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Summary

This report presents results for a wolverine (*Gulo gulo*) DNA mark-recapture study conducted near Napaktulik Lake, Kitikmeot region, Nunavut, to establish baseline population abundance and density estimates for long-term regional monitoring. In addition, monitoring of the wolverine population is also important as part of predator research and management as it informs caribou management. Wolverines are listed as a species of Special Concern under the federal Species at Risk Act (SARA) and are an important cultural and economic resource traditionally harvested by Inuit. This project was done collaboratively with the Kugluktuk (Angoniatit Association) Hunters and Trappers Organization (HTO). Genetic analysis was used to identify sex and individual wolverines from DNA in hair samples collected non-invasively by a science-driven study design and logistics facilitated by local hunters. From early March through late April 2018 and 2019, the field team sampled a grid of 154 posts baited with caribou (*Rangifer tarandus groenlandicus*) and muskox (*Ovibos moschatus*) legs and scent lures. The posts were spaced in 5x5 km (25 km²) cells for three 10-day sessions within a 4,000 km² area northwest of Napaktulik Lake.

In total, 22 individual wolverines (11F:11M) were detected in 2018 and 27 wolverines in 2019 (13F:14M), including 10 individuals (6F:4M) identified first in 2018 and then recaptured in 2019. Spatially explicit capture-recapture (SECR) methods were used to estimate population density. Wolverine density was estimated as 3.10 wolverines/1,000 km² (95% CI: 2.00–4.78) in 2018 and 4.14 wolverines/1,000 km² (95% CI: 2.78–6.18) in 2019, with no significant difference between years. These SECR yearly density estimates pertain only to wolverines with home range centers within the DNA sampling grid. Our results suggest that the population of wolverines in the proximity of the grid varies spatially and temporally in its usage of the grid area, which may be responsible for the apparent inter-annual variation in density estimates. There was little difference between sexes in the extent of movements on the grid in 2018, but a clear separation in 2019. Median observed range length of detected males (24 km) was similar to that of detected females (23 km) in 2018, but consistently larger in 2019.

Wolverines in the region exist at low densities and are being exposed to increasing levels of human activity through mining and subsistence harvest. Our results, which contribute to baseline data for wolverine ecology, could be used to provide a quantitative basis to establish future sustainable harvest limits and could support input to the Nunavut Impact Review Board (NIRB) review process. DNA based surveys offer a practical and cost-effective method to monitor wolverine populations in tundra situations. For a better understanding of wolverine population in the area, we

recommend long term monitoring by involving local HTOs and industry. This study demonstrates the efficiency of joint research projects to inform wildlife management.

Key words: density estimates, DNA, *Gulo gulo*, Napaktulik Lake, Kitikmeot, Nunavut, spatially explicit capture-recapture, wolverine.

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Naitumik titiraqhimayuq

Una ilitugidjutikhaq naunairutiqaqhimayuq qalvingnik (*Gulo gulo*) DNAnik nanigiaqvakhimayut aulatiffaaqhimayunlu nunamun ihivriudjutikharnik talvani Napaktulik Tahiani, Kitikmeot, Nunavunmi, aulatitihimayut naunairutikharnik amihuaryuit unalu amihuaryungit nallautiqhimayunik hivutunigaalukmik avikturvingmi munagidjutikharnik. Ilauhimayuq, munagidjutikharnik qalvingnik amigaitilaangat akhurnaqturlu ilagigamiut angitiugamik huraadjanik ihivriudjutikharnik munagidjutikharnik naunaiyaivakami tuktunik munagidjutikharnik. Qalviit naunairutiqaqtun huraadjat lhumagiyauyukharnik talvuuna kanatami Huraadjat Ayungnautiqaqtun Maligaaq (SARA) unalu akhurnaqtun pitquhiqaqtun maniliurutikharnik ilitquhiqaqhimayut anguniaqtauvakhimayut Inuinarnik. Una havaaqhaq havakpakhimayuq havaqatigiikhuta Kugluktuk Anguniaqtuliyiyit Katimayiingit (HTO). Atupaktugut idjuhiqharnik kangikhidjutikharnik qanurimangaangit nanminigiyaayuniklu ilitagidjutikahrnik qalvingnik taima DNAnik amiinik naunaitkutikhaqpakhutik pukuktauvakhimayut ilaungitunik talvuuna nallunaqtunik ilituginahuarnikkut aulayut ihivriudjutikharnik naunaitkutikharnik aulatitivakhimayut nunalaani anguniaqtiyuyunik. Qiqailruq atulihaaliqtiluni talvuuna Qitiqqautiyurmun 2018mi - 2019mun, hanigaini havaqatigiiktunik pukukpakhimayut hunavalungnik hanigarni 154nik napaqutingnik niqihiqhimayunik tuktunik (*Rangifer tarandus groenlandicus*) Umingmakniklu (*Ovibos moschatus*) kanaarnik tipigikhautiqaqtunik upautauyaanganik. Tapkuat napaqutit ungahiqtilaaqaqtun taima 5X5nik kmnik (25 km²) avatilgit pingahunik 10nik ublunik upautauyukharnik talvuuna 4,000 km² hanigaini avatilgit tunnganirmi Napaktulik Tahiani.

Talvuuna atautimiitun, 22nik qalvingnik talvani (11F:11M) ilauvakhimayut talvuuna malrungnik ukiunganik ihivriudjutikhaqaqpakhimayut, 2018 ilauplugitlu 27nik qalvingnik 2019mi (13F:14M) ilitagiyaavakhimayut hivulirpaarmi 2018mi taimalu nangiaqtauvakhimayut 2019mi. Inikhavikhangit nanigiaqtauvangani (SECR) hanaqidjutikhangit atuqtauvakhimayuq nallautigiangani amigaitilaangat nunagiyainik. Qalviit nunami nayugaini angiktilaangit 3.10nik qalviinguyut/1000nik ungahiktilaaqaqtun (95% CI: 2.00-4.78) 2018mi unalu 4.14nik qalvingnik/1000nik ungahiktilaaqaqtun (95% CI: 2.78-6.18) 2019mi, taima allanguqtivyaangitumik talvuuna ukiungnanik. Ukuat SECRngit ukiuk tamaat nallautiqhimayut aulaniaqtun talvuunaluaq qalvingnun aihimavikhaqaqtunik nayugaini talvani DNAnik ihivriudjutikharnik avatiliqaqtunik. Naunaitkuhiqhimaqptingnik naunairutiqaqtun taima amihuaryungit qalviit talvani nayugaaniitunik avatiliqarvingmi naunairutiqaqhimayuq amihuaryungit hanigaini talvanilu atuqtauvanganik talvani avatiliqirmi nayugaani, taima munagidjutiqarniaqtun talvuuna ukiungani nallautirutikharnik nunami nayugainik nallautiqhimayunik. Allatqiiniqaqtunlu talvuuna anguhaliut arnarluitlu talvuuna aulaviingit nayugarni naunaiyagiikhimayunik 2018mi, kihimi naunailuaqhimavakhimayuq 2019mi.

Naunairutikhangit qunngiaktauhimayut aulavingit anguhaluit (24nik ungahiktilaaqaqtun) aadjikiivvaktumik naunaiqhimayuq arnarluit (23nik ungahiktilaaqaqtun) 2018mi, kihimi angikliyumiqhimaliqhuni 2019mi.

Qalviit talvani avikturviangani hanigainiitun aulainaqtn taima mikinirmi amihuaryungit taimalu naunairutiqliqtun amigairyumiktumik qullirutiqaliqtun inungnik hulilukaaktunik talvuuna uyaraqhiuqtunik anguniaqtaunginaqtuniklu. Taima naunaitkutikhangit, uminga ihivriudjutikharnik, naunaitkuhiqtitivakhimayuq naunairutikharnik talvuuna qalviit nayugainik, atugiaqaqtun taima tuniyaangat amigaitunik naunairutikharnik piqagianganik hivunikharnik anguyauyukhat kiklivikharnik ikayuutiginaqtunlu naunairutikharnik tapkuninga Nunavut Ayungnautiqqaqtunik Ihivriuqtiuyut Katimayiinun (NIRB) ihivriudjutikharnik hanaqidjutingnik. DNAnik naunairutiqaqtunik ihivriudjutikharnik aituihimaarniaqtun ihuaqtumik akiligiaqaqtuniklu hanaqidjutikharnik munagiyaangat qalviit amihuaryungit nunamiitunik aulahimaaqtunik. Taima ihuaqtumik ilitugidjutikharnik qalvingnik amihuaryungit talvani hanigarni, atuquniaqtugut hivutunigaalukmik munagidjutikharnik ilauniqarniaqtun nunalaani HTOnit havagvingitlu. Una ihivriudjutikhaq naunairutiqarniaqtuq ihuaqtumik aulavikharnik ilauqatigiiktukharnik ihivriudjutikharnik havaaqhangit naunaiyaiyaanganik uumayuliqiyungit munaqtiuyunik.

Naunaitkutikhangit taiguangit: amihuaryungit nallautiqhimayut, DNAnit, *Gulo gulong*, Napaktulik Tahiani, Nunavut, hanirangit nanigiaqtauvingit aulagtiffaaqhimayutlu, qalvik.

Sommaire

Ce rapport présente les résultats d'une étude de capture-recapture de carcajous (*Gulo gulo*) aux fins d'ADN menée près du lac Napaktulik dans la région du Kitikmeot au Nunavut. L'étude visait à établir les renseignements de base sur la taille de la population et sa densité à des fins de monitoring à long terme. De plus, le monitoring des populations de carcajou est important, car il fait partie de la recherche et la gestion des prédateurs, et contribue à la gestion du caribou. Les carcajous ont été placés sur la liste des catégories préoccupantes en vertu de la Loi fédérale sur les espèces en péril et constituent une ressource traditionnelle économique et culturelle récoltée par les Inuits. Ce projet a été réalisé en collaboration avec l'Association des chasseurs et trappeurs de Kugluktuk (Angoniatit Association). L'analyse génétique a été utilisée pour identifier le sexe et les individus au sein de la population à partir de l'ADN provenant des échantillons de poil recueillis de manière non invasive, et selon le concept et la logistique d'une étude scientifique en collaboration avec les chasseurs locaux. Du début mars à la fin avril 2018 et 2019, l'équipe de terrain a pris des échantillons d'une zone quadrillée de 154 pieux dotés d'appâts composés de pattes et d'odeurs de caribou (*Rangifer tarandus groenlandicus*) et de bœuf musqué (*Ovibos moschatus*). Les pieux étaient répartis en cellules de 5 km sur 5 km (25 km²) durant des périodes de 10 jours, et disposés sur une aire de 4 000 km² au nord-ouest du lac Napaktulik.

