THE COMMUNITY ECOLOGICAL MONITORING PROGRAM ANNUAL DATA REPORT 2023

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Key Ecosystem Changes in 2023

- Climate change continues with warming greater in winter than in summer
- White spruce cone crop very low at all sites
- Ground berry crops variable with only low to moderate abundance at Mayo, Kluane and Whitehorse, and very low at Faro and Watson Lake. Soapberries low in all areas
- Mushrooms low at all sites
- Snowshoe hares have entered the increase phase of the 9–10-year cycle at Watson Lake, Faro, Kluane, and Mayo but are still very low around Whitehorse
- Red squirrels at Kluane increased to very high numbers in 2023
- Small rodents (voles and mice) at high numbers at Kluane and Whitehorse, BUT moderate to low abundance at other sites
- Abundance of hare predators (lynx and coyotes) are still low but will start to increase with the hare cycle moves into the increase phase
- No forest fires affected most of our study sites but there were several large fires in the Mayo area that affected the sampling schedule.

Executive Summary

To determine how the boreal forest ecosystem is responding to climate change we have been monitoring white spruce cone crops, ground berry production, mushroom biomass, and the abundance of small mammals, snowshoe hares, and carnivores at Kluane Lake, Mayo, Faro, Watson Lake, and Whitehorse. This is the 23rd annual report to summarize these data and we recently published a paper summarizing our results to date (Krebs et al. 2023). Winter 2022-2023 had moderate snow depths, with spring arriving around mid-May. White spruce cone counts were near zero at all sites in 2023. Soapberry counts were low at Kluane, Mayo and Whitehorse in 2023 after 2 years of higher counts at Kluane and Mayo. Red-backed voles remained at moderate to high numbers at Kluane and Whitehorse, perhaps assisted by the deep snow overwinter. Snowshoe hares at Kluane, Mayo, and Faro began increasing in spring 2023 and increased rapidly in the summer of 2023. Hares around Whitehorse remained low in 2023. Hares at Watson Lake and Faro had began their cyclic increase already in 2021-2022. Red squirrels at Kluane were at very high density in spring 2023 and stayed at high numbers in the autumn of 2023, accelerated by high spruce cone production in the previous year. Snow track counts in winter 2022-2023 for mammalian predators were completed at Kluane and Mayo. Lynx numbers began increasing in the winter of 2022-2023 at Kluane but stayed low at Mayo. Marten increased slightly at Mayo, and ermine

were at moderately high density in 2022-2023 at Kluane. Coyote numbers are rapidly increasing at Kluane.

We continue to investigate whether remote cameras can substitute for snow tracking to census mobile predators and possibly moose and bears in the Kluane region on Kluane First Nation (KFN) and Champagne-Aishihik First Nations (CAFN) Traditional Territories. In 2023, 72 cameras at permanent sites were monitored. We also used 25 automated recording units (ARUs) to monitor relative abundance of avian predators of hares and small rodents (i.e, hawks and owls), as well as alternate prey species such as grouse.

The climate models we have developed can make predictions of how the monitored mushroom and plant populations will perform in 2024, and a table of predictions for 2024 is provided, along with the predicted and observed results for 2023. As we accumulate more data, these models should become more precise in their predictions but there are still some failures in the models that are now being checked and recalibrated.

The key predictions for 2024 are:
1 – Moderate spruce cone counts everywhere
2 – Low to moderate mushroom crops everywhere (if July 2024 rainfall low)
3 – Soapberries low everywhere except Whitehorse
4 – Hares beginning to increase and rodents declining to low numbers, with lynx, coyotes, and great-horned owl populations recovering, and grouse abundant.

Introduction

Since detailed ecological studies of the Kluane boreal forest began in 1973, we have been monitoring the ecological integrity of the Kluane region on the Traditional Territories of Kluane First Nation and Champagne and Aishihik First Nations. Over the years, we have tested and improved the monitoring methods being used. In 2005 we were able to expand some of the monitoring protocols to Mayo, Watson Lake, and Whitehorse, and in 2007 we began collecting data at Faro. This has permitted us to focus on regional trends in measures of ecosystem health and change. The **Community Ecological Monitoring Program** (CEMP) is a partnership between biologists at Environment Yukon, various universities (Yukon University, UBC, Alberta, Toronto, Trent), the Kluane Red Squirrel Project, and the Outpost Research Station at Kluane Lake. Additional monitoring in the Yukon is being done by Parks Canada and other research groups but we cannot summarize this monitoring here. We concentrate here on the CEMP monitoring being carried out in the central and southern Yukon.

Why Monitoring is Needed and our Goals

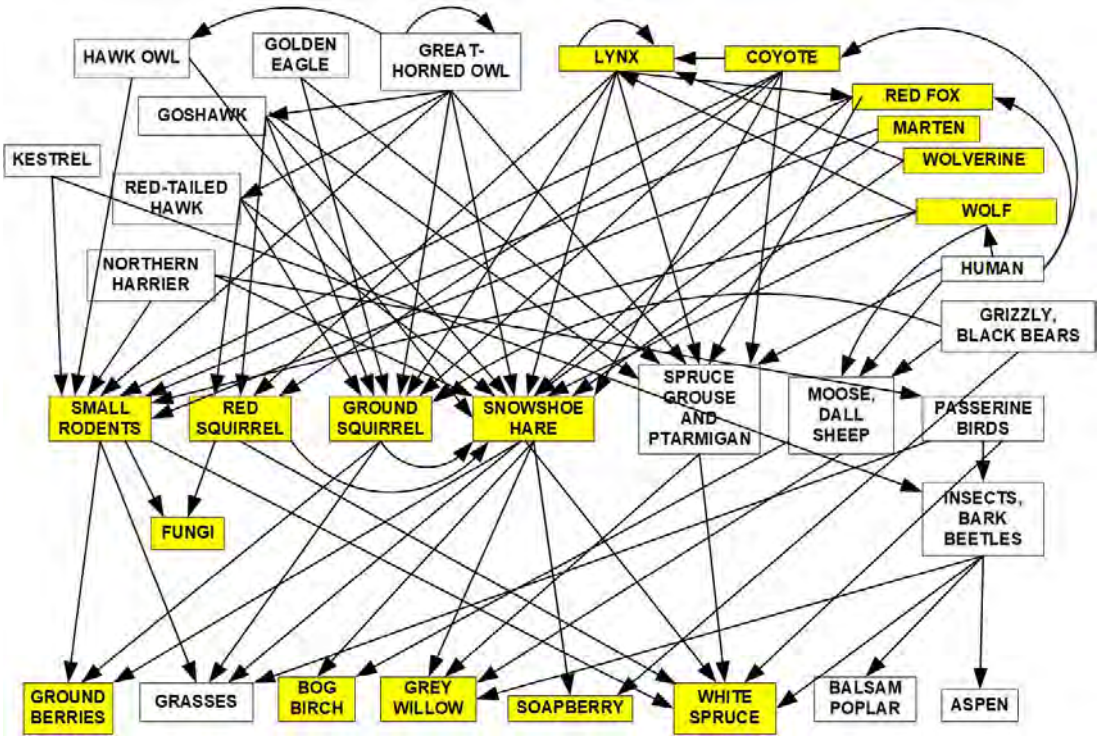
It is important to keep in mind where we are headed in any monitoring design. The key question we need to be able to answer is ***how will the Yukon's ecosystems respond to climate change*?** The answer to this simple question is not simple. Some parts of our Yukon ecosystems like spruce cone crops are directly dependent on climatic variables like temperature and rainfall. Others, for example snowshoe hares, depend immediately on the abundance and hunting success of predators like lynx, so the question then becomes will climate change affect predator hunting success.

The key to these approaches is to have a comprehensive monitoring program in place that gathers data year after year. We cannot start and stop monitoring programs for a few years any more than we can stop and start reporting on the weather for a few years. The need is thus for a commitment in funding and in people to carry these goals forward. This is what we have begun in the CEMP program, and we summarize here what we have so far achieved.

Protocols Monitored and Cooperating Research Programs

Figure 1 shows the food web of the boreal forest in southern and central Yukon. If we wish to monitor ecological integrity, we need to measure key components in each of the levels of this food web. However, we cannot monitor everything, and we have concentrated our efforts on the significant indicators highlighted below. We believe that these indicators constitute a start for obtaining early warning of ecosystem change, establishing baseline data on the natural range of variation of key ecosystem components, evaluating forest management practices, and advancing our understanding of the dynamics of boreal ecosystems. The species that are being monitored are indicated in yellow in Figure 1. In future we are hoping to be able to monitor some of the larger mammals with remote cameras (Kenney and Krebs 2022). However, we do not have the funding to monitor large mammals like caribou and Dall sheep directly, and these large mammals are monitored by other programs in Environment Yukon and by First Nations.

