Research Article

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Carcass weight of Greenlandic lambs in relation to grazing area biomass

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Abstract: This study set out to investigate possible relationships between lamb carcass weight and quality with feed availability during the main growing season in southern Greenland where farms are sparsely distributed over a large area. In early May, ewes and new-born lambs are let out to graze permanent nature areas until slaughter towards the end of September. In our study, we used data from 157,477 lambs slaughtered between 2010 and 2017 as well as the Normalized Differentiated Vegetation Index (NDVI) as an indicator of biomass growth. Mean carcass weight of lambs ranged from 13.4 kg in 2015 to 16.5 kg in 2010 where 70.5% of all lambs scored well for conformation and fat. Both farm, year, and NDVI significantly correlated with carcass weight and quality. Lambs raised in the northern and the southern grazing areas generally were smaller than lambs raised in the central part. Finally, NDVI explained between 0 and 74% of the variation in mean carcass weight across years within each grazing area. Our work exemplifies the use of satellite-derived data to attempt an explanation of spatial variation in productivity, which in the future could be coupled with other spatial variables such as soil quality, vegetation, and topography.

Keywords: Greenland; Sheep; Mountain pastures; Carcass weight; Vegetation index

1 Introduction

Modern livestock farming began in southern Greenland in the early 1900s with the import of a flock of sheep from Iceland and the Faroe Islands (Austrheim et al. 2008). There has since been only limited importing of breeding animals, and hence today, the majority of sheep are relatives of the Icelandic short-tailed breed. Farmers mainly raise sheep, and some recently began to raise cattle and in 2018 there were 18,212 sheep and 254 cattle in Greenland across a total of 38 farms (Greenland Statistics, n.d.). These livestock are kept inside where they are fed silage, hay and concentrates from around October until May when they are let out to graze permanent nature areas in the mountains (Austrheim et al. 2008). Hence, the quality of the grazed areas could potentially reflect the carcass weight and quality of lambs.

Harsh conditions with fjords, cliffs, sparse vegetation and long distances between villages, farms and grazing areas characterise southern Greenland, where farms are scattered either individually or in small groups over a large area (Figure 1). The vegetation varies greatly from the inner to the outer part of the fjords and from lower to higher altitudes. Dwarf-shrub heath communities dominate large areas along with areas with grasses, ferns, forbs, willow and birch (Austrheim et al. 2008; Thorsteinsson 1983), and the short-tailed Icelandic breed used in Greenland is particularly suitable for these conditions (Dýrmundsson and Ninikowski 2010). Sheep-grazing management may adversely affect the different plant communities in these subarctic nature areas (Dýrmundsson 2006; Olsen et al. 2014; Ross et al. 2016) by altering their species composition.

The effect of grazing on species composition may become even more important with predicted increasing temperatures (Christensen et al. 2016), which may support a higher number of sheep. Expansion and intensification falls in line with a political ambition of the Government of Greenland to increase self-sufficiency with food (Landbrugskommissionen 2014). From 2013 to 2016, Greenland imported around 14.1 mil. kg of meat, which, with a pop-

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ulation of 56,000 is the equivalent of 173 g per person per day (Greenland Statistics, n.d.). In comparison, the slaughterhouse Neqi A/S in southern Greenland produced 1.2 mil. kg of lamb and mutton (Kunuk Albrechtsen and Viggo Djuurhus, pers. comm.) over the same years or the equivalent of 15 g per person per day or 8.7% relative to imported meat (excluding fish). Hence, utilising the potential for expansion and intensification of Greenlandic agriculture (Caviezel *et al.* 2017; Westergaard-Nielsen *et al.* 2015) without eventually damaging local plant communities require attention to site-specific carrying capacity and potential environmental effects of proposed increased grazing intensity (Ross *et al.* 2016).

