

SEMI-ARID REGIONS OF THE BOREAL ZONE AS DEMONSTRATED
IN THE YUKON BASIN*

With 7 figures, 6 photos and 3 tables

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Zusammenfassung: Trockengebiete in der borealen Zone am Beispiel des Yukonbeckens

Der Vergleich von Niederschlag und potentieller Evapotranspiration (kalkuliert mit der PENMAN-Formel und durch einige Messungen verifiziert) zeigt eine semi-aride bis aride Periode meist von April bis August im Innern von Alaska und vom kanadischen Yukon-Territorium. Dieses Wasserdefizit fällt normalerweise in der Waldvegetation nicht auf, weil die Bäume sich durch extrem niedrige Zuwachsraten angepaßt haben. Aber wenn die sensibelste Jahreszeit von April bis Juni vollariid ist, dann dünnt der Wald auf gut drainierenden Stellen aus (wo das Schmelzwasser abrinnt, bevor es eindringen kann), und auf sonnen-exponierten Hängen verdeutlichen lockere Espenhaine und Wald- bis Zwergstrauchsteppen die zunehmend ariden Bedingungen. Eine Aufbesserung durch Schmelzwasser ist dort unerheblich, denn die Schneedecke bekommt Lücken durch Wind oder im Spätwinter infolge höherer mikroklimatischer Temperaturen und Verdunstungswerte als bisher angenommen, und der Rest fließt ab. Weiße Dickhornschafe und bis Faro die südlichere Varietät Schwarze Dickhornschafe benötigen diese Hänge zum Überleben in der Winterzeit.

Landwirtschaftliche Projekte, die von der relativ hohen Sommertemperatur angelockt wurden, waren teilweise Mißerfolge durch Trockenheit. Die Farmer müssen möglichst bewässern.

Semiaride Regionen in der borealen Waldzone sind typisch für deren inneren Teil (wo antizyklonale Kaltluft im Winter dominiert und die feuchte zyklonale Luft im Sommer sich vorher aberegnet hat). Diese intrazonalen Regionen werden infolge azonaler abschirmender Gebirge etwas verlagert: in Nordamerika westwärts und in Sibirien ostwärts.

Summary: The comparison of precipitation and potential evapotranspiration (calculated by the PENMAN formula and verified by several measurements) shows a semi-arid to arid period in the interior of Alaska and the Canadian Yukon Territory mostly from April to August.

This water deficit is normally not evident in the forest vegetation because of the trees' compensation by an extremely slow growth rate. If the most critical season from April to June, however, is very arid, then forest thins out on free draining sites (where the snow-melt water runs off before it can infiltrate the still frozen soil). On south-facing slopes aspen parklands, prairies and sagebrush manifest the increasingly arid conditions. Melt water is irrelevant there because the snow-cover becomes discontinuous through the effects of wind and in late winter of the sun, which causes higher microclimatic temperatures and evaporation than anticipated. The remaining water is lost by runoff. Dall sheep and – up to Faro – the southern variety of stone sheep depend on these slopes for survival during winter.

Agricultural projects attracted by the relatively high summer temperature failed partially due to water stress. The farmers need to irrigate.

Semi-arid regions in the boreal zone are typical of its inner portion (where the anticyclonic air dominates in winter and cyclonic moist air is kept off in summer). These intrazonal regions are slightly shifted by azonal mountain ranges: in North America westward and in Siberia eastward.

1 Introduction

In his classification of climates CARL TROLL already determined a zone of "highly continental boreal climate", characterized by dry coniferous forests, (TROLL u. PAFFEN 1964, II 3), assuming the dry winter season to be the main reason. But a different amount of winter precipitation does not cause significant differences in vegetation. The water deficit is most critical during the early growing season until July. In northeast Siberia the total mean precipitation from November to March is

only 30–40 mm as a result of the stable cold air anti-cyclone. In the Yukon Basin more precipitation falls in winter due to increased cyclonic activity, 70–90 mm (Fig. 1). But even this amount of melt-water can only in flat, poorly drained areas partly cover the monthly deficit between precipitation and evaporation during spring and summer. On slopes most of the water is lost before it can infiltrate the ground, which is still frozen during snow-melt. In summer, when the monthly average of rainfall reaches about 50 mm, the potential evapotranspiration is more than twice as high (Fig. 1). Exposed trees die in years with low rainfall. In northeast Siberia and in the Yukon Basin, conditions are locally too dry for forest.

