10 The productive herd

Past, present and perspectives

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Introduction

The essence of reindeer pastoralism is the conversion of natural resources into animal products to satisfy human needs. However, the ecological niche of reindeer pastoralists is hard to manipulate. To meet production goals in the short and long term and secure the animals' survival, adjusting herd size and composition to ecological conditions become essential. These goals are dynamic and must be placed in a social-ecological context (e.g., Paine 1994; Næss 2020). Obviously, the transition from traditional pastoralism to present-day market-oriented meat production has created tensions between and within herders' communities. The authorities' push for rationalization by use of economic incentives and regulations created frustration among the herders (e.g., Hausner et al. 2011; Riseth et al. 2019) and is still ongoing (Chapter 9). It is therefore imperative to investigate how herders traditionally managed and selected animals to meet their production goals and to explore the transition to the current market-oriented meat production and its implication for herd size and composition, as well as slaughter regimes and selection.

Herd dynamics and production depend on an array of abiotic and biotic factors: quality and seasonal balance of pastures, climatic conditions, anthropogenic disturbances and predator pressure, as well as management practices. Animal density and herd composition are influenced by slaughter and selection practices (Danell & Petersson 1994). Even the appropriate measures to describe a herd's (meat) productivity can be disputed (Marin et al. 2020). Indeed, ecological and social factors affecting production are often overlooked. Most of the production-oriented research has focused on variation of productivity within a country (Lundqvist 2007; Tveraa et al. 2007; Riseth 2009; Næss 2020; Marin et al. 2020, but see Helle & Kojola 2008). Obviously, an analysis of differences in meat productivity both between and within countries is due.

A warmer and wetter climate in Fennoscandia may have detrimental effects on reindeer well-being. Increased rain-on-snow events, which make the ground vegetation layer inaccessible (e.g. Tyler et al. 2021), may drain the animals' body reserves. Further, a mismatch between the peak of resource demands by

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reproducing animals and the peak of forage availability has been suggested in *Rangifer* (Post & Forchhammer 2008). The relative role of phenotypic plasticity and microevolutionary response to a warmer and wetter environment with frequent fluctuations remains largely unquantified in semi-domesticated reindeer (but see Holand et al. 2020). We, therefore, end this chapter by discussing challenges and strategies for maintaining viable and productive herds in a changing north.

Past

In the early phase of reindeer pastoralism, reindeer supplied an array of products from both live and slaughtered animals. However, in the 1800s, these small multipurpose herds evolved in many regions into large herds with seasonal migrations, with a focus on meat production. This became the main form of pastoralism among Sámi herders in Fennoscandia (Chapter 1). Transportation of household equipment between seasonal dwelling sites became essential. Before entering the transportation squad, selected males had to be trained and finally castrated at 3–4 years old. The traditional Sámi strategy was to keep reproductive females in good condition and predominantly slaughter adult males, including castrates. The proportion of males in the herd could reach 50% (Skuncke 1964).

The Sámi herders' rationality

The herd represents the owners' and their household's investment for their future. The herders' rationale was to withstand unpredictable events by keeping large and robust herds (Ingold 1980). This was achieved by having a herd that contained a high proportion of the age classes with low mortality. The drive for a larger herd often led to overaccumulation across consecutive good years. This was followed by crashes in reindeer numbers as the pastures were not able to permanently bear high stocking rates. Such crashes were caused by extreme winter conditions resulting in starvation often amplified by disease outbreaks (Päiviö 2006). The fluctuations in herd size were also modified by social interactions between herders, as movements to mitigate poor range conditions relied on reciprocal access to pastures and mutual agreements among neighbouring herding groups (Chapter 7).

Viable and productive herds depend on sufficient pasture resources, escape habitats and functional corridors during all seasons. Likewise, a diverse and functional herd adapted to a fluctuating environment is a prerequisite for using the natural resources optimally and thus confers resilience to the herd, inherent in the "beautiful herd" (*čappá eallu*) concept (Magga 2006).

An optimal herd composition was, and still is, the foremost goal in herd management (Oskal 1999). The owners' success depends on their ability to assess the performance of individual reindeer as well as the performance of their herd and the herds of other members of their herding group. In addition to favouring specific phenotypic traits such as large-bodied animals, selecting for specific behaviours, such as maternal care or following behaviour contributed to the domestication process.

New ideas enter the scene

As early as the late 1930s, Soviet researchers (e.g., Dobrotvorsky 1938) started to advocate for changes in herd composition to increase meat production. They suggested restructuring herds towards a higher proportion of reproductive females and introduced the slaughtering of calves. These ideas entered Fennoscandia in the late 1950s. Varo (1964; 1972) analysed phenotypic and genetic variation in important production traits and promoted calf slaughter to utilize the high growth potential of the juvenile segment of the population. This new practice was also advocated by Norwegian and Swedish researchers (e.g., Skuncke 1964; Skjenneberg & Slagsvold 1968). However, without the transportation revolution brought about by the availability of snowmobiles in the 1960s, the new herd composition and slaughter regime would have been hard to implement.

