ATTACHMENT A

Supplementary Documentation for Peer Review of the USFWS Proposed Listing Determination for the Wolverine in the Contiguous United States

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Document Reviewed: USFWS proposal to list the distinct population segment of the North American wolverine occurring in the contiguous United States as a threatened species under the Endangered Species Act

Purpose of Peer Review: "to ensure our listing determination and critical habitat designation are based on scientifically sound data, assumptions, and analyses" (p. 114).

BACKGROUND

Proposed Listing Determination:

1) "the primary threat to the DPS is from habitat and range loss due to climate warming" (p. 100)
2) "the contiguous United States wolverine DPS presently meets the definition of a threatened species due to the likelihood of habitat loss caused by climate change resulting in population decline leading to breakdown of metapopulation dynamics" (p. 101)
3) "we base this determination on the immediacy, severity, and scope of the threats" (p. 101)
4) "other minor threats that could become significant when working in concert with climate change if they further suppress an already stressed population include
    a) harvest including incidental harvest
    b) demographic stochasticity and genetic diversity due to small effective population sizes " (p. 101)

Premise for the Proposed Listing Determination:

"We find that McKelvey et al. (2011, entire) represents the best available science for projecting the future impacts of climate change on wolverine habitat for four primary reasons:

1) their habitat projections are based on global climate models that are thought to be the most reliable predictors of future climate available (IPCC 2007a, p. 12)
2) they conducted downscaling analyses to infer geographic climate variation at a scale relevant to wolverine habitat
3) they used a hydrologic model to predict snow coverage during the spring denning period (the strongest correlate with wolverine reproductive success)
4) they used the habitat model developed by Copeland et al. (2010, entire) to relate projected climate changes to wolverine habitat" (p. 59)

REVIEW

Most responses in my review of the proposed listing determination are in the form of edits and comments directly on the Word version of the document provided by Shawn Sartorius. However, I have added this separate document (Attachment A) to provide detailed explanations of why I believe that the proposed listing determination is not based on the "best available science" because 1) there is consequential information that was not considered in the proposed listing determination and 2) there are errors in the data analyses relative to "persistent spring snow," which was integral to projecting future wolverine habitat under climate warming in the McKelvey et al. (2011) paper. McKelvey et al. (2011) cited Aubry et al. (2007), Schwartz et al. (2009), and Copeland et al. (2010) as their sources of information on wolverine habitat use and movements in relation to persistent spring snow cover (p. 2884, *Modeling snow*). McKelvey et al. (2011) used the 15 May MODIS-based snow cover data from Copeland et al. (2010) to analyze the effects of climate warming on future wolverine habitat in the western states. The dates chosen for modeling "persistent spring snow" are the primary basis for the climate models developed by McKelvey et al. (2011). In this supplementary documentation (Attachment A), I point out erroneous assumptions about wolverine habitat requirements in Copeland et al. (2010) associated with the 15 May MODIS-based snow cover, then discuss how climate models in McKelvey et al. (2011) were affected by these errors, and add a few comments regarding Schwartz et al. (2009) on dispersal and connectivity in relation to projected wolverine habitat under climate warming. I summarize my conclusions at the end of this document. Many of the points made below

are referred to in my comments on the Word document of the proposed listing determination. It is important to note that I am listed as an author on the Copeland et al. (2010) paper, which I had the opportunity to review before it was submitted for publication. At that time, I mentioned my concerns regarding the 15 May MODIS dates, as did one of the official reviewers for the Canadian Journal of Zoology during the review process (Attachment B). The ramifications of failing to consider problems with the 15 May MODIS data would not be fully apparent until the publication of McKelvey et al. (2011) and the subsequent use of this paper as the basis for this proposed determination. I feel it is important to bring my concerns forward here to ensure the listing determination is based on scientifically sound data, assumptions, and analyses. In addition, some information presented below was published subsequent to Copeland et al. (2010) and McKelvey et al. (2011) so the authors may not have had access to or known of the existence of this information prior to publishing their paper. This more recent research is cited in my discussion below where relevant.

1. Review of Copeland et al. (2010):

The failure of the bioclimatic envelope developed by Copeland et al. (2010) to encompass wolverine distribution and den sites across the species' entire range invalidates assumptions about the *obligatory* nature of spring snow cover (i.e., 15 May MODIS) for defining wolverine habitat. In this section, I present arguments why dates used by Copeland et al. (2010) for developing the bioclimatic envelope of the wolverine are in error and do not provide the best scientific data on wolverine denning and year-round habitat.

1a. *The Bioclimatic Envelope and Relevance to the 15 May MODIS Snow Model*

Copeland et al. (2010, p. 234), in their introductory remarks, stated that:

> "bioclimatic models consider climatic variables as correlates of a species' current distribution and are often used to predict range shifts that may result from different climate change scenarios [reference cited here]. These correlative approaches are sometimes criticized because they fail to account for interactions with biotic factors [references cited here] and may not accurately reflect the ecology, behavior, or physiology of the target species [references cited here]. *Consequently, evaluating an organism's*

> *climatic requirements by correlating current range with climatic factors is problematic* [italics mine]. However, if researchers possess reliable understandings of both an organism's geographic range and its climatically linked biological requirements, they can evaluate whether current range is consistent with the climatic conditions needed to fulfil those requirements [no reference cited]. This approach is taken here".

In other words, the authors are stating that they have a reliable understanding of the wolverine's geographic range and its "climatically linked biological requirements," which in this case refers to "persistent spring snow" for denning and the "upper thermal limits" for the species (p. 235-236). They conclude on p. 244 that "the strong concordance of wolverine den sites with the spring snow coverage clearly reflects an obligatory relationship with snow cover for reproductive dens."

To be clear, the term "spring snow coverage" and "persistent spring snow" in Copeland et al (2010) refers to snow cover that lasts to 15 May in at least 1 of 7 years in the period 2000–2006 as measured by MODIS at a 500-m resolution (p. 235). Any 500-m pixel determined to be bare of snow in the period 24 April–15 May was removed from the snow cover layer for that year. These data were used to produce a map referred to as the "spring snow coverage" (p. 235), which was subsequently used as the basis for the 15 May MODIS map in McKelvey et al. (2011, Fig. 2B, p.2887). No biological reasons were stated in either Copeland et al. (2010) or McKelvey et al. (2011) for why "persistent spring snow" would be required *in as few as 1 of 7 years* for wolverine habitat or why they excluded arctic regions that consistently have "persistent spring snow" every year.

What is the scientific basis for stating that wolverines require "persistent spring snow" to 15 May? Copeland et al. (2010) stated "it has been hypothesized that deep, persistent snow cover is an obligate component of wolverine reproductive denning habitat (Magoun and Copeland 1998)" (p. 234). Copeland et al. (2010) do not define "deep" in their paper nor do they refer to snow depth from the Magoun and Copeland (1998) paper. A careful reading of the Magoun and Copeland (1998) paper does not reveal a hypothesis that wolverines require deep snow until 15 May. That paper reports on a combined 10 natal dens and 8 maternal dens from Alaska and Idaho and reviews information about dens from earlier publications. Although the Alaska dens were in "deep snowdrifts" (p. 1315), the depth to the deepest point in one den was reported as

>1m, with the maximum depth in snow tunnels measured at 2.5 m. No depth measurements were provided for Idaho. From their study and their review of the literature on wolverine dens, Magoun and Copeland (1998) stated that "*almost all* verified wolverine reproductive dens were under 1–5 m of snow" (p. 1317) [italics mine]. One den was found in <1m of snow (i.e., ≤80 cm in Pulliainen 1968). Subsequently, Inman et al. (2007c) reported an occupied wolverine den that had <25 cm of snow covering a portion of the den (p. 71).