* Dedicated to CARL TROLL on the occasion of his 100th birthday.

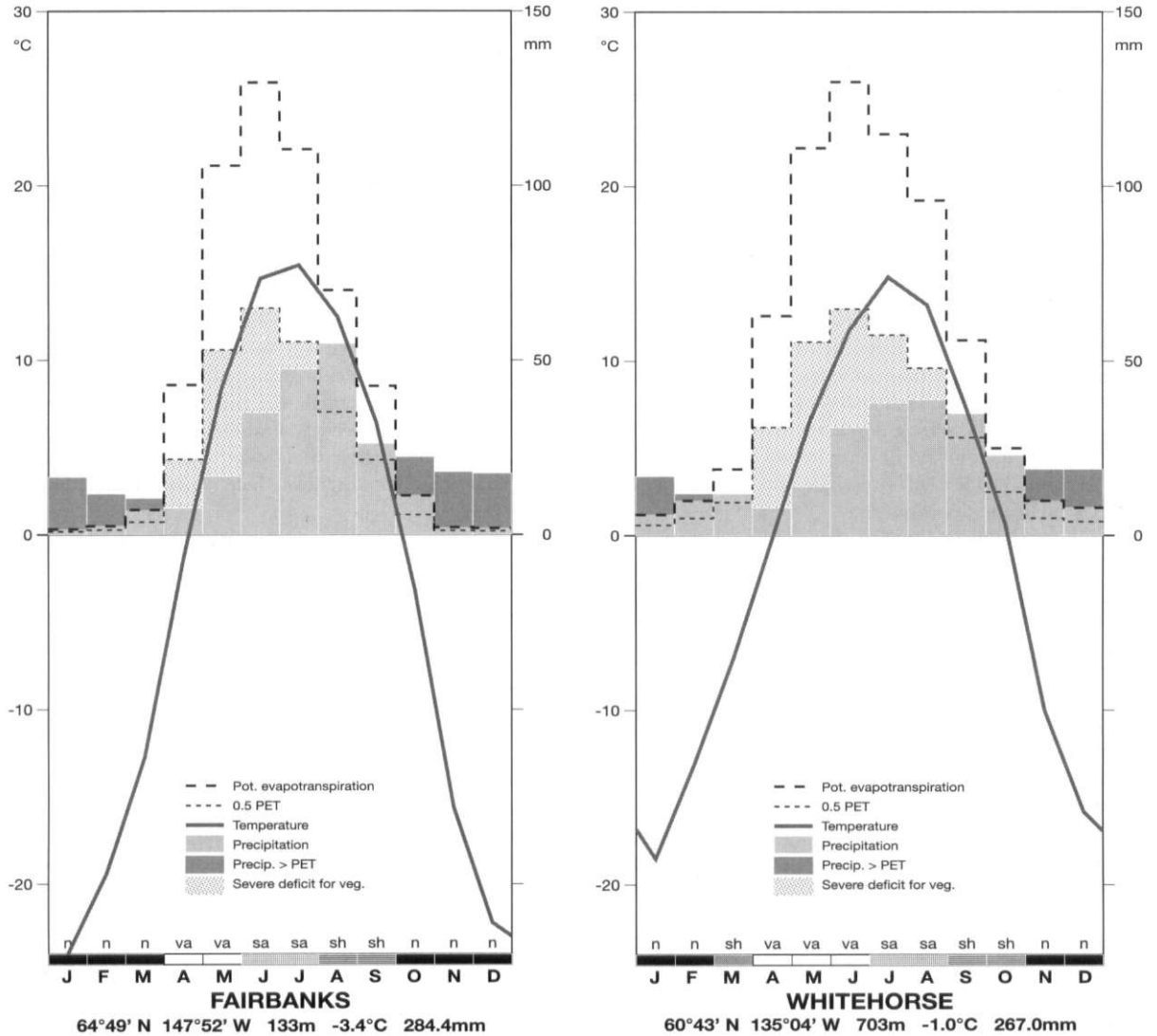


Fig. 1: Climate diagrams in Central Alaska and the upper Yukon Basin

The potential evapotranspiration (PET) was calculated by the PENMAN formula (1956). In months with snow (albedo 0.8) it is only evaporation resp. sublimation. For mesic vegetation, water deficits down to 50% of the PET mean still bearable semi-humid conditions = sh; if the precipitation is between 50% to 25% of the PET, the conditions are semi-arid = sa, the deficit becomes severe; if the precipitation drops below 25% of the PET the conditions are very arid = va, the deficit becomes very severe. In winter snowy months are nival = n; if snow cover diminishes by evaporation seminival = sn