Herd investigation and transformation

In Norway, the transformation towards new herd composition aimed at maximizing production started among the Sámi in the South. In the 1960s, the herders in several *sijtes* agreed on internal resource distribution, including a maximum number of animals per household (Fjellheim 1999). This was possible given the small number of herders and enabled them to join forces to withstand external pressures (Næss 2020). The aim was to develop a herd structure and slaughter strategy that combined tradition-based practices with modern production theory.

Reproduction rates, as well as the timing of conception, were investigated and related to female slaughter weight and male age structure during the rut. Female body mass was identified as a quantitative and objective proxy for reproductive performance (Figure 10.1). Lenvik and Fjellheim (1988) documented a high correlation for autumn body mass between calves and yearlings. Therefore, phenotypic selection based on female calves' autumn body mass would improve their body mass at 1.5 years of age. The female's pre-rut body mass at 1.5 years should be 60 kg to give birth to viable calves in the following spring (Lenvik 1988, Figure 10.1). Lenvik argued that a male:female ratio of 1:10 and the use of 1.5 years old males with a body mass larger than 60 kg during rut would secure full conception. Realizing the animals' growth potential required an appropriate pasture balance (Lenvik 1988). Where such conditions were met, prime age females reached a spring body mass of around 70 kg and reproduced each year with minimal calf mortality (Figure 10.1). Females that were too large were regarded as disadvantageous as they required more energy, and hence more winter forage without any production gain.

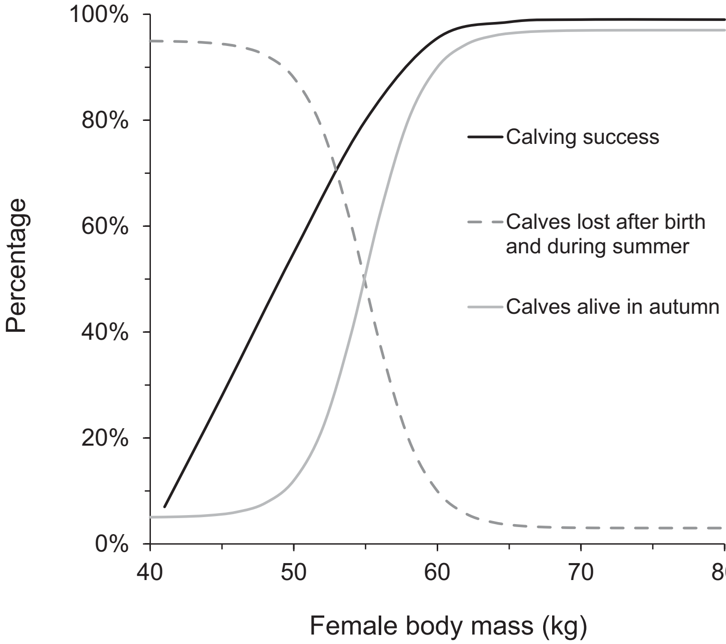

Figure 10.1 Female calving success and mortality of their calves in relation to the females' own spring body mass (redrawn after Lenvik (1990)).

Changes in the herd's sex ratio and age structure took place by trial and error during the 1970s and early 1980s in many Sámi districts in southern Norway (Figure 10.2). Selection improved animal condition and meant that most 1.5-year-old females were able to reproduce regularly for about 10 years. The proportion of reproducing females increased in the winter herd, accompanied by higher culling (phenotypic selection) of female calves. Among the male calves, the selection was even stronger. Around 80% of the male calves were slaughtered in autumn and early winter. The transformation was fuelled by a calf slaughter bonus since 1977, agreed annually by the government and the Norwegian herder's association (NRL). As a result, the strategy started to spread to northern Norway.

Longitudinal data generate new knowledge

Ruvhten Sijte (Jämtland, Sweden) started an individual recording programme in the early 1980s, which is still running. Petersson and Danell (1993) demonstrated that the body mass of calves in autumn had a substantial genetic component and therefore phenotypic selection would yield an appreciable response. However, they underlined that the long-term advantages from such

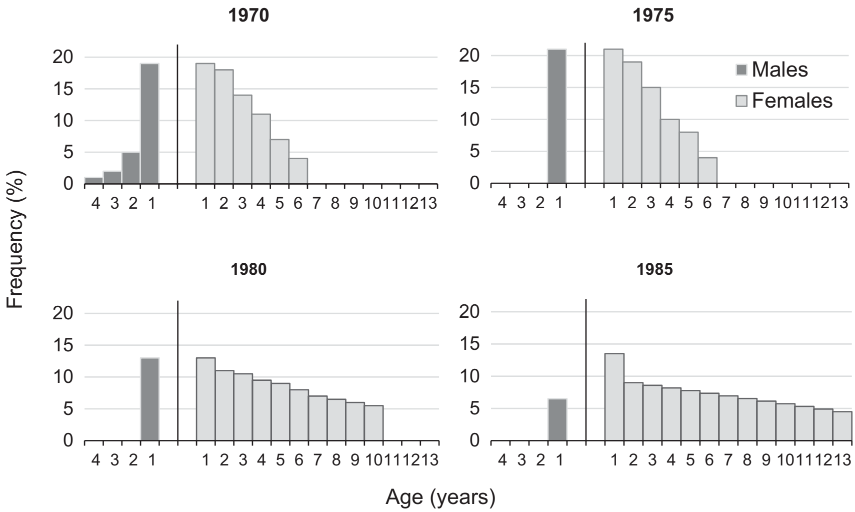

Figure 10.2 The gradual change in winter herd sex and age composition during the 1970s and early 1980s in Gåebrien sijte (redrawn after Lenvik (1990)).

a selection regime should be further dissected in relation to longevity, lifetime reproductive success and maternal traits. Rönnegård and Danell (2003) used an expansion of the same data set and found an increase of 0.35 kg in body mass of calves in autumns after 11 years of selection. By comparing the rate of inbreeding, including the maternal effect in their analyses, Rönnegård et al. (2003) concluded that there is no risk of losing genetic variation if the herd size exceeds 2,000 animals.

