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Climate-impacts on autumn lamb weight

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Abstract. Year to year variation in weather conditions might affect lamb growth in different ways. The climate conditions might affect the animals directly, through increased stress levels and altered grazing behaviour. The main effect however, is expected to be indirect, through climate affecting the quantity and quality of the vegetation. Furthermore, previous studies indicate that the climate effect on lamb growth depend on the area under study. In Norway, lambs are born indoor in the spring (April and early May) and left out on pasture for grazing until slaughter in September when the lambs are five to six month of age. In this paper, we sum up results from three surveys performed on lambs grazing on mountain pastures in southern and northern parts of Norway. Study I and II include 83,331 and 38,587 lambs, respectively, during the years 1992 to 2007. Study III includes 8,696 lambs during the years 1983 to 2002.The results indicate that snow depth during the previous winter, precipitation and temperature in spring and summer affect lamb autumn body weight either positively or negatively. The effects are not consistent between study areas. We found a positive effect of early spring plant growth, an earlier spring resulting in heavier lambs in the autumn. Climate change effect studies are complex; however, by use of long-term databases, it is possible to reveal long-term trends. By use of climate statistics, satellite derived vegetation data and agricultural statistics, we have been able to show how climate changes might influence autumn weight for lambs in Norway. Our results might alter recommendations for sheep management during summer grazing.

Keywords. Climate change – Norway – Sheep management.

Impacts du climat sur le poids des agneaux à l'automne

Résumé. *La variation interannuelle des conditions météorologiques pourrait affecter la croissance des agneaux de plusieurs manières. L'effet des conditions climatiques sur les animaux pourrait être direct, via l'augmentation du niveau de stress et la modification du comportement au pâturage. Toutefois, l'effet principal serait indirect, à travers l'impact des conditions météorologiques sur la quantité et la qualité de la végétation. En outre, des études précédentes indiquent que l'effet du climat sur la croissance des agneaux dépend de la zone considérée, l'impact pouvant être positif ou négatif et d'intensité variable. Dans cet article, nous résumons les résultats d'études effectuées sur les agneaux qui pâturent dans des zones de montagne méridionales et septentrionales de la Norvège. Les résultats indiquent que la hauteur de neige au cours de l'hiver précédent, les précipitations et la température au printemps et en été influencent le poids des agneaux à l'automne. Nous avons également constaté un effet positif d'un développement précoce de la végétation, un printemps précoce donnant lieu à des agneaux plus lourds à l'automne. Les études sur l'effet du changement climatique sont complexes; néanmoins, l'utilisation de séries de données historiques pourrait révéler des tendances à long terme. Par l'utilisation conjointe des statistiques agricoles, des données météorologiques et de données satellitaires relatives à la végétation, nous avons été en mesure d'indiquer la façon dont les changements climatiques pourraient influencer le poids des agneaux à l'automne en Norvège. Nos résultats pourraient modifier les recommandations relatives à la gestion des ovins pendant la saison de pâturage.*

Mots-clés. *Changement climatique – Norvège – Gestion des ovins.*

I – Introduction

Local weather conditions affect ecosystems in general and the performance of out-door grazing livestock in particular. Though climate effects are operating on local scales, global climate indices such as the North Atlantic Oscillation (NAO) have proved to be useful tools for explaining local phenomena. NAO has been shown to represent large-scale weather patterns across Europe ultimately affecting ecosystems at local scales (Stenseth *et al*. 2003). Climate change might affect livestock production due to e.g. increased precipitation or drought. Alpine and arctic ecosystems are regarded in particular sensitive to climate changes as future changes are expected to be most severe at high latitude and elevation (IPCC, 2007). Under these conditions, temperature during early summer as well as snow accumulation the previous winter affect the start of the vegetation season and are regarded as key factors determining plant growth and phenology and in turn quality for alpine grazers (Nielsen *et al*., 2012; Nielsen *et al*., 2013; Nielsen *et al*. *submitted*). Plant growth and phenology can be quantified with the aid of the satellite-derived Normalized Difference Vegetation Index (NDVI) and several measures of NDVI have shown to correlate with the performance of animals (Pettorelli *et al*., 2005; Pettorelli *et al*., 2011).