Date of den abandonment was variable for the Alaska and Idaho dens. Of the 18 dens that made up the sample in Magoun and Copeland (1998), only 2 in Alaska were known to be abandoned in May (p. 1316). These maternal dens were in 1) a remnant snowdrift (i.e., spring snowmelt had progressed to such an extent that the only snow left in the area occurred as lingering snowdrifts) and 2) a rock cave (not snow-covered; Magoun, personal observation). All other dens were abandoned (or could have been abandoned) before May (den abandonment date for one den in Alaska fell somewhere between 18 April and 5 May; Table 1, p. 1315). None of the dens in Idaho were used after 30 April. Magoun and Copeland (1998) concluded that "we believe a critical feature of wolverine denning habitat is dependability of deep snow throughout the denning period. *At least 1 m of snow, distributed uniformly or accumulated in drifted areas, should be present by February and persist until May"*(p. 1318) [italics mine]. It should be evident from this statement that "deep" refers to ≥1m, that snow need not be covering the entire area but could be in the form of remnant snowdrifts, and snow should persist *until* May (not 15 May). The "denning period" was defined in that paper as February–April (p. 1314).

At the time Magoun and Copeland (1998) was published, most wolverine reproductive dens had been "located in alpine, subalpine, taiga, or tundra habitat" and rarely "reported in low-elevation, densely forested habitats, although wolverines occupy these habitats" (p. 1317). Banci (1994, p. 10) speculated that the reason most dens were reported in tundra habitats [alpine and subalpine should be included here] was an artifact of where researchers searched for dens. The first detailed published account of a den site in lowland boreal forest in North America (or perhaps anywhere) was Dawson et al. (2010) for a den in Ontario, Canada [other than the mention of an unusual den in an

abandoned beaver lodge in Alaska reported by Rausch and Pearson (1972) that could have been in a lowland forested area]. The Ontario den was located in snow-covered boulders, and kits were later moved under a snow-covered fallen tree nearby and to another site in a dense stand of trees. Snow depth at these sites was not measured, however, snow depth was likely <1m at the time the den was established because snow depth in Red Lake, Ontario (the nearest weather station; located 40 miles SW of the den site) was 59 cm on 23 March 2004, the day the lactating female was captured. This was the deepest snow measured at this station during the denning season (February–April; Attachments D–F). Snow depth had fallen to 37 cm on 1 April, 19 cm on 8 April, and only 4 cm on 18 April, the last day with measurable snow at the Red Lake weather station (Environment Canada National Climate Data and Information Archive (Attachment F), except for a snowstorm on 12 May that produced 7 cm of ephemeral snow that disappeared by 16 May. Snow depths were similar in other areas of the region, with maximum snow depth during February–April at the Pickle Lake weather station 120 miles ENE of the den site measured at 69 cm (Attachments G–I). As mentioned above, wolverine dens sometimes occur under <1m of snow, with Pulliainen (1968) reporting a den with 3 kits in March in Finland that was located beneath 70–80 cm of snow (Den No. 20, p. 340).

Copeland et al. (2010) stated that this Ontario den "and all other dens that occurred outside the spring snow coverage [i.e., the 15 May MODIS snow cover] were located at sites containing adequate snow cover for establishing a reproductive den" (p. 242). To explain the position of the Ontario den outside the "spring snow coverage," Copeland et al. (2010) concluded that "there may be areas classified as snow-free at the southern extent of the spring snow coverage (at 500-m resolution) that contain enough drifted snow for reproductive dens" (p. 242). However, the Ontario den was not in drifted snow (A. Magoun, personal observation; Attachment J) but rather in a large pile of snow-covered boulders, and subsequently the kits were moved to a site under a snow-covered fallen tree (Dawson et al. 2010). This reproductive female was not an outlier in the region. At least 3 other resident female wolverines were captured in the Ontario study where this den site was found (Dawson et al. 2010), none of which had home ranges within the "spring snow coverage" (Neil Dawson, Ontario Ministry of Natural Resources,

unpublished data) and another lactating female was photographed in March in the area after the study was completed (Kim Austen, Ontario Ministry of Natural Resources, personal communication). Therefore, a resident breeding population of wolverines occurred in this region of Ontario and denned outside of the "spring snow coverage." Clearly, there was no deep snow persisting until 15 May in the area where these females lived (if deep is defined as ≥1m; e.g., Magoun and Copeland 1998, Pulliainen 1968).

Why then was 15 May MODIS data selected as the basis for determining the "spring snow coverage" that is necessary for wolverine denning? Copeland et al. (2010) did not offer an ecological explanation for the choice of 15 May but stated:

> "A portion of each daily MODIS image was typically obscured by clouds or, occasionally, by night. Generating cloud- and night-free images required compositing 21 consecutive daily images from 24 April to 15 May, which generally corresponds to the period of wolverine den abandonment (Magoun and Copeland 1998) and is consistent with the time period used by Aubry et al. (2007) to correlate historical occurrence records with spring snow cover." (p. 235) [see also Attachment C].

Is 15 May a realistic date for designating *obligate* snow cover for wolverine distribution and dens? Although wolverines use snow dens in May in many areas of their distribution, one cannot conclude that they *must* have snow for dens in May, certainly there need not be "persistent spring snow" as measured by 15 May MODIS because, as stated above, wolverines live and den outside this spring snow coverage (also, see Section 1c below). Spring snowmelt and den abandonment is variable, with wolverines having some flexibility in when they abandon dens. Spring snowmelt and abandonment of snow dens has occurred by the end of April in as varied habitats as northwestern Alaska (Magoun 1985), Siberia (Zyranov 1989), Idaho (Magoun and Copeland 1998), and certainly in Ontario where snow had disappeared by the end of April at the Red Lake weather station (Attachment F). At high elevation and at high latitudes, wolverines may keep kits at snow dens into May (at least at maternal dens; Magoun and Copeland 1998) if spring snowmelt is relatively late [e.g., under a remnant snowdrift to 9 May in northwestern Alaska; Magoun and Copeland (2010); Table 1, p. 1315]. Use of snow dens into May, and especially to 15 May, is clearly not *obligatory*, especially where boulders, blowdown, and avalanche debris provide alternate sites for protecting kits.

Copeland et al. (2010) recognized that the range of wolverines extends "slightly beyond the spring snow coverage, particularly in areas with low topographic relief" (p. 239) and stated that "their presence outside the spring snow coverage probably reflects accelerated spring snow melt characteristic[s] of a topographically flat landscape." However, these observations offer no explanation of how the "extralimital" wolverines fit into the theory of a bioclimatic envelope that requires "spring snow coverage" to 15 May, or how wolverines biologically exist outside the bioclimatic envelope. Rather, the authors concluded that "the spring snow coverage should be viewed as an approximation of underlying bioclimatic requirements" (p. 244). They also concluded there is a "strong concordance of wolverine den sites with the spring snow coverage" and likely "an *obligatory relationship* with snow cover for reproductive dens" (p. 244, italics mine). Yet, the question is not whether wolverines require snow cover for reproductive dens, but how much snow cover, in what form, and f*or what portion of the denning season*. Given that wolverines sometimes abandon dens before the end of April, the best scientific data indicate that use of snow-covered dens at the *end* of the denning season is *optional* rather than *obligate*.