Based on detailed life history data collected since 1969 from the Finnish Reindeer Herders' Association experimental reindeer herd at Kutuharju (northern Finland), Eloranta and Nieminen (1986) confirmed the effects of maternal age and female body mass on calf birth weight and survival. Weladji et al. (2008) explored the reproduction costs of females in the Kutuharju herd. Comparing age-specific survival and reproduction between four reproductive states, they found no cost of gestation and lactation in terms of future reproduction and survival. Females that successfully raised their first calves early remained successful throughout their life, suggesting the existence of substantial variation in female maternal quality (Weladji et al. 2006). However, supplementary feeding during winter, first implemented in 1986, might conceal reproductive costs.

In the same herd, Muuttoranta et al. (2013; 2014) investigated the genetic variation in traits related to calf growth. Genetic variation was substantial in the traits related to birth weight and even birth date (see also Holand et al. 2020). They also found that the female's body mass is inversely related to her maternal care. However, there is too little data to investigate the variation in traits prone to non-genetic variation and for understanding the consequences on fitness traits of artificial selection for meat production.

Herders' selection practice

Muuttoranta and Mäki-Tanila (2011) surveyed the attitudes of the Finnish and Sámi leaders of the herding districts in Finland towards the use of selection to improve production. The leaders considered selection and optimization of herd composition to be the most important management operations.

Calf slaughter is a common strategy among the herders to modify the herds' age distribution and sex ratio for higher productivity and profitability. The leaders interviewed were aware of female age affecting calf body mass and survival. During autumn slaughter, the most vigorous calves are left alive to increase the vigour of the herd and future generations. The main selection criteria in Finland are calf health, vigour, body size and muscularity. The calf's temperament had only a small effect on selection. The leaders indicated an inverse relationship between an individual's own and the mother's effects on calf growth, as reported by Muuttoranta et al. (2014).

About half of the districts marked all their breeding animals individually. One-third had an individual bookkeeping system. Indeed, it is essential that the pedigree information can be related to phenotype measurement, such as calves' autumn body mass. Muuttoranta and Mäki-Tanila (2011) reported that calves are never weighed at the autumn round-up, and selection is based on visual assessments. This would obviously compromise quantification of the selection efficiency although it is most practical in terms of time requirements and infrastructure.

Production

Herd productivity depends on factors such as quality and seasonal balance of pastures, climatic conditions, anthropogenic disturbances and predator pressure, as well as management practices; animal density and herd composition are influenced by slaughter and selection practices (Figure 10.3). The net profit of production is a function of production costs and revenues (Chapter 11). While costs are not directly related to herd size, revenues depend on meat production volume, sale of by-products (e.g., skins and antlers) and market conditions. Indeed, product prices vary seasonally, between age classes and with quality.

Herd dynamics and meat production measures

Primary production of forage resources suitable for reindeer grazing depends on biotic and abiotic conditions, with high spatial and temporal variations. Furthermore, stochastic weather and climate events (in particular snow conditions) have a strong impact on the population dynamics of reindeer (Helle & Kojola 2008; Bårdsen et al. 2017). This implies that a dynamic stocking rate,

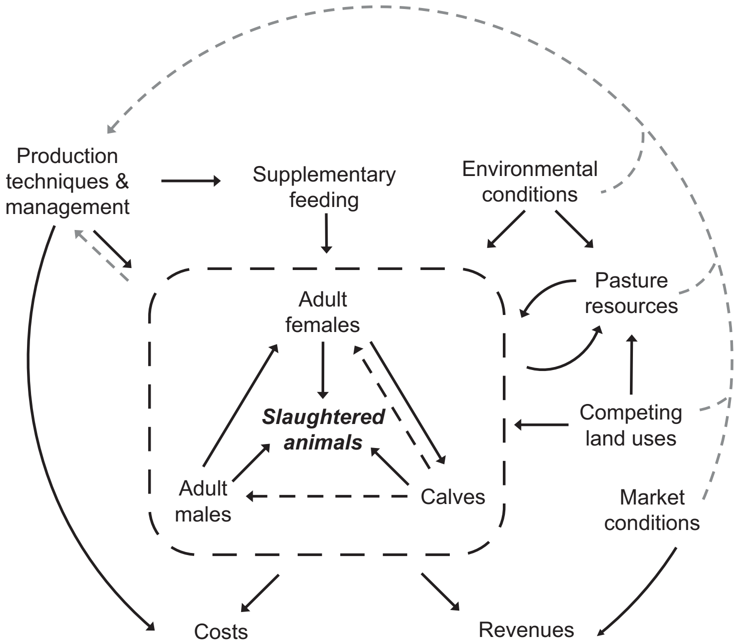

Figure 10.3 Herd dynamics and production depend on herd composition and slaughter strategy, indicated by links between animal classes within the dashed box; these are influenced by an array of external factors and natural conditions. Outside the box, solid arrows represent direct effects whereas dashed lines indicate possible influences (redrawn after Danell and Petersson (1994)).

