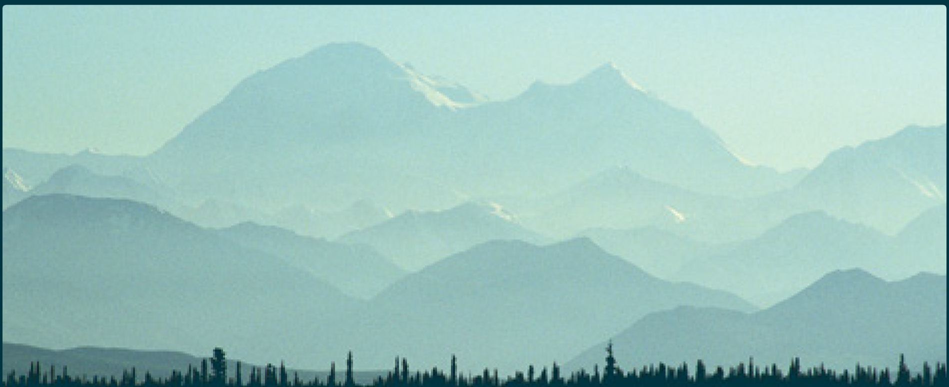

YUKON THINHORN SHEEP

HORN GROWTH, GENETICS AND CLIMATE CHANGE

Yukon
Environment

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CONTENTS

INTRODUCTION

The Government of Yukon has been collecting information about sheep horns since the early 1970s. This consistent monitoring has left Yukon with, at this point, more than 40 years of continuous data related to thinhorn sheep. It's an unusual and valuable scientific resource, and researchers have made good use of the information. This booklet summarizes briefly the major results of their work. For those who want more than a summary, the appendix contains a list of major scientific papers, posters and publications based on Yukon sheep data.

1. YUKON SHEEP – SOME BACKGROUND

Yukon has more wild sheep than any other region of Canada—about 22,000 altogether, living on mountain peaks from the territory's southern border to near the Arctic coast. Yukon's wild sheep are thinhorn sheep (*Ovis dalli*), a species found only in northwestern Canada and in Alaska. Two types of thinhorns live in Yukon. Dall's sheep (*Ovis dalli dalli*), the only wild white sheep in the world, are abundant southwest of the Yukon River and spread more thinly in scattered northern pockets and within a broad band that arcs across central Yukon. The darker-coloured Stone's sheep (*Ovis dalli stonei*) inhabit a range that stretches north from the British Columbia border as far as central Yukon. Dall's sheep out-number Stone's sheep by about six to one.

Both thinhorn ewes and rams have curved, amber horns. Ewes' horns are gently backswept and quite short. Mature rams' horns curve first back and down, then forward and up in a flaring spiral. The length along the curve of a ram's horn can be more than one metre.

Source: A. Frid 2000

The name *thinhorn* comes from the fact that the rams have much thinner horns than those of their more southerly cousins, Rocky Mountain bighorn sheep. Northern thinhorns are generally smaller and weigh less than bighorns. Thinhorn rams weigh up to 115 kilograms, about two-thirds the weight of bighorn rams. Stone's rams are usually somewhat heavier than Dall's rams and also have slightly longer horns. Ewes are about a fifth smaller in stature than rams and only half the weight.

It's a sheep's life

Thinhorn sheep spend the summer grazing in alpine meadows high among the peaks. From green-up to first frost, they eat grasses, sedges, and juicy, broad-leaved forbs, building up fat to help them through the winter. As temperatures drop in the fall and frost kills off high-country vegetation, thinhorns move toward their winter range, which can be nearby or many kilometres away. The sheep use the same migration routes generation after generation, drifting slowly through the high country, but hurrying across valleys where they are more vulnerable to attack by wolves, coyotes, or grizzlies. They settle in for the winter on south-facing slopes at fairly low elevations and spend up to nine months there. Dall's sheep usually stick to open grasslands above treeline. Stone's sheep also use treed and shrubby areas. For both kinds of thinhorn, windswept slopes are important for easy escape and spring lambing.