Au total, 22 carcajous individuels (11 femelles; 11 mâles) ont été recensés en 2018, et 27 (13 femelles; 14 mâles) en 2019, dont 10 individus (6 femelles; 4 mâles) déjà répertoriés en 2018, puis recapturés en 2019. Des méthodes spatialement explicites de capture-recapture (SECR) ont été utilisées pour estimer la densité de population. La densité des carcajous fut estimée à 3,10 carcajous par 1 000 km² (95 % CI : 2 à 4,78) en 2018 et 4,14 carcajous par 1 000 km² (2,78 à 6,18) en 2018 par 1 000 km² (95 % CI : 2,78 à 6,18) en 2019, sans différence significative entre les années. Ces estimations annuelles SECR de densité ne portent que sur les carcajous dont le territoire est concentré au sein de la grille d'échantillonnage d'ADN. Nos résultats suggèrent que la population de carcajous à proximité de la grille varie spatialement et temporairement quant à l'usage de la zone grillagée, ce qui pourrait expliquer l'apparente variation annuelle des estimations de densité. Il y eut peu de différence entre les sexes quant à l'étendue des déplacements au sein de la grille en 2018, mais une séparation claire en 2019. L'étendue du territoire médian observée chez les mâles (24 km) était similaire à celui détecté chez les femelles (23 km) en 2018, mais systématiquement plus grand en 2019.

La population de carcajous de la région est de faible densité et est exposée à un accroissement des activités humaines, les mines et la chasse de subsistance notamment. Nos résultats, lesquels participent aux données de base de l'écologie des carcajous, pourraient

être utilisés pour procurer une base quantitative afin d'établir d'éventuelles limites de récolte durable. Ils pourraient aussi servir à enrichir les processus d'évaluation de la Commission du Nunavut chargée de l'examen des répercussions. Les études fondées sur l'ADN offrent une méthode pratique et efficiente pour assurer le suivi des populations de carcajou dans les zones de toundra. Pour une meilleure compréhension de la population de carcajous dans la région, nous recommandons l'implantation d'un monitoring à long terme en collaboration avec les OCT et l'industrie. Cette étude démontre l'efficacité de projets de recherche conjoints pour soutenir la gestion de la faune.

Mots clés : estimation de la densité, ADN, *Gulo gulo*, lac Napaktulik, Kitikmeot, Nunavut, capture-recapture spatialement explicite, carcajou

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1.0 INTRODUCTION

In Nunavut, the wolverine (*Gulo gulo*) is listed both as a furbearer (Schedule 5.2) and a big game species (Schedule 5.1) under the Nunavut Agreement. The wolverine is a solitary carnivore of the Arctic tundra and is an important cultural and economic resource traditionally harvested by Inuit. Nunavut represents the north-eastern edge of wolverine distribution in Canada. There are limited baseline data on wolverine distribution and density within Nunavut. Currently, there is no quantitative limit on their harvest by Inuit. Nevertheless, wolverine densities are believed to be moderate in the western mainland of Nunavut but low on the Arctic islands and in the eastern mainland (Slough 2007, Species at Risk Committee 2014). Inuit observations and recent harvest reports suggest that wolverine numbers in Nunavut are either stable or slightly increasing, and the species may be expanding its range eastward and northward (Awan et al. 2014, COSEWIC 2014, Awan 2020).

The wolverine was assessed as a species of Special Concern in Canada by the Committee on the Status of Endangered Wildlife in Canada in 2014 and listed as Special Concern under Schedule 1 of the *Species at Risk Act* (SARA) in 2018. While there are no associated effects on Inuit harvest in Nunavut, under SARA a national management plan must be developed within three years of being listed to prevent a species from becoming threatened or endangered. Habitat fragmentation and loss due to development and climate change were considered the primary threats during the SARA listing process. While this is true for most parts of the species' southern range and for western North America, the range fragmentation and habitat loss issues that affect southern or western populations may have limited application to wolverines in Nunavut. However, there has been an increase in wolverine-human conflicts associated with mineral development projects (Agnico Eagle Mines 2014, 2018; Mulders 2019) and there have been substantial declines in wolverine numbers in the central barrens (Boulanger and Mulders 2013, Species at Risk Committee 2014, Efford and Boulanger 2018). Wolverine-human conflicts can be expected to escalate in Nunavut with the amount of development projects growing over time (NIRB 2012).

Arctic climates and ecosystems are changing at the fastest rates on Earth (McLennan et al. 2012). It is believed that wolverines are demographically susceptible to impacts from climate change (Inman et al. 2012, GRRB 2014). Compared with other species adapted to cold, snowy environments, wolverines are particularly sensitive to the impacts of predicted warming trends on snowpack (McKelvey et al. 2011). While climate change impacts are preeminent in the southern part of the wolverine range, they are expected to amplify northward (Inman et al. 2012). McKelvey et al. (2011) hypothesized that the geographic extent and connectivity of suitable wolverine habitat in western North America will decline with continued global warming, and Heim et al. (2017) suggest that cumulative effects of climate and landscape change can limit species local adaptation and dispersal capabilities. Conversely, Webb et al. (2016) described that wolverines may be more flexible in their habitat selection and likely developed local adaptations depending on habitat type and resource availability. Various studies have highlighted wolverine's requirement of persistent snow cover for denning, birth, caching food and reproductive success (Lee and Niptanatiak 1996, Copeland et al. 2010, Peacock 2011, McKelvey et al. 2011). Magoun and Copeland (1998) noted that at least 1 m of snow, distributed uniformly or accumulated in drifted areas, should be present throughout the denning period (February until May). However, in northern Sweden, Aronsson and Persson (2017) found that the wolverine population expanded and colonized into areas without persistent spring snow cover. How climate change might influence spring snow cover and affect larger ungulates remains uncertain (COSEWIC 2014). Recent ecological studies of the impact of diminishing snow cover in Labrador suggest a negative impact on boreal caribou survival due to enhanced predation by wolves, which can more easily access their prey with the loss of deep snow in winter (Schmelzer et al. 2020).

The wolverine is both a scavenger and opportunistic predator throughout its range, caching food in boulder fields, snowbanks, or bogs for later use (Banci 1987, Mulders 2000, Mattisson et al. 2016, van der Veen et al. 2020). Within the Arctic ecosystem, caribou (*Rangifer tarandus groenlandicus*) is an important prey species sustaining much of the tundra biodiversity, and trends in their numbers are important in the

structure and functioning of the tundra ecosystem (Gunn et al. 2011). Arctic wolverines rely predominantly on migratory caribou (Mulders 2000, Awan et al. 2012, L'Hérault et al. 2016), although diet composition changes according to available resources (Mattisson et al. 2016). Since wolverine breeding propensity is likely limited mostly via winter food availability (Persson 2005), the recent decline in caribou abundance and substantial contraction of their range in the Canadian north (Gunn et al. 2011, Adamczewski et al. 2015; 2020) is expected to affect wolverines in Nunavut, but any effects are difficult to identify or quantify since the demographic response of resident wolverine populations to variation in prey abundance is unknown (Dalerum et al. 2009).

Baseline population data for wolverines remain scarce throughout their circumboreal range, including most of Canada (Barrueto et al. 2020). Nunavut contributes substantial numbers to the national harvest even though ecological data for tundra wolverine are sparse, especially in the north-eastern edge of distribution. Similar to other northern parts of the wolverine range, the Nunavut mainland is comprised of large undisturbed areas away from communities harvesting range. These areas with no or limited harvest act as reservoirs or refugia (source) to maintain or repopulate hunted populations (sink) of wolverines near communities (Mulders 2000, Cardinal 2004, Krebs et al. 2004, Golden et al. 2007, Species at Risk Committee 2014, Gervasi et al. 2016). As these areas (refugia) become more accessible due to resource development and increased use of highly efficient snowmobiles by local hunters, populations of wolverines become more susceptible to overharvesting and disturbance. Having baseline information for wolverines allows for future monitoring of population trends as the ecosystems and harvesting pressures change over time.

Wolverine typically occur at low densities (Mulders 2000, Royle et al. 2011, Efford and Boulanger 2018, Awan et al. 2018), maintain large home ranges (Mulders 2000, Dumond et al. 2012), and have long dispersal movements (Inman et al. 2012). Numerous survey methods have been used to estimate wolverine population density, abundance or trends, including telemetric monitoring (Magoun 1985, Banci 1987),

monitoring natal dens (Landa et al. 1998), identifying individuals using deoxyribonucleic acid (DNA) from hair collected at bait sites (Mulders et al. 2007, Boulanger 2012, Rescan 2014, Efford and Boulanger 2018, Fisher et al. 2013, Awan et al. 2018), motion-detection cameras (Lofroth and Krebs 2007, Royle et al. 2011) and aerial (Becker 1991, Becker et al. 1998, Golden et al. 2007) and ground (Golder 2007) snow track surveys. Using DNA-based mark-recapture in the Lac de Gras region, Boulanger and Mulders (2008) estimated density for females from 2.7 to 6.2 and for males from 1.3 to 4.5 wolverines/1,000 km². Using DNA-based mark-recapture in the Kivalliq region, Awan and Boulanger (2016) and Awan et al. (2018) estimated density from 1.6 to 4.4 wolverines/1,000 km². However, in the Kitikmeot region, there is little information about wolverine abundance and ecology, making it difficult to make pro-active recommendations for harvest management (Lee and Niptanatiak 1993).

Similar to other large carnivores, live-capture and tracking of wolverine in the remote tundra is expensive and difficult (Dumond et al. 2012, Efford and Boulanger 2018). The Nunavut Agreement established Hunters and Trappers Organizations (HTO) and Regional Wildlife Organizations with specific roles and authorities, and through these organizations, Inuit are co-partners in Nunavut wildlife management, including wildlife research. In Nunavut, harvest of wolverine and other furbearers for clothing and income is a seasonal and traditional activity, where opportunity for other employment is scarce. Inuit community concerns over wildlife handling has led to the implementation of culturally acceptable, non-invasive research approaches. This study uses DNA-analysis with a field method that integrates the use of local Inuit hunter's skills and capacities (Inuit Tapiriit Kanatami 2016), and provided local employment and training. Boulanger and Mulders (2008) and Golder (2007) argue that DNA-based methodologies are more powerful and robust for monitoring wolverine populations than track count methodologies. The hair-snagging sampling technique in a mark-recapture framework is feasible in the tundra habitat for both wolverine and grizzly bear (*Ursus arctos*) (Mulders et al. 2007, Dumond et al. 2012, 2015; Awan and Boulanger 2016; Efford and Boulanger 2018; Awan et al. 2018), and this approach

was selected to estimate density and monitor wolverine population trends in the Kitikmeot region of Nunavut.

1.1 Objectives

Our primary objective was to estimate wolverine density and develop protocols that could lend to community-based monitoring. The use of culturally acceptable (non-invasive) scientific methods and local knowledge was a priority in study design and implementation. This project aimed to be the basis for long-term monitoring of the species in Nunavut.

The specific objectives of the study were to:

- Estimate wolverine density within the Napaktulik Lake study area;
- Establish baseline wolverine population data which can be used for long-term population monitoring; and
- Provide training for local field staff, facilitate knowledge transfer between study participants, ensure meaningful Inuit involvement in wildlife research, and improve collaboration between the GN and co-management partners.

2.0 METHODS

2.1 Study Area

We used two approaches to establish a regional long term DNA sample plot to monitor representative wolverine densities over the long-term. First, we interviewed 10 wolverine hunters and elders from Kugluktuk to identify wolverine habitat and distribution and hunter harvest patterns, as well as caribou and muskox distribution. Second, we considered future mineral resource development, potential linear developments, and long-term patterns of wolverine harvest in the Kitikmeot region. The selected study site comprised ~4,000 km² area in the vicinity of Napaktulik (aka. Takijuk) Lake (66° 29'. 21N, 113° 28'.45W) in the Kitikmeot region of Nunavut, approximately 170 km southeast of the community of Kugluktuk (Fig. 1). The study area consisted of snow covered tundra with shrubs protruding above the snow, numerous frozen small lakes, elevations ranging from 400 to 600 m with high ridges blown free of snow, and dense fields of boulders.