herd composition and harvesting approach would be appropriate to respond to density-dependent and independent factors that can influence population dynamics (Bårdsen et al. 2017). Given a highly female skewed winter herd, the stochastic simulation predicts that maximum annual meat production is reached when around 70% of the calves are slaughtered (Bårdsen et al. 2017). However, such herds have high growth potential and will run into food shortages if not harvested appropriately. An optimal harvest also depends on its timing, to utilize the high summer growth rate and to minimize mortality during winter. If the availability of winter grazing resources is limited, the slaughter should take place before the herd enters the winter pasture.

The females' risk-averse life history strategy (Bårdsen et al. 2008) is essential to understand the herd dynamics, which are primarily driven by female body mass and condition. The changes in a female's condition are reflected in the performance of her offspring (Rönnegård et al. 2003). Indeed, the autumn calf carcass weights and the herd's autumn female:calf ratio are two measurable proxies for females' condition. Further, these two parameters indicate the herd's welfare status and ability to withstand extreme winter events.

The growing integration of reindeer pastoralism into the market economy in the latter half of the twentieth century rationalized production and meant that most of it passed through approved slaughterhouses. In Norway, Sweden and Finland, the recording of slaughter data for carcass weight, sex, age class and carcass quality was established. Thus, reliable and systematic data have been available since the late twentieth century in these countries. The summed statistics do not fully reflect the total production, leaving out some privately sold meat and subsistence use. However, the proportion moved through official channels is high, estimated to average around 90%, because many of the subsidies are connected to official slaughter records. The slaughterhouse data, combined with information on herd size and size of pasture area, allow several aspects of the production to be quantified and analysed at different spatial and temporal scales: total production, production per animal in the winter herd after slaughter or per pasture area.

Herd adjustment

Given sufficient pasture resources, almost all adult females give birth to a calf every year. However, climatic variation has a strong influence on the females' productivity and the growth of their calves. Production per animal in the winter herd, therefore, reflects the winter herd composition and slaughter strategy. Herd production per pasture area can be used to adjust herd size to available grazing resources. Both measures are proxies and must be adapted locally. Adapting herd size to available grazing resources requires careful monitoring of the state of pastures. In particular, terrestrial lichens, the principal winter grazing resources, are very sensitive to rapid increases in herd size and are thus a bottleneck for sustainable herd size. In parts of Finnmark, a strong inverse relationship between lichen biomass and reindeer herd size has been shown (Tømmervik et al. 2014). In several herding districts in Finland where there is no pronounced separation between summer and winter grazing areas, trampling of the unprotected lichen cover during summer has strongly decreased its availability as a winter grazing resource (Kumpula et al. 2014). Navigating the balance between-herd size and forage availability, therefore, requires decisions regarding herding and slaughter strategy, as well as herd composition at the level of herding units. This is particularly the case as strategies regarding herd composition and slaughter by individual reindeer owners may vary, thus influencing the inter-owner productivity (Weladji et al. 2002).

Between-herd comparison

Comparisons can be made at different spatial scales, such as herding district, region and country level. Variation in productivity may be due to pasture quality and size of the seasonal pastures, herd size, climate and herd management, including herding, driving and round-up practices. Comparisons, therefore, need to be based on the production per animal, or pasture area. Potential effects of encroachment on pastures and disturbance by other forms of land use must also be considered (Chapter 4). This may reduce the usable pasture area, and if the herd is not reduced proportionally, the stocking rate will increase. Disturbance may also influence forage acquisition negatively and hence growth. We acknowledge that overgrazing and overstocking are debated concepts (Mysterud 2006) and are often misinterpreted and taken out of context. Indeed, these concepts and the regulation enforcement practised have to be put into a political ecology context as discussed in Chapter 9.

Production in the three countries – similarities and differences

In the following, we present statistics from the official national records: the Finnish Reindeer Herders' Association reports (Paliskuntain yhdistys) 2010–2020, the Norwegian Government reports (Landbruksdirektoratet) 2010–2020 and the Swedish Sámi Parliament database.

The average annual total production in the last decade has been highest in Finland, followed by Norway and then Sweden (Table 10.1). Finland stands out even more when measured as production per km^2 and the production per animal in the winter herd. The high productivity in Finland cannot be explained by range quality, slaughter practice or winter herd composition, which is rather similar at the country level (Table 10.1). We suggest it is primarily related to the extensive use of supplementary feeding during winter in Finland, which secures high female fertility and calf survival. Nieminen (2010) estimated that, in Finland, ca. 100 kg of pellets were fed per reindeer each winter. In addition, he estimated that the amount of roughage fed was similar in energy content but considerably higher in weight per animal. In Sweden and Norway, supplementary feeding is not currently a regular practice to the same degree as in Finland. However, the use of this practice has increased in both countries in the last decade (Chapter 12).