In May and early June, pregnant ewes head for the steep cliffs of the lambing grounds. Ewes stay for a few days to have their lambs and then join together to form nursery groups. After three or four weeks, when all the ewes have lambed, the sheep move toward their summer range, following the line of snowmelt and newly sprouted green shoots back up to the alpine for the summer. Sometimes they pause for days or even weeks at mineral licks, where they restock the micronutrients they lost over the long winter. Ewes, young rams, and new lambs remain together throughout the year. Rams aged three years and older band together and go their own way for most of the year, mixing with other sheep for only a month or two on winter ranges, around the time of the rut.

Thinhorn sheep are social animals. The ram with the largest horns is dominant and treats all other sheep, regardless of sex or age, as subordinates. Every thinhorn has its place in the structure. However, there are constant squabbles as sheep test the social order and try to reposition themselves. Leadership challenges can happen at any time of year, but the fiercest clashes take place in November and December during the rut. Young rams move up through the ranks very slowly since their horns aren't large enough to challenge a leading ram until they are five to seven years old. Once they achieve top status, rams put a lot of energy into defending receptive ewes from other rams. As a consequence, they rarely live beyond 12 years. Ewes, on the other hand, can reach 20 years of age.

"The sheep settle in for the winter on south-facing slopes at fairly low elevations and spend up to nine months there."

Forty years of information

Yukon's *Wildlife Act* and harvest regulations are designed to maintain a healthy sheep population with sufficient genetic diversity to ensure its future. Females, lambs, and younger rams are protected. Only full-curl rams may be taken on a Big Game Hunting Licence. The goal is to allow as many rams as possible to reach full maturity and participate in breeding.

What does full curl mean? Sheep horns continue to grow year after year. Rams' horns grow toward the sheep's back and then curl down and forward in a spiral. When viewed from the side, a full-curl male has at least one horn that extends beyond a line running from the centre of the nostril to the lowermost edge of the eye (Figure 1). Most rams don't achieve full curl before the age of eight.

Rams add horn length and volume every year, but growth is uneven through the year and through the ram's lifetime. The horns grow through the summer and stop growing in the winter, creating visible rings or annuli where growth slowed or stalled. In their first year, lambs add only about 7 cubic centimetres of horn. In the next growth season, they might add 10 times that amount. The longest horn growth occurs in the 2nd and 3rd year of life. The heaviest horn-growth period in a ram's life is the ages of 4 and 7. Then the pace of growth slows, with rams reaching their maximum horn size, typically, between the ages of 8 and 10. By that age, horn growth is so slow that it is often balanced by wear at the tips.

FIGURE 1:
The straight line indicates how full curl is measured. The breaks in the horn show the annual growth divisions, which reveal the sheep's age. This sheep is in its ninth growth season.
Source: Environment Yukon

2. SHEEP HORNS TELL A TALE

Yukon regulations implemented in the late 1970s require that successful sheep hunters deliver the sheep's horns, attached to the skull, to a conservation officer or wildlife technician soon after the hunt. Department officials measure the horns to make sure the ram is full curl, count the annual growth rings to determine its age, and take a small core out of the horn in order to insert a numbered metal identification plug designed to combat theft and illegal trade in sheep horns.

By the end of the 1990s, Environment Yukon had more than 25 years of data on the horns of thinhorn sheep rams from all the hunted populations in the territory. By then, the Yukon climate was warming noticeably. One of the ways to track that warming is through tree rings, where good and bad seasons are clearly recorded in the width of the rings. Rams' horns grow like tree trunks, putting on length and volume each growing season. Researchers decided to examine the accumulated horn data to see if horn growth also reflected environmental conditions.

Climate leaves its mark

The researchers started with the records of 2,481 individual rams harvested between 1974 and 1999 in the Ruby Range of southwest Yukon. The birth year was known for more than half of the animals, which allowed the researchers to track cohorts (rams born in the same year) born between 1969 and 1992.

Rams' horns grow both longer and thicker each year. From the measurements taken when the horns were submitted, the scientists calculated both the length and volume of yearly growth as marked by the annuli. They found that the annual growth in length decreases after the age of two, but volume increases as the horns get thicker.

