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Prioritizing habitats based on abundance and distribution of molting waterfowl in the Teshekpuk Lake Special Area of the National Petroleum Reserve, Alaska

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ABSTRACT

The National Petroleum Reserve in Alaska (NPR-A) encompasses more than 9.5 million hectares of federally managed land on the Arctic Coastal Plain of northern Alaska, where it supports a diversity of wildlife, including millions of migratory birds. Within the NPR-A, Teshekpuk Lake and the surrounding area provide important habitat for migratory birds and this area has been designated by the Bureau of Land Management as the Teshekpuk Lake Special Area (TLSA) because numerous waterfowl species use the area for breeding and molting. Our goal was to provide a mechanism for land managers to assess relative value of areas for molting waterfowl. This approach was based on the population densities of Pacific black brant (*Branta bernicla nigricans*) and cackling geese (*Branta hutchinsii*) and pre-defined thresholds for the minimum fraction of the population contained within selected areas. Prioritizations were based on long-term records of population density combined with global-positioning system data to reveal small-scale patterns of habitat use. The highest population density of the Pacific black brant was found along the Beaufort Sea coast on the eastern edge of the study area, whereas cackling geese were somewhat more widely distributed. Depending on the criteria used for prioritization and width of protective buffers placed around selected units, 52–85% of the Goose Molting Area was identified as high-priority area. The effectiveness of this approach to protection of molting birds assumes that buffers around high value units are wide enough to provide adequate protection from disturbance related to oil and gas development.

1. Introduction

The National Petroleum Reserve in Alaska (NPR-A) encompasses more than 9.5 million hectares (ha) of federally managed land on the Arctic Coastal Plain (ACP) of northern Alaska, USA, where it supports a diversity of wildlife, including millions of migratory birds. The Bureau of Land Management (BLM) is responsible for regulating the use, occupancy, and development of federal land in the NPR-A to protect wildlife and mitigate the negative effects of oil and gas leasing (Bureau of Land Management, 2015). Within the NPR-A, construction of the first oil-production facility was initiated in 2015, and active leasing and exploratory operations show potential for future oil and gas development (Bureau of Land Management, 2015). The ACP is largely undeveloped and sparsely inhabited,

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raising concerns about the effects of human activities on the area's abundant wildlife. Potential effects of industrial activity could be indirect (such as loss of habitat, increased predator abundance through construction of infrastructure) or direct (such as disturbance, displacement of birds caused by human activities), but little is known about the potential magnitude of such effects in undeveloped regions of the Arctic (Hockin et al., 1992; National Research Council, 2003; Liebezeit et al., 2009; Meixell and Flint, 2017). Management agencies are tasked with issuing permits for hydrocarbon extraction and the associated infrastructure, while minimizing disturbance to wildlife. To accomplish this task, managing agencies require a detailed understanding of the abundance, population trends, and spatial distributions of species during key periods in annual cycles, such as the breeding and molting periods for birds.

Waterfowl undergo a flightless period during their post-breeding molt, and flightless birds are potentially more susceptible to the negative effects of anthropogenic disturbance (Fox et al., 2014). Molting birds have high energy requirements because they need to acquire nutrients necessary for feather production (Fox et al., 2014). If anthropogenic disturbances exclude molting waterfowl from high-quality feeding areas with adequate access to safety, birds may experience decreased survival and increased risk of depredation. The BLM has designated the area of the NPR-A around Teshekpuk Lake as the Teshekpuk Lake Special Area (TLSA), which typically hosts a large percentage of the Pacific black brant population (referred to as black brant; *Branta bernicla nigricans*) during molt each July (Bollinger and Derksen, 1996). Additionally, numerous other waterfowl species use the area for breeding and molting, including greater white-fronted geese (*Anser albifrons*), snow geese (*Chen caerulescens*), cackling geese (*Branta hutchinsii*), and tundra swans (*Cygnus columbianus*; Flint et al., 2008). The landscape of the TLSA is changing rapidly due to permafrost thaw and coastal erosion, which has led to increased saltwater incursion into freshwater habitat (Tape et al., 2013). Concurrent with these landscape changes, waterfowl species have changed in distribution and abundance (Flint et al., 2008; Amundson et al., 2019). Greater white-fronted geese have become seven times more abundant over three decades, whereas the black brant population has remained stable but shifted towards coastal habitat with salt-marsh plant communities (Flint et al., 2008).

