 74 samples (50%) from 28 of the 34 (80%) collections. We obtained unique genotypes for 13 individuals (8 M, 5 F) but DNA was insufficient for genotyping the sixth female identified in photos. Two wolverines wore radiocollars, having been captured in live traps in

2008 as part of another study (A. J. Magoun, unpublished report), so identification for these two was aided by the collars and sex was known. Therefore, we based our test of sex identification from photographs on the remaining 11 individuals that we genotyped. Of the 13 individuals identified by both photographs and DNA in 2009, we identified 5 in just 1 collection each and 8 in 2–6 collections. We identified all individuals in multiple collections by both photographs and DNA in each collection. The 5 we identified from photos and DNA in only 1 collection we did not genotype at any other station in 2009, but we genotyped 2 of these individuals in multiple collections in 2010.

In 2009, we also identified 4 wolverines (1 M, 2 F, and 1 unknown) from photographs for which we had no hair samples. We were not able to collect hair from these individuals for 1 of 3 reasons: the triggered clips had not snagged hair, the clips were already triggered by another animal, or the wolverines failed to trigger clips. Of these 4 individuals, we later obtained genotypes for 3 in 2010 (see below) and verified ID and sex determined from the 2009 photos. The fourth individual (F) was the only wolverine of the 18 we identified by ventral patterns in 2009 that we were unable to genotype by the end of the study, despite willingness of the individual to climb run poles and access baits, because either the trigger clips were all dislodged before she arrived at the station or hair collected from her did not contain adequate DNA for genotyping. Finally, photographs of partial ventral patterns indicated that there were 2 additional wolverines visiting camera stations in 2009 and that they were still present in the study area in 2010, at which time we were able to photograph the full ventral pattern and determine the sex of one of them (F).

In 2010, we obtained photographs of wolverine ventral patterns at 11 of 12 C&H stations (92%) and from these photographs we identified 13 unique wolverines (5 M, 6 F, and 2 unknown). We performed DNA extractions on 25 of 186 hair samples (12%) from 17 of 38 collections (40%) and obtained genotypes for 10 of the 13 photographed individuals (76%). Using the DNA results, we verified that we had also photographed and genotyped 5 (3 M and 2 F) of the 10 genotyped individuals in 2009. Of the remaining 5 genotyped individuals, we had photographed but not genotyped 4 (1 M and 3 F) in 2009, and we photographed the other (M) for the first time in 2010. Of the 3 wolverines photographed in 2010 for which we obtained no genotype, we had photographed 2 in 2009. The third was a new wolverine (sex unknown) that we had not previously photographed and it left no hair during the single visit it made to a camera station. In the 2 years of our study, we detected only 1 wolverine that repeatedly visited C&H stations but would not use run poles to access baits so we could not obtain a full ventral pattern. We obtained numerous photographs of this individual from cameras placed near the ground in 2009 and 2010 and were able to identify it from its unusual light coloration, incomplete photographs of the ventral pattern, and thinly-furred tail. This individual visited at least 3 C&H stations, which were also visited by other wolverines we were able to identify by their ventral patterns.

DISCUSSION

Our integrated system of cameras and hair snags worked well in a wild population of wolverines in Southeast Alaska and we were able to validate the use of photographs for determining the ID and sex of individual wolverines. There was 100% agreement between identification from ventral patterns and DNA linked to those individuals, and our determination of sex from photographs matched that from DNA in every instance. The number of wolverines we documented and the success rate of obtaining genotypes for these individuals were dependent upon several factors, including size of the study area and density of wolverines, number and location of C&H stations, and number of times we checked C&H stations to add bait and collect hair. In 2010, our frequent (1–2 weeks) visits to stations provided sufficient time during the field season to collect hair from 3 shy individuals that required adjustments to the station set up. To entice a shy individual to approach the bait, we removed the support structure and hair-snag posts until the wolverine began to feed on the bait and then gradually added the structure and snag posts to the end of the run pole, beginning with 1 snag post and finally adding the support structure if we wanted more detailed photos with evidence of sex or lactation (i.e., enlarged teats in Mar–Jun).

Alligator clips were superior to barbed wire (e.g., Mulders et al. 2007, Fisher et al. 2009) or other hair-snag devices because the clips were easy and fast to deploy, reduced risk of injury, made it possible to link genotypes to ventral patterns, and reduced cost of DNA analysis by >74% without compromising our ability to identify all individuals that left hair at C&H stations. The savings in DNA analysis was even higher than indicated here because we did not have to analyze all hairs within each sample envelope when the station was visited by >1 wolverine and we did not have to collect hairs if a review of photographs in the field indicated that no wolverines had approached the hair-snag posts (i.e., hair in trigger clips was from non-target species). By associating a genotype with a unique ventral pattern, hair collections from multi-year or large-scale studies can be sorted by individual and would not require DNA analysis when photographs indicate a known individual. Effort can then be concentrated on obtaining hair at stations where photographs indicate wolverines without known genotypes are using the sites, including new individuals that may be offspring of known individuals.