Figure 1. Food web for the boreal forest in the southern and central Yukon. The species being monitored in at least two of the CEMP sites are shaded. Only the major feeding linkages are shown.



We have prepared a separate handbook of the details of the monitoring protocols for each of the species' groups listed above (CEMP Monitoring Handbook, available for download at http://www.zoology.ubc.ca/~krebs/kluane.html).

Two general questions underlie this monitoring program. First, *is there synchrony among sites in these indicators?* Regional synchrony can be achieved by ecological indicators responding to weather variation that has a widespread regional signature, or by large-scale dispersal of animals like lynx and coyotes. Second, *are there regional patterns of variation in the density or productivity of indicators?* For example, snowshoe hares may be on average more abundant in some areas than they are in others. In turn, all these regional similarities or differences need to be explained ecologically.

Results and Discussion

Climatic warming continues across the Yukon. Lavergne et al. (2021) reported for the Kluane area that over the last 50 years winter temperatures had increased 3.75ºC and summer temperatures had increased somewhat less with 1.45ºC increase over the last 50 years.

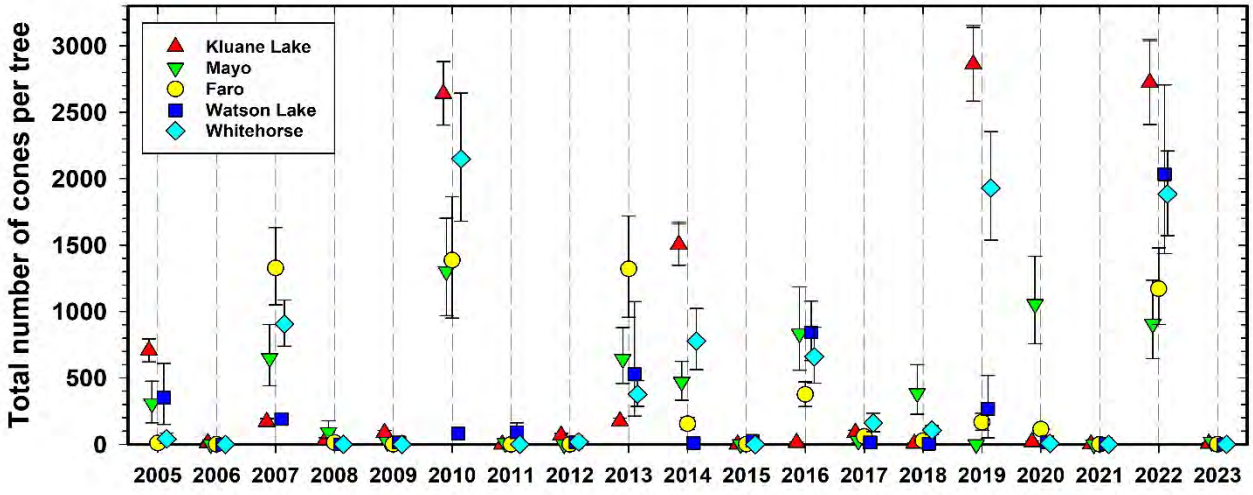
For this 2023 Annual Report, we discuss some of the findings from the main protocols that may reflect on the changing climate. In the results below we report mean abundances and 95% confidence limits unless indicated otherwise.

(a) White Spruce Cone Production

White spruce trees produce a variable number of cones each year, and at irregular intervals very large crops are produced in mast years. We have been counting cones on spruce trees in the Kluane area since 1987, and Figure 2 shows the cone counts over the CEMP sampling sites since 2005. We have 18 years of data at all the CEMP sites, but 37 years of data at Kluane. White spruce cone crops were very low on all our sites in 2023. Since years of high cone production are driven by weather variables, we should be able to correlate our weather data with these cone production events, and thus explain some of the reason for this trend (Krebs et al. 2017). Red squirrels and seed-eating birds provide a responsive index of high cone crops. Red squirrels were increasing at Kluane in 2023 as a response to a high cone crop in 2022.

We recalculated the predictive regression for white spruce cone counts in 2023 and it is similar to the 2020 model. The two key variables to predict cone crops remain the mean temperature in July one and two years prior to the actual cone crop. No rainfall variable is a significant predictor. The cone crop predictions for 2023 (Table 1) were in error because of the biological constraint that it is not possible to have two large mast years in succession, no matter what the weather (see Table 1). Presumably this is because the energy reserves of spruce trees require a minimum of 2 years to restock. We have used this same regression to predict cone counts for 2024 from the weather data of 2022 and 2023 (see Table 2 for specific predictions). We predict that all areas will have low to moderate cone counts in 2024. If high cone crops increase in frequency, we might expect a trade off between cone output and current growth.

Figure 2. Average white spruce cone counts on CEMP sites for 2005 to 2023. Green cones are counted on the top 3 m of a tagged set of trees each August. These index counts are converted to total cones per tree by the LaMontagne conversion (LaMontagne et al. 2005). There was high cone production in 2005, 2007, 2010, 2013, 2014, 2016, 2019, 2020 (in Mayo) and 2022 at all sites. Means ± 95% confidence limits. There were virtually no cones in 2023 at any site.



(b) Ground Berry Production

Five species of ground berries are counted in permanent quadrats each year. The major berry-producing plants are bearberry (*Arctostaphylos uva-ursi*), crowberry (*Empetrum nigrum*) and cranberry (*Vaccinium vitis-idaea*). We use permanent quadrats for our counts because in any particular area it is possible for some small patches of berries to be abundant when the general landscape has few berries overall. Figure 3 shows the data we have accumulated on three of the species of ground berries since 2005.

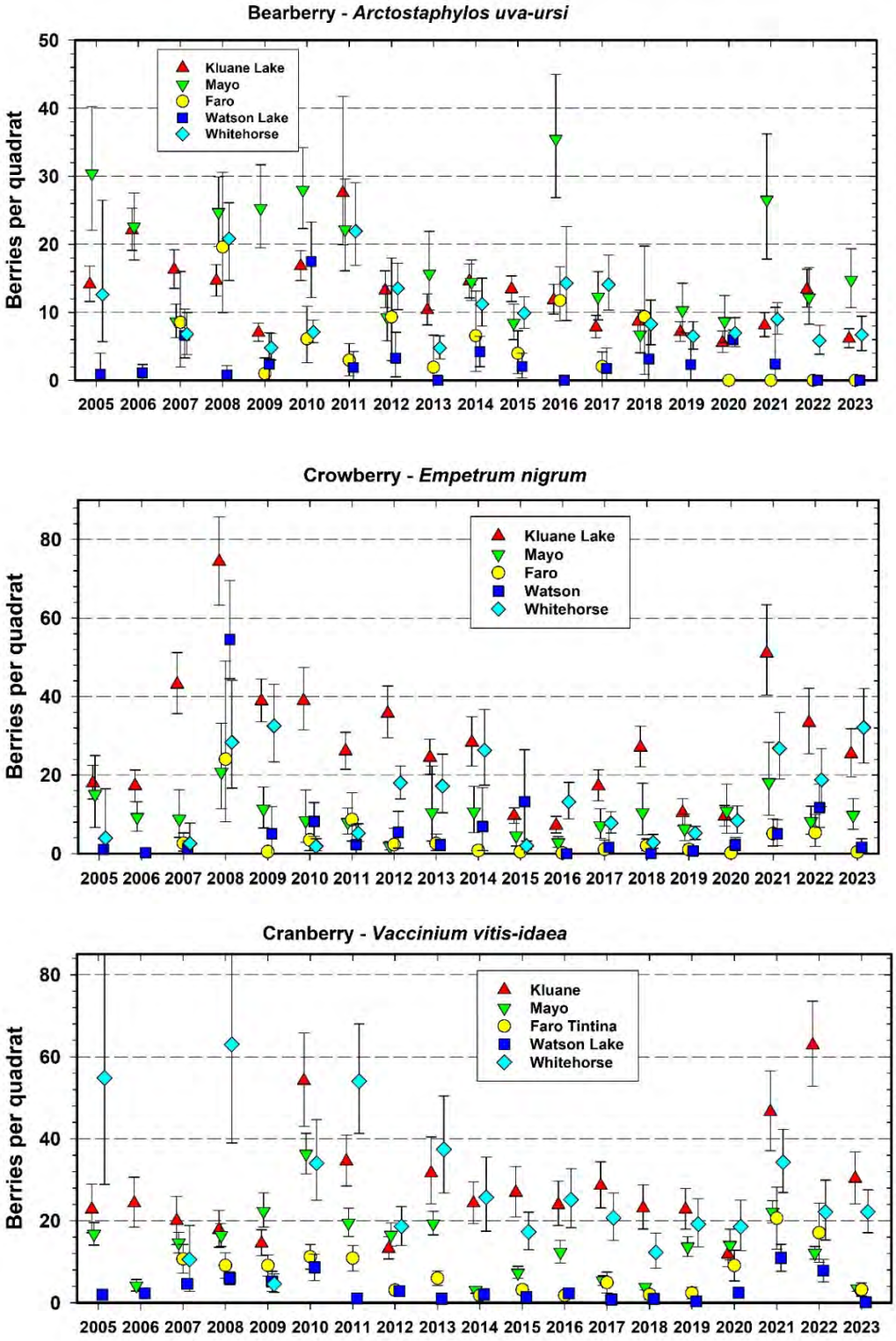
Bearberry counts can be highly variable among our monitoring areas but in 2023 all five CEMP areas had low to moderate bearberry counts. The emerging pattern is a long-term trend toward reduced bearberry crops since 2011 (although Mayo was an exception with high counts in 2016 and 2021. There has been a long-term trend toward reduced bearberry crops since we began this project in 1997 (Krebs et al. 2023).