The 2008 BLM Record of Decision (ROD; Bureau of Land Management, 2008) proposed opening the TLSA for petroleum development by leasing large blocks of land and defining specific sections of the "Goose Molting Area" where no anthropogenic surface occupancy would be allowed (Fig. 1). The 2008 decision nominally relied on molting-goose distribution data, but the process by which the data were used to determine the area proposed for "no surface occupancy" was not delineated in the document. This plan was superseded by the 2013 ROD (Bureau of Land Management, 2013), in which the TLSA was expanded from 1.75 million acres to 3.65

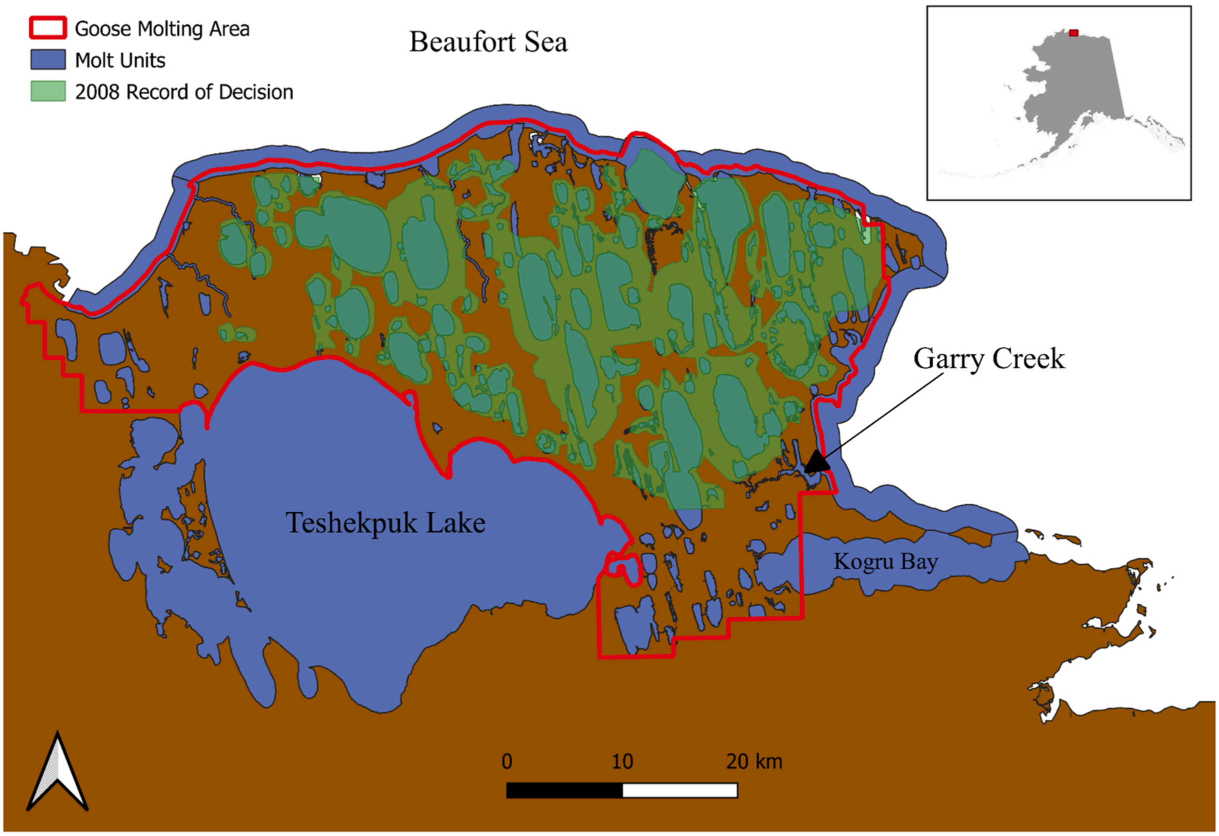

Fig. 1. Map showing the designated Goose Molting Area (tan color with dashed line boundary; 0.45 million acres) within the Teshekpuk Lake Special Area of the National Petroleum Reserve—Alaska. Areas in green designate "no surface occupancy" from the 2008 Record of Decision (Bureau of Land Management, 2008). Blue polygons indicate molt units, which are connected groups of lakes or regions of the coast used as habitat by molting geese. Two coastal molt units (Garry Creek and Kogru Bay) used as molting habitat by Pacific black brant have been labeled on the map.

million acres. Within this expanded footprint, 3.1 million acres were designated unavailable to leasing and exploratory drilling, and 1.1 million acres were also designated as off limits to new infrastructure, including pipelines. The entire Goose Molting Area was contained within this 1.1-million-acre zone with maximum restrictions on surface development. In these two examples, decisions were made regarding land use alternatives without ever stating clear management goals or outlining the approaches used to achieve the outcome.

Our goal in this paper was to develop an objective, science driven and adaptable approach to defining and prioritizing habitats for special status relative to development activities in the TLSA. The basic process involved identification of all relevant data, a priori determination of objectives, and application of GIS to define the areas that meet the objectives (Doherty et al., 2011). The key objective was to define a means to identify the minimum area that would