The potential future expansion of sheep farming calls for methods to predict suitable grazing areas based on biomass production that could shed light on potential landscape and environmental effects of increased grazing. These methods could include a common satellite derived vegetation index such as Normalized Differentiated Vegetation Index (NDVI), which have been shown to accurately describe biomass production and quality of a Mediterranean ewe grazing system (Serrano *et al.* 2018). A previous study used NDVI to describe grazing areas suitable for sheep production in Greenland (Westergaard-Nielsen *et al.* 2015) without coupling this with actual farm-measured data. We argue that area, farm and individual animal data can support monitoring of environmental effects and possibly over-grazing. Here, we attempt to describe spatial-varying relationships between farm-specific lamb-carcass variables and the vegetation based on satellite-derived data.

The main objective of this study was to investigate carcass weight and carcass quality of lambs from southern Greenland and the potential relationship with feed availability represented as area-specific biomass growth between 2010 and 2017. This study may support future work on expansion and productivity gains in Greenlandic sheep farming including spatial variation in biophysical factors.

2 Materials and methods

The study for this paper comprised weather data and spatially varying farm-related data including slaughter data from lambs, farm location and grazing area as well as remote-sensed satellite data as a proxy for biomass productivity from southern Greenland. Weather data were

used as indicators of climatic growing conditions and satellite data as an indicator of biomass productivity.

2.1 Farm data

2.1.1 Sheep breed

All sheep farms in Greenland raise Greenlandic sheep, which with minor influences from other breeds are descendants from the original flock of Icelandic short-tailed sheep imported about a century ago (Austrheim *et al.* 2008; Dýrmundsson and Ninikowski 2010; Ross *et al.* 2016). The Greenlandic sheep still resemble the Icelandic sheep (Austrheim *et al.* 2008) with white wool, a short tail and short legs.

2.1.2 Carcass weight and quality

Spatial farm related data included slaughter data from sheep and lambs, farm location and grazing area. Slaughter data, which included carcass weight and score for conformation and fat, were used as response variables. Scores for conformation and fat, based on the EUROP classification scheme (EC Regulation 461/98), were obtained from the slaughterhouse Neqi A/S in Narsaq in southern Greenland (Kunuk Albrechtsen and Viggo Djuurhus, pers. comm.). Both conformation and fatness are scored on scales from 1 to 5 where a conformation score of 1 is best and 5 is poorest. A fatness score of 1 is very lean and 5 is very fat with 3 being normal. The dataset included 157,477 lambs and 12,007 sheep slaughtered in the years 2010 to 2017 of which conformation and fat scores for 47 lambs and 4,071 sheep were missing.

2.1.3 Farm location and grazing area

The locations of farms and coupling with their outfield grazing area were obtained through a combination of Google Earth and a map from the Government of Greenland (Kenneth Primdal, pers. comm.). The locations of grazing areas were obtained from the public government repository Nunagis (www.nunagis.gl) where 22 grazing areas varying in size from 37 ha to 883 ha (Figure 1) could be coupled with a farm location and slaughtered lambs. Data from 114,571 lambs and 10,696 sheep included a known farm location, of which the majority of data with a missing farm location came from 2011 and 2012.

2.2 Growing conditions

2.2.1 Weather data

A climate station near Narsarsuaq in southern Greenland (Latitude: 61.0939; Longitude: -45.2532) was the closest available near the main sheep producing areas (Figure 1) with monthly weather data (Cappelen 2018). Average daily mean temperature, average daily minimum temperature and average daily maximum temperature per month were weighted with the number of days per month to obtain average daily mean, minimum and maximum temperatures per year and for the summer (May - September) and the winter period (October - April) preceding that summer, respectively. Hence, the winter period included data from three months from the preceding calendar year. Precipitation was summarized per year and for the summer and winter periods, respectively.

