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The combined effects of centralization and carnivore management on sheep farmers and sheep farming in Norway

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ABSTRACT

Sheep farmers in areas with large carnivores experience economic loss, psychological stress, and perceived alienation from political processes. This can result in decisions that differ from those made by farmers in areas without large carnivores, possibly influencing the whole farming system. We used applications for farming subsidies to examine changes in sheep farming in Norway 1999 to 2017. Along the urban-rural dimension, we found a stronger decline in increasingly rural areas. The decline was furthermore larger inside regions used for the reintroduction of large carnivores than outside these regions. The observed decline in some regions was compensated by growth in central regions, outside carnivore prone areas, and on managed land where the sheep was protected from carnivores. The result complements studies of mental dispositions and decision processes aiming to explain how large carnivores and the carnivore management policy influence the farmers' attitudes and decisions, resulting in behaviors that effect larger social systems.

KEYWORDS

Carnivore management; livestock; abandonment; urban-rural dimension

Introduction

Farmers' decisions are determined by several interacting factors, spanning from economy and socio-demographics to psychology (Edwards-Jones, 2006). Farmers rearing livestock in the presence of large carnivores respond in ways, driven by contextual factors like economy and social norms, but also by attitudes, risk perception, and emotions (Amit & Jacobson, 2017).

Populations of large carnivores are increasing throughout Europe. This is a result of the meticulous development and implementation of successful conservation strategies by national environmental protection authorities (Chapron et al., 2014; Eriksson, 2017; Treves & Karanth, 2003; Woodroffe, 2000). The reintroduction of carnivores is possible because the agricultural sector in Europe is industrialized. The bulk of meat, poultry, and dairy production is unaffected by the presence of carnivores because the infrastructure used by the larger, more centralized production units (e.g., fences, buildings) is sufficient to prevent depredation. Contrary to the pre-industrial situation, carnivores no longer represent any threat to the food security for the majority of the increasing human population in the more industrialized and affluent societies. Only in rural settlements practicing a more traditional form of husbandry with free-ranging animals foraging on natural or semi-natural pastures are carnivores still a threat to the European farmers' income and livelihood.

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The change in the carnivore policy in the industrialized countries in western Europe takes place during a period also characterized by urbanization and depopulation of rural areas (Fielding, 1989; Lasanta et al., 2017). Traditional and less intensive production methods are economically marginalized in the wealthiest countries (Breman et al., 2010). Most of the population of these countries today has no first-hand knowledge of agriculture and negligible understanding of the rural society (Doerfert, 2011; Kovar & Ball, 2013; Meerburg et al., 2009). The reintroduction of the large carnivores has therefore found general acceptance among this growing urban population (Dressel et al., 2015).

While much of the food production becomes increasingly industrial, rearing livestock on natural pastures is still practiced in parts of Europe. This production is vulnerable to carnivore depredation, leading to livestock losses when carnivores are present (Kaczensky, 1999; Mabille et al., 2015). The result is an evolving conflict over the carnivore policy when large carnivores are reintroduced into these environments (Bautista et al., 2019; Treves & Karanth, 2003).

Predation on livestock occurs when predators gain access to domestic animals. Losses may be small relative to the total numbers of livestock but can constitute a significant proportion of total livestock mortality locally (Baker et al., 2008). Losses are highly variable, even over short distances, resulting in an unequal distribution of burdens and very high loss for some herders (Kaartinen et al., 2009). Allowing carnivores and livestock in the same areas is always precarious and, in many cases, incompatible. Preventive measures are consequently needed to reduce conflicts and limit the damage (Graham et al., 2005; Hansen et al., 2019; Mattiello et al., 2012).

Norwegian sheep farmers have suffered losses from the reintroduction of large carnivores, starting in the latter part of the 20th century. The economic impact for individual farmers could be severe (Asheim & Mysterud, 2004). The losses also incited conflicts between stakeholder groups and a need for mitigation measures to amend these conflicts (Miller et al., 2016). When the goal is coexistence, the main key to success is to limit livestock losses to levels that are acceptable to a majority of the farming community (Dorresteijn et al., 2013).

The Norwegian government has implemented a spatially differentiated carnivore management system aiming to balance agricultural and environmental interests in the human-carnivore conflict (Strand et al., 2019). This strategy is based on a political consensus reached through decision 687 (June 17, 2011) over proposal 163 S (2010–2011) in the Norwegian parliament. The decision seeks to reconcile continued livestock production using unmanaged pastures with the maintenance of viable carnivore populations.