Copeland et al. (2010) stated that, for their sample of dens in North America, "most dens (45/65; 69%) were located in areas that were snow-covered for 6–7 years" of the 7 years in their dataset (p. 239). Viewed from a different perspective, this means that the locations of many dens, nearly one-third (20/65; 31%), were either in areas that were snow-covered in only 1–5 years out of 7 in 2000–2006 or in areas not snow-covered in any of the 7 years. In fact, as noted by the authors themselves (p. 239), most dens were not actually located in the years used for the MODIS analyses. Twelve dens were located outside the "spring snow coverage" (i.e., "occurred in areas where snow cover was insufficient to classify the 500 m X 500 m area as persistently snow-covered through 15 May") (p. 239). When positing a bioclimatic envelope for wolverines that is based on "an obligatory relationship with snow cover for reproductive dens", and this relationship is defined as the "spring snow coverage" map (Figs, 2, 3, and 8 in Copeland et al. 2010), the best test of an *obligatory relationship* would be to look for evidence of dens that do not adhere to the criteria for this relationship. Reasons provided for why 12 dens fell outside the "spring snow coverage" included the explanation that a subpopulation in Sweden had

"recently colonized lowland forests, but the viability of this population is unknown" (p. 240) and that populations in Alberta, Saskatchewan, and Manitoba in Canada are "at the southern extent of the spring snow coverage" and populations in Ontario and Finland are at the "extreme southern extent of current wolverine range" in these regions (p. 242). In other words, dens in areas where wolverines were recently established or occurred at the southern extent of their range were excluded from the bioclimatic envelope but no biological reasons were given for this exclusion. Nevertheless, large areas of lowland boreal forest in North America are occupied by wolverines outside the "spring snow coverage" (see Section 1c below).

An explanation for why 15 May worked reasonably well for the analysis of wolverine habitat requirements in Copeland et al. (2010) rests at least in part on den locations used in the analysis that were skewed toward dens located in mountain habitats, with 87% from Norway and Sweden alone. Other den sites in mountains were from British Columbia and the Rocky Mountains in the western United States. Therefore, it is not surprising that 97.9% of 562 dens were located in areas that were snow-covered until 15 May (i.e., in the "spring snow coverage"). By using 15 May as the target date for the "spring snow coverage", it is much more likely that mountain dens will fall within the "spring snow coverage," while low elevation dens in the southern boreal forests will fall outside the "spring snow coverage" due to the lower winter snow depth and earlier spring melt that occurs in the boreal compared to mountain regions. For example, see Attachment K for a comparison of temperature and snow depth data in April 2004 (the year the Ontario wolverine den was located) for Red Lake, Ontario and Banner Summit, Idaho; Banner Summit was the nearest SNOTEL station to a wolverine den found in the Idaho study area referred to in Magoun and Copeland (1998).

The large percentage of dens located in the "spring snow coverage" in Copeland et al. (2010), mainly in mountain and tundra habitats (i.e., high elevation or high latitude), is an artifact of where most dens have been found to date and bias of research toward mountain habitats within wolverine range. The location of these dens does not constitute a scientific argument for an *obligatory* relationship of wolverine dens to snow cover through 15 May. In fact, it speaks to criticisms of correlative approaches to bioclimatic models mentioned by Copeland et al. (2010, p. 234), i.e., that bioclimatic models may

"fail to account for interactions with biotic factors" and "may not accurately reflect the ecology, behavior, or physiology of the target species." Researchers need to take a closer look at the bioclimatic niche of the wolverine and obtain better information on the ecology, behavior, and physiology of wolverines to understand the habitat requirements of wolverines at the global scale of the bioclimatic envelope. A theory of an obligatory relationship between wolverine dens and snow cover must apply to all wolverine dens; the relationship simply cannot be considered obligatory.

1b. *Snow Patches and Thermal Cover*

Without knowing the extent, distribution, and quality of snow patches near the end of the denning season, it may not be possible to delineate wolverine habitat using remotely-sensed snow metrics, at least not at the scale of a wolverine den site. Wolverines continue to use snow for cover even after the end of the denning period and into the summer months in some regions (e.g., northwestern Alaska, Magoun 1985, p. 73, Attachment L; Montana, Inman et al. 2007, Ch. 4, p. 84, Photo 11). Snow cover in the form of remnant snowdrifts is thought to be important to wolverines for kit-rearing habitat and food storage (Magoun and Copeland 1998, p. 1318; Inman et al. 2012, J. Mamm.). The MODIS snow cover data used in Copeland et al. (2010) [MODIS/Terra snow cover daily L3 global 500m grid, Version 4, 24 April – 21 May 2000–2006, National Snow and Ice Data Center, Boulder, Colorado; Copeland et al. 2010, p. 234 and 245] does not take into consideration the presence of fractional snow (i.e., discontinous snow within the 500-m pixels), which later versions of the MODIS products incorporate (Salomonson and Appel 2004; Painter et al. 2009; Raleigh et al. 2013). Even with versions that measure fractional snow, MODIS is unreliable in detecting snow cover if it covers <20% of a pixel (i.e., up to 12 acres of the pixel could be covered in snow and the pixel could be classified as bare ground) (Dorothy Hall, NASA Goddard Space Flight Center, Greenbelt, Maryland, personal communication; Attachment M).

The existence, size, distribution, and longevity of remnant snow patches in mountain habitats in the western states may be key to the way wolverines adapt to climate warming in the region. Remnant snow patches were used by wolverines as maternal dens and rendezvous sites on the tundra of northwestern Alaska from late April

to at least the end of June (Magoun 1985, p. 73) and were one of the few structures available in the home ranges of some females to protect kits (personal observation). Snow patches (remnant snowdrifts and snow beds) are much more numerous and last much longer in mountain terrain in the western United States than in the tundra environment of northwestern Alaska (A. Magoun, personal observation, Attachment N). In an experiment on melt patterns of snowdrifts in arctic Alaska and alpine Colorado, arctic drifts in Alaska melted out over 1.5 months before the alpine drifts in Colorado, despite identical drift size and nearly identical snow water equivalent, "a consequence of the different solar insolation regimes in the two regions. In a growing season of only about 90–100 days, this is a major difference indicating that increased snowfall could have more significant ecosystem consequences in the alpine than in the Arctic" (Walker et al. 1999, p. 2327-2328). In the context of wolverine habitat, alpine areas that have increased snowfall (as projected for some mountain habitat in the western states with climate warming; McKelvey et al. 2011, p. 2887) could even see positive benefits in the foreseeable future for wolverines, especially if deeper snow produces snow patches that linger in the mountains for longer periods.

There may be a number of reasons why snow patches may be beneficial for wolverines (Inman et al. 2012, J. Mamm., entire) but, at the *end* of the denning period, thermal cover would not be one of them. The need for snow as thermal cover (Magoun and Copeland 1998, p. 1318) would only apply during the coldest part of the denning period, when kits are small and not thickly furred (Attachment O). Pulliainen (1968) wrote "hunters reported that the female may leave the cubs alone in the den for a day or two. Thus the cubs must be well protected against cold. Besides the snow cover, the very dense pelage and huddling behaviour of the cubs form a good protection" (p. 342). Just after parturition, reproductive female wolverines remain in the dens with their kits for an average of 5.7 days; range 2–11 days (Jens Persson, unpublished data based on GPS collars) and a reproductive female with a GPS collar in Montana remained in her den for 10 days (Bob Inman, unpublished data). When the mother leaves the den, kits huddle together (Dale Pedersen, personal observation), presumably because of the energetic advantages of huddling (Marchand 1996, p. 101). Under most snow conditions, the "hiemal threshold" [i.e., "snow cover thickness at which the subnivean environment is

insulated from diel fluctuations of the ambient temperature" (Pruitt 1957, Pruitt 1970 as cited in Aitchison 2001, p. 229)] is generally reached when snow depth is ~20 cm (Aitchison 2001, p. 230), and even under the densest snow (i.e., snow with less insulative properties), the "hiemal threshold" is reached by 50 cm (Marchand 1996, p. 22).