Crowberry counts show variation among the CEMP sites, with a moderate production year in 2023 at Kluane and Whitehorse, while Mayo, Watson Lake, and Faro had low crowberry counts in 2023. Mayo crowberry counts are always low.

Cranberry counts show a similar pattern to crowberry counts with rising berry counts on most areas in 2021 and 2022 but returning to average or low counts in 2023. Watson Lake has very few cranberries in most years.

Over all species berry counts were relatively low from 2014 to 2020, compared with the previous six years which showed more regional variation with an occasional good year in only one species at one site (like bearberry at Mayo in 2016 and 2021). The same berry plots are counted each year.

Figure 3. Absolute berry counts for three species of ground berries (bearberry, crowberry, and cranberry) at fixed CEMP sites from 2005 to 2022. Quadrat size is 40 by 40 cm. Error bars are 95% confidence interval for the number of berries per quadrat.



We have re-analyzed the climatic controls of ground berry production in 2023 (Krebs et al. 2023) to update those given in Krebs et al. (2009). Each species of ground berry in the Kluane area responded to different signals of temperature and rainfall, and there was no general climate pattern to which all the species of ground berries responded. Our working hypothesis is that ground berries respond to regional weather patterns but that individual berry species require a different suite of weather variables (monthly temperatures, monthly rainfall) from the current and previous years to produce a large berry crop.

An alternative and important view is that pollinator abundance has a strong influence on berry crops in correlation with weather, but at present we have no regional data on pollinator abundance at our sites. A second alternative view is that small mammals feeding on berry flowers in spring reduce potential berry crops, which would lead to the prediction of high berry crops in low vole years. Alternatively other insects could produce galls on flower buds and reduce berry crops. Whether the long-term (20 years, 2004 to 2023) trend to lower abundance of berries will continue has important consequences all the species that eat these berries, including First Nations and other Yukoners

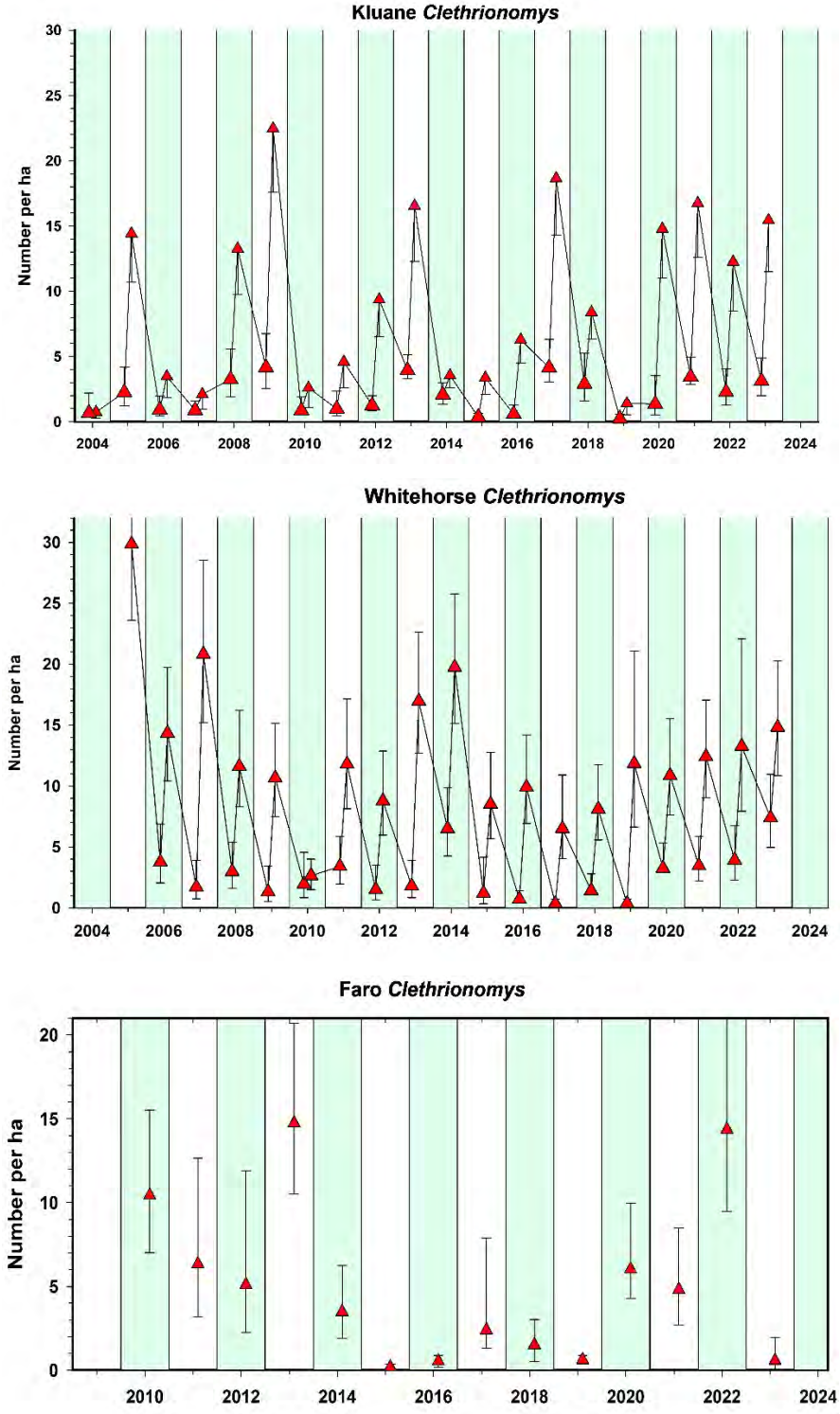
(c) Small Rodent Numbers

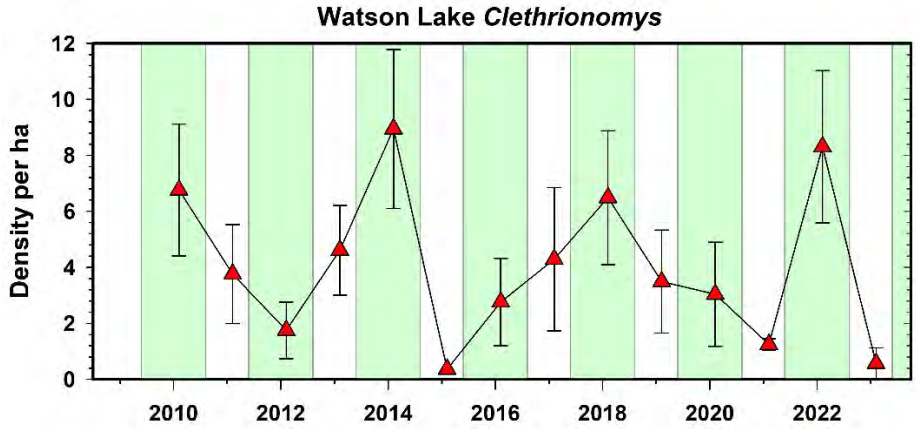
The most common rodent on all CEMP sites is the red-backed vole (*Clethrionomys rutilus*), and we have estimated the abundance of this species by live trapping, marking, and releasing individuals. Live trapping at Kluane and Whitehorse is done in spring and late summer, and only in late summer at Mayo, Faro, and Watson Lake. Figure 4 shows the changes in red-backed vole numbers for the period 2004 to 2023.