Design: R. JÄTZOLD and R. KELLER

Klimadiagramme im zentralen Alaska und oberen Yukonbecken

Die potentielle Evapotranspiration (PET) wurde mit der Formel von PENMAN (1956) und den Breitenkreis-Korrekturwerten von McCULLOCH (1965) berechnet. Für die normale Vegetation herrschen allerdings bei Wasserdefizit zunächst noch ertragbare semihumide Verhältnisse und erst semiaride, wenn der Niederschlag unter die Hälfte der PET sinkt, und sehr bzw. vollaride, wenn er weniger als ein Viertel beträgt. Schneemonate sind nival. Albedo Mai–Sept. 0,2 (grüne Veg.), Okt.–April 0,8 (Schnee). sh = semihumid, sn = seminival, n = nival, sa = semiarid, va = very arid. In Fairbanks gibt es weniger Trockenhänge, denn im Hochsommer mildern Gewitter die Trockenheit dort mehr als im abgeschirmteren Whitehorse

Therefore, the boreal zone is not only covered by forest but shows regional variations with semi-arid steppe mosaic. This fact should be added to the next edition of the monograph about the boreal zone by U. TRETER (1987, 30) where humid conditions over the whole year are still designated as a general characteristic. Even the ecosystem analyst J. SCHULTZ (1995, 157) considers semi-arid conditions in the boreal zone only to occur temporarily and supposes that they do not show any effects.

The semi-arid regions in the Yukon Basin are not local northern extensions of the summer-dry steppe zone (stretching through the intramontane semi-arid areas of British Columbia), but show their own characteristics with a maximum rainfall in high summer mainly caused by thunderstorms.

Initial calculations of the arid and humid seasons in North America (JÄTZOLD 1961) already resulted in considerable semi-arid areas in the Yukon and Tanana Basin but these were not reflected in any vegetation map, although Fairbanks shows five and Carcross in the Yukon Territory even seven arid months. Research studies by the author in Alaska and the Yukon Territory and discussions with colleagues at the University of Alaska, Fairbanks as well as of the Department of Renewable Resources in Whitehorse in 1997 and 1998 brought an explanation: the forest has adapted to the low precipitation (and the short vegetation period) through extremely slow growth. It is a "boreal dry forest". Aspen parklands and forest steppe develop in the driest basins of the Yukon Territory where the water-supply is not sufficient even for dry coniferous forest while dry steppe can be found on south-facing slopes. The areas are too small to appear on generalized vegetation maps, although they are very impressive in the landscape.

2 Determination of aridity

Forty years ago, the determination of aridity was carried out (JÄTZOLD 1961) with an aridity index which, however, was not yet sufficiently supported by data as only very few measurements of evaporation (in the boreal zone) were available. Therefore, new calculations of the potential evaporation or evapotranspiration respectively were carried out by the author and his assistant RENATE KELLER by the formula of PENMAN (1956) which is generally accepted today, especially when using the correction figures with respect to different latitudes by MCCULLOCH (1965). PENMAN calculations had not been done yet in Alaska or in the Yukon Territory, except for one local exception (NAKAO 1981,

see below). On the one hand, radiation measurements were missing and, on the other hand, as meteorologists focussed on the main problem of cold, there was hardly any interest in finding out if dryness may also be a limiting factor for the growth of vegetation.

There are still only few measurements for local verification of evaporation calculations but they confirm, as well as additional measurements by the author, that the evaporation figures calculated by this method are realistic. The measuring of evaporation in Class-A-Pans, which is common in American meteorological stations of the first order, is not carried out in Alaska, probably due to the problem of icing. Only on two research occasions short-time measurements were taken: in the 1970s within the study of Harding Lake, a lake without outlet 80 km southeast of Fairbanks, Class-A-Pan measurements of evaporation were carried out by JOHN FOX (1975) of the University of Alaska (cf. KANE et al. 1979). With that, the first approximate figures for the estimation of evaporation and therefore for the effectiveness of precipitation were presented for the interior of Alaska. These figures could be considered as representative of the drier part of the Tanana Basin because of the lake's location there, and due to the similar elevation and precipitation regime also of the middle Yukon Basin. NAKAO (1980 and 1981) tried to compensate for the lacking temporal representativity of these few measurements by calculating the potential evaporation using the PENMAN formula (1956), and the long-term climatological records of the neighbouring Eielson Air Force Base, substituting the missing radiation figures through an approximate calculation on the base of the hours of sunshine (the author also had to do that, except for the stations Fairbanks and Whitehorse). Reaching 621 mm from May until September, the figures are not significantly lower than those measured by FOX (674 mm).

