Audubon
ALASKA

ECOLOGICAL IMPACTS OF ROAD- AND AIRCRAFT-BASED ACCESS TO OIL INFRASTRUCTURE

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July 2017

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Executive Summary

This report synthesizes a wide range of literature to make a series of recommendations regarding oil and gas development on Alaska's North Slope. In particular, these recommendations focus on the ecological impacts of the two modes of site access: road-based and aircraft-based (roadless).

Oil and gas extraction relies on a transportation network to move people, equipment, and materials. Historically, oil fields have been developed using a combination of gravel roads, winter-only ice roads, and aircraft. More recent drill sites have demonstrated that it is logistically possible to produce oil from a site with no permanent road connection to other infrastructure. Projects currently in the permitting phase have also considered aircraft-only access as an alternative approach.

Regardless of the mode of access, roads and aircraft have direct and indirect impacts on wildlife. Direct impacts can be broadly classified as disturbance (behavioral change) or displacement (avoidance of a previously used area), and indirect impacts include habitat alteration or changes in food abundance. This study focuses on a few focal taxa: caribou, geese, loons, eiders, shorebirds, and freshwater fish. Each are examined for how road-based and roadless development may impact individuals and populations.

There is agreement among published research that roads and other linear infrastructure have individual-level impacts on wildlife such as caribou, with the magnitude of impact dependent on season, individual demographics, and a variety of other factors. However, there is little agreement on whether and how these individual-level impacts scale up to the population level. Historically, these impacts have been interpreted as not significant due to generally stable or increasing wildlife population trends. However, now that three of the four North Slope caribou herds are declining in population, the cumulative impacts of oil development on caribou and other wildlife should be re-examined. In particular, the spatial arrangement of development may obstruct key habitat such as calving grounds. If infrastructure is constrained to a smaller footprint, rather than an expansive network, the same number of drill sites could have a lesser ecological impact.

Furthermore, gravel roads cause apparently permanent geophysical changes to the landscape, altering permafrost freeze-and-thaw cycles and creating topographic features known as thermokarst. The biological implications of thermokarst are not well understood—significant changes in vegetation communities may displace preferred forage species, although fine-textured terrain roughness and beaded streams provide suitable habitat for some wildlife species. Regardless, gravel roads leave a long legacy of changes to the surrounding ecosystem.

Alternatively, roadless development typically involves a larger gravel pad to accommodate an airstrip and necessary facilities and increased air traffic. Low-flying aircraft disturb many species of wildlife, and may displace individuals from preferred habitats at key times of year. However, these impacts are likely short-term and localized, and can be mitigated with seasonal, geographic, or species-specific flight restrictions similar to existing best management practices.

Roadless development appears to be the least ecologically damaging mode of oil-field access on Alaska's North Slope. This is due to the short duration of aircraft disturbance, the limited additionality of disturbance given already dense aircraft traffic, and apparent effectiveness of temporal and spatial mitigation measures.

Introduction

Oil and gas extraction uses a transportation network to move people, equipment, and materials. The two options that exist for year-round transportation are road-based and aircraft-based (roadless) access. Although much of an oil field's initial development can be completed using winter-only ice roads, continuous production typically involves some sustained level of access (National Research Council 2003). Historic oil fields have been developed using a series of connected gravel roads and, within Alaska's North Slope, there are more than 600 miles (960 km) of gravel roads outside of residential communities (Bureau of Land Management 2004). Two emerging projects would construct 15.7 additional miles (25 km) of gravel roads within the National Petroleum Reserve – Alaska (NPRA) (Bureau of Land Management 2014;2016), and another proposed project would develop 24.9 miles (40 km) of gravel roads at Nanushuk, just east of the NPRA (Repsol 2015) (see Figure 1). Additionally, the Willow project could add an additional expanse of gravel roads and pipelines in the NPRA (ConocoPhillips Alaska Inc. 2017).

Oil development involves an increase in aircraft traffic, as well. Estimates vary widely, but to develop and operate a single pad, approximately 200 flights may occur each year (Bureau of Land Management 2014). Due to existing oil developments, ecological and archaeological fieldwork, and commercial activity, a high volume of aircraft traffic already transits the North Slope (Figure 2).

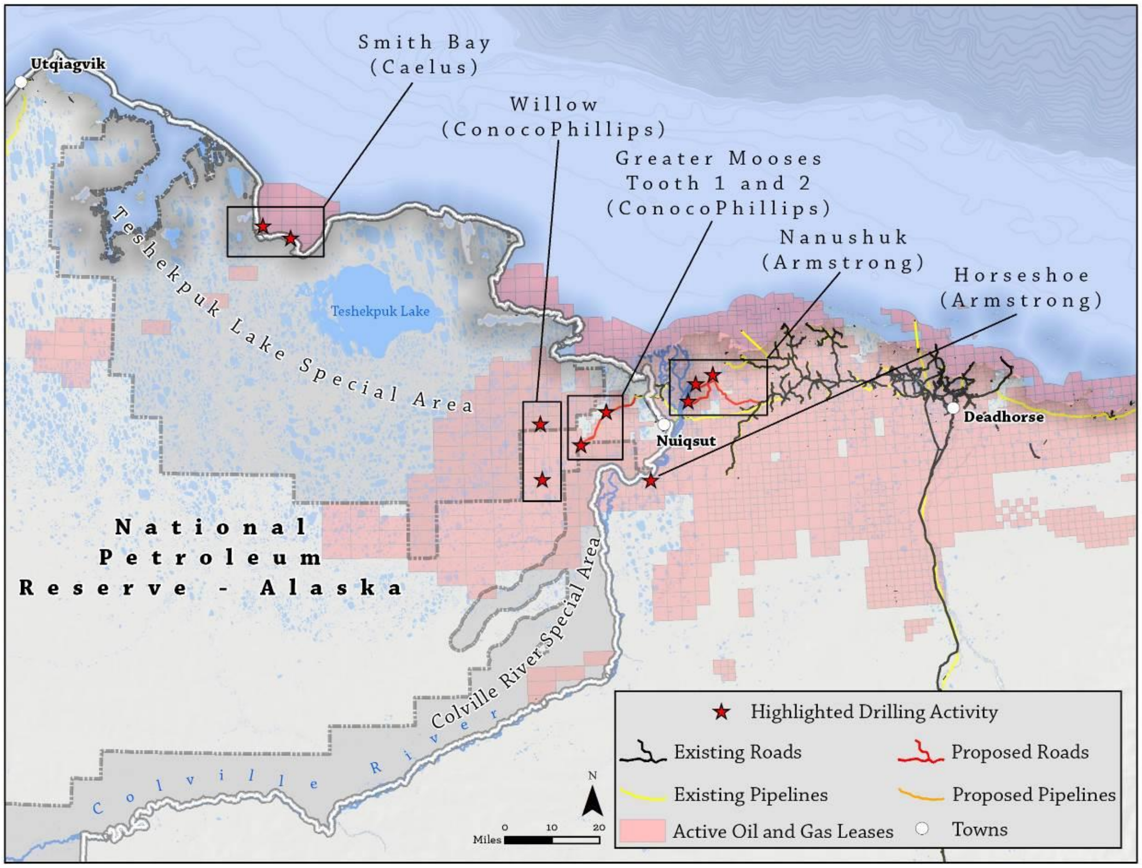
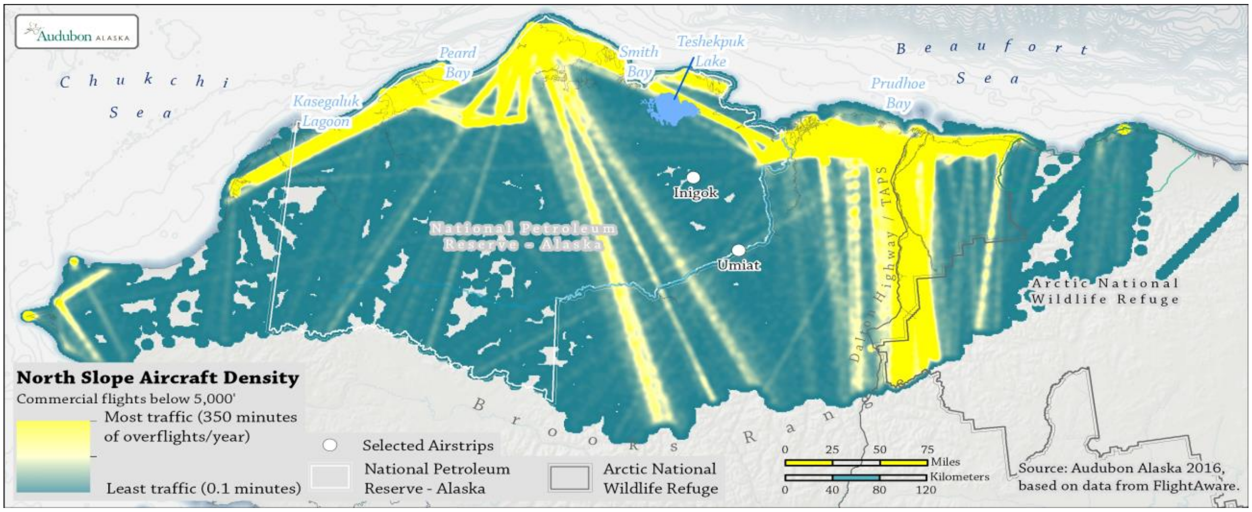


Figure 1. Existing and proposed infrastructure on Alaska's North Slope. Proposed developments are highlighted by red stars.


North Slope Aircraft Density

Commercial flights below 5,000'

Source: Audubon Alaska 2016, based on data from FlightAware.

Figure 2. Medium-altitude (5,000 feet and below) aircraft traffic on the North Slope from 2014-2015. Data provided by FlightAware.

Regardless of the mode of access, roads and aircraft have impacts on wildlife. The impacts can be broadly classified as disturbance (behavioral change) or displacement (avoidance of a previously used area). Both roads and aircraft can act as an acute disturbance, although some habituation may occur over continual exposure without obvious consequences. The degree of habituation is mediated by phenology, type of exposure, species-specific factors, and individual proclivities (Conomy 1998, Cronin et al. 1998a, Reimers and Colman 2006a). In terms of displacement, the physical footprints of roads and gravel pads – both of which are elevated off the tundra surface by several feet – can act as a barrier to movement and cause prolonged avoidance (Fancy 1983, Vistnes and Nellemann 2007, Wilson et al. 2016). Such factors may also prevent a species from using a suitable but unoccupied area, restricting alternative habitats that could otherwise be valuable if displacement occurs on occupied habitat (Cameron et al. 1992). Similarly, an animal's acoustic habitat could be altered, with noise from increased aircraft densities causing long-term displacement (Barber et al. 2010). Notably, these impacts occur at the individual level; effects may be attenuated, decoupled, or altogether absent at the population level (Cronin et al. 1998b). To further complicate matters, there are extensive time lags in the Arctic ecosystem (Walker and Walker 1991): displacement of caribou from optimal foraging habitat, for example, took decades before manifesting as a resultant decrease in caribou abundance (Vors et al. 2007). Given potentially confounding ecological interactions and high natural variability, it is essential to include qualifying details such as season, species, or demographic factors when quantifying the impacts of oil-related development.

This report uses a species-specific approach to describe impacts of road-based and roadless access, incorporating peer-reviewed scientific publications, agency reports, industry-commissioned studies, graduate student theses, academic textbooks, and environmental impact statements. First, the most salient aspects of Arctic ecology are described, beginning with a series of focal species (primarily, large vertebrates) and concluding with a summary of key cross-taxa commonalities. Next, the impacts of roads are outlined, beginning with a discussion of geophysical changes and following with a species-by-species description of relevant impacts. The impacts of aircraft are described using the same overall framework. An analysis is provided to briefly compare these relative impacts, followed by a series of conservation recommendations connected to specific management guidelines and planning processes.

Ecological Foundations

This study focuses on the ecology of Alaska’s North Slope and the Arctic Coastal Plain. The North Slope refers to the land north of the crest of the Brooks Range and south of the Chukchi and Beaufort Seas; the Arctic Coastal Plain is a wetland-covered, low-relief tundra region of the North Slope (Figure 3). The entire area is characterized by cold winters that keep surface water and soils frozen for about nine months every year, with subsurface soils remaining permanently frozen (permafrost) (Truett and Johnson 2000). Although the region receives little rainfall, much of the Coastal Plain is comprised of wetlands, ponds, and lakes, a consequence of poor drainage through permafrost (Walker et al. 1987). As part of adaptation to the harsh climate, many wildlife species inhabit the Arctic only seasonally and have highly fluctuating population cycles as a response to high interannual variation in weather conditions (Ims and Fuglei 2005).