However, that doesn't mean that rams' horns always grow at the same rate. There are good years and bad years for sheep horn growth, just as there are for trees, and they show up in the horns. Moreover, the horns showed that the good and bad years affected all sheep in the Ruby Range, whatever their age, and the impact of those years lasted throughout the rams' lives. At age eight, the horn volumes of individual cohorts were up to 10 percent greater or less than the long-term mean volume, depending on the conditions they encountered during their prime growing years.

From 1969 to 1999, the pattern of good and bad years followed a regular cycle that ran in close parallel with other cyclical patterns in the region. The best documented was the snowshoe hare population cycle and the fluctuations in temperature and precipitation recorded in ice-cores from the summit of Mt. Logan, only 100 kilometres west of the Ruby Range. All three sets of records show a pattern that repeats, over the long term, every 10 to 11 years.

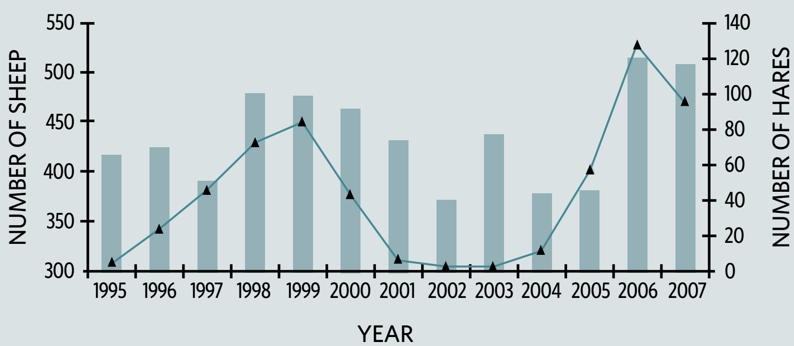


FIGURE 2.
Adult Dall's sheep recorded on aerial surveys during mid-June (bars) and roadside counts of snowshoe hares along a standard 40-km section of road during mid-June (triangles and solid line) in the central Alaska Range, USA, 1995-2007. Source: Arthur and Prugh (2010)

The researchers concluded that horn growth patterns are related to the influence of climate on the sheep's alpine ranges. When plants are plentiful and the forage is good, the rams put on plenty of horn. When forage is sparse, their horns grow less. The growth rings on a thinhorn ram's great curving horns are a record not just of the animal's individual life but also of the profound impacts of climatic variability on the world in which it lived.

More detail leads to new understanding

A few years after the initial study linking horn growth to climate patterns, researchers returned to Yukon's horn growth data to see what more it could reveal about sheep and climate. They managed to expand the time range of the horn information from 1963 to 2000, and they included sheep harvested in other parts of the territory.

Source: J. Loehr 2008

This time, they found that both horn growth and lamb production paralleled the cycles produced by a major weather pattern called the Pacific Decadal Oscillation (PDO)—the same pattern linked with the temperature and precipitation variations recorded in Mount Logan ice cores. Moreover, the PDO, and the local weather it produces, clearly influence both sheep horn growth and lamb production right across Yukon, not just in the Ruby Range.

Fluctuations in sheep horn growth, the data revealed, are strongly associated with April and May temperatures and less clearly with spring rainfall. The conclusion: warm springs with fairly high levels of rainfall mean greater horn growth. Good years for lamb production had warm springs and relatively low snowfall. Since April and May temperatures and precipitation in Yukon are influenced by the PDO, it appears that the PDO is the driving force influencing horn growth and lamb production among Yukon thinhorn sheep.

Is it climate or genes?

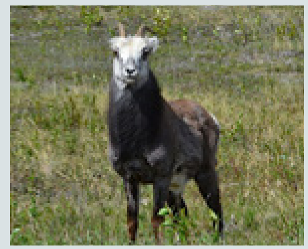
A decade after the study that first linked the horn growth patterns in thinhorn sheep with climate fluctuations, researchers came back to the data with a new question: could the differences in horn growth be explained partly by genetic differences between rams? Or was weather as powerful an influence as the earlier studies suggested? By this time, the information came from more than 8,000 individual thinhorn rams, representing 42 years of horn growth.