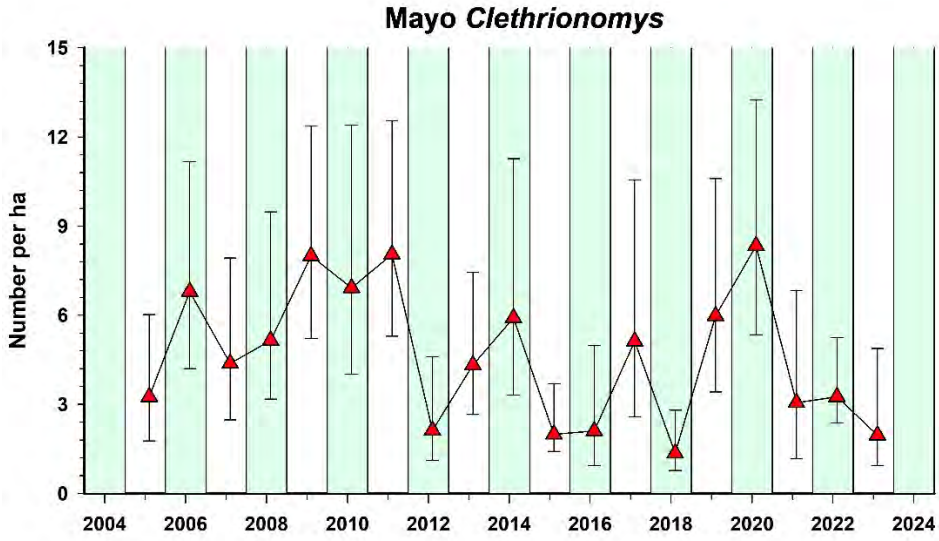
Red-backed voles at Kluane have fluctuated in 3-to-4-year cycles for the past 25 years and this pattern is shown in Figure 4 with peak years of 2005, 2009, 2013, 2017 and 2020, but peak summer densities are now an annual occurrence (2020-2023) suggesting that changes are occurring in population dynamics, but the cause is not yet clear. Whitehorse vole numbers have been moderate but slowly increasing for the past four years (2019-2023). Faro and Watson Lake populations were very low in summer 2023. Mayo decreased in 2021 from a high in 2020 and remained low in 2022 and 2023. The pattern to date does not suggest any close synchrony in fluctuations of red-backed vole numbers in the southern and central Yukon.

Since winter declines of red-backed voles at Kluane are correlated with mushroom and ground berry production of the previous summer, and summer increases are correlated with summer berry production, we might expect the differences in density between the five CEMP sites to reflect the abundance of food resources at each site.

Figure 4. Population estimates for red-backed voles in five CEMP areas, 2004-2023. Trapping grids have an effective trapping area of about 3 ha. For clarity, alternating years are highlighted in green and white. Spring and late summer estimates are available only for Whitehorse and Kluane. Other areas have late summer estimates only. Note that the graphs for the five different areas show different density scales.







The only other small mammal that is common to many of the CEMP sites is the deer mouse, *Peromyscus maniculatus*. At present the number of captures of this species are too low on most of the sites to discern any clear patterns of population change. The Mayo Rusty Creek site has a nearly 3-year cycle in deer mouse density, but we need a longer time series to be certain about the pattern. Deer mice remained between 1-4 per ha on all sites from 2005 to 2019 and then increased to high density in 2021 at Whitehorse (10 mice /ha) but were very low at Whitehorse, Kluane, Faro, Mayo, and Watson Lake in 2022 and 2023. The deer mouse is near the northern limit of its range and is adapted to winters by going into torpor and storing food. The hantavirus carried by *Peromyscus* in the USA and southern Canada causes serious disease in humans and could potentially be at low prevalence in the southern Yukon. But it is unlikely that the hantavirus will be able to take hold in the Yukon because the low density of Yukon deer mice would impair the transmission between mice.

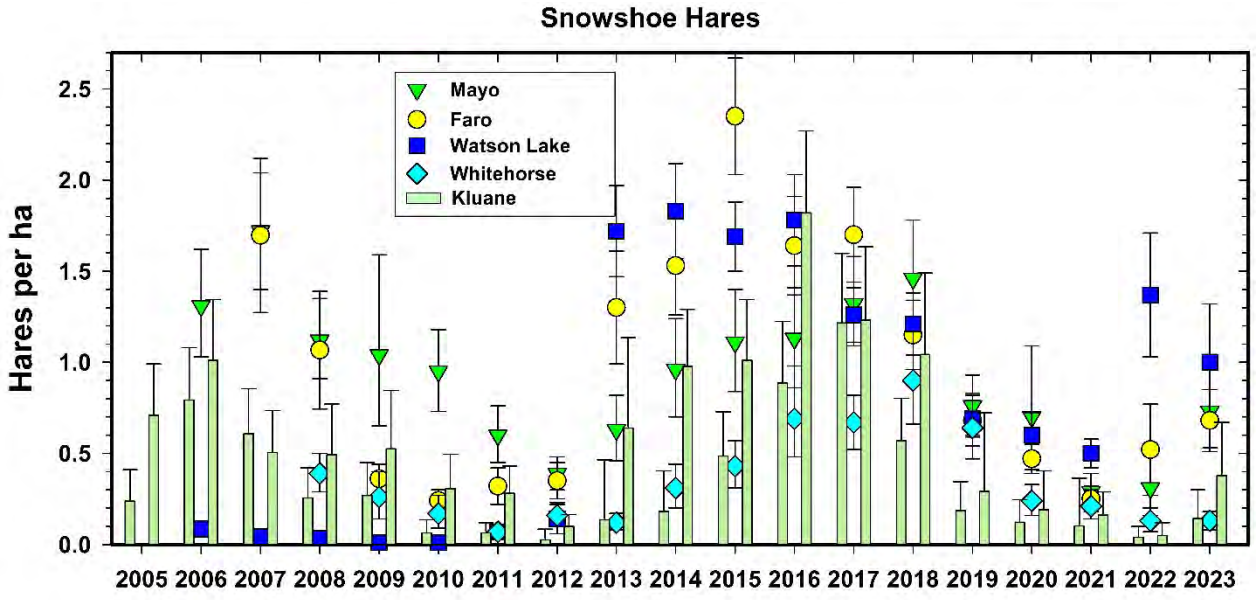
Since most of these mice and voles weigh approximately 25 g, a density of 5/ha would provide a predator with only 125 g per ha of potential food per day, assuming the predator could catch and eat all of them in 1 ha of habitat. In this simple model a hypothetical coyote would clean off all the small rodents in 1.5 km^2 per month if it was able to eat 625 g per day. Simple calculations of this type suggest that medium to large

sized predators in the boreal forest cannot make a living on small rodents which must be an incidental part of their diet, at least until climate change increases rodent carrying capacity substantially. A similar calculation for ermine suggests that they too will have to exist at low numbers in relation to their small rodent prey. Thus, snowshoe hare and other prey likely make up a substantial part of the diet of these and other smaller predators in the Yukon boreal forest

(d) Snowshoe Hare Numbers

The snowshoe hare is a keystone species in much of the boreal forest because it is the prey of so many predators (see Figure 1). Snowshoe hare abundance fluctuates in 9-to-10-year cycles throughout the boreal zone. At Kluane we have estimated the abundance of snowshoe hares by live trapping, marking, and releasing individuals. We have also developed a simple census method for hares by means of fecal pellet counts carried out once a year in summer (Krebs et al. 2001) and this technique has been used at all the CEMP sites for comparative data. Figure 5 shows the changes in hare numbers at the CEMP sites

Figure 5. Population density estimates for snowshoe hares in 5 CEMP areas, 2005-2023. Mark-recapture data from Kluane are given as a bar graph for spring and fall of each year. Estimates from fecal pellet counts at CEMP sites are given as points (95% confidence limits). Note that the data from fecal pellet counts integrate hare density over the previous year. Mayo data from Rusty Creek site only. Watson Lake counts only from the two burn sites.