meet the management goals in terms of the proportion of the population contained within the high priority area (Rainho and Palmeirim, 2013). This process was used to inform a new ROD, issued in 2020, which reduced the no surface occupancy designation to a series of fixed buffers and a targeted sub-set of lakes that were selected based on molting goose density (Bureau of Land Management, 2020).

2. Materials and methods

2.1. Description of available data

Molt Survey Data. Molting-waterfowl survey data consist of more than 30 years of aerial counts done by the U.S. Fish and Wildlife Service, Division of Migratory Bird Management, Alaska Region (Flint et al., 2008; Shults and Zeller, 2017). These surveys were done annually in approximately mid-July during the peak of flightless molt for waterfowl in the TLSA. As the pilot and observer fly over the study area, they count waterfowl observed on or near each specific body of water. However, geese respond to aircraft disturbance by running to the nearest body of water, so almost all birds were observed as swimming in a lake. Thus, the observations do not accurately describe how birds are distributed at a local scale when undisturbed.

Transmitter derived Lakeshore-Use Data from Black Brant and Greater White-Fronted Geese. Molting geese use the surface waters of the lakes in the TLSA as escape and roosting habitat, and they feed along the shorelines of these lakes (Lewis et al., 2011; Flint and Meixell, 2017), so we used Global Positioning System (GPS) location data for flightless black brant (Lewis et al., 2011) and greater white-fronted geese (Flint and Meixell, 2017) to account for fine-scale spatial patterns of terrestrial-habitat use around lakes. In these datasets, undisturbed molting black brant were located an average of 31 m inland from the lakeshore, whereas greater white-fronted geese were located an average of 63 m inland when flightless. The maximum distance from a lakeshore recorded for undisturbed molting black brant was approximately 800 m (Lewis et al., 2011), while molting greater white-fronted geese traveled a maximum distance of 1070 m over land from the nearest lakeshore in the absence of external disturbance (Flint and Meixell, 2017).

