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The grazing impacts of four barren ground caribou herds (*Rangifer tarandus groenlandicus*) on their summer ranges: An application of archived remotely sensed vegetation productivity data

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ABSTRACT

Barren ground caribou (*Rangifer tarandus groenlandicus*) herds experience significant fluctuations in abundance through time. A proposed hypothesis for these fluctuations involves the overgrazing of vegetation on herd summer ranges at high herd densities resulting in a reduction in available forage. Semi-domesticated reindeer (*Rangifer tarandus*) herds in Scandinavia negatively affect vegetation productivity at high herd densities and exclosure experiments have indicated that overgrazing may also affect barren ground caribou herds. However, overgrazing of summer range vegetation has yet to be tested at the landscape level or related to herd densities for barren ground caribou herds. Accordingly, the question examined in this study was — does barren ground caribou herd density have an effect on summer range vegetation productivity? To answer this question, summer home ranges for four herds in the Northwest Territories and Nunavut, Canada, were delineated using caribou telemetry data. Yearly overall productivity and vegetation seasonality (the change between the maximum and minimum productivity throughout the year) metrics were calculated by year using Moderate Resolution Imaging Spectroradiometer and Advanced Very High Resolution Radiometer data and related to herd densities. Overall vegetation productivity was negatively related to herd density, indicating that some summer range degradation may have occurred at high densities. Conversely, and contrary to our expectations, vegetation seasonality was positively related to herd density. The Bathurst herd, which experienced densities more than three times those of the other herds examined, had the least negative association with overall productivity. Given the negative relationship detected between each herd's densities and overall vegetation productivity, it is likely that some summer range degradation occurred as herd densities increased. Considering the results of the Bathurst herd however, it is difficult to conclude that overgrazing has been a major factor governing herd abundance in the herds examined here. This study demonstrated the utility of archived remotely sensed productivity data and how productivity indices can be useful tools for providing information on large mammal grazing impacts.

1. Introduction

Barren ground caribou (*Rangifer tarandus groenlandicus* Borowski) are the most numerous large herbivore that fulfills a portion of their life history north of the treeline in Canada's arctic and represent North America's longest-range large mammal migrant (Berger, 2004). They are typically grouped into herds which have distinct calving and summer ranges (Gunn & Miller, 1986; Schaefer, Bergman, & Luttich, 2000); winter ranges are usually larger and may overlap between neighboring herds (Schaefer et al., 2000). Barren ground caribou affect their arctic and subarctic habitats, playing an important role in modifying these environments through grazing and trampling (Manseau et al. 1996; Zamin & Grogan, 2013).

Barren ground caribou herds undergo rapid (within a few decades) large fluctuations in herd abundance (Gunn, 2003). These fluctuations are commonly loosely synchronized across herds (Vors & Boyce, 2009); however, this is not always the case (Joly, Klein, Verbyla, Rupp, & Chapin, 2011). Since the 1980s all monitored herds occurring within the Northwest Territories (NWT) have declined in abundance, in some cases by more than an order of magnitude (see Table 1 in Caribou herd size estimates section).

Overgrazing and trampling (hereby referred to as overgrazing) on herd summer ranges resulting in forage degradation have been proposed as a possible factor contributing to caribou and reindeer (*Rangifer tarandus*) herd fluctuations (Skogland, 1985; Manseau, Huot, & Crete, 1996; Tveraa, Stien, Bardsen, & Fauchald, 2013). Overgrazing

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Table 1
Abundance estimates and 95% confidence intervals from 1986 to 2013 for the four herds analyzed here (Government of the Northwest Territories data). Abundances lacking confidence intervals indicate that a full photographic census of the herd's calving grounds was conducted, therefore the number of animals counted was recorded as the herd abundance.

Year	Cape Bathurst	Bluenose-West	Bluenose-East	Bathurst
1986	13,476	88,369 ± 6889		472,000 ± 11,101
1987	12,516 ± 3504	106,887 ± 4655		
1990				351,683 ± 16,039
1992	19,278 ± 5397	112,360 ± 25,556		
1996				349,046 ± 17,519
2000	11,089 ± 1756	76,376 ± 14,347	119,584 ± 25,419	
2003				186,005 ± 8626
2005	2434 ± 257	20,800 ± 2040	70,081 ± 8120	
2006	1821 ± 149	18,050 ± 527	66,754 ± 5182	128,047 ± 5944
2009	1934 ± 349	17,897 ± 1310		31,895 ± 10,932
2010			98,646 ± 7125	
2012	2427	20,465 ± 3490		34,690 ± 9756
2013			68,295 ± 18,040	

on herd summer ranges resulting in range degradation, in particular, was suggested as contributing significantly to the decline in the George River herd in Quebec/Labrador, Canada, when the herd size exceeded 600,000 individuals (Manseau et al., 1996). Additionally, overgrazing effects have been clearly demonstrated in heavily managed reindeer herds in Scandinavia (Skogland, 1985; Tveraa et al., 2013). This hypothesis indicates that as herd densities increase, a reduction in forage quantity and/or quality occurs. Overgrazing effects were demonstrated at the plot level using exclosure experiments on caribou and reindeer summer ranges (Manseau et al., 1996; Olofsson, Moen, & Östlund, 2010) where a near doubling of certain preferred forage species' biomass was observed in one exclusion study (Zamin & Grogan, 2013). The overgrazing hypothesis has not, however, been extended from the plot to the landscape level for barren ground caribou, which is a critical step if it is to be supported or rejected as a possible cause of herd fluctuations in abundance. The recent declines of multiple herds of caribou in continental North America provides a unique opportunity for a natural experiment examining the effects of changes in herd density on productivity at the landscape scale (Zamin & Grogan, 2013) without relying on artificial exclosures.

