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Greenlandic sheep farming controlled by vegetation response today and at the end of the 21st Century

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HIGHLIGHTS

- Vegetation has responded to climate change with increasing biomass in SW Greenland over the past 20 years.
- Climate models have successfully been used to forecast biomass production.
- Increasing sheep breeding capacity in Greenland
- New sheep farming areas have been identified but infrastructure development is required.

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ABSTRACT

The spatial heterogeneity of vegetation greenness and potential aboveground biomass production for sheep farming has been assessed for Southwest Greenland. A Multi-Criteria Evaluation (MCE) model was set up to identify biophysical constraints on the present spatial distribution of farms and fields based on all existing sheep farms in a detailed study area. Time-integrated NDVI (TI-NDVI) from MODIS and observed temperatures (2000–2012) have been combined with a downscaled regional climate model (HIRHAM5) in order to establish a spatio-temporal model for future TI-NDVI, thus forecasting the dry biomass production available for sheep farming in steps of decades for the next 85 years. The model has been validated against observed biomass production and the present distribution of fields. Future biomass production is used to discuss the expansion of current farms and to identify new suitable areas for sheep farming. Interestingly, new suitable areas are located where sheep farms were situated during the Norse era more than 1000 years ago; areas which have been abandoned for the past 500 years. The study highlights the potential of establishing new areas for sheep farming in Arctic Greenland, where current and future climate changes are markedly amplified compared to global trends. However, for the study area the MCE model clearly indicates that the potential of expansion relies on contemporary infrastructural development.

1. Introduction

Agriculture in the Arctic has long been feasible and has recently been under rapid development due to changes in climate and improved infrastructure of which the latter stimulates both the demand of products and allows the transport of goods, e.g. fertilizers and crops (Gasser, 1948; Mick and Johnson, 1954; Hansen, 1991a; Merzlaya et al., 2008). Currently Arctic agriculture mostly consists of cool-season forage crops, cool-season vegetables, small grains and livestock production, in addition to reindeer herding. The production is limited by the cold climate, short growing seasons, and in some areas moisture stress and erosion (Jacobsen, 1987). However, changes in climate are projected to move production limits northward and annual yields are generally expected to increase (ACIA, 2005; Kirtman et al., 2013).

Some of the oldest evidences of Arctic agriculture are from the Norse era in Greenland dating back to year 985 when Eric the Red settled down in Greenland (Hansen, 1991a). For at least 400 years the Norse people relied on agriculture. The people settled in two areas on the western coast of Greenland, known confusingly as the Eastern Settlement (Østerbygden in southern Greenland) and the Western Settlement approximately 480 km further north (Vesterbygden near the present town Nuuk). In the beginning of the 14th century when habitation peaked, there was an estimated population of around 4000–5000, living on nearly 200 farms in Østerbygden (Austrheim et al., 2008a) and 90 farms in Vesterbygden. It is furthermore estimated that the

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sheep and goat population peaked with possibly more than 100,000 animals, lasting until the late 1400s when all traces of the last settlers disappeared (Jacobsen, 1987). The ruins of farms, sheep shelters and churches are well-described (Nørlund, 1924; Arneborg et al., 1999 among others) and show that Norse people, in contrast to Inuit, relied up to 80% on terrestrial food sources, mainly agriculture, and that sheep farming probably was the single most important source of terrestrial food for them.

The current agricultural period began in 1924 when modern full-time sheep farmers were established near the old Eastern settlement. Until 1966, the number of sheep in stables during winter increased to 45,000. However, two cold winters with heavy snow fall in 1966/1967 and 1971/1972 resulted in a halving of the sheep population (Austrheim et al., 2008a). The number of sheep has remained relatively constant since 1990 (about 40,000 sheep on grass during the summer and about 20,000 in stables during winter (www.stat.gl — last visited April 2014)), while the area farmed has grown by 89% (460 ha in 1990 to 970 ha in 2003) according to Statistics Greenland, Home Rule Government, and Nunalerinermut Siunnersorteqarfik/consultancy service for agriculture (www.stat.gl). The increase in the farmed area is due to cultivation of a large quantity of coarse fodder. Records indicate that in 2003 there were a total of 59 livestock herds, with 57 sheep herds and 2 herds of domestic reindeer in the subalpine central region between Upernaviarssuk, Qagssiarssuk and Sdr. Igaliko in Southern Greenland. Hence, both during the Norse era and today, Greenlandic agriculture mostly consists of sheep, and their breeding relies on two local sources of fodder: during winter, sheep are confined to stables and forage on hay produced on cultivated fields, while during the summer, they roam the local areas and feed on natural vegetation.

