

Isle Royale National Park
National Park Service
U.S. Department of the Interior



WOLVES

and the Isle Royale Environment:

RESTORING AN ISLAND ECOSYSTEM

2018–2020

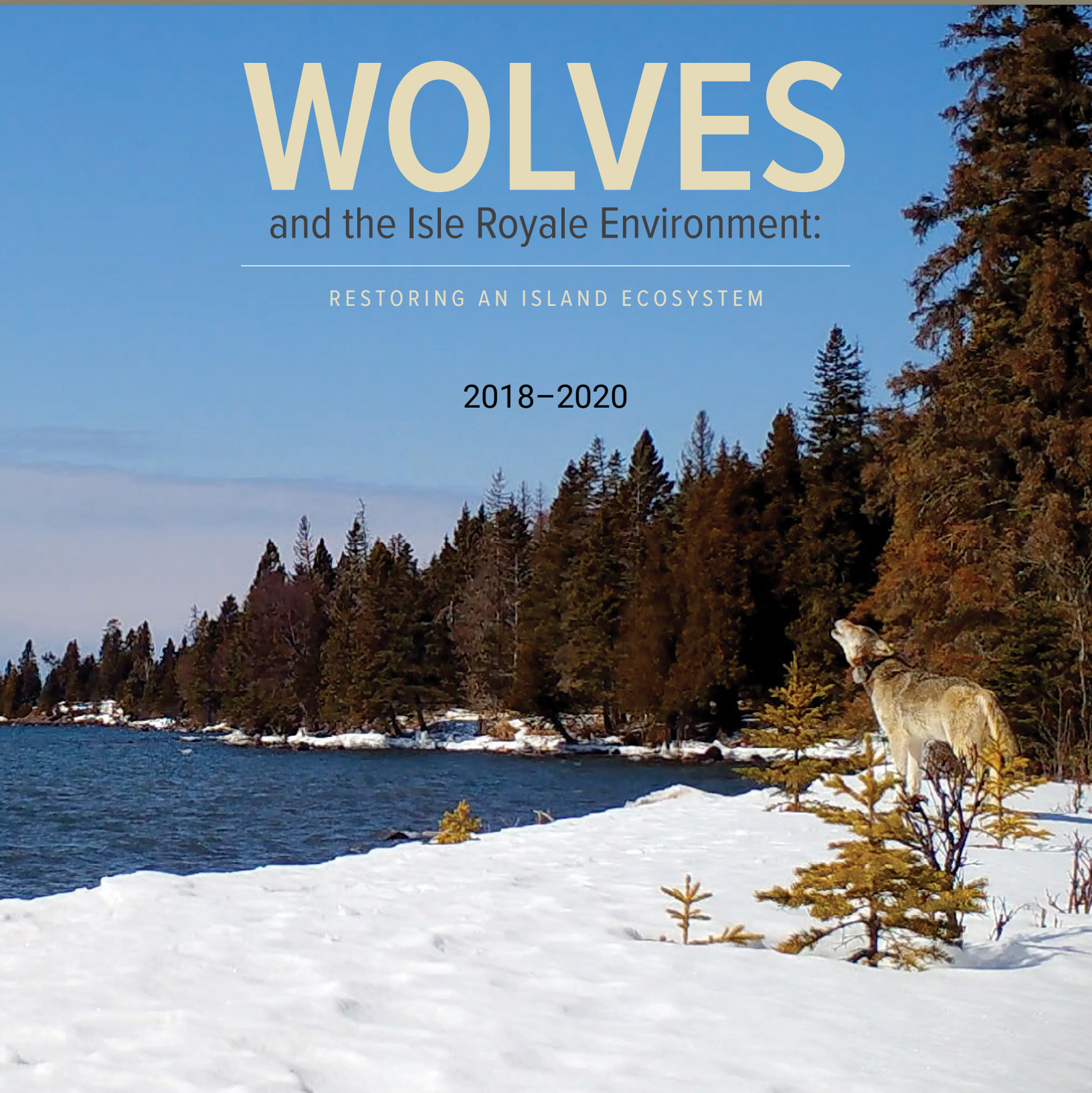




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WOLVES AND THE ISLE ROYALE ENVIRONMENT: RESTORING AN ISLAND ECOSYSTEM 2018-2020

▼ AUTHORS

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Led by the National Park Service-Isle Royale National Park with assistance from the Global Wildlife Conservation Center at SUNY ESF, the success of this project is the direct result of our collaboration with many partners (*see page 33*). To learn more about our work visit: <https://globalwildlifec.org/research/species-recovery/isle-royale-wolf-recovery>

▼ SUMMARY

The National Park Service made a determination to augment the number of gray wolves (*Canis lupus*) on Isle Royale National Park to restore this apex carnivore and predator-prey relations. This report summarizes project results from September 2018 to April 2020. Nineteen wolves captured in Michigan, Minnesota, and Ontario during September 2018–2019 were translocated to Isle Royale. We estimated 14 wolves present on Isle Royale on 14 April 2020. Eight wolves died with the most common cause of mortality intraspecific aggression.

GPS location data suggested female wolf 014F denned in spring 2019 and established several rendezvous sites. Images from a remote camera in September 2019 support at least two pups were reared. Location data from GPS collars also demonstrated denning activity for wolf 001F in early April 2020. Genetic analysis of scat samples will provide additional support for reproduction of these wolves. Limited data suggested potential for denning activity for wolves 012M and 015F during spring 2020; however, collar failure precluded confirmation.

Median monthly movement rates varied among collared wolves, with male wolf movements greater overall than those of female wolves. Male movements overall declined from introduction through April 2020 whereas female movements were more consistent. Overlap of movements between males and females was greatest during winter and spring 2020, when wolf associations were greatest. Spatially, wolves tended to traverse greater portions of the archipelago shortly after introduction with areas occupied becoming smaller over time. Associations among introduced wolves varied, with strength and consistency increasing overall through April 2020. We developed an interactive online application allowing users to observe individual and group wolf movements, space use, and social organization over time.

We investigated clusters of wolf GPS locations during May–September 2019 to estimate predation or scavenging events. Of 381 location clusters investigated, we identified 50 predation events of which 24 were moose (*Alces alces*): 18 calves, 4 yearlings, 2 adults; 19 were beaver (*Castor canadensis*), 3 were snowshoe hare (*Lepus americanus*), and 4 were other species. We documented 117 instances of concurrent space use by wolves at these clusters. Thirty-one instances (26.5%) were associated with prey remains, 62.4% were associated with rest sites, and 11.1% were unknown.

Though no external parasites or evidence of disease were detected during capture and translocation, preliminary serological testing revealed previous exposure to canine parvovirus and canine distemper in more than half of the wolves translocated. We initiated a genomic monitoring program for Isle Royale wolves; preliminary results suggest genetic variation of translocated wolves are representative of their source populations.

We estimated abundance of moose during 14–15 March 2020 using a double-count distance sampling framework from a helicopter. We surveyed about 95% of Isle Royale and observed 236 moose in 136 groups. Overall, we estimated 584 moose (95% confidence interval [CI] = 441.3–772.3) available for detection during the survey, representing a mean density of 1.09 (95% CI = 0.82–1.44) moose/km².

During summer 2019 we installed 156 remote cameras about 1 km apart on and off trails to document wolf distribution in relation to prey species and determine how wolves and other mammals respond to visitor abundance and distribution. We will continue monitoring wolf and moose populations with our partners to characterize their effects on this ecosystem and the success of the wolf introduction program.

▼ INTRODUCTION

Isle Royale is an archipelago in northwestern Lake Superior (Figure 1) and was authorized by Congress as a national park in 1931. The National Park Service (NPS) assumed management of this archipelago in 1936 and established the park in 1940. Dedication took place in 1946 (Beyer et al. 2006). In 1976, 98% of the park was designated as wilderness and in 1981 Isle Royale National Park was designated an International Biosphere Preserve (NPS 2016).

Isle Royale represents a unique and dynamic biogeography with limited human influence. The archipelago's size, habitats, topographic features, distance to mainland, climate, past human activities, and federal administration have influenced species composition and population dynamics. Isle Royale is located

within an ecological transition zone between northern boreal coniferous forests and more southern temperate deciduous-hardwood forests (Goldblum and Rigg 2010). Mammalian fauna on Isle Royale include the gray wolf (*Canis lupus*), red fox (*Vulpes vulpes*), short-tailed weasel (*Mustela erminea*), river otter (*Lutra canadensis*), moose (*Alces alces*), beaver (*Castor canadensis*), muskrat (*Ondatra zibethicus*), snowshoe hare (*Lepus americanus*), red squirrel (*Tamiasciurus hudsonicus*), little brown bat (*Myotis lucifugus*), and big brown bat (*Eptesicus fuscus*) (Peterson 1977). Bird species include numerous passerines and waterbirds, including warblers, waterfowl, shorebirds, corvids, flycatchers, woodpeckers, and sparrows (Egan and Gostomski 2013).



Figure 1. Isle Royale National Park, Michigan, USA, is a remote, island wilderness in northwestern Lake Superior. The island's biogeography is greatly influenced by its distance from the mainland and the cool waters of the lake.

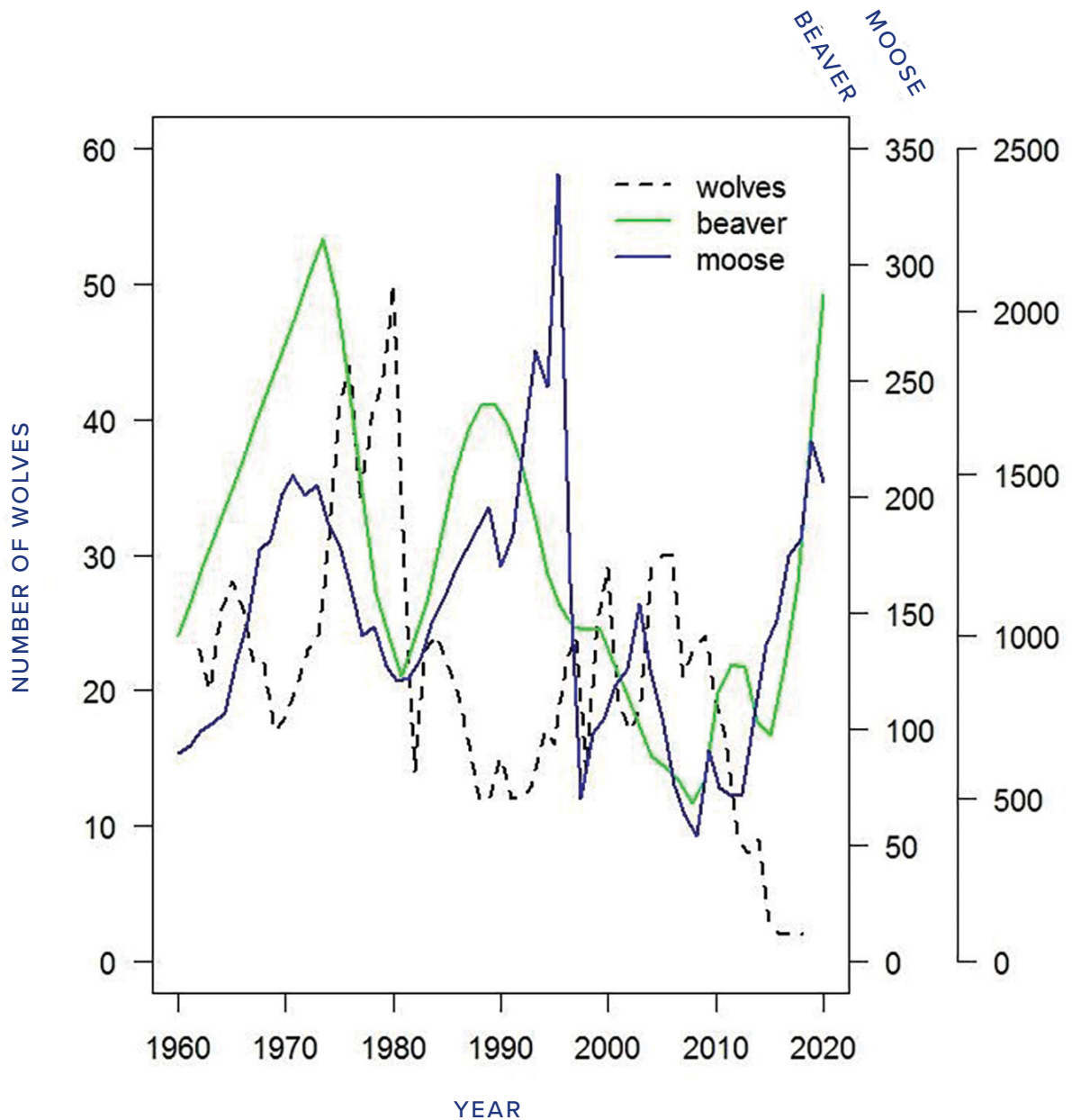


Figure 2. Estimated abundance of wolves, moose (NPS and MTU, unpublished data) and beaver (NPS, unpublished data), Isle Royale National Park, Michigan, USA, 1958–2018.