The core element of the spatially differentiated carnivore management system used in Norway is the formal delineation of Carnivore Management Zones (CMZ, Figure 1). Unmanaged pasture can be used inside a CMZ, but only provided that sufficient and adequate steps are taken to avoid conflicts with carnivores. Such means include fencing and shepherding or physically moving the livestock to new locations to avoid the presence of carnivores (Linnell et al., 2005).

Unmanaged pastures are traditionally important in Norwegian husbandry (Vatn, 2009). Grass produced on the farm during the short summer season is stored and used as fodder during the long winter. This is partly replaced by imported feed concentrates, but unmanaged pastures still constitute an essential element in Norwegian sheep production. The potential for conflict is therefore present when carnivores are reintroduced in the grazing areas.

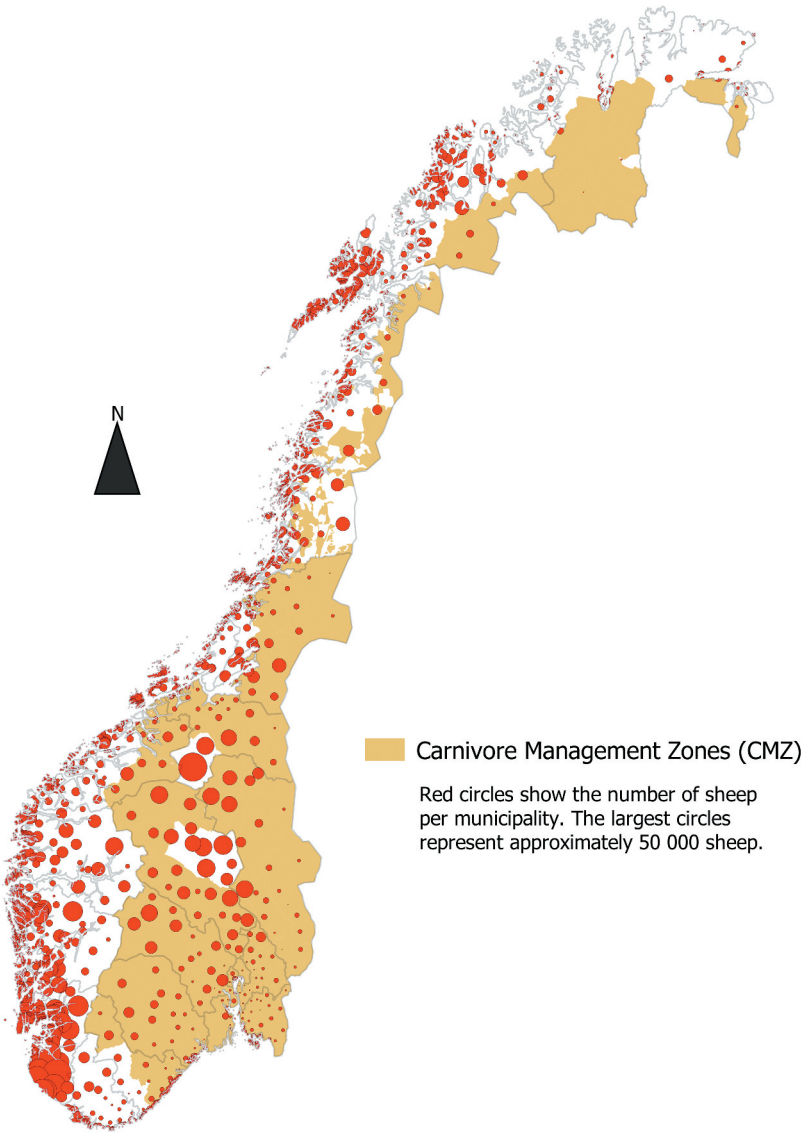

Figure 1. Carnivore management zones. Based on data from the Norwegian Environment Agency published 09/2015. Number of sheep (2017) per municipality based on data from the Norwegian Agricultural Agency. The largest circles represent approximately 50 000 sheep.

Sheep farmers in areas with large carnivores experience economic loss, psychological stress, and perceived alienation from political processes (Zahl-Thanem et al., 2020), possibly resulting in decisions that differ from those made by farmers in areas without large carnivores. But the reintroduction of carnivores also coincides with an ongoing social change process characterized by urbanization and centralization (Langørgen, 2007). The reported abandonment of sheep farming in areas where carnivores are reintroduced (Strand et al., 2019, 2016) is therefore not necessarily related to the carnivores but could equally well

be an effect of the ongoing urbanization where people leave the sheep industry for better paid jobs in the cities.