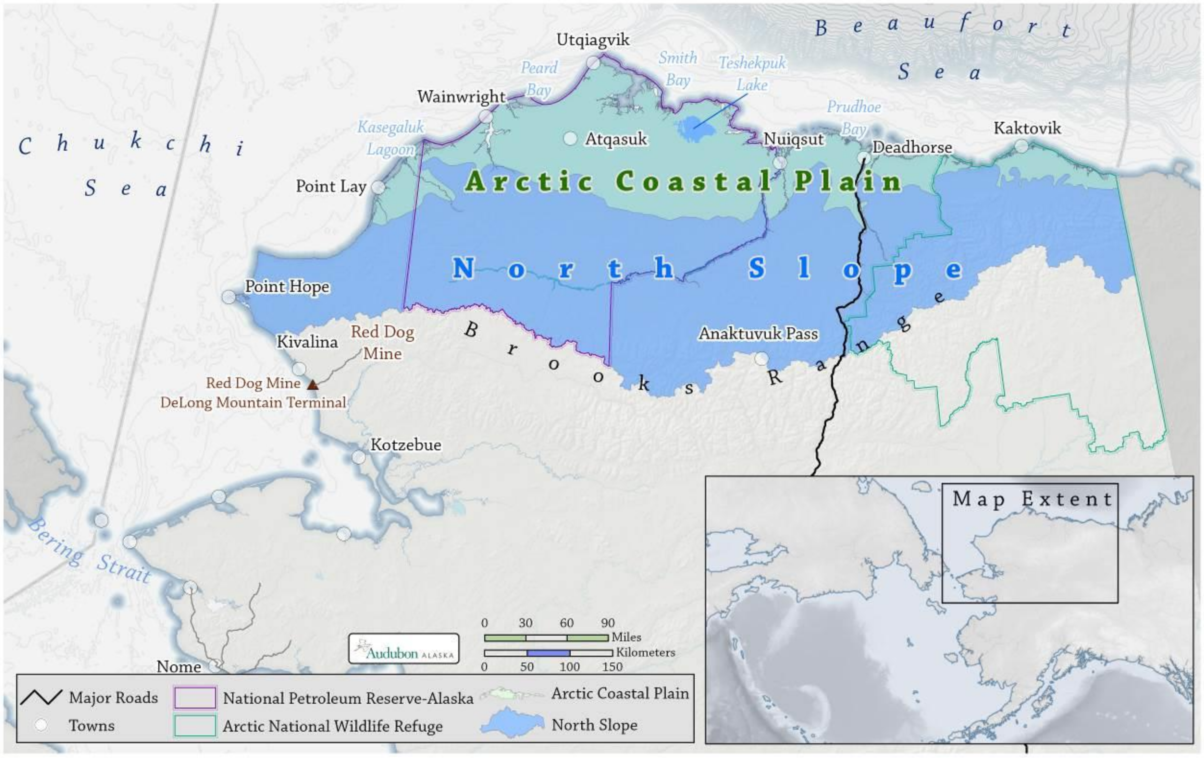


Figure 3. General study area, highlighting North Slope region (in blue) and Arctic Coastal Plain (in green).

Focal Species

In the interest of limiting the scope of this report to a reasonable length and extent, only selected species are examined in depth: caribou, geese (particularly Black Brant, Long-Tailed Ducks, Snow Geese, and Greater White-Fronted Geese), loons, eiders, shorebirds, and freshwater fish (particularly Arctic grayling and broad whitefish). These species have particular significance due to their ecological roles, importance to subsistence hunting, and also because areas critical to their life history overlap with historic, current, or future development (Hartsig 2016). For example, undeveloped areas in close proximity to potential future oil and gas infrastructure include molting sites for waterbirds (Reed et al. 2003), breeding sites for shorebirds (Andres et al. 2012), and calving and insect-relief habitat for caribou (Person et al. 2007). Although this report does not address subsistence activities directly, all of these focal species are utilized by North Slope communities (Burns 1988, Bureau of Land Management 2012).

Caribou

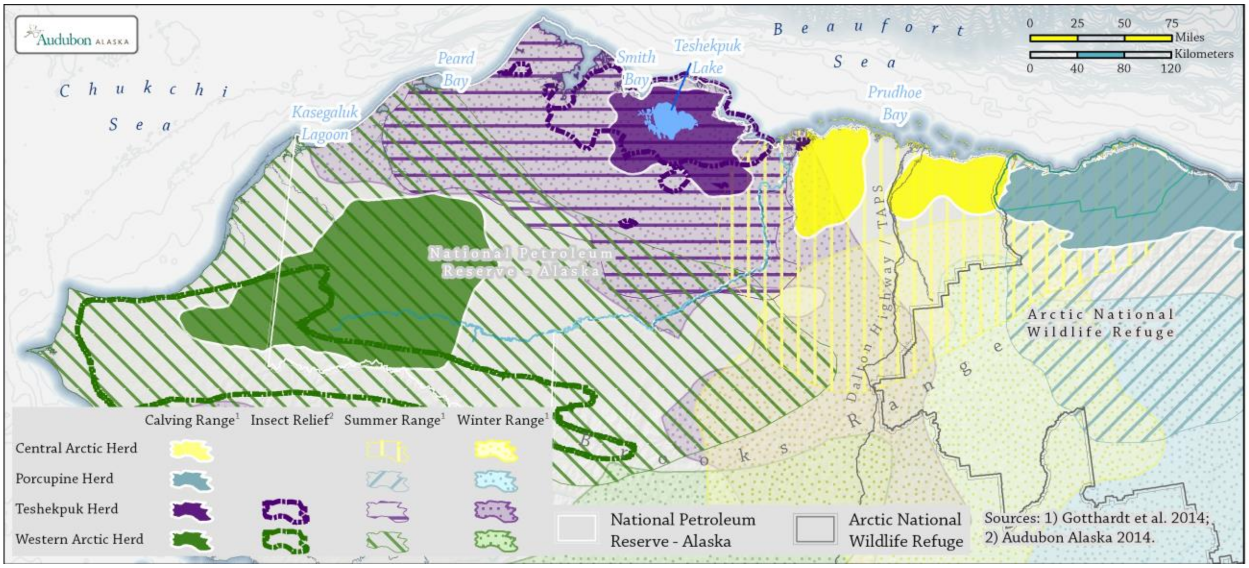
Overview

Caribou (*Rangifer tarandus*) are large ruminant mammals of the deer family. There are several subspecies of caribou, including reindeer, but the barren-ground caribou (*R. t. granti*; also called Porcupine caribou or Grant's caribou) is the only extant subspecies in Arctic Alaska (Hemming 1971), although some caribou-reindeer hybrids are likely present within these herds. This report focuses on barren-ground caribou whenever possible; however, when studies of similar subspecies provide unique or irreplaceable information, these results are included as well.

Caribou are gregarious and at many times during the annual cycle form large aggregations in the tens of thousands. Synchronous breeding occurs in October and November during migration to wintering grounds. Reproductive success is highly correlated with nutritional status, and the likelihood of producing a calf is linked to body condition during the previous autumn (Cameron et al. 1993). Calving takes place in the spring, generally from late May to late June (Hemming 1971), with females usually giving birth to one calf. From late June to mid-August, mosquitoes and oestrid flies harass caribou, greatly influencing caribou behavior and movement (Wilson et al. 2012a). Insect harassment can reduce foraging efficiency and increase physiological stress (Cameron 2005).

Caribou undertake extensive migrations, covering distances as long as 3,000 miles (5,000 km) (Fancy et al. 1989), in order to find adequate food and to birth calves in areas relatively free of predators (Griffith et al. 2002). The migration is sequential, led by parturient cows and followed by bulls and the rest of the herd. The sequential arrival may optimize the quality of forage as it becomes available over time and reduce forage competition with the remainder of the herd (Whitten and Cameron 1983). Russell et al. (1993) found that staggered migration allowed both parturient females and bulls to maximize body weight by late June.

Despite variability in specific routes taken between years, cows typically return to the same areas for calving (Figure 4). Caribou herds—aggregations ranging from thousands to hundreds of thousands of individuals—are delineated based on use of traditional calving areas (Hemming 1971), although there may be herd overlap and admixture outside of the calving period (Person et al. 2007). Within general calving areas, calving concentrations may shift gradually over years or change abruptly due to environmental conditions such as late snowmelt (Carroll et al. 2005, Hinkes et al. 2005). During calving and immediate post-calving periods, cows and calves form larger groups and appear to be most sensitive to human disturbance (Cameron 2005).Caribou of the Central Arctic herd typically seek out coastal areas, river deltas and bars, and non-vegetated habitats such as gravel roads and pads for relief from insects.



Sources: 1) Gotthardt et al. 2014; 2) Audubon Alaska 2014.

Figure 4. Seasonal distribution of caribou in Alaska's Western Arctic. Historic and proposed development overlaps with concentration areas for the Teskekpuk Herd and the Central Arctic Herd.

Central Arctic Herd

The Central Arctic Herd's range extends from the Colville River to the Canning River, and from the Beaufort Sea coast to the southern slope of the Brooks Range (Figure 4). The herd calves in two main areas within and adjacent to the Prudhoe Bay oil field and winters in the northern and southern foothills and mountains of the Brooks Range (Lenart 2011). This population is currently in decline (Figure 5) after reaching a peak population of 68,442 in 2010 (Lenart 2015). The most recent survey, in 2016, estimated the population at approximately 22,000 caribou (Lenart 2016), a decrease from 50,753 in 2013 (Lenart 2015).

Teshekpuk Caribou Herd

The primary range of the Teshekpuk Caribou Herd is the North Slope west of the Colville River. The peripheral range sometimes extends south of the Brooks Range to the Nulato Hills and east to the Canning River. Most of the herd's annual use is in the northern portion of the NPRA and the herd calves in the vicinity of Teshekpuk Lake. The calving grounds of the Teshekpuk Caribou Herd are primarily in the northeastern portion of NPRA near Teshekpuk Lake although annual variation in size and location within this area occur (Carroll et al. 2005). In general, Teshekpuk Caribou Herd distribution during calving has been quite predictable (Parrett 2011). After calving, most of the Teshekpuk herd moves on the north side of Teshekpuk Lake, traveling through the narrow corridors between the lake and the Kogru River to the east or between the lake and Smith Bay to the west (Yokel et al. 2011). The herd has been declining since 2008 (Figure 5) and is currently estimated at 39,172 individuals, down from 68,932 in 2008 (Parrett 2015).

Western Arctic Herd

The Western Arctic Herd is the largest caribou herd in Alaska in terms of geographic extent and population (Western Arctic Caribou Herd Working Group 2011). Although the herd's seasonal ranges span over 150,000 square miles (380,000 square km) (Dau 2015), parturient females return to a relatively small area in the Utukok River Uplands to give birth (Figure 4). Aside from communities, the only major permanent infrastructure in the Western Arctic Herd's range is the Red Dog Mine, a large zinc and lead mine in the DeLong Mountains. The Red Dog Mine has a 53-mile road connecting the extraction site with a shipping terminal, and a small portion of the herd encounter this road during fall migration (Dau 2015). The Western Arctic Herd is especially important to subsistence users, as over 40 communities regularly harvest caribou from this herd (Western Arctic Caribou Herd Working Group 2011). This herd has been estimated to contain as many as 490,000 individuals, although the population has been declining dramatically since its 2003 maximum to approximately 201,000 (Parrett 2016) .

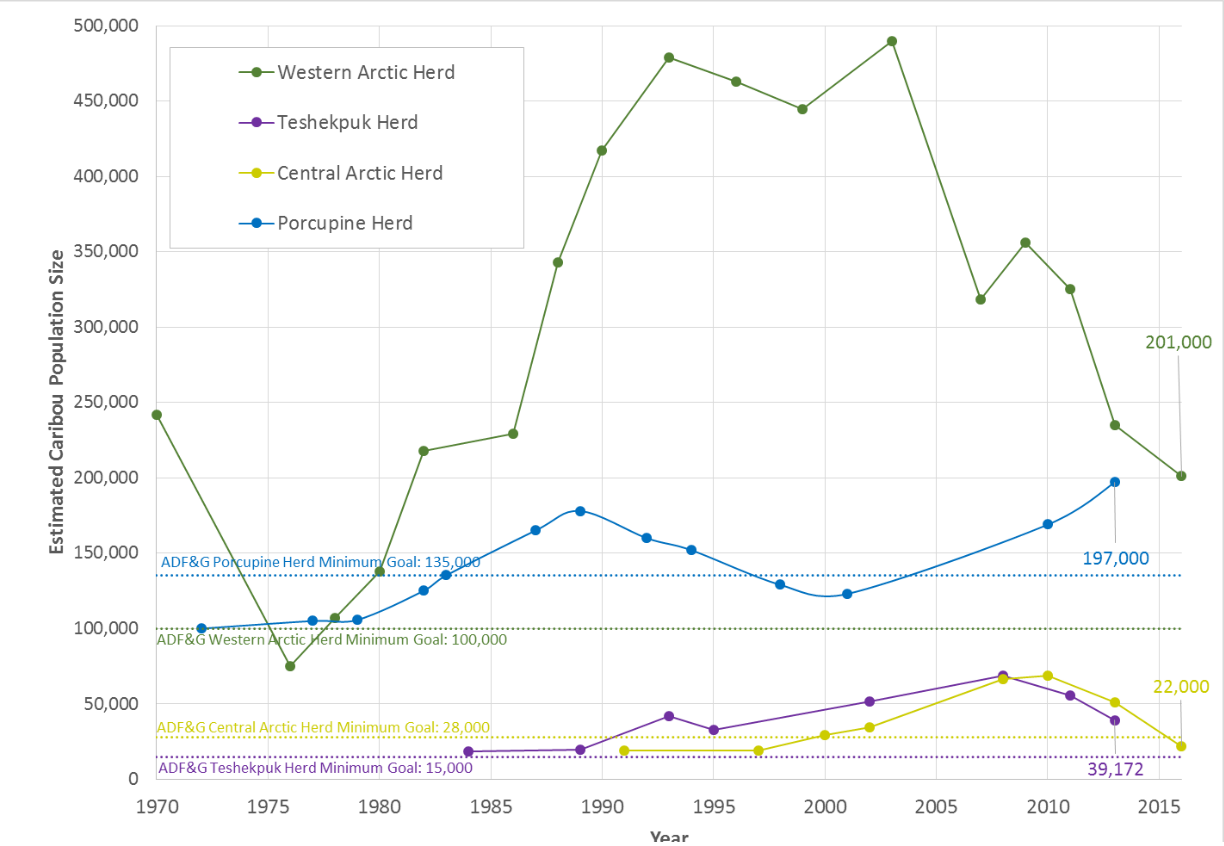


Figure 5. Arctic caribou population dynamics by herd. Most recent population estimates labeled. Sources for Western Arctic Herd: Western Arctic Caribou Herd Working Group (2011), Parrett (2016), and Western Arctic Caribou Herd Working Group (2016). Source for Porcupine Herd: Caikoski (2015). Sources for Central Arctic Herd: Lenart (2015) and Lenart (2016). Source for Teshekpuk Herd: Parrett (2015). The Western Arctic Herd has multiple population management thresholds; here the lowest threshold is shown (Western Arctic Caribou Herd Working Group 2011).