Table 10.1 Yearly average (2010–2020) production statistics for Finland, Norway and Sweden Coefficient of variation (%) in brackets. Herd composition during winter and slaughter composition are divided into male/female/calf (M/F/Calf)

Country	*Av. tot. prod. (tons)*	*Av. prod (kg) per animal in winter herd*	*Av. prod. (kg)/km^2 available pasture*	*Winter herd composition (%) M/F/Calf*	*Slaughter composition (%) M/F/Calf*
Finland	1957 (10%)	10.2 (11%)	17.4 (10%)	7/78/15	8/16/76
Norway	1526 (10%)	6.8 (12%)	10.5 (10%)	6/78/16	11/10/79
Sweden	1366 (9%)	5.5 (9%)	6.0 (9%)	8/68/24	10/20/70

Sources: Landbruksdirektoratet (2021); Paliskuntain yhdistys (2010–2020); Swedish Sámi Parliament (2021).

Higher productivity in Norway compared to Sweden (per animal in the winter herd) may partly be explained by the higher proportion of females in the winter herd and the higher percentage of slaughtered calves (Table 10.1). Further, the lower production per area in Sweden may be attributed to a larger proportion of the potential pasture area not being available. Indeed, estimates of the Swedish total pasture area vary. We have used Sandström's (2015) estimate of 226,000 km^2.

Considerably larger populations of predators, compared to the other two countries (Chapter 6), are another potential explanation for low productivity in Sweden, but see Bårdsen et al. (2017). According to Hobbs et al. (2014), every reproduction of lynx or wolverine may reduce the annual harvest by, on average, around 100 reindeer. With the present Swedish reindeer populations, this corresponds to 20,000–25,000 reindeer and will obviously impact the population dynamics and slaughter off-take. The impact due to bears is unknown, but predation of neonatal calves may be high when bears are present in the calving area (Sivertsen 2017).

In all three countries, the total production of the winter population has varied considerably over the last hundred years (Chapter 1). Since 2012, the winter populations of the three countries have been rather stable, as has the total production (Figure 10.4). This may indicate an appropriate stocking rate in all three countries combined with no extreme winter events in the last decade. However, winter 2020 was difficult in many parts of northern Fennoscandia and resulted in extensive emergency feeding. Nevertheless, losses to starvation

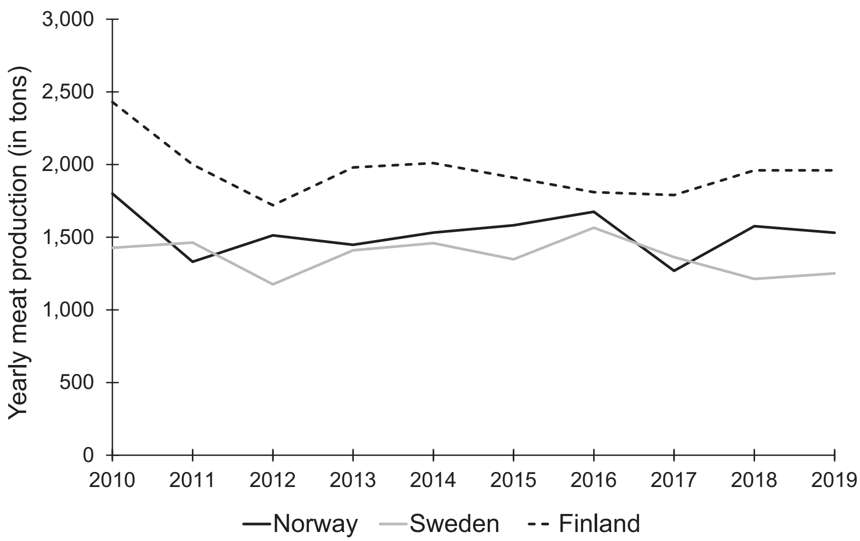

Figure 10.4 Yearly total meat production (in tons) in Finland, Norway and Sweden passing through official slaughterhouses in the last decade.

were high and preliminary data from Norway suggest a pronounced decrease in the number of animals slaughtered in autumn 2020.

Variation within the countries

In all three countries, the herding regions mostly follow administrative borders, meaning that the inter-regional comparison, based on official statistics, should be interpreted with caution, because they may hide larger within-region variation in natural conditions as well as management practices.

In Finland, the reindeer herding area is divided into three main regions (Chapter 1). The average production per animal in the winter herd during the last decade has been rather similar across these regions, probably reflecting the almost identical winter herd composition and slaughter strategy (Table 10.2) as well as feeding practices. The lower productivity per pasture area in the southern part seems partly related to intensive forestry practices and disturbance. In Finland, the southern districts have considerably less variation in meat production between years, most likely due to higher supplementary feeding.

In Norway, the differences in productivity between regions are pronounced (Table 10.3). Herd composition and slaughter strategy are similar, probably due to high calf slaughter subsidies, and cannot explain the variation. The proportion of slaughtered animals for home consumption and local sale and thus outside the official channels seems to be highest in the north and may explain some of the variations. The production per animal in the winter herd is highest in the southern regions, where there is also lower between-year variation (Table 10.3).

