From:	A J
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Date:	Wednesday, March 1, 2017 1:59:50 PM
Attachments:	WSB-16-132_Magoun_revised_manuscript.docx Untitled attachment 02529.htm

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Betty
Here is the text of the WSB paper. Jens mentioned that he owes you an email so I'm sure you will hear from him soon. We are on our way to see a den site tomorrow with very little snow!

Sent from my iPhone

Begin forwarded message:

> **From:** A J <222wsheridan@gmail.com>
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2 January 2017
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Detecting Snow at the Den Site Scale in Wolverine Denning Habitat

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ABSTRACT The relationship of wolverines (*Gulo gulo*) to persistent spring snow (PSS) may be obligate at the den site scale but this relationship has yet to be examined at this scale. Our objective was to detect snow at the den site scale in late May using low-altitude aerial photography in wolverine denning habitat both in the Rocky Mountains of western USA and in northwest Alaska. In the Rocky Mountains, we detected snow on 31 May 2016 in low to heavy categories in 82% of 40 transect segments flown through home ranges of 4 reproductive female wolverines that had denned in Idaho and Montana prior to our study. In the Alaska study area, we detected snow on 29 May 2016 at 4 den sites of reproductive female wolverines that denned in 2016. By then snow remained only in occasional, widely scattered patches. Remnant snowdrifts

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remained at all 4 den sites. High-latitude tundra habitats in Alaska may lose PSS sooner than montane habitats at the southern extent of wolverine distribution. To manage wolverines and their habitat and to incorporate PSS in models of future wolverine habitat, we must understand the relationship of wolverines to snow and measure PSS at an appropriate resolution and scale that is biologically meaningful for the species.

KEY WORDS Aerial photography, Alaska, climate change, den site scale, denning habitat, *Gulo gulo*, Rocky Mountains, persistent spring snow, threatened species, wolverine.

Recognizing that a warming climate could have negative impacts on wolverine habitat by reducing the amount and distribution of persistent spring snow (PSS) (Copeland et al. 2010, McKelvey et al. 2011), the U. S. Fish and Wildlife Service (USFWS) proposed listing the wolverine as a threatened species in the Rocky Mountains of western USA under the Endangered Species Act in 2013 (USFWS 2013). After scientific review of the listing proposal, the USFWS concluded that the wolverine did not warrant listing at that time (13 August 2014) because a threat to wolverine habitat had not been shown to be imminent in the foreseeable future (USFWS 2014). This finding was subsequently litigated in court, resulting in a court order that the USFWS reconsider listing the wolverine as a threatened species (Defenders of Wildlife vs. Sally Jewell, U.S. Department of the Interior and Daniel M. Ashe, U.S. Fish and Wildlife Service, 4 April 2016, Case 9:14-cv-00246-DLC, Document 108).

In its finding, the USFWS emphasized the need for more information on the relationship of wolverine distribution to PSS at the den site scale. Copeland et al. (2010:244) concluded that the "strong concordance of wolverine den sites with the spring snow coverage clearly reflects an obligatory relationship with snow cover for reproductive dens." The basis for this conclusion was that most documented den sites were in areas with snow lasting from 24 April–15 May in at least 1 of 7 years from 2000–2006 (hereafter, 15 May MODIS PSS). The snow metric used in their analysis was satellite-detected, daily snow cover at a 500-m resolution classified with Moderate-Resolution Imaging Spectroradiometer (MODIS-based snow). However, the spatial and temporal coarseness of the analysis introduced uncertainty regarding the obligatory nature of the relationship between 15 May MODIS PSS and wolverine habitat, resulting in the USFWS selecting a panel of scientists to review the specific relationship of wolverines to PSS (Wolverine Science Panel 2014). The panel agreed that an obligatory relationship probably exists at the den site scale but was less certain that a relationship existed at the scale of home range or species distribution. Panel members did not explicitly define den site scale so we searched the literature for information on studies of wolverine den sites, particularly natal dens (Magoun and Copeland 1998), for an approximation of den site scale. Magoun (1985) measured wolverine dens excavated in snow in tundra habitats in northwest Alaska. The longest distance spanned by the tunnel system of a natal den was about 30 m. Dawson et al. (2010) found a den in a boulder complex within the boreal forest of Canada that was 60 m long and 30 m wide. May (2011) used a 10-m radius and Makkonen (2015) a 20-m radius around natal dens in Scandinavia to study den selection at the scale of a den site. Using these examples, we judged the 500-m resolution of MODIS-based snow too coarse to capture snow at the scale of a den site particularly at the end of the denning season. Copeland et al. (2010) used 15 May to mark the end of the wolverine denning season.