Birds

The Arctic Coastal Plain, a region extending from the western boundary of the NPRA to the eastern boundary of the Arctic National Wildlife Refuge, is known as "America's Bird Basket" due to the enormous diversity and abundance of breeding birds it supports. The NPRA seasonally provides a variety of habitats for migratory birds, from wetland complexes for molting geese to shorebird staging sites on the coast to high-center tundra polygons for nesting waterbirds such as loons.

Geese

Tens of thousands of geese nest in areas close to existing and proposed oil and gas developments on Alaska's North Slope (Stickney and Ritchie 1996, Truett et al. 1997). Black Brant (*Branta bernicla nigricans*) breed in coastal wetlands (Stickney and Ritchie 1996), typically 25 miles (40 km) or closer to the Beaufort Sea coast (Derksen et al. 1981). Greater White-fronted Geese (*Anser albifrons*) generally nest in small, loose colonies farther inland, selecting elevated sites near shallow wetlands to beaded streams—channels regularly interspersed with deeper pools—as pairs or pairs with broods (Derksen et al. 1981). There are four known nesting colonies of Snow Geese (*Chen caerulescens*) in the Alaskan Arctic Coastal Plain (Burgess et al. 2011). The largest colony is located on the Ikpikpuk River delta and regularly contains over 10,000 nesting birds (Ritchie et al. 2013). The colony at Howe Island on the Sagavanirktok River delta contains thousands of Snow Geese and is in close proximity to oil infrastructure, roads, and vehicle traffic (Johnson 1998, Stickney et al. 2011).

Aside from nest sites, the Arctic Coastal Plain also provides molting habitat for some birds (Derksen et al. 1982, Shults and Dau 2016). During the wing molt phase, birds shed and regrow flight feathers, a process that renders them flightless for several weeks (Derksen et al. 1982, Taylor 1995, Mallek 2010). Birds that successfully breed typically remain near nest sites to molt, but birds that are too young or otherwise fail to breed select different areas to molt (Reed et al. 2003).

The area around Teshekpuk Lake provides particularly important molting habitat for non-breeding geese such as the Black Brant, Cackling Goose (*B. hutchinsii*), Greater White-fronted Goose, and Snow Goose (Bollinger and Derksen 1996, Shults and Dau 2016). Long-tailed Ducks (*Clangula hyemalis*) also molt in the Alaskan Arctic, but generally use offshore lagoons rather than inland lakes in the NPRA (Flint et al. 2004).

The largest known concentration of molting Black Brant uses wetlands along the north and northeast of Teshekpuk Lake, with as many as 36,817 individuals (about 30% of the total Pacific flyway population) (Mallek 2010). The most recent surveys observed 12,814 Black Brant, 6,891 Cackling Geese, 40,904 Greater White-Fronted Geese, and 6,595 Snow Geese within this area (Shults and Dau 2016).

The abundance and spatial distribution of molting geese has changed over the past 30 years: Black Brant numbers are increasing and expanding into adjacent and coastal areas (Flint et al. 2014), and numbers of Greater White-fronted Geese increased seven fold (Flint et al. 2008). Molting Black Brant have changed their distribution within the Teshekpuk Lake Special Area, moving from inland, freshwater lakes toward coastal, brackish wetlands (Lewis et al. 2010b). Black Brant visit multiple wetlands prior to settling on their primary molt wetland, with significant time in both inland and coastal habitats during the pre-molt period (Lewis et al. 2010a).

Loons

Three species of loons, Pacific (*Gavia pacifica*), Red-throated (*Gavia stellata*), and Yellow-billed (*Gavia adamsii*), breed in the region. Loons arrive in late May and establish breeding territories on tundra lakes and ponds as soon as the margins of these habitats are free of ice and snow. Both Pacific and Yellow-billed Loons feed primarily in terrestrial wetlands during the breeding season while one study found that coastal-nesting Red-throated Loons forage in the marine environment (Bergman and Derksen 1977a). Pacific Loons show site fidelity to breeding locations, often re-using the wetlands in successive years (Kertell 2000). A small population of Yellow-billed Loons nests along the margins of deep-water lakes, primarily in two concentration areas, the Colville River delta and the wetlands between the Meade and Ikpikpuk Rivers. After nesting, most loons move to marine habitats before migration in August and September (Johnson and Herter 1989).

Eiders

All four species of eiders breed in Alaska (Larned et al. 2006). Common Eiders generally nest on offshore barrier islands and along the coastline (Johnson 2000); because they are not typically distributed in the terrestrial areas covered in this report, they are not covered in much detail here. Steller's and Spectacled Eiders are both listed as threatened under the Endangered Species Act. Steller's Eiders occur in very low numbers on the Arctic Coastal Plain, with the greatest nesting density near Utqiagvik (Obritschkewitsch et al. 2008, Stehn et al. 2013). Spectacled Eiders nest generally near the coast and breeding density varies across the region (Larned et al. 2006). Different species of eiders have different migration patterns, timing, and habitat characteristics, but generally Spectacled and King Eiders have similar preferences, nesting on tundra then moving to marine areas for brood rearing (Larned et al. 2006). Important habitats for these two species include large river deltas and wetland complexes with emergent vegetation (primarily *Arctophila* and *Carex spp.*) with nests located on polygon ridges and small islands (Derksen et al. 1981). Spectacled and King Eiders arrive on the breeding grounds in late May and early June (Oppel et al. 2008, Sexson et al. 2014). The males depart in mid-June, moving to coastal lagoons. Hatching occurs in mid-July and females with broods move to marine areas as the young fledge. Nest success is highly variable and predation is identified as a key factor in nest failure (Johnson 2000, Bentzen et al. 2008, Liebezeit et al. 2009b).

Shorebirds

Millions of shorebirds migrate to the North Slope to nest every year (Andres et al. 2012), including at least 29 species that breed in or in close proximity to the Arctic Coastal Plain (Johnson et al. 2007). Table 1 highlights the 28 breeding shorebird species occurring in highest abundance. Because of the range of foraging and habitat preferences among these taxa, shorebird distribution varies widely (Troy 2000), but suitable breeding habitat generally increases at lower elevations and within coastal areas of the NPRA and the Arctic National Wildlife Refuge (Saalfeld et al. 2013). Gravel beaches, mudflats, and marsh/pond edges all satisfy habitat requirements for different foraging guilds of staging shorebirds (Taylor et al. 2010). Generally, shorebirds nest in tundra sites further inland around June and move to coastal areas in mid-July to early September (Connors et al. 1981). The very short timespan, typically limited to a few weeks between arrival and nest initiation, means that phenology and availability of suitable habitat are of critical importance (Smith et al. 2010). As with eiders, nest predation is the most important cause of nest failure for shorebirds (Troy 2000, Liebezeit et al. 2009a).

Common Name	**Scientific Name**	**Troy (2000)**	**Alaska Shorebird Group (2008)**	**Andres et al. (2012)**	**Johnson et al. (2007)**	**Armstrong (2015)**
American Golden-Plover	*Pluvialis dominica*	*	*	*	*	*
Baird's Sandpiper	*Calidris bairdii*	*	*	*	*	*
Bar-Tailed Godwit	*Limosa lapponica*	*	*	*	*	*
Black Turnstone	*Arenaria melanocephala*		*			
Black-Bellied Plover	*Pluvialis squatarola*	*	*	*	*	*
Buff-Breasted Sandpiper	*Tryngites subruficollis*	*	*	*	*	*
Dunlin	*Calidris alpina*	*	*	*	*	*
Least Sandpiper	*Calidris minutilla*		*			*
Lesser Yellowlegs	*Tringa flavipes*		*			
Long-Billed Dowitcher	*Limnodromus scolopaceus*	*	*	*	*	*
Pectoral Sandpiper	*Calidris melanotos*	*	*	*	*	*
Red Knot	*Calidris canutus*		*			*
Red Phalarope	*Phalaropus fulicaria*	*	*	*	*	*
Red-Necked Phalarope	*Phalaropus lobatus*	*	*	*	*	*
Red-Necked Stint	*Calidris ruficollis*					*
Ruddy Turnstone	*Arenaria interpres*	*	*	*	*	*
Sanderling	*Calidris alba*		*		*	*
Semipalmated Plover	*Charadrius semipalmatus*	*	*		*	*
Semipalmated Sandpiper	*Calidris pusilla*	*	*	*	*	*
Spotted Sandpiper	*Actitis macularius*		*			*
Stilt Sandpiper	*Calidris himantopus*	*	*	*	*	*
Surfbird	*Aphriza virgata*		*			
Upland Sandpiper	*Bartramia longicauda*		*			
Wandering Tattler	*Tringa incana*		*			
Western Sandpiper	*Calidris mauri*	*	*		*	*
Whimbrel	*Numenius phaeopus*	*	*		*	*
White-rumped Sandpiper	*Calidris fuscicollis*	*	*		*	*
Wilson's Snipe	*Gallinago delicata*		*		*	*

Table 1. Regularly occurring shorebirds known to breed on Alaska's North Slope. Species present only as casual or accidental excluded.

Fish

There are 21 species of freshwater fish known to occur on the Arctic Coastal Plain of Alaska (Moulton and George 2000) and at least 20 additional fish species that are anadromous or live in adjacent coastal areas (Bureau of Land Management 2012). This study focuses on Arctic grayling (*Thymallus arcticus*) and broad whitefish (*Coregonus nasusas*) as representative species because of widespread abundance and because these are relatively well-studied species. During the winter, most waterways are frozen solid and freshwater fish are constrained in deep-water refugia containing sufficient dissolved oxygen and of sufficient depth to prevent total freezing (Laske et al. 2016). Once the spring melt opens up shallower tundra ponds and drainages, Arctic grayling, broad whitefish, and other species disperse into these seasonal habitats to take advantage of high productivity and access foraging and breeding areas (Heim et al. 2015). Winter habitat is generally regarded as the limiting factor (Moulton and George 2000), although populations also rely on natural flow patterns and hydrological connectivity to both access these seasonal habitats and return to overwintering sites (Morris 2003, Heim et al. 2015).

Other Species

As mentioned in the ecological overview, this report is deliberately limited in scope to a few taxa and excludes many important species. Seal and walrus haulouts may be sensitive to disturbance from aircraft (Bureau of Land Management 2015), and climate change may be forcing more pinnipeds to haul out in nearshore areas subject to relatively high rates of air traffic (Fischbach et al. 2016). Regardless of the legal status of polar bear critical habitat as designated under the Endangered Species Act, biological studies suggest that nearshore areas provide essential maternal denning habitat (US Fish and Wildlife Service 2013). Roads and aircraft may disrupt polar bears during this key time (Amstrup 1993). Microtines such as lemmings may be a key food source during years of abundance and divert predator pressure away from Arctic-nesting birds (Bêty et al. 2002). Roads may affect microtine forage, with cascading implications for microtine body condition and predator nutrition. Finally, muskoxen are widely but sparsely distributed through the North Slope (Lawhead et al. 2013) and are known to respond to aircraft overflights with behavioral changes (Miller and Gunn 1979). Little is known about impacts of roads on muskoxen behavior or movement.

This report does not directly consider marine areas or the marine/terrestrial interface. River deltas and nearshore areas are very biologically productive, and host major populations of wildlife such as shorebirds (Troy 2000). Roadside thermokarst, dust deposition, and erosion may affect river hydrology and therefore deltas, and aircraft noise may disturb marine animals as well as terrestrial wildlife.

Cross-Taxa Trends

Seasonality

Most species of wildlife only seasonally inhabit the North Slope, wintering elsewhere and migrating to the Arctic in the spring to track emergence of vegetation, aquatic invertebrates, and upper trophic levels (Truett and Johnson 2000). Although there is interannual variation in specific migration routes, caribou generally return to the same areas every year on a seasonal basis (Nicholson et al. 2016). For most of the winter, birds and some mammals are absent from the area, and fish are typically dormant in wintering sites. Table 2 (below) highlights typical seasonal patterns for focal species.