Wildlife species extirpated from Isle Royale include the federally endangered woodland caribou (*Rangifer tarandus caribou*), federally threatened Canada lynx (*Lynx canadensis*), and coyote (*Canis latrans*) (Mech 1966, Beyer et al. 2006). American marten (*Martes americana*), once thought extirpated for almost 75 years, was recently rediscovered (Romanski and Belant 2008, Manlick et al 2018). However, the most prominent wildlife species associated with Isle Royale are gray wolf and

moose, whose interactions are a well-studied illustration of predator-prey relations (Mech 1966, Peterson 1977, Vucetich et al. 2012).

Moose were first documented on Isle Royale in the early 1900s, followed by wolves in the late 1940s. Wolves are the only predators of moose on Isle Royale and moose are the primary prey of wolves, each affecting the other's distribution and abundance on the island (Figure 2). Beaver are an important secondary prey of wolves and, consequently,

wolves influence their distribution and abundance (Romanski 2010). Relationships among wolves, their prey, and the environment have been affected by fluctuating population numbers, moose and beaver effects on browse, wolf inbreeding depression, disease, vegetation dynamics, and climate change (Nelson et al. 2011).

The legal status of the gray wolf in the United States has changed several times at the federal and state level, particularly for the Western Great Lakes Distinct Population Segment (Michigan DNR 2015). Following litigation challenging their delisting from the Endangered Species Act, on 20 February 2015, the U.S. Fish and Wildlife Service (USFWS) reinstated federal protection for gray wolves in the western Great Lakes area (endangered status in Michigan and Wisconsin, threatened status in Minnesota) effective 19 December 2014. This decision also reinstated formerly designated critical habitat outlined in 50 CFR 17.95(a) for gray wolves in Minnesota and Michigan (USFWS 2015). Though considerable debate has surrounded the taxonomy of wolves in the Great Lakes region (e.g., vonHoldt et al. 2016), the USFWS recognizes the species of wolf on Isle Royale as the gray wolf (USFWS 2011).

As wolf abundance on Isle Royale declined and extirpation seemed likely (Vucetich and Peterson 2015), in 2015 the NPS began to formally determine how to manage wolves and assessed 4 management alternatives documented in an environmental analysis (NPS 2018a). The selected alternative included one or more introductions of wolves to Isle Royale

within 5 years (NPS 2018b). The intent of this alternative was to introduce enough wolves to function as an apex predator and to facilitate pair formation and pack establishment (NPS 2018b). Implementation of this alternative required the NPS to translocate approximately 20–30 wolves from multiple locations in the Great Lakes region with appropriate genetic diversity and mixture of age and sex. The long-term average annual number of wolves on Isle Royale is 22 (Vucetich and Peterson 2016).

The NPS established a panel of scientists to consider aspects of translocating wolves to Isle Royale (NPS 2018a). Issues addressed included types of research and monitoring to conduct, sources of wolves for translocation, genetic characteristics, disease risk and mitigation, capture and handling strategies, and demographic attributes. The outcome was used to aid planning of wolf translocations and identify approaches to quantify ecological responses of wolf restoration.

In June 2018, the NPS and partners began implementation planning considering the panel's recommendations to achieve restoration objectives. Objectives included introduction of wolves from a broad geographic area within the Great Lakes region that was genetically diverse with characteristics (e.g., experience hunting moose) considered important to their persistence. State, provincial, and tribal partners have authority to capture wolves within their respective jurisdictions and coordinated these efforts.

▼ PERMITTING

Under the Endangered Species Act [16 USC 1531 *et seq.*], “take” for conservation purposes can be exempt, permitted, or otherwise authorized. Through consultation with the USFWS, the NPS was authorized to conduct wolf capture and translocation following completion

of Section 7 interagency consultation and a Biological Opinion's incidental take statement (NPS 2018a). Wolf capture and translocation from Michigan was conducted through the Michigan Department of Natural Resources (DNR) using their authorities under Section

6(c) of the Endangered Species Act to designate NPS personnel and their collaborators as “agents of the state”. The Minnesota DNR used authorities under the Endangered Species Act (50 CFR 17.40(d)) to conduct capture operations and provided a research permit (Special Permit No. 24276) to the NPS and its collaborators.

Gray wolves from Canada are not protected under the Endangered Species Act until released on Isle Royale. Gray wolves are currently listed in Appendix II under the Convention in International Trade of Endangered Species (CITES) treaty, requiring a CITES export permit from Canada (Permit numbers

18CA00016ONPB 18CA00017ONPB, 19CA-00003ONPB, 19CA00004ONPB) and a US-FWS wildlife import declaration cleared two months before importation (Dec. Control No. 2019511805, 2019559054).

Importing wolves to Michigan from another state required an interstate certificate of veterinary inspection completed by a licensed veterinarian. Based on physical examinations, each animal must be apparently free from infectious or contagious diseases, which could endanger the animal, other animals, or public health. There are no specific requirements for intrastate movement of animals (i.e., Upper Peninsula of Michigan to Isle Royale).

▼ PARTNERSHIPS

Conduct of the wolf introduction and associated ecosystem monitoring required collaboration among numerous governments, agencies, institutions, and non-governmental organizations. Partners included the Grand Portage Band of Lake Superior Chippewa, Michigan DNR, Minnesota DNR, Ontario Ministry of Natural Resources and Forestry (OMNRF), U.S. Department of Agriculture Animal and Plant Health Inspection Service-Wildlife

Services, U.S. Fish and Wildlife Service, and U.S. Geological Survey. Support from universities included the State University of New York College of Environmental Sciences and Forestry, University of Minnesota, Michigan Technological University, Colorado State University, and Trent University. The National Parks of Lake Superior Foundation and International Wolf Center were instrumental in generating financial support.

▼ WOLF CAPTURE SITES

We captured wolves in northeastern Minnesota, Ontario, and the western Upper Peninsula of Michigan (Figure 3).

Minnesota: The Grand Portage Indian Reservation in Minnesota comprises about 193 km² and is bordered on the north by Ontario; the south and east by Lake Superior; and the west by federal, state, and private land in Minnesota. Glacial activity produced steep ridges and valleys with elevations from 183 to 553 m. There are 68 km of permanent streams and 89 km of intermittent streams. Seventeen inland lakes cover 3.3 km² and there are 29 km² of wetlands (Heinselman 1999, Lenarz et

al. 2009). Moose occur at low density (0.27 individuals/km²) throughout the reservation (Grand Portage, unpublished data). White-tailed deer (*Odocoileus virginianus*) also occur throughout the reservation and concentrate near Lake Superior in winter. Beavers are common. At least three wolf packs with an average of 4.7 individuals per pack occur on the Reservation, representing a density of 8–9 individuals/100 km² (Grand Portage, unpublished data). Vegetation is typical of the southern boreal forest, with upland forests dominated by quaking aspen (*Populus tremuloides*), paper birch (*Betula papyrifera*), bal-

sam fir (*Abies balsamea*), white spruce (*Picea glauca*), and jack pine (*Pinus banksiana*) (Faber-Langendoen et al. 2007).

Michipicoten Island: Michipicoten Island (184 km²) is located in northeastern Lake Superior, about 16 km from mainland Ontario. Currently, most of Michipicoten Island (> 80%) is a provincial park, while the remainder consists of private and federal government properties (Ontario Parks 2004). Human visitation to the island is low and generally limited to summer. Vegetation on the island is dominated by forests (~87%), consisting mostly of deciduous tree species (e.g., sugar maple [*Acer saccharum*], paper birch, and yellow birch [*Betula alleghaniensis*]; Ontario Parks 2004). The mammal community on Michipicoten Island is limited and has included wolves, caribou, beaver, red foxes, mustelids, snowshoe hare, and muskrats. Michipicoten Island was colonized by three to four gray wolves in the winter of 2013–2014 and the population increased to 18–20 individuals by winter 2017–2018. The caribou population on Michipicoten decreased from about 450 individuals in winter 2014–2015 to suspected extirpation in spring 2018, following translocation of 15 individuals

to predator-free islands for conservation purposes (A. Rodgers et al., OMNRF, unpublished data). The estimated number of active beaver colonies also declined from >1000 in fall 2015 to <100 in fall 2018 (OMNRF, unpublished data).

Jostle Lake, Mainland Ontario: Jostle Lake is located about 20 km west of Wawa, Ontario, and east of Pukaskwa National Park, within traditional lands of the Michipicoten First Nation. Jostle Lake is in the Lake Superior Highlands Conservation Reserve, a 621-km² area managed by the OMNRF. The vegetation consists primarily of birch, fir, aspen and spruce. White pine (*Pinus strobus*) and red pine (*Pinus resinosa*) occur on sandy ridges and white cedar (*Thuja occidentalis*) in valleys. The Lake Superior Highlands Conservation Reserve's mammalian community is typical of north-western Ontario and includes gray wolf, black bear (*Ursus americanus*), red fox, lynx, river otter, fisher (*Martes pennanti*), moose, beaver and snowshoe hare. Declining numbers of woodland caribou, a threatened species in the region, have been observed on the reserve. Moose are the primary prey for wolves in this region (Forshner et al. 2003).



Figure 3. Capture locations for wolves translocated to Isle Royale National Park, Michigan, USA, September 2018-2019.

Michigan: The project area in Michigan was in the western Upper Peninsula, including Baraga (2,769 km²), Gogebic (3,823 km²), Houghton (3,890 km²) and Ontonagon (9,689 km²) counties. Human population and road densities are low (US Census Bureau 2010, State of Michigan 2019). Major land uses are logging and mining. The area is largely northern hardwood forests including dominant tree species such as sugar maple and trembling aspen in upland deciduous forests, black spruce (*Picea mariana*) in lowland coniferous forests, and red pine in plantations (Derosier et al., 2015). Similar to the other capture sites, the mamma-

lian community includes gray wolf, black bear, coyote, moose, white-tailed deer, red fox, bobcat (*Lynx rufus*), river otter, fisher, American marten, moose, beaver, eastern cottontail rabbit (*Sylvilagus floridanus*) and snowshoe hare. White-tailed deer are the primary prey of wolves, comprising 70–78% of their diet in the Upper Peninsula, with other mammals and livestock also consumed (Petroelje et al., 2019). While moose are available to wolves in the Upper Peninsula, they are seldom consumed and wolf predation is considered to have negligible effects on moose population dynamics (Beyer et al., 2011).

▼ WOLF CAPTURES AND TRANSLOCATIONS

We used foothold traps to capture wolves in Minnesota from 24 September to 5 October 2018 and in Michigan from 4 to 14 September 2019 (Figure 4). In each area we prebaited

sites with nuisance beaver and vehicle-killed white-tailed deer carcasses to facilitate captures. We captured wolves using net guns from helicopters in Ontario during 24 Feb-



Figure 4. Adult female wolf recovers from anesthesia following capture in a foothold trap, Grand Portage Indian Reservation, Minnesota, USA, September 2018.



Figure 5. Wolf 009M, captured on Michipicoten Island, Ontario, Canada, recovers from anesthesia before translocation to Isle Royale National Park, Michigan, USA, on 1 March 2019. Credit: Ashley McLaren, OMNRF.

ruary–1 March and 23–24 March 2019. We attached a GPS collar, ear tags, and a passive integrated transponder to wolves before translocation. Estimated age, sex, and condition of captured wolves was assessed by one or more veterinarians. All capture methods were approved by each agency’s animal care and use procedures where that agency had jurisdiction and led capture operations. An In-

stitutional Animal Care and Use Committee (IACUC) protocol for all aspects of the translocations (e.g., holding, transportation, and release; Figure 5) were approved by the NPS IACUC.

Overall, 19 captured wolves were translocated to Isle Royale (Table 1). In Grand Portage, we captured 22 wolves in 1,062 trap nights. Two wolves, 1 male (008M) and 1 female (001F)

TABLE 1. ATTRIBUTES OF TRANSLOCATED WOLVES, ISLE ROYALE NATIONAL PARK, MICHIGAN, USA, 2018–2019.

WOLF ID/SEX	DATE OF RELEASE	AGE	WEIGHT (KG)	PELAGE COLOR	CAPTURE LOCATION
001F	27 SEP 2018	4	27.2	GRAY	NORTHEASTERN MINNESOTA
003F	3 OCT 2018	4	30.6	GRAY	NORTHEASTERN MINNESOTA
004F	4 OCT 2018	2	22.6	GRAY	NORTHEASTERN MINNESOTA
005F	26 FEB 2019	2	29.0	BLACK	JOSTLE LAKE, WAWA, ONTARIO
006M	28 FEB 2019	2	41.3	BLACK	JOSTLE LAKE, WAWA, ONTARIO
007M	28 FEB 2019	Adult	39.5	GRAY	MICHIPICOTEN ISLAND, ONTARIO
008M	27 SEP 2018	5	34.5	GRAY	NORTHEASTERN MINNESOTA
009M	1 MAR 2019	+5	39.9	GRAY	MICHIPICOTEN ISLAND, ONTARIO
010M	23 MAR 2019	3	44.5	GRAY	MICHIPICOTEN ISLAND, ONTARIO
011F	23 MAR 2019	2–4	32.7	GRAY	MICHIPICOTEN ISLAND, ONTARIO
012M	23 MAR 2019	2–4	44.5	GRAY	MICHIPICOTEN ISLAND, ONTARIO
013M	23 MAR 2019	2–4	37.2	GRAY	MICHIPICOTEN ISLAND, ONTARIO
014F	23 MAR 2019	6–7	34.9	GRAY	MICHIPICOTEN ISLAND, ONTARIO
015F	23 MAR 2019	2	27.2	GRAY	MICHIPICOTEN ISLAND, ONTARIO
016M	23 MAR 2019	Adult	44.9	BLACK	JOSTLE LAKE, WAWA, ONTARIO
017M	6 SEP 2019	2–4	31.8	GRAY	UPPER PENINSULA, MICHIGAN
018F	8 SEP 2019	2–4	33.5	GRAY	UPPER PENINSULA, MICHIGAN
019M	11 SEP 2019	2–4	29.0	GRAY	UPPER PENINSULA, MICHIGAN
020F	13 SEP 2019	2–4	27.5	GRAY	UPPER PENINSULA, MICHIGAN



FIGURE 6. Release of wolf 003F, captured on the Grand Portage Indian Reservation in northeastern Minnesota, onto Isle Royale National Park, Michigan, USA, 2 October 2018.

were captured on 25 September 2018, and translocated and released near Windigo, Isle Royale on 26 September 2018. Female wolf 003F was captured on 29 September 2018 and translocated to Windigo on 2 October (Figure 6). Female wolf 004F was captured 2 October 2018 and released near Siskiwit Bay, Isle Royale on 4 October. A fifth wolf (female 002F) died soon after capture due to an adverse reaction to anesthetics.