Copeland et al. (2010) pointed out that wolverine dens located in northwest Alaska (Magoun 1985) occurred well within the circumpolar spring snow coverage compared to the Rocky Mountains at the southern extent of wolverine distribution in North America. However, over the last 60 years, climate in Alaska has been warming more than twice as rapidly as in the rest of the USA (Chapin et al. 2014), so latitude of den sites in northern Alaska may not confer an advantage over den sites in the Rocky Mountains in future climates. McKelvey et al. (2011) used global climate models (GCM) to predict future loss of wolverine habitat in the Rocky Mountains of western USA based on 15 May MODIS PSS. To validate their GCM analysis, McKelvey et al. (2011) conducted a similar analysis of MODIS-based PSS from 24 April–29 May (rather than 15 May) thereby forcing spring snowmelt 2 weeks earlier as a proxy for future PSS on 15 May (hereafter, 29 May MODIS PSS), consistent with a 2-week earlier onset of spring conditions over the last 50–100 years in the Rocky Mountains. Following this reasoning, we examined snow at the den site scale at the northern and southern extent of wolverine distribution in North America in late May 2016.

Specifically, our objective was to use low-altitude aerial photography to document and compare snow persisting to 29 May at the den site scale in a sample of wolverine denning habitat in the Rocky Mountains and northwest Alaska as a potential method for documenting changes in snow at this scale over time.

STUDY AREA

Our study area comprised home ranges of 2 reproductive female wolverines that denned in the Rocky Mountains in central Idaho in the Payette National Forest near McCall (44º 53.32'N, 116º 06.105'W) and 2 in southwest Montana in the Madison and Gravelly Mountains near Ennis (45º 16.46'N, 111º 38.93W), hereafter referred to as the Rocky Mountains samples, and the den sites of 4 reproductive female wolverines that denned in northwest Alaska near Umiat (69º 22.196' N, 152º 8.174' W), hereafter referred to as the Alaska samples (Fig. 1). Habitats in the Rocky Mountains samples were alpine and montane forest communities with elevations 1,600–3,000 m. Habitats in the Alaska samples were tussock tundra and shrub communities with elevations 70–

300 m. Average annual snowfall at McCall (elevation 1,530 m) was 340 cm (water years 1905–2016) compared to 84 cm (water years 1949–2001) at Umiat (elevation 79 m) (Western Regional Climate Center; www.wrcc.dri.edu). Snowfall increases at higher elevations in the Rocky Mountains. Although snowfall was appreciably more in the Rocky Mountains than in northwest Alaska, strong winds on the Alaska tundra formed deep snowdrifts along drainages and lake shores. Average monthly temperatures for April and May measured at MCall (1905–2012) were 3.3º C and 8.5º C, respectively, and at Umiat (1949–2001) they were -17.7º C and -4.4º C, respectively.

METHODS

We conducted our aerial photography in 2016 in areas that were verified reproductive habitat, either in the past or in 2016, rather than select areas randomly from within known wolverine habitat (Copeland et al. 2010, Magoun 1985). For the Rocky Mountains samples, we used previously documented home ranges of denning female wolverines (Fig. 1). The 2 Idaho females (ID F1 and ID F2) denned in the Payette National Forest in 2010 (F1 and F2 in Heinemeyer et al. 2010) and the 2 Montana females denned in the Madison (MT F105) and Gravelly (MT F121) Mountains in 2004 and 2007, respectively (F105 and F121 in Inman et al. 2007). We established flight lines along transects through the long axis of these home ranges, positioning transects through or close to where den sites were located in those years. We conducted low-altitude aerial photography flights in these home ranges on 31 May 2016. Flights occurred on 31 May due to unfavorable weather conditions on 29 May. We used a GoPro Hero 4 camera (GoPro, Inc., San Mateo, California, USA) mounted on the wing of a fixed-winged aircraft (Marcot et al. 2014) to photograph snow along a flight transect that bisected the long axis of each home range of the 4 female wolverines. We had no information on whether females still occupied these home ranges but we had no reason to believe these home ranges no longer comprised denning habitat. Average flight altitude above ground level (AGL) was approximately 300 m. We did not attempt to maintain the same altitude AGL during the flights because we were seeking only confirmation of presence of snow along the flight routes rather than documenting the total amount of snow in the home ranges. We programmed the camera to take a photograph every 5 seconds to provide overlap of photographs along transects (Marcot et al. 2014). We stitched photographs together for each home range and eliminated overlap to provide continuous photographic coverage of each transect. We divided each transect into 10 equal segments and plotted the segmented transects on snow cover maps for 15 May MODIS PSS and 29 May MODIS PSS (Copeland et al. 2010 and McKelvey et al. 2011, respectively) (Fig. 2).