Table 10.2 Yearly average (2010–2020) production statistics for different reindeer herding regions in Finland. Coefficient of variation (%) in brackets. Average winter herd composition divided into percentage of male/female/calf (M/F/Calf) and average slaughter composition (M/F/Calf) for the same period are also given.

Main regions	*Av. tot. prod. (tons)*	*Av. prod. (kg) per winter head*	*Av. prod. (kg)/ km² available pasture*	*Winter herd comp. (%) M/F/Calf*	*Slaughter comp. (%) M/F/Calf*
Sámi homeland area	845 (18%)	10.8 (17%)	17.8 (18)	7/80/13	10/17/73
Special reindeer herding area excluding the Sámi homeland	356 (14%)	8.7 (20%)	18.9 (14%)	8/76/16	7/17/76
Southern part of the reindeer herding area	755 (8%)	10.0 (9%)	13.3 (8%)	7/78/15	7/16/77

Source: Paliskuntain yhdistys (2010–2020).

Table 10.3 Yearly average (2010–2020) production statistics for different reindeer herding regions in Norway. Coefficient of variation (%) in brackets. Average winter herd composition divided into percentage of male/female/calf (M/F/C) and average slaughter composition for the same period are also given.

Regions	*Av. tot. prod. (tons)*	*Av. prod. (kg) per winter head*	*Av. prod. (kg)/ km² available pasture*	*Winter herd comp. (%) M/F/ Calf*	*Slaughter comp. (%) M/F/ Calf*
Øst-Finnmark	500 (22%)	6.9 (23%)	16.3 (22%)	6/78/16	9/10/81
Vest-Finnmark	456 (24%)	5.1 (23%)	17.2 (24%)	6/78/16	8/11/81
Troms	37 (24%)	3.1 (24%)	2.0 (24%)	10/71/19	17/12/71
Nordland	58 (10%)	4.1 (12%)	1.8 (10%)	10/70/20	19/15/66
Nord-Trøndelag	107 (15%)	10.8 (14%)	4.8 (15%)	6/76/18	16/15/69
Sør-Trøndelag/ Hedmark	166 (12%)	13.1 (11%)	19.3 (12%)	4/77/19	14/12/74
Non-Sámi	213 (7%)	16.9 (6%)	34.7 (7%)	5/73/22	18/14/68

Source: Landbruksdirektoratet (2021).

In the south, the herds have been kept rather stable based on internal regulation and high production output since the late 1970s. A paradox is that here the disturbances and fragmentations are considerable. For production per area, the non-Sámi region stands out, producing almost 35 kg per km^2. The Sámi southern (Sør-Trøndelag/Hedmark) and northern (Øst- and Vest-Finnmark) regions produce 16–19 kg per km^2. The considerable differences between South and North in production per animal in the winter herd suggest that the production potential in Finnmark is high. Indeed, some districts in Øst-Finnmark match the per winter head productivity of the non-Sámi area. Næss (2020) argued that internal competition and lack of trust, within and between districts, have contributed to what he calls an "Assurance game" resulting in herd accumulation and size fluctuation in parts of Finnmark. The new regulations implemented in the early 2010s seem to have stabilized herd size but have induced mistrust between herders and the authorities and increased internal conflicts (Chapter 9). In Troms and Nordland, the productivity is low (Table 10.3). Tveraa et al. (2007) argued that the shortage of winter pastures in these two regions limits production, even though the summer pastures are excellent. The high predator pressure may also contribute to the low output.

The variation in productivity between the reindeer herding regions in Sweden is pronounced (Table 10.4). The low productivity in the mountain reindeer herding districts (RHDs) in northern Norrbotten can be partly explained by a large number of herders having few reindeer and a large personal outtake, not accounted for in the official statistics. The same is true for the concession RHDs. The highest productivity measured per winter head and per km^2 pasture area is in the mountain RHDs in southern Jämtland (Table 10.4) and may be partly explained by the high female percentage in

Table 10.4 Yearly average (2010–2019) production statistics for different reindeer herding regions (RHDs) in Sweden. Coefficient of variation (%) in brackets. Average winter herd composition divided into percentage of male/female/calf (M/F/Calf) and average slaughter composition (M/F/Calf) for the same period are also given.

Regions	*Av. tot. prod. (tons)*	*Av. prod. (kg) per winter head*	*Av. prod. (kg)/ km² pasture*	*Winter herd comp. (%) M/F/ Calf*	*Slaughter comp. (%) M/F/ Calf*
Mountain RHDs					
Norrbotten county North	166 (22%)	2.2 (21%)	4.3 (22%)	9/63/28	11/14/75
Norrbotten county South	264 (16%)	5.9 (16%)	6.8 (16%)	9/68/23	14/25/61
Västerbotten county	302 (14%)	6.6 (17%)	6.3 (14%)	9/68/23	13/22/65
Jämtland county North	106 (27%)	5.3 (26%)	2.6 (27%)	7/69/24	12/18/70
Jämtland county South	313 (17%)	12.5 (16%)	16.4 (17%)	6/77/17	8/16/76
Forest RHDs	174 (15%)	5.8 (14%)	6.4 (15%)	8/70/22	5/21/74
Concession RHDs	42 (19%)	3.7 (16%)	3.1 (19%)	8/69/23	11/17/72

Source: Swedish Sámi Parliament (2021).

the winter herd. Lundqvist (2007) argued that different animal densities and the length of the growing season contribute to the variation. Supplementary feeding seems not to be the main explanation for differences between regions, as feeding is least common in the southernmost region. As mentioned previously, predator pressure has been shown to affect slaughter volume (Hobbs et al. 2012) and may therefore be an important explanation for differences in productivity between regions.