Assessing how caribou interact with their environment presents substantial challenges. They are highly mobile species, traveling thousands of kilometers in any one year (Berger, 2004). Categorizing their environment thus requires data which are equally expansive. Additionally, caribou utilize habitat in the northern portion of Canada and in-situ data collection in Canada's tundra is both difficult and expensive. Fortunately, satellite remote sensing programs are available to address these challenges by monitoring vegetation at a global scale in a repeatable manner through time, in some cases starting in the 1970s or 1980s. In particular, the Moderate Resolution Imaging Spectroradiometer (MODIS) allows for near daily coverage of Canada's tundra ecosystems and has a suite of vegetation indices for assessing how these ecosystems are changing through time. Unfortunately, these indices are only available since satellite launch, limiting their historical archive to 2002, which does not provide a long enough sequence to detect changes occurring over longer time frames than the archive. Recent work has extended certain MODIS products back in time by correlating them with imagery acquired by older sensors with longer archives. Specifically, Fontana et al. (2012) developed relationships between reflectances observed by MODIS and the Advanced Very High Resolution Radiometer (AVHRR) to extend satellite observations from the present back to 1987. As a result, it is now possible to use remote sensing archive data to assess caribou–vegetation productivity relationships over a 27 year period dating from 1987 to 2013 using these two datasets.

An important vegetation metric calculated from the MODIS and AVHRR reflectance information is the fraction of photosynthetically active radiation (fPAR) absorbed by vegetation in a given pixel. The fPAR metric describes vegetation productivity, ranging from 0 or no light interception due to vegetation (barren ground) to 100, or complete light interception owing to vegetation (Knyazikhin, Kranigk, Myneni, Panfyorov, & Gravenhorst, 1998). In terms of vegetation, fPAR values measured throughout the growing season can describe the amount of green leaf cover within a pixel (Coops, Wulder, Duro, Han, & Berry, 2008). Currently, fPAR is employed less than vegetation metrics such as the normalized difference vegetation index (NDVI); however, when calculating gross primary productivity of above ground vegetation biomass, it is fPAR rather than NDVI that is required as a model input (Monteith, 1972).

Changes in annual fPAR can be summarized using indices such as the Dynamic Habitat Index (DHI) which has been used successfully to describe vegetation productivity in multiple studies across in Canada (Coops et al., 2008; Coops, Wulder, & Iwanicka, 2009a) and Australia (Berry, Mackey, & Brown, 2007). While originally applied as an index to describe plant communities (Coops et al., 2009a; Fitterer, Nelson, Coops, & Wulder, 2012) and animal diversity (Coops, Wulder, & Iwanicka, 2009b; Andrew, Wulder, Coops, & Baillargeon, 2012; Fitterer, Nelson, Coops, Wulder, & Mahony, 2013; Rickbeil, Coops, Drever, & Nelson, 2014b), DHI is also a useful predictor of individual coastal bird species distributions (Rickbeil et al., 2014a) and for describing forage conditions for moose (*Alces alces*) in Ontario, Canada (Michaud et al., 2014). The DHI estimates three components of landscape productivity — the yearly sum or overall productivity, the seasonality (the change between the maximum and minimum productivity throughout the year), and the minimum annual productivity (not considered here as all arctic vegetation goes to 0 in terms of fPAR values owing to the short growing season). The yearly overall productivity metric relates to the amount of photosynthetically active plant biomass in a given pixel (Coops et al., 2008; Coops, Fontana, Harvey, Nelson, & Wulder, 2014). The seasonality metric offers a means to evaluate changes in variability in vegetation productivity, which is especially important in arctic environments where plant green up and senescence occurs quite rapidly.

The decline of multiple caribou herds within the NWT as well as the development of long term productivity data presents an opportunity to examine how caribou herd densities and vegetation productivity interact. Specifically, we asked the following question — is caribou density related to summer range vegetation productivity at the landscape scale? We hypothesize that: (1) caribou density will be negatively related to overall vegetation productivity, and (2) caribou density will be negatively related to vegetation seasonality; both effects being attributed to a reduction in annual vegetation productivity due to grazing pressure. Lastly, (3) we expect that more intensely grazed areas on each herd's summer range will have a greater increase through time in overall productivity and seasonality owing to the larger release of grazing pressure on these areas due to the recent declines in herd densities.