2.2. Analysis

The molting-waterfowl survey dataset was based on a long-term study design where individually identified lakes were surveyed and the number of birds counted. Many of these lakes are interconnected and flocks of molting geese can move collectively among lakes from one day to the next. For all spatial analyses, we identified sets of interconnected lakes from satellite imagery and defined them as unique molting units (MUs). The survey count for each MU was the sum of the survey counts for each interconnected lake. Using this approach, we identified 139 MUs in the Goose Molting Area delineated by the 2013 ROD. Because the number and distribution of molting geese has been changing over time, we restricted our analysis to aerial survey data from 2010 to 2016 to indicate how molting birds are currently distributed in the TLSA. We calculated the average density of each bird species for each MU over these years.

We derived a GIS layer of MUs by merging our defined MU's with lake polygons from the NHDwaterbody layer produced by the National Hydrography Dataset for Hydrographic Unit (HU) 1906 (U.S. Geological Survey, 2019). At BLM's request, we first created fixed spatial buffer areas that extended 1.6 km (1 mile) inland from the Beaufort Sea coast, including all major bays and estuaries, and 4.8 km (3 miles) along the shoreline of Teshekpuk Lake using GIS tools from the rgeos and rgdal packages in R (Bivand et al., 2019; Bivand and Rundel, 2019, R Developement Team, 2019). These fixed buffer areas included lands that were considered high priority for reasons other than waterfowl density (for example, protection of habitat for caribou). If most of a MU was included in these fixed buffer areas, we considered the entire MU to be covered by the buffer. We calculated the total areas of these buffers and the proportion of each species within them. We then ranked the remaining MUs in terms of the average densities of black brant and cackling geese (separately) and determined the minimum number of molting units that accounted for 75–90% of the total number of birds for each species. This approach provided a series of data layers that represented different levels of population coverage for the priority areas in the TLSA.

2.3. Molt-unit buffers

The MUs represent the lake areas surveyed, but geese forage along the shoreline habitats of these lakes (Lewis et al., 2011; Flint and Meixell, 2017). Using GIS, we added buffer areas to the perimeter of the lake-defined MUs to include the shoreline habitats that are used by molting birds. For any given set of MUs, we created 0.8 km buffers along the shoreline of the water bodies within the MUs, which represented the likely extent of lakeshore habitat used by undisturbed black brant (Lewis et al., 2011). We also created a set of 1.6 km buffers, which included the region of lakeshore feeding habitat as well as an additional 0.8 km buffer to account for the potential sensitivity of molting waterfowl to disturbance at a distance. For each set of buffers, we calculated the total area included within the boundaries of the Goose Molting Area in the TLSA (based on the 2013 ROD), and the proportion of each species (black brant, cackling geese, snow geese, white-fronted geese and tundra swans) that was observed within the selected area. While some molt-unit buffers, including the buffer around Kogru Bay, extended outside of the Goose Molting Area boundaries, we only report the area of buffers included within the Goose Molting Area in the results. Buffers were not truncated in any of the output maps even if a MU extended outside of the original Goose Molting Area boundary.

3. Results

The fixed buffer along the coastline included more than 30% of the molting black brant population and more than 45% of the snow goose population (Table 1). Within this buffer, the MU surrounding the inlet of Garry Creek (see Fig. 1) accounted for an average of 29% of the total black brant population that was using the Goose Molting Area. The larger buffer along Teshekpuk Lake included less molting habitat than the coastline buffer and significant numbers (>10%) of only greater white-fronted geese and tundra swans (Table 1).

Because geese are not randomly or uniformly distributed across the landscape, the proportion of the molting population included in any given sub-set of the area was greater than the total proportion of area in the sub-set (Table 2). Proportional coverages of black brant and cackling geese were similar when molting units were prioritized by cackling goose density (Fig. 2). Maps of the highest priority areas make it clear that black brant and cackling geese were primarily distributed in the Northeastern part of the goose-molting area (Fig. 3); however, prioritizations based on black brant versus cackling geese led to different levels of protection for non-target species (Table 2). Specifically, the area that included 85-percent of the cackling geese would have placed surface-occupancy restrictions around MUs containing 81% of black brant, 74% of snow geese, and 65% of greater white-fronted geese, whereas a area that included 85-percent of the black brant- would cover only 56% of snow geese and 48% of greater white-fronted geese (Table 2). Cackling geese and black brant were both widely distributed throughout the Goose Molting Area, and an area that included 90% of either black brant or cackling geese would occupy nearly all available surface area (Table 2, Fig. 3).