The results of the second study confirmed the earlier results: annual fluctuations in horn growth are closely related to climate. Only a small percentage of the variation in growth could be explained by individual genetic variation. Overwhelmingly, the governing influence on horn growth was climate—specifically, the PDO and its impacts on Yukon weather. Even the general warming of the Yukon climate over the past few decades showed up in the horn measurements. Horn growth in Yukon sheep increased steadily from 1963-2000 as April-May temperatures increased.

Source: K. Meister

3. PIECING TOGETHER THE PUZZLE OF THE PAST

Yukon thinhorn sheep have a wide range of coat colours, from the pure white Dall's sheep to the dark brown, black, and grey of Stone's sheep. For the better part of a century, biologists assumed that the colour patterns were part of what defined thinhorn sheep subspecies. They identified the white Dall's sheep as one subspecies, dark-coated Stone's sheep as another subspecies, and the more variegated coats of central Yukon's Fannin's sheep as the result of hybridization between the two subspecies where their ranges overlap.



Source: M. Clarke 2012

Source: K. Meister 2007

Source: R. Leduc 2005

Source: J. Loehr 2004

Top row: Stone's sheep; *middle row:* Dall's sheep; *bottom row:* Fannin's sheep.

Two major theories were advanced as explanations for the evolution of these three groups. One theory was that Dall's sheep are one branch of the thinhorn species and Fannin's and Stone's sheep are closely related outgrowths of another branch. According to another theory Dall's and Fannin's sheep survived the last major glaciation in the ice-free Beringian refugium in Alaska and northwestern Yukon. After the ice retreated, the sheep spread southward, and the darker Stone's sheep evolved in the southernmost extent of their new range.

Both explanations seemed reasonable, given the progressive variation in coat colour from southeast to northwest. Then, along came advances in genetic research that gave scientists tools to trace the history of species and their relationship with each other through their genetic codes. Fortunately, the genetic material for Yukon sheep was easily available. In 1995, Environment Yukon began saving the drill shavings produced when horns are plugged as part of the compulsory submission process. Those shavings were a source of genetic material for more than 3,000 rams from all parts of the territory's sheep range. Just as importantly, detailed horn measurements and kill information had been recorded for each sample. Researchers were eager to get to work.

DNA delivers a surprise

One research project concentrated on mitochondrial DNA, which is inherited through the mother. It can provide useful information about the history of populations because it serves as a kind of molecular clock. Mutations in mitochondrial DNA happen at a fairly constant rate, so an analysis of the mutations in different sheep populations can show roughly how long the populations have been separated. The goal of the research project was to explore the evolutionary history of thinhorn sheep and determine which of the principal theories came closest to the truth. The results were a surprise. The genetic evidence supported *neither* of the two major theories.

The genetic evidence showed that the British Columbia Stone's sheep are not post-ice-age newcomers that evolved after the glaciers retreated about 12,000 years ago. In fact, they've been separated from other thinhorn sheep populations for as much as 130,000 to 300,000 years. That's well before the most recent glaciations, which peaked in northwestern North America about 22,000 years ago.

> **"...genetic evidence showed that the British Columbia Stone's sheep are not post-ice-age newcomers..."**

So where did they go, and how did they survive the ice age? To solve the puzzle, the researchers looked at the mitochondrial DNA of bighorn sheep, which now live south and east of the Stone's sheep range. There they found a new clue: genetic evidence of a link between bighorn sheep and Stone's sheep that was far more recent than any genetic link between bighorns and other Yukon thinhorns. The new results suggest a revised family tree. On one branch are the two groups of northern thinhorn sheep, Dall's and Fannin's. On the other branch are Stone's sheep, apparently the result of long-ago hybridization between thinhorns and bighorns.