The study area lies in the Takijuk Lake Upland Ecoregion of the Southern Arctic Ecozone. The area of the ecoregion is characterized by cool summers and very cold winters. Mean summer and winter temperatures are 6°C and -26.5°C, respectively, and mean annual precipitation ranges 200-300 mm. The ecoregion is classified as having a low arctic eco-climate, with massive Archean rocks that form broad, sloping uplands, plateaus, and lowlands. The ecoregion has high mineral development potential and substantial exploration activity has taken place (Ecological Framework of Canada 2019). The vegetation is characterized as shrub tundra, consisting of dwarf birch, willow, northern Labrador tea, *Dryas* spp., and *Vaccinium* spp., a ground cover of mosses and lichens with scattered stands of spruce along the southern boundary (Ecological Framework of Canada 2019).

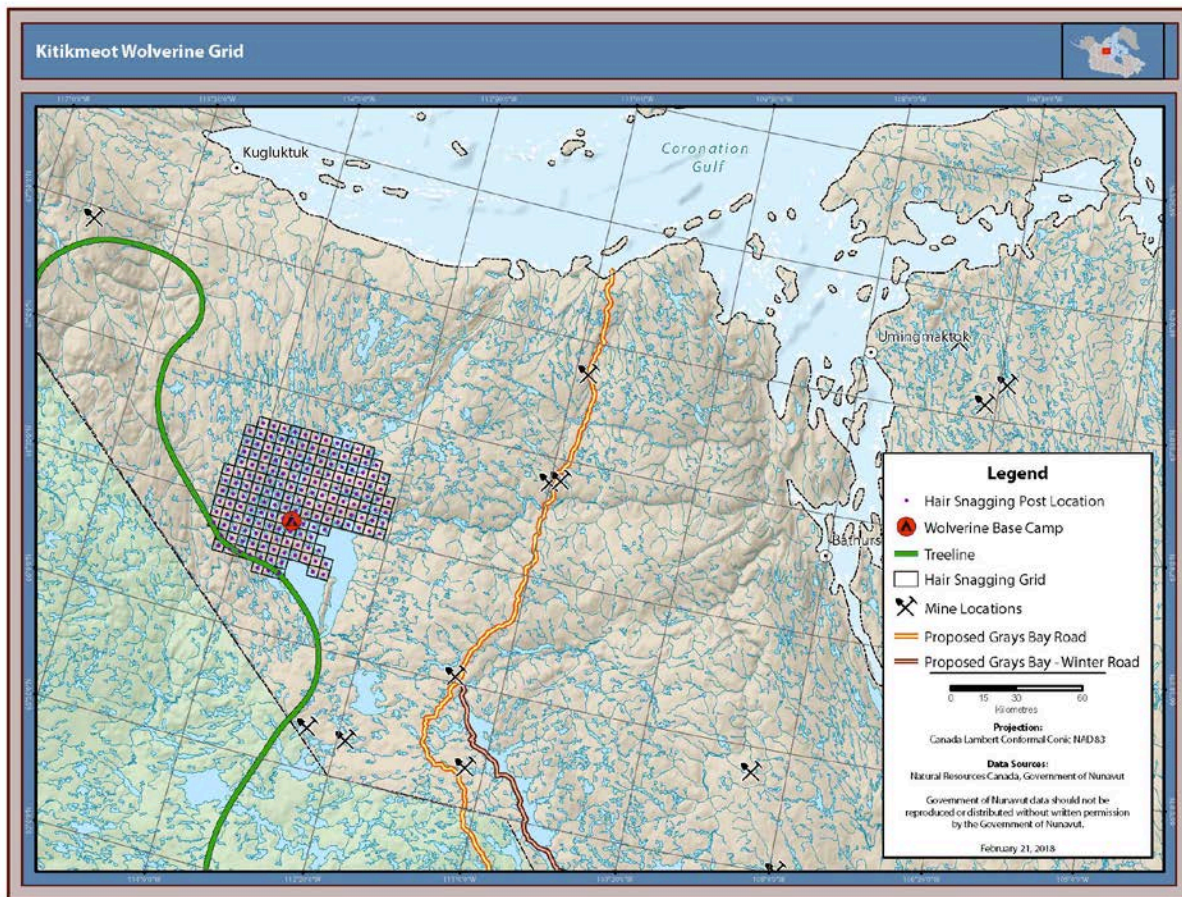


Figure 1. Study area for DNA survey of wolverine population near Napaktulik Lake, Nunavut 2018-2019.

The study area overlaps with the summer range of the Bluenose-east caribou herd (Boulanger et al. 2019) in the west, with the Dolphin and Union caribou herd winter range in the east (Environment and Climate Change Canada 2018), and within the annual range of Bathurst caribou herd (Virgl et al. 2017, WFATWG 2017), with light hunting activity. The study area is part of a traditional travel route by snowmobile from the Kugluktuk to the Contwoyto Lake area (Lee and Niptanatiak 1993). During the summer months, this area is accessible only by aircraft.

In 2018 March/April, we observed no caribou or tracks of caribou in the study area during the sampling period. However, during the 2019 sampling period we

encountered caribou and caribou tracks daily. The Beverly herd wintered in the vicinity of the study area in 2019 (J. Adamczewski pers. com. to Kugluktuk HTO in Feb 2019) and caribou and wolves were harvested around Napaktulik Lake by Kugluktuk hunters. Human caused mortality was higher for wolverine and wolves in 2019 winter as wolves and wolverine followed the group of Beverly caribou herd as they wintered in the area. A Government of Nunavut wolf (*Canis lupus*) sample collection program was put in place in 2019 to improve research efforts on wolves. The program led to increases in the level of wolf harvest in the region. Caribou gut piles and wolf carcasses attracted wolverines and high wolverine harvest happened in the study area. Five years (2014-18) of reported annual average wolverine harvest from the study area was 3 wolverines, with zero reported harvest in 2017, 2018 and 2020. However, in 2019, 24 wolverines were reported killed by hunters in the early winter between the 2018 and 2019 genetic mark-recapture survey. Most of the wolverine harvest occurred in conjunction with caribou and wolf hunting during early winter. We asked hunters to report the day and location of kill and return the skull for age determination.

Low densities of muskoxen (*Ovibos moschatus*) live year round in the area (Leclerc 2015) and may provide food to support wolverine through the winter. Smaller prey species include Arctic hare (*Lepus arcticus*), Arctic ground squirrels (*Spermophilus parryii*), voles and lemmings (Muridae), ptarmigan (*Lagopus* spp), and migratory bird species (Mulders 2000, Samelius et al. 2002, Dalerum et al. 2009, Awan et al. 2012). Other carnivores in the area included Arctic fox (*Vulpes lagopus*), red fox (*V. vulpes*), wolf and grizzly bear.

2.2 Field methods

We conducted DNA sampling during early spring in 2018 and 2019 following the non-invasive procedure developed by Mulders et al. (2007) and updated methods of Awan et al. (2018). This study was designed to involve local hunters in the collection of samples, with 3 Kugluktuk HTO members hired as part of the field research team. The

DNA grid (Fig. 1) was sampled from March 8 to April 20, 2018 and March 9 to April 22, 2019.

The actual posts sampled in the DNA sampling area varied by year. Low snow depth in 2018 resulted in the dropping of 17 of 160 bait posts proposed for sampling in the original design, and 6 bait posts in 2019 were dropped due to lack of access. Snow in the south west corner (near tree line) of the sampling grid was soft and deep and made snow machine travelling difficult. We sampled, 143 bait posts in 2018 and 154 in 2019 (Fig. 2) in a systematic sampling grid within 5x5 km grid cells, each hosting a post in the cell centre.

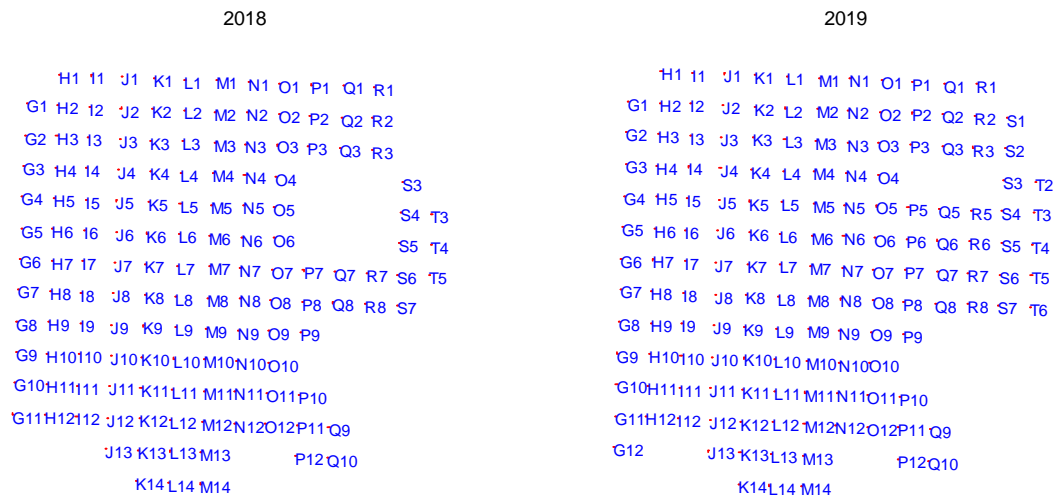


Figure 2. Locations sampled for wolverine DNA in 2018 (143 posts) and 2019 (154 posts). Each location has an alphanumeric label (G1 etc.). Sampling of some marginal sites only in 2019 resulted in a slight change in the area surveyed.

Each hair snare bait post was ~1.6m long, 10x10 cm wide, wrapped with barb-wire to trap wolverine hair, and anchored in packed snow (Appendix 3). We attached bait (~250g caribou or muskox leg bone) and a combination of commercial lures (Beaver Castor and Long Distance Call, O’Gorman Lures, Montana, USA) to the top of each

post with haywire. We used frozen caribou/muskox leg bones, which we cut in chunks, drilled a hole in the bone, and wired the bone to the top of the post. There were numerous gut piles of hunter-killed caribou and wolf carcasses during the 2019 sampling period. We recorded the GPS position of each bait post. We used snowmobiles to visit each post 3 times at about 10-day intervals. At each visit, we collected all visible hairs from the barbed wire, post, and from the ground around the post. We used a propane torch to remove any remaining hair. Each individual clump of hair was removed from the post and placed in a labeled individual coin envelope (post number, location on post and date) for storage. We installed a fresh set of bait and lures after every check. We recorded the number of muskoxen, and other prey species sighted or wildlife signs observed during the post set-up and while driving between posts.

We installed 12 motion triggered digital cameras (Reconyx PC-800 Hyperfire Professional IR, Holmen, WI) facing bait posts to capture wolverine activity. We programmed cameras at high sensitivity, 5 images per trigger, one second apart. The cameras documented wolverine sighting date and time of the visit and time spent at the hair snagging post, and captured images of other animals visiting the post.