In Norway, the sheep production industry depends on free-range grazing during summer. The sheep are kept indoors during the winter from mating in November until lambing in April and early May. During winter the ewes are fed mainly silage and some concentrate. Shortly after lambing, the sheep typically graze cultivated pastures and, as soon as the vegetation in the mountains allows for grazing (June), the sheep are released onto the mountain pastures. Each year, approximately two million sheep graze unfenced mountain or forest pastures over summer, until the autumn (September) when most lambs are slaughtered, five to six month of age. The mountain pastures represent a high value food source during summer and, although the quality of the pastures might vary within region and between districts, mountain grazing lambs have been shown to grow faster and bigger than lambs grazing in the lowlands (Nielsen *el al., submitted*; Gudmundsson, 2001).

Year-to-year variation in weather conditions might affect lamb growth on mountain pastures over summer. Climate conditions might affect the animals directly, through increased stress levels and altered grazing behaviour. Despite this, the main effect of year-to-year variation in lamb autumn weight is considered indirect through climate affecting the quantity and quality of the vegetation. Previous studies indicate however, that climate effects operate on different spatial scales and that they are spatially inconsistent. For instance, Nielsen *et al*. (2012) found that lamb autumn weight was positively affected by spring temperature in two areas, negatively affected in one area and not affected in the fourth area.

We have been involved in three studies investigating direct and indirect effects of climate on growth or autumn live weight of lambs grazing Norwegian mountain pastures during summer. The studies were performed along a significant climate gradient from Setesdal in the south (N59°) to Tjøtta in the north (N66°) of Norway using long-term data series for climate and sheep production. This paper sums up the results from the three studies.

II – Materials and methods

In study I (Nielsen *et al*., 2012), the dataset included 83,331 Norwegian white sheep (NWS) lambs from years 1992 to 2007 grazing in four alpine ranges (Setesdal, Hardangervidda west, Hardangervidda east and Forollhogna) in southern Norway. Study II (Nielsen *et al*., 2013) included the NWS lambs from Forollhogna in study I in addition to Norwegian spel lambs from the same area and during the same period, making up a total of 38,587 lambs. The aim of study II was to compare climate effects on different breeds. The third study, study III (Nielsen *et al*., *submitted*) included 8,696 domestic lambs from the years 1983 to 2002 from one single farm in northern Norway

(Tjøtta research farm). In this study several breeds and combinations thereof were included in the dataset. Focus in this paper was not on breed and this variable was therefore not included in our models. All focal areas are located outside the core areas for large carnivores and mortality rates were within the range of 'normal losses' in Norway at 4%.

The datasets from Study I and II were derived from the Norwegian Sheep Recording System. A local sheep recording system for ewes and lambs has been maintained at Tjøtta research Farm since the early 1970'ies and the dataset from Study III was derived from these records. For all datasets in this paper, lamb age at autumn weighing (between 110 and 160 days), litter size (single, twin or triplet), sex and maternal age (1 to 9 years) were included as individual based covariates in the models where the climate variables (Table 1) were main factors.

For all studies, we used the North Atlantic Oscillation Index (NAO) to quantify large scale among years variation in winter conditions, snow depth (Hurrell, 1995). We used winter NAO as this has shown to be a stronger predictor than spring NAO. We used the Principal Component (PC) based index over the months December to March. NAO has been shown to be related to the amount of winter precipitation, with high NAO resulting in more snow, at least in mountain areas.

To measure the year-to-year variations in plant growth and phenology we used the Normalized Difference Vegetation Index (NDVI) (Pettorelli *et al*., 2005). This index is derived from the red – near infrared reflectance ratio (NDVI = (NIR-RED)/(NIR+RED), where RED is red reflectance and NIR is near infrared reflectance from the vegetation). NDVI is presented as a value between -1 and +1, where higher values indicate greener vegetation and negative values indicate lack of vegetation. Despite its coarse spatial scale (8 km x 8 km pixels), the Global Inventory Monitoring and Modelling Study (GIMMS) dataset used has proven to be a very useful measure for inter-annual variation in vegetation growth and phenology. Spring NDVI (here NDVI in the second half of May) has been shown to provide a good representation of annual variation in spring green-up, indicating the arrival of spring.

