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West Greenland caribou explosion: What happened? What about the future?

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Abstract: In West Greenland, the 1993 caribou (*Rangifer tarandus groenlandicus*) population size estimate was 7000 to 9000 animals. Eight years later in 2001, the estimate was ca. 140 000. Relatively rapid rise and fall cycles of abundance in West Greenland caribou have been noted since the 1700s. Caribou have no natural predators in West Greenland. Combined with their high fertility and recruitment, this suggests that overabundance might be their greatest threat to stability. The 2005 population surveys indicate poor recruitment in two major populations and decreasing abundance in one. Given stocking densities are three to six-times the value considered sustainable, we expect strong competition between individuals for available food resources. Although the management goal is sustainable harvest of natural resources, if populations continue at their current size or increase further, there is a clear risk of range overgrazing and trampling. Unsustainable range use may result in density-dependent forage limitation with subsequent relatively rapid population decline over a series of years, e.g. a decade. As in the past, populations are expected to recover, and if true to the past, recovery will take the better part of a century. Furthermore, the role of catastrophic weather events may be of major importance. Abrupt collapse could be precipitated by a disastrous single year event, e.g. thaw-freeze icing or deep snow, because possibilities for dispersal to new ranges are limited. Regardless of management initiatives taken now, population declines or crashes may be inevitable for some West Greenland herds in the foreseeable future, but accurate predictions about herd trends are impossible. To understand the potential impact of future developments, Greenland caribou and their range must be studied within the wider context of climate change.

Key words: Aerial survey, catastrophic weather, climate change, estimates, population collapse, population cycles, *Rangifer*, reproduction.

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Introduction

West Greenland caribou abundance was high in the early 1970s and speculated at approximately 100 000 caribou (Clausen *et al*., 1980; Thing & Clausen, 1980; Grønnow *et al*., 1983; Roby & Thing, 1985; Vibe, 1990; Thing & Falk, 1990). This was followed by surveys in the 1980s and 1990s suggesting low abundance. Then, in less than 10 years, caribou in West Greenland swung from being considered by the managers as few in number to more than ever before estimated. Since range is a finite quantity in West Greenland, the recent high abundance created caribou densities that could defeat the sustainable harvest goal of the Greenland Home Rule managers because the range may be compromised by overgrazing and trampling. Current estimates indicate decreasing abundance or poor recruitment in two of the major populations. With no natural predators and a documented potential for high fertility and recruitment (Cuyler & Østergaard, 2005), forage induced population cycles might be inevitable. This paper reviews recent and past population trends and discusses the possible future for caribou in West Greenland.

Background

As recently as 1993-1996, caribou in West Greenland were managed as one herd, although several discrete populations existed (Fig. 1). Further, policy makers believed that caribou were few based on fixed-wing aerial surveys of abundance (Fig. 2). However, these population estimates must be viewed cautiously. In the past, West Greenland aerial surveys estimating caribou abundance were invalidated by harvest data. For example, in 1980 the estimated population size was 7000 to 9000 caribou, which increased to 15 000 by 1982. At the same time, the reported harvest in 1980 was 6000 animals and over 9000 animals in both 1982 and 1983 (Fig. 3). If the 1980s estimates

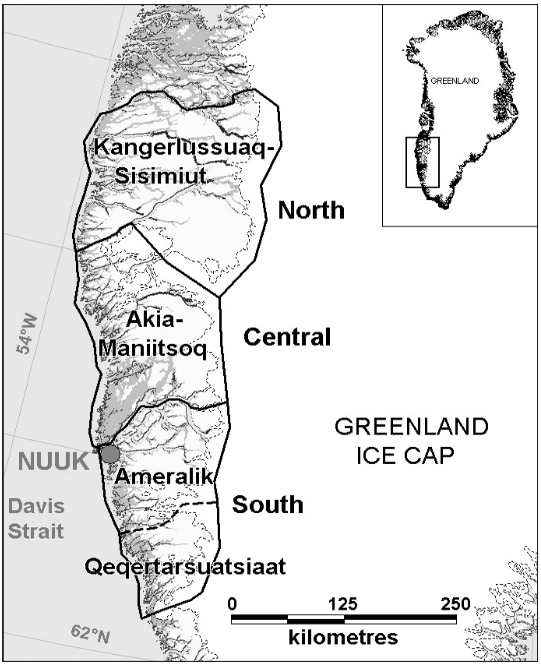

Fig. 1. Three West Greenland (North, Central, South) regions and the four caribou herds studied.