<table>
<tr><th colspan="2">Month</th><th>Caribou</th><th colspan="5">Birds</th><th>Fish</th></tr>
<tr><td colspan="2">Jan - Apr</td><td>Wintering</td><td></td><td></td><td></td><td></td><td></td><td rowspan="5"></td></tr>
<tr><td rowspan="3">May</td><td>early</td><td rowspan="3">Spring migration</td><td></td><td rowspan="2">SNGO arrival</td><td></td><td></td><td></td></tr>
<tr><td>mid</td><td></td><td></td><td></td><td></td></tr>
<tr><td>late</td><td rowspan="2">BLBR arrival</td><td></td><td rowspan="2">PALO arrival</td><td rowspan="2">Eider arrival</td><td rowspan="2">Shorebird arrival</td></tr>
<tr><td rowspan="3">Jun</td><td>early</td><td rowspan="2">Calving</td><td rowspan="2">SNGO nesting</td></tr>
<tr><td>mid</td><td rowspan="2">BLBR nesting</td><td rowspan="4">PALO nesting</td><td rowspan="3">Nesting; Male eiders move offshore</td><td>Shorebird nesting</td><td rowspan="3">Fish spring migration</td></tr>
<tr><td>late</td><td>Post-calving</td><td rowspan="2">SNGO hatching</td><td rowspan="4"></td></tr>
<tr><td rowspan="3">Jul</td><td>early</td><td rowspan="2">Mosquito harassment</td><td rowspan="3">Peak BLBR molt</td></tr>
<tr><td>mid</td><td rowspan="5">SNGO brood rearing</td><td rowspan="2">Eider hatching, move to coastal areas</td><td rowspan="5"></td></tr>
<tr><td>late</td><td rowspan="2">Oestrid fly harassment</td><td></td></tr>
<tr><td rowspan="3">Aug</td><td>early</td><td rowspan="2"></td><td rowspan="5">PALO move to coastal areas</td><td rowspan="2"></td><td rowspan="3">Shorebird migration</td></tr>
<tr><td>mid</td><td rowspan="4">Late summer</td></tr>
<tr><td>late</td><td>BLBR migration</td><td rowspan="5">Eider migration</td></tr>
<tr><td rowspan="3">Sep</td><td>early</td><td></td><td rowspan="2">SNGO migration</td><td></td><td rowspan="3">Fish fall migration</td></tr>
<tr><td>mid</td><td></td><td></td></tr>
<tr><td>late</td><td rowspan="3">Fall migration</td><td></td><td></td><td>PALO migration</td><td></td></tr>
<tr><td colspan="2">Oct</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="2">Nov</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="2">Dec</td><td>Wintering</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="2">Sources</td><td>Wilson et al. 2012</td><td>Sedinger & Stickney 2000; Taylor 1995</td><td>Johnson 2000</td><td>Kertrell 2000</td><td>Johnson 2000; Larned et al. 2006</td><td>Troy 2000</td><td>Heim et al. 2015</td></tr>
</table>

Table 2. Generalized seasonal patterns of use of Arctic Coastal Plain by focal species. BLBR = Black Brant, SNGO = Snow Goose, PALO = Pacific Loon, Eider = Spectacled Eider and King Eider.

Site Fidelity

Many species demonstrate site fidelity, the tendency of an organism to consistently remain in or return to the same location at certain times of year. Fine-scale, specific site selection varies based on seasonal factors, such as redistribution of calving caribou according to forage abundance or geese prospecting across multiple sites in a molting area (Lewis et al. 2010a), but many Arctic species return to the same general area every year.

Parturient caribou choose to calve in specific areas such as the lowlands northeast of Teshekpuk Lake (Wilson et al. 2012b) or the Utukok River Uplands (Dau 2015). Large concentrations of caribou have been observed in the Utukok Uplands and along the coast between the Meade and Colville Rivers since the earliest surveys of the NPRA in the 1940s (Reed 1958), and these areas have remained important seasonal habitats. About 92% of collared caribou in the Teshekpuk Herd demonstrated calving ground fidelity to the areas near Teshekpuk Lake (Person et al. 2007). Some studies have predicted that caribou that cannot access preferred calving habitats experience lower survival (Griffith et al. 2002).

Most bird species in the Arctic exhibit site fidelity: Pacific Loons (Kertell 2000), Snow Geese (Johnson 1998), Tundra Swans (Ritchie and King 2000, Stickney et al. 2002), Spectacled Eiders (Sexson et al. 2014), King Eiders (Bentzen and Powell 2015), and Common Eiders (Johnson 2000) all return to similar locations for various life history stages. Although some studies concluded that up to 95% of brant return to the same lake for molting (Bollinger and Derksen 1996), recent telemetry research indicates that brant visit multiple sites before selecting a final molting lake (Lewis et al. 2010a), suggesting that there may be different scales of selection at work.

Arctic grayling and broad whitefish habitually utilize distinct summer foraging and breeding sites (Moulton et al. 2007, Bureau of Land Management 2012, Heim et al. 2015). Within the Arctic, the biological rationale is clear: given the short duration of the productive summer, there is not sufficient time to search for and move to a different suitable site (Buzby and Deegan 2000, Heim et al. 2015).

Mobility

The focal taxa in this report are highly mobile and rely on extensive travel. Migration is a key part of caribou life history (Kelsall 1968). An individual may travel as far as 3,100 miles (5,000 km) over the course of a single season (Fancy et al. 1989), and, for the Teshekpuk Caribou Herd, individuals travel an average of 1,459 miles (2,348 km) every year (Person et al. 2007). Molting geese travel over 62 miles (100 km) while prospecting for suitable sites (Lewis et al. 2010a) and overland movements are common for Pacific Loon adults and young (Bergman and Derksen 1977b). Grayling travel as much as 63 miles (101 km) between overwintering and summer sites (West et al. 1992), and broad whitefish commonly cover more than 62 miles (100 km) between seasonal habitats (Morris et al. 2006). Surface water connectivity is key for fish movements (Heim et al. 2015, Laske et al. 2016), and terrestrial connectivity is similarly important for caribou and other migratory mammals (Berger 2004). Notably, terrestrial and aquatic connectivity are not as essential for birds to access suitable habitats, aside from the molting period for geese.

These three features—seasonality, site fidelity, and mobility—mean that many arctic taxa need a permeable landscape in order to access seasonally important habitats. Therefore, connectivity is of paramount importance to maintain viable populations of these species.

Impacts of Roads

Globally, the development of roads and other infrastructure has been linked to declines in species diversity and abundance (Nellemann et al. 2003) and threatens migratory shorebirds (Melville et al. 2016, Szabo et al. 2016). Broad multi-taxa reviews spanning multiple ecosystems identify a few spatial thresholds at which these effects are most prevalent: roads have direct impacts on wildlife up to about 3 miles (5 km) for mammals and about 0.6 miles (1 km) for birds (Benítez-López et al. 2010), although indirect effects have been noted up to 6 miles (10 km) for 98% of 151 species surveyed (mostly bird and mammal species, Vistnes and Nellemann 2007). Broadly, these impacts have been linked to declines in abundance within 3 miles (5 km) of a road for over 90% of 204 species (again, mostly bird and mammal species, Nellemann et al. 2003).

Within Alaska's Arctic, roads have at least six major ecological impacts: habitat avoidance and displacement, altering movement, vehicle-related disturbance, geophysical changes and dust fallout, hydrological changes, and introduction of pollutants (Table 3). Where relevant, each of these impacts are discussed in greater detail at the species level, with the exception of pollutants. Because some species and some impacts have been more thoroughly studied than others, the length of descriptions varies widely.

	Impact on Focal Taxa		
Ecological Effect of Road	**Caribou**	**Birds**	**Fish**
Habitat Avoidance and Displacement	X	X	X
Vehicle-related Disturbance	X	X	
Movement Alterations	X	X	X
Geophysical Changes and Dust Fallout	?	X	X
Hydrological Changes		?	X
Pollutants	?	X	X

Table 3. Major ecological impacts of roads on focal taxa. X represents likely impact, ? represents uncertain or hypothesized impact.

Pollutants

Roads may introduce heavy metals, salts, organic molecules, and ozone into waterways, as well as increase the risk of oil spills due to vehicle traffic (Forman and Alexander 1998, Trombulak and Frissell 2000). Given that Arctic fish are sensitive to small concentrations of contaminants (Nahrgang et al. 2016) and oil spills and resultant plumage oiling are particularly dangerous for birds (Burger and Fry 1993, Jenssen 1994), discharges of pollutants have the potential to have catastrophic effects if spilled in areas where large numbers of birds are congregated (Taylor et al. 2010). Aside from terrestrial- and water-soluble pollutants, industrial development in general will introduce airborne pollutants including nitrogen oxides (NO_X), sulfur dioxide (SO_2), carbon monoxide (CO), particulate matter (PM), and a variety of other compounds, all of which can cause respiratory problems in wildlife and people alike (Bureau of Land Management 2014).

Recovery and Rehabilitation

All evidence suggests that gravel roads leave behind a long legacy of impacts on the landscape. Some studies propose that natural recovery of tundra vegetation occurs on the scale of millennia (Peterson and Billings 1980, Forbes and Jefferies 1999) or may never occur (Williams et al. 2013, Hinkel et al. 2016). Other evidence suggests that vegetation communities tend toward a new stable state, rather than return to their original composition (Raynolds et al. 2014b, Becker and Pollard 2015). In one study, there was no evidence of recovery after 60 years of abandonment of an airstrip (Becker and Pollard 2015). Even with deliberate and intensive efforts at rehabilitation such as fertilization and transplanting, the recovery process takes at least decades (McKendrick 1987, Jorgenson and Joyce 1994, Forbes and Jefferies 1999). For areas that have experienced thermal slumping or other subsidence, rehabilitation is very expensive or even impossible (Raynolds et al. 2014a).

Other Types of Roads

Non-gravel roads are also heavily used in the North Slope as part of routine oil development. A large network of ice roads are constructed each winter and are typically in operation from January to April (Gilders and Cronin 2000). Ice roads likely have major impacts that persist into other seasons and can severely alter hydrology, natural thermal regime, and a wide variety of ecological aspects (Williams et al. 2013). In addition to ice roads, roads made of compacted snow may also be used on a temporary basis. Although off-road activity is strongly discouraged in oil fields and subject to biologically protective regulations within the NPRA (Best Management Practices L-1 and C-2, Bureau of Land Management 2013), a single off-road vehicle track disturbs thermal and nutrient cycle regimes for 20 years or longer (Forbes 1998).

Geophysical Mechanisms

Due to the prevalence of roads in historic North Slope development, many longitudinal studies have examined the long-term effects of roads on vegetation communities, hydrology, and the geophysical environment. A consistent effect is deeper permafrost thaw (Walker and Everett 1987, Auerbach et al. 1997), lower aboveground biomass (Auerbach et al. 1997), earlier snowmelt in close proximity to the road (Walker and Everett 1987), and development of thermokarst (Truett and Kertell 1992, Raynolds et al. 2014a, Hinkel et al. 2016), although effects are typically mediated by site-specific factors (Lawson 1986) such as tundra acidity (Walker et al. 1987, Auerbach et al. 1997). Thermokarst affects hydrology and vegetation, with implications for wildlife (Williams et al. 2013, Raynolds et al. 2014a). Figure 6 (below) illustrates an example of thermokarst development after construction of a gravel road in 1969.

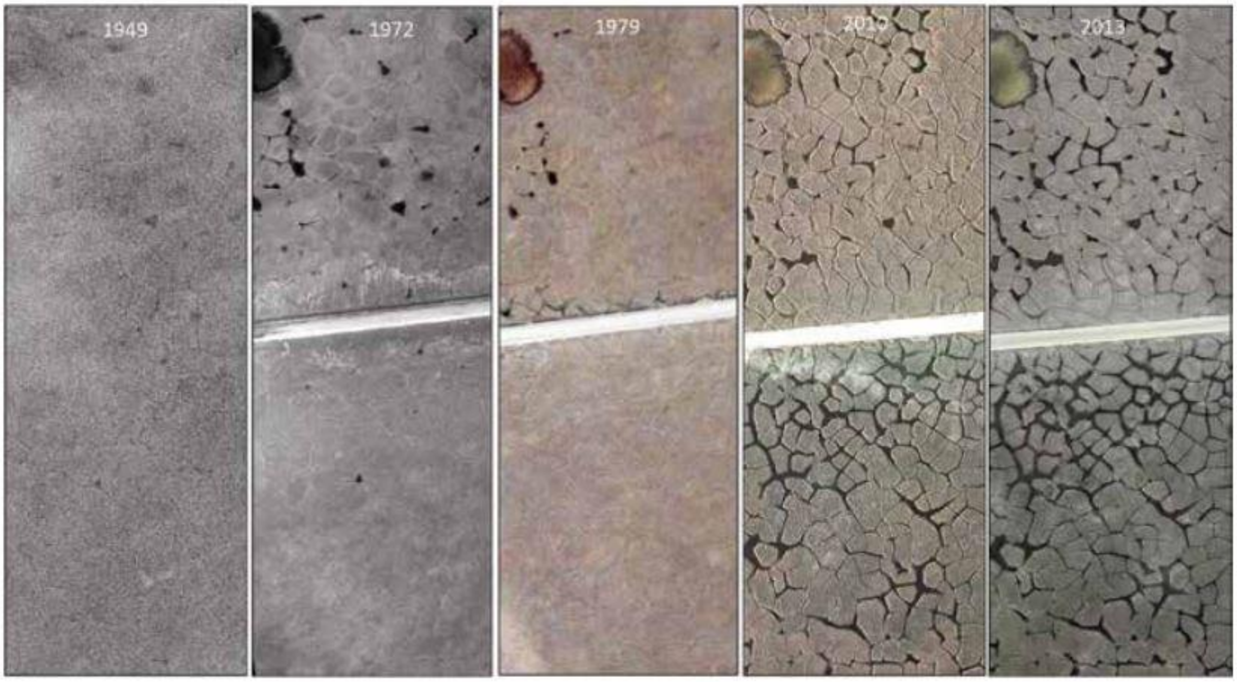


Figure 6. Adapted from Walker et al. (2014). Development of extensive thermokarst after construction of a gravel road. Aerial imagery near Lake Colleen, 1.9 mi (3 km) north of Deadhorse, Alaska.