The advantage of snow cover on thermoregulation is greatest in areas with very cold temperatures. Subnivean temperatures generally vary between 0°C and –10°C, depending on snow depth and density, but in hard tundra snow conditions, the subnivean temperature may drop to less than –20°C (Aitchison 2001, p. 230). These temperatures do not consider presence of 2 or 3 wolverine kits in a snow den, which would warm the den space to some degree (A. Magoun, personal observation from tests with a 30-kg dog in a snow den at -25°F air temperature; snow den temperature +10°F). Intranivean temperatures (i.e., within the snow column where some wolverine dens occur) are usually colder than subnivean temperatures. For example, where an extreme subnivean temperature of –18°C was recorded under at least 20 cm of snow in Siberia, intranivean temperature was –26°C while the ambient temperature was –48°C. However, in a warm maritime climate, the intranivean temperature may not be so different from the subnivean or ambient temperature (Aitchison 2001, p. 230).

In conclusion, there is no biological reason that kits need thermal cover once air temperatures are warming above freezing (or even approaching the freezing point). Snow cover in the form of remnant snow patches may still be useful for protection from wind or predators and are used by wolverines after the denning period and into summer (Magoun 1985; p. 73, Attachment L). Remnant snowdrifts are likely to be most critical for thermal cover in tundra habitats, where very cold temperatures can occur even in May (e.g., *minus* 30°F; personal observation), and where, for some reproductive female home ranges, few other structures such as boulders might be available for protection from predators (e.g., Attachment P). Before we can adequately define wolverine habitat in mountain habitats, more information is needed on wolverine use of snow patches and the effects of climate warming on decreasing or increasing the availability of snow patches at the end of the denning season.

1c. *Wolverines Distribution Outside the Spring Snow Coverage*

Despite lack of descriptions of wolverine dens in lowland boreal forest (Magoun and Copeland 1998), there is ample evidence that wolverines occupy and reproduce in areas outside the 15 May MODIS "spring snow coverage," especially where wolverines occur in lowland boreal forest:

Alberta

In a report on wolverine harvest in Alberta from 1985–2011, the distribution of female wolverines (based on harvested individuals) is mapped relative to the "spring snow coverage" (Webb et al. 2013, Fig. 6, p. 21). From this map, it is apparent that female wolverines are distributed largely throughout the Boreal Forest regions of northern Alberta (Attachment Q). In this report, the authors stated

> "the snow cover map indicates more consistent spring snowpack in the Rocky Mountains and a patchy distribution, with large areas devoid of spring snow cover, throughout most of northern Alberta (north of 56 degrees latitude; Figure 6). And yet, we have evidence of fairly consistent long term wolverine harvest from many areas that appear to lack large areas of spring snow cover (WMU 524, 527, 530, 541; Figure 6; Appendix 1)."

The authors also stated

> "we were surprised to find that large areas of the Boreal Forest lacked persistent spring snow cover, yet had consistent wolverine harvests through time (1985-2011). Studies have suggested that wolverines have an obligate need for persistent spring snowpack which is linked to successful denning recruitment (Copeland et al. 2010). Exploring other metrics, such as distance to the nearest spring snow cover, would help in determining whether wolverines tend to occur closer to places with spring snowpack."

In an email on 13 February 2013 (Attachment R), the lead author of the report wrote that lactating and pregnant females have been documented outside the spring snow cover.

Saskatchewan

The locations of female wolverines harvested in Saskatchewan has not been documented, but I reviewed the locations of harvested wolverines (by Fur Harvest Block), both sexes combined, from 1999-2000 to 2011-2012 and constructed a map of wolverine distribution based on trapper harvest for this period (Attachment S, Map A; Map A and harvest database provided by Saskatchewan Ministry of Environment, Fish

and Wildlife Branch, Saskatoon). I drew the approximate southern edge (dashed line) of contiguous Fur Conservation Blocks that contained harvested wolverines during the 13-year sampling period on the "spring snow coverage map" from Copeland et al. (2010) (Attachment S, Map B). The southern edge of contiguous Fur Conservation Blocks with harvested wolverines occurred at least 100 km south of the "snow cover layer," with >50 wolverines harvested outside the "spring snow coverage" during the 13-year period. Some wolverines were harvested even south of the dashed line on Map A. Most of the "spring snow cover" in Saskatchewan comprised areas with "spring snow cover" in ≤3 years out of 7 (Map B provided by Neil Dawson, Ontario Ministry of Natural Resources).

Manitoba

Wolverine harvest from Manitoba from 2000-2001 through 2011-2012 ranged from 24 to 72 per season. Most have been taken in the area above the dashed line in Attachment T, which includes area outside the "spring snow coverage" of Copeland et al. (2010). For example, the wolverine harvest from the Snow Lake trapping area averaged 6–8 wolverines annually (Attachment T). Some wolverines are also taken south of the dashed line, well outside the "spring snow coverage," including at least one female in 2012-2013 that was taken in southern Manitoba outside the species' current range in that province (Dean Berezanski, Manitoba Conservation and Water Stewardship, personal communication). The trapping area with the highest annual harvest (Pikwitonei) occurs at the southern edge of the "spring snow coverage" in an area where snow lasted until 15 May in only 1 year out of 7 analyzed by Copeland et al. (2010). Most of

Ontario

Wolverines appear to be expanding their range in Ontario, with detections during aerial track surveys becoming more common in the Hudson Bay Ecozone since 2004, coincident with expansion of the range of woodland caribou in this ecozone (Ontario Wolverine Recovery Team 2011; Ray et al. 2011). Aerial surveys for wolverine tracks since 2004 also indicate that wolverines may be more common now in areas that were considered peripheral habitat in 2004 (Attachment U). While some of the apparent wolverine range expansion is occurring within the "spring snow coverage," wolverines are also expanding outside the "spring snow coverage." Within the Copeland et al. (2010) snow cover layer in Attachment U, the majority of wolverine track detections are from

areas that had 15 May MODIS snow cover for ≤2 years. [Note that the density of detection locations in Attachment U is influenced by the number of aerial track surveys carried out in different portions of wolverine range in Ontario and do not represent relative densities of wolverines]. The core wolverine habitat in the western portion of Ontario near the Manitoba border extends south to about 51° N, outside the snow cover layer and somewhat south of where the den site was located in Ontario in 2004. Below this latitude, significant anthropogenic changes to landscapes and ecoystems have occurred and may limit wolverine distribution further south (Bowman et al. 2010, entire).