4. Discussion

The scenarios in this report represent potential surface-occupancy restrictions on 954–1576 km^2 within the Goose Molting Area (52–85% of surface area in the Goose Molting Area, or 6–10% of the total surface area in the 2013 ROD boundaries of the TLSA), depending on the choice of target objective. The maps we developed represent the minimum area used by the stated percentage of geese, which was determined for the most recent years when complete aerial surveys were conducted over the entire Goose Molting Area (2010–2016). Molt units were selected for priority classification based on pre-defined objective criteria (i.e., the population density of a desired species), a method that is efficient in terms of area required, objectivity, and repeatable. Although cackling geese were distributed similarly to black brant, they were more widely dispersed, and prioritization focused on black brant required a smaller area to reach a given threshold of population coverage for the target species; however, prioritization focused on cackling geese was more broadly inclusive of other species. Although the primary goal of the TLSA is to provide habitat protection for molting black brant, prioritization based on black brant habitat might not be the optimal strategy for protecting all other species of waterfowl in the area. These results highlight the importance of defining clear management priorities when designating land for development restrictions.

Regardless of the focal species used, the stated level of protection (percentage of population) for each scenario depends on the assumption that the buffers around MUs are wide enough to both allow access to grazing habitat and eliminate the negative behavioral and energetic consequences of disturbance. Limited data are available to evaluate this assumption for molting waterfowl in the TLSA, and our results should be interpreted with this caveat in mind. Buffers that include 0.8 km around selected MUs are likely to cover more than 90% of the grazing habitat used by geese (Lewis et al., 2011; Flint and Meixell, 2017). These buffers, however, may not be sufficient to prevent molting flocks from responding to disturbance from industrial activity. Based on experimental overflights, Jenson

Table 1
Numbers and percentages of goose and swan populations included in fixed buffers along the coastline (1.61 km width) and the shore of Teshekpuk Lake (4.83 km width).

Fixed Buffer[a]		
	Coastal	Teshekpuk Lake
Area with 0.8 km molt-unit buffers	344.37 km^2 (19%)	406.13 km^2 (22%)
Area with 1.6 km molt-unit buffers	358.13 km^2 (19%)	459.68 km^2 (25%)
Number of black brant	5157 (31%)	88 (1%)
Number of cackling geese	1122 (8%)	446 (3%)
Number of snow geese	3572 (46%)	203 (3%)
Number of greater white-fronted geese	3592 (9%)	3946 (11%)
Number of tundra swans	16 (6%)	75 (27%)

2. Area covered by a given fixed buffer in addition to 0.8 km or 1.61 km buffers placed around all molt units that were partially covered by that fixed buffer (greater than; 50-percent overlap). Values in parentheses are percentages of the Goose Molting Area inside the Teshekpuk Lake Special Area that is included in a buffer.

a . Fixed buffers were included in all analyses if a majority of the MU was within the buffer.

Table 2
Total area contained in the selected area and numbers and percentages of goose and swan populations included in selected layers based on thresholds that include 70–90% of the total population.