In Ontario, a female wolf (005F) was captured near Jostle Lake, Ontario on 26 February 2019 and released that same day on Isle Royale. A male wolf (006M) was also captured from the Jostle Lake area on 27 February 2019 and released on 28 February on Isle Royale. A male (007M) was captured from Michipicoten Island on 28 February 2019 and translocated to Isle Royale that same day. On 28 February 2019, a male (009M) was captured on Michipicoten Island and released on Isle Royale on 1 March. During 23–24 March 2019, 7 wolves were captured in Ontario and translocated to Isle Royale, 4 males (010M, 012M, 013M and 016M)

and 3 females (011F, 014F, and 015F). Six of these 7 wolves were captured on Michipicoten Island and one wolf (016M) was captured near Jostle Lake.

In Michigan, 4 wolves were captured in 431 trap nights and translocated to Isle Royale. Male wolf 017M was captured and translocated to Hay Bay, Isle Royale, on 6 September 2019. Female wolf 018F was captured and translocated to Malone Bay, Isle Royale, on 8 September. Male wolf 019M was captured on 10 September 2019, held overnight, then translocated and released on 11 September near Edisen Fishery, Isle Royale. Female wolf 020F was captured on 12 September 2019 and held overnight before being released the next day at Edisen Fishery, Isle Royale.

We provided moose carcasses as supplemental food for introduced wolves. Six Isle Royale moose (5 males and 1 female) in fall 2018, and 1 female moose in March 2019 were euthanized by trained personnel of USDA APHIS Wildlife Services. Necropsies were performed and data will provide insights regarding their



FIGURE 7. Moose carcasses provided near release sites as supplemental food were used by wolves and other wildlife species: A) 001F first use of moose carcass about two days following release, B) ravens and bald eagles consumed large amounts of supplemental carcasses, C) red foxes occasionally visited these locations, and D) 008M visit to a carcass site about 30 hrs after release. Isle Royale National Park, Michigan, USA.

health, including occurrence of diseases and parasites. Portions of moose carcasses were frozen and distributed near release locations or left on site when practical. About 45 kg of carcass was distributed at each location, except for the female moose euthanized in March 2019, where the entire carcass re-

mained where euthanized. Location data from GPS collars and remote cameras confirmed wolf use; however, substantial consumption of carcasses was attributed to other wildlife (e.g., ravens, bald eagles, red fox; Figure 7).

▼ CURRENT POPULATION

As of 14 April 2020, there were potentially 5 uncollared and 9 GPS-collared wolves on Isle Royale. Uncollared wolves could include F193, a native Isle Royale wolf; 009M, whose collar prematurely came off in July 2019; 013M whose collar prematurely came off in February 2020 and two uncollared wolves observed

with 014F (Hoy et al. 2020). The two uncollared wolves could be 009M, F193; a pup or pups of 014F; or other unknown wolves. The remaining wolves include females 001F, 011F, 014F, and 015F and males 007M, 012M, 016M, 017M, and 019M.

▼ REPRODUCTION

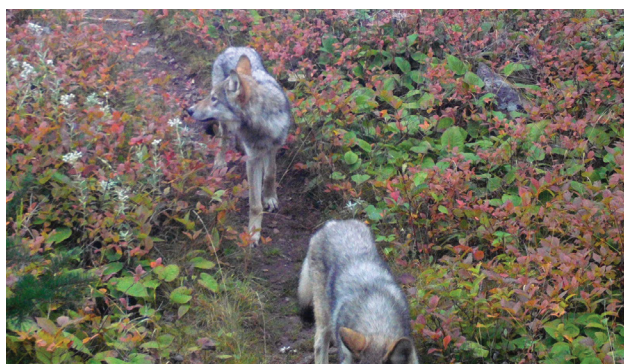


FIGURE 8. Images taken on 29 September 2019 from a remote camera show two putative pups born to wolf 014F in Spring 2019, Isle Royale National Park, Michigan, USA.

We are evaluating reproduction using multiple lines of evidence, including DNA-based evidence from scats collected, GPS collar data, remote cameras (see below), acoustic recording units, and information from aerial observations made by researchers at Michigan Technological University (Hoy et al 2020). GPS location data suggest 014F denned in 2019 and established several rendezvous sites. Remote camera images acquired 29 September 2019 indicate at least two pups born to 014F (Figure 8). Similarly, Hoy et al. (2020) reported observations of a putative pup, based on behavior and size of the individual. We will use genetic analyses of scats collected and if confirmed, 014F would have bred on Michipicoten Island before translocation. Timing of translocations and GPS location data suggest no other reproduction occurred in 2019.

Evidence suggesting reproductive behavior in wolves was reported in winter 2020 (Hoy et al. 2020). Our analyses of GPS location data suggest denning activity in early April for wolf 001F. This wolf's GPS collar attempted collar fixes during 7–13 April 2020 but failed, indicating the collar was either underground or under thick vegetation. Limited data suggested potential for denning activity for wolves 012M and 015F during spring 2020; however, collar failure precluded confirmation. Location data from the remaining potential breeding female (011F) did not suggest denning activity.

▼ MORTALITY

Since fall 2018, 8 wolves have died (Table 2). We recorded 4 cases of intraspecific mortality (M183 [native island adult male], 004F, 010M, and 018F). Intraspecific strife is common as wolves defend and establish territories and social hierarchy. Therefore, mortality from intraspecific interactions during group and pack formation was not unexpected.

Two wolves died shortly after translocation; cause of death for one wolf was cellulitis (bacterial skin infection) and suspected septicemia (blood poisoning from infection) secondary to a trap wound (020F). The second wolf (008M) had pneumonia at time of death and tested positive for anaplasmosis (*A. phagocytophilum*), indicating this wolf was infected during translocation. Wolf 008M died about one month after release and was submitted

to the USGS National Wildlife Health Center for necropsy. There was evidence of interstitial pneumonia and lymphoid depletion, but cause of death could not be determined. Canine distemper virus also was detected in wolf 008M, but whether this was a result of recent vaccination or active disease could not be determined. All other diagnostic tests for this wolf were negative. Anaplasmosis can cause immunosuppression and increased susceptibility to secondary infections, but it is unknown if the anaplasma infection detected in wolf 008M was related to its death.

Due to limited access during park closure, cause of death could not be determined for 005F (6 January 2020) and 006M (31 March 2019).

TABLE 2. ATTRIBUTES OF WOLF MORTALITIES, ISLE ROYALE NATIONAL PARK, MICHIGAN, USA, 2018–2020.

WOLF ID/SEX	DATE OF DEATH	CAUSE OF DEATH
008M	17 OCT 2018	PNEUMONIA
006M	31 MAR 2019	UNKNOWN
020F	14 SEP 2019	CELLULITIS AND SUSPECTED SEPTICEMIA
004F	29 SEP 2019	INTRASPECIFIC AGGRESSION (ATTACKED BY OTHER WOLVES)
M183 (UNCOLLARED)	15 OCT 2019	INTRASPECIFIC AGGRESSION (ATTACKED BY OTHER WOLVES)
005F	6 JAN 2020	UNKNOWN
018F	6 JAN 2020	LIKELY INTRASPECIFIC AGGRESSION (ATTACKED BY OTHER WOLVES)
010M	9 JAN 2020	LIKELY INTRASPECIFIC AGGRESSION (ATTACKED BY OTHER WOLVES)

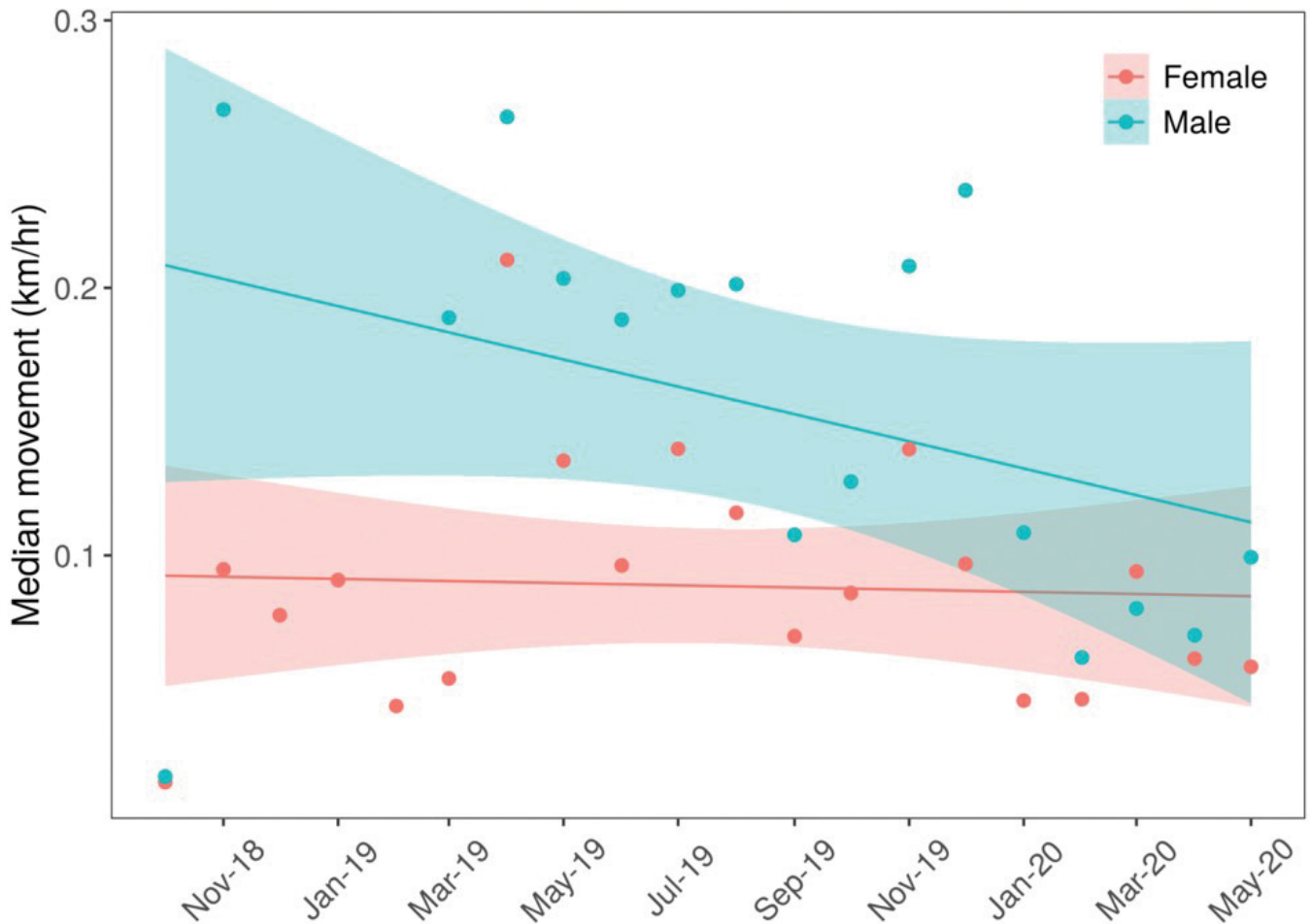


FIGURE 9. Median monthly movements of GPS-collared wolves introduced to Isle Royale National Park, Michigan, USA, November 2018–April 2020.

▼ SPACE USE & SOCIAL ORGANIZATION

For wolves with functioning GPS collars, we calculated movement rate as the average distance moved per hour (km/hr) for each pair of consecutive GPS locations. These distances were similarly used to estimate relative proximity among individuals to infer social organization (e.g., Silk et al. 2017).

Median monthly movement rates of collared wolves varied, though male wolf movements were overall greater than those of female wolves (Figure 9). Male movements declined overall from introduction through April 2020 whereas female movements were more constant. Overlap of movement rates between

males and females was greatest during winter and spring 2020, when wolf associations were greatest.

Wolves tended to traverse greater portions of the archipelago shortly after introduction with areas occupied becoming reduced through time. For example, wolves 012M and 015F have occurred throughout Isle Royale since introduction (Figure 10), with movements limited to the northeastern portion of the island during February–April 2020 (Figure 11).