Surviving the ice

That took researchers back to the question of where Stone's sheep spent the long winter of the last ice age. Recent geological evidence has shown that Beringia was not the only ice-free refugium. Smaller patches of land remained ice-free along the mountainous spine of western Canada. Some of them would be just the kind of steep, wind-swept slopes that still suit mountain sheep today. The researchers determined that sheep survived in four different glacial refugia, including a very small one near Fort St. John that was only identified in 1996. This was the first evidence that any organism survived the last ice age there.

Sheep not only survived the ice but were shaped by it. Since sheep arrived in North America, the ebb and flow of ice during successive ice ages has forced populations to shift and move with it. These range shifts have provided opportunities for gene flow between populations and species, and the hybrid lineage of Stone's sheep in British Columbia appears to be a result of this history. In the future, our definitions of sheep species and subspecies might need to be adjusted. Real-life diversity, according to the DNA evidence, doesn't fit neatly into the old categories.

"Recent geological evidence has shown that Beringia was not the only ice-free refugium."

A population jigsaw puzzle

While mitochondrial DNA provided a window into the sheep's past, another kind of DNA—nuclear DNA—told about what is happening in the present. Again using horn shavings, another researcher examined nuclear DNA to try to understand how modern thinhorn groups are divided up and how they are related to each other. She was able to assign sheep to eight different populations, based on their genetics. Sheep tend to stick to their ranges in the mountains and avoid the forests that separate mountain ranges, so there's very little mixing between populations. Most thinhorns appear to spend their lives within the traditional ranges their ancestors staked out. The researcher also looked for evidence that thinhorn sheep have undergone massive disease-related die-offs, but found none.

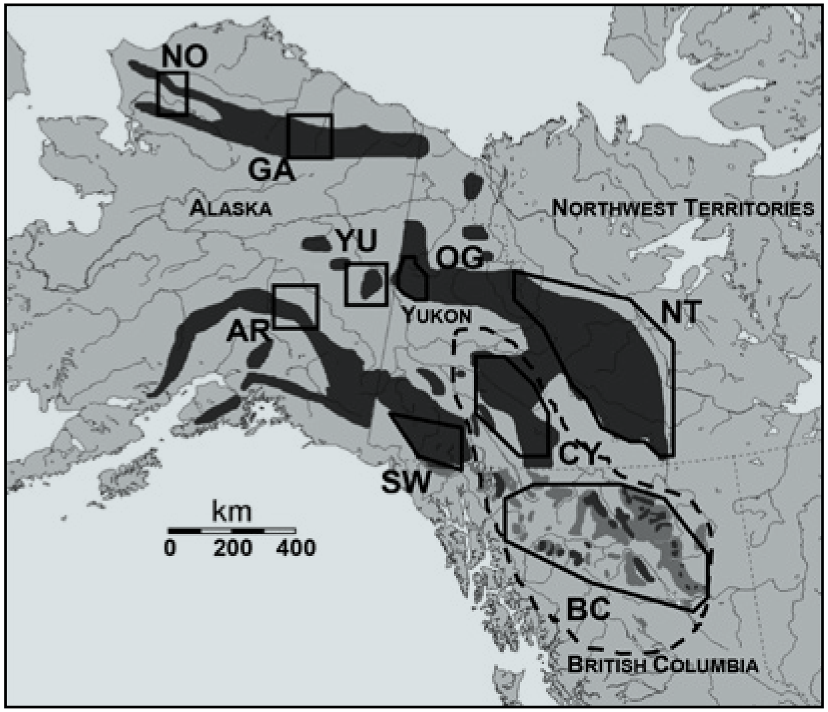


FIGURE 3:
Thinhorn sheep populations in northwestern North America.

NO=Noatak
GA=Gates of the Arctic
YU=Yukon Charley
AR=Alaska Range
OG=Ogilvie Mountains
NT=Northwest Territories
SW= Southwest Yukon
CY=Central Yukon
BC=British Columbia

Sheep distribution, subspecies, and populations. Shaded areas represent approximate range. The amount of detail varies by jurisdiction. In BC, darker shaded areas are populations of medium to high density; lighter shaded areas are low density areas. Dotted line shows approximate boundary between Dall's sheep (outside dotted line) and Stone's sheep (inside dotted line). Source: Loehr et al. (2006)

4. BEHAVING LIKE A SHEEP

We've learned a lot from and about thinhorn sheep horn growth and coat colour, but it's the kind of information that interests humans, not sheep. Researchers have also looked at what horns and coat colour mean to sheep. Since it's impossible to interview a sheep, they spend hours, days, and months watching sheep behaviour, documenting it carefully, and puzzling out what it means.