Priority Species[a] Threshold[b]	BLBR 75%	CACG 75%	BLBR 80%	CACG 80%	BLBR 85%	CACG 85%	BLBR 90%	CACG 90%
Area (^{km2})with 1.6 km buffer[c]	1135.2	1351.36	1181.1	1390.19	1294.77	1480.1	1449.83	1575.65
(%)[d]	(62%)	(73%)	(64%)	(75%)	(70%)	(80%)	(79%)	(85%)
Area (^{km2}) with 0.8 km buffer	953.64	1126.24	990.36	1156.11	1078.27	1244.6	1199.51	1342.12
(%)	(52%)	(61%)	(54%)	(63%)	(58%)	(67%)	(79%)	(85%)
Black brant	12,442	12,924.4	12,970	13,469.1	14,106.7	13,587	15,016.2	14,477.1
(%)	(74%)	(77%)	(77%)	(80%)	(84%)	(81%)	(90%)	(86%)
Cackling goose	5650.5	9967.7	7178.9	10,270.2	8496.4	11,129	9251	11,940.2
(%)	(42%)	(75%)	(54%)	(77%)	(64%)	(83%)	(69%)	(89%)
Snow goose	4063.4	5309.2	4099.7	5316.9	4418.3	5790.8	4712.7	5974.3
(%)	(52%)	(68%)	(52%)	(68%)	(56%)	(74%)	(60%)	(76%)
Greater white-fronted goose	12,720	20,264.6	13,684	20,957.5	17,151.8	23,451	19,070.8	24,853.8
(%)	(35%)	(56%)	(38%)	(58%)	(48%)	(65%)	(53%)	(69%)
Tundra swan	111.7	134.8	114.8	138.2	123.4	148	131.8	152.0
(%)	(41%)	(49%)	(42%)	(50%)	(45%)	(54%)	(48%)	55%)

[a] Species codes are BLBR:black brant, CACG:cackling goose.
[b] Percentage of the molting population included within the selected area.
[c] This includes buffers around all selected molt units as well as the area of the 1.61 km fixed buffer along the coast and the 4.83 km fixed buffer along the shore of Teshekpuk Lake. Both fixed buffers were included in all scenarios.
[d] Percentage of the Teshekpuk Lake Special Area that is included in a buffer.

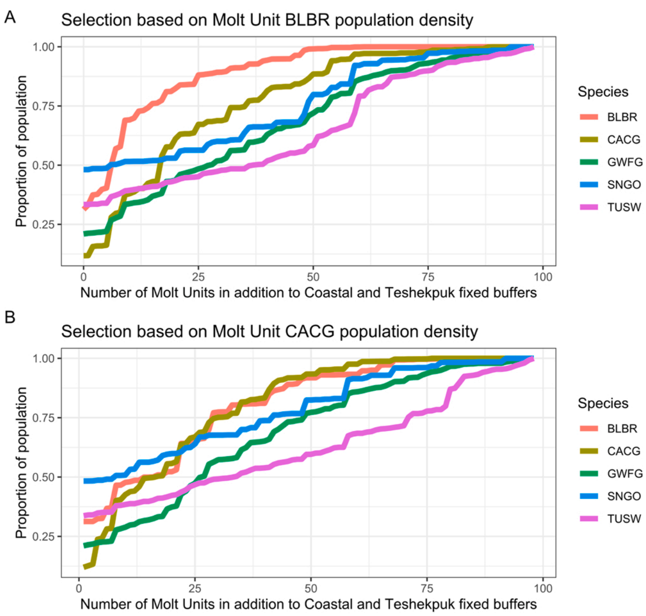

Fig. 2. Cumulative proportion of geese and swans included when molt units in the Goose Molting Area of the Teshekpuk Lake Special Area were selected based on population density of black brant (BLBR; panel A) and cackling geese (CACG; panel B). Molt unit prioritization was based on population density of a given species to ensure that the desired population threshold could be achieved using the minimum number of molt units. These graphs represent the relative gain by adding molt units to pre-defined Coastal and Teshekpuk Lake buffers. The proportions represented when zero molt units are included represents the birds occurring within the two fixed buffers. Species abbreviations are black brant (BLBR), cackling goose (CACG), greater white-fronted goose (GWFG), snow goose (SNGO), and tundra swan (TUSW). The stated levels of population coverage assume that the buffers around molt units are wide enough to alleviate behavioral and energetic consequences of disturbance.