VIERECK (1993, 904) reports measurements of evaporation in standard evaporation pans (Class A) during the warmer season 1987 until 1990 (May 20th to September 15th) from the Bonanza Creek forestry research station located 30 km southwest of Fairbanks in the fluvial plain of the Tanana River. Due to the relatively high atmospheric moisture of the location and more frequent days with rainfall in this area, the evaporation data are about one third lower than those of Harding Lake but close to those the author calculated for Fairbanks.

In the Yukon Territory evaporation was measured by Class-A-Pan from 1951 to 1980 by the Meteorological Office in Whitehorse and converted into lake evaporation data (Atm. Env. Service 1984). Due to the higher elevation of Whitehorse the figures are lower than

Table 1: Evaporation records and calculations in Central Alaska and in the upper Yukon Basin

Verdunstungsmessungen und -berechnungen in Zentral-Alaska und im oberen Yukonbecken					
	May	June	July	Aug.	Sept.
Pan-evaporation near Harding Lake 1975 (FOX in: KANE et al. 1979)	158	188	166	109	53 mm
Potential evaporation at nearby Eielson, calculated by the PENMAN formula (NAKAO 1981) 1944–73	110	172	173	111	54 mm
Lake evaporation near Whitehorse 1951–80, calculated from pan-evaporation records (Atmosph. Env. Service 1984, Tab. 2)	104	125	110	98	48 mm
Potential evapotranspiration in Whitehorse, calculated by the PENMAN formula (average)	111	130	115	96	56 mm

those of the Tanana Basin mentioned above, but they are similar to those we calculated (Tab. 1).

When comparing the evapotranspiration to the average precipitation, amazingly high deficits show up for the months May and June (Tab. 2). In Fairbanks in the Tanana Basin only 16% in May and 27% of the potential evapotranspiration in June are covered. The barrier effect of the coast ranges is of particular significance during this time as south-westerly winds are dominating then. The deficit in May cannot be balanced by snow-melt water (there is an average of 75 cm of snow = 100 mm of water in early April around Fairbanks), as hardly any water can infiltrate the deeply frozen soil and it runs off even in areas with little inclination. Only on flat ground does some of the melt water remain and may even cause waterlogging when the upper layer of the ground is thawing, as permafrost in the subsoil stops infiltration. According to estimates recorded at the Delta Agricultural Project near the Tanana River, an average of 30 mm of plant-available soil moisture in flat loessial soils is normal at the beginning of the growing season in May. On slopes, to cover some of the water deficit, the accumulated moisture of the previous September, before the ground freezes¹⁾, is the only soil water deposit in spring. But there is usually no surplus in this month which could be accumulated (see Tab. 2, where the loss by run-off is not even subtracted). Normally, no moisture is left from the summer months, as the water balance in July and August is negative too.

In the cold season the actual evaporation is often even higher than the calculated one. The general opinion that there is no evaporation when the average mean temperatures are below 0°C and that the PENMAN formula could not be used in this case, was disproved by the author's own measurements in the late

winter of 1998. The actual evaporation figures were even higher than the calculated ones, especially microclimatically on south-facing slopes, as radiation is very intense because of the dry and clear air, even when the position of the sun is low, and because there is more wind. Between the 18th and 30th of March 1998, 22 mm of evaporation were measured in the plain north of Whitehorse above soil which was kept moist, and 29 mm on a 35° slope in the same area, with a mean temperature of -1,3°C. The PENMAN calculations for this period amounted to 10 mm and 18 mm respectively.

For the months November until March the total mean evaporation of snow is about 25 mm, as becomes evident from the difference between the recorded precipitation in this cold period and the water content of the accumulated snow cover on the 1st of April. This is in accordance with the scale of the author's calculations of evaporation. All in all, aridity is probably even stronger than the map (Fig. 2) and the diagrams (Figs. 1 and 3) show