We examined segments for presence of snow and subjectively placed each of the 40 transect segments in one of the following categories depending on the distribution and amount of snow in the segment: none, occasional, occasional–low, low, low–moderate, moderate, moderate–heavy, and heavy. Occasional snow refers to snow patches distributed in widely scattered locations on the landscape, usually along ridgelines, lakeshores, and drainages. Low snow refers to small patches of snow scattered regularly through the segment or occurring only in larger patches near the margin of the segment. Moderate snow refers to large amounts of snow distributed across the segment but with melt-out areas also evident over large areas. Heavy snow refers to snow cover over most of the segment, showing little difference from winter snow cover. Because abrupt changes in elevation occurred within some segments, there were also abrupt changes in snow categories within some segments so for those segments we bridged the snow category between 2 of the 4 categories defined above resulting in 8 total categories.

In Alaska we used 4 den sites that wolverines established in 2016. In the Alaska samples (Fig. 1), we did not photograph snow along transects through home ranges because in 2016 snow was largely absent by 29 May. Instead, we flew to the 4 den sites on 29 May in a helicopter and photographed any remaining snow at the sites. The Wildlife Conservation Society (WCS) provided locations of den sites from an ongoing research program in the National Petroleum Reserve-Alaska (NPRA) in northwest Alaska. The WCS conducted research in 2016 under the University of Alaska-Fairbanks Institutional Animal Care and Use Committee Permit 847738.

RESULTS

In the Rocky Mountains study areas, we sampled 40 transect segments and documented snow on 31 May 2016 in all but 1 transect segments (Fig. 3). Of the 40 segments, 82% retained snow in low to heavy categories and 58% in moderate to heavy categories. Very deep snow was evident in some photos where wind had formed snow cornices over winter (e.g., Figs. 4a and 4b). Even the home range with the least amount of snow (MT F121) had snow in all transect segments and 3 segments had moderate amounts of snow (e.g., Fig. 4b). Transect segments categorized as having low snow had many snow patches scattered across the segments (e.g., Fig. 4c).

Snow in the Alaska study area had largely disappeared by 29 May with only widely scattered patches of snow remaining along some drainages, lake shores, and ridgelines where deep drifts had formed in winter (i.e., occasional snow). We photographed remnant snowdrifts at all 4 den sites on 29 May 2016 (Figs. 5a–5e).

DISCUSSION

There is considerable interannual variation in the timing of spring snowmelt depending on spring temperatures and the amount of snow that accumulates over winter (Kivinen 2012, Macander et al. 2015). Nevertheless, we were surprised at how little PSS remained in the Alaska samples on

29 May compared to the Rocky Mountains samples on 31 May considering the high latitude of the Alaska samples. The home ranges in our Rocky Mountains samples had considerable PSS through 31 May with at least occasional snow even at lower elevations. If our observed PSS in Alaska on 29 May was within normal variability (i.e., not an unusual anomaly in 2016), we might expect PSS in the Alaska study area in future climates to be confined to widely scattered patches on 15 May, particularly if spring melt advances even more rapidly than in the Rocky Mountains.