(1990) concluded that molting flocks of flightless black brant can react to an airborne helicopter that is up to 3.5 km away. Flocks frequently ran more than 100 m towards the nearest water body in response to an approaching helicopter, and geese have remained swimming for up to 45 min before returning to land (Jensen, 1990). Computer simulations based on those findings indicated that molting black brant exposed to more than 50 overflights per day could experience significant weight loss (potentially reducing their survival probability), although these effects could be reduced by the use of smaller aircraft flying at an elevation above 600 m (Miller et al., 1994). In a separate study, Derksen et al. (1982) noted that molting black brant flocks subjected to multiple aircraft disturbances could respond by swimming as far as 3 km. Molting geese are easily disturbed by field biologists on foot as far as 500 m away (Derksen

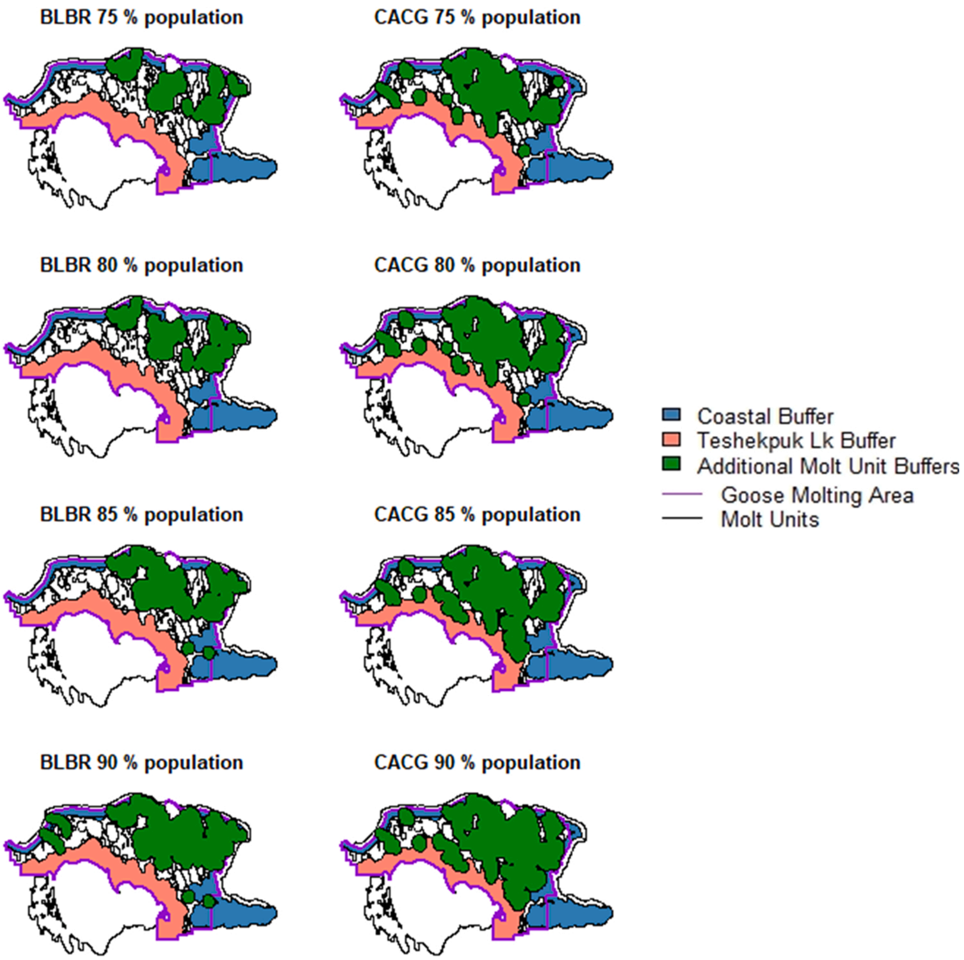

Fig. 3. Maps showing selected priority habitats for black brant and cackling geese northeastern part of the goose-molting area, Teshekpuk Lake Special Area of the National Petroleum Reserve, Alaska. The title for each map describes the prioritization used for each specific map. For example, "BLBR 75-percent population" represents the minimum area that included 75% of the black brant population counted in the Goose Molting Area of the Teshekpuk Lake Special Area (TLSA) between 2010 and 2016. Each scenario included fixed coastline and Teshekpuk Lake buffers, with 1.6 km buffers added around molt units selected to achieve the stated level of coverage. The stated level of protection for each scenario in this report assumes that the buffers around molt units are wide enough to alleviate behavioral and energetic consequences of disturbance. (black brant, BLBR; cackling goose, CACG).

et al., 1982). They could also be sensitive to visual and auditory disturbance caused by industrial activity on the ground, such as processing facilities, construction, and road traffic, but we are unaware of studies that would allow us to estimate the magnitudes of those effects. Because of the limited available data, it is not clear whether 0.8 or 1.6 km around selected MUs would be sufficient to completely eliminate disturbance effects. These studies suggest a need for additional investigation into how development might affect the behavior, energetics, and population dynamics of molting waterfowl in the NPR-A.

Evaluation of the scenarios outlined in this report should consider the fact that molting goose populations in this area are changing in numbers and/or distributions. As of 2008, snow and white-fronted geese were increasing in abundance, whereas black brant and cackling geese numbers were stable (Flint et al., 2008). At the conclusion of their study, Flint et al. (2008) found that black brant had moved away from inland freshwater lakes and were primarily molting along the coast in estuarine waters. The distribution of MUs with high black brant population density described in this report suggests that this pattern has continued in more recent years. Between 2010 and 2016, a single coastal MU (the Garry Creek Estuary) hosted almost 30% of the black brant population despite occupying less than 1% of the total surface area in the Goose Molting Area. The methods outlined here could be used to account for future population dynamics by selecting MUs based on increasing or decreasing trends rather than current distributions.