Sweden

In recent years wolverines have been expanding their range into the forested areas of southern Sweden and reproduction is occurring there (Persson and Brøseth 2011, Figs. 1a-e; Aronsson and Persson 2012, entire). Copeland et al. (2010) explained the occurrence of an "extralimital den" in Sweden as one "believed to be associated with a subpopulation that recently colonized lowland forests, but the viability of this population is unknown" (p. 240). Copeland et al. (2010) did not have the most up-to-date information on this range expansion in Sweden at the time their paper was published. In a 25 March 2013 email (Attachment V), Malin Aronsson, referring to the Aronsson and Persson (2012) paper, wrote:

> "we try to [summarize] the information we have about wolverines in the "forest areas" outside of "traditional wolverine area[s]" (mountains and forest close to the mountains). Figure 2 shows the documented den sites (from the national inventory) with a 20 km buffer zone (blue). The red line is our definition of the limit for "traditional wolverine areas" based on land use, vegetation, the mountain range and reindeer herding practices. We classify the den sites found to the east of that line as being outside of traditional wolverine areas. Our red line matches "the snow model" [i.e., Copeland et al. 2010] pretty well in the southern half of the Swedish wolverine distribution and if you compare Copelands paper with the maps in the two reports you can see that [the] area [has] quite a few den sites outside of the snow model in [recent] years. The blue triangles in figure 3 shows the number of documented den sites east of our red line, most of these den sites are found [in] the southern half of the wolverine distribution and hence outside of the snow model. From 2008 and to today 12-15% of the den sites have been found east of the red line (10-18/year and it looks like a majority of those are outside of the snow model, in the area where it says "Sweden" in figure 4 in Copelands paper). But still a majority of the total den sites (90-110/year) are found inside the snow

> model. As for distances den sites are found from just outside the snow model to approximately 140 km outside of the snow model (rough estimates because I don´t have a GIS layer of the snow model)."

Finland

Copeland et al. (2010) document the locations of 8 wolverine dens outside the "spring snow coverage" in Finland and simply stated that the Finland dens "represent populations at the extreme southern extent of current range." No other information on snow depth at the dens or dates of den abandonment was provided. The authors add that the presence of the dens "outside the spring snow coverage probably reflects accelerated spring snow melt characteristic of a topographically flat landscape" (p. 242). However, one would expect that dens falling outside the "spring snow coverage" would most likely be found at the southern extent of the distribution of the species and in areas with accelerated spring snow melt. Such dens would provide the best test of the "spring snow coverage" model, and the bioclimatic envelope for wolverine, and therefore should not be dismissed when searching for biologically-meaningful explanations of wolverine distribution.

1d. *15 May MODIS Snow Model Compared to Other Models of Wolverine Occurrence*

The proposed listing determination does not adequately address alternative models for distribution and habitat requirements of wolverines, choosing instead to emphasize the simplistic snow cover model of Copeland et al. (2010) (p. 59). However, as stated by the authors, the 15 May MODIS "spring snow coverage should be viewed as an *approximation* of underlying bioclimatic requirements" for the wolverine (Copeland et al. 2010; p. 244) [italics mine]. This paper does not explain all known den site locations or distribution of wolverines across the species' global range. Furthermore, other models of wolverine habitat have not found the "15 May MODIS spring snow coverage" to be one of the "explanatory variables for reproductive den site selection and year-round habitat use" or that "the strong concordance of wolverine den sites with the spring snow coverage clearly reflects an obligatory relationship with snow cover [i.e., snow cover to 15 May for at least 1 year out of 7 from 2000-2006] for reproductive dens" (Copeland et al. 2010; p. 244). For example, the location of primary and maternal wolverine habitat in the western United States determined by Inman et al. (2013, Paper III, Fig. 2) using a

resource selection function (RSF) model is very similar to the 15 May MODIS snow cover in Copeland et al. (2010) (with the exception of the California Sierras and Oregon Cascades for maternal habitat), but the RSF model did not use snow cover on 15 May, but rather snow depth on 1 April, distance to snow, and other variables (e.g., latitude-adjusted elevation, ruggedness, forest edge, high-elevation talus, and human density) for predicting wolverine primary and reproductive habitat (Table 2).

In Scandinavia, Rauset et al. (2013, Paper IV) did not find that the "spring snow cover" of Copeland et al. (2010) was a strong predictor of the distribution and frequency of wolverine reproductions. In their study, Rauset et al. (2013) examined the following parameters: three continuous topographical raster maps (elevation, terrain ruggedness, and slope), one categorical vegetation raster, one raster representing a proxy for primary production (integrated normalized difference vegetation index, NDVI), a spring snow cover index raster (Copeland et al. 2010), one vector map of roads, and five binary maps representing human land use and management policies: country (Norway or Sweden), management zones (wolverine reproductions allowed or not), national parks, designated reindeer areas (semi-domesticated and wild reindeer), and calving grounds of semi-domesticated reindeer. Because elevation and the 15 May MODIS spring snow coverage are correlated environmental variables, they were modeled separately. The "spring snow coverage" was not among the variables that best predicted where wolverine reproductions occurred in Scandinavia, but elevation and NDVI were strong predictive variables (Rauset et al. 2013, Paper IV, Tables 1–3). Moreover, predictors of wolverine distribution and denning in Scandinavia were complex and interactive, and some were specific to the Scandinavian situation.

1e. *Defining Dens, Denning Period, and Period of Den Abandonment*

Central to acceptance of the Copeland et al. (2010) snow model and the subsequent use of the snow model in McKelvey et al. (2011) for predicting future wolverine habitat in the western states, one must accept that wolverine denning extends to 15 May and continuous snow cover is required until then in the western states. As stated above, Copeland et al. (2010) provided no definitive biological or ecological rationale for choosing 15 May or assuming obligatory "spring snow cover." Indeed, available empirical evidence related to the timing of wolverine denning and 15 May MODIS "spring snow cover" does not support an obligatory relationship. The analysis of birth dates for wolverines in the western United States and information about den abandonment over the global range of the wolverine (see Section 1a above) suggest flexibility in the timing of wolverine den abandonment, including dates in April (e.g., 23 April). However, there is some confusion over the definition of the "wolverine denning period" because few studies have documented parturition dates or dates of den abandonment. For example, Myrberget (1968) reported dens found by hunters from 7 March to 12 May in Norway, and Myrberget and Sørumgård (1979) stated no kits seem to be born as late as April. Pulliainen (1968) concluded young are born in February and March and leave the den in April and May, with the latest 14 May in the Finnish fells. Zyranov (1989) reported finding a wolverine den in Russia on 28 March beneath 1 m of snow with 3 kits no more than 4 weeks old. When he returned to the den on 23 April, the den was abandoned, most of the snow had melted, and there was standing water all around. On 26 April they relocated the kits under windthrown trees that were not under snow. Serebryakov (1983) reported finding wolverine dens on 14 April and as late as 17 May in the tundra of Siberia. Rauset et al. (2013) stated that the ground in their Scandinavia study area is usually snow-covered from October *until* May (Paper III, p. 5) and the denning period was January–May and *den abandonment* May–June (Paper III, p. 6). Magoun and Copeland (1998) defined wolverine dens based on timing of parturition (natal dens), movement of kits to new locations (maternal dens), and age of kits to weaning (after which, the term rendezvous site was used instead of den). They defined the denning period as February–April (p. 1314) for dens located in northwestern Alaska and Idaho (p. 1314), although two maternal dens were abandoned as late as 9 May (Table 1). After maternal dens were abandoned, wolverines used rendezvous sites, which may or

may not have been under remnant snowdrifts (Magoun 1985, p. 73). Therefore, the definition of the "denning period" in the literature consulted by Magoun and Copeland (1998) depended not only on when kits were found in dens but also on whether authors discriminated between reproductive dens (natal or maternal) and rendezvous sites. Some of the reports of "dens" in May (or even April) in the early literature could have been rendezvous sites, but without knowing the date of den initiation or the age of the kits, it would not be possible to separate dens from rendezvous sites. Any place kits were found in snow, under trees, or in boulders or caves were referred to as dens before Magoun (1985; p. 73) began to differentiate between dens and rendezvous sites and Magoun and Copeland 1998 differentiated between natal and maternal dens.