The present article supplements research that examined the mental dispositions and processes among sheep farmers in the presence of urbanization, social change, economic uncertainty, and large carnivores with research addressing the consequences in terms of the effect their decisions have on the larger farming system. The approach can be described as falsification. The association between changes, abandonment, carnivore management, and the urban-rural dimension is tested statistically to examine the presence or absence of expected relationships. Failure to falsify a relationship does not imply that causality is present but does strengthen plausible explanations involving an association between the involved factors. The paper examined the structural changes in Norwegian sheep farming over a period of almost 20 years (1999 to 2017) and their relationship with (a) the spatially differentiated carnivore management system used in Norway and (b) changes along the urban-rural dimension.

Methods

The study area is Norway, a mid-sized country of approximately 324,000 km^2 on the northern fringe of the European continent. The entire country was included in the study. The situation with respect to sheep production and grazing in 2017 was compared to the situation in 1999, covering a period of almost 20 years.

Spatially differentiated carnivore management in Norway is practiced for four large carnivore species: brown bear (*Ursus arctos*), wolverine (*Gulo gulo*), gray wolf (*Canis lupus*), and lynx (*Lynx lynx*). A digital map of the carnivore management zones, made by the Norwegian Environment Agency, was downloaded from the Norwegian spatial data infrastructure (www.geonorge.no) and restructured into two categories: Areas outside (0) or inside (1) carnivore management zones (Figure 1).

The dependent variables used to characterize the changes in sheep farming were extracted from the database of applications for agricultural subsidies maintained by the Norwegian Agriculture Agency and published online at the public data portal https://data.norge.no/. Active farmers annually submit applications for subsidies, along with documentation of their farming activities. Data from 1999 to 2017 (both years inclusive) were used in the study. Data before 1999 were not available.

Three attributes were extracted from the applications: The farm identification code, the number of sheep (ewes and lamb combined) held by the farm, and the number of sheep foraging on unmanaged pastures during the summer. Unmanaged pastures in Norway are found in forests, mountains, mires, heaths, and moors, often (but not always) far from settlements. The geographical coordinates of each farm were retrieved from the central farm register (*Landbruksregisteret*, a database managed by the Norwegian Agricultural Agency containing information about all agricultural properties in Norway) and added to the project database.

The urban-rural dimension was described using the Norwegian "centrality index" available for the approximately 14,000 "basic statistical units" (BSUs) in Norway (Høydahl, 2017). A map of the BSUs, with the centrality index attached as an attribute, was provided by the national statistical authority, Statistics Norway. Centrality is measured on a scale from 0 (inaccessible, remote land) to 1,000 (the center of large cities). A spatial intersection (point in

polygon operation using qGIS®) was used to assign the centrality index and the BSU identification code to each farm. A similar point in polygon operation was used to assign information about the presence/absence of carnivore management zones to the farms.

The descriptive analyzes were carried out using the number of sheep foraging on unmanaged pastures and the remaining number of sheep, that forage on managed pastures close to the farms. Some of the sheep confined to these managed pastures are owned by farmers who also have sheep grazing on unmanaged pastures. Two binary variables were created to count the number of farmers with sheep foraging on unmanaged pastures and the number of farmers with sheep only foraging on managed pastures. The four variables were aggregated to provide counts (of sheep as well as farmers) per year, and to calculate relative changes (in percent) between 1999 and 2017.

The impact of carnivore management and centralization on sheep farming was examined in a spatial context. The spatial units used for this purpose were "Statistical tracts." Statistical tracts are composed of several spatially continuous BSUs merged into larger areas, but still smaller than the smallest administrative units (municipalities). The total number of statistical tracts in Norway is approximately 1,550. The statistical tract is usually quite homogenous with respect to centrality, agricultural structure, and carnivore management. One thousand one hundred and ninety-eight statistical tracts contained sheep farms either in 1999 or 2017 (or both years).

The variables were aggregated to statistical tracts and the difference between 1999 and 2017 calculated as a standardized quantity

$$y_k = \frac{\sum_i^{n_{k,t2}} x_{i,t2} - \sum_j^{n_{k,t1}} x_{i,t1}}{\sum_i^{n_{k,t1}} x_{i,t1} + \sum_i^{n_{k,t2}} x_{i,t2}}$$

where y_k is the standardized relative change of the quantity x in statistical tract k. n_k is the number of applications for agricultural subsidies (farmers) in statistical tract k. $t1$ and $t2$ represent the first (1999) and last (2017) year, respectively.