2.2.2 Area-specific biomass productivity

Values for biomass productivity were based on the NDVI (Tucker 1979) derived from the Moderate Resolution Image

Spectroradiometer (MODIS) product MOD13A3 (Heute et al. 1999). This index utilises the fact that chlorophyll absorbs red light (RED) and reflects near-infrared (NIR) light through remotely-sensed surface-reflectance, and it has previously been proved suitable for Arctic regions (Raynolds et al. 2008). The relationship between RED and NIR defines NDVI and can be interpreted as a proxy for primary productivity:

$$\text{NDVI} = (\text{NIR} - \text{RED}) / (\text{NIR} + \text{RED}) \quad (1)$$

NDVI ranges from -1 to 1 where negative values generally corresponds to water, values close to zero barren land or snow, while higher values reflects forest (Sinergise, n.d.). The MOD13A2 product represents data where NDVI is recorded every month in a 1 km resolution. Using the 22 grazing areas as geographic zones, mean values of NDVI for all grazing areas for each month during the main growing months (May-September) for each year 2010-2017 were calculated using geographical information systems ArcGIS version 10.6 (ESRI 2019).

Figure 1: Location of farms and grazing areas in southern Greenland overlaid with average annual mean NDVI for 2010 (left) and 2015 (right) in 1 x 1 km grid

2.2.3 Statistical analysis of slaughter data

The statistical analysis of slaughter data was done with 4 different models that combined investigated slaughter data in relation to farm, year, NDVI and grazing area. In model 1, the effects of farm and year (categorical) on slaughter data (continuous) were analysed:

$$\text{Model 1: } y_{ijk} \sim \text{farm}_j + \text{year}_k + \text{farm}_j \times \text{year}_k + e_{ijk}$$

Where y is weight, conformation score or fat score of lamb i from farm j in year k , farm is farm ID, year is year and e is the error term.

In model 2, the effect of NDVI (continuous) and year (categorical) on slaughter data (continuous) were analysed:

$$\text{Model 2: } y_{ijk} \sim \text{NDVI}_j + \text{year}_k + \text{NDVI}_j \times \text{year}_k + e_{ijk}$$

Where y is weight, conformation score or fat score of lamb i from a grazing area with an NDVI value j in year k , year is year and e is the error term.

Afterwards, the 22 different grazing areas with slaughter data available were grouped in 7 groups based on their geographic location. Group 1 included grazing areas 1-4 located around Qassarsuk, group 2 included grazing areas 5-7 located around Bredefjord, group 3 included grazing areas 9 and 10 located around Igaliku, group 4 included grazing areas 11-13 located around Upernaviarsuk, group 5 included grazing areas 19-23 located south of Igaliku Fjord, group 6 included grazing areas 24-26 located north of Lichtenau Fjord and group 7 included grazing areas 33 and 34 south of Tasermiut near Nanortalik.

In model 3, the effect of grazing area group (categorical) and year (categorical) on the carcass weight of lambs (continuous) was analysed:

$$\text{Model 3: } \text{weight}_{ijk} \sim \text{group}_j + \text{year}_k + \text{group}_j \times \text{year}_k + e_{ijk}$$

Where weight is weight of lamb i from grazing area group j in year k , group is grazing area group, year is year and e is the error term.

In model 4, the effect of mean NDVI (continuous) on mean carcass weight of lambs (continuous) within each grazing area was analysed:

$$\text{Model 4: } \text{weight}_i \sim \text{NDVI}_i + e_i$$

Where weight is mean weight of lambs in year i and NDVI is mean NDVI in year i within each of the 22 grazing areas. Hence, model 4 was used separately for each grazing area

to produce a correlation coefficient and squared correlation coefficient (r^2), which gave the direction of the relationship and the proportion of variance explained by variation in NDVI, respectively.

Finally, all residuals of the different models were tested for and found to be normally distributed, and R version 3.5.3 was used for all statistical analyses (R Development Core Team 2019).

3 Results

3.1 Farm data

3.1.1 Carcass weight

Mean carcass weight of lambs decreased 3.1 kg from 2010 to 2015 before regaining some of the lost weight, 1.0 kg, by 2017. The mean carcass weight of lambs from 2010 to 2017 was 15 kg with a standard deviation of 2.9 kg. Furthermore, the number of slaughtered lambs varied over the years with the largest number slaughtered in 2012 and the lowest number in 2016 (Table 1).