Associations among introduced wolves were variable and dynamic, with strength and con-

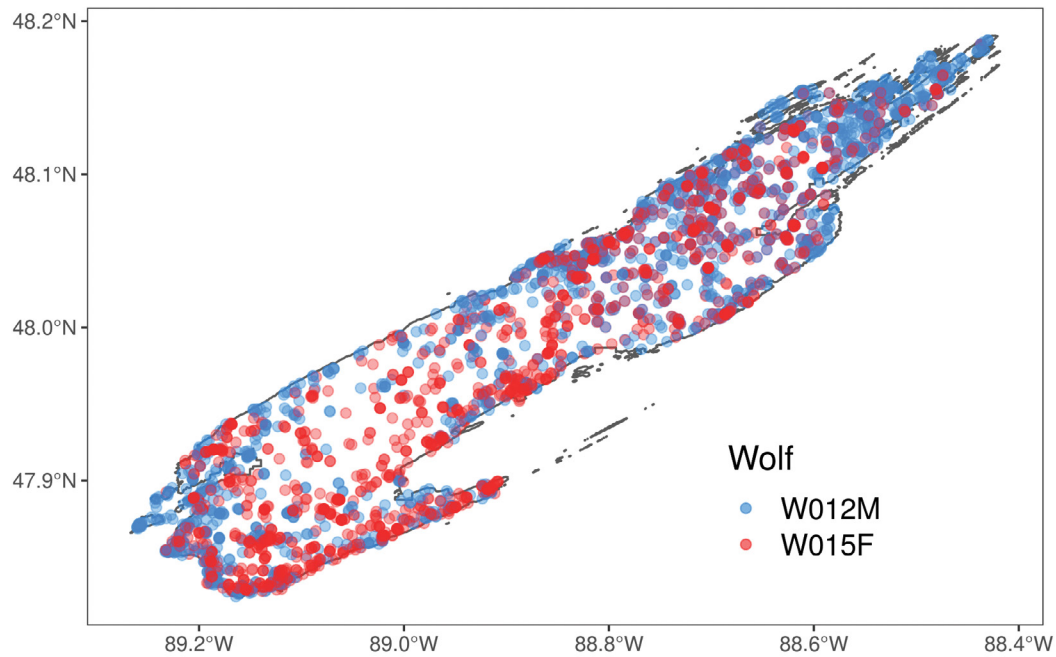


FIGURE 10. Locations of wolves 012M and 015F, Isle Royale National Park, Michigan, USA, March 2019–April 2020. Color ramping from light to dark represents recency of location, with darker shading being most recent.

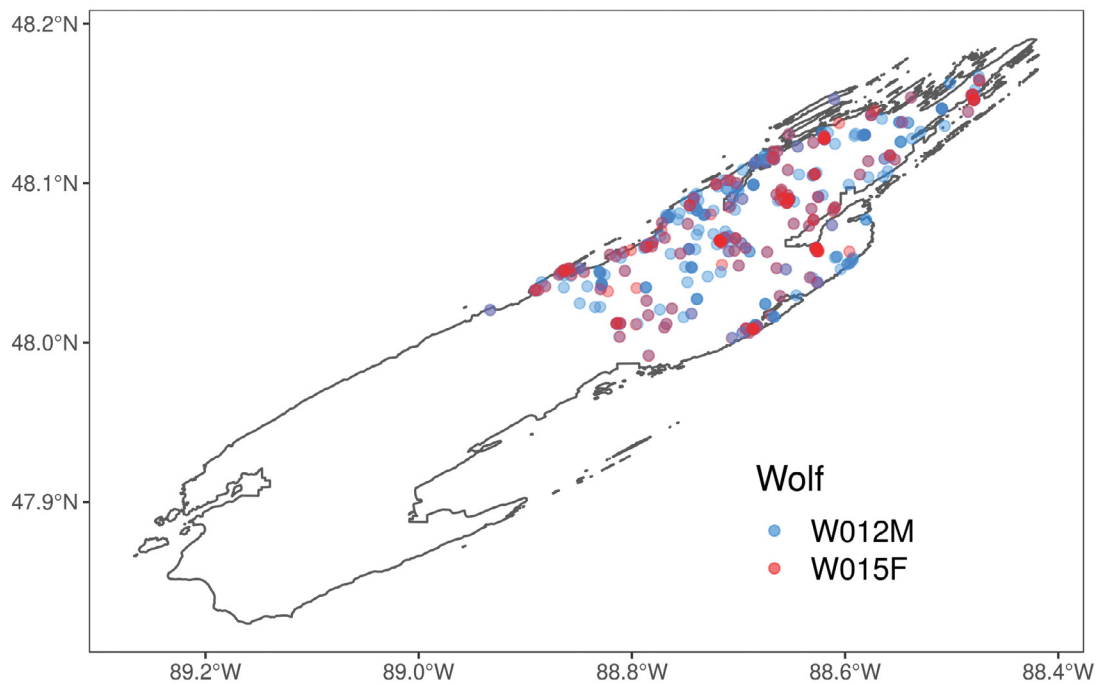


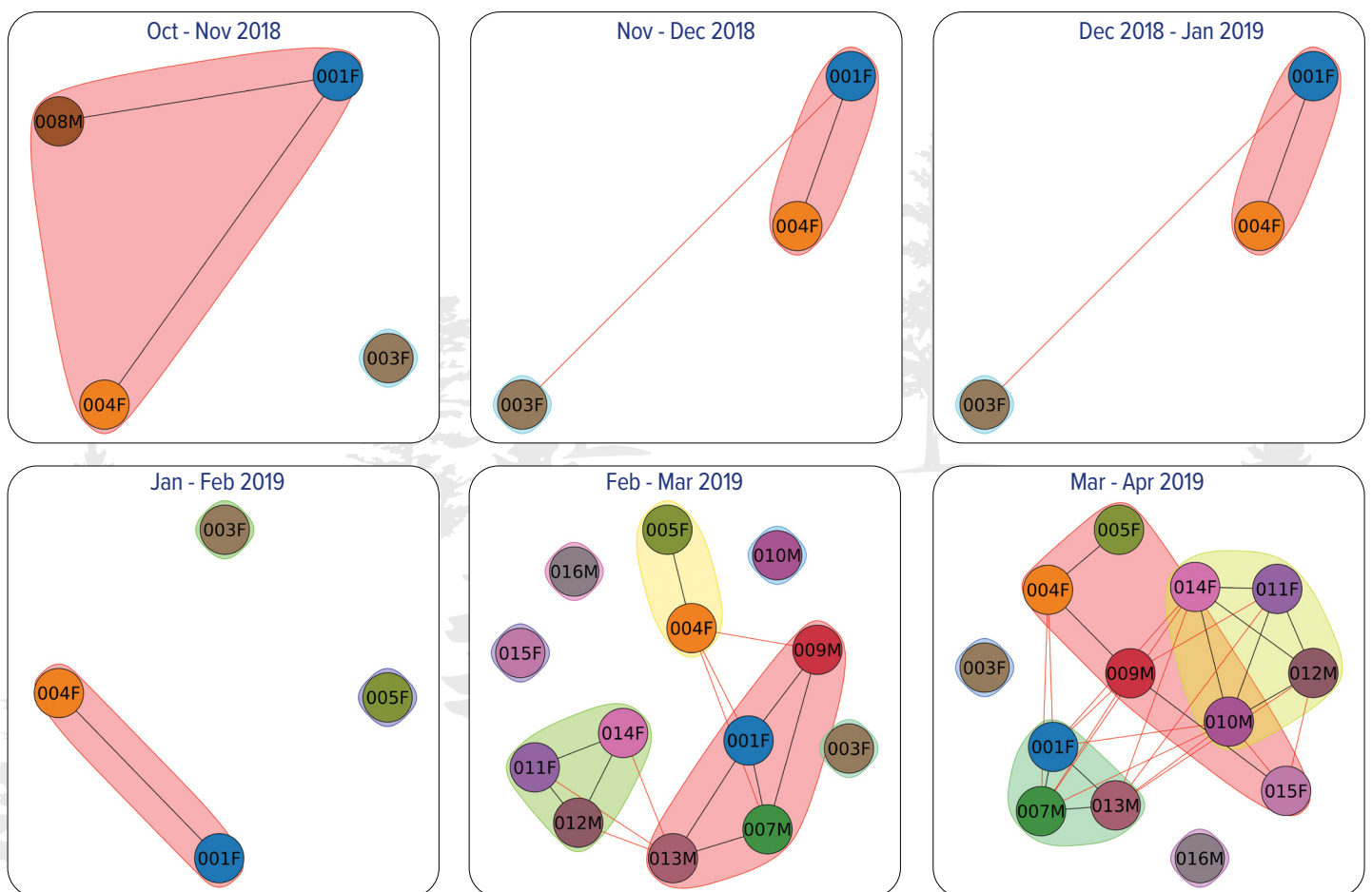
FIGURE 11. Locations of wolves 012M and 015F, Isle Royale National Park, Michigan, USA, February–April 2020. Color ramping from light to dark represents recency of location, with darker shading being most recent.