It was uncommon to collect hair in trigger clips from >1 individual in a collection, occurring only 3 times during our study. Usually, either 1 individual visited a station between camera checks or the first wolverine to visit dislodged most of the trigger clips. Of the 99 hair samples we analyzed, only 1 sample proved to be a different wolverine than we had anticipated from reviewing the photos, but we had tagged this sample as "uncertain" prior to DNA analysis because the hair was caught on the base clip, not in the trigger clip, and 2 wolverines had visited the site before we collected the hair.

One disadvantage of using alligator clips is that once animals have triggered all clips, subsequent visits by wolver-

ines before clips are reset will not yield hair for DNA analysis. We believe this disadvantage is outweighed by the advantage of eliminating samples that could contain hairs from multiple animals, including non-target species, and by the ability to link wolverine genotypes to ventral patterns. Using alligator clips to collect hair, we were able to genotype 86% of wolverines photographed at our stations and we believe that we can improve on this success rate with additional refinements in our hair-snagging technique (e.g., adjusting the length of the bait cable relative to the hair-snag posts, adding additional hair-snag posts, and using alternative designs that incorporate natural materials at the C&H station for sampling shy individuals; Magoun et al. 2011). We do not know how well our success rate compares to other hair-sampling techniques because no information is available on the success rate of collecting hair and genotyping wolverines using other techniques, although Fisher et al. (2009) reported that wolverines in their study area sometimes visited hair-snagging stations without depositing hair in their barbed-wire snagging devices. Nevertheless, when photographs indicate that $\geq$2 wolverines are repeatedly visiting the same C&H station, but only 1 individual is triggering all the clips, use of a multiple-capture snagging device such as barbed wire could be added to the C&H station to collect hairs from the other wolverines. Linking hair from these devices to a particular individual in the photographs may not be possible if $\geq$2 wolverine visited the station, especially if the camera stopped operating before the hair samples were collected.

Although thousands or even tens of thousands of photos may be collected at C&H stations during a camera-trapping season, we found that reviewing photos of wolverines and linking them to specific hair samples can be accomplished quickly and efficiently on a computer with inexpensive photo-editing software. Because we were sorting only for photos showing ventral patterns of wolverines on run poles, we could scan the entire collection of photos from each camera check in only a few minutes. Once we linked genotypes to particular ventral patterns, we only needed to scan subsequent photographs for new ventral patterns.

We suggest the following precautions when applying the technique. Time delays between photographs should be as short as possible so that wolverines visiting C&H stations do not have time to trigger hair snags without being photographed. Whenever possible, $\geq$2 hair collections should be used to link ventral patterns to genotypes as a way to cross-validate the linkage. In multi-year studies, it should be possible to obtain genotypes for most of the resident animals and costs for DNA analysis should go down over time if turnover rate in the population is low. We also strongly recommend that only full ventral patterns (i.e., frontal view of the entire throat and chest) be linked to genotypes to avoid errors in the initial linkage leading to incorrect associations in subsequent collections of photos or hair. Furthermore, if there is any doubt that a particular clip was triggered by the wolverine in the photograph, then $\geq$1 additional hair sample for that individual should be genotyped if available. Loose hairs on the support structure and hair-snag posts or hairs caught in base clips should not be used to link a genotype to a particular wolverine, even if no other wolverine was photographed at the station, to prevent mistakes in matching genotypes to ventral patterns. However, extra hairs can be used to verify that a wolverine with a different genotype had visited the station, if photographs indicate that this might be the case. Even if photographs indicate that extra hairs are almost certainly from a particular individual, verification from another collection should still be made before assigning a final genotype to that ventral pattern. Finally, DNA may not be required for some research goals; nevertheless, inexperienced researchers who plan to use photographs to identify wolverines without genotyping should first test their ability to determine ID and sex from photographs by testing themselves on photographs of known individuals, validating their results with DNA until they are confident of their ability to determine ID and sex, or obtaining a second opinion from another researcher experienced in using the technique.

Management Implications

Besides providing information on wolverine ID, sex, and genotype, the integrated system of motion-detection cameras and hair snags can potentially provide data on familial relationships, effective population size, dispersal patterns from DNA, survival rates in multi-year studies, lactation in females, centers of activity, population density using capture-recapture models, and behavioral information such as association of individuals based on the date and time stamp on photographs. In fact, we believe that the full value of the system will not be realized until other researchers and managers apply the technique to their particular conservation and management needs. We encourage modifications of the system to improve the design and to suit different habitat types (e.g., tundra vs. forest) and different wolverine populations where behavior of wolverines might differ (e.g., trapped vs. untrapped). Finally, the photographs we obtained of marten (*Martes americana*) at our C&H stations suggest that a similar integrated system of cameras and hair snags would work equally well for martens with modifications for the smaller size of this forest carnivore.

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