The range of these standardized variables was between −1.0 (abandonment) and +1.0 (new startup). No change will be represented as 0, decline as negative numbers, and increase as positive numbers. Using the sum of sheep in 1999 and 2017 in the denominator overcomes the issue of missing values occurring when ordinary percentages are used (due to the division by zero when no sheep were present in 1999). The standardization was also insensitive to the size of the sheep industry in each tract. A standardized change has the same weight irrespective of the numbers behind this change. Standardized change at the tract level was therefore suitable for spatial studies.

The centrality (CEN) of the statistical tract was calculated as the mean centrality index of the sheep farms in the tract. Centrality was then grouped into six classes, following the classification used by Statistics Norway (Høydahl, 2017): Class 1 is the most central, urban areas (city centers), while class 6 is the most peripheral rural areas. Finally, class 1 and 2 (city centers and their surrounding suburbs) were merged into a single class 2 because there were very few (14 in 1999 and 25 in 2017) sheep farmers in class 1 (inner cities). The effective range of CEN was thus from 2 to 6 (Figure 2).

Descriptive analysis was carried out using the original farm subsidies application database (for national figures) and the data for the statistical tracts (to study the changes in a spatial context). The assumption that the dependent variables conform to a normal

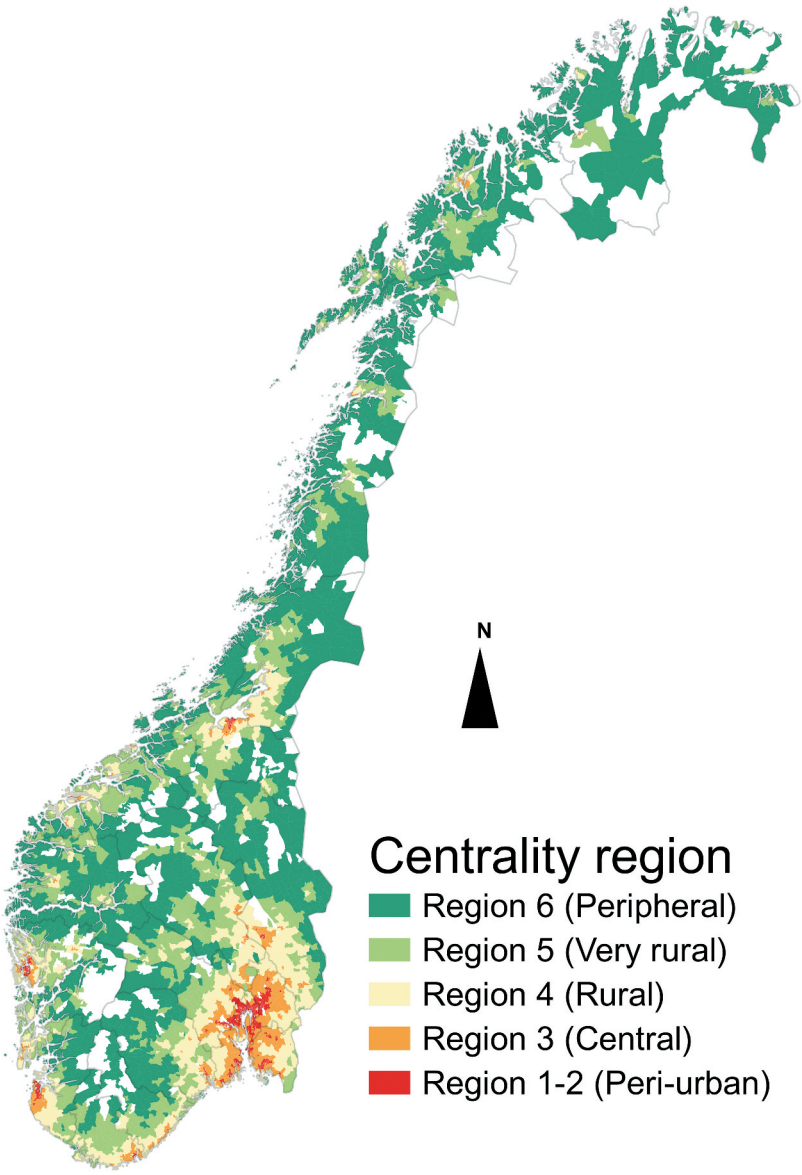

Figure 2. Centrality regions. Based on data from Statistics Norway (Høydahl, 2017).

distribution was checked graphically. Two-way factorial ANOVA was used to test the standardized dependent variables against the two exploratory variables at the statistical tract level. The statistical analysis was carried out using SPSS® (IBM SPSS 25).