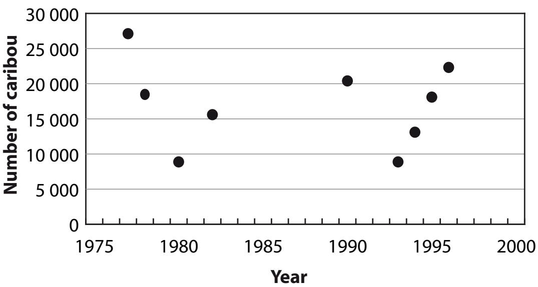

Fig. 2. Caribou population estimates resulting from aerial surveys, 1977 to 1996 (Clausen *et al.*, 1980; Thing, 1980; Strandgaard *et al.*, 1983; Holthe & Lassen, unpubl. in: Thing, 1984; Roby & Thing, 1985; Thing & Falk 1990; Rasmussen, 1995; Ydemann & Pedersen, 1999). All estimates lack confidence intervals, and prior to 1993 systematic method was absent.

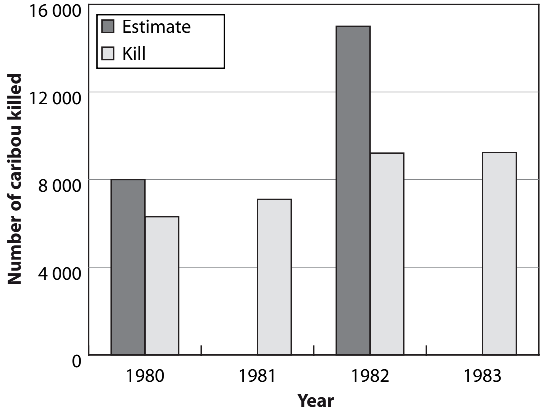

Fig. 3. Comparison of aerial survey estimates of caribou number and reported caribou harvest from1980 to 1983.

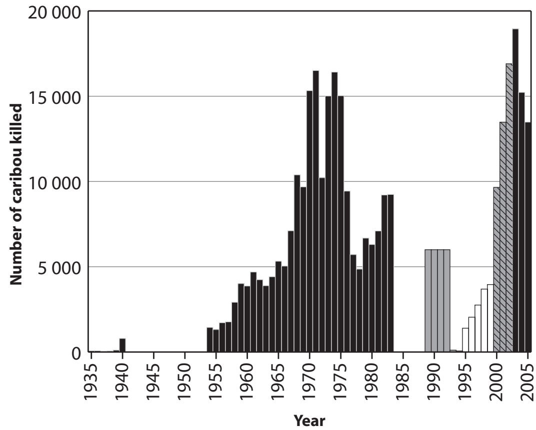

Fig. 4. Caribou harvest records 1935-2005 (Anon: Grønlands fangstlister, Piniarneq). No records were kept from 1983 to 1995. Dark columns, 1935-1983 and 2003-2005, are open harvest. Light grey columns, 1989-1992, are assumed harvest level (Peter Nielsen, pers. comm.). Open columns, 1995-1999, are harvests attained when legal quotas were low. Grey columns with diagonal lines, 2000-2002, are reported harvests attained when legal quotas were dramatically increased.

were accurate then extirpation of the caribou population would have been expected, even if one assumes a generous annual 1.3 increase in population. At the time no restrictive management initiatives were taken and this discrepancy between estimates and harvests went unnoticed.