Perspectives

Building on the knowledge and practice from the past and present relating to herd dynamics and productivity, we discuss how climate change and globalization may affect the viability of reindeer pastoralism from a production point of view.

Climate change

Rapid climate change may threaten the stability and functioning of Arctic ecosystems. As the Arctic is warming, it has been widely observed that shrubs expand their distribution, abundance and size in the hitherto treeless areas, contributing to regional warming due to increased absorption of solar radiation and other ecosystem effects (Verma et al. 2020). High summer grazing pressure may slow down "shrubification" (Verma et al. 2020) and hence prevent a decreased albedo. However, a too high stocking rate may reduce the production output per winter head. This may increase the enteric methane emission per kg meat produced and hence the herds' CO_2 footprint.

There is a lack of knowledge about the ecological and evolutionary adaptations of large northern herbivores to a changing and fluctuating environment. Climate change is anticipated to increase winter precipitation in the form of snow, at least in the mid-term, but also lead to increased risk of rain-on-snow events which render the ground vegetation layer inaccessible (e.g., Tyler et al. 2021). This will reinforce reliance on supplementary winter feed to prevent starvation (Horstkotte et al. 2020). However, extensive winter feeding may change the animals' natural foraging behaviour and weaken their forage acquisition skills. More frequent occurrence of ice crusts may also have implications for herd size and age and sex composition as strong animals in good condition (including males and castrates) are better able to break ice layers. The effects of fragmentation of ranges and habitat loss, expressed through disturbance of their foraging and movement pattern and habitat use (Chapter 4), amplify these negative consequences. Positive effects can also be anticipated. Climate warming and increased precipitation will prolong the growing season, reducing the length of the winter. This may improve the animals' body condition (Weladji & Holand 2006; Tveraa et al. 2013) and hence their ability to cope with harsh winter conditions. However, during extremely warm events reindeer become "heat trapped", jeopardizing their heat balance. They must allocate time and energy to thermoregulate and hence are not able to fully realize their growth potential.

Parturition and mating behaviour of reindeer have evolved along with their migratory behaviour, feeding specialization and social structure of large and mobile herds. Ultimately, the mating synchrony reflects their need to time births according to the onset of vegetation green-up during spring for optimal survival of young. Due to climate change, there is increasing concern regarding the potential for a mismatch between the peak of resource demands by reproducing animals and the peak of forage availability that individuals rely on to ensure the survival of their young. However, testing the so-called Match/Mismatch Hypothesis has yielded contradictory results in *Rangifer* (Post & Forchhammer 2008; Tveraa et al. 2013; Paoli et al. 2019).

Using the Kutuharju life history dataset, Paoli et al. (2018) found that climate change may affect reindeer reproductive phenology. The calving season advanced by approximately seven days in the period from 1970 to 2015 (see also Holand et al. 2020). Advanced birth dates were correlated with lower precipitation, mainly in the form of snow and a reduced snow cover in April and warmer temperatures in April–May. No increasing mismatch between parturition time and the earlier emergence of spring was found, suggesting the reindeer to be a highly plastic species (Paoli et al. 2019). However, simultaneously the calving synchrony in this herd has weakened, indicating that the climatic trend also affects the variation in females' calving date.

The relative role of plasticity and microevolutionary change remains largely unquantified in reindeer. However, Holand et al. (2020) estimated breeding values and showed that earlier parturition in the Kutuharju herd has a substantial micro-evolution component. They also found directional and stabilizing selection towards a combination of earlier birth date and heavier birth mass, with an intermediate optimum, and that these traits have a negative genetic correlation. This indicates that in reindeer there is an optimal trade-off between birth weight and birth date as the environment changes. A stochastic environment induces a selection pressure for highly plastic phenotypes, but as environmental changes progress plasticity may not be sufficient or too costly and there will be selection for genetic changes. This emphasizes the importance of maintaining genetic and phenotypic variation and has implications for selection of animals for production.

Advances in selection schemes

To achieve and maintain an optimal herd composition requires systematic slaughter, which automatically leads to changes in the herds' genetic composition. The herders implement balancing selection based on calf growth and reindeer mother's capacity to care for the calf. The coordinated development and utilization of genetic variation are, to a large extent, overlooked in domestic reindeer management. In particular, little is known about the consequences of selection. Animal breeders have developed models to answer such questions (Willham 1963). We have developed a method to find out what kind and how much data is needed to analyse the outcome and consequences of selection in reindeer herds (Pietarinen et al. 2018; Pietarinen & Mäki-Tanila 2020). The method allows the comparison of cases based on genetic parameters, information sources and selection intensity.