2.3 Laboratory methods

We sent hair samples to Wildlife Genetics International (WGI), Nelson, BC for individual wolverine identification. We analyzed two samples per collection event (post/session combination) when there was more than one sample of suitable quality available. If possible, we selected the two samples from different sides of the post and used an average of 5.6 guard hair roots per extraction — counting underfur as 0.2 guard hair roots. DNA was extracted using QIAGEN DNeasy Tissue kits, aiming to use 10 clipped guard hair roots, when available. In 2018, we identified individual wolverines using a ZFX/ZFY gender marker and the 7 microsatellite markers, applied to other wolverine projects in the tundra (Mulders et al. 2007, Awan and Boulanger 2016, Awan et al. 2018). After 2018 DNA analysis we observed slightly low genetic variability of wolverines in the Kitikmeot region (0.68 across 7 markers, compared to

0.71 in the Kivalliq region, Awan and Boulanger 2016, Awan et al. 2018), and to compensate for this we used 9-locus analysis (8 microsatellites plus ZFX/ZFY for sex) to identify individual wolverines in 2019. The quality assurance methods of Paetkau (2003) were used to ensure the accuracy of individual identifications.

A tooth (lower canine) was removed and submitted for aging to Matson Laboratory (Montana, USA) using cementum annuli from wolverines reported killed by hunters in the early winter between the 2018 and 2019 DNA survey. Following Banci and Harestad (1988) and Vangen et al. (2001) individuals were then grouped into three age classes: juvenile (0-1 year, date of birth is set to March 1st), yearling (1-2 years) and adult (≥ 2 years).

2.4 Data analysis

We summarized the number of wolverines detected as a function of active posts each session. In addition, we plotted the approximate paths of wolverines based upon unique post detections per session.

2.4.1 Spatially explicit capture–recapture

We used spatially explicit capture–recapture (SECR), an extension of conventional capture–recapture methods specifically for estimating the density of spatially distributed populations (Efford 2004, Borchers and Efford 2008, Royle et al. 2014). SECR avoids most of the concerns about geographic closure that featured in earlier analyses using conventional closed-population methods (e.g., Mulders et al. 2007).

The data for SECR are spatial detection histories; each history is a record of the particular sites (posts) at which each individual was detected. The detected individuals are a selection of those centred in the surrounding area – the chance of being detected declines with distance. By fitting a curve for the decline in detection probability with distance we are able to estimate both (i) parameters of the curve, and (ii) the density of activity centres (including animals that were not detected). SECR has

developed over the last 18 years and now exists in two main types characterised as ‘maximum-likelihood’ (Borchers and Efford 2008, Efford 2018) and ‘Bayesian’ (Royle et al. 2014).

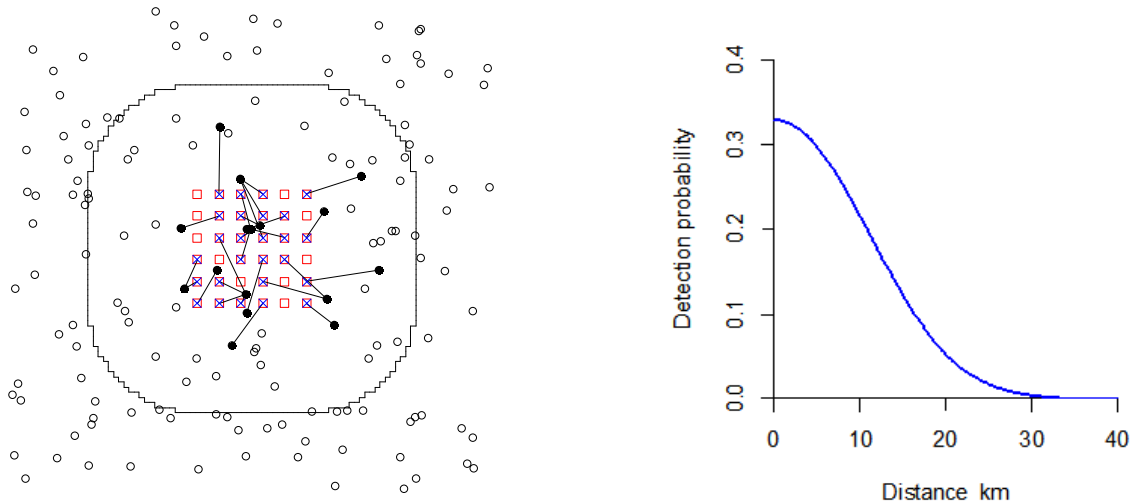


Figure 3. Spatially explicit capture–recapture conceptual model. Animal activity centres (dots) are distributed across the wider landscape. Animals centred near a post (red squares) have a high probability of detection (blue crosses; see also hypothetical distance–detection function on right). The centres of animals detected at least once are shown as filled dots (a single sampling interval is shown). Animals centred beyond an arbitrary outer perimeter (solid line) have such low probability of detection that they can be ignored in model fitting.

For SECR the population is thought of as a distribution of animal activity centres in 2 dimensions (open circles in Fig. 3). We can ignore centres that are very far from detectors because these animals stand negligible chance of detection, and this has computational benefits. Using the method of maximum likelihood it is necessary to integrate the probability of detection over space (the potential locations of activity centers). This is easier when space is finite and can be discretized as many small pixels.

The criterion for ignoring distant animals is usually a buffer of a certain width around the detectors (represented by the perimeter line in Fig. 3). The area within this boundary becomes the area of integration for maximum likelihood or the ‘state space’

of centres in Bayesian models e.g. Royle et al. (2014) (the term ‘habitat mask’ is used in R package ‘secr’).

Where habitat extends indefinitely in all directions, as appears to be the case for mainland Nunavut wolverines, the placement of the boundary is arbitrary. The area should merely be large enough that enlarging it further has no effect on density estimates because only un-detectable animals are added. This is achieved by using a buffer around the posts that is large compared to the radius of home ranges. Whether the buffer is large enough can be tested once pilot values are available for σ , the spatial scale (width parameter) of the blue detection curve in Fig. 3.

2.4.2 SECR modelling of wolverine data

SECR models were fitted with the R package ‘secr’ version 4.2.2 (Efford 2020). A 50-km buffer was used to define the habitat mask; lakes and other areas of water were included in the mask as these were frozen during the sampling period.

The hazard of detection was modelled as a function of distance considering possible sex effects, differences between years, and different shapes of detection function (halfnormal vs negative exponential). For this phase of the analysis a conditional likelihood model was used, avoiding the need to specify a model for density (Borchers and Efford 2008).

For density estimation we used a ‘hybrid mixture’ model in which sex was used to define mixture classes; this allowed the individual covariate ‘sex’ to be included in models for density.

The best model among various possibilities was selected by Akaike’s Information Criterion (AIC) – smaller values of AIC indicate a better model. We used a likelihood ratio test (LRT) where a hypothesis test was needed to distinguish between two nested models (the statistic is compared to a X^2 distribution with degrees of freedom equal to the difference in number of estimated coefficients).

2.4.3 Population turnover

The turnover parameters ϕ (apparent survival (ϕ): the probability that a wolverine that was in the sampling area in 2018 was still in the sampling area in 2019) and f (recruitment: the number of new wolverines in 2019 per wolverine in 2018) were estimated from non-spatial and spatial robust-design forms of the Pradel–Link–Barker model (Efford and Schofield 2020) using the R package ‘openCR’ (Efford 2019). We note that apparent survival will include death as well as emigration of wolverines from the sampling area and recruitment will include both births of wolverines and immigration of wolverines into the sampling area between 2018 and 2019. These estimates describe the turnover between summer 2018 and summer 2019.

3.0 RESULTS

3.1 Summary of data

In 2018, we collected 175 wolverine hair samples, 12 (7%) lacked suitable material for analysis and 24 (14%) failed during genotyping. We successfully analyzed 123 hair samples which were assigned to 22 individual wolverines (11F:11M). In 2019, we collected 220 wolverine hair samples, 75 (34%) lacked material suitable for analysis and 21 (10%) failed during genotyping. We assigned 106 successful samples to 27 wolverines (14F:13M; Table 1), of which 10 (6F:4M) were ‘recaptures’ from 2018 sampling. No individuals from this study area matched to any individual from other Arctic datasets or study areas (D. Paetkau, WGI, unpubl. data). The DNA samples from harvested individuals will be processed and incorporated into future analyses.

In both years, more DNA samples (detections) were collected in later sessions, while the number of newly detected individuals tended to decline suggesting sampling was effective in sampling wolverines on the grid and surrounding area.

Table 1. Summary statistics for DNA sampling of wolverines near Napaktulik Lake, Nunavut, in 2018 (143 posts at 5-km spacing) and 2019 (154 posts at 5-km spacing).

Session	Year of sampling							
	2018				2019			
	1	2	3	Total	1	2	3	Total
Detections	15	33	44	92	26	30	41	97
New animals	9	6	7	22	13	9	5	27