The late winter pre-calving surveys conducted in 1993 - 1996 were the first well-designed, systematic surveys conducted to date and employed distance sampling. Nonetheless, like their predecessors, they were of questionable accuracy because they were not tailored to Greenland's rugged mountain landscape, a shortcoming that likely promoted missing many animals present on surveyed transects. Methods included using a fixed-wing aircraft at high speed (167 km/h), high and variable altitude (≥ 152 m) and wide strip width (1.4 km). Caribou detectability was further compromised by observer fatigue, as long transects (80 to 100 km) were not unusual and the north south transect orientation meant that half the

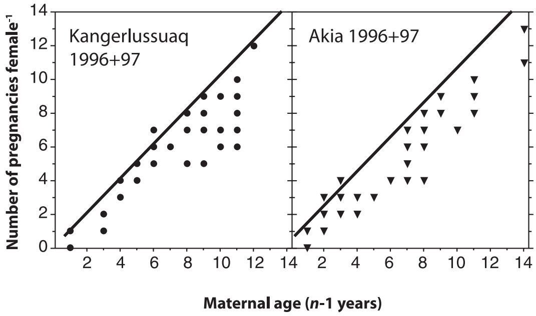

Fig. 5. Fertility of Kangerlussuaq-Sisimiut and Akia-Maniitsoq females (Cuyler & Østergaard, 2005). The line indicates the maximum lifetime reproductive potential, i.e. one calf produced for each year of age. Age is given as reproductive lifespan age (*n*-1 year). One Kangerlussuaq and two Akia females exceeded this maximum.

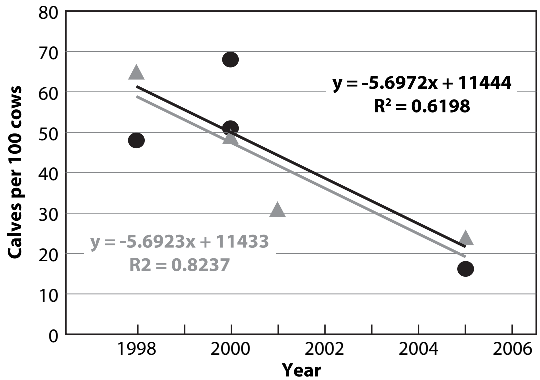

Fig. 6. Changes in late winter recruitment (calves per 100 cows) in two West Greenland herds, Kangerlussuaq-Sisimiut stock (●,— , P = 0.21), and Akia-Maniitsoq stock (▲, — , P = 0.092); linear regression lines with R^2 values.

observation time was spent squinting against solar glare. Regardless of estimate accuracy, the results from the 1993-1996 surveys should be comparable, since methods, observers and analysis were consistent. There appears to have been a trend of steady population growth from 1993 to 1996.

The 1993 aerial survey indicated 7000 to 9000 caribou in West Greenland (Ydemann & Pedersen, 1999). Harvest data, which could have assisted assessment of this estimate, were not available because Greenland had ceased to collect harvest data 10 years earlier. Prior to 1983, however, reported annual harvests indicated a steady increase from almost nothing in the 1930s to over 16 000 in the 1970s, while harvests in the early 1980s ranged from 7000 to 9000 animals per year (Fig. 4). Further, policy makers assumed the annual harvest was from 4000 to 6000 caribou (Peter Nielsen, pers. comm.) for the four years prior to the 1993 survey. With the 1993 maximum of 9000 caribou and an assumed 50% population reduction since 1990, a crisis was declared and restrictive management initiatives were implemented. All hunting was prohibited for two years until the summer of 1995.

After the 1995 and 1996 estimates of 18 000 and 22 000 caribou respectively (Ydemann & Pedersen, 1999), policy makers permitted quotas of 2000 to 4000 animals from 1995 to 1999. The two-year prohibition and subsequent low quotas resulted in heavy debate and scepticism from hunters, who were unanimous that caribou were plentiful (Cuyler *et al.*, 2003). My own anecdotal observations on the Ameralik caribou population supported the local knowledge. On 28 October 1998, in six hours sailing along 33 km of the Davis Strait coast, I counted 951 caribou and these were only the animals visible within the first 300 metres from the shore.

Fertility and late winter recruitment

In 1996/97, based on Cuyler & Østergaard's (2005) retrospective ovarian analysis, two West Greenland caribou populations, the Kangerlussuaq-Sisimiut and the Akia-Maniitsoq, had a high percentage of pregnant subadults (females under 3-years old) and 25% of all females attained their maximum reproductive potential, while 2-4% of collected animals exceeded that maximum (Fig. 5). Observations of conception in a female caribou's second autumn and twinning suggest that West Greenland caribou ranges were excellent prior to 1996 (Cuyler & Østergaard, 2005).