3.1.2 Carcass quality

The conformation score (Table 2) of 75% of lambs was either 1 (very good) or 2 with a further 21.5% scoring 3 (good). Moreover, 38.9% of lambs scored 3 (normal) for fatness with a further 53.2% scoring 4 (fat). The combination of a conformation score of 1 and 2 with a fat score of 2, 3 and 4 included 70.5% of all lambs whereas the combination of a conformation score of 4 and 5 with a fat score of 1 through 5 covered 3.5% of all lambs. The distribution of conformation and fat scores, respectively, varied across years (Table 3) with no apparent linear trend in either score, albeit 2010 was particular different from the other years.

Furthermore, the highest mean carcass weight of 2010 corresponded with only 3.5% of lambs scoring 1 in conformation compared with 49.3% in 2015, which had the lowest mean carcass weight. Similarly, 43.4% of lambs scored 4 in fat in 2010 compared with 64.8% in 2015. Hence, lambs were smaller in 2015 but fatter with better conformation compared with 2010.

3.2 Growing conditions

3.2.1 Weather data

The number of degree-days during the main growing seasons from May to September varied from 1,124 in 2013 to 1,617 in 2010 with a 30-year average of 1,283 (Table 4). The winter months preceding the main growing season, which included October through April, varied from -1,178 degree-days in 2015 to -55 in 2010, and the variation in degree-days was greater during winter than summer. Mean daily temperature during summer periods have been 0.5°C higher during 2010-2017 compared with the 30-year average whereas mean precipitation has been 38 mm less (13.1%). Similarly, the winter periods have been 0.9°C warmer and precipitation 59 mm less (17.2%) than the 30-year average.

The highest carcass weight in the year 2010 coincided with the mildest preceding winter and warmest following growing season, albeit precipitation was less than the 30-year average for both summer and winter. Similarly,

the lowest carcass weight in 2015 coincided with a summer close to the 30-year average, but the mean temperature of the preceding winter was 2°C (56%) colder.

3.2.2 Area-specific biomass productivity

NDVI showed spatial variation in all years (e.g. in years 2010 and 2015; Figure 1). Average mean NDVI for all grazing areas during the main growing period from May to September varied from 0.40 to 0.47 across years with a standard deviation of 0.12-0.20 whereas NDVI for individual grazing areas varied from -0.03 to 0.73 across years (Figure 2). Mean NDVI was significantly lower ($P < 0.05$) in 2015 compared with all other years except 2012 with the years 2010 and 2015 representing the highest and lowest mean NDVI, respectively. The highest NDVI in 2010 (Figure 1a) and the lowest in 2015 (Figure 1b) matches with the highest and lowest carcass weight across years (Table 1), respectively, albeit the picture is less clear for the years in between (Figure 2 and Table 1).

Table 1: Number of slaughtered lambs and sheep and their carcass weight

Year	2010	2011	2012	2013	2014	2015	2016	2017	2010-17
Lambs									
Slaughtered, n	21,112	21,359	21,807	20,290	19,811	17,281	17,255	18,832	157,747
Carcass weight, kg (SD)	16.5 (3.1)	15.2 (2.8)	14.7 (2.7)	14.6 (2.7)	14.5 (2.8)	13.4 (2.6)	15.9 (3.0)	15.4 (2.8)	15.0 (2.9)
Sheep									
Slaughtered, n	1,242	1,414	1,603	1,550	1,968	1,378	1,117	1,735	12,007
Carcass weight, kg (SD)	24.7 (4.1)	23.3 (3.9)	24.1 (4.1)	22.6 (4.2)	23.3 (4.1)	22.1 (4.0)	24.9 (4.2)	24.3 (4.3)	23.6 (4.2)

Table 2: Percent of slaughtered lambs in Greenland within each combination of fat and conformation score¹ for 2010-2017

		Conformation score					
		1	2	3	4	5	Total
Fat score	1	0.00	0.02	0.04	0.01	0.00	0.07
	2	0.25	1.09	1.67	0.34	0.01	3.36
	3	3.83	20.54	12.06	2.35	0.08	38.86
	4	16.52	28.28	7.68	0.70	0.01	53.18
	5	3.65	0.85	0.02	0.00	0.00	4.52
	Total	24.25	50.77	21.47	3.40	0.11	100.00

¹Based on the EUROP classification system (EC Regulation 461/98).