Copeland et al. (2010) did not define a specific denning period, rather they stated that reproductive denning begins in early February to mid-March, post-weaning den abandonment occurs in late April and May (p. 2340), and the period 24 April–15 May "generally corresponds to the period of wolverine den abandonment" (p. 235). From the literature cited in the paragraph above, the reported period of den abandonment, regardless of the definition of a den, fell within the period 23 April–17 May on a global scale. These dates indicate flexibility of at least 23 days in the seasonal occurrence of den abandonment across the wolverine's range. The selection of 15 May for the "spring snow coverage" map in Copeland et al. (2010) falls near the end of this den abandonment period. As Copeland et al. (2010, p. 244) pointed out, "although 15 May represents the approximate end of denning, the actual date likely varies geographically. We made no attempt to fit the snow coverage to either the collected data or the heuristically derived range map, but recognize that slight shifts in the analysis period result in *significant* changes in the areal snow cover" [italics mine]. In other words, shifting the dates used for analysis of MODIS snow cover by small amounts in the den abandonment period has a significant effect on whether MODIS will classify a pixel as snow-covered or not, and consequently, on the strength of the correlation between areas with "persistent spring snow" and wolverine den locations.

The exact dates of snow den abandonment on a regional scale are probably determined by all of the following: wolverine birth dates; depth and density of snow; snow distribution; snow temperature at different depths at the time spring snowmelt

begins; range and duration of spring ambient temperatures (thawing degree days); structures within dens; and availability of alternate den sites in the latter part of the denning season that do not include snow. Together, these factors will determine how far into the spring months kits will use snow for dens and rendezvous sites, *whether or not this use is obligatory*.

There is no evidence that use of snow dens after April in the mountains of the western United States is obligatory. From the available data on known birth dates of wolverines in the western United States, wolverines give birth in February. For Idaho, estimated parturition dates were 16–23 February (n=3) (Magoun and Copeland 1998; Table 1); and also for Idaho 16–23 February (n=3) (Heinemeyer et al. 2010, p. 16-17). Copeland and Yates (2008) reported that wolverines in Glacier National Park occupied dens by late February (p. 7, no dates provided). For Greater Yellowstone, estimated latest possible parturition dates, excluding one based on tooth eruption, were 10–23 February (n=6) in Inman et al. (2007, Ch. 4, p. 69). Only one parturition date in March was reported in this study (8 March; Inman et al. 2007, Ch. 4, p. 69). However, this parturition date was based on tooth eruption pattern for a kit captured on 17 May (Bob Inman, personal communication; Attachment W) and this estimated date was recently revised and falls in the period 22 February–1 March, with the most likely date closer to 22 February than 1 March (Clint Long, information from hand-reared wolverines, personal communication, Attachment X). I could find evidence of only one possible birth occurring in March in the western states (Northern Cascades in Washington), but this date was an estimate based on Sirtrack satellite collar locations and the birth could have occurred from the end of February until sometime in the first week of March (Cathy Raley, USFS, personal communication).

In summary, the sample size of wolverine parturition dates for the western United States is still small and future investigations may reveal births in March, but the best scientific data at this time show births occurring largely, if not entirely, in February in the western states. The lack of verified birth dates after February 23 indicates that wolverine kits in the western states are likely to be at least 8–10 weeks old (and most at least 9 weeks old) by the end of April. Therefore, the use of a 15 May date for *obligatory* snow cover for denning wolverines in the western states is not supported by current scientific

data, even if we assume kits need snow cover to 9 weeks of age. Therefore, the use of a 15 May date for obligatory snow cover for denning wolverines in the western states is not supported by current scientific data. For analyzing effects of climate warming on wolverine denning habitat and distribution in general in the western United States, the best scientific data indicate that an assumption of an obligatory requirement for snow cover should not extend past 30 April, and could possibly be even earlier, based on data on birth dates and kit development.

2. Review of McKelvey et al. (2010):

As mentioned in the proposed listing determination (p. 59), McKelvey et al (2011) is considered "the best available science for projecting the future impacts of climate change on wolverine habitat" in the western United States in part because their analysis "used the habitat model developed by Copeland et al. (2010, entire) to relate projected climate changes to wolverine habitat." As argued above, however, the 15 May date used for developing the "spring snow coverage" in Copeland et al. (2010) and used subsequently by McKelvey et al. (2011) for developing climate change models [and by Schwartz et al. 2009 for analyzing dispersal habitat and connectivity] is not based on "the best available science." Despite the fact that McKelvey et al. (2011) is considered "the most sophisticated analysis regarding climate change effects to wolverines" (proposed listing determination, p. 50), the key assumption on which the analysis is based is in error and therefore invalidates the conclusions about the effect of climate warming on wolverine habitat in the western United States. Without further analysis using scientifically defensible information on denning requirements for wolverines in the western United States, McKelvey et al. (2011) cannot be considered "the best available science" for projecting the future impacts of climate change on wolverine habitat.

2a. *Projected Future Wolverine Habitat in the Western United States*

As stated in the proposed listing determination (p. 56), McKelvey et al. (2011) used two approaches to project the impacts of climate change on wolverine habitat in the western United States: 1) downscaling global climate models and 2) projecting the onset of spring snowmelt to occur 2 weeks earlier than it currently does. Both of these methods

were directly tied to the MODIS-derived "spring snow coverage" in Copeland et al. (2010), which has been shown to be problematic (see Section 1 above). In the first instance, the authors compared (cross-walked) the MODIS-based 15 May snow cover and a hydrologic model of snowpack that was based on an interpolation of historical temperature and precipitation data. This simply means that they found the best fit between their hydrologic model of snow depths and the "spring snow coverage" of Copeland et al. (2010) for 15 May. [The best fit occurred "when 1/16-degree pixels with average snow depth values >13 cm were considered snow covered and those with <13 cm were not" (p. 2887). The 13-cm cut-off may have been influenced by the fact that they chose snow depth on 1 May (not 15 May) "as the metric to match to MODIS-derived persistent spring snow cover" (p. 2885), presumably because temperature and precipitation used in the hydrologic model were input on the 1st of each month (McKelvey et al. 2011, p. 2885).]

McKelvey et al. (2011) took a more direct approach in the second method they used to model the effects of climate warming on wolverine habitat. McKelvey et al. (2011)'s first approach involved "localizing and downscaling GCMs, transforming temperature and precipitation data in snow cover through VIC [see cited references for details on methods], and cross-walking GCM-based snow depth to MODIS-based snow cover", with all the attendant errors that this approach necessarily involves and that were recognized by the authors (McKelvey et al. 2011, p. 2886). In part to avoid these errors and as a validation of their GCM analysis (see Methods, p. 2885-2886), the authors simply reanalyzed the MODIS snow cover data "based on persistent snow cover through 29 May rather than 15 May, thereby forcing spring snow melt two weeks earlier" (p. 2886). Unfortunately, McKelvey et al (2011) did not attempt to do the same analysis on different possible dates for the "den abandonment period" so we do not know how the GCMs might have looked under a 30 April MODIS analysis, for example, which would have been a more accurate estimate of the end of the wolverine denning period in the mountains of the western states (as examined in Section 1 above). However, one could take the same approach the authors used to model future climate when they projected the snow melt period 2 weeks earlier (i.e., 29 May). With this 29 May approach, McKelvey et al. (2011) determined that "spring snow cover in 29 May MODIS is most similar to

Ensemble 2085 projections (Table 2, compare Fig. 4A with Fig. 4 D)" (p. 2890). That is, the 29 May MODIS-projected snow cover is similar to that projected for the period 2070-2099 by the Ensemble 2085 GCM. By the same logic and using the more realistic date of 30 April as the end of the wolverine denning season in the western United States (see Section 1 above), one can project a more realistic future snow cover during the denning period in 2070-2099 by again projecting snow melt 2 weeks earlier, which would be 15 May. Because McKelvey et al. (2011) already presented the 15 May MODIS projection in Fig. 2A (p. 2887), the MODIS data need not be reanalyzed and it is therefore apparent that the "spring snow coverage" for 30 April ~2085 is the present-day spring snow coverage on 15 May.