Two points stand out in Figure 5. First, Watson Lake sites showed almost no snowshoe hares until in 2013 when Don Reid realized their fluctuations occurred only on burn sites in that area. Watson Lake forest or logged sites do not show hare cycles but burn sites do. There is clear natural history information for Watson Lake that the hare cycle exists but may be one year out of phase compared to other Yukon sites. Second, all the CEMP sites followed the last hare cyclic decline phase, with peak populations in 2016-2017 and declining populations from 2018 to 2021. Faro hare

numbers increased rapidly in the summer of 2022 and Watson Lake even more rapidly, and this argues that 2023 was in the increase phase for all CEMP sites. We should have a continuation of rapid increase of all local hare populations in the southern and central Yukon during 2024 with the next hare peak expected in 2025 or 2026.

Regional synchrony is well established in snowshoe hares in much of Yukon, but as we get more regional details, we find that not all areas in western Canada and Alaska tend to be in phase. We have summarized the hare data from Yukon, Alaska, northern BC and the NWT in Krebs et al. (2013, 2014). This analysis of regional synchrony strongly suggests a travelling wave of hare peaks that moves from northern BC into Yukon one year later and then moves north in Yukon with a further one- year delay and west into Alaska to peak 2 years later than BC. As far as we can determine, this travelling wave occurred in the recent hare cycle of 2015-2023, and our colleagues in Alaska and NWT are gathering hare data comparable to ours to answer this question whether the cyclic peak migrates west into Alaska. Frank Doyle has been gathering data similar to our hare data from central B.C. and will be analyzing these hare data to discuss regional synchrony and the landscape issues with fire and logging on hare populations in these more southerly areas.

The most promising explanation for regional synchrony involves predator movements, particularly of lynx and great-horned owls, and depending on the geometry of the highs, such movements could produce a travelling wave of density changes. The University of Alaska group headed by Knut Kielland is analyzing lynx movements from central Alaska with satellite collars throughout the current hare cycle.

(e) Lynx Abundance

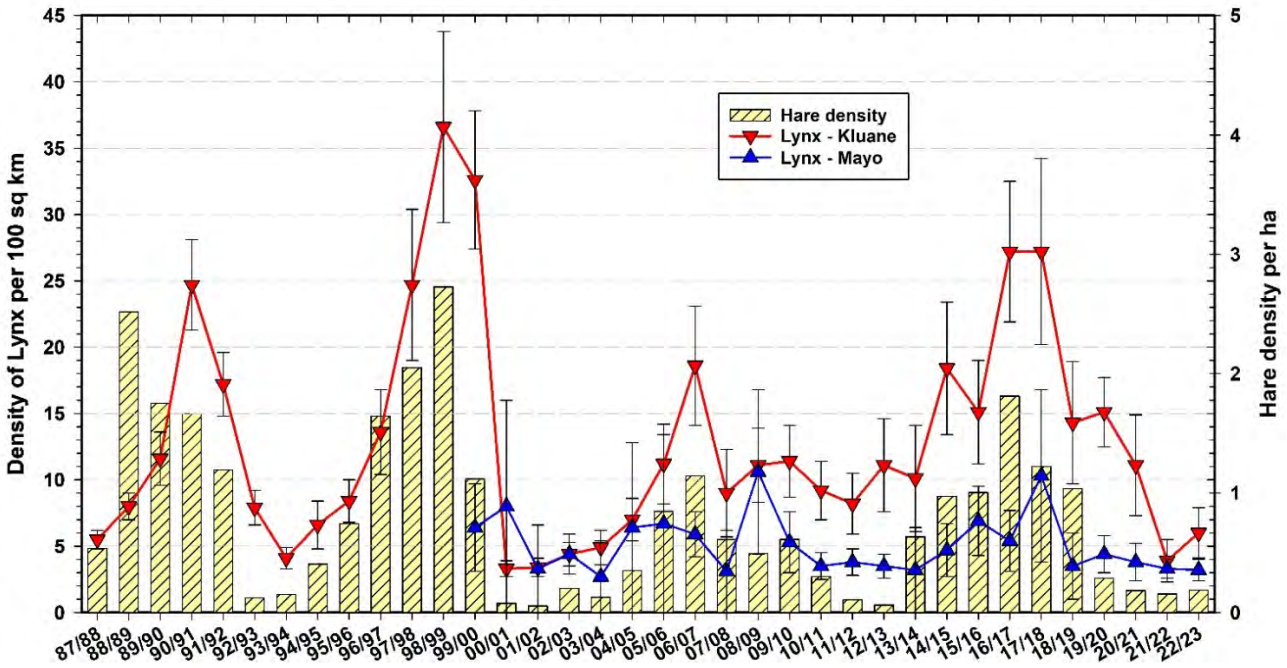
We have been following lynx abundance in the Kluane region since 1987 by means of winter snow track counts along established routes (O'Donoghue et al. 2023). We expanded this predator tracking to Mayo in 1999. We count lynx tracks crossing snowmobile routes after fresh snowfalls each winter, depending on wind conditions. On average about 200 km are tracked each winter at Kluane and about 200-250 km at Mayo. But during some years poor snow conditions in winter have limited our ability to use snow tracking.

Figure 6 shows the changes in abundance of lynx in Mayo and Kluane as estimated by snow tracks. Because our winter snow tracking cannot be done in identical habitats in all areas, we do not expect the absolute number of tracks to directly indicate lynx density but only trends in density. Two points stand out in this graph. First, the lynx peak at Kluane in 2006-07 was the lowest we have seen, coincidental with the lowest hare peak we have seen at Kluane. Second, lynx at Mayo appear to be out of phase with lynx at Kluane by a delay of 1 year. In winter 2020-2021 lynx were at a low at Mayo and were still declining in the Kluane area. Hares at Kluane and Mayo reached a low level by spring 2022 and have moved into the increase phase at Kluane in 2023.

We do not have comparable snow tracking data from Faro, Whitehorse, or Watson Lake because of a shortage of snow fall events in some years or the lack of personnel to do this work. Because this is a serious problem that will likely get worse due to climate change, we began in autumn 2015 to install a set of trail cameras in the

Kluane area to take automatic photos year-round of animals moving along game trails and paths. After 8 years of comparing camera data to snow track transect data, we have determined that camera data is a reliable method for obtaining an index of predator abundance (Kenney et al. 2024).

Figure 6. Snow tracking density estimates for Canada lynx at Kluane and Mayo,1987 to 2023 with 95% confidence limits. Hare data are from control grid live trapping at Kluane in the autumn preceding the winter predator data.



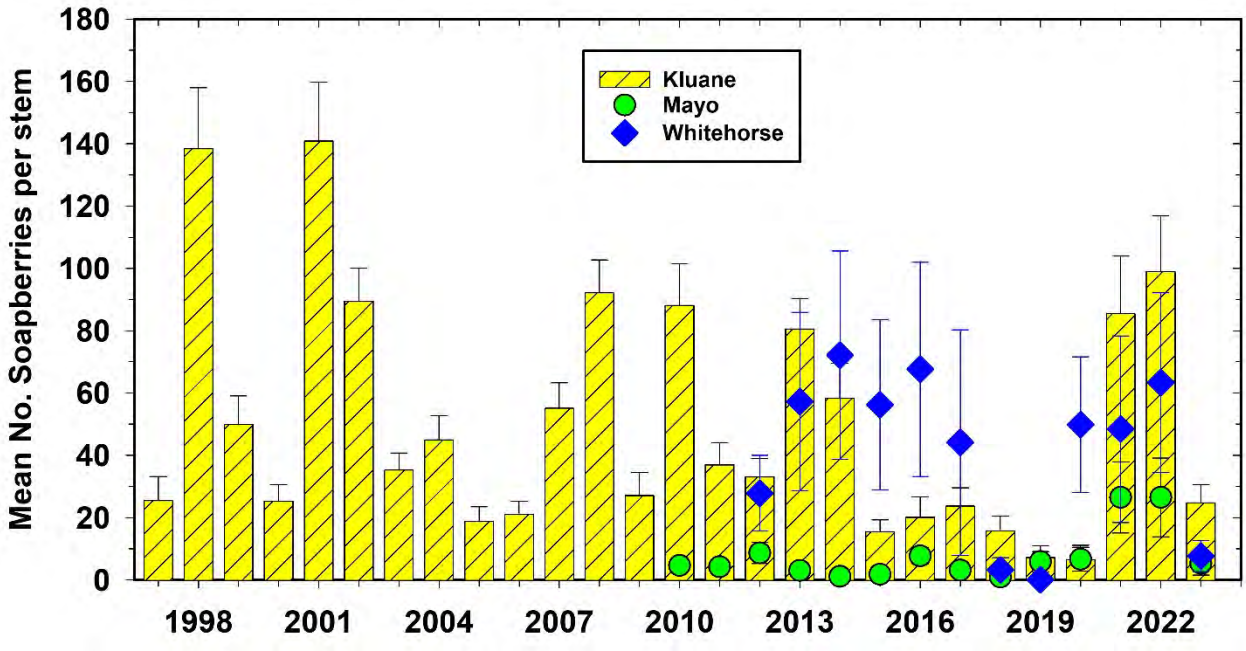
Lynx increased in numbers on all areas to a peak from 2016 to 2018 but did not seem to reach the high levels they were at in 1998-1999 (Figure 6) and visual field evidence from the summer and early winter of 2022-2023 suggests that lynx are scarce but increasing with hare numbers.