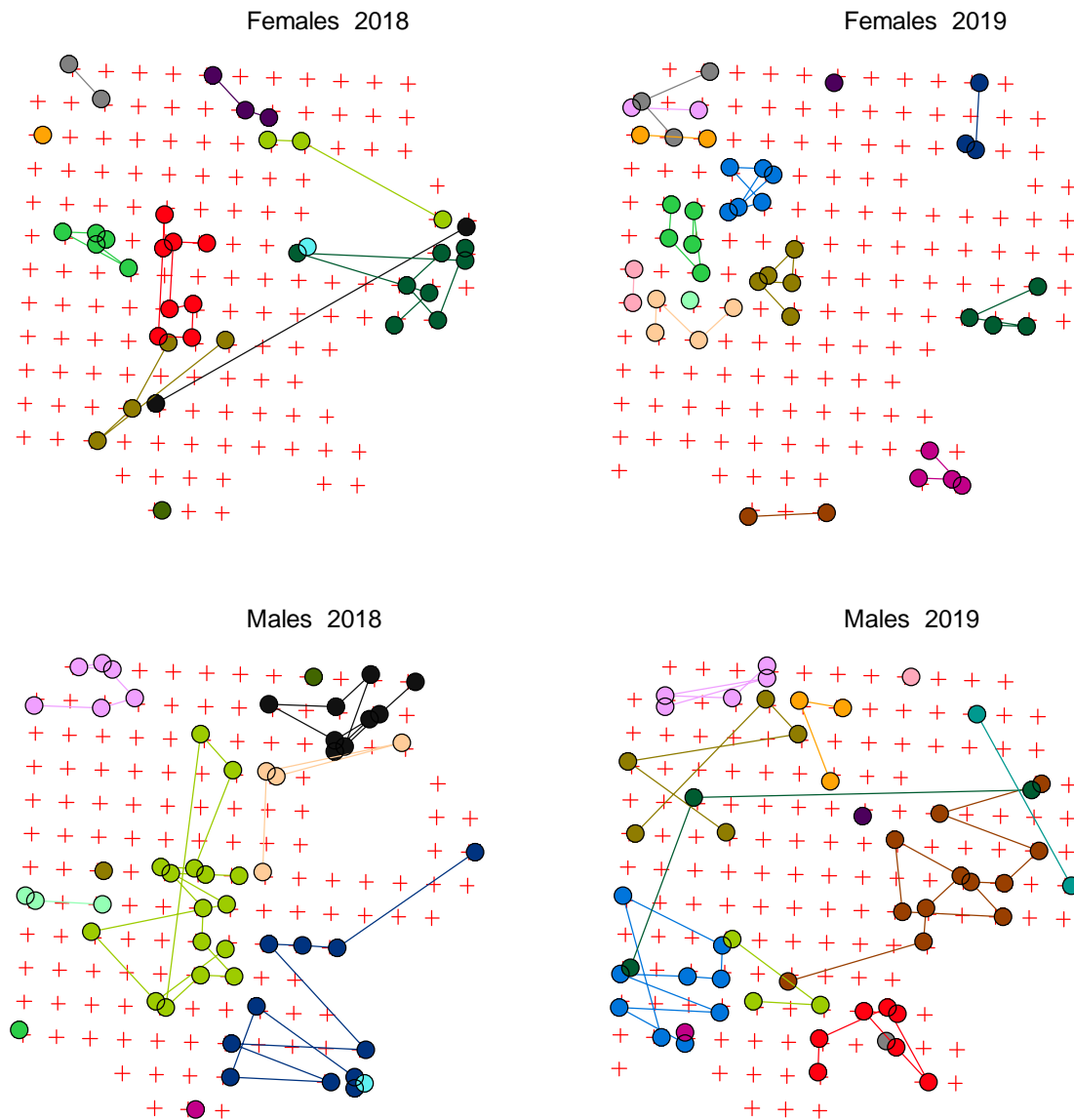


Figure 4. Detection locations of wolverines on grids of posts (red crosses) near Napaktulik Lake in 2018 and 2019. Known locations of an individual are joined (individuals distinguished by colour with the same colors used for individuals detected in both 2018 and 2019).

3.2 Sex differences

Approximately equal numbers of male and female wolverines were detected in each year. The 22 wolverines detected in 2018 comprised 11 males and 11 females; the 27 wolverines detected in 2019 comprised 13 males and 14 females (see also Table 2). The distance between the most extreme locations of each animal (observed range length) is a convenient individual-level summary of the extent of movements. The raw data (Appendix 2) suggest little sex difference in observed range length in 2018, but a clear separation in 2019 (Fig. 5). Median observed range length was similar for females in 2018 (23 km), males in 2018 (24 km) and males in 2019 (22 km), but noticeably different for females in 2019 (10 km). The longest observed range (67 km) belonged to a male detected 3 times in 2019. It is unclear whether the difference between years was due to altered behaviour or to differences in age structure or random effects. However, the evidence suggests that detection should be modelled separately in the two sexes.

Table 2. Number of detections per wolverine, by sex and year. Zero shown as “.”; excludes repeat detections at a site within a session.

Sex	Sessions																
Female																	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Total
2018	3	2	2	1	1	.	.	2	.	.	.	.	.	.	.	.	11
2019	2	4	2	3	2	1	.	.	.	.	.	.	.	.	.	.	14
Male																	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Total
2018	5	.	1	1	.	1	.	.	1	.	1	.	.	.	.	1	11
2019	4	1	3	.	2	.	1	.	1	.	.	1	.	.	.	.	13

The number of detections per individual influences the observed range length (Fig. 5). Interpretation of SECR detection parameter and detection function plots provides a way to assess the movement of wolverines that is independent of sampling intensity, as we show later.

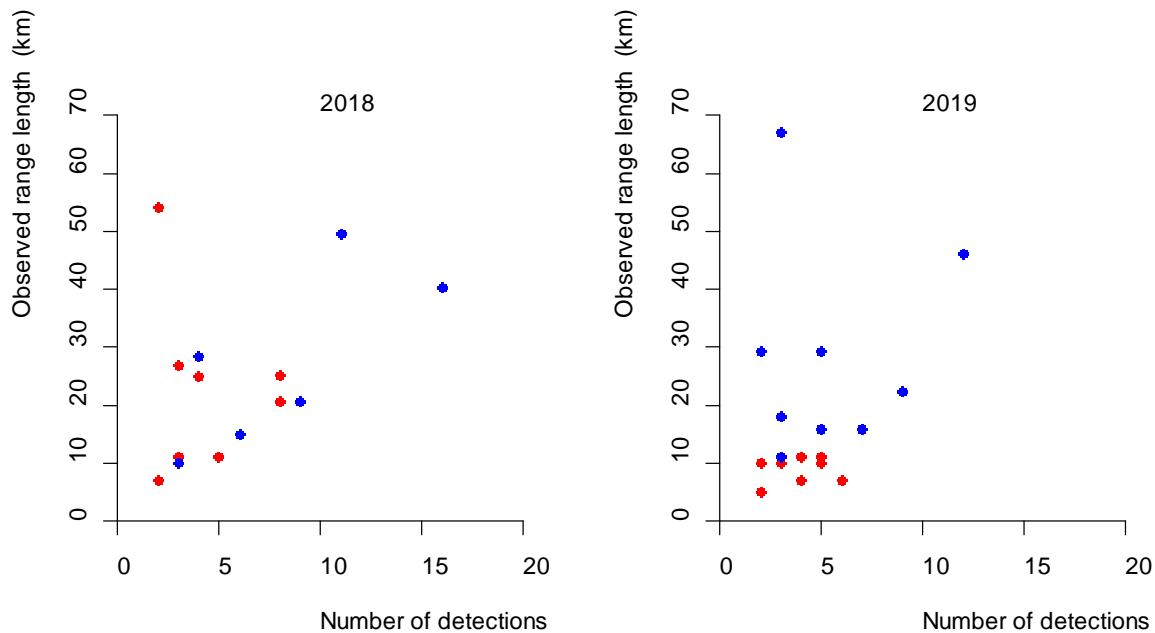


Figure 5. Observed range length (maximum distance between detections) for individual male (blue) and female (red) wolverines.

3.3 Selection of detection model

A negative exponential detection model had substantially lower AIC than a halfnormal model ($\Delta\text{AIC} = 40.5$; Appendix 1). This is commonly the case when there are occasional long-distance movements (Fig. 4) and we used the negative exponential detection function for all subsequent models.

Models that included sex differences in detection were preferred by AIC, especially when the sex effect was allowed to differ between years (Appendix 1). An additive post-specific learned response ($\lambda_{0i} \sim \text{Sex} \times \text{Year} + b_k$) gave a small reduction in AIC compared to the $\text{Sex} \times \text{Year}$ model (Appendix 1), but the effect on density estimates was negligible ($<2\%$; details not shown) and learned responses were not included in further models. The number of detections appeared to increase across sessions within a year (Table 1) and models with a temporal within-year trend fitted better than those

without such a trend (Appendix 1). However, including a temporal trend in λ_0 had almost no effect on the density estimates (Appendix 1) and one was not included in subsequent models.

3.4 Modelling to estimate wolverine density

A model with differing density in 2018 and 2019 did not fit better than a constant-density model (LRT = 0.95, 1 df, $P = 0.33$). We report estimates from the full year-specific model in Table 3, noting that the change in density between years is not significant. A model with differing sex ratio did not fit better than a model with differing density and constant sex ratio (LRT = 0.017, 1 df, $P = 0.90$).

Estimates of density and detection parameters are given in Table 3.

Table 3. Estimates of wolverine density and parameters λ_0 (intercept) and σ (spatial scale) of the negative exponential spatial detection function in 2018 and 2019.

Metric	Year	
	<u>2018</u>	<u>2019</u>
<u>Density/proportion females</u>		
Density (wolverines / 1000 km ²)	3.10 (2.00–4.78)	4.14 (2.78–6.18)
Proportion females	0.510 (0.373–0.646) (held constant across years)	
<u>Detection parameters</u>		
<u>Females</u>		
Detection at home range center (λ_0)	0.354 (0.182–0.691)	0.967 (0.526–1.778)
Scale of movement (σ ; km)	4.76 (3.50–6.47)	2.50 (1.93–3.25)
<u>Males</u>		
Detection at home range center (λ_0)	0.717 (0.414–1.242)	0.249 (0.140–0.443)
Scale of movement (σ ; km)	5.40 (4.27–6.83)	7.78 (5.70–10.62)

Detection function plots based on detection parameters (Table 3) reveal a wider range of movement related to sites for males (Fig. 6). Detection at home range center

increased for females in 2019 but decreased for males. Conversely, scale of movement decreased for females but increased for males in 2019.

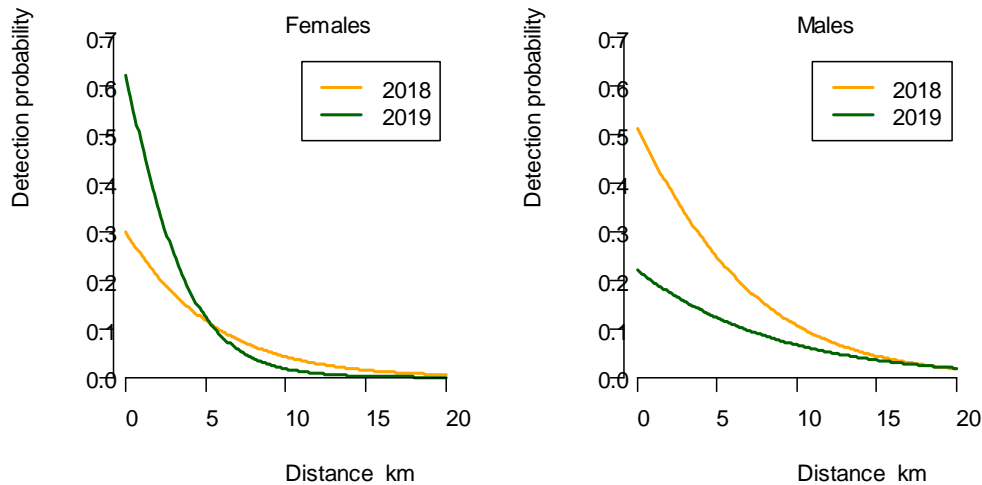


Figure 6. Modelled probability of detection as a function of distance, by sex and year based on detection parameters listed in Table 3.

3.5 Population size

There was no natural boundary to the sampled wolverine population, so the nominal population size depends on the area chosen. We present population size estimates in Table 4 for two arbitrary areas, 20-km and 50-km buffered areas around the post array.

Table 4. Estimated numbers of wolverines within different distances of post locations (annual difference not statistically significant).

Buffer around posts	Year	
	2018	2019
20-km buffer (9495 km ²)	29	39
50-km buffer (22936 km ²)	71	95

3.6 Harvest

Reported wolverine harvest for Napaktulik Lake area was zero in 2018. Hunters reported killing 24 wolverines around Napaktulik Lake in 2019 winter, including 20 males and 4 females (Fig. 7), most were harvested ($n = 20$) before the first session of the DNA trapping. Twenty two were aged including 6 juveniles (27%), 9 yearlings (41%) and 7 adults (32%). Wolverine harvest locations suggest wolverine harvest occurs in conjunction with caribou and wolf hunting. The male:female ratio of the harvest was highly biased towards males (Fig 7). The age distribution of the killed wolverines was weighted more towards sub adult animals.