A sheep's-eye view of colour

The coat colour of thinhorn sheep doesn't reveal as much as researchers thought, but colour is of significance among sheep, at least within some populations. The Fannin's sheep of the Pelly Mountains in central Yukon have distinctive patterns of light and dark colouring in their coats—so distinctive that individuals can be identified by them. A researcher observed the behaviour of rams and ewes in November and December, in both 2003 and 2004, to see if colour was linked with dominance.

Rams' faces tend to get darker as they get older. The researcher noted that ram facial darkness was associated with dominance rank and mating opportunities. Simply put, dark-faced rams of the same age mated more often and with more ewes during the rut than light-faced rams. In ewes, the link with colour was not as clear, although there appeared to be a slight tendency for darker ewes to be dominant over lighter ewes.

The researcher also found that darker-faced rams tended to have faster-growing horns. He speculated that facial darkness might work as a signal—along with horn and body size—to advertise the ram's strength to other rams. Using colour to communicate is common in animals other than mammals—from peacocks to cuttlefish—but only a few mammals do so, most of them primates. The colourful sheep of the Pelly Mountains might be a rare exception.

Despite the dominance of dark rams, the general sheep population in the Pelly Mountains is not getting noticeably darker. That might be because the dark rams mate with ewes of all shades. It's also possible that dark rams live short, fast lives. They mate earlier and more often in a season than their lighter brothers, but the dominance battles take a toll. They may well die younger, on average, than lighter rams, leaving the light-coloured rams with a few more seasons of breeding opportunity.

Growing horns fast carries a cost

During the first five seasons of horn growth, the prime growth years, rams put a lot of energy into increasing the length and volume of their horns. Do they pay for that energy expenditure in a shorter life span? Or does rapid horn growth confer an advantage that leads to a longer life?

> **"On average, rams with rapid horn growth can mate at a earlier age than those with slower growth."**

Researchers examined horns collected from populations that aren't hunted, where the rams died of natural causes, and compared them with the data from hunter-killed rams in Yukon. They found a clear pattern: rams with rapid horn growth die young. Interestingly, the pattern applied to both hunted and un-hunted populations.

A possible explanation, the researchers suggested, is the natural cost of early reproduction. Dominance in thinhorn rams—and, therefore, the chance to mate—depends heavily on horn size. On average, rams with rapid horn growth can mate at an earlier age than those with slower growth, sometimes as young as five or six years. But entering the mating population carries risks, both from combat with other rams and from the energy spent guarding and defending ewes. Rams that successfully mate while young may be less likely to survive those risks than older, larger, and more experienced rams.

5. ANSWERS AND QUESTIONS

Forty years of sheep data and 20 years of sheep research have taught us a great deal. We know that climate has a profound influence on the lives of thinhorn sheep, and that influence plays itself out in a recurring pattern. We know that sheep horns provide second-hand, or proxy, evidence of that climate pattern.

We know more about the lives of sheep than we did a few decades ago. We have evidence of the price rams pay for working their way to the top of the sheep's social pyramid and of how they minimize that price by signalling their power to avoid defending it.

We know how little we knew just a decade ago about the true relationships among the different colour variations and populations of thinhorn sheep, and we have an inkling of how much we still have to learn. We know much more about the evolution of thinhorn sheep through millennia and the coming and going of the ice sheets. We also suspect they can teach us much more about ancient landscapes and about how life changed, adapted, and survived through so many years and so many changes.

Environment Yukon continues to collect data on every sheep harvested in the territory and continues to build its unique data set. Future researchers may well use this data to answer some of these questions or ask and answer entirely new questions.

6. APPENDIX

Publications based on Yukon sheep research:

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