Our data demonstrate that we cannot assume that high-latitude habitats have more extensive and longer-lasting PSS than areas at the southern extent of the wolverine's distribution. PSS in scattered patches that is not detectable by remote sensing techniques (e.g., Copeland et al. 2010, Macander et al. 2015) may persist long enough at den sites to provide cover for wolverines in future climates. This may be true for wolverine denning habitat in the Rocky Mountains as well. In the home range of MT F121, 5 of 10 transect segments fell outside the 29 May MODIS PSS in McKelvey et al. (2011) (Fig. 2d), yet all segments had snow at least at the den site scale when we photographed them on 31 May 2016. In other words, some MODIS pixels predicted to lose wolverine habitat in the future (McKelvey et al. 2011) might still retain snow at the den site scale on 15 May, at least in some years.

The scientific panel convened by the USFWS concluded that spring snow cover is obligatory for wolverines at the den site scale (Wolverine Science Panel 2014), but there was no consensus on how much snow is needed for denning or how long it needs to last. Copeland et al. (2010) used 15 May to derive the snow layers in their bioclimatic model, but neither these authors nor the scientific panel stated that snow cover was obligatory for denning until 15 May. In fact, Copeland et al. (2010) provided evidence that snow cover, at the scale measured in their study, may not be obligatory through 15 May because dens were located in areas that had 15 May MODIS PSS in as little as 1 of 7 years. In North America, 31% of dens fell within areas that had MODIS snow in ≤5 of the 7 years examined. Use of snow-covered den sites may not be obligatory through 15 May, or may not be obligatory at the scale in Copeland et al. (2010), nevertheless wolverines may continue to use snow-covered sites as long as they are available. All den sites in the Alaska samples had snow patches on 29 May that were large enough to shelter females with young. Female AK F3 used her den site until at least 24 May (Wildlife Conservation Society, unpublished data). Magoun (1985) documented use of snow patches by some females with young even in July in northwest Alaska.

Future assessment of snow over large areas at the home range or range-wide scale will undoubtedly continue to rely on relatively coarse satellite imaging, but low-altitude aerial photography may be the most accurate method for the foreseeable future for rapidly assessing the extent and duration of PSS at a scale that is biologically meaningful for wolverines. Moreover, documenting snow at the den site scale in home ranges of denning females in the Rocky Mountains would not require a large number of flight hours. Marcot et al. (2014) used low-altitude aerial photography to produce images of land-cover types in northwest Alaska, flying 2,590 km in approximately 18 hours at an altitude of 300 m AGL. In our study, the average length of transects through each of the 4 home ranges in the Rocky Mountains was 23.5 km. Using aircraft with an airspeed of approximately 265 km/hr, we estimated less than 3 hours of flight time would be needed to sample snow in as many as 20 wolverine home ranges (not including transition time between home ranges). Low-altitude aerial photography could be used to determine interannual variability in the extent of snow at the den site scale on a given date as well as the variability in the date of snowmelt in different portions of wolverine denning habitat.

It does not rely on timing of satellite positions and is not affected by high-altitude cloud cover obscuring the ground. Low-altitude aerial photography could form the basis of a relatively inexpensive, long-term monitoring program of wolverine denning habitat based on PSS at the den site scale. It could also be used to ground-truth the results of remote sensing techniques used to detect PSS on a larger scale (e.g., Macander et al. 2015).

We strongly encourage more research on the relationship of wolverines to spring snow at the den site scale. There are no studies that have focused on when, how, and why wolverines use PSS at the den site scale and whether this use is in fact obligatory for successful reproduction. The strong concordance between wolverine den locations and MODIS-based PSS reported by Copeland et al. (2010) in as few as 1 of 7 years may have been influenced by presence of PSS undetectable with MODIS satellites. Snow present only in scattered patches, as we observed at den sites in Alaska on 29 May, could be sufficient to provide cover for wolverines at the end of the denning season and beyond. On the other hand, snow in any form may not be obligatory across the entire denning season when other structures afford protection for wolverine kits near the end of the denning season. Webb et al. (2016) suggested that wolverines may be resilient to loss of PSS under some circumstances, which could explain wolverine persistence in some areas outside modeled habitat in Copeland et al. (2010). Finally, there is a possibility that the concordance of PSS and wolverine dens is tied to some other driver of wolverine distribution that is correlated to 15 May MODIS PSS (Copeland et al. 2010) but has yet to be measured and defined (e.g., Inman et al. 2012).