Vegetation and thermal regimes are intricately linked in terrestrial systems in Arctic Alaska (Lawson 1986). Geophysical changes manifest themselves at the vegetation level, reducing diversity (Truett and Kertell 1992), altering nutrient cycling regimes (Forbes 1998), and changing species composition. Broadly, graminoids tend to increase in abundance (Truett and Kertell 1992, Myers-Smith et al. 2006) while lichens experience declines (Walker and Everett 1987, Myers-Smith et al. 2006). Because both of these plant families are good forage for wildlife – geese and swans prefer graminoids (Truett and Kertell 1992) and lichens are critical for caribou (Valkenburg et al. 2003, Joly et al. 2009) – some species would benefit and some species would suffer from this vegetation change.

However, the increased microsite variability (fine-scale heterogeneity) associated with thermokarst may benefit wildlife. Thermokarst-related heterogeneity appears to increase nesting bird abundance (Troy 1991), and terrain roughness appears to be a key feature of foraging quality for caribou in both the winter and summer (Nellemann and Cameron 1996, Wolfe 2000, Wilson et al. 2014), although the relationship is complex and varies by caribou demographics and season (Wolfe 2000, Wilson et al. 2012a). Finally, migratory fish species benefit from habitat with a range of temperatures and hydrological conditions, specifically beaded streams, a common product of thermokarst (Arp et al. 2015).

Because the organisms highlighted in this report return to the same general area every year, but weather conditions and biological productivity are highly variable from year to year (Ims and Fuglei 2005), a homogenous area may be catastrophic if conditions are poor. Instead, if a wider range of microhabitats are available, the biological consequences of variability may be mitigated.

For example, parturient females arrive at calving grounds immediately before snowmelt occurs, relying on vegetation in early phenological stages (Nellemann and Thomsen 1994, Griffith et al. 2002, Carroll et al. 2005). If an area is entirely flat and snowmelt occurs later than usual, caribou may be unable to find sufficient food. However, in an area with significant microrelief, snowmelt may be staggered, providing a longer duration of superior forage as different areas fill in with emerging plants. Aside from caribou, a more heterogeneous area likely has a more diverse assemblage of plants (Wookey 2007, Kivinen et al. 2012), meaning that rugged areas can meet a wider range of habitat preferences.

The geophysical changes associated with road construction extend far beyond the gravel footprint (Forbes 1998, Raynolds et al. 2014a) and, between flooding and thermokarst, the spatial extent of road-related impacts more than double the actual surface area disturbed (Walker et al. 1987). The effects of dust fallout can extend to 0.6 miles (1 km) on either side of a road (Kumpula et al. 2011), major changes to vegetation community within 656 feet (200 m) (Myers-Smith et al. 2006), and immediate snow melt occurs most strongly within 328 feet (100 m) (Walker and Everett 1987).

Gravel Extraction

The volume of gravel required in construction of roads, pads, and airstrips often requires the creation of project-specific gravel mines (Bureau of Land Management 2004;2016). As of 2000, over 60 million cubic yards (46 million cubic meters) of gravel have been mined on the North Slope, with a direct footprint of over 6,000 acres (2,500 ha) (National Research Council 2003). In the early 1970s, few regulations existed regarding gravel mining and gravel was often sourced from active riverbeds (Ott et al. 2014), resulting in environmental impacts such as streamflow alteration, reduction in the local water table, changing distribution of open water in winter, sedimentation, and habitat loss for gravel-reliant invertebrates and their predators (Johnson 1987, Kondolf 1994, National Research Council 2003). Because of concerns over high fish mortality, policy shifted gravel extraction to large, open pit mines typically located away from major streams and lakes (McLean 1993). Although direct stream impacts may be mostly mitigated, open pit mines require extensive overburden removal – for example, over 50 feet (16 m) of vegetation and soil needed to be excavated to reach suitable gravel in the mines created for the Kuparuk development (Ott et al. 2014). The resulting overburden stockpile disturbs natural tundra, and the gravel pit itself, when flooded, causes permanent changes to the area's thermal regime due to "thaw bulbs" forming in the permafrost around the unfrozen water (Bureau of Land Management 2014). Indirect effects such as these have led some researchers to approximate that a one acre (0.4 ha) gravel pit may impact as much as 25 acres (10 ha) surrounding the site (Johnson 1987).

If properly rehabilitated and flooded, open-pit mines can potentially benefit fish populations by providing deep-water refuge (McLean 1993, Ott et al. 2014), since overwintering habitat is a limiting factor in Arctic freshwater fish populations (West et al. 1992). However, because Arctic freshwater fish have high site fidelity (Moulton et al. 2007) and short seasons preclude exploration of novel habitats (Laske et al. 2016), fish may not naturally encounter these anthropogenic habitats and may need to be deliberately introduced to establish populations (Ott et al. 2014).

Impacts of Roads on Caribou

Direct impacts to caribou range in intensity from collision-based mortality, escape response, general avoidance, or more subtle adjustments to activity budget (Fancy 1983, Murphy and Curatolo 1987, Wolfe et al. 2000); but even a behavioral change as small as a delay in crossing (Wilson et al. 2016) can be energetically costly. The combination of roads and pipelines, especially when sited in close proximity, causes avoidance responses in caribou (Cronin et al. 1994), and vehicle traffic on those roads has a synergistic effect with other manmade structures (Curatolo and Murphy 1986, Lawhead et al. 2006).

Habitat Avoidance and Displacement

Road-related disturbance and displacement are compounded by synergistic effects as part of a cumulative effect network including vehicle traffic and adjacent infrastructure, most commonly pipelines (Cronin et al. 1994). Additive effects of disturbance over time may lead to displacement and ultimately abandonment of previously used habitat. Although there are a handful of exceptions in the literature (Cronin et al. 1998a, Noel et al. 2004), scientific consensus including the Alaska Department of Fish and Game (Harper 2011) generally indicates season-, gender-, and distance-mediated displacement as a result of linear infrastructure such as roads (Cronin et al. 1994, Nellemann and Cameron 1996, James and Stuart-Smith 2000). Limited baseline data has made it difficult to assess absolute effects of oil development on caribou distribution (Cronin et al. 1994). However, in the 1980s, calving was relatively common in the Kuparuk oil field, but calving data from 1993 to 2002 indicated a shift approximately 12 miles (19 km) south (see Figure 7) (Wolfe 2000, Cameron et al. 2002, Lenart 2003).

A specific distance threshold appears to exist for parturient female caribou, where these individuals avoid infrastructure by about 2.5 miles (4 km) (Cameron et al. 1992, Nellemann and Cameron 1996, Joly et al. 2006). Some studies estimate smaller displacement—significant avoidance within 0.6 miles (1 km) (Cronin et al. 1994)—but the general trend is that calving caribou density decreases with intensity and proximity to linear infrastructure (Cameron 2005). The density of infrastructure is also likely a key component of caribou avoidance and movement alteration, although previous studies have found it difficult to specify a precise threshold of density (Cameron et al. 1995).

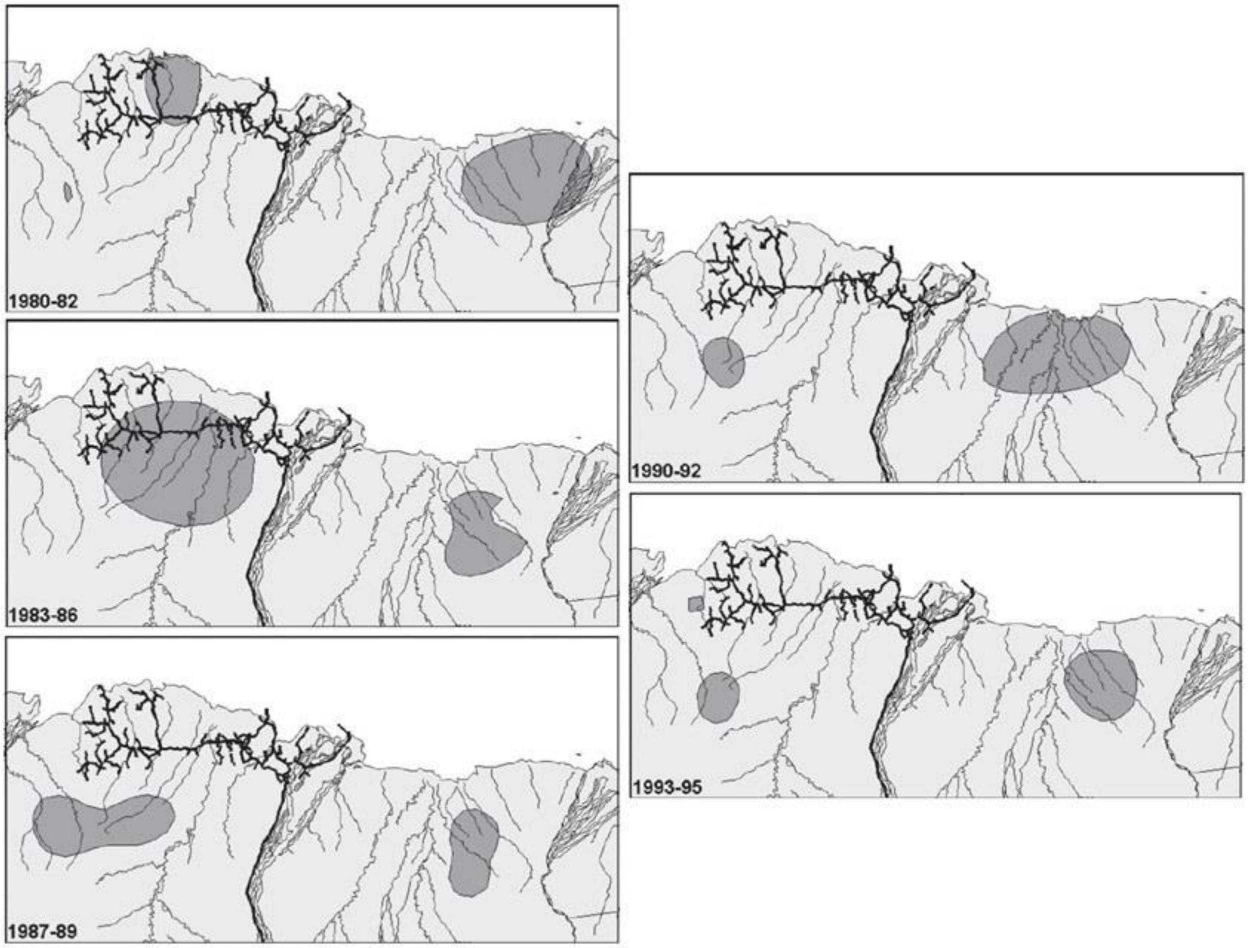


Figure 7. Adapted from Cameron et al. (2002), based on data from Wolfe (2000). Changes in concentrated calving areas for the Central Arctic Herd over 15 years. Concentrated calving areas west of Sagavanirktok River and the Trans-Alaska Pipeline System shift southwest, away from oil development, while the eastern concentrated calving grounds—mostly removed from anthropogenic influence—show no consistent pattern of change. Wolfe (2000) suggests that this shift may reflect parturient caribou avoiding dense oil-related infrastructure during the calving period.

Vehicle-related Disturbance

Roads are most consistently a disturbance when vehicles are present (Cameron and Whitten 1980, Reimers and Colman 2006b). Early experiments noted a "flight response" when caribou were approached by a single vehicle, causing about 85% of the caribou to trot or run away (Horejsi 1981). Traffic of four vehicles or more per hour elicited significant responses (Wilson et al. 2016), with stronger impacts observed in cow caribou (Wolfe et al. 2000) and when greater traffic was present (Shideler et al. 1986). Whether or not acute behavioral response is observed, roads generally act as a barrier or at least an impediment to caribou movement, although these impacts are attenuated by other factors such as insect activity, nearby infrastructure, vehicle traffic, and season (Shideler et al. 1986, Cronin et al. 1994, Cameron 2005).