(f) Brief Notes on Other Monitoring Measurements

Soapberries

Soapberries (*Shepherida canadensis)* are a favourite food of bears, and are being counted at Kluane, Mayo, and Whitehorse. We place a high priority on counting soapberries at all sites but there are few soapberries on some of our sites which makes this a challenge. Mayo has not seen a high count of soapberries from 2010 to 2020. In summer 2021 and summer 2022 soapberries were very abundant at Kluane, Whitehorse and Mayo, but in 2023 soapberries were at low abundance at all 3 sites (Figure 7).

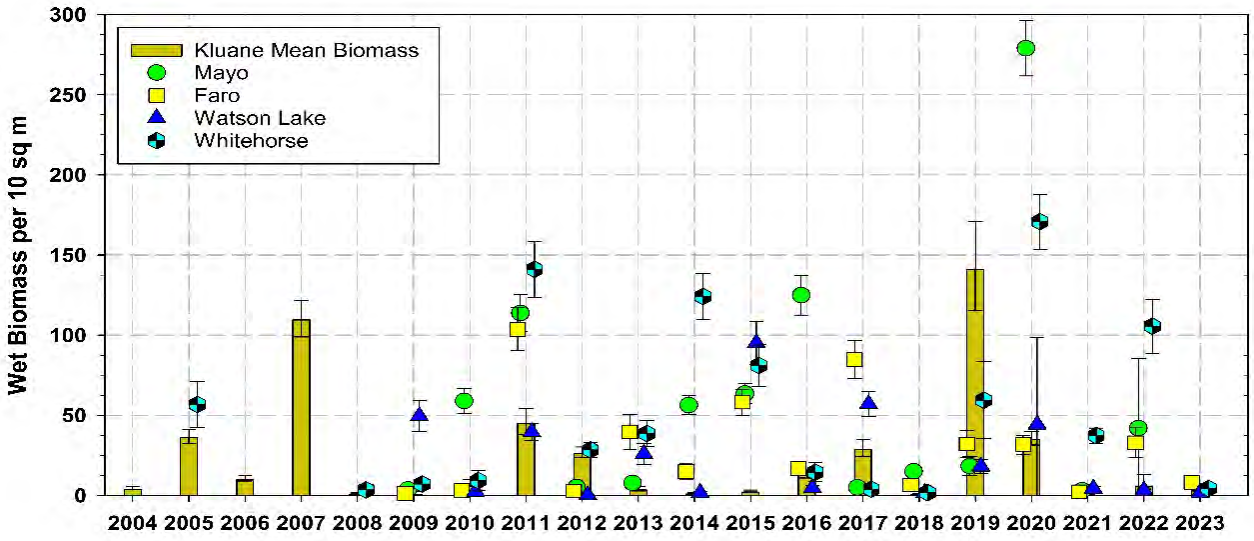
Figure 7. Soapberry counts at Kluane, Mayo, and Whitehorse. Counts are the number of berries on an average 10 mm diameter stem.



Mushrooms

In 2023 mushrooms were impossible to count at Mayo due to forest fires, and mushroom biomass was very low at Kluane, Whitehorse, Faro, and Watson Lake (Figure 8). In previous years mushrooms have been highly variable among the five sites we monitor. There is a suggestion that heavy rains during the current mushroom season may produce a late crop of mushrooms that our late July and early August counts are missing, and this must be investigated further and perhaps mushrooms should be counted in August on all sites as they are now at Mayo. A very few large mushrooms were noted at Kluane in late July 2023 after heavy rains in that month. While moose feed on large mushrooms (from camera photos) it is not clear if very large mushrooms are of benefit for most small mammals.

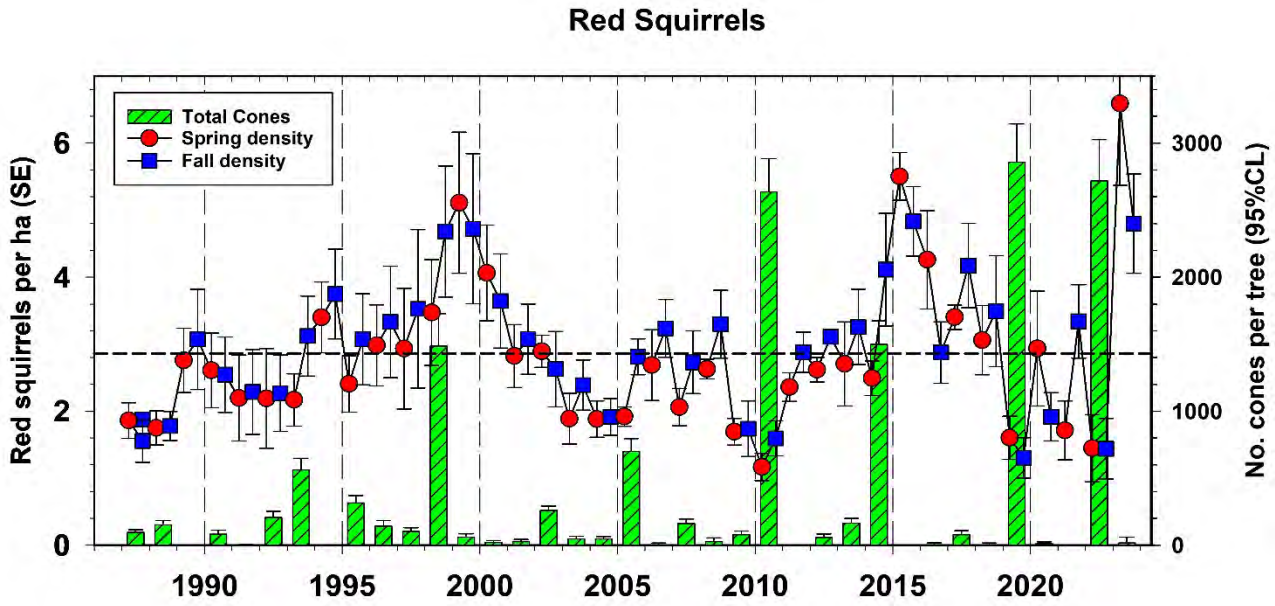
Figure 8. Mushroom biomass at Kluane, Mayo, Faro, Watson Lake, and Whitehorse, 2004-2023. Biomass wet weight (g) of all species of mushroom combined per 10 sq. m. No Mayo data available for 2023 due to forest fires.



Red Squirrels

Red squirrel numbers have been studied extensively at Kluane for years by Stan Boutin's Kluane Red Squirrel Project (https://redsquirrel.biology.ualberta.ca/). In general, red squirrel numbers have been relatively stable in the boreal forest around Kluane at 2.8 per ha, but they increased rapidly in 2015 after a good cone crop in 2014. They then began a slow decline from 2016 to 2022 and there was little recovery despite the large cone crop in 2019 due to the cones opening and dispersing their seeds too early to allow the squirrels to harvest successfully. There was virtually no white spruce cone crop in 2021, and red squirrel middens contained almost no cones. Red squirrels collapsed to low numbers in 2021 and remained low in 2022 but recovered quickly to high numbers in 2023 in response to the large cone crop in 2022 (Figure 9). Population growth by autumn 2022 was underestimated because litters were late in recruiting, so population growth occurred only after the fall trapping was completed. We expect high numbers in spring 2024 from late autumn 2023 recruits.

Figure 9. Red squirrel density changes on all control study areas at Kluane in relation to white spruce cone crops, 1987-2023. Dashed horizontal line is the long-term average red squirrel density for Kluane (2.9 squirrels per ha).