Results

The number of active farmers in Norway declined from 66,709 in 1999 down to 40,414 in 2017. The reduction was substantial (−39%). Despite the considerable reduction in the

number of farmers, the amount of farmland remained stable. The acreage was reduced by −4% during the study period, and tilled grassland (used for fodder) remained unchanged. The number of sheep increased (+5%) and so did the number of sheep foraging on unmanaged pastures (+1%).

The number of applications for subsidies for sheep farming was reduced from 22,185 applications in 1999 down to 14,825 applications in 2017 (Table 1). This −33% reduction was smaller than the reduction in the overall number of farmers (−39%). The numbers also show that while the number of sheep farmers declined, the total production in the sheep industry increased. The sheep are also increasingly produced on managed pastures. While 86% of the sheep foraged on unmanaged pastures in 1999, the share was reduced to 81% in 2017. Correspondingly, the percentage of farmers using unmanaged pastures decreased from 86% to 79%.

Table 2 (sheep) and Table 3 (sheep farmers) provide a more detailed description of the development. In these tables, the changes were calculated individually for centrality zones,

Table 1. Number of sheep and sheep farmers. Changes in 1999–2017.

	1999	2017	Change (%)
Total number of sheep	2,304,963	2,485,157	7.82
Sheep foraging on unmanaged pastures	1,989,961	2,011,734	1.09
Sheep foraging on managed pastures only	315,002	473,423	50.29
Total number of sheep farmers	22,185	14,825	−33.18
Sheep farmers with sheep foraging on unmanaged pastures	19,031	11,684	−38.61
Sheep farmers only utilizing managed pastures	3,154	3,141	−0.41

Note. Data source: Norwegian Agricultural Agency, applications for agricultural subsidies. The numbers vary slightly (± 0.3%) between different versions of the database, probably due to correction of errors between releases

Table 2. Relative change (%) in number of sheep 1999–2017 by the urban-rural dimension and the presence of carnivore management zones (CMZ).

	Sheep grazing on unmanaged pastures		Sheep using managed pasture only	
	Change (%) 1999–2017		Change (%) 1999–2017	
CMZ present	No	Yes	No	Yes
Peri-urban	−41.50	98.53	−6.49	106.81
Central	14.38	9.99	31.05	172.85
Rural	15.11	−1.72	20.19	93.22
Very rural	3.35	−5.24	62.63	76.92
Peripheral	1.76	−16.84	81.54	62.14

Based on data from the applications for agricultural subsidies (Norwegian Agricultural Agency), centrality index (Statistics Norway) and carnivore management zones (Norwegian Environment Agency).

Table 3. Relative change (%) in number of sheep farmers 1999–2017 by the urban-rural dimension and the presence of carnivore management zones (CMZ).

	Farmers using unmanaged pastures		Farmers using managed pastures only	
	Change (%) 1999–2017		Change (%) 1999–2017	
CMZ present:	No	Yes	No	Yes
Peri-urban	−51.79	−13.95	−5.00	45.00
Central	−25.50	−31.60	−10.69	19.25
Rural	−26.37	−37.87	−23.98	8.44
Very rural	−39.27	−42.65	13.68	13.99
Peripheral	−42.19	−46.88	12.89	−8.89

Based on data from the applications for agricultural subsidies (Norwegian Agricultural Agency), centrality index (Statistics Norway) and carnivore management zones (Norwegian Environment Agency).

and inside and outside the carnivore management zones. Both tables revealed a considerable difference between sheep farming using managed pastures and sheep farming using unmanaged pastures. There were also systematic differences between centrality regions and between areas inside and outside the carnivore management zones.

The development in the peri-urban and central regions was different from the development in the rural, very rural, and peripheral regions where most of the sheep were found. There was also a noticeable difference linked to the presence of carnivore management zones among those using unmanaged pastures (except in the peri-urban region). The development inside carnivore management zones was consistently negative while the development outside the zones was positive with respect to national figures.

Statistical tracts were used as spatial units to implement the spatial analysis and control for the effect of the high concentration of sheep in certain areas. The spatial analysis was carried out with standardized figures, due to the large geographical variation in sheep production. There were statistical tracts with a single farmer keeping a single sheep, while the tracts with the largest production could have up to 276 sheep farmers and more than 50,000 sheep in a single tract. The average was 15 farmers and 2,129 sheep per tract.

The results from the two-way factorial ANOVA of the standardized changes in sheep and sheep farmers, analyzed against the two explanatory factors Centrality and Carnivore Management Zones, are summarized in Table 4. The change in number of sheep foraging on unmanaged pastures becomes increasingly negative as areas become more rural. At the same time, the change was consistently more negative in the presence of carnivore management zones – irrespective of the urban-rural dimension. There was no significant interaction effect between the two factors.