Meanwhile from 1998 to 2000, calf recruitment in March was between 48 and 68 calves per 100 cows (Fig. 6). Four to five years later, March calf recruitment dropped to 16-24 calves per 100 cows. In fact, late winter calf recruitment appears to have declined steadily since 1998. Regression R^2 values are close to 1 and indicate the strength of the relationship observed; however, the P-values were not significant. Aside from suspected increased intra-specific competition, no apparent causes (e.g. severe winter weather events) have occurred that could account for the decrease in recruitment (Cuyler *et al.,* 2005).

2000 and after

Given the scepticism surrounding earlier caribou estimates, aerial surveys techniques in West Greenland were further improved (Cuyler *et al.,* 2002; 2003; 2005). Helicopters replaced fixed-wing aircraft, because when flying transects, helicopters can maintain a slow speed and constant altitude over mountainous terrain. Reliable estimates of abundance require detection of most, if not all the animals actually present within the surveyed transects. In Greenland, methods required to achieve this standard include low flight speed (45-65 km/h), low constant altitude (15 m) and narrow strip width (0.6 km). The 0.6 km strip width (300 m x 2) was based on observer capability to detect caribou given small group size and behaviour (remaining lying down or stationary) in combination with the difficult terrain and snow cover typical of West Greenland (Cuyler *et al.,* 2002; 2004). Although West Greenland is treeless alpine, tundra, exposed rock or ice, survey observers sighted most caribou between 0 and 300 m from the helicopter. Few were sighted beyond 300 m, although animals were just as likely to be present in that strip area (Cuyler *et al.,* 2002; 2004). Caribou detectability was aided by reducing observer fatigue with: 1) short transects (7.5 km), which limited the time spent in full concentration by observers; and 2) flight path in a direction not looking directly into the sun when on a transect. Direction of flight was also important because solar glare reflecting off the snow surface reduces caribou sightability (Cuyler *et al*., 2005). Transects of random location and heading were possible because in late winter (March-April) caribou group size averages less than 6 animals and variability is low (Roby & Thing, 1985; Thing, 1982; Thing & Falk, 1990; Ydemann & Pedersen, 1999; Cuyler *et al.,* 2002; 2003; 2005), which reduces sampling error and aids precision. The mean group size, ca. three, remained constant even when herds were large and the caribou were widely scattered over all elevations throughout a region (Cuyler *et al.,* 2002; 2003; 2005). A correction for missed caribou was also incorporated into the resulting population estimates, following Cuyler *et al.* (2003). The 2001-2005 surveys might still have underestimated herd sizes, because the low flight altitude (15 m) often created "dead-ground", i.e. terrain features could hide some of the strip width.

New survey results available by spring 2001 supported local hunter knowledge and estimated a total of about 135 000 caribou for only four West Greenland populations (Table 1). Just five years earlier, the total for all six or seven populations in West Greenland was about 22 000. With estimates over six times that number, caribou management changed overnight. Rather than few, they were now considered abundant. Given the finite range available in

Table 1. Recent pre-calving estimates of caribou abundance in four West Greenland herds.

Region	Population	1993[1]	1996[1]	2000[3]	2001[2]	2005[3]
North	Kangerlussuaq-Sisimiut	3800	10 900	51 600 (42 664 – 61 495)		90 464 (70 276 – 113 614)
Central	Akia-Maniitsoq	3500	6800		46 200 (37 115 – 55 808)	35 807 (27 474 – 44 720)
South	Ameralik	1200	4500		31 900 (24 721 – 39 305)	-
South	Qeqertarsuatsiaat	181	-		5400 (2864 – 8244)	-

[1] Ydemann & Pedersen (1999).
[2] non-parametric (bootstrap) 80% CI's (Cuyler *et al.,* 2003).
[3] non-parametric (bootstrap) 90% CI's (Cuyler *et al.,* 2002; 2005).