Disturbance takes place within a certain distance of the road. About 80% of caribou reacted strongly (trotted or ran) to vehicles when within 400 feet (122 m), a percentage that dropped to 19%

from 400–800 feet (122-244 m), and only 0.3% reacted when beyond 800 feet (244 m) (Curatolo and Reges 1985). The distance between a pipeline and road is also very important—anything less than 400 feet (122 m) of separation can impede caribou movement (Curatolo and Reges 1985). For roads with higher vehicular traffic (>15 vehicles per hour), greater separation distances are recommended (Curatolo and Reges 1985).

Movement Alterations

Even when appropriate mitigation measures have been followed during planning and construction, roads with adjacent pipelines may act as a barrier and displace individuals, particularly parturient females and cows with new calves (Cronin et al. 1994, Lawhead et al. 2004). Season also matters, as during the insect-relief season, caribou are much more willing to cross, with little evidence of movements being impeded by linear infrastructure (Curatolo and Murphy 1983, Lawhead et al. 2004). Females during the calving season, however, appear much more sensitive to these same structures (Cameron et al. 1992). Finally, directionality – whether caribou approach perpendicular or parallel to a road – is an important yet poorly understood aspect of caribou responses to roads (Lawhead et al. 2006, Wilson et al. 2016). Historic studies have noted caribou being deflected from migration routes and parallel linear infrastructure for long distances, until they find a suitable crossing point or reach the structure's terminus (Child 1973, Curatolo and Murphy 1983).

Movements of the Western Arctic Herd in relation to the Red Dog Mine access road have been studied over a number of years. Because only a small proportion of the Western Arctic Herd migrates near the road, there is no evidence of herd-level alteration of fall migration. However, in some years, caribou are substantially delayed in crossing roads (Dau 2013): for caribou that approached within 9 mi (15 km) of the road, about 30% of collared individuals altered usual rates of travel and took about ten times as long to cross the road (33.3 days compared to 3.1 days for other caribou, Wilson et al. 2016). Two sample movement paths from these data are shown below in Figure 8. Interannual differences in crossing success are hypothesized to be related to a wide range of environmental, social, and demographic variables (Wilson et al. 2016). In particular, if the leaders of migration are disturbed while crossing a road, subsequent caribou will be hesitant to cross. On the other hand, if leaders are not disturbed, then the rest of the herd may cross easily and quickly (Dau 2013, Wilson et al. 2016).

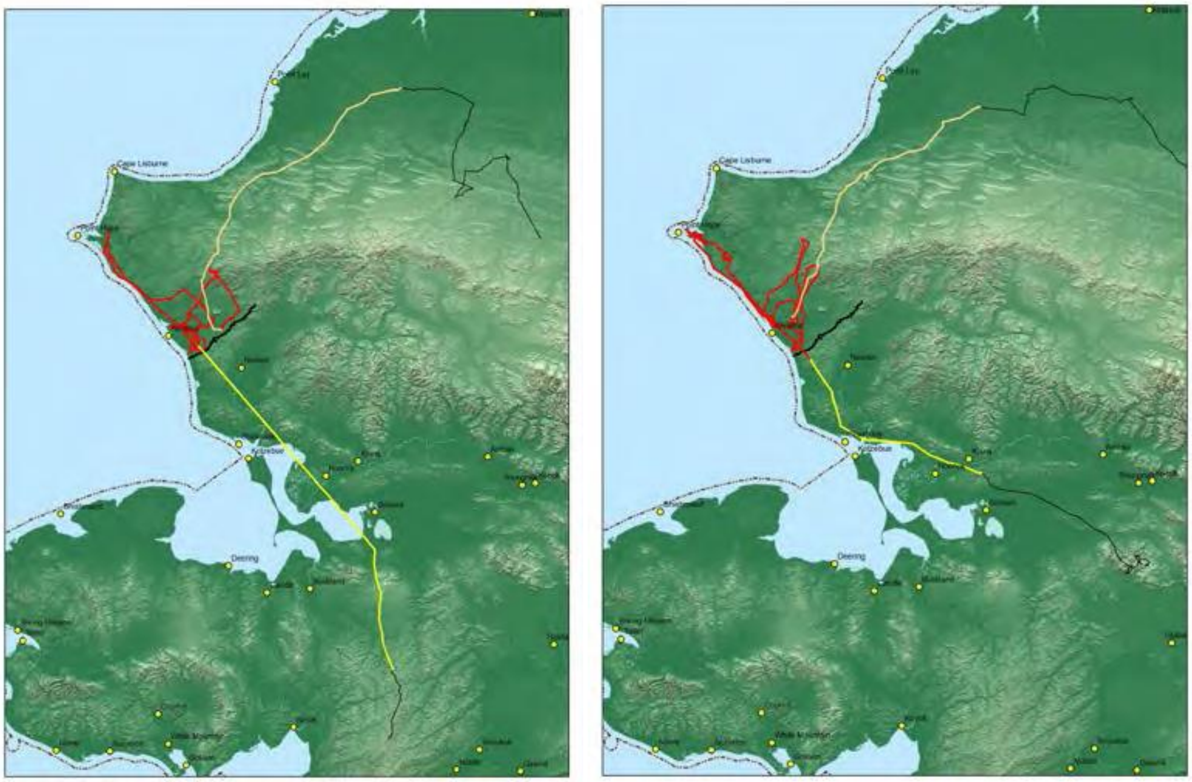


Figure 8. Adapted from Dau (2013). Sample movements of two satellite-collared caribou in proximity to the Red Dog road. Normal fall migration moves SW from the Utukok Uplands, then south over the Red Dog road area toward Kotzebue. These 2 caribou were deflected >100 miles (160 km) northwest and delayed crossing for an average of 44 days. Tan lines show caribou traveling along normal migratory route, prior to encountering road. Red lines show abnormal movement after encountering the road, and yellow lines show resumed migration. Although in other years, caribou showed less difficulty crossing the road, even deflections from traditional migratory routes can have negative energetic impacts.

Geophysical Changes and Dust Fallout

As mentioned above, the geophysical changes associated with roads and gravel placement on top of permafrost could have positive or negative effects on caribou. Thermokarst creates micro-topographic relief, and terrain roughness—topographic relief at a slightly coarser spatial scale—is often correlated with good foraging quality (Nellemann and Cameron 1996, Wolfe 2000, Wilson et al. 2014). Although Arctic disturbance ecology varies dramatically when examined at different spatial scales (Walker and Walker 1991), the connection between thermokarst, topographic relief, and caribou forage should be further examined.

Impacts of Roads on Birds

Road-specific effects on Arctic birds have not been studied as extensively as they have been for caribou, and given the species richness and different preferred habitat of each species, it is difficult to predict the effects across all species of birds (Taylor et al. 2010). The main impacts to birds are habitat avoidance and displacement, vehicle-related disturbance, movement alterations, and geophysical changes and dust fallout.

Habitat Avoidance and Displacement

Nesting birds and their eggs are particularly vulnerable to disturbance, as displacement of parents may increase exposure to nest predators. Nest predation is the primary source of nest failure on the North Slope (Bêty et al. 2002, Liebezeit et al. 2014), primarily by Glaucous Gulls (*Larus hyperboreus*), Parasitic Jaegers (*Stercorarius parasiticus*), and arctic foxes (*Alopex lagopus*) (Liebezeit and Zack 2008). Disturbance and corresponding displacement of nesting loons has been linked to reduced nest survival for both Pacific and Yellow-Billed Loons, as these species may be more willing to abandon their nest rather than return to a nest site with high exposure to human-created disturbance (Uher-Koch et al. 2015).

Some evidence suggests that oil infrastructure results in subsidized predator populations (Lehner 2012), allowing for higher predator density, increased nest predation, and decreased bird abundance in highly developed areas (Truett et al. 1997). However, inter-annual variation appears to be a stronger determinant of predation-related nest failure than proximity to infrastructure (Liebezeit et al. 2009a).

Oil infrastructure-related artificial habitat, such as roadside vegetation communities, can provide good habitat for birds. Species such as Pacific Loons have been noted to nest in artificial habitats (Kertell 1996), and Red Phalaropes have been observed staging in sewage treatment ponds (Taylor et al. 2010).

Vehicle-related Disturbance

Generally, moving vehicles and other human activities may disturb birds, resulting in increased energy expenditure and displacement from preferred habitats (Bureau of Land Management 2014).

Movement Alterations

Some research suggests that roads may make overland travel difficult, preventing young birds from accessing different habitats (Kertell 2000). However, construction of a road and causeway in close proximity to key Snow Goose habitat has not been a barrier to dispersal of post-nesting Snow Geese and broods of young (Johnson 1998), and oil-related development has not caused any discernable shifts in North Slope-wide distribution of Brant and Snow Geese (Truett et al. 1997)

Geophysical Changes and Dust Fallout

Road-related thermokarst development changes vegetation communities. For wetland-dependent birds, linear gravel features will alter habitat, and it is difficult to predict whether these impacts will improve, degrade, create, or eliminate bird habitat (Bergman et al. 1977).

Impacts of Roads on Fish

The most significant impacts of roads on Arctic fish have to do with hydrological changes and associated movement alterations. Because these two effects are linked for fish, they are discussed together. Other impacts to fish–such as risks of hazardous material spills along roadways and erosion–may exist, but are subject to lease stipulations, best management practices, required operating procedures, and other regulations (Bureau of Land Management 2012).

Movement Alterations and Hydrological Changes

Roads constructed through streams block or significantly impede fish movements (Cott et al. 2015, Heim et al. 2015). If properly sized, installed, monitored, and maintained, culverts can potentially mitigate the impacts of roads on stream crossings, but, due to the site-specific nature of Arctic fish populations, a single inadequate culvert can impact an entire fish population by restricting access to key seasonal habitats (Cott et al. 2015). According to testimony from community members, culvert failure and resulting fish movement blockage has historically been a recurring problem in the North Slope, compounded by a years-long repair backlog (Burns 1988). Furthermore, the physical barrier imposed by roads has more complex effects on drainage network (Heim et al. 2015) and can significantly alter hydrology (Forman and Alexander 1998, Jones et al. 2000). Linear development, and roads in particular, intercepts natural water flow (Walker et al. 1987), which is a driver of connectivity for fish (Heim et al. 2015).

Geophysical Changes and Dust Fallout

As stated above, beaded streams provide superior fish habitat, and, depending on drainage and freeze/thaw patterns, thermokarst may enhance or create entirely new beaded streams (Arp et al. 2015). Gravel roads and associated traffic mobilize sediment and dust, which then is deposited into nearby streams and ponds. Increased freshwater sediment loads alter water chemistry, can reduce primary productivity, and smother habitat used by fish for spawning and foraging (Cott et al. 2015).

Impacts of Aircraft

Aircraft-only access could result in more facilities being localized at each drill site, requiring a larger gravel footprint (Bureau of Land Management 2014). Because of this, the effects noted for roads under the Geophysical and Vegetation sections above will also hold true for aircraft, albeit in a more localized way: at gravel pads and airstrips rather than along continuous linear features. Aircraft-only access may still involve the construction of above-ground pipelines and therefore may still disrupt wildlife movements, particularly for caribou (Murphy and Curatolo 1987). Sensitive watersheds or geophysical features could be entirely avoided through appropriate siting of airstrips and expanded or redundant facilities. Avoiding these features with a continuous infrastructure network, on the other hand, may require expensive detours and diversions that would lengthen the overall road network and increase environmental impacts as more gravel is required.

Aside from the effects of an enhanced gravel footprint, aircraft-based access has two major ecological effects: habitat avoidance and displacement, and pollutants (Table 4). Aircraft can cause acute behavioral responses from a wide range of taxa, primarily large vertebrates. Caribou and birds may flee from the zone of disturbance or have altered activity budgets (Calef et al. 1976, Miller 1994), and marine mammals such as whales may alter swimming and breathing patterns, taking short dives, short surfacing, and abrupt turns (Patenaude et al. 2002). Generally, these reactions are more pronounced for helicopters than for fixed-wing aircraft for waterbirds (Komenda-Zehnder et al. 2003), caribou (Shideler et al. 1986), and marine mammals (Patenaude et al. 2002).

A number of studies have examined the distances at which aircraft elicit behavioral responses in wildlife. These results are summarized in the Key Distances and Altitudes section below. Although site- and condition-specific factors may change the absolute distances mentioned, these numbers are valuable as a general guideline.

	Impact on Focal Taxa		
Ecological Effect of Aircraft	**Caribou**	**Birds**	**Fish**
Habitat Avoidance and Displacement	X	X	
Pollutants	X	X	X

Table 4. Major ecological impacts of aircraft on focal taxa. X represents likely impact.

Impacts of Aircraft on Caribou

Habitat Avoidance and Displacement

Caribou—particularly females with calves—will run away, and stronger responses include panic or escape reactions, causing stumbling, collision, and potential injury (Calef et al. 1976). Research generally concurs that these behavioral changes have energetic impacts for individuals (Luick et al. 1996, Ward et al. 2000). Even mild responses may have stronger cumulative effects over a longer time period (Lawler et al. 2005), although, as with road-based disturbance, it is difficult to directly translate short-term, individual responses to long-term, population-level effects (Bergerud et al. 1984). At minimum, a caribou's activity budget (ratio of time spent on different behaviors) is disrupted (Maier et al. 1998). Energy-neutral or energy-positive behaviors such as resting or feeding are interrupted by energy-intensive behaviors such as fleeing (Maier 1996). If these changes are severe enough, they could be manifested in poor body condition. In one study, increased noise exposure in the post-calving period resulted in lower body fat and subsequent lower probability of pregnancy for female caribou (Luick et al. 1996).