We recommend that techniques for detecting PSS in wolverine habitats should have a resolution capable of detecting snow patches of a size and configuration known to be used by wolverines in spring, including snow that persists only in long, narrow bands along drainages, lake shores, and ridgelines. We also emphasize the need for information on PSS at the den site scale in diverse wolverine habitats, particularly where wolverines currently reproduce but where it could be difficult for them to adapt to future ecological conditions brought about by climate change (e.g., habitats at the southern extent of wolverine distribution and tundra habitats with few structural features as alternate cover). We echo the sentiment of Webb et al. (2016:1468): "Documenting den structures, snow conditions at dens, and duration of use, particularly in areas outside of the expected distribution of spring snow cover, is needed to clarify the relationship between wolverines and snow." To this statement we add that studies of wolverines and snow should extend beyond the apparent need of PSS for denning to include other possible uses of snow as an important component of wolverine habitat (Inman et al. 2012, Webb et al. 2016). The use and importance of lingering snow patches in spring have received little attention in studies of wolverine habitat. To manage wolverines and their habitat and to incorporate snow in models of future wolverine habitat, we must understand the ecological relationship of wolverines to snow and measure snow at an appropriate resolution and scale that is biologically meaningful to the species.

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Figure Captions

Figure 1. Study areas where we photographed persistent spring snow (PSS) with low-altitude aerial photography on 29–31 May 2016. The base map is PSS detected with Moderate-Resolution Imaging Spectroradiometer 24 April–5 May 2000–2006 from Copeland et al. (2010). C. Raley (USDA Forest Service, Pacific Northwest Research Station, Olympia, Washington, USA) provided the ArcGIS raster data.

Figure 2. Flight transects through home ranges of female wolverines (*Gulo gulo*) where we photographed persistent spring snow (PSS) using low-altitude aerial photography on 31 May 2016 in Idaho and Montana, USA. The base maps are PSS detected with Moderate-Resolution Imaging Spectroradiometer (MODIS) for 24 April–5 May 2000–2006 (15 May MODIS PSS; Copeland et al. 2010) and for 24 April–29 May 2000-2006 (29 May MODIS PSS; McKelvey et al. 2011). Transects for Idaho females ID F1 and ID F2 are mapped on 15 May MODIS PSS and 29 May MODIS PSS in Figs. 2a and 2b, respectively, and transects for Montana females MT F105 and MT 121 are mapped on 15 May MODIS PSS and 29 May MODIS PSS in Figs. 2c and 2d, respectively. C. Raley (U.S. Forest Service, Pacific Northwest Research Station, Olympia, Washington, USA) and J. Copeland (The Wolverine Foundation, Inc., 4444 Packsaddle Road, Tetonia, Idaho, USA) provided ArcGIS raster data for 15 May MODIS PSS and 29 May MODIS PSS, respectively.

Figure 3. Extent of snow cover detected with low-altitude aerial photography on 31 May 2016 along flight transects bisecting the home ranges of 4 reproductive female wolverines (*Gulo gulo*): ID F1 and ID F2 that denned in the Rocky Mountains near McCall, Idaho in 2010 (F1 and F2, respectively, in Heinemeyer et al. 2010) and MT F105 and MT F121 that denned near Ennis,

Montana in 2004 and 2007, respectively (F105 and F121, respectively, in Inman et al. 2007). We divided each of the 4 transects into 10 equal segments and categorized snow in each segment as one of the following: none, occasional, occasional–low, low, low–moderate, moderate, moderate–heavy, and heavy.

Figure 4. Examples of heavy (Fig. 4a), moderate (Fig. 4b), low (Fig. 4c) and occasional (Fig. 4d) snow cover photographed on 31 May 2016 along transects that bisected the home ranges of female wolverines (*Gulo gulo*) that denned in the Madison (Fig. 4a) and Gravelly (Figs. 4b and 4d) Mountains in Montana, USA and in the Payette National Forest (Fig. 4c) in Idaho, USA. Conifer trees provide scale in the photos.

Figure 5. Snow photographed at the den sites of female wolverines (*Gulo gulo*) AK F2 (Figs. 5a and 5b), AK F3 (Fig. 5c), AK F4 (Fig. 5d), and AK F5 (Fig. 5e) near Umiat, Alaska on 29 May 2016. The snow patch in Fig. 5a is a close-up of the small snow patch at the head of the drainage in photo Fig. 5b. Helicopter shadows against the tussock tundra and shrubs provide a scale for the size of snow patches in Figs. 5c–5e.

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