Table 2. Recent estimates of caribou density in four West Greenland herds.

		High density stratum[1]	
Region	Population	2000 – 2001	2005
North	Kangerlussuaq-Sisimiut	2.8 / km^2	6.2 / km^2
Central	Akia-Maniitsoq	4.0 / km^2	3.0 / km^2
South	Ameralik	3.8 / km^2	-
South	Qeqertarsuatsiaat	1.1 / km^2	-

[1] Cuyler *et al.* (2002; 2003; 2005).

West Greenland, caribou densities up to 4 per km^2 in 2001 (Table 2), and overgrazing a possibility, policy makers now sought to reduce abundance to protect the future of caribou herds and their ranges. An imprecise conservative target density of 1.2 per km^2 was recommended to the policy makers.

The target is based on studies of carrying capacity elsewhere. At densities of 1.03 to 1.41 reindeer per km^2, females become sexually mature and conceive for the first time when just over 1-year old, which suggests this density is compatible with optimal range (Reimers *et al.,* 1983). In contrast, a density of 4 reindeer per km^2 is too high to sustain lichen heath at optimal condition in Finland (Helle *et al.,* 1990). Observations from Svalbard (Norway) support this. Fifteen reindeer introduced on the Brøggerhalvøya peninsula (Svalbard) at an initial density of 0.25 per km^2 increased over 15 years to 400, or 6.7 per km^2, and the once lush preferred macro-lichens *Cetraria nivalis* and *Cladonia mitis* had disappeared (Staaland *et al.,* 1993). In a winter icing event, the population crashed to 100 (Jacobsen & Wegener, 1995), but animals had already begun to leave the peninsula (Staaland, pers. comm.). Skogland (1985) observed that recruitment fell sharply at densities over 2.5 per km^2 owing to a decline in calf productivity of the subadult females, but that calf productivity of females 3-years old and older also fell slightly even at densities of 2 per km^2. When caribou reach densities exceeding 2 per km^2, movement increases and distribution can be unpredictable (Skoog, 1968; Baskin, 1990). Although possibilities are limited, dispersal or movement have been observed in West Greenland populations (Cuyler *et al.,* 2003). Population dispersal or movement shifts to new range could delay the effects of food shortage in limiting numbers and Messier *et al.* (1988) suggested that caribou populations could overshoot range capacity because of these delays. Although the target density of 1.2 per km^2 is not now based on studies of carrying capacity on West Greenland ranges, it may favour the preservation of range quality and availability, which will benefit caribou populations and the sustainability of future harvests. A halt to population increase, or a reduction in numbers, would give time for more precise target densities to be derived from appropriate studies.

If reducing abundance was to be achieved, increasing the portion of females in the harvest was important, since caribou harvests (mid-August to mid-September) until then were otherwise about 90% male-biased (Loison *et al.,* 2000). To reduce abundance, season length was increased from one month to five and a half months, which included the rut, and was broken into an autumn and winter hunt. More animals were shot, specifically more females, as rutting males are considered unpalatable. Beginning in 2000, harvest quotas rose by about 10 000 animals each year until 2003, when open harvests were implemented. Reported harvests rose to and exceeded levels observed in the 1970s.

A 2005 aerial transect survey for the two largest caribou herds in West Greenland revealed a dramatic decline in recruitment (Fig. 6), while densities remained well above the recommended target (Cuyler *et al.,* 2005). The Akia-Maniitsoq herd had decreased in abundance by 22% over four years. In contrast the estimate for the Kangerlussuaq-Sisimiut herd was almost double the 2000 estimate but an interpretation of population trend is difficult since methods differed. The Kangerlussuaq-Sisimiut survey of 2000 was the first employing the new survey methods and highlighted the need to further reduce altitude, speed and strip width to detect most or all caribou on transect. In contrast to all subsequent surveys, in 2000, the altitude, speed and strip width were 100 m, 100 km/h, and 1 km respectively (Cuyler *et al.,* 2002). The presence of more experienced observers in 2005 probably also affected numbers detected, making the 2005 estimate more accurate.