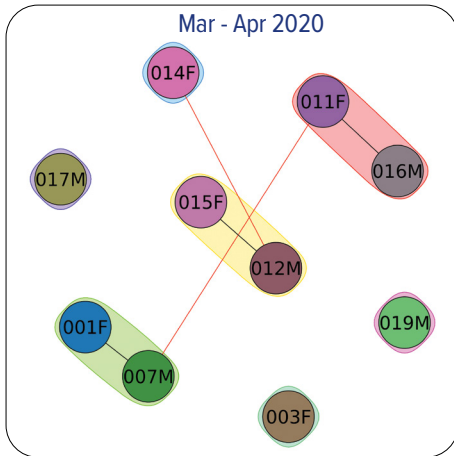
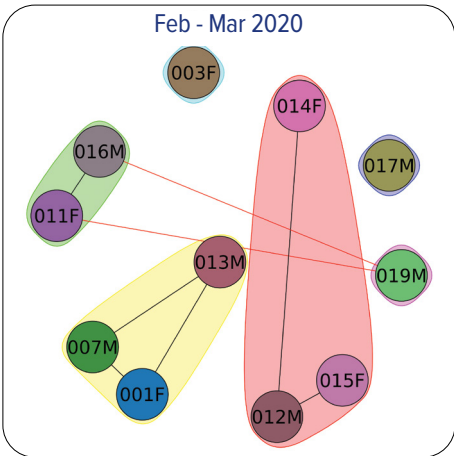
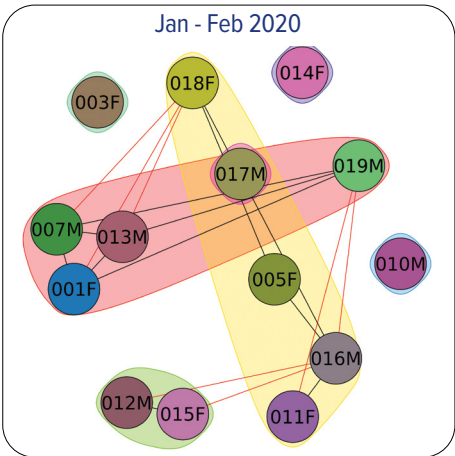
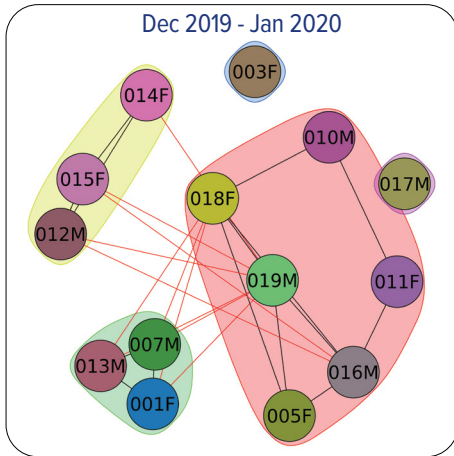
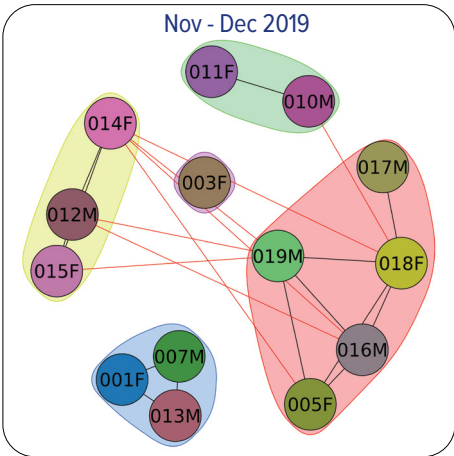
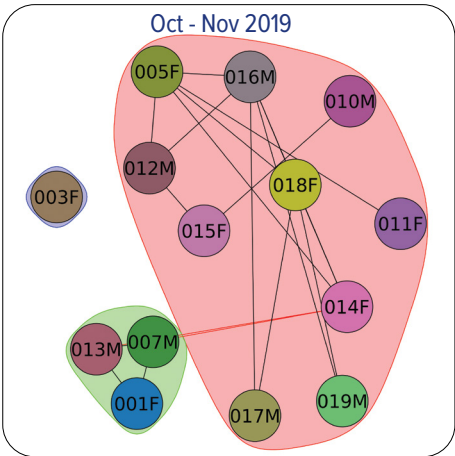
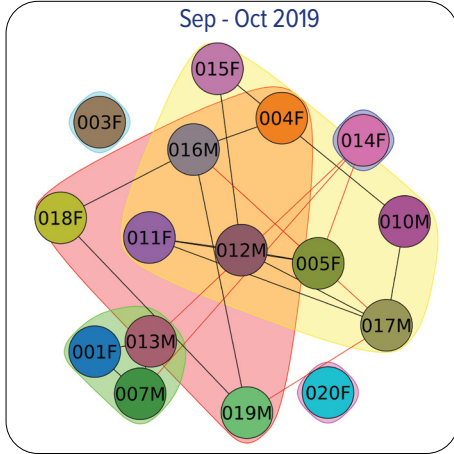
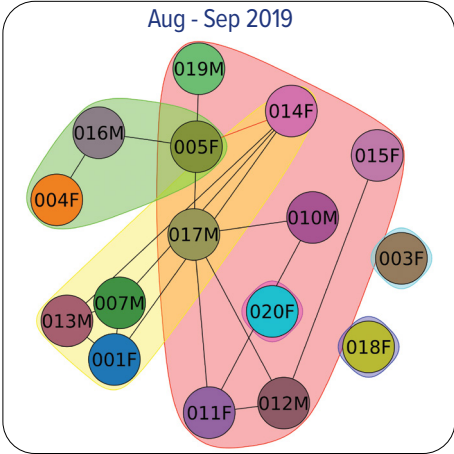
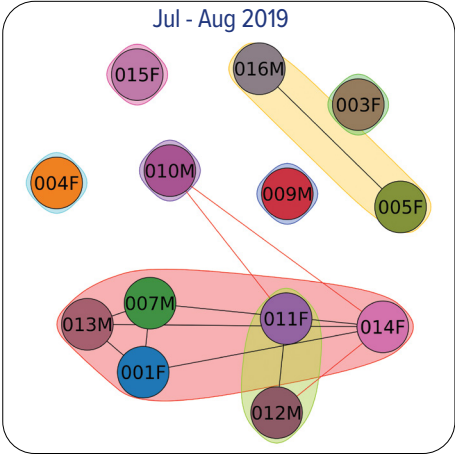
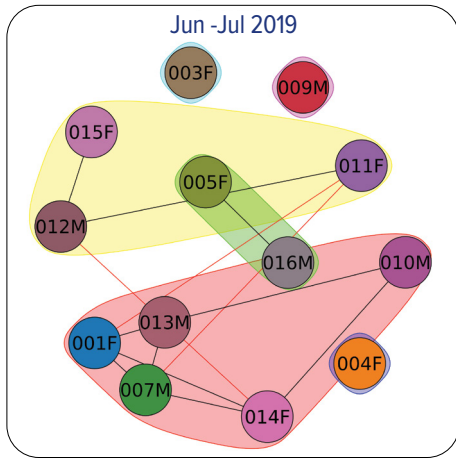
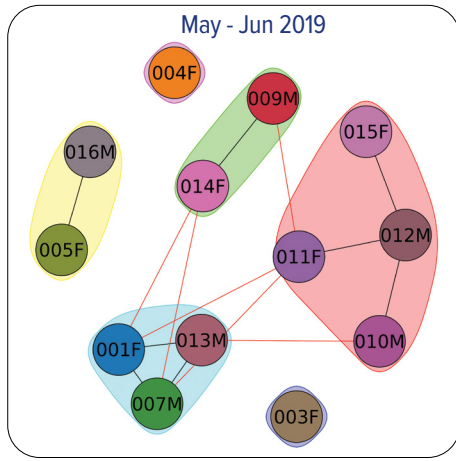
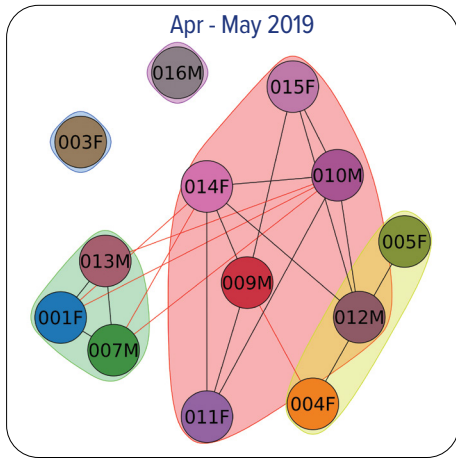
sistency increasing through April 2020 (Figure 12). Individual wolves and their associations are described in greater detail below. Further, an interactive online application allowing users to observe individual and group wolf movements, space use, and social organization has been developed (<https://belantlab.shinyapps.io/wolf-networks>).

001F, 007M, 013M—This group formed mid-to late-March 2019 and consists of a female (001F) translocated from northeastern Min-

nesota, and two males (007M and 013M) translocated from Michipicoten Island. This group has traveled together since formation, but periodically moved independently during summer 2019. This group occupied areas in southwestern Isle Royale from Rainbow Cove northeast to Malone Bay, and north to Minong Ridge and Todd Harbor (Figure 13, excludes 013M whose collar fell off prematurely in February 2020).

FIGURE 12. Bimonthly plots of wolf spatial proximity based on GPS locations, Isle Royale National Park, Michigan, USA, October 2018–April 2020. Lines represent interactions between wolves, with shorter lines representing more time spent in close proximity. Wolves within shaded polygons represent individuals that spent more time near each other than to other wolves.





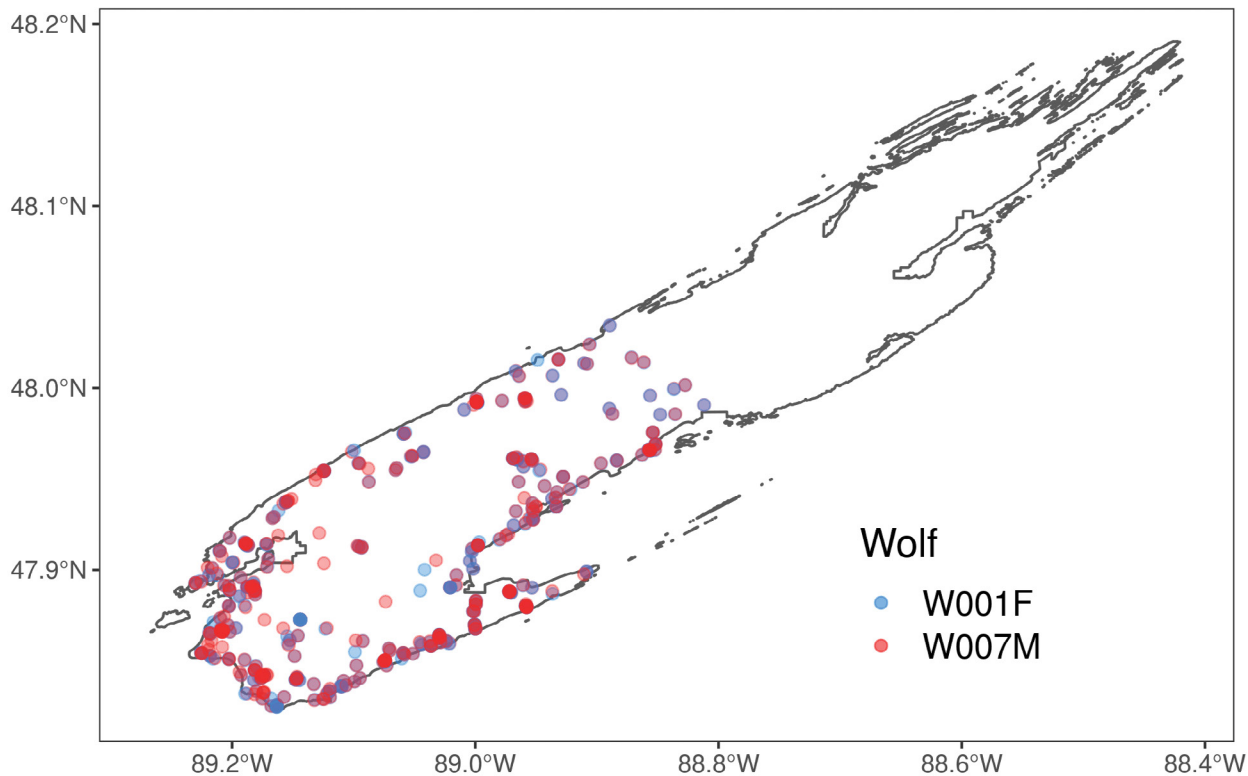


FIGURE 13. Locations of wolves 001F and 007M, Isle Royale National Park, Michigan, USA, February–April 2020. Color ramping from light to dark represents recency of location, with darker shading being most recent.

014F and 2 unknown wolves—This group consists of female 014F translocated from Michipicoten Island and two uncollared wolves she was observed with in winter 2020 (Hoy et al. 2020). Identity and age of the uncollared wolves observed with 014F are unknown. Before translocation, 014F was the breeding female on Michipicoten Island, and it was uncertain if she was pregnant when she was translocated to Isle Royale. Wolf 014F briefly associated with 009M (breeding male from Michipicoten) for two weeks in May 2019, but 009M spent June and July in areas separate from 014F. Potential associations between these wolves could not be determined after July 2019, when 009M’s collar prematurely came off. Based on 014F’s GPS collar data, this group’s movements were in the central portion of Isle Royale with greater use along the south shore from Houghton Point north-

east to Chippewa Harbor and as far northeast as Tobin Harbor.

012M, 015F—Wolves 012M and 015F are a male and female translocated to Isle Royale from Michipicoten Island in late spring 2019. The two first associated in June 2019 at a moose carcass and have been together consistently since late October 2019. Following the death of M183 near Hatchet Lake, these wolves occupied an area from the northeast end of Siskiwit Lake to Lane Cove and Tobin Harbor (Figures 9-10), previously occupied by M183 and F193.

011F, 016M—Wolf 011F is a female translocated to Isle Royale from Michipicoten Island and 016M is a male translocated from Jostle Lake, Ontario. Both wolves were translocated in late March 2019 and were together January through mid-March 2020 but spent less time

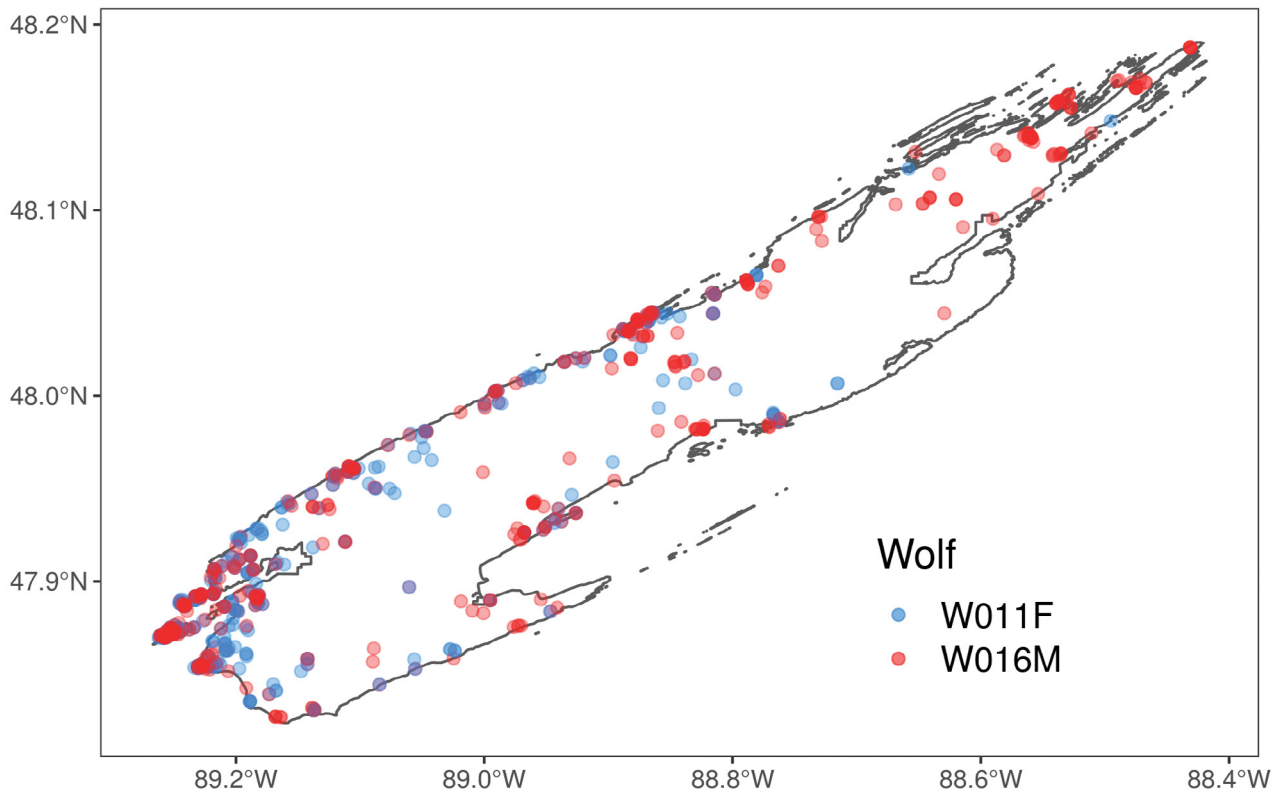


FIGURE 14. Locations of wolves 011F and 016M, Isle Royale National Park, Michigan, USA, February–April 2020. Color ramping from light to dark represents recency of location, with darker shading being most recent.

together in late March and even less in early April 2020. These wolves frequented islands in the Washington Harbor area (e.g., Washington, Thompson, and Johns islands) and the north shore of Isle Royale to the south end of Todd Harbor. Recent movements were across much of Isle Royale but these wolves most often occurred in the Washington Harbor area (Figure 14).