Recent warming in the Arctic has been occurring almost twice as fast as the global average (Kirtman et al., 2013), resulting in mainly higher summer temperatures. This has already caused a well-documented greening of the Arctic. Jia et al. (2003) reported a 16.9% increase in the Normalized Difference Vegetation Index (NDVI) from 1981 to 2001 in Northern Alaska. Similar changes have been reported for Southwest and South Greenland, where the changes in biomass from 1982 to 2010 were 31.8 g m^{-2} and 10.8 respectively (Epstein et al., 2012). A warmer climate with a longer growing season is also expected to increase biomass production in Southwest Greenland, with positive effects on both production of winter fodder from the agricultural fields and grazing potential during the summer (ACIA, 2005).

This study explores the possibilities of an expansion of Greenlandic agriculture for an area from 60°N to 65°N covering the southern and south-western parts of Greenland (see Supporting Fig. 1). We hypothesize an increasing biomass production as a result of a warmer climate. Our specific aims are 1) to identify the geographical area currently suited for sheep production and 2) to identify the potential of expansion and intensification under future climate conditions. The potential of an expansion of the cultivated area is analyzed along with the potential grazing capacity of the natural vegetation. We based the analysis on a Multi-Criteria Evaluation (MCE) of spatial data including climatic, topographic, infrastructural, biophysical conditions, and future temperatures according to the regional climate model HIRHAM5 developed by the Danish Meteorological Institute (Christensen et al., 2006; Stendel et al., 2007). These multi-criteria are the only data used in the subsequent discussion of "suitable" sheep farming today and in the future.

2. Methodology

2.1. Study area

The studied region includes a detailed area covering all active sheep farms located in an area of South Greenland, as well as a larger area representing the ice-free part of Greenland (60–65°N) extending from the southern tip of Greenland along the south-western coast to the Nuup Kangerlua fiord system (Godthåbsfjorden) near Nuuk. See Supporting Fig. 1.

The detailed study area between 60°22′N and 61°27′N and between 44°74′W and 46°20′W is characterized by fiords, valleys, and steep mountains. The vegetation quantity is mainly determined by climate and local topography. The climate gradient within the detailed study area ranges from a mean July temperature of 7.2 °C at the coastal location of Qaqortoq to a mean July temperature of 10.3 °C roughly 60 km further inland near Narsarsuaq (monthly mean values based on Danish Meteorological Institute (DMI) stations 2000–2010). The mean annual precipitation is highest in the coastal areas with 849 mm in Qaqortoq and 610 mm at Narsarsuaq (Supporting Fig. 1). Grassland dominates the slopes, while fens can be found along lakes and streams. Vegetation abundance increases inland due to the higher temperatures. Valleys protected against wind are in places dominated by birch and willow (Hansen, 1991a).

Results of the modeling of aboveground biomass and abiotic conditions from the detailed study area are scaled up to the larger study area which is characterized by being surrounded by oceans to the West and the Inland Ice Sheet to the East. The result is a gradient with marked variations in temperatures and precipitation from coast to ice within the main fiord (Hansen, 1991b). Monthly mean values for air temperature and precipitation recorded at the main stations within the larger study area (60–65°N for the period 1961–1990) are shown in Supporting Fig. 1.

2.2. Multi-Criteria Evaluation (MCE) model

The MCE model identifies areas with similar physical conditions as observed today for sheep farming. It is carried out with different criteria including future temperature scenarios according to the regional HIRHAM5 climate model. In that way, this study makes use of the MCE model as a tool to discuss suitable sheep farming based on only objective criteria observed for fields which are farmed today. Parameters considered important for the location of known farms and fields i.e., infrastructure, topography, biophysical attributes and climate were extracted by overlaying polygons of existing farms and fields with the following data sources: Elevation, slope and aspect, generated from a 30 m ASTER-based digital elevation model (DEM). Biophysical parameters consisting of a vegetation index measured from remotely sensed data (the MODIS-based MOD13Q1 NDVI product). Climatic conditions are described by temperature (measured air temperatures and MODIS-based MOD11A2 land surface temperatures). Data on infrastructure was obtained from digitized maps of existing settlements, towns, farms and grazing fields, as well as coastline.

Moreover, a Landsat ETM + based Normalized Difference Water Index (NDWI) map was used as an indicator for bedrock, open water and ice (Xu, 2006; Ji et al., 2009; McFeeters, 1996) where farming or grazing will be impossible. For elevation, slope, aspect, and distance to coast we used the 95% confidence interval from the mean values found for existing fields as the preference interval for the MCE. Maximum existing distance to settlements and towns was used in the MCE to evaluate the constraining factor of these parameters.

Aboveground biomass was estimated using time-integrated NDVI (TI-NDVI) based on MODIS data (see supporting material for details), analyzed over the existing fields and used as proxy for aboveground biomass (Hansen, 1991a; Jia et al., 2006). The minimum requirement to estimated aboveground biomass was used as a criterion in the MCE in order to assess the weight of biomass as a constraint.

Data processing and the final Multi-Criteria Evaluation (MCE) model were based on ESRI's (Environmental System Research Institute) ArcMap version 10.0.