Discussion

The 2000-2001 helicopter surveys, which used improved methods to reduce the negative bias of missed caribou, resulted in a pre-calving estimate of caribou numbers six times greater than estimated in 1996. How was this possible? Although caribou numbers can increase rapidly given ideal conditions (Heard & Ouellet 1994; Staaland *et al.,* 1993), was fertility alone responsible for the large jump in herd sizes from 1996 to 2000-2001? While small, the

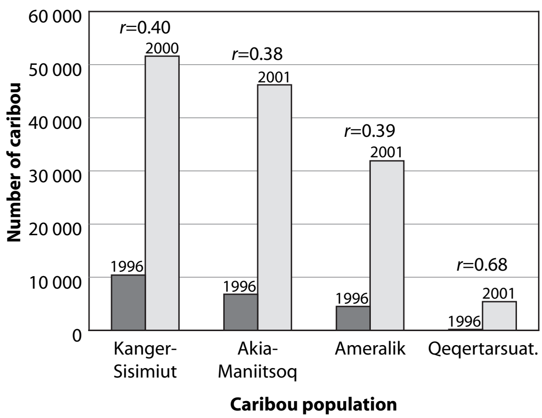

Fig. 7. Caribou abundance and calculated actual rates of increase "*r*" for four herds in West Greenland from 1996 to 2000-2001.

harvest quotas in place from 1995 to 1999 were 10-18% of the 1996 estimated abundance and could have been sufficient to prevent population growth. West Greenland caribou, however, were surprisingly fertile and had high recruitment rates (Cuyler & Østergaard, 2005). Both provided the potential for rapid population growth in West Greenland in the 1990s, but do not account for the disparity between population estimates from 1996 to 2000-2001. The actual rate of increase between estimates can be calculated (Krebs, 1972):

$$r = \frac{ln \text{ herd size } t_2 - ln \text{ herd size } t_1}{\text{Time period in years}}$$

Resulting *r* values are unrealistic, i.e. 0.40, 0.38, 0.39 and 0.68 in four West Greenland populations (Fig. 7), since the maximum or intrinsic rate of increase, r_m, for caribou in a predator and harvest free environment is 0.30 (Bergerud, 1980). The rate of increase for the growth trend observed from 1993 to 1996 was also improbably high, being 0.32 with a finite rate of $\lambda = 1.377$ per individual per year ($\lambda = e^{rm}$ (Krebs, 1972)). In contrast, caribou on Southampton Island in the Canadian Arctic had a rate of increase of 0.233 ($\lambda = 1.262$) (Heard & Ouellet, 1994), although like West Greenland there were no predators, the range was good, and the caribou showed no decrease in population growth even as density increased. The unrealistic estimated rates of growth, in combination with the 1993-1996 survey methods and consistent local knowledge to the contrary, make it probable that the 1993-1996 surveys underestimated herd sizes. Also possibility the 1993-1996 surveys were not as consistent as previously assumed, e.g. otherwise experienced observers became more proficient at sighting caribou with each survey, thus increasing each subsequent estimate. Alternately, recent surveys may have been optimistic if observers consistently made caribou observations over a larger area than stated. However, this is unlikely given the methods used by Cuyler *et al.*, (2002; 2003; 2005). The inaccurate 1990s surveys resulted in conservative management decisions (two-year hunting prohibition 1993-94, followed by five years of restrictive quotas), which contributed to herd growth and the high densities observed on West Greenland ranges by 2000. Male-biased hunting, the lack of large predators, and excellent range conditions in the 1980s and 1990s (Aastrup, 1984a, 1984b; Thing & Falk, 1990) were also factors. An area examined in the South region revealed average lichen cover was 45-55% (Aastrup, 1986), which provided the ideal conditions for fertility and recruitment.

Annual harvest data for the past 40 years suggest that caribou abundance has been relatively high since the late 1960s. Given local knowledge and the 2000-2005 abundance estimates, it is possible that caribou density has been high for about a decade. If too many caribou have been present for too many years on the finite amount of range available between the Ice Cap and sea, it could result in overuse of available vegetation and therefore compromise the abundance of these herds, owing to density-dependent forage limitation. Three cycles of caribou abundance in West Greenland have been noted since the 1700s (Fig. 8), suggesting that high abundance might be the greatest threat to population stability and lead to a new population decline. As in past cycles, populations are expected to recover slowly over the better part of a century.