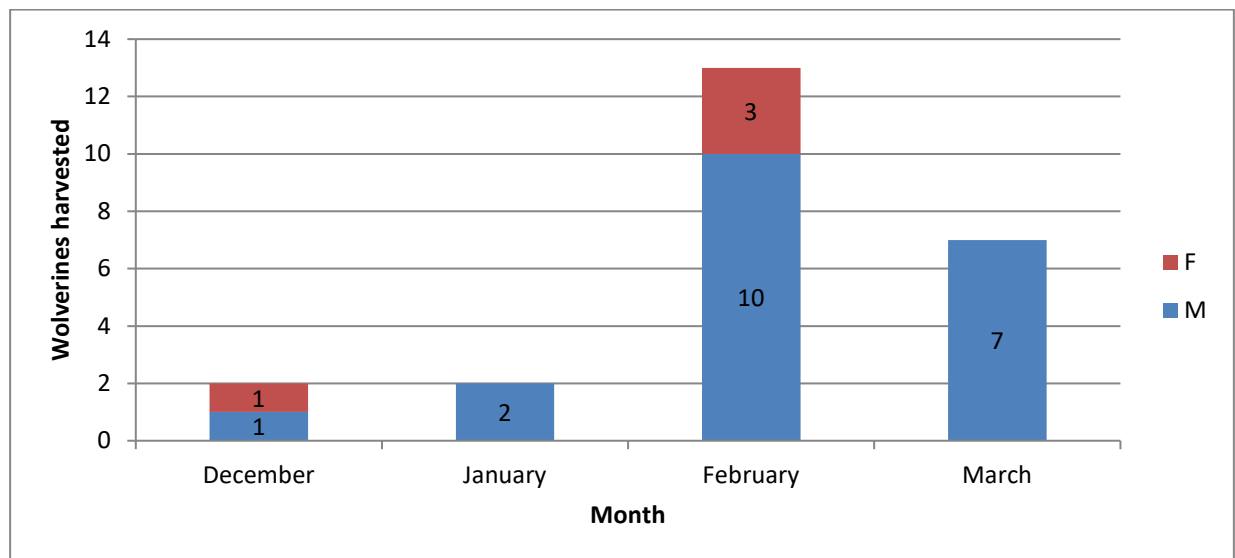


Figure 7. Monthly reported wolverine harvest in the study area during winter 2018-19.

The reported harvest locations of wolverines killed between the 2018 and 2019 surveys were concentrated in the southeast of the post grid, particularly around the northeast end of Napaktulik Lake (Fig. 8).

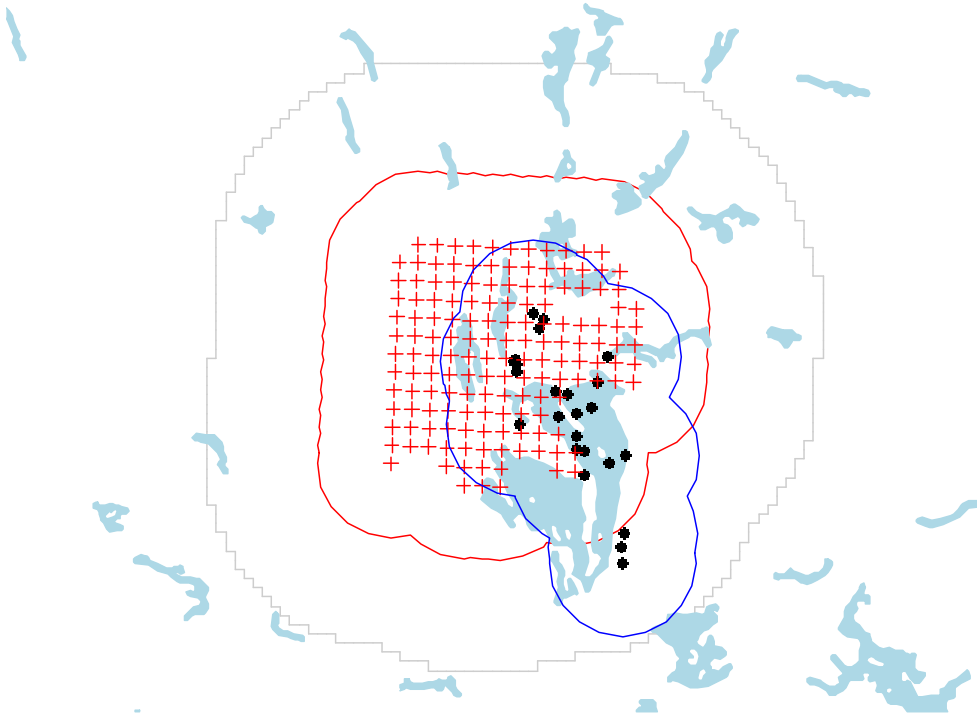


Figure 8. Harvest locations (black dots) of 24 wolverines killed in the winter (December 2018 to March 2019) between the 2018 and 2019 DNA surveys. Locations jittered slightly to reduce overlap. Red crosses mark post locations. The red and blue lines mark a 20-km buffered area around the posts and the harvest locations, respectively. These indicate the catchments from which post-detected and harvested animals were drawn with high probability (95%): the catchments overlap substantially but not completely. Outer grey line is 50-km buffered area used for SECR modelling of post data; a small minority of detected wolverines were likely centred between the red and grey lines.

3.7 Changes between 2018 and 2019

Wolverines that were detected in both 2018 and 2019 remained in essentially the same locations (Fig. 9), suggesting that they were resident of the area. Estimates of apparent survival and recruitment from a spatial robust-design Pradel–Link–Barker (PLB) model (Efford and Schofield 2019) were similar to those from a non-spatial model, but confidence intervals were wide (Table 5). The estimated population growth rate (λ relative change in density over the duration of sampling – unrelated to λ_{00}) is the sum of apparent survival and per capita recruitment, and may also be estimated directly by fitting a PLB model parameterized with λ . Direct estimates of λ

were 1.23 (0.80–1.89 95% CI) from the non-spatial model and 1.21 (0.78–1.86) from the spatial model.

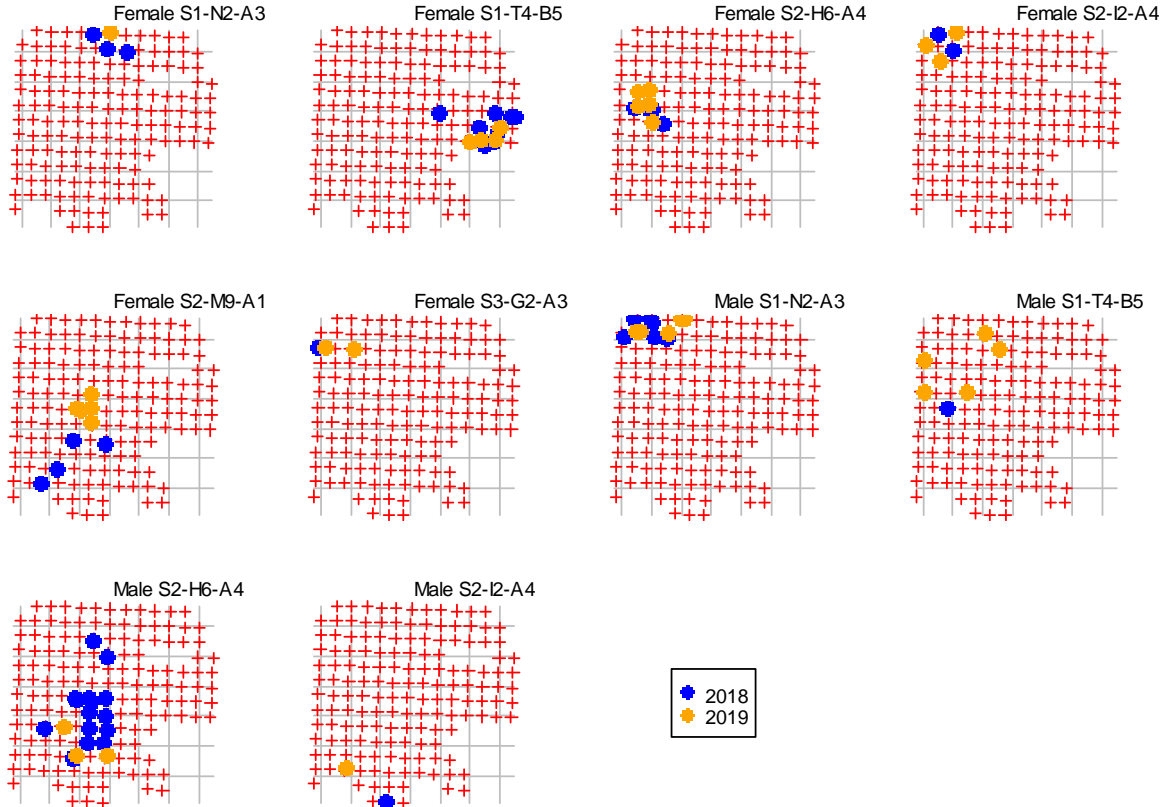


Figure 9. Locations of wolverines detected in both 2018 and 2019. Female S2-M9-A1 and male S3-K11-C3 appeared to shift their centres of activity between years.

Table 5. Estimates of detection and demographic parameters from robust-design 2-year open population models. The parameter for the magnitude of detection is ‘p’ for the non-spatial (Pradel–Link–Barker) model and ‘lambda0’ for the spatial model. Sigma (spatial scale of detection) is not estimated in the non-spatial model.

Model	Detection parameters		Demographic parameters	
	lambda0/p	sigma	Apparent survival	Per capita recruitment
Non-spatial	0.56 (0.46–0.65)	–	0.50 (0.28–0.71)	0.73 (0.37–1.43)
Spatial	0.12 (0.10–0.16)	8.9 (8.1–9.9)	0.52 (0.30–0.73)	0.69 (0.35–1.38)

Camera data showed that wolverine visited the bait posts on average 7 days (SD = 4.2, $n = 15$) after deployment, compared to the Henik Lake study, done in the Kivalliq region of Nunavut, where estimate was 3.6 days (Awan et al. 2018). While visiting the baited post, wolverine spent on average 22.8 minutes around the post. Wolverines visits and activity at the posts was equally distributed during day and night.

3.8 HTO Participation

Ground-based surveys, which can involve local HTO and community participation, are a labour intensive but a cost-effective methodology for studying wolverines. The necessary land skills needed for this type of fieldwork were attained by hiring three experienced hunters from the Kugluktuk HTO as field technicians. The field technicians were very knowledgeable on the local area and wildlife, actively participated in the field work, and learned standardized wildlife survey techniques (sampling protocol, hair collection and data recording). The skills acquired by the field technicians increased chances that those individuals could participate in running this program in future years with minimal supervision and technical assistance. The skills acquired by the field technicians also makes them more qualified to work as technical staff (e.g. wildlife monitors) with other organizations such as exploration/mining camps.