Figure 3 illustrates the relationship between the standardized change in number of farmers with sheep foraging on unmanaged pastures, centrality, and presence of carnivore management zones. The pattern was the same for the number of sheep (not shown). In both cases, change becomes increasingly more negative in increasingly rural areas. The trend was

Table 4. Results from two-way factorial ANOVA of the sheep farming and two explanatory factors: the urban-rural dimension (centrality) and presence of carnivore management zones.

		d.f.	F	p
Standardized change (1999–2017): Number of sheep foraging on unmanaged pastures	Centrality	4	2.60	.04
	CMZ	1	11.62	<.01
	Centrality x CMZ	4	1.72	.14
	Error	1,096		
Standardized change (1999–2017): Number of sheep foraging on managed pastures only	Centrality	4	2.00	.09
	CMZ	1	0.66	.42
	Centrality x CMZ	4	1.04	.38
	Error	1,152		
Standardized change (1999–2017): Number of sheep farmers with sheep foraging on unmanaged pastures	Centrality	4	5.28	<.01
	CMZ	1	4.43	.04
	Centrality x CMZ	4	0.80	.52
	Error	1,096		
Standardized change (1999–2017): Number of sheep farmers with sheep foraging on managed pastures only	Centrality	4	1.34	.25
	CMZ	1	0.96	.32
	Centrality x CMZ	4	0.65	.62
	Error	1,007		

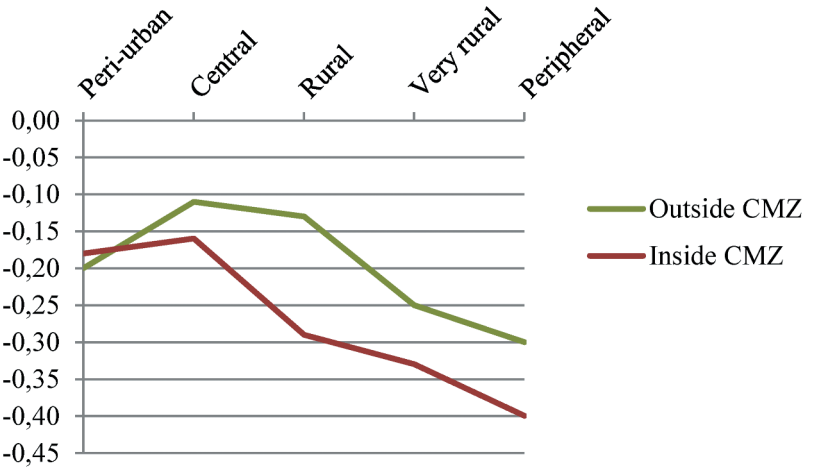

Figure 3. Number of sheep (2017) per centrality region 2017 by presence of carnivore management zones.

consistent and independent of the presence of CMZs. On the other hand, there was also a difference between areas inside and outside CMZs. The change was more negative inside CMZs than outside CMZs when controlling for centrality. This difference was consistent and independent from the urban-rural dimension. Finally, the development in the peri-urban areas was different from all other regions, and neither associated with centrality nor carnivore management.

Discussion

Norwegian agriculture is described as industrial agriculture (Jepsen et al., 2015) dominated by grass-based dairy farming, beef, and sheep production, supplied by potato, vegetables, fruit, and cereals where this is climatically feasible (Mittenzwei et al., 2017). The agricultural sector is not sufficiently economically viable to maintain many small farms, and the number of active farmers in Norway has declined almost continuously since World War II, also during the study period. A less industrialized segment of the agricultural sector is sheep farming, where many farms remain small and traditional practices like grazing on unmanaged pastures persists.

Low profitability and long working hours combined with a strong and attractive urban labor market and other political, economic, and social factors associated with centralization have meant that income from agriculture has been insufficient to stem a steady decline in the number of active farms (Forbord et al., 2014). Still, the amount of farmland remains stable. The number of sheep increased (5%) from 1999 to 2017, and so did the number of sheep foraging on unmanaged pastures (1%). Fewer farmers now manage the same amount of land and produce more sheep than before. There was, however, also noticeable change: An increasing share of the production relied on managed pastures and the relative number of sheep reared by farmers in regions inside the carnivore management zones has decreased from 32% in 1999 to 31% in 2017. Most sheep in Norway were using unmanaged pastures and a considerable number still do so inside the carnivore management zones.

Managed and Unmanaged Pastures

The main structural changes in sheep farming are linked to the use of unmanaged pastures. Around 80% of the sheep produced in Norway forage on unmanaged pastures. The sheep foraging on unmanaged pastures are (as a herd, lambs included) expected to find around 50% of their annual fodder uptake on these pastures (Anonymous, 2015). This allows farmers who are using unmanaged pastures to produce more sheep than can be reared on the farm alone.