017M, single—Translocated to Isle Royale from the Upper Peninsula of Michigan in fall 2019, 017M initially traversed the entire island. During winter 2020 he frequented the northcentral and northeast portions of the island traveling along the north shore on the periphery of areas occupied by the other wolf groups identified above. Wolf 017M was located near 018F in late November–December 2019.

M183, F193—Without telemetry collars, information about this group was limited to opportunistic sightings, remote camera images, and GPS data of newly released wolves’ use of this group’s territory. M183 and F193 were the last two native island wolves. These wolves shared the same mother and were related to each other as father and half-siblings. They were not documented to have produced pups that survived to the end of the year and were therefore not considered a breeding pair. They were consistently observed traveling together during January–early March 2018–2019 (Peterson et al. 2018, Hoy et al. 2019) in the central part of the island. In fall 2019, NPS staff located the remains of M183 on a hiking trail near Hatchet Lake. Although there were no apparent external injuries, a necropsy revealed internal injuries and trauma consistent with intraspecific aggression. The fate of F193 is unknown.

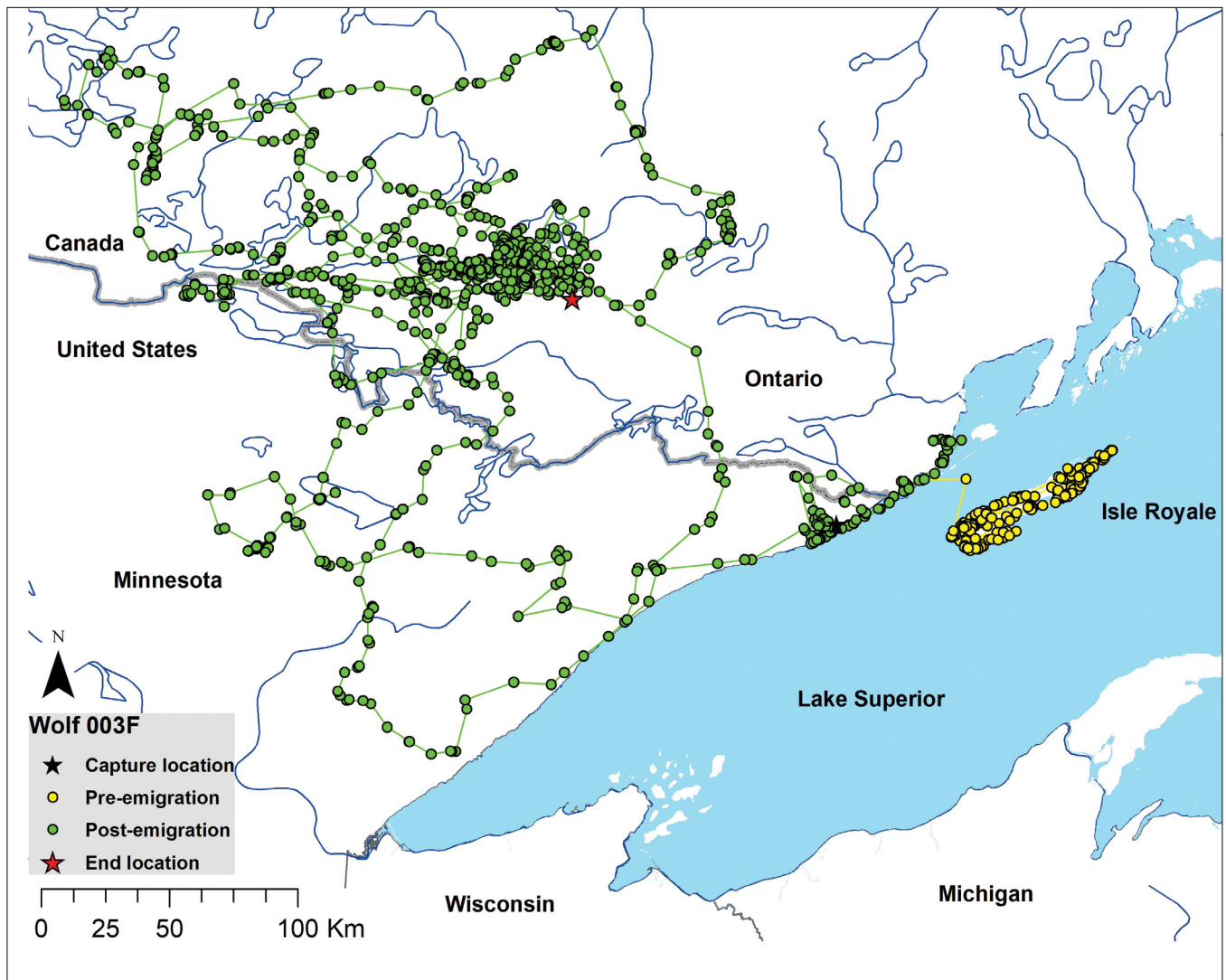


FIGURE 15. GPS locations from 2 October 2018 to 31 March 2020 of an adult female wolf introduced to Isle Royale National Park, Michigan, USA that emigrated to the mainland on 31 January 2019.

019M, single—Translocated to Isle Royale from the Upper Peninsula of Michigan in fall 2019, early movements of this wolf encompassed the entire island. During winter 2019–2020 this wolf spent most of his time in the central and north-east areas of the island.

009M—This male was translocated to Isle Royale in early March 2019 from Michipicoten Island where he was considered a breeding male. His early space use encompassed all of Isle Royale, and his summer 2019 movements centered southwest of Siskiwit Lake around Siskiwit Bay. He briefly associated with 014F

(a breeding female from Michipicoten) for two weeks in May but was more distant in June. His collar prematurely came off in early July 2019 near Malone Bay. He is currently uncollared and his fate is unknown.

003F—This female was translocated to Isle Royale from northeastern Minnesota in fall 2018. Early movements encompassed the entire island. On 31 January 2019 she emigrated over an ice bridge to mainland Ontario, traveling back to her capture location in northeastern Minnesota by February (Figure 15; Orning et al. 2020). After spending a month there, this

wolf travelled extensively in Minnesota and Ontario. She remained in Ontario from July to September 2019. Subsequently, she returned to an area west of her capture location on the Grand Portage Reservation for a month (Sep–Oct 2019), returned to Ontario, and made two excursions into Voyageurs National Park during February–March 2020 before returning to an area near Atikokan, Ontario.

004F—This female was translocated from northeastern Minnesota in fall 2018. Early movements included the entire island, but she primarily used the southwest part of Isle Royale from Feldtmann Lake to Siskiwit Bay. Her summer 2019 movements ranged over the entire island, but she primarily used the central (Little Todd to Siskiwit Bay) and far west portions (McGinty Cove) of the island. Over summer 2019 she also used Amygdaloid Island and made numerous crossings of North Gap to Thompson Island. This wolf associated with wolves *011F* and *016M*. This female died 29 September 2019 from wounds sustained by 1 or more wolves.

005F—This female was translocated from Jostle Lake, Ontario in winter 2019. Her winter 2019 movements encompassed the entire island. Her summer 2019 movements were primarily in the northcentral part of the island from Little Todd Harbor to McCargoe Cove, but she also used areas southwest of Siskiwit Lake and areas around Huginnin Cove. She used Amygdaloid Island during summer 2019 and associated with *016M* and *012M*. This female died on 6 January 2020 in the central portion of the island and her remains could not be recovered before extensive scavenging occurred; cause of death could not be definitively determined. She travelled with *016M* for 3 weeks before her death.

006M—This male was translocated from Jostle Lake, Ontario in late February 2019. His movements covered an area southwest of a line from Little Todd Harbor to Houghton Point. He briefly associated with *004F* in

mid- to late-March 2019. This male died of unknown causes on 31 March 2019.

008M—This male was translocated from northeastern Minnesota in fall 2018. Early movements were on the southwest end of the island from Washington Harbor to Lake Desor and as far northeast as the south end of Siskiwit Lake. This male died 17 October 2018 of pneumonia.

010M—This male was translocated from Michipicoten Island in late March 2019. His winter and summer 2019 movements included the entire island and emphasized the southwest portion from Rainbow Cove north to McGinty Cove and northeast to Lake Desor and Hay Bay. This male died 9 January 2020 after an interaction at a moose carcass. His remains were scavenged before retrieval, but temporal and spatial overlap with other wolves identified from GPS data suggest this mortality was likely due to intraspecific aggression. There was no evidence he consistently associated with other wolves.

018F—Translocated to Isle Royale from the Upper Peninsula of Michigan in fall 2019, this female initially traversed the entire island, but spent considerable time in the central and northeast portions of the island. This female died 6 January 2020 after an interaction at a moose carcass. Her remains were scavenged before retrieval, but temporal and spatial overlap with other wolves identified from GPS location data provides evidence this mortality was due to intraspecific aggression. This wolf had associated with *016M* and *017M*.

020F—Translocated to Isle Royale from the Upper Peninsula of Michigan in fall 2019, this female died 14 September 2019, one day after translocation, as a result of cellulitis (bacterial skin infection) and suspected septicemia (blood poisoning from infection) after release on Isle Royale.



FIGURE 16. Wolf GPS collar locations were used to investigate predation events from May to October 2019 on Isle Royale National Park, Michigan, USA. A) moose calf, B) yearling moose, C) beaver, and D) snowshoe hare.

▼ PREDATION

We investigated consecutive GPS locations that occurred in the same area where wolves spent at least 4 hours. These groups of locations, or clusters, occur when wolves are feeding or resting, or during other activities. We conducted systematic searches at selected clusters using a web pattern within 50 m of the cluster’s center point (Svoboda et al. 2013). We used evidence at the site

and characteristics of prey remains to determine whether the cluster represented a predation, scavenging event, or resting site.

We assessed summer wolf predation during May–October 2019 by searching for prey remains at 381 location clusters generated from GPS collars for 12 wolves. Crews hiked over 3,828 kilometers (2,379 miles)

to locate the remains of 56 carcasses (15% of searched sites). Based on field evidence, we determined probable predation or scavenge events for 98.2% of located prey remains. Of the 56 carcasses, 89.3% and 10.7% were identified as predation and scavenge events, respectively. Moose were located at 24 sites (47.1%) determined as probable predation. Non-moose prey remains were present at 26 sites (52.9%) determined as probable predation events.

Of the 24 moose predations, 18 were calves (<1 year, 75%), 4 were yearlings (1–2 years, 16.7%), and 2 were adults (≥ 2 years, 3%; Figure 16). Of the 26 non-moose predations,

19 were beaver (73.2%), 3 were snowshoe hare (11.5%), and 4 were other prey (15.3%). Other prey included 2 red fox kits (7.7%), 1 bird (3.8%), and 1 muskrat (3.8%). All 6 carcasses determined as scavenge events were moose.

We documented 117 instances of two or more wolves concurrently using the same cluster sites. Thirty-one cases (26.5%) of space use overlap were associated with prey remains and feeding behavior (predation or scavenge events), 62.4% were associated with rest sites, and wolf use for the remaining 11.1% of sites was not determined.

▼ DISEASE



FIGURE 17. Wildlife veterinarian completes health examination of wolf 011F captured on Michipicoten Island, Ontario, Canada, March 2019.

We used the World Organisation for Animal Health (OIE) and International Union for the Conservation of Nature (IUCN) guidelines for wildlife disease risk analysis (DRA; OIE and IUCN 2014) to assess and mitigate potential disease risks associated with capture and translocation of wolves. Specifically, we used the DRA framework to determine mitigation measures including: 1) criteria for selection of wolves for translocation, 2) disease surveillance at time of capture, 3) targeted prophylactic treatments, and 4) biosecurity measures to prevent disease transmission.

Criteria considered for selecting wolves for translocation included age and physical condition, potential to reproduce, presence of ectoparasites, and apparent disease (Figure 17). We collected a blood sample from each wolf to test for heartworm using a rapid snap test. We used serum samples to test for exposure to other pathogens including canine parvovirus (CPV), canine distemper (CDV), canine adenovirus (CAV-2), *Neospora caninum*, *Leptospira* serovars, West Nile Virus (WNV), *Borellia burgdorferi* (Lyme disease), and *Anaplasma phagocytophilum*. We tested whole blood from each wolf for active infections of

TABLE 3. PREVALENCE OF PATHOGEN EXPOSURE IN TRANSLOCATED WOLVES (N=19), ISLE ROYALE NATIONAL PARK, MICHIGAN, USA, 2018–2020.