2b. *Dispersal and Connectivity*

McKelvey et al. (2011) repeated the analyses of Schwartz et al. (2009) to investigate the effects of climate warming on wolverine dispersal and connectivity of wolverine habitat in the western states. The analysis by McKelvey et al. (2011) may have underestimated the area occupied by reproductive females. McKelvey et al. (2011, p. 2891) stated that "each point where a wolverine could originate requires a contiguous snow area larger than 15 X 15 km (225 km^2), which is the approximate home range size for female wolverines (Schwartz et al. 2009)". This statement indicates that the authors assumed that female wolverines only occupy home ranges that are 225-km^2 in size with continuous snow cover on 15 May (in at least 1 year out of 7; 2000-2006). They concluded that "the number of potential start locations [for dispersal] decreases from 558 in the Historical Reconstruction [present day] to 194 in Ensemble 2085 [under climate warming] and this decrease, in turn, leads to an order-of-magnitude reduction in the number of pairwise least-cost paths" [i.e., a large reduction in the number of corridors for dispersal]. However, Schwartz et al. (2009) stated that

> "we overlaid a 15 X 15 km grid of locations across the study area, eliminating those grid nodes that were not in areas characterized by spring snow to model corridors connecting spring snow areas large enough to support wolverine reproduction. This density of nodes was based on minimum female home range size (Banci 1994) and guaranteed that at least one grid node would occur in each snow-covered area large enough to support at least one resident female wolverine (Krebs et al. 2007)."

This appears to mean that each grid point used in the analysis of dispersal corridors fell within a MODIS pixel (500-m resolution; 0.25 km^2) that was classified as snow-covered in the 15 May MODIS snow cover map. If my interpretation is correct, for areas where snow melt had advanced far enough by 15 May to create patchy snow cover across the area (including areas that might have been entirely snow-covered in February–April), some grid nodes were eliminated that could have occurred in home ranges of reproductive females.

However, a more important point is that neither Schwartz et al. (2009) nor McKelvey et al. (2011) were claiming that wolverines need snow for dispersal, rather, the argument presented was that, with fewer areas capable of supporting female wolverines as a result of climate warming (i.e., habitat defined by snow cover on 15 May ~2085), wolverines in the future will have to disperse further to reach areas of wolverine habitat (as predicted by McKelvey et al. 2011 using present-day 29 May MODIS spring snow cover, Fig. 4D, p. 2889). In other words, in the future, wolverines will have to travel through areas that are classified as snow-covered on 15 May today but will not be classified as snow-covered on 15 May in the future [as measured by MODIS]. In the context of the climate models in McKelvey et al. (2011), the 15 May MODIS snow cover "acts as a surrogate for wolverine's within-home range movements and dispersals year-round" (Schwartz et al. 2009, p. 3230). In other words, Schwartz et al. (2009) and McKelvey et al. (2011) recognized that wolverine habitat is not just snow cover on 15 May but the underlying year-round landscape and ecology of areas that fall within the boundaries of the 15 May MODIS snow cover map. However, as I argued above, the best available science does not support a 15 May date for obligatory snow cover for wolverine denning and consequently for defining the area of year-round wolverine habitat. Regardless, it is undisputed that wolverines disperse outside the 15 May MODIS spring snow cover map, sometimes over long distances (Inman et al. 2009, entire; Packila et al. 2007, Ch. 7, Photo 5, p. 119), including females (Aubry et al. 2012, Fig. 5, p. 23).

Although the data on the timing, duration, and characteristics of dispersal in wolverines are still limited, the best available science indicates that dispersal (or initiation of dispersal) peaks in the period late January–early April but can occur over a much broader period (November–June, at least) (Inman et al. 2012, Fig. 2, p. 637). There have been few detailed accounts of wolverine behavior or habitat use during dispersal movements. However, the detailed movements of a male wolverine (M56) dispersing from Wyoming to Colorado, and documented by researchers in the Greater Yellowstone study (Inman et al. 2009, p. 22–25), illustrate the dispersal capabilities of the species (Attachment Y). This wolverine may have been making exploratory movements as early as March, when snow was widespread, because his signal was not heard after 13 March until he was located on 6 April (Mark Packila, personal communication). Between 6 April and 5 June, when he arrived in the Rocky Mountain National Park in Colorado, this wolverine traveled through atypical wolverine habitat, much of which was not snow-covered or even tree-covered during the time he was passing through, although at the time he initiated dispersal movements, snow cover would have been widespread. However, he did appear to select areas of topographic relief outside of snow-covered habitat (small isolated mountain ranges like Granite Mountains, Green Mountains, Shirley Mountains, and Elk Mountain; Mark Packila, unpublished data) when available (Attachment Z).

The point here is that wolverines will disperse through atypical habitat when necessary, but their movements may be influenced by landscape features with which they are familiar or which offer some sense of security. Consequently, in the western United States, one can logically expect wolverines to select for high elevation topography when dispersing, if this habitat is available, because they occupy mountain habitats in the western United States (Aubry et al. 2007, entire) and appear to select high elevation habitat there (Copeland et al. 2007, entire; Inman et al. 2013, Paper III, entire). Because the 15 May MODIS spring snow cover strongly correlates with elevation (or latitude-adjusted elevation) in the western states, a correlation of wolverine locations with 15 May MODIS snow cover is not surprising. Logically, this correlation would support the least-cost path analysis of gene flow in the Rocky Mountains used by Schwartz et al. (2009), but it does not prove a causal relationship between 15 May MODIS snow cover and wolverine gene flow and dispersal pathways. Schwartz et al. (2009) did not do similar analyses using any alternative variables that might explain wolverine habitat, dispersal corridors, or gene flow. For instance, the proposed wolverine habitat map in Copeland et al. (2010) and the one proposed by Inman et al. (2013, Paper III) are so similar that logic suggests that the least-cost path analysis used by Schwartz et al. (2009) with the 15 May MODIS snow cover would provide similar results using the habitat map of Inman et al. (2013, Paper III), which does not use 15 May MODIS snow cover but rather latitude-adjusted elevation, snow depth on 1 April, ruggedness, and other variables that may be strongly correlated with where snow cover is broadly distributed on 15 May in the mountains of the western states. In fact, the circuitscape analysis of wolverine habitat in Inman et al. (2013, Paper IV) better predicted the movement path of M56 than did the least-cost path analysis of Schwartz et al. (2009) (Attachment Y).