Factors such as gender, season, and even time of day may influence response as well. Female caribou with young demonstrated the strongest responses, and caribou are most sensitive in the calving and post-calving period, although overflights may interrupt resting and alter activity budgets in the winter (Maier et al. 1998). At a broader scale, there appear to be population-specific differences in how caribou respond to aircraft disturbance (Reimers and Colman 2006b). Caribou herd-based responses to aircraft are in part based on that herd's exposure to hunting (Shideler et al. 1986), although other factors such as habituation to chronic, high-frequency overflights may be more significant for populations such as the Teshekpuk Caribou Herd and the Central Arctic Herd (L. Parrett, pers. comm.).

Chronic exposure to aircraft noise has been hypothesized to displace caribou (Calef et al. 1976). In the aftermath of a disturbance, affected individuals may continue to avoid loud areas, in some instances by relatively large distances. Once disturbed, maternal caribou groups displaced as much as 1.8 miles (3 km) from the aircraft (Shideler et al. 1986).

Impacts of Aircraft on Birds

Habitat Avoidance and Displacement

For breeding birds, the energetic costs of disturbance may be compounded by increased nest predation while the disturbed bird is away. After Snow Geese were flushed by helicopter overflights, gulls and jaegers took advantage of the abandoned nest to prey on eggs (Barry and Spencer 1976). Molting geese can be displaced as much as 1.8 miles (3 km) from the disturbing aircraft (Derksen et al. 1982), and eiders typically dive under water in an attempt at avoidance (Mosbech and Boertmann 1999).

Habituation to aircraft-related disturbance depends on species and population-specific history of encounters (Conomy 1998). King Eiders do not show evidence of habituation (Mosbech and Boertmann 1999), although some duck species do (Conomy 1998). Noise-related displacement is harder to quantify than acute behavioral responses, although chronic noise exposure has been known to create barriers to migration and dispersal for birds (Barber et al. 2009).

Key Distances and Altitudes

Lateral and vertical (altitude) distance between the wildlife and aircraft are generally considered key drivers of response level (Banfield et al. 1981, Ward et al. 1999). Aircraft flying at altitudes lower than 4,000 feet (1,219 m) will often elicit an acute behavioral response for molting geese (Miller 1994, Ward et al. 1999) and post-breeding eiders (Mosbech and Boertmann 1999). The aircraft generally must also be flying within 4,000 feet (1,219 m) laterally of the birds to cause disturbance: responses are strongest within 3,280 feet (1,000 m) for eiders and 5,280 feet (1,610 m) for molting geese, although disturbance may extend to as far away as 16,400 feet (5,000 m) for eiders and 15,840 feet (4,828 m) for molting geese (Mosbech and Boertmann 1999, Ward et al. 1999). Although altitude wasn't recorded, Snow Geese were observed being flushed by helicopters up to 7,800 feet (2,377 m) away, laterally (Barry and Spencer 1976).

Due in part to the high mobility of caribou, altitude has been more studied than lateral distance, although helicopter landings displace maternal caribou groups within 6,000 feet (1,829 m) (Shideler et al. 1986). During calving periods, most literature suggests that aircraft flying above 1000 feet (305 m) would elicit few strong reactions (Calef et al. 1976, Shideler et al. 1986), with flights above 2,000 feet (610 m) almost entirely mitigating disturbance (Shideler et al. 1986, Lawler et al. 2005). Flights under these altitudes caused strong panic reactions in approximately 70% of caribou in the Porcupine Caribou Herd during the calving season (Calef et al. 1976). Outside of calving, a minimum altitude of 500 feet (152 m) may be sufficient to avoid major disturbance (Calef et al. 1976).

Cetaceans are generally less sensitive to disturbance from aircraft overflight, responding when aircraft are lower than 500 feet in altitude and closer than 820 feet (250 m) laterally (Patenaude et al. 2002). Pinnipeds such as walruses may be disturbed by aircraft up to 1,000 feet (305 m) in altitude, showing heightened sensitivity when hauled out on ice or land (Bureau of Ocean Energy Management 2015).

Analysis

Spatial Extent

Roadless access would involve construction of an airstrip, an airstrip-to-drill-site gravel road, and storage and housing pads that would not be necessary if year-round roads were constructed (Bureau of Land Management 2015). Using the most recent proposal for a single drill site in close proximity to existing infrastructure (the Supplemental Environmental Impact Statement for Greater Mooses Tooth 1), road-based access would have a 72.7-acre (29.4 ha) footprint, including 7.7 miles (12.4 km) of road, whereas roadless access would use an 87.4-acre (35.4 ha) footprint with 1.2 miles (1.9 km) of road and a 5,000 foot (1,524 m) airstrip. Restricting access to aircraft only would result in a 20% increase in gravel footprint, coupled with an 84% reduction in road length (Bureau of Land Management 2015).

Ecologically, the absolute quantity of gravel used may not be as important as how that gravel is acquired and how it is distributed across the landscape. Although developed for land-use planning regarding agriculture, the concept of intensive vs. extensive use (Foley et al. 2005, Fischer et al. 2008) has useful takeaways when applied to oil development. Although there are many trade-offs to consider and many questions that must be resolved before extrapolating between ecosystems, a small area of intensive disturbance (for example, using a series of independent, aircraft-accessed drill sites) may be less ecologically destructive than distributing the same amount of disturbance over a larger area (for example, using roads to connect a wide network of oil infrastructure).

Key Point: The spatial arrangement of development may be more ecologically significant than the absolute extent of development. Heavily concentrated (intensive) infrastructure may have less impact than the same amount of infrastructure distributed widely (extensive) across the landscape. A thorough comparison of intensive and extensive use should be conducted as part of a cumulative effects analysis for future development on the North Slope.

Given the high degree of mobility and necessity of accessing seasonal habitats, even single roads have the potential to negatively impact Arctic wildlife by disrupting migration corridors. If sufficient alternate habitats are not available and movement is impeded, then the consequences could manifest for caribou (Wilson et al. 2016), shorebirds (Troy 2000), and freshwater fish (Heim et al. 2015). In this context, a sprawling oil development network, even one constructed following best practices, could have dramatic ecological consequences.

On the other hand, if intensive oil development is concentrated in areas with the least ecological significance—for example, places not designated as Special Areas by the NPRA's Integrated Activity Plan (Bureau of Land Management 2013)—and does not impede wildlife access to these areas, the same amount of development could be accomplished with minimal environmental consequences.

Evidence suggests that linear developments such as roads do not completely restrict movement for caribou (Cronin et al. 1994), fish (Fechhelm et al. 2001), or molting birds (Johnson 1998). However, even delayed or deflected crossings (Panzacchi et al. 2013, Wilson et al. 2016) have the potential to be energetically costly, especially when coupled with the highly variable environmental conditions of

Alaska's Arctic. Given that these impacts can be avoided with properly sited roadless development, aircraft-only access appears to be a better option in terms of spatial extent of impact, although evaluation of the potential for aircraft traffic to delay, deflect, or divert caribou movements continues.

Temporal Extent

Temporal restrictions—for example, eliminating overflights or vehicle traffic at certain particularly sensitive times of year—could be effective at mitigating acute disturbance. Bull caribou and those in smaller groups (Murphy and Curatolo 1987) are typically willing to cross roads, particularly during the insect harassment season (Curatolo and Murphy 1983), provided there is no traffic and there is sufficient spacing between the road and any adjacent pipelines.

Key Point: Due to the seasonality of Arctic ecology, temporal restrictions on activities that cause disturbance are a viable approach to reduce conflict with wildlife. Industrial developments that cause permanent ecological changes should be minimized.

However, many of the most significant effects of roads are not related to acute disturbance. The geophysical impacts of roads and their construction—primarily, thermokarst development and gravel mining, respectively—are long lasting and affect a variety of taxa. If an oil drilling pad is abandoned, aircraft flights can be discontinued immediately and gravel roads can be disassembled, but the gravel footprint (including roads) leaves a significant ecological legacy in the tundra, wetlands, soils, hydrology, and underlying permafrost. The long duration of effects from roads makes aircraft-based access a better option, especially in the long term, after a field is shut down.

Population Level Impacts

A key question of this study is whether and when individual-level changes at fine spatial or temporal scales will aggregate into broader or persistent effects at the population level. Some researchers predict that acute disturbance and displacement will have bioenergetic consequences on wildlife, which could manifest as reproductive and eventually demographic impacts (Luick et al. 1996, Ward et al. 2000). However, this argument assumes that insufficient or inferior alternate habitats exist; on the North Slope, studies have not shown this to be the case. For shorebirds, breeding habitat availability does not appear to be the limiting factor in population (Troy 2000), and, as evidenced by recent Black Brant and Greater White-Fronted Goose expansion, previously unused, good-quality habitat for molting geese exists outside the Teshekpuk Lake Special Area (Flint et al. 2014).

The connection between oil development and population level effects has not been definitively demonstrated for any of the focal bird taxa studied in this report. Historic studies suggested that Black Brant and Snow Geese nesting in close proximity to Arctic Alaskan oil fields have not suffered declines or changes in abundance, distribution, and reproduction (Truett et al. 1997), and recent molting surveys show dramatic increases in Greater White-Fronted Goose populations, although there are noted declines in abundance of observed Black Brant, Snow Geese, and Cackling Geese near Teshekpuk Lake (Shults and Dau 2016).

Significantly more studies have examined potential population-level effects of infrastructure on caribou herds in Alaska, with few conclusive results. In the decades immediately following widespread development in barren-ground caribou ranges, effects on abundance were not documented (Bergerud et al. 1984, Cronin et al. 2000). There are numerous examples of caribou herds that encounter road systems during their migrations/movement in Alaska, including, but not limited to, the Nelchina, Forty-mile, Delta, Western Arctic, and Central Arctic Caribou Herds. Population declines—including the dramatic reduction of the Delta Herd to 41% of its minimum population goal target as of the most recent estimates (Young Jr. 2015)—have occurred, but climatic factors and predation have been suggested as more likely culprits than development (Valkenburg et al. 1996).

The latest population abundance estimate for the Central Arctic Herd, which has been exposed to the greatest amount of infrastructure and displacement from historic calving range, shows a major decline in the last several years, decreasing below the minimum management guideline (see Figure 5). However, the long-term nature of caribou population fluctuations compounded with the lack of pre-development data make it difficult to identify a proximate cause of any particular increase or decrease (Cronin et al. 1998b, Vors et al. 2007), and similar declines have been noted in the Western Arctic Herd and the Teshekpuk Caribou Herd (Parrett 2015, Parrett 2016).

Previously, some researchers have cited record high caribou populations in the 1990s and 2000s despite decades of exposure to roads, pipeline, gravel pads, and vehicle and aircraft traffic to emphasize the narrative of compatibility between oil development and caribou (Cronin et al. 2000, Lenart 2011). However, the recent major declines in three of the four Arctic caribou herds highlight the significant uncertainty around population dynamics. To date, anthropogenic habitat change in Alaska may have been insufficient to cause irreversible declines, but these circumstances could vary among different herds (Griffith et al. 2002), different development densities (Sorenson et al. 2008), and changing vegetation and precipitation regimes (Murphy et al. 2010).

Key Point: There is scientific consensus that roads and other linear infrastructure have individual-level impacts on caribou, mediated by gender, season, and other factors. Historically, these impacts have been interpreted as insignificant due to herd population increases. Now that three of the four Arctic caribou herds are declining, the cumulative impacts of oil development on caribou should be re-examined.

Additionality

The ecological impacts of the mode of access should be considered based on the principle of additionality. Additionality refers to what impacts would occur beyond the baseline of what would already occur in a no-action alternative. For example, there are a number of development-related flights within the North Slope as part of routine transportation of people and materials for existing drill sites. These baseline flights likely already have ecological impacts. In terms of aircraft-related wildlife disturbance, the impact of new flights used for development of a proposed drilling pad may not have significant additionality if the baseline for disturbance is already high.

Using the most recent estimates available, without any additional drilling or construction, there are already about 2,997 flights per year (8.2 flights per day) that land or take off from the Alpine Central Processing Facility (Bureau of Land Management 2014). The majority of these baseline flights occur from May to September, the short summer window on the North Slope. For road-based development of an additional drill site, significant numbers of aircraft would still be utilized: about 3,193 flights would occur per year (8.8 flights per day), an increase of about 0.6 flights per day or 6.5%. For roadless development of the same drill site, there would be about 3,645 flights per year (10 flights per day), an increase of about 21.6% from the baseline or 1.8 flights per day (Bureau of Land Management 2014).

If there are already 8.2 aircraft per day passing overhead in a given area, it remains to be seen whether an additional 1.8 aircraft per day would exceed a hypothetical ecological threshold and cause more disturbance to nearby wildlife. Furthermore, current methods of both road-based and roadless access involve some level of increased aircraft traffic. The small relative increase in flight traffic associated with aircraft-based development may not incur significant additional impacts, and whatever impacts occur may be offset by the associated reduction in road density and vehicle traffic. A comparison of flight traffic across baseline, road-based, and aircraft-based development scenarios is shown below in Figure 9.