Table 3: Distribution (%) of conformation and fat scores¹ for Greenlandic lambs from 2010-2017

Year	Conformation score					Fat score				
	1	2	3	4	5	1	2	3	4	5
2010	3.5	50.0	34.2	12.0	0.3	0.0	4.0	49.9	43.4	2.7
2011	16.8	52.1	28.0	3.1	0.0	0.0	1.8	42.8	52.0	3.3
2012	23.0	53.5	21.0	2.5	0.0	0.0	1.2	43.4	52.7	2.6
2013	42.2	39.8	14.8	3.0	0.3	0.3	11.3	41.5	38.8	8.2
2014	20.3	42.6	35.1	2.1	0.0	0.0	1.7	25.3	68.6	4.3
2015	49.3	39.9	10.3	0.5	0.0	0.1	1.3	25.7	64.8	8.2
2016	28.7	53.7	16.3	1.3	0.1	0.1	2.3	34.4	60.4	2.9
2017	13.9	71.7	13.2	1.1	0.1	0.1	2.4	39.4	53.7	4.4
2010-17	24.3	50.8	21.5	3.4	0.1	0.1	3.4	38.9	53.2	4.5

¹Based on the EUROP classification system (EC Regulation 461/98).

Table 4: Selected climate data¹ for Narsarsuaq² in southern Greenland

	Year								1988-2017	
	2010	2011	2012	2013	2014	2015	2016	2017	Mean	SD
Main growing period (May - September)										
Degreedays	1,617	1,289	1,501	1,124	1,382	1,221	1,437	1,308	1,283	130
Temperature, °C	10.6	8.4	9.8	7.3	9.0	8.0	9.4	8.5	8.4	0.8
Maximum temperature, °C	15.1	12.7	14.3	11.6	13.4	12.4	14.3	12.9	12.6	1.1
Minimum temperature, °C	6.0	4.4	5.5	3.1	4.6	3.7	4.7	4.3	4.3	0.7
Precipitation, total mm	240	210	362	302	280	271	109	233	289	90
Winter preceding main growing period (October - April)										
Degreedays	-55	-246	-882	-70	-675	-1,178	-755	-667	-764	416
Temperature, °C	-0.3	-1.2	-4.2	-0.3	-3.2	-5.6	-3.6	-3.1	-3.6	2.0
Maximum temperature, °C	3.4	2.4	0.0	3.1	0.5	-1.5	0.6	0.6	0.3	1.8
Minimum temperature, °C	-4.3	-5.0	-8.3	-4.2	-7.2	-9.9	-8.0	-7.2	-7.8	2.1
Precipitation, total mm	154	229	427	288	322	308	235	312	343	133

¹Degreedays: sum of mean monthly temperature x days in month; Temperature: weighted mean temperature; Maximum temperature: weighted mean daily maximum temperature; Minimum temperature: weighted mean daily minimum temperature. Based on data from Cappelen (2018).

²Climate station: Latitude: -45.2532; Longitude: 61.0939.

3.3 Slaughter data in relation to farm, year, NDVI and grazing area

Farm, year and NDVI significantly correlated with carcass weight, conformation score and fat score (Table 5), but no model explained more than 22% of the variation in data as indicated by the adjusted R^2 . Despite the skewed nature of the distribution of conformation and fat scores, log transforming the observed values did not improve the model fit. The number of parameter levels created highly complex model fits where e.g. NDVI in some years (2013 and 2014) had a negative relationship with carcass weight. A simple

linear regression between NDVI and carcass weight produced an intercept of 14.2 kg and a coefficient for NDVI of 0.56 kg per unit of NDVI. However, a plot of carcass weight against NDVI showed an oval distribution of observations.