To model the direct and indirect effects of different climate change scenarios, we built hierarchical path models and fitted them with Bayesian inference. This modeling framework allows us to estimate direct climate effects on the lambs together with indirect effects operating through climate effects on the vegetation. Our results are therefore the expected effect of a certain climate change based on the combination of direct and indirect processes. See Nielsen *et al*. (2012, 2013) for details on the methods.

III – Results and discussion

The results from the three studies reveal some general pattern (Table 1), but our general conclusion is that climate effects are spatially inconsistent. Snow depth the previous winter (high NAO index) had the most consistent effect on lambs' autumn live weight. We expect that snow cover have an indirect effect on lamb growth rate due to the effect of snowmelt on the onset of plant growth in the spring as well as the length of the melting season. Snow rich winters in the mountains extend the period of fresh vegetation emerging in snow beds, increasing the quantity and quality of forage for a prolonged period. The animals follow the snowmelt and are thus allowed fresh forage for a longer period of time.

Spring temperature has a positive effect in the colder areas but a negative effect in the warmer areas. In Northern and alpine regions, low temperatures are the limiting factor for plant growth, and consequently climate warming might increase primary production. The same global warming might, however, limit water availability, cause heat stress to plants in warmer and arid environments, and thus cause the opposite effect. Encroachment of shrubs as well as an elevation of the tree line is however expected with increasing temperatures at these latitudes. Early summer temperature (July) has a negative effect in the warmer areas and a positive effect in the colder areas while late summer temperature (August – with high values most likely indicating prolonged plant growing season) in general has a positive effect. Precipitation has a positive effect in the dryer areas and a negative effect on the wetter, more western areas. This suggests a potential for drought stress in the vegetation in dry and warm summers. We also found a positive effect of early spring plant growth and phenology (NDVI index spring) indicating that an earlier spring resulted in heavier lambs in the autumn. The NDVI is a representation of the greenness of whole plant communities. In study II, it is suggested that plant functional groups respond differently to similar climate conditions. This might have implications for the development of the plant communities under future climate conditions.

Table 1. Factors affecting lambs' autumn live weight. +: positive effect, -: negative effect, 0: no significant effect, na: not included based on initial model selection procedures, or in the case of precipitation in Study III data not available. Note that the results from Forollhogna (study I) are identical to the results from study II

	Study I; Nielsen *et al.*, 2012				Study III; submitted
	Setesdal	Forollhogna (Study II; Nielsen *et al.*, 2013)	Hardanger West	Hardanger East	
NAO previous winter	0	+	+	+	+
Spring temperature	0	+	–	+	–
Spring precipitation	Na	–	–	+	na
July temperature	–	na	–	+	+
August temperature	+	+	na	na	+/–
July precipitation	–	na	–	+	na
August precipitation	–	+	na	na	na
NDVI	+	+	0	+	+

NAO: North Atlantic Oscillation, NDVI: Normalized Difference Vegetation Index.

There is little doubt that the global mean temperature is increasing and at the same time the regional climate variations, particularly of precipitation, are expected to be more unpredictable. The ability of plant functional traits to adapt to disturbances from herbivores is well documented. It is on the other hand not clear how plant communities along the browse – grass continuum adapt to annual climate variations. The changes in both temperature and precipitation may affect the communities in contrasting ways depending on the main limiting factor.

IV – Conclusions

By use of climate statistics, satellite derived vegetation indices and agricultural statistics we have been able to show how climate changes might influence autumn weight for lambs in Norway. Our main conclusions are that the severity of the previous winter is important and that climate change effects in general are site specific suggesting that local conditions play a significant role. We therefore recommend the farmers not to take into account the potential effects of future climate change when deciding on their use of different pastures, but rather focus on adapting the length of the grazing season to optimize meat production.

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