The study generated about 400 person-days of employment to local hunters and elders. This seasonal employment to local hunters helps alleviate some pressures due to the high cost of living in the North, and offsets expensive maintenance costs for hunting equipment needed to carry out subsistence harvesting activities and traditional lifestyle (Stevenson 1996). The project also helped the local HTO to build technical expertise, experience, and monitoring capacity for future HTO-led projects or collaborations with co-management partners. The baseline information collected within the socio-cultural framework will be used for future monitoring and wolverine management. HTO board members reviewed, discussed and contributed to the proposed research project and field methods, provided guidance throughout the

project, and in turn obtained increased awareness about the species status at the national and international level. The involvement of hunters and the HTO in the study improved their collaborative relationship with the GN and may be a mechanism to increase local interest and involvement in wildlife management. The project provided opportunity to hunters to use their land skills and wildlife knowledge, which enhanced study results. The lead biologist and other participating GN staff had the opportunity to improve their land skills and learn more about how HTO/community members want to be involved in scientific studies and conservation in Nunavut. Local participants acted as stewards of the land on a daily basis and provided guidance to GN staff to ensure the fieldwork was completed and accomplished safely.

4.0 DISCUSSION

Our estimates of density and the average number of wolverines with home-range centres on the sampling grid at a single time varied between 2018 and 2019. The estimated population density increased (non-significantly) between 2018 and 2019. We note a theoretical possibility that the baited-post survey methodology or wintered caribou herd in the Napaktulik Lake area in 2019 may have induced a change in late winter wolverine distribution. The presence of wintering caribou in the study area likely resulted in higher wolverine density, high wolverine harvest, and higher male wolverine movements in 2019, consistent with Krebs et al. (2007) that winter food resources influence habitat selection in wolverines. Arctic wolverines rely predominantly on migratory caribou (Mulders 2000, Dalerum et al. 2009, L'Hérault et al. 2016) and Magoun et al. (2018) documented that wolverines pursuing caribou over long distances on snow covered tundra. The telemetry study findings suggested that wolverine repeatedly visited and spent more time in areas with larger prey in winter (Inman and Packila 2015, Scraftford and Boyce 2018). This suggests an increased density of wolverines in 2019, possibly by transient wolverines. Similarly, Stoner et al. (2013) demonstrated that the transient segment of the cougar (*Puma concolor*) population swells during livestock production and Hayes et al. (2016) documented that distribution of tundra wolves depends on where caribou are in any given year. Further, wolf carcasses and caribou gut piles in the area by hunting activity attracted more wolverines into the study area in 2019 –see Mulders 2000).

Several studies have emphasized the importance of caribou in sustaining the tundra biodiversity, its central role in the lives of Inuit (Ljubicic et al. 2018), and as a common proportion of the diet of predators and scavengers (Dalerum et al. 2009, Gunn et al. 2011). Caribou wintered less frequently in the Napaktulik Lake area, which is likely due to low caribou numbers in the region since the early 2000s (Adamczewski et al. 2009) and subsequent reduction in their annual range (Virgl et al. 2017). The area has, therefore, not been frequented as much by Kugluktuk hunters during this period. Comparatively, high wolverine and wolf harvest occurred in the past out of Kugluktuk

when caribou herds wintered nearby (Hayes et al. 2016), because hunters spent more time on the land to hunt caribou. While hunting caribou, harvesters usually pursued wolverine when they saw wolverine or found fresh tracks., (Awan 2020). In 2018, wolverine harvest was zero, which was apparently due to the absence of wintering caribou in Napaktulik Lake area. According to collaring data and local knowledge, the Beverley caribou herd has not been wintered in Napaktulik Lake area in recent years. However, in 2019 a group of Beverley caribou wintered in this area (J. Adamczewski pers. com. to Kugluktuk HTO in Feb 2019). Arctic wolverines are known to follow (Magoun et al. 2018) and eat caribou (Mulders 2000, L'Hérault et al. 2016). Thus, wintering caribou attracted more predators and hunters in the area near the study site. Along with prey abundance over winter in 2019, higher hunting activity (gut piles and wolf carcasses) and availability of vacant wolverine territories due to high harvest in early winter, likely resulted in higher wolverine density and larger male wolverine movements in 2019.

In northern Sweden, Aronsson and Persson (2018) observed high fidelity at total wolverine territory level, however, they found that more intensively used core areas varied among years with resource availability. Royle et al. (2011) described a shift in home ranges due to resource variability in multi-year studies.

In many carnivores, annual variation in prey availability and environmental conditions can change animal distribution, density, and shift home range size and location, including grizzly bears (McLoughlin and Ferguson 2000, McLoughlin et al. 2003); wolverine (GRRB 2014, Efford and Boulanger 2018, Olsson 2020) and wolves (Hayes et al. 2016). Moorhouse and Boyce (2016) associated yearly variation in SECR density estimates of grizzly bears in Alberta with change in home-range centers. Our results reflect a snapshot of wolverine status in early spring over 2 years. The apparent inter-annual variation in density estimates highlights the need for multi-year monitoring to better determine spatial and temporal drivers of local abundance and how wild populations change over time (Harris et al. 2005, Mulders et al. 2007, Moorhouse and Boyce 2016).

We compared the present estimates with other estimates of wolverine density from capture–recapture studies (Table 6). The estimated wolverine density near Napaktulik Lake was similar to that from Henik Lake in the Kivalliq region (Awan et al. 2018) and slightly higher than that from Aberdeen Lake (Awan and Boulanger 2016).

Table 6. Estimates of wolverine population density from capture–recapture studies. Methods SECR spatially explicit capture–recapture, CR closed population, JS Jolly-Seber.

Locality	Year	Density (per 1000km ²)	Proportion females	Method	Source
<u>Nunavut</u>					
Aberdeen Lake	2013	2.36 (2.09–3.33)	0.57	SECR	Awan & Boulanger 2016
	2014	1.66 (1.12–2.53)	0.61		
Henik Lake	2015	4.42 (3.29–5.93)	0.43	SECR	Awan et al. 2018
	2016	3.38 (2.89–3.96)	0.49		
Napaktulik Lake	2018	3.10 (2.00–4.78)	0.51 ¹	SECR	This study
	2019	4.14 (2.78–6.18)	0.51 ¹		
<u>NWT</u>					
<u>Daring, Ekati, Diavik</u>	2014	3.32 (2.62–4.20)	0.56	SECR	Efford & Boulanger 2018
<u>British Columbia</u>					
Omineca	1996–97	6.5		JS	Lofroth & Krebs 2007 ²
Columbia	1997–98	5.8			
<u>Alaska</u>					
Tongass NF	2008	9.7 (5.9–15.0)		SECR	Royle et al. 2011 ³

1. Proportion female assumed constant across years

2. Ear tagging and transmitter implants

3. Camera trapping with identification by pelage differences

Higher wolverine densities were estimated in the central Arctic (6.85 wolverines/1,000 km² at High Lake in 2008 and 4.80/1,000 km² at Izok Lake in 2012; Poole 2013), however, both of these study areas have very limited wolverine harvest and this higher density was likely associated with comparatively higher caribou numbers in the region in 2010 and 2012. Around our study area, with wolverine tracks, Lee and Niptanatiak (1993) estimated density as 1/136-226 km². Estimated average wolverine density at the three sites in the central barrens (Daring Lake, Diavik and Ekati)

declined by about 40% between 2005 and 2014, from an average of 5.57 wolverines/1,000 km² to 3.32/1,000 km² (Efford and Boulanger 2018), concurrent with declines in the Bathurst caribou herd. Gervasi et al. (2015) described that population properties, such as density or survival rates, often vary due to uneven spatial distribution of resources and mortality risks. Similar to grizzly bears, it has been generally assumed that wolverine densities are higher in the West Kitikmeot and lower to the north and east (Slough 2007), and that population density is driven by productivity and seasonality (McLoughlin 2001). In North America, wolverine densities vary across ecological areas and habitat quality, to a maximum of about 5-10 wolverines/1,000 km² (COSEWIC 2014, Species at Risk Committee 2014).

Effect of harvest

The estimated population density increased (non-significantly) between 2018 and 2019. There is therefore no evidence that the harvest reduced the population between 2018 and 2019, but an impact cannot be ruled out owing to the statistical uncertainty in the estimates. It is also possible that the population was increasing naturally, and that density estimates would have increased even more without harvest.

The relatively high harvest in our study area during the winter of 2019 was primarily attributed to a wintering caribou herd in the area. About a third of harvest locations lay outside the perimeter of the post grid. Thus, while most harvested wolverines would have been detectable at posts, some likely had peripheral home ranges with low probability of detection at posts as indicated by the harvest high-probability catchment area (blue) outside the post catchment area (red) in Fig. 8. This component of the harvest would therefore not be expected to impact on the measured population density.

Localisation of harvest effort in the southeast of the study area was linked to caribou hunting opportunities. In the southeast, it is easy to chase caribou and predators by snow machine on the frozen lakes. In the north and western portion of sampling grid,

the terrain is comparatively steep and rugged, providing escape features for wolverines to avoid being chased by snow machines and shot. There was no evidence for higher wolverine density in the southeast of the post grid, but we cannot exclude the possibility that density was higher away from the grid to the southeast. A hypothetical pocket of high density there, possibly coupled with rapid replacement of harvested males by immigrants, may have existed to the southeast of the post array; this may help explain the apparent inconsistency between the SECR and harvest data. Alternatively, the SECR estimates may underestimate the overall population density, perhaps because some component of the population (perhaps young animals) was under sampled.

Estimates of apparent annual survival were low (0.5) for this study (Table 5) compared to the Daring Lake study (Efford and Boulanger 2018) where estimates were 0.73 (CI=0.66-0.80) and 0.67 (CI=0.59-0.75) from 2004-2014. Per capita recruitment was much lower in the Daring Lake study (females 0.19, CI 0.13–0.28; males 0.27, CI 0.20–0.35) and as a result the population there declined substantially over time. The comparison should be viewed cautiously given the short time series (2 years) for the Napaktulik Lake data set. Wolverines that were detected in both years ($n = 10$) generally showed fidelity to mean capture areas (Fig. 9), therefore the apparent lower survival may be due to either true low survival or emigration of younger wolverines to other areas. It is likely the harvest of wolverines between yearly sessions increased mortality rates of wolverines therefore reducing apparent survival. Krebs et. al. (2004) reported higher survival rates in non-harvested populations. Like other mammals, high male-biased dispersal (Pusey 1987) and intersexual home range overlap is reported in wolverine populations (Vangen et al. 2001, Dalerum et al. 2007, Bischof et al. 2016). Others have reported long dispersal movements in yearlings from their natal area before reaching sexual maturity (Copeland 1996, Mulders 2000, Vangen et al. 2001, Inman et al. 2012) and migration of wolverines from areas with lower mortality to those with higher mortality (Gervasi et al. 2015, 2016). It is likely that the Napaktulik Lake population is part of a source and sink dynamic, with emigration from outside areas replenishing harvested animals or sustaining the harvest through immigration

(Mowat et al. 2020). This apparent low survival may be due, in part, to dispersing transient wolverines that spend only a portion of time on the grid, as also described by Mulders et al. (2007) in the central Arctic. This is consistent with the 2014 COSEWIC assessment, which indicates that a sizeable proportion of the wolverine populations, normally sub-adults, are transient at any given time.