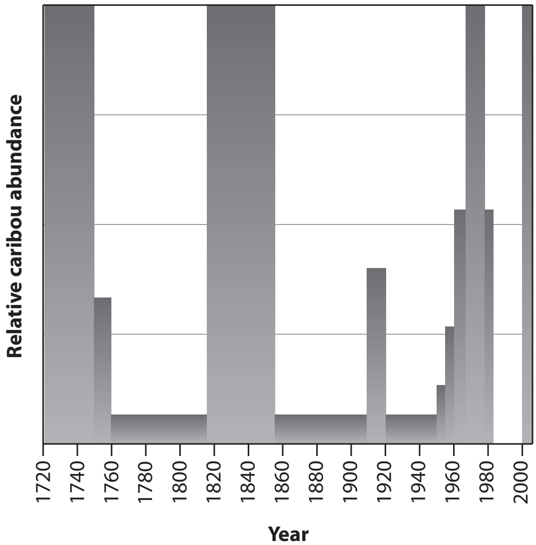

Fig. 8. Historical rise and fall cycles of relative caribou abundance in West Greenland based on Vibe (1967), Meldgaard (1986) and the 2001 abundance estimate. Only general trends are illustrated, since the caribou populations in West Greenland do not cycle in absolute synchrony (Meldgaard, 1986), and estimates were unavailable except for in 2001. During periods of low abundance, records suggest the caribou had disappeared almost entirely. No harvest records were available from 1983 to 1995.

Have there been too many caribou? Late winter calf recruitment is in decline in the two largest herds. Are density-dependant factors at work? Since densities are 3 to 6x the recommended target there is reason to suspect intra-specific competition for food resources. Although no quantitative studies exist, overgrazing and trampling of lichens has been observed on the Akia-Maniitsoq and Ameralik winter ranges (Cuyler *et al.,* 2003; pers. observation), and general trampling of vegetation has been noted on the Kangerlussuaq-Sisimiut range (Cuyler *et al.,* 2005; pers. observation).

How long can this situation continue before substantial protracted declines in caribou population size occur?

West Greenland caribou are fortunate to live in a simple predator-free low arctic environment, which is topographically isolated. They have few competing herbivores, i.e. muskox *Ovibos moschatus*, arctic hare *Lepus arcticus*, geese *Anser* and *Branta* spp., rock ptarmigan *Lagopus mutus,* and human development is minimal or limited to the seacoast. However, the various caribou populations currently inhabit most available range. Under present conditions, dispersal possibilities are limited or non-existent. This makes the future of West Greenland caribou uncertain. In addition to protracted decline brought on by density-dependent forage limitation, disastrous weather events may be of major importance and able to cause abrupt collapse in several or all herds (Vibe, 1967; Meldgaard, 1986). Temperatures and precipitation are expected to increase in Northeast Greenland (Rysgaard *et al.*, 2003). Temperature trends, however, are often opposite between east and west Greenland (Box, 2002). Will climate change bring better or worse conditions? For example will there be changes in winter length, snow depths, severity or frequency of winter thaw-freeze icing events, summer precipitation, or other? Extreme icing or snow depth restrict access to forage and may cause near total mortality across age classes (Miller, 1990; Jacobsen & Wegener, 1995). Although in West Greenland spring and summer temperatures over the past century cooled and several of the coldest winters coincided with major volcanic eruptions (Box, 2002; Hassol, 2004), a general warming and greater precipitation is expected, but it will not be as pronounced as in Northeast Greenland (Rysgaard *et al.,* 2003). Equally important is how climate change will affect the vegetation, because in West Greenland caribou abundance and distribution is controlled from the "bottom-up", i.e. through the quantity, quality and availability of vegetation. Regardless of management initiatives taken now, population declines may be inevitable for some West Greenland herds within the foreseeable future, but accurate predictions about herd trends are impossible. To understand the potential impact of future developments, caribou and their range must be studied within the wider context of climate change.

Acknowledgements

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