PATHOGEN	PREVALENCE (%)
LEPTOSPIRA SEROVARS ¹	0
BORRELIA BURGENDORFERI	32
ANAPLASMA PHAGOCYTOPHILUM	37
CANINE ADENOVIRUS	68
CANINE DISTEMPER	58
CANINE PARVOVIRUS TYPE 2C	53
NEOSPORA CANINUM	42
WEST NILE VIRUS	68

¹Includes *Leptospira pomona*, *hardjo*, *icterohaemorrhagiae*, *grippityphosa*, and *canicola*

various tick-borne pathogens. Feces were collected when available to determine presence of internal parasites (e.g., *Taenia* spp., *Echinococcus granulosus*). We vaccinated each wolf for CDV, CPV, CAV, rabies, leptospirosis, and prophylactically treated each for internal and external parasites. Sera were analyzed by the Cornell University College of Veterinary Medicine Animal Health Diagnostic Center; whole blood was analyzed at the University of Minnesota, Department of Entomology; and fecal samples were analyzed at Colorado State University.

We observed no ticks or evidence of disease in wolves during capture and translocation. Heartworm infection was not detected in any of the translocated wolves. Because translocated wolves were released as soon as possible after capture, results of serologic and fecal tests were not available until after release. However, we will use this information to refine the DRA as warranted and to provide a baseline for comparative and retrospective analyses of pathogen prevalence in this population. Preliminary results of serologic testing identified pathogen exposure in translocated wolves (Table 3).

▼ GENETICS

We initiated a genomic monitoring program for the wolves of Isle Royale. Objectives include curation of wolf genetic samples, genetic assessments of the new founding wolves, and development of a noninvasive fecal assay for population monitoring. Samples were curated from all translocated wolves and wolf fecal samples collected during summer 2019 and winter 2020. We have also curated Isle Royale moose samples ($n = 26$) collected during captures for a concurrent study. We are developing a database with searchable accession numbers for each sample and associated metadata, and an interface with associat-

ed kinship matrix. We measured standard genetic diversity estimates and population structure of the Isle Royale founders relative to three reference populations (eastern wolves (*Canis sp. cf. lycaon*) [$n = 24$], northeastern Ontario, gray wolves [$n = 30$], and northwestern Ontario gray wolves [$n = 22$]) using 18 microsatellite loci. We included eastern wolf samples given the history of Great Lakes wolves, where it has been suggested that eastern/gray wolf hybrids from Manitoba, Ontario, and Minnesota recolonized the region where Isle Royale founders were trapped. Also, eastern wolves occur in Algonquin Provincial Park, Ontario, making it plausi-

ble that individuals with eastern wolf ancestry were translocated to Isle Royale.

Preliminary results suggest Isle Royale founders are representative of their source populations with similar baseline genetic variation and with little or no eastern wolf ancestry. Observed heterozygosity for translocated wolves ($H_o = 0.78 \pm 0.16$ [standard deviation]) was similar to eastern wolves ($H_o = 0.72 \pm 0.10$), northeastern Ontario gray wolves ($H_o = 0.77 \pm 0.11$), and northwestern Ontario gray wolves ($H_o = 0.73 \pm 0.08$). The average allelic richness across loci for translocated wolves (5.88 ± 1.96) was also similar to that of eastern wolves (6.66 ± 1.67), northeastern Ontario gray wolves (6.74 ± 2.04), and northwestern Ontario gray wolves (6.01 ± 1.94). The population structure of Isle Royale founders indicated all individuals had a high probability of assignment to clusters associated with

the other two reference gray wolf populations with little admixture from eastern wolves. In addition, wolves translocated from Michipicoten Island, Ontario, contained high average pairwise relatedness supporting that these individuals are likely a family group; pedigree analyses further support this finding. Overall, translocated wolves are genetically diverse and represent the gray wolves of the Great Lakes region, but the presence of a family group should be monitored relative to potential inbreeding. We have generated genome-wide data for each translocated wolf to assess heterozygosity, relatedness, and functional genetic variation. We will use these data to develop a reduced-representation assay for individual identification and to monitor inbreeding through analysis of wolf feces. This assay will be used to develop a wolf pedigree and assess founder contributions through time.

▼ MOOSE ABUNDANCE & DISTRIBUTION



FIGURE 18. A minimum of 7 moose, within frame, observed during a telemetry flight, Isle Royale National Park, Michigan, USA, February 2019.

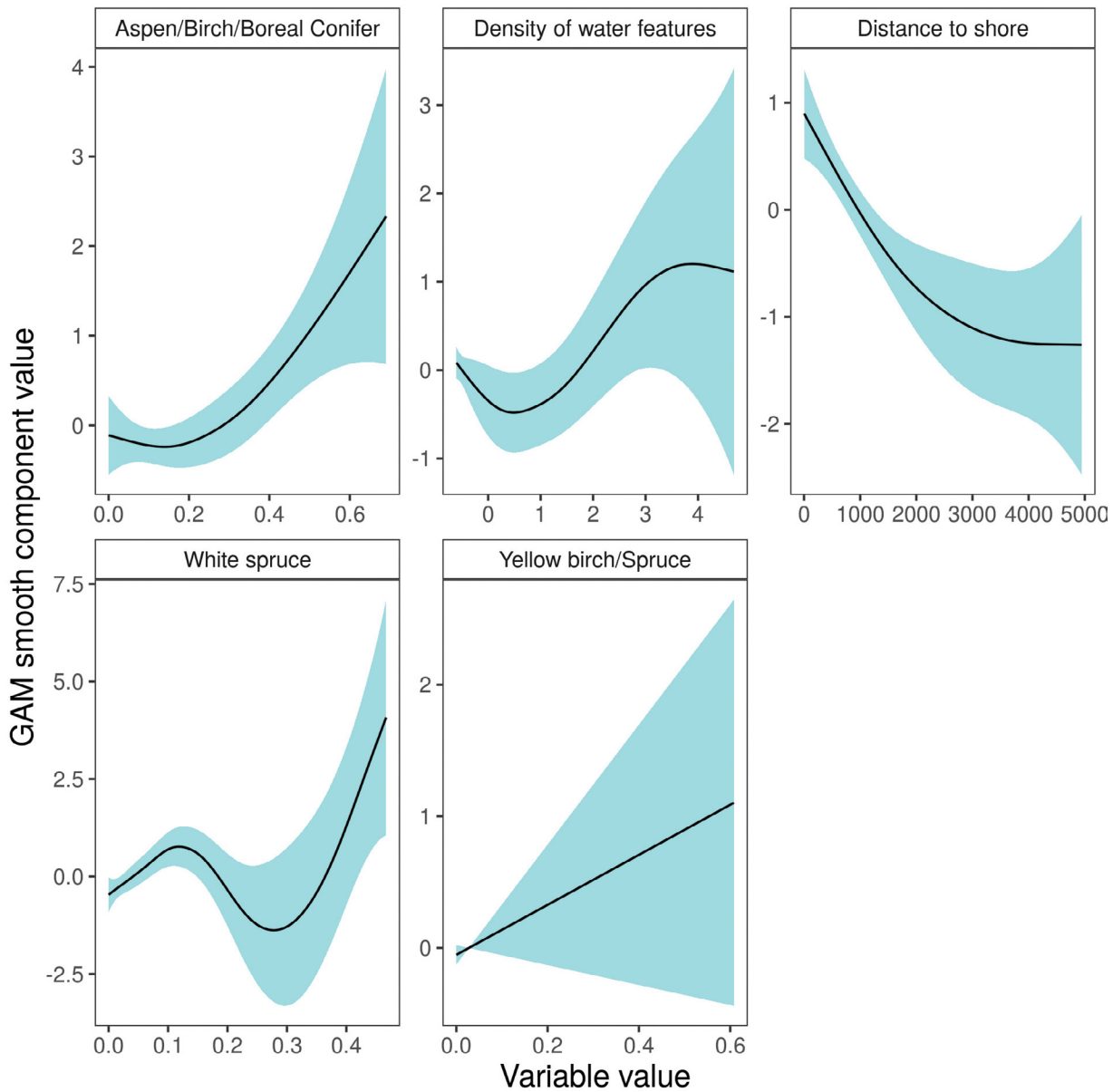


FIGURE 19. Parameters influencing density of moose available for detection, Isle Royale National Park, Michigan, USA, March 2020. Parameter effects were estimated using density surface modeling. Higher generalized additive model (GAM) smooth component values correspond with higher estimated density, and vice-versa.

We estimated moose abundance on Isle Royale during 14–15 March 2020 using a double-count distance sampling framework (e.g., Oyster et al. 2018) from a helicopter. We flew parallel transects oriented northwest-southeast at 500-m intervals, 75 m above ground level at a speed of 75 km/hr. The pilot and an observer seated behind searched for moose on the right side of each transect and two additional observers in a front and rear seat

on the left side of the helicopter searched for moose on the left side of each transect. We excluded areas within 25 m of transect lines beneath the helicopter that were not visible to rear seat observers and areas more than 250 m from transect lines to avoid overlapping observation areas with adjacent transects. Observers recorded location, group size, and composition (i.e., sex, age) of all moose observed (Figure 18).

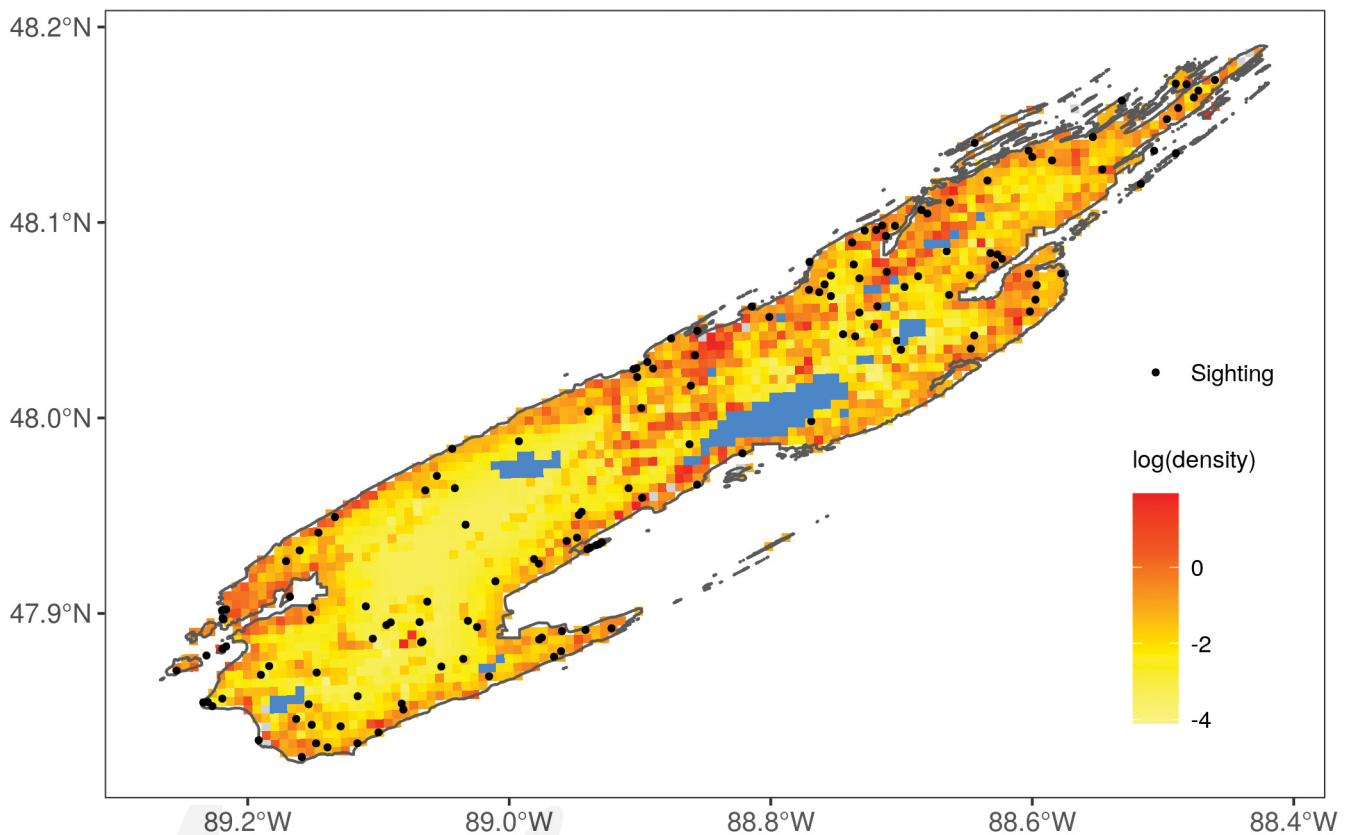


FIGURE 20. Moose sightings (black circles) and estimated spatial variation in relative density of moose available for detection, Isle Royale National Park, Michigan, USA, March 2020.

We surveyed 507.6 of 535 km² of Isle Royale and observed 236 moose in 136 groups (mean group size = 1.93). Overall, we estimated 583.8 moose (95% confidence interval [CI] = 441.3–772.3) available for detection (e.g., not completely obscured by dense canopy; Oyster et al. 2018) during the survey for a mean density of 1.09 (95% CI = 0.82–1.44) moose/km².

We applied density surface modeling (using our fitted distance sampling model) to exam-

ine how several habitat characteristics influenced distribution of moose on the island. Density of moose was negatively associated with distance from Lake Superior shoreline (Figure 19). Estimated density of moose varied markedly across the island with greater densities overall in the northeastern half of the island and near the Lake Superior shore (Figure 20). We will continue to refine survey design and analyses to ensure accurate estimates of moose abundance and density.