The non-uniform distributions of black brant and cackling geese results in a non-linear response of diminishing returns as the proportion of the population included in the selected area increased (Fig. 2). Because molt units were selected based on rank density, and density was not uniform across the study area, the functional curve asymptotically approaches 100% coverage. This implies that the relative value of the last unit selected is less than the first. The same is not true for other species that were more uniformly distributed where the relative value of molt units differed little regardless of the threshold used. We developed this approach by selecting high-priority habitat for a single species at a time but selecting for multiple species simultaneously could be chosen as a more generalized method. We focused our analyses on black brant, which is a high-priority species in the TLSA; however, habitat protections based on the distribution of black brant appear includes molting areas used by other waterfowl species under the concept of using black brant as an "umbrella species" (Gamo et al., 2013).

The scenarios we used were not designed to identify habitat used by waterfowl during the breeding season. A recent study found that industrial activity had little influence on the behavior of nesting white-fronted geese (Meixell and Flint, 2017). However, the Teshekpuk Lake region is used as nesting habitat by a variety of duck and goose species—including the Spectacled Eider (*Somateria fischeri*), a species listed as threatened under provisions of the Endangered Species Act—that may have different sensitivities to disturbance. The general approach we used could be expanded to include nesting data but weighting factors would have to be used since breeding occurs at a far lower density than molting.

5. Conclusions

We have described an objective approach to defining priority habitats within the Goose Molting Area of the TLSA based on available data. This approach is dependent on three key criteria: (1) define any areas previously designated as protected for reasons not related to molting waterfowl, and quantify their value as molting habitat; (2) define the goals of the habitat-prioritization process in terms of species and proportions of population that should be protected; and (3) choose the buffer size to be included around additional habitat units on the basis of available data and a clear biological rationale (for example, protection of grazing habitat and(or) reduction of disturbance effects on molting geese). Once these steps have been completed, the methods outlined in this study will allow land managers to determine the minimum area of habitat that meets all specified criteria.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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