Unmanaged pastures have historically been an important source of income for small and medium-sized farms. But while 86% of the sheep farmers reared sheep that were foraging on unmanaged pastures in 1999, this proportion had decreased to 79% in 2017. This development was expected, since international studies show that the risk of farm abandonment is higher for extensive livestock grazing systems like sheep farming using unmanaged pastures than for other production systems (Terres et al., 2015).

The use of managed pastures was increasing inside carnivore management zones, where farmers turn to managed pastures to protect the sheep from carnivores. Managed pastures can be fortified with carnivore repellent fences. Guard dogs can also be used inside the fences, but there is too limited evidence to assess their effectiveness in Norway (Eklund et al., 2017). The human presence on the farm may repel the carnivores and keep them away from the livestock, although it is not known to what extent large carnivores perceive humans as predators and react accordingly (Smith et al., 2017).

Sheep are also kept on managed pastures to maintain the agricultural landscape. Grants are provided for grazing livestock that counteract the overgrowing of former agricultural land with shrubs (Aune et al., 2018). Agricultural specialization was a recent phenomenon and farmers who specialize on grain, potatoes, or vegetables often have an old barn on the farm. They can resume rearing sheep on a smaller scale to manage the landscape and benefit from subsidies allocated to landscape management (Strand et al., 2018).

The Urban-Rural Dimension

The relative change in the number of sheep and sheep farmers was related to the urban-rural dimension. The negative development in more peripheral areas was consistent with the development in extensive agricultural systems in other parts of Europe (Lasanta et al., 2017; Terres et al., 2015). These authors found that the risk of farm abandonment was higher in areas with low population density and remote from urban centers. The explanation was related to socio-economic factors, mainly migration from rural toward more urban areas offering better service functions and improved economic opportunities (Benayas et al., 2007; Busch, 2006). Even in the presence of carnivores, farmers sometimes reported that the major factor limiting sheep production was a low consumer demand for sheep products (Kovařík et al., 2014).

The spatial study shows that the urban-rural effect was similar inside and outside CMZs. It seems reasonable to conclude that this is a relationship that takes effect independent of carnivores or carnivore management. The result agreed with the expected drivers for farm abandonment in Norway, which include low income, aging of farmers, limited farm size, and declining population density (Steinshamn et al., 2018).

The Presence of CMZs

The results demonstrated an association between the presence of carnivore management zones and the farmers use of grazing resources from unmanaged pastures. The difference between regions inside and outside the CMZs was noticeable, with a consistently more negative development inside the CMZs. This difference was independent of the urban-rural dimension.

Carnivore management zones are administrative features. They do not necessarily imply that carnivores are present or that these carnivores, if present, prey on livestock. Using the carnivore management zones as a proxy for carnivores was based on the assumption that carnivores were more likely found inside the zones than outside, and that the risk of depredation was higher when carnivores are present on a regular basis (Graham et al., 2005; Kaartinen et al., 2009).

This assumption is supported by studies from many parts of Europe. According to Kaczensky (1999) there is no example in Europe of extensive sheep farming with low losses in areas with bear or wolf. Blekesaune and Rønningen (2010) found that people living within the area where sheep have been killed by bears during the last decade were much more negative to bears. Landa et al. (1999) found a positive relationship between the number of lost ewes and the number of wolverine in their study area in Norway, and lynx attacks on sheep in the French Jura increased from three in 1984 to 188 in 1989 when lynx were reintroduced in the main sheep rearing areas (Stahl et al., 2001). Such experienced losses have economical as well as mental impact on the farmers and can lead to a decline in sheep farming (Asheim & Mysterud, 2004). A Swedish study also reported that the sheep production was reduced by the mere presence of carnivores (Widman et al., 2017), although this allegation is disputed by other studies (e.g., Ramler et al., 2014).

The Peri-Urban Areas Inside CMZ

The effect of centrality and CMZ did not hold for the peri-urban and most central areas. Farmers keeping sheep in the peri-urban agricultural areas rarely have sheep farming as their main source of income. Many farms in these areas are comparatively large and the main produce is cereals, potatoes, vegetables or, in climatically less advantaged parts of the country, dairy products, or cattle. Small peri-urban farms are pursued as homes by people working in the cities but attracted by a more rustic lifestyle. Sheep grazing on the farm can in both cases help keep the landscape open and attractive (Strand et al., 2016).