▼ REMOTE CAMERAS

During summer 2019 we installed 156 remote cameras about 1 km apart on and off trail to document relationships between wolves and prey species and determine how wolves and

other mammals respond to visitor abundance and distribution (Figure 21). We positioned cameras on trees 1.5 m above ground and checked cameras periodically to retrieve

images and provide maintenance. We also will place cameras opportunistically near wolf den and rendezvous sites when practical to iden-

tify pups and near moose carcasses to determine their use by wolves and other wildlife.

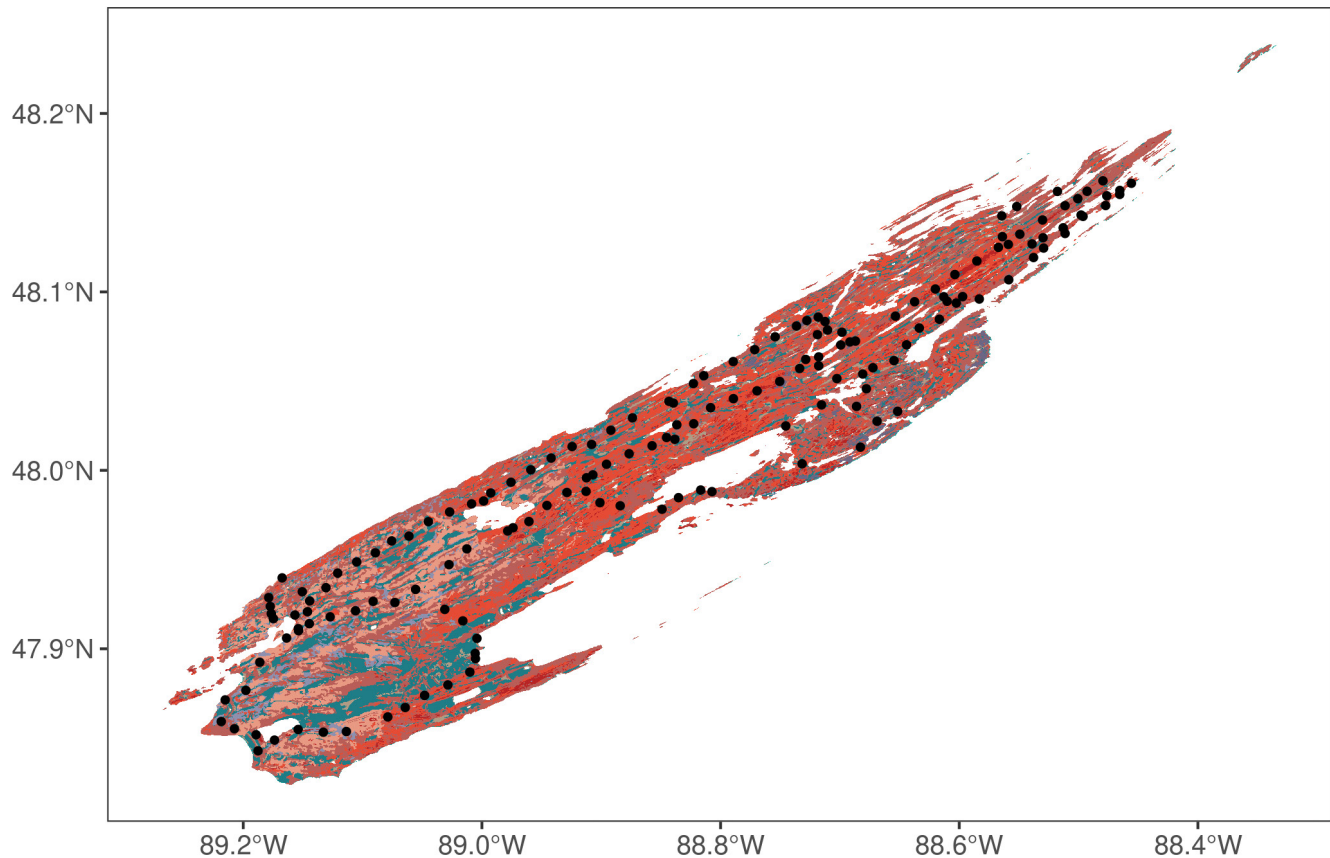


FIGURE 21. Network of 156 cameras (black circles) installed on and off the trail network to assess relationships between wolves and other wildlife and how they respond to human visitation, Isle Royale National Park, Michigan, USA, 2019. (See inside back cover for images from these cameras)

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THIS PROJECT WAS MADE POSSIBLE BY THE FOLLOWING ORGANIZATIONS AND INDIVIDUALS. WE APOLOGIZE FOR ANYONE INADVERTENTLY OMITTED.

Arctic Wings: Don Glaser

Bighorn Helicopters:
Clayton Thibeault, Clay Wilson

Canadian Border Patrol: Tracy Gagnon

Colorado State University: Lora Ballweber

Cook County Sheriff's Office: Will Sandstrom

Government of Newfoundland and Labrador, Department of Fisheries and Land Resources:
John Pisapio

Grand Portage Band of Lake Superior Chippewa: Yvette Chenaux-Ibrahim, EJ Isaac, Tony Swader, Roger Deschampe Jr., Heather Fox, Krishna Woerheide, Jim Dahl

HeliWild: Harry Hensberg, Roy Hensberg, Justin Thompson, Ryan VanDeVentner

International Wolf Center: Nancy Gibson, Rob Schultz

Michipicoten First Nation: Aaron Bumstead, Leo LaPiano, Chayse Penno

Michigan Department of Natural Resources: Brad Johnson, John Pepin, Dan O'Brien, Kelly Straka

Minnesota Department of Natural Resources: Deborah Beyer, Michelle Carstensen, Lou Cornicelli, Erik Hildebrand, Dan Stark, Pete Takash

Michigan Technological University: Samuel Harvey, Sarah Hoy, Ky Koitsch, Lisa Koitsch, Rolf Peterson

National Parks of Lake Superior Foundation: Daniel Cojanu, Amie Heeter, Louis Lamar,

Sona Mehring, Dave Miller, Drew Rush, Kim Schneider

NATIONAL PARK SERVICE

Biological Resources Division-Wildlife Health: Danielle Buttke, Elaine Leslie, Jenny Powers, Tracy Thompson, Liz Wheeler, Margaret Wild

Grand Portage National Monument: Sherri Anderson, Lori Anishnabie, William Clayton, William Dahl, Beth Drost, Carrie Dlutkowski, Matt Estrada, Maddie Frey, Melvin Gagnon, Kaysie Gallup, Mary Gremer, Tyler Gordon, Craig Hansen, Ann Hendricks, Kalina Hildebrandt, Carolyn Howard, Danielle Kiesow, Karl Koster, Pam Neil, Rosie Novitsky, Amber Pfeil, Pat Pierre, Margaret Plummer-Steen, Mike Plummer-Steen, Bryce Premo, Evan Priebe, Brandon Seitz, Steve Veit, Robert Walker, Sharon Walker, Jared Wicks, Sadie Young

Everglades National Park: Clayton Camblin

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Isle Royale National Park: Chris Amidon, Michael Ausema, Rob Bell, Gregory Bickings, Heather Boyd, John Boyle, Sean Carey, Marley Chynoweth, Coral Conway, Molly Cooper, Helen DeMarsh, Nathan Fettig, Jennifer Gendelman, Phyllis Green, Jeff Henquinet, Fred Hoeft, Anna Johnson, Kathryn Keller, Jason Killoran, Kaitlin Knick, Lea Korsmeyer, Bruce Linn, Steve Martin, Valerie Martin, Ross Mitchell, Marty Olgren, Corey Process, Justin Peltz, Aaron Personnaire,

Randy Rastello, Anthony Richno, Randy Savage, Marcus Tanskanen, Matt Uphaus, Liz Valencia, Emily Wells

Lake Mead National Recreation Area: Scott Taylor

Midwest Regional Office: Robert Bryson, Carol Daniels, Connie Dworak, Nancy Finley, Dan Morford, Pat Pearson, Alexandra Picavet, Cameron Sholly, Lee Smith, Terri Tharp, Patricia Trapp, Quoya Waters

Sleeping Bear Dunes National Lakeshore: Joe Lachowski,

Voyageurs National Park: Steve Windels

Washington Office: Guy Adema

Yellowstone National Park: Jacob Frank, Jim Peaco, Doug Smith,

Yukon Charley Rivers National Preserve: Nicholas Thompson

Ontario Ministry of Environment, Conservation and Parks, Ontario Parks: Bob Elliot

ONTARIO MINISTRY OF NATURAL RESOURCES AND FORESTRY

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Trent University: Linda Rutledge

University of Minnesota: Uli Menderloh, Arno Wuenschmann

University of Nebraska-Lincoln: Dave Keiter

US Customs and Border Patrol: Craig Kalar

USDA Wildlife Services: Tony Aderman, Tony Duffiney, Tanya Espinosa, Kevin Fuller, Many Hight, David Hughley, Earl Kromm, Gary Nohrenberg, Duane Sahr

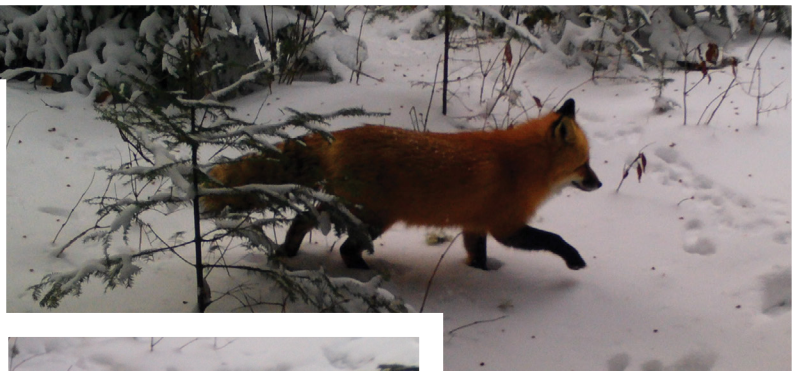
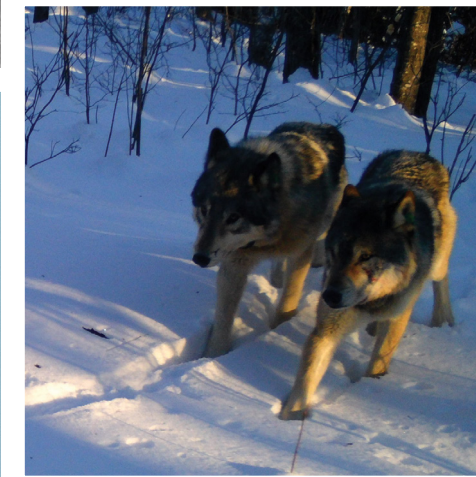
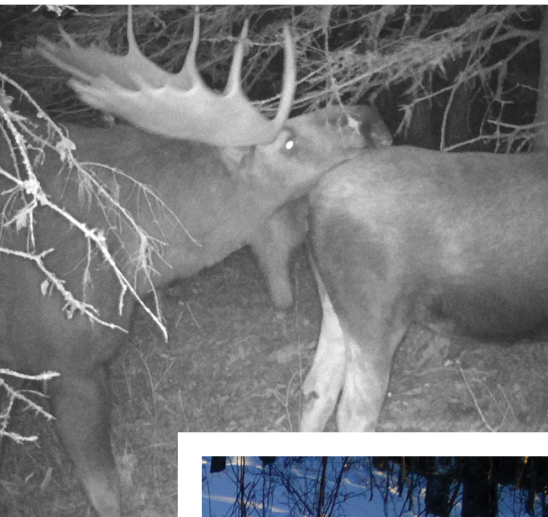
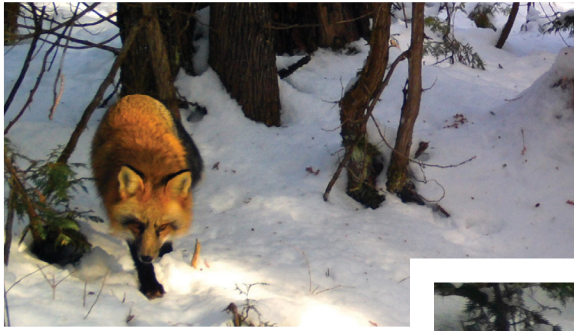
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US Geological Survey: Shannon Barber-Meyer,

Up-North Aerials: Don Murray

WiskAir: Ann Desormeaux, Kale Wiskemann, Mark Wiskemann

Also: Nicole Chandler, Graham Crawshaw, Jim Hummel, Mark Johnson, Terry Kreeger, Andy Miller, Sarah Pikora, Bryce Olson, Myles Walimaa, Ryan Wetelainen



“A thing is right when it tends to preserve the integrity, stability and beauty of the biotic community. It is wrong when it tends otherwise.”

—Aldo Leopold





Suggested Citation: Romanski, M.C., E.K. Orning, K.F. Kellner, D.E. Beyer Jr., K.E. Brzeski, J. Hart, D.H. Lonsway Jr., A.A.D. McLaren, S.A. Moore, B.R. Patterson, L.R. Potvin, M.L. Verant, T.M. Wolf and J.L. Belant. 2020. Wolves and the Isle Royale Environment: Restoring an Island Ecosystem, 2018-2020. National Park Service, Isle Royale National Park, MI, USA. 36pp.