Key Point: There are already very high levels of aircraft traffic on the North Slope. The additional flights required to implement roadless access may not be ecologically significant, while affording a significant reduction in miles of road needed to access oil wells and facilities.

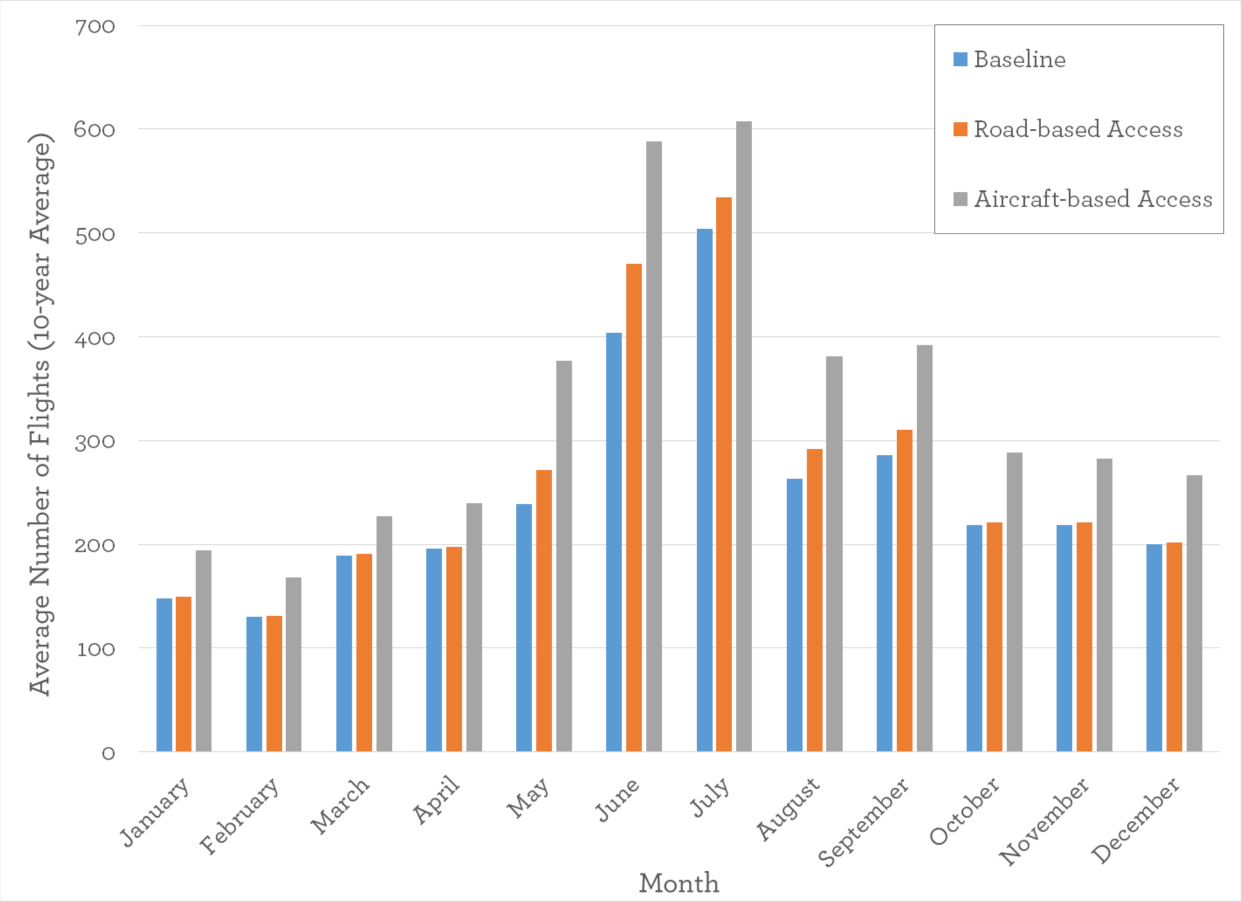


Figure 9. Average number of monthly flights landing or taking off from Alpine Central Processing Facility. Baseline (blue bars) represents flights that occur regardless of whether new development occurs; road-based access (orange bars) represents flights that would occur with primarily road-based construction, drilling, and operation; and aircraft-based access (gray bars) represents flights that would occur if aircraft were the only means of site access (besides seasonal ice roads). Extrapolated from Table 2.8-5 in the GMT1 Supplemental Environmental Impact Assessment (SEIS) to examine first ten years of project (Bureau of Land Management 2014).

Quantifying Extent of Impact

Using estimates from the same drill site (Bureau of Land Management 2014), construction would add about 80,621 vehicle trips per year (220.9 trips per day), decreasing to 26,675 vehicle trips per year (73.1 trips per day) for the operation phase of the project. Many of these trips – an average of 1,929 trips per month (63 trips per day) – would occur from May to September every year during the operation phase. Under an aircraft-based development scenario, the only vehicle traffic would be between the residential facility, the airstrip, and the pad, a 1.3-mile (2.1 km) distance at most (Bureau of Land Management 2014). Table 5 summarizes relative impacts between the two modes of access.

Metric	Mode of Access	
	Road-based	**Aircraft-based**
Gravel Footprint (acres)	87.0	72.7
Flights per Day	0.5	1.8
Vehicles per Day, Ice Roads (January – April)*	374.7	457.0
Vehicles per Day, Gravel Access Roads (May – December)	66.3	0.0

*Table 5. Intensity of development between road-based and aircraft-based access for key metrics. Vehicle traffic split by road type: from January through April, vehicles move along ice roads, and from May through December, vehicles move between pads along gravel roads. In the aircraft-based scenario, traffic would move between the airstrip, the gravel pad containing residential facilities, and the drilling pad when ice roads are not available. *: after gravel roads are constructed in the road-based scenario, vehicles would no longer utilize the ice roads and instead use the gravel roads. Adapted from Table 2.8-4 in the GMT1 SEIS (Bureau of Land Management 2014).*

Community Resource Use

Subsistence use of resources by Arctic communities is largely outside the scope of this wildlife-focused report. Certainly, gravel roads may extend access into new areas (Guettabi et al. 2016) and aircraft overflights may disturb efforts to harvest resources (Bureau of Land Management 2015). However, due to the paramount importance and complexity of subsistence access and maintaining sustainable harvest levels, communities should be consulted directly to address these issues.

Conservation Recommendations

Roadless access has substantial yet less pernicious ecological impacts than road-based access, based on this summary of ecological, spatial, and temporal extent of effects, population-level effects, and additionality. Incremental increases in air traffic to achieve an associated reduction in road density and vehicle traffic appears to be the more ecologically sound approach to development.

Design Criteria for Roads

Existing best management practices (BMPs) for roads may be ineffective at reducing ecological impacts. BMP E-7 requires road design to provide for "free movement of caribou (Bureau of Land Management 2013)," although, as found by Wilson et al. (2016), some caribou cannot pass certain road types freely or without delay. Through the process of applying for deviation from BMPs, BLM recommendations may be circumvented on the grounds of economic viability. Development and enforcement of more stringent lease stipulations and BMPs outside of special areas will better conserve critical migration routes.

Because roads have a lasting impact (Walker et al. 1987), planning and permitting processes should carefully consider placement and should consider them to be semi-permanent, long-term development. Additionally, due to the critical importance of hydrological connectivity for freshwater fish (Heim et al. 2015), roads must be designed to facilitate fish passage and should be regularly maintained to ensure that fish migration is not compromised.

Spatially Explicit Planning

The broad-scale site fidelity across taxa means that certain regions of the Arctic are more biologically important to a given species than other regions. Current BLM management, such as the Integrated Activity Plan (IAP), allows oil and gas leasing in certain areas and restricts development in special areas identified as ecologically important (Bureau of Land Management 2013). Such spatially explicit planning efforts help ensure that resource extraction and biological conservation remain compatible. Future environmental assessments and development plans should follow similar scientific, ecological, and spatial guidance.

Fish Passage and Hydrology

A variety of BMPs are in place to protect fish habitat and hydrologic regimes. Some are specific restrictions on water withdrawals, particularly in the winter (BMPs B-1 and B-2), some relate to facility construction (BMP E-2), and others refer to specifics of culvert design (E-14). This study does not analyze the engineering adequacy of these recommendations, although the mention of these considerations appears to be a good sign. However, the BLM explicitly states that in their mission to maintain ecologically functioning rivers, infrastructure crossings would not be made "impracticable or non-economic (Bureau of Land Management 2013)," suggesting that economics may overrule ecological best practices.

Caribou Population Management

The Alaska Department of Fish and Game, tasked with managing caribou populations on the North Slope, has set a series of goals related to population status. Two of the three goals for the Central Artic Herd is to minimize the adverse effects of development on caribou and provide the opportunity for a subsistence harvest (Lenart 2015). These goals are operationalized based on explicit population targets

("Maintain a population of at least 28,000–32,000 caribou") and more general statements ("Maintain accessibility of seasonal ranges for CAH caribou") (Lenart 2015). The current Central Arctic Herd population estimate is 22,000 individuals, below the management goal and threatening future harvest opportunities (Lenart 2016). Research suggests that calving caribou have been displaced by oil development (Cameron et al. 1995, Wolfe et al. 2000), so seasonal accessibility has been compromised for decades. However, because the population status had previously not been imperiled, no action had been merited (Cronin et al. 1998b). Now, in the face of new evidence of herd-level declines across all three Arctic herds that regularly migrate through areas with human infrastructure, the assumption that oil development and caribou habitat suitability are compatible should be critically re-examined.

Flight Altitude Best Management Practices

Generally, maintaining a 4,000-foot (1,219 m) lateral and 4,000-foot (1,219 m) vertical buffer between aircraft and known concentration areas may mitigate impacts to molting birds and greater than 2,000 vertical feet (610 m) may mitigate impacts to calving caribou. Although this suggested caribou mitigation buffer is equivalent to the BLM recommendations, the bird mitigation buffer is significantly greater than BLM's recommended distances.

As part of the Integrated Activity Plan, the BLM generated a series of BMPs regarding aircraft overflights (Bureau of Land Management 2013). The BLM recommends maintaining a minimum altitude of 2,000 feet (610 m) over goose molting areas and caribou calving grounds during the summer (for both the Western Arctic Herd and Teshekpuk Herd; BMP F-1e and BMP F-1f); 1,000 feet (305 m) over caribou wintering areas (BMP F-1b); and 1,500 feet (457 m) in altitude and 0.5 mile (0.8 km) laterally from raptor nests (BMP F-1a). For marine mammal haulouts, the BLM recommends minimum distances of 3,000 feet (914 m) in altitude and 1 mile (1.6 km) laterally from seal aggregations (BMP F-1i); 3,000 feet (914 m) in altitude and 1 mile (1.6 km) laterally from walrus with helicopters (BMP F-1h); and 2,000 feet (610 m) in altitude and 0.5 mile (0.8 km) laterally with fixed-wing aircraft (BMP F-1h). With the exception of the goose molting altitudinal buffer, the BLM's BMPs for aircraft avoidance align with available scientific literature.

Exceptions to Best Management Practices

Exceptions to these BMPs can be made and compromise otherwise carefully designed mitigation practices. The Integrated Activity Plan leaves it up to future discussion to define "essential pipelines and road crossings" (BMP E-2) and where a separation of 500 feet between road and pipeline is not considered feasible (BMP E-7c). As seen in the Greater Mooses Tooth 1 plan, the first approved oil production project includes deviations from both of these BMPs as well as the widely accepted 7 foot (2.1 m) minimum pipeline clearance above ground (Bureau of Land Management 2015). If these regulations are to be effective, they must be enforced consistently on the basis of ecological, not economic, realities.

Conclusion

The findings, data, and literature reviewed in this report are applicable to any development projects that may arise on the Arctic landscape, whether they occur on federal, state, or private land. As indicated by near-record bidding in December 2016 for the lease tracts just south of the Teshekpuk Lake Special Area, oil industry interest on the North Slope continues to intensify. Non-drilling proposals and potential projects—primarily, a potential trans-NPRA pipeline from Smith Bay and a proposed road to the Ambler mining district—may also involve significant ecological impacts. Comprehensive regional planning should ensure that the cumulative effects of such projects are accounted for. Mitigation measures, best management practices, and environmental impact statements should adequately evaluate the range of access-related ecological impacts. Finally, further expansion of the industrial network of pipelines, gravel pads, and roads merits an explicit assessment of the cumulative impact of the spatial configuration of infrastructure with regard to wildlife movements.

Acknowledgements

This work was funded by the Wilburforce Foundation. This project was conceived by Melanie Smith, Nils Warnock, Jim Adams, Stan Senner, and Rosa Meehan. Melanie Smith, Nils Warnock, and Susan Culliney made significant contributions to research and synthesis. Lois Epstein, Debora Nigro, and Lincoln Parrett reviewed this report and provided invaluable feedback.

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ECOLOGICAL IMPACTS OF ROAD- AND AIRCRAFT-BASED ACCESS TO OIL INFRASTRUCTURE

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