Let us assume that, for a selected trait in reindeer, there is a genetic component in the phenotypic variation for both direct and maternal effects, and the effects are inversely related.

We will base the analysis on the information available for a reindeer calf during the autumn slaughter, when the slaughter decision is made. If the selection is based only on the calf's weight, the change in maternal effect would be negative. We need additional data on the females' performance to improve the responses of the selection strategy. Because reindeer are uniparous and, over their whole life, produce few progenies, we need information on the relatives and, in particular, on the sire's relatives (Figure 10.5). Even if there is an inverse relationship between direct and maternal effects, with suitable information about relatives, it is possible to improve both effects simultaneously.

As reindeer production occurs in a harsh and fluctuating environment, ongoing natural selection needs to be accounted for in the herders' long-term selection for optimized production. Extensive data bodies on traits like survival and reproduction are needed to assess the relationship between production and fitness traits. Natural selection among male reindeer can be very intensive, strongly affecting the outcome of artificial selection by the herders. To maintain the genetic variation within the herd, the minimum number of breeding males has to be 50–100. With 10% selection among male candidates,

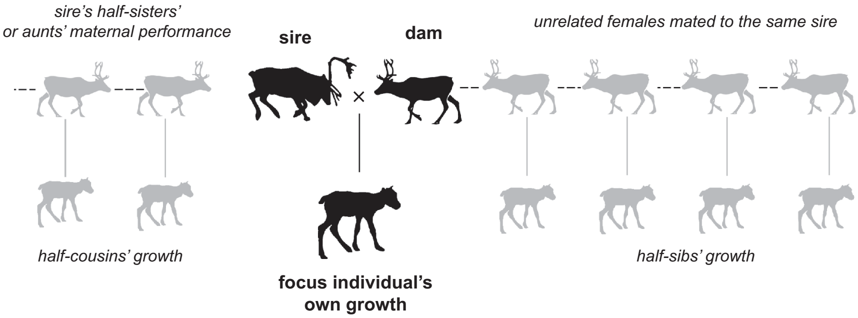

Figure 10.5 The possible core type of collateral relatives to be used in evaluating reindeer calves for maternally affected traits.

the optimal number of selection candidates is 1,000–2,000 with the other half being females (Rönnegård et al. 2003).

New technology – implications

The snowmobile revolution in the 1960s changed the mode of production. Lately, GPS collars and drones have been introduced to ease daily herding and surveillance. Virtual fencing technology has the potential to improve herding of free-ranging animals (Campbell et al. 2021). Such remote real-time control of the herd may mitigate conflicts with other land users and reduce predator losses but may decouple the close association between herders and their animals. On the other hand, supplementary feeding during winter will strengthen that association. However, extensive feeding will have consequences for breeding, as survival traits adapted to extreme environmental conditions will be deemphasized. Animal breeding now relies more and more on genomic information. Genomic selection would require a cheap and dense panel of DNA markers and an extensive number of genotyped and phenotyped individuals which could be read by ID chips. Building the marker panels is feasible as the reindeer genome has been sequenced (Li et al. 2017).

New technologies have associated costs and will have management consequences and cascade into larger herds and reduce the labour force demand. This works in tandem with the authorities' goals to professionalize and rationalize production and will result in less diversified pastoralism. However, new technology and innovation may generate new job opportunities, e.g., microprocessing of meat and new niche products.

Conclusions

Herd size and composition, and slaughter and breeding strategies are interrelated and reflect the herders' production goals. These goals will change over time, influenced by natural, social and economic conditions and the technology available. The governments have employed regulations and subsidies to rationalize the sector by stimulating meat production and market integration. This has influenced herd composition and slaughter strategy, as well as herd size.

Given limited winter pasture resources, a herd composition dominated by productive females and not exceeding the size that can be supported by available winter resources will contribute to reduced winter herd mortality, a high proportion of calves in the summer herd and a high percentage of calves to be slaughtered in autumn. Many herders follow this adaptive management strategy and consider the relevant traits that contribute to high productivity. However, herd size, as well as the herd's sex and age composition, may have an intrinsic value for the herders which is not compatible with the optimization of meat production. This is manifested in the large variation in productivity between herding districts and regions.

Integrating resilience to environmental variability into reindeer breeding programmes may improve the capacity of the production system to tackle anticipated detrimental extreme climatic events. A successful reindeer breeding scheme, including genomic selection, relies on quantifying, utilizing and securing genetic variation by the build-up of large phenotypic and genomic data sets, not only for economically important production traits but also for less heritable traits which contribute to the animals' fitness.

To understand the adaptation of reindeer to climate change, either extensive site-specific longitudinal data or the exposure of genetically related animals to different environmental conditions is necessary. Both types of data would give answers to pertinent questions on how the reindeer population may cope with a warming climate.

Losses of land, especially winter pastures, exacerbated by high predation and human disturbance, reduce production output and increase herding costs. This may result in reliance on supplementary winter feeding. By securing access to forage during winter through supplementary feeding, females may allocate less resources to survival and more to reproduction. This may result in two management regimes: one based on intensive feeding and one based on extensive year-round ranching.

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