The mean carcass weight of lambs from the 7 grazing area groups varied from 10 to 20.2 kg across years and grazing area groups (Table 6). Within year, the variation was between 2.6 and 5.8 kg. Grazing area groups 1 and 7 more often ranked lower in mean carcass weight whereas grazing area group 4 more often ranked higher compared with the remaining grazing area groups. Group 1 repre-

Table 5: The ability of farm, year and NDVI to explain variation in weight, conformation and fat score

	Weight	Conformation score	Fat score
Model 1 ¹			
<i>P</i> -value: farm	< 0.001	< 0.001	< 0.001
<i>P</i> -value: year	< 0.001	< 0.001	< 0.001
<i>P</i> -value: farm x year	< 0.001	< 0.001	< 0.001
Adjusted-R ²	0.16	0.22	0.10
Model 2 ¹			
<i>P</i> -value: NDVI	< 0.001	< 0.001	< 0.001
<i>P</i> -value: year	< 0.001	< 0.001	< 0.001
<i>P</i> -value: NDVI x year	< 0.001	< 0.001	< 0.001
Adjusted-R ²	0.06	0.16	0.04

¹Explanatory variables farm and year were treated as factors whereas NDVI was treated as numeric. Weight, conformation score and fat score were treated as numeric and fitted separately with a standard linear model.

Table 6: Mean (SE¹) carcass weight for each grazing area group²

Grazing area group							
Year	1	2	3	4	5	6	7
2010	^a 15.9 (0.0)	^b 17.4 (0.1)	^c 16.6 (0.1)	^d 20.2 (0.1)	^e 17.0 (0.1)	^b 17.6 (0.1)	^f 15.2 (0.1)
2011	^a 16.1 (0.2)	^a 15.3 (0.3)	^a 15.7 (3.5)	^a 18.0 (1.2)	^a 16.5 (0.8)	^a 13.4 (1.0)	^a 14.9 (2.5)
2012	^{ab} 14.1 (0.3)	^a 13.5 (0.3)	^b 15.2 (0.4)	^{ab} 13.9 (3.5)	^{ab} 15.7 (0.8)	^{ab} 14.1 (1.2)	^{ab} 10.0 (2.5)
2013	^a 14.9 (0.0)	^a 14.7 (0.1)	^b 15.3 (0.1)	^c 17.6 (0.1)	^b 15.4 (0.1)	^b 15.4 (0.1)	^d 14.0 (0.1)
2014	^a 14.6 (0.0)	^b 16.2 (0.1)	^c 15.9 (0.1)	^d 19.3 (0.1)	^{ce} 15.7 (0.1)	^e 15.4 (0.1)	^f 13.5 (0.1)
2015	^a 13.6 (0.0)	^b 14.4 (0.1)	^c 14.9 (0.1)	^c 15.0 (0.1)	^b 14.5 (0.0)	^{bc} 14.8 (0.1)	^d 11.5 (0.1)
2016	^a 16.0 (0.0)	^b 17.5 (0.1)	^{bc} 17.1 (0.1)	^d 18.5 (0.1)	^c 16.9 (0.1)	^d 18.3 (0.1)	^e 14.6 (0.1)
2017	^a 15.6 (0.0)	^b 18.2 (0.1)	^c 16.1 (0.1)	^d 17.2 (0.1)	^c 16.3 (0.0)	^d 17.5 (0.1)	^d 17.0 (0.1)

Different superscript letters within rows denote significance at $P < 0.05$.

¹Standard error was in several cases below 0.05 with 0.03 being the lowest.

²Grazing areas included in the different groups were: Group 1) 1-4; Group 2) 5-7; Group 3) 9-10; Group 4) 11-13; Group 5) 19-23; Group 6) 24-26; Group 7) 33-34.

sents 49% of the lambs slaughtered whereas group 7 represents 4%.

Finally, the squared correlation (r^2) between NDVI and mean carcass weight across years within each grazing area ranged from 0 to 0.74 (Figure 3). Grazing areas 5, 12, 21 and 22 had a negative correlation between NDVI and mean carcass weight, which means that more biomass support smaller lambs. The remaining grazing areas had a positive correlation between NDVI and carcass weight.