Sex differences in movement

The movements of males were noticeably greater than those of females but only in 2019. Other studies have reported consistently greater movements of males (Efford and Boulanger 2018). We speculate that harvest in 2019 may have affected movement patterns. The harvest in the study area was in winter (54% in February), when juvenile and yearling wolverine dispersal typically begins in January, and males dispersing more commonly than females (Vangen et al. 2001, Gervasi et al. 2015). Of the animals harvested between 2018 and 2019 (Fig. 7), 83% were males. The harvest of subadults (68%) around the study area was slightly higher than the Kitikmeot regional harvest (59%, Awan 2020). The actual sex ratio in the population is 1:1, however, male biased harvest sex ratio reflects immigration and enhanced harvest availability of young males in the study area or difference in vulnerability to harvest by sex.

Kukka et al. (2017) describe the high proportions of young males in the harvest, because vacant areas created by the harvest of resident animals may be filled by dispersing young males (Magoun 1985). Others have reported long dispersal movements in yearlings from their natal area before reaching sexual maturity (Copeland 1996, Vangen et al. 2001, Inman et al. 2012). The high harvest of younger males (61%) may have resulted in vacant male territories and dispersal to nearby vacant territories likely led the higher male movement. Long distance dispersals are documented in Arctic wolverines, especially dispersing juvenile wolverines from un-hunted areas fill the voids left by harvested animals (Mulders 2000). Various studies have documented vacant territory occupation (Vangen et al. 2001) or rapid

recolonization of empty territories (Kortello et al. 2019). In mammals, emigration (and therefore immigration) most often occurs in juveniles, especially young males (Adamczewski et al. 2009).

Power to detect change in density

The estimates of wolverine density from Napaktulik Lake may be used in future as a baseline against which to assess change. Statistical power to detect such a change depends (in part) on the precision of the density estimates. We estimate the precision of the 2018 estimate by its relative standard error (RSE), also known as its CV. The 2018 Napaktulik Lake density estimate ($3.10 / 1000 \text{ km}^2$) had $\text{RSE}(D) = 0.225$. A single later survey using the same methodology could be expected to yield a similar RSE, except for changes in sample size due to changed density. Efford and Boulanger (2019) gave a method¹ for predicting the statistical power of a 2-survey comparison with RSE constant except for density effects. We used their method to predict that a repeat survey would meet the threshold of 80% power to detect a 64% reduction or 95% increase in density, given a relaxed type-I error rate $\alpha = 0.1$. Changes of lesser magnitude would not be expected to show a significant difference, as for the 2018–2019 comparison in the present study. This emphasises the difficulty of monitoring such a sparsely distributed species. Other studies on wolverine (Efford and Boulanger 2018, Awan et al. 2018) provide further guidance on survey intervals and study design.

We note that the estimate of trend from this project should be interpreted very cautiously given that it is based on 2 years of sampling with a substantive harvest in between sampling years. To establish longer-term demographic trend would require a multi-year survey effort. Multiple surveys would provide estimates of the process variation – possibly random components of annual variation in density unrelated to long-term trend – while also accumulating information on trend itself, thereby leading

¹ The method is implemented on the Power tab of the online app *secdesign* (<https://www.stats.otago.ac.nz/secdesignapp/>). Adjust the alpha level on the Options page.

to greater statistical power. Conversely, the presence of process variation complicates both study design and interpretation. We can only speculate on the magnitude of process variation in the Napaktulik Lake wolverines – it seems unwise to extrapolate from the Daring Lake population whose dynamics were apparently quite different. We note that removal of harvested individuals between sampling complicates estimation of trend. Genotyping of harvested wolverines which is underway would assist in determining the relative impact of harvest on trend in the sampling grid.

Analysis of microsatellite DNA allows individuals to be identified from hair, given adequate samples. A hair sample can fail in an individual identification if it is too small (less hairs) or degraded (Long et al. 2008). The sample quality, estimated from the genotyping success rate was variable in both years. In both years, we set aside samples that contained no guard hairs with roots and <5 underfur (classed “Xinadequate”). In 2018, only 7% (n=12) samples lacked suitable material for analysis, while in 2019, 34% (n=75) samples were too small, having only few snagged hairs and deemed unsuitable for analysis — indicating a reduction in quality relative to 2018. The number of guard hair roots per successful sample was down to 3.8 in 2019, from 5.6 in 2018. This could be explained by a factor like wind, but maybe the capacity of wire to pluck hair goes down over time because the same wire (posts) was used in 2004-05 for a wolverine study around Kugluktuk (Dumond et al. 2012). Another factor that might have contributed to the quantity of snagged hairs in the samples was the presence of caribou (alternate source of food) in the area during the sampling period (March/April). We believe that one reason our hair samples in 2018 had more snagged hairs, was due to the fact that there were no caribou in the vicinity of the study area during the 2018 sampling period. The absence of caribou during the sampling period may have caused wolverines to be more interested in visiting the baited posts and lures. Apparently, hungry wolverines were spending more time on the posts in an attempt to remove the bait and left additional hair samples. With abundant caribou and wolf carcasses available in 2019, wolverines in the study area were probably not interested in bait on the posts. Wolverines may have been distracted by scattered gut piles from harvested caribou and possibly less attracted by

baited posts. Therefore, they were visiting and climbing up on the posts to explore scent lures, but wolverines were possibly less hungry and not sufficiently enticed by bait to remain for a longer time on the posts in order to leave more hairs. In other words, wolverines with less access to prey species would likely be more interested in visiting the baited posts (R. Mulders pers. comm. March, 2019).

Among the successful samples (having more hairs with roots), sample quality and genotyping success was good, with 2018 samples resulting in 86% success, compared to 83% in 2019, up from 81% in 2015 (Awan et al. 2018) and 82% in 2012 (Poole 2013) in comparative Arctic tundra wolverine density studies. These are all solid numbers, and do not suggest problems with collection or storage methods. This >80% success rate was still at the high end of the rates in projects that use remote sampling. (Paetkau 2019 unpublished data). We recommend replacing barb wire on the wood posts to snag wolverine hairs and continuing with the use of 9 microsatellite markers to identify individual wolverines in future projects. Genotypes from harvested wolverines provides valuable information, we recommend genotyping of harvested wolverines from the study area to incorporate mortality data in the future analysis.

In summary, our results contribute to knowledge of wolverine ecology in the study area and can be used for future monitoring and to generate very rudimentary regional population estimates. This could inform the evaluation of current harvest in Nunavut and future management recommendations for sustainability. A database containing “DNA fingerprints” of individual wolverine has been established for Nunavut, which will be used for population delineation. We suggest genotyping of wolverine harvest samples from Kugluktuk for future demographic analysis. Our study can be used to refine and optimize DNA sampling methods for future wolverine studies on the tundra.

Wolverine is a culturally and economically important furbearer for Inuit. There is currently no wolverine monitoring program at the mines in Nunavut, so potential effects of industrial development are unknown. Given the low density, yet high occurrence of wolverines at the mine sites (Agnico Eagle Mines 2018), we recommend multiple years of DNA sampling to accurately determine population

trends, mitigation and monitoring needs by involving the industry through the Nunavut Impact Review Board (NIRB) and the HTOs.

5.0 FIELD TEAM

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8.0 APPENDIX

8.1 Appendix 1. Comparison of detection models.

Tables use these abbreviations: npar number of parameters, logLik log-likelihood, AIC Akaike's Information Criterion, dAIC difference in AIC from best model, AICwt AIC model weight.

Lambda0 and sigma are parameters of the detection model. The notation ~1 indicates a model with constant

1. Halfnormal vs negative exponential detection model, sexes pooled.

model	npar	logLik	AIC	dAIC	AICwt
lambda0~1 sigma~1 exponential	2	-576.8	1157.5	0.0	1
lambda0~1 sigma~1 halfnormal	2	-597.0	1198.0	40.5	0

2. Sex and year effects on detection, negative exponential.

model	npar	logLik	AIC	dAIC	AICwt
lambda0~Sex*Year, sigma~Sex*Year	8	-551.6	1119.3	0.0	0.992
lambda0~Sex, sigma~Sex	4	-560.4	1128.9	9.6	0.008
lambda0~Sex+Year, sigma~Sex+Year	6	-558.9	1129.8	10.5	0.000
lambda0~1, sigma~1	2	-576.8	1157.5	38.3	0.000

3. Site-specific learned response (bk) and within-year temporal trend (T), on top of sex and year effects, negative exponential (AIC not directly comparable to above because sessions not collapsed)

model	npar	logLik	AIC	dAIC	AICwt
lambda0~Sex*Year+T, sigma~Sex*Year	9	-722.9	1463.9	0.0	0.615
lambda0~Sex*Year+T+bk, sigma~Sex*Year	10	-722.4	1464.8	0.9	0.385
lambda0~Sex*Year+bk, sigma~Sex*Year	9	-729.5	1477.1	13.2	0.000
lambda0~Sex*Year, sigma~Sex*Year	8	-731.8	1479.6	15.7	0.000

Density estimates (wolverines / 1000 km²) from the top model (Sex*Year and within-year temporal trend in lambda0) and the 95% CI were almost the same as estimates of year-specific density from one without a temporal trend:

model	2018	2019
D*Year lambda0~Sex*Year+T, sigma~Sex*Year	3.095 (2.003–4.784)	4.139 (2.772–6.178)
D*Year lambda0~Sex*Year, sigma~Sex*Year	3.091 (1.999–4.779)	4.144 (2.776–6.187)

8.2 Appendix 2: Observed range lengths (ORL) of individual wolverines detected in 2018 or/and 2019.

Female id	year				Males id	year			
	2018 ORL	n	2019 ORL	n		2018 ORL	n	2019 ORL	n
S1-N2-A3	11.2	3		1	S1-G1-A5	15	6	15.8	5
S1-T3-A3	54.1	2		0	S1-Q2-A4	20.6	9		0
S1-T4-B5	25	8	11.2	4	S2-G11-A3		1		0
S2-H6-A4	11.2	5	11.2	5	S2-N4-A4	28.3	4		0
S2-I2-A4	7.1	2	11.2	3	S3-G7-A3	10	3		0
S2-M9-A1	25	4	10	5	S3-I7-A6		1	29.2	5
S2-N3-A3	26.9	3		0	S3-K11-C3	40.3	16	18	3
S3-G2-A3		1	10	2	S3-L14-A3		1		1
S3-K14- GROUND		1		0	S3-M12-A4	49.5	11		0
S3-L6-A4	20.6	8		0	S3-O1-C6		1		0
S3-O6-GROUND		1		0	S3-Q10- GROUND	1		0	
S1-G1-A2		0	10	2	S1-G9-A3		0	22.3	9
S1-J5-A3		0	7.1	6	S1-L10-A3		0	46.1	12
S1-K14-A2		0	10	2	S1-N5-A3		0		1
S2-H8-A2		0	11.2	4	S1-S3-A2		0	67.1	3
S2-I8-A4		0		1	S2-O12-A2		0		1
S2-P12-A1		0	7.1	4	S3-M2-A2		0	11.2	3
S2-Q3-A7		0	10	3	S3-O1-A2		0		1
S3-G6-A2		0	5	2	S3-P12-A1		0	15.8	7
					S3-Q2-A3		0	29.1	2

8.3 Appendix 3: Wolverine hair snagging posts.