The owner can claim subsidies for rearing sheep when the property is a registered farm. Some farmers also rent out sheep to other farmsteads where the owner would like the keep the landscape open but does not desire to keep his own herd. It is possible to claim additional subsidies for landscape management for these sheep. There are also funds available for fencing (to protect the sheep against carnivores) inside the CMZs. Grants are provided to sheep farmers in wolf management areas in order to cover the additional cost of having to keep the sheep on managed fields instead of allowing them to forage freely on unmanaged pastures. The extra cost is supposed to cover medication, moving animals between enclosures and compensate for the reduced meat production on managed pasture. The combined grants and subsidies provided in the CMZ for wolf means that farmers having their main income outside the sheep industry can keep small herds of sheep for

landscape management or simply as an avocation and have their expenses covered. Predation may occur but have few consequences for the framers' total economy. This is an example of unintended consequences (Merton, 1936) of the mitigating efforts directed at livestock producers in areas with little livestock.

The situation was different in the more rural and peripheral regions where rearing sheep constitute a larger part of the income for farmers and their economy depends on using the grazing resources on unmanaged pastures. By exploiting the unmanaged pastures, the farmer can store the grass harvested on the farm for use as fodder during the winter. Less grass is available as winter fodder when the sheep must be kept inside enclosures on the farm during the summer to protect them from carnivores. The number of sheep the farmer can maintain is substantially lower when carnivores are present, implying that the income is reduced equally. While CMZ management stimulated more farmers to take up small-scale sheep production in central areas, especially in the CMZ for wolf, the same policy led to a decrease in sheep farming in the more rural areas, especially when bear or wolf were present (Strand et al., 2019, 2018).

Explanatory Model

The results can be summarized in an explanatory model for the changes in sheep farming, related to centrality and the presence of CMZs. The model can be expressed as:

$$y_i = a(x_i - x_0) + y_0 - b\Delta y_0 | x_i \rangle x_0$$

where y_i is the expected change in sheep farming at location i when x_i is the rurality at the same location. x_0 is a threshold value, the rurality where the model starts to take effect (the model does not apply for more central locations than x_0) and y_0 is the expected change when the rurality is x_0, while Δy_0 is the difference in change between areas inside and outside the carnivore management zones when the rurality is x_0. Finally, a and b are parameters representing the effect of rurality (a) and the presence or absence (binary) of carnivore management zones (b).

The model is a generalization of Figure 3, and the predictive power of the model has not been tested. Note also that potential predictive power only demonstrates correlation and not proof of causality. Studies show that fluctuations in production costs and market prices explain most of the variation in sheep numbers (Berger, 2006). The model provided a formalized summary of the results of the study with respect to the objective of the paper. There was a correlation between changes in the sheep-farming system and the urban-rural dimension, but also an independent effect of the presence of carnivore management zones. These changes were the compound results of decisions made individually by a large number of farmers. The results should be complemented by studies of how farmers react to economic and societal factors and make decisions in the presence of carnivores and carnivore management policies.

Conclusion

This article supplemented research that examined the sheep farmers' attitudes and decision-making in the presence of large carnivores with research addressing the consequences on the larger farming system. Structural changes in Norwegian sheep farming over the last

20 years were examined, emphasizing the relationship with the urban-rural dimension and the spatially differentiated carnivore management system used in Norway. Data from applications for agricultural subsidies were used, with locations (statistical tracts) as study objects.

The main finding could be expressed in a simple model: Changes in the sheep farming using unmanaged pastures were associated with the urban-rural dimension. Farmers are more likely to reduce their activities or change to managed pastures in increasingly rural areas. There was also an independent, negative relationship with carnivore management zones. The development was more negative inside carnivore management zones, independent of the position along urban-rural dimension. This observed correlation is no proof of causality, but the presence of carnivores is a plausible explanation. Neither centrality nor carnivore management was associated with the changes in the most central regions.

A next step is to test the predictive power of the explanatory model and examine deviations from the predicted change. Hot-spots of positive (or negative) deviations from the model in certain areas could be used to investigate additional hypothesis about the structural changes in sheep farming, including the abandonment of unmanaged pastures. The anomalies observed in peri-urban and central regions are also a topic for further research about the farmers' behavior and decisions. The changes in these regions were influenced by forces entirely different from those that were examined here.

The associations between carnivore management, assumed carnivore presence, and change in sheep farming are ultimately driven by the reasoning and decision-making of sheep farmers. The results and conclusions from this research demonstrate the complementarity between studies that examine the attitudes, mental dispositions, and decisions made by individual farmers and studies of the consequences in terms of the combined effect on larger farming systems.

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