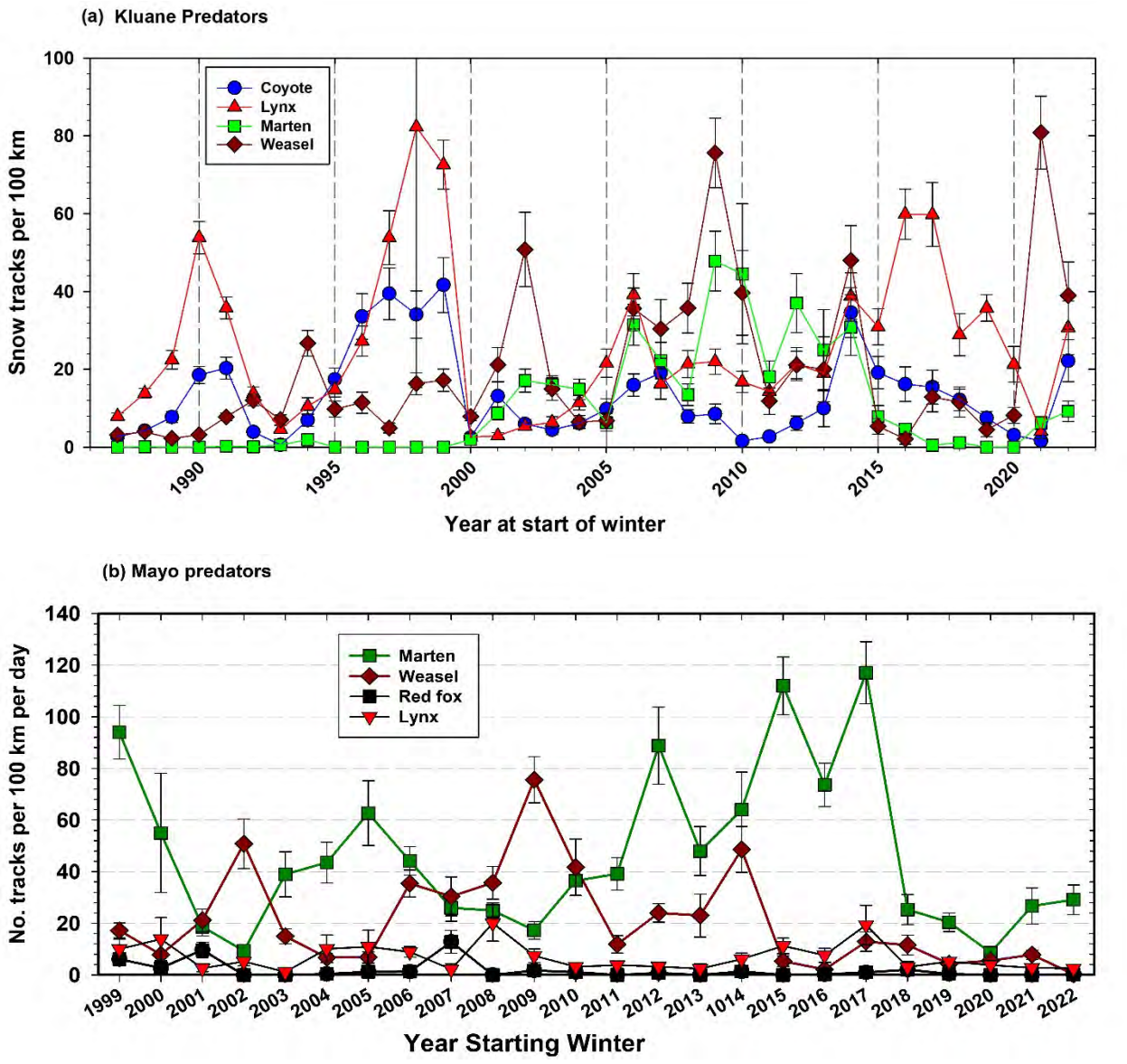


Predator Snow Track Data

Snow track transect data show trends in several predator species as well as lynx (Figure 10). Marten were nearly absent at Kluane for the last 6 years but began to increase slightly in the winter census of 2022-2023. Weasels in 2022-23 remained at a moderately high level, about half of the highest density index ever observed in 2021-2022. In general, 2023 was a year of increasing numbers of lynx and coyote at Kluane but lynx did not increase at Mayo in 2023. Weasels (*Mustela erminea*)

responded dramatically to the extended rodent peak of 2020-2023 at Kluane. There are few coyotes at Mayo, but coyote distribution has been slowly moving north in the Yukon although deep winter snow cover may limit their expansion into the central Yukon.

Figure 10. Snow tracking abundance estimates with SE (a) for coyote, Canada lynx, marten, weasel, and red fox at Kluane, 1987 to 2023 and (b) for Mayo 1999 to 2023. Track counts are affected by activity as well as by abundance, so must be considered an index of abundance.



Ground Squirrels

Arctic ground squirrels remain at extremely low numbers in the forested areas around Kluane and they are mainly associated with human buildings and disturbed areas like airstrips. We have caught none in 2023 in any of our live trapping grids in the Kluane forests where they used to be abundant 20 years ago. We are currently

exploring funding opportunities to launch an investigation into the causes, ecosystem consequences and restoration opportunities for ground squirrels in southwest Yukon.

Shrub Monitoring

The structure of the boreal forest is undergoing substantive changes owing to climate change, with a regional increase in shrubs in recent decades and notable spruce tree mortality (at Kluane) related to a spruce bark beetle infestation from1998-2006. These processes may impact composition and function of the boreal ecosystem, including changes in food and cover for snowshoe hares and moose, hunting habitat for lynx and raptors, and standing dead trees for cavity nesting birds. Shrubification may also impact the distribution and abundance of open areas for ground berry production. In 2022, we began monitoring shrub abundance using trail cameras and remote sensing surveys using RGB and LiDAR sensors affixed to an unmanned aerial vehicle. In 2023, we initiated extensive ground surveys to determine the biomass of shrubs and the proportion that is consumable by snowshoe hares (<5 mm twig biomass) at different times of the year as a function of snow depth. Preliminary results reveal strong correlation between shrub (willow, birch) biomass and consumable biomass and height-from-ground (0-2m). Our long-term goals are to quantify and track shrubification at Kluane and model its impacts on wildlife.

The availability of small twigs so important to snowshoe hares during winter is heavily influenced by changing snow depths. As snow accumulates some important shrubs (birch) get completely covered while taller willow shrubs get pushed down by the weight of the snow. Deeper snow allows hares to reach twigs of spruce up to 1.5m above ground. We are using trail cameras to watch how twigs available to hares change by tagging a sample of twigs with flagging tape and taking a picture each day. 2023 was our first winter of work and preliminary analyses suggest that the proportion of shrub twigs covered by snow and not available to hares can reach 100% for periods of time.

Julianna Baluffi-Fry completed feeding trials with hares where she fed individuals diets that differed in protein and fiber content. The diet with the lowest protein content fell just below levels measured in twigs while the other diets had protein contents slightly above to well above that measured in twigs. Juliana found that hares could not maintain weight on the lowest quality diet but did so on the other diets. It appears that hares are highly sensitive to the protein content of their food, and she will link her findings to how protein content of twigs available to hares changes with changing snow depth.

Bird Monitoring

Bird surveys in Yukon are not being done on the CEMP sites, but we would like to get coverage at all CEMP sites. Our focus is on the species that are major components of the boreal forest food web in Figure 1. In 2022 Stan Boutin, Frank Doyle, Dennis Murray and Tom Jung began deploying acoustic sound recorders in the Kluane area. Mark O’Donoghue at Mayo has carried out standardized Owl Surveys since 2003, Breeding Bird Surveys since 2004, and Nighthawk Surveys in central Yukon since 2016. Other bird surveys have now been put in place to obtain a better picture of regional trends for the southern Yukon. Natural history observations suggest high grouse populations at Kluane in 2016 and declining numbers from 2019 to 2020 but an

increasing population of spruce grouse in 2022 and 2023 from visual sightings. In Whitehorse grouse were common in fall 2019 but seem to have disappeared by 2022.

Monitoring of the bird community at Kluane was a focal part of our research from 1986-1996, and over the past 2 years we have been exploring the use of Automated Recording Units (ARU's) as tool to allow us to monitor these same species. We are interested to see if our bird community is responding to climate change through changes in community composition (presence-absence) or shifts in location that may be associate with changes in vegetation cover, or species distribution.