The problem with the Schwartz et al. (2009) analysis of dispersal corridors and gene flow is not with the use of the 15 May MODIS spring snow cover to examine gene flow, but with the assumption that the 15 May MODIS snow cover *defines* wolverine habitat and therefore can be used to support the proposed loss of habitat in the future due to climate warming (McKelvey et al. 2011). Copeland et al. (2010) acknowledges that the 15 May MODIS snow coverage should be viewed as an "*approximation of underlying bioclimatic requirements*" (p. 244). McKelvey et al. (2011) argued that the decline in the area of 15 May MODIS snow cover by ~2085 (based on the present day 29 May MODIS snow cover), and the least-cost path analysis that they did based on 29 May MODIS snow cover, can be interpreted to mean that there will be a loss in connectivity and greater genetic isolation by the end of the 21st century. However, this assumption fails to take into account that neither the 15 May MODIS snow cover nor the 29 May MODIS snow cover *defines* wolverine habitat or future wolverine habitat in the western states, but rather they are correlates of other variables that together define wolverine habitat year round (e.g., boulder scree, elevation, snow cover in February–April, avalanche debris, etc.) and there is no evidence that these variables will change *on a scale that will affect wolverine distribution and habitat use within the foreseeable future*. The majority of wolverine year-round habitat (>90%) in the area of the proposed listing occurs within U.S. Forest Service or National Park Service lands that are not subject to direct loss of wolverine habitat due to infrastructure development according to the proposed listing determination (p. 74 and p. 83). In addition, activities such as logging, road-building, and recreation on these lands can be managed by these agencies to mitigate detrimental effects on wolverines. Therefore, we can expect that ecosystems that support wolverines will remain relatively intact *for the foreseeable future* on these federal lands even under climate warming. In other words, because wolverines do not need snow as a prerequisite for dispersal movements, their movements through habitats where they currently occur should not be affected by a 2-week-earlier spring snow melt in ~2085. An earlier spring snow melt over the 21st century will not adversely affect wolverine movements through landscapes characterized by relatively high elevation, ruggedness, boulder scree, or many other habitat variables that together comprise wolverine habitat in mountain terrain (Inman et al. 2013, Rauset et al. 2013). References cited in the proposed determination

(p. 54) supporting the hypothesis that advances in tree line will have adverse effects on wolverine habitat in the western states in the foreseeable future are unconvincing (see comments on the proposed listing document). The only variables that will change current dispersal habitat to the point that wolverines will be impeded or stopped from dispersing occur on the lands that fall *outside* the federal lands mentioned above. Over the rest of this century, the growth of housing developments, industrial complexes, roads, traffic volumes, other infrastructure, etc. in the interstices of current or potential wolverine habitat in the western states, without regard for establishing wildlife dispersal corridors, is of much greater significance to isolation and loss of connectivity for the wolverine metapopulation in the western states than is the predicted climate warming effects on *snow cover on 15 May* in the mountains.

2c. *Limitations of the MODIS Data*

The limitations of MODIS-based snow cover models should be recognized and taken into consideration when evaluating the accuracy of snow model predictions. For example, McKelvey et al. (2011) recognized that there are issues with the scale at which the MODIS data can be applied:

> "in areas where snow is highly fragmented or limited to linear areas along ridgelines, the best fit [referring to "statistically fitting the MODIS snow coverage to VIC-derived snow depth" p. 2895] will produce larger pixels that are consistently classified as snow free. The excess (when compared to MODIS) snow cover in the Historical Construction [referring to "the optimal fit between snow depth and MODIS snow cover" p. 2885] in areas such as northern Washington and British Columbia, and the lack of snow in areas such as Idaho, is at least partially due to these scaling issues and is unavoidable" (p. 2896).

In addition, Version 4 of MODIS that was used to derive the spring snow cover map in Copeland et al. (2010) is considered problematic (Dorothy Hall, personal communication, Attachment M), however, this version may have been the only data set available at the time the lead authors analyzed global snow cover. Moreover, MODIS measures "snow cover" not "snow depth" and the 500-m resolution will not accommodate analyses of the distribution and size of snow patches that linger into the summer months in mountain and tundra habitats in wolverine range, unless methods for estimating fractional snow (Salomonson and Appel 2004, Painter et al. 2009) are used, although fractional snow models are not without problems (Raleigh et al. 2013). Version 4 of MODIS did not measure fractional snow. Measuring the size, distribution, and persistence of snow beds and incorporating this information into models of wolverine habitat is important for understanding how climate warming will impact wolverine habitat in the future.

Moreover, MODIS data will not differentiate between snow cover produced by late spring snowstorms (referred to as ephemeral snow on p. 25 in Copeland et al. 2010) and snow that has persisted throughout the entire denning period. Eliminating ephemeral snow in the "spring snow coverage" in the Copeland et al. (2010) analysis required a 21-day period over which MODIS was queried for pixels bare of snow. Consequently, the earlier the dates used for MODIS analyses, the more difficult it is to eliminate areas of ephemeral spring snow from regions that are not considered wolverine habitat (e.g., lower elevations in the Rocky Mountains and the northern prairies). A combination of methods used to detect snow cover, snow depth, snow beds, and spring snowstorms would be the most appropriate approach to measuring snow features important to wolverine habitat.

Finally, predictions of the effects of climate warming on wolverine habitat should also consider the possible beneficial effects in some areas of the wolverine's distribution. McKelvey et al. (2011, p. 2893) concluded that "given a warming trend, spring snow cover is expected to decline and snow-covered areas are expected to become more fragmented and isolated" but this statement derives from their analysis of spring snow cover on 15 May. If one considers that snow cover is important for denning wolverines during the period when temperatures are relatively cold and kits are relatively young (e.g., before 30 April or even earlier), then a warming trend that accelerates the spring

snow melt by only 2 weeks by ~2085 could actually have beneficial effects on wolverines, particularly if the same climate processes that cause earlier spring melting simultaneously increase early winter precipitation in the form of snow, i.e., in December/January/February (McKelvey et al. 2011, p. 2887). More snow earlier in the winter in the mountains may increase snow depths by the time denning is initiated, while an earlier onset of spring green-up will lengthen the period of primary production. In their analysis of factors affecting reproduction in female wolverines, Rauset et al. (2013, Paper II, entire) found that summer primary production as measured by NDVI positively influenced reproductive output of wolverines in Scandinavia. NDVI refers to the normalized difference vegetation index, which is a remotely-sensed measure of vegetation greenness (Pettorelli et al. 2005). “Increased primary production is assumed to positively influence the abundance of various small prey, and the limited information on summer diet in wolverines indicates that small prey constitute the major summer food items” (Rauset et al. (2013, Paper III, p. 15).

SUMMARY AND CONCLUSIONS

Errors in defining wolverine habitat have significant repercussions for projections of future wolverine habitat in the western United States under climate warming. The proposed listing determination relies heavily on a few research studies as the "best available science" relative to wolverine habitat in the western states. As a consequence, I have focused my review in Attachment A on these particular studies: Aubry et al. (2007), Schwartz et al. (2009), Copeland et al. (2010), and McKelvey et al. (2011). In each of these studies, the assumption of obligate snow cover extending to 15 May [14 May in Aubry et al. 2007] was a critical component of the authors' conclusions regarding denning and year-round habitat for wolverines. Copeland et al. (2010) assumed that a suitable surrogate for where wolverine habitat occurs on a global scale is obligate snow cover on 15 May as determined by MODIS snow cover data. Even though the authors cautioned that the spring snow cover was an approximation of underlying bioclimatic requirements and that slight shifts in the analysis period could result in significant changes in areal snow cover, the 15 May MODIS snow cover was used to project future wolverine habitat under climate warming in McKelvey et al. (2011). However, the best available science does not support the assumption that the 15 May MODIS snow cover defines wolverine habitat for reasons detailed above in this Attachment. Consequently, conclusions regarding the effect of climate warming on future wolverine habitat in McKelvey et al. (2011) are invalid. The best available science indicates that snow cover as a requisite for wolverine denning in the western states is not obligatory after 30 April, possibly even earlier in April. Following the same approach as McKelvey et al. (2011, p. 2885–2886) to project future wolverine habitat in 2070–2099 (~2085) based on 29 May MODIS data and using a 30 April date for obligatory snow cover rather than a 15 May date, one must conclude that spring snow cover in ~2085 on 30 April will be similar to present-day 15 May snow coverage. Therefore, the projected loss of critical habitat for wolverines in the foreseeable future (i.e., over the 21st century) in the western United States is not supported by the science presented in the proposed listing determination.

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