4 Discussion & perspectives

The political ambition in Greenland to increase self-sufficiency with food (Landbrugskommissionen 2014) may be supported by improved growing conditions caused by climate change (Christensen et al. 2016) 2016, and several have assessed the potential for an expanded sheep production in Greenland (Caviezel et al. 2017; Thorsteinsson 1983; Westergaard-Nielsen et al. 2015). This potential expansion points at the need for future studies on how to detect suitable grazing areas while taking both slaughter potential and the local environment into account. Our

Figure 2: Mean and SD of NDVI per grazing area for years 2010-2017. Top and bottom horizontal bars represent maximum and minimum, respectively. Different letters denote significant differences with $P < 0.05$

study pioneers the use of measured slaughter data in combination with satellite data for Greenland and attempt a description of the drivers, which we exemplify with NDVI, of carcass weight and quality as well as how this relationship can vary spatially. Here, we have shown a spatial variation in the squared correlation between NDVI and carcass weight (Figure 3), and hence there are regional differences in how well the variation in NDVI can describe variation in carcass weight. This pattern may be caused by other spatially varying variables such as soil quality, vegetation type, feed quality and topography as well as spatial variation in animal behaviour, animal competition or simply farm management and genetic variation within breed. Furthermore, these variables may explain why for some areas we find a negative correlation between NDVI and carcass weight. Hence, to improve the understanding of what drives carcass weight and quality, it would be valuable, for an area such as Greenland, to increase the use of satellite data, since these data show both temporal and spatial consistency.

In addition, we used weather data recorded by the climate station near Narsarsuaq (Figure 1), which illustrate the variation in temperature and precipitation over the years near the main sheep production area. However, the mean annual temperature is on average 0.6°C lower here than in Qaqortoq, which is further out towards the ocean (Data not shown - based on Cappelen 2018). Sheep farms in southern Greenland are situated near both inner and outer parts of the fjords (Figure 1), which will create different growing environments. Hence, there is a need for more spatially detailed weather data. Finally, other measured biophysical data as well as social- and farm-related data are limited and tend to show non-consistency.

Figure 2: Mean and SD of NDVI per grazing area for years 2010-2017. Top and bottom horizontal bars represent maximum and minimum, respectively. Different letters denote significant differences with $P < 0.05$

This could help elucidate why some farms (model 1), NDVI (model 2) and some grazing areas show inconsistent effects over the years as indicated by the interactions in these models. Ultimately, both farm productivity data and remotely sensed data can support monitoring of environmental responses to increased grazing pressure and support the location of areas that can feed a larger number of animals. Hence, this will help farmers and authorities adjust grazing pressure to minimize negative environmental effects as well as increase the area utilized for sheep farming. Both improved productivity and increased area will be needed to substantially increase the contribution of sheep meat to overall meat consumption.

5 Conclusions

Mean carcass weight of lambs ranged from 13.4 kg in 2015 to 16.5 kg in 2010 where the combination of conformation scores 1 and 2 with fat scores 3, 4 and 5 covered 70.5% of all slaughtered lambs. Lambs slaughtered in 2010 with the

highest carcass weight were fatter and scored poorer for conformation compared with 2015, when carcass weight was lowest. Both farm, year and NDVI significantly correlated with carcass weight and quality, albeit the squared correlation coefficient ranged from 0.04 to 0.22. Lambs raised in the northern-most and the southern-most grazing areas generally were smaller than lambs raised in the central grazing areas. Finally, the squared correlation between NDVI and mean carcass weight across years within each grazing area ranged from 0 to 0.74, and hence variation in NDVI could explain a high proportion of the variation in mean carcass weight for only some of the grazing areas. Our work exemplifies the use of satellite-derived data to attempt an explanation of spatial variation in productivity, which in the future could be coupled with other spatial variables such as soil quality, vegetation, weather and topography.

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