ARU's can pick up bird calls for hundreds of meters around the deployment position. In 2023 twenty of these units were placed 1.5 km apart along the length of the Kluane study area to look at changes in the raptor-owl-corvid community. In addition, 20 units were also placed on 5 monitoring grids at the same locations as were used as Breeding Bird Point count stations in 1987-1995.

The ARU's placed along the length of the study area in 2023 have picked up Great Horned Owls and Boreal Owls on all units, and detected American Kestrels, Northern Harriers, and Red-tailed Hawks. Work will continue to determine the presence of other species on all units in 2023 and 2024 in order to compare with the community composition 30 years ago. These ARU's will be useful addition to the CEMP monitoring program by allowing us to assess change in the avian component of the food web we have depicted in Figure 1, as well as providing data on neotropical migrants.

(g) Predictions for Indicator Species in 2023 and 2024

We combined the statistical models we have for mushrooms and plant species and patterns we have seen for mammals to produce the predictions we made last year for 2023. We used the resulting values we measured in 2023 to test the accuracy of our predictive models (Table 1). The model for spruce cones was inaccurate for 2023 because large cone crops (2022) are always followed one year by near-zero cone crops, presumably due to an energy limitation. Our above-ground mushroom production predictions for 2023 were good for all five sites in predicting low crops. Rainfall on local areas is variable and the Yukon has a very sparse system of public weather stations that record precipitation. The question is always whether the monitoring plots received the rainfall measured at these standard weather stations. The data we have gathered suggests high variation in local rainfall in summer (Krebs et al. 2018), and it would be useful to install soil moisture meters on CEMP plots to measure soil conditions directly. Some species of mushrooms are dependent on in-season June and July precipitation, and it may not be possible to predict crops accurately a year in advance. Soapberries were correctly predicted to be low at Kluane and Mayo, but incorrect for Whitehorse. Small rodents remained at quite high numbers at Kluane despite the large number of weasels there. We continue to revise our models for these indicator species and this work is underway now.

Table 2 contains the predictions for many of our monitored species for 2024. The major plant prediction is for spruce cone crops to be moderate for all areas in 2024. If June and July rainfall for 2024 are average, moderate mushroom crops should occur in all areas. Since we are moving into of the increase phase of the snowshoe hare cycle,

the predictions for all areas for hares and their predators are for rapid growth and improved breeding success for hares and their predators.

Testing all these models as the years go by will allow us to determine how reliable our understanding is of how this boreal forest ecosystem is responding to climate change, and whether the main effects are top-down from predators or bottom-up from climate and food supplies.

Closing Remarks

In this report we have presented a few of the time series of monitoring results that we have obtained from the CEMP program. With only 19 years of data for many of our indicators, our conclusions to date must be tentative, but we have a firm foundation for coordinating these regional data sets. The boreal forest ecosystem is a boom-bust ecosystem with all the major components showing strong fluctuations in abundance. Determining the associations between these fluctuating components of the ecosystem is underway, and in the same way that we have needed a long time-series of weather data to recognize climate change, achieving an understanding of this northern ecosystem will require long-term ecological data.

In the short term we need to answer three questions:

1. How can we get a better index of changes in predator populations in a time when snowfall and winter conditions have become so variable? Can we utilize remote camera trapping (Abolaffio et al. 2019, Becker et al. 2022, Tabak et al. 2019) as one way of spreading our sampling and overcoming weather changes?
2. How much correlation is there between the Kluane Lake sites and other sites in the southern Yukon at Mayo, Faro, Watson Lake, and Whitehorse? Are all these independent for many species?
3. How much correlation is there in patterns of abundance of species between climatic measurements and biological measurements? For example, can we develop a predictive equation for plant production from temperature and rainfall data that will apply across all CEMP sites?

The database management system for CEMP is well set up, and we have developed a good group of workers with skills to make the needed measurements. With the data we have gathered and will continue to gather, we can provide a detailed assessment of how climate change is affecting biodiversity in the boreal forest of the Yukon. In collaboration with local knowledge a broad picture of how the Yukon environment is changing and is emerging from these efforts.

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Squirrel Project and the Green Team to produce the data tallied here, with special mention this year to Anneke Aasman, Katarina Anderson, Seth Bennett, Alyssa Bergeron, Rayden Blake, Shailyn Drukis, Zach Fogel, Cooper Fraser, Finnegan Gallant, Toshibaa Govindaraj, Presley Jobin, Cedy Krueger, Carson Lopatka, Robin Mennel, Hannah Miller, Heather Milligan, Avery Murray, Patrick O'Sullivan, Emilienne Roberts, Finn Roberts, Han Shier, Kendal Singleton, Anna Smith, Micah Taggart-Cox, Carson Lopatka, Kaitlyn Courchesne, Francis Quinby, and Anna Tolgyesi.For comments, additions or corrections on this report please contact Charles Krebs by email *krebs@zoology.ubc.ca*

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Table 1. Testing the predictions (red) made in autumn 2022 for year 2023 for monitored species at all CEMP sites and actual (blue) measured values. Range in the comments refers to empirically measured range over all the years of measurement. Cells highlighted in yellow indicate poor predictions for the past year of 2023.

Species / Group	Kluane	Faro	Mayo	Watson Lake	Whitehorse	Comments made in Fall 2022
White spruce cone crop[1]	**378** **7**	**778** **0**	**906** **18**	**721** **0**	**778** **1**	Moderate to large crops in all sites. Historical range has been 0 to 2000 cones per tree
Above-ground mushrooms	**22** **3**	**23** **0**	**72** **0**	**24** **0**	**15** **4**	Grams wet weight per 10 m^2. Few to moderate mushrooms on all sites for 2023. Range has been 1 to 280 g/10m^2
Soapberries	**18** **25**		**11** **5**	-	**106** **8**	Small crops at Kluane Mayo, and Whitehorse. Berries per 10 mm stem. Range has been 0 to 141
Small mammals	decline high	decline ~ 2/ha	low low	decline ~ 1-2/ha	decline high	Red-backed voles moving into decline phase of 4 year cycle
Red squirrels	low **high**	low	low	low	low	Predation from hare predators, low cone crops
Snowshoe hares	low **increase**	low	low **increase**	low[4]	low **low**	Increase phase at all sites except Whitehorse from the low phase of 10 year cycle
Lynx and avian predators	**low** **increase**	**low**	**low** **low**	**low**	**low** **increase**	All predators should continue to decline in 2022 and breeding will cease or be unproductive
Coyotes	**possibly increasing** **increasing**	**few**	**few** **low**	**few**	**few** **low**	Coyotes increasing after lynx decline and mice increase in 2021

[1] White spruce cone crops are predicted solely from weather data in the previous two years. The single exception is that cone crops are always near zero in the year following a large masting event. This explains the poor predictions in this table since 2022 produced a major cone crop.

Table 2. Predictions (red) made in autumn 2023 for summer 2024 for monitored species at all CEMP sites. Range in the comments refers to empirically measured range observed over the last 30 years of measurement.

Species / Group	Kluane	Faro	Mayo	Watson Lake	Whitehorse	Pre-season Comments
White spruce cone crop	**314**[2]	**234**	**975**	**3**	**619**	Moderate to high crop in all sites except Watson Lake. Historical range has been 0 to 2000 cones per tree
Above-ground mushrooms[3] - (model 12)	Depends on June and July rainfall of 2024 **19**	Depends on June and July rainfall of 2024 **34**	Depends on June and July rainfall of 2024 **55**	Depends on June and July rainfall of 2024 **46**	Depends on June and July rainfall of 2024 **24**	Grams per 10 m^2. Moderate mushrooms on all sites for 2024. Range has been 1 to 280 g/10m^2
Soapberries	**17**	-	**2**	-	**13**	Low crop at all sites. Berries per 10 mm stem. Range has been 0 to 141 (Model 7 estimates)
Small mammals (*Clethrionomys*	decline to low	decline to low	decline to low	decline to low	decline to low	Red-backed voles only; Other species unknown.
Snowshoe hares	increase	increase	increase	increase	increase	Continuing upswing of ten-year cycle from low phase
Lynx and other predators	increase	increase	increase	begin increase	begin increase	All predators should begin to increase from low numbers and breeding should begin again

[2] The predictions given here in red are based on a model using the July temperatures of the previous years.

[3] Predictions from the best mushroom model (model 12) is from (June+July) rainfall of the current year but these values are unknown the year before for prediction, so the best guess of 2024 mushroom production is based on average June+July rain for each area (Kluane 68mm, Mayo 116 mm, Whitehorse 77 mm, Faro 92 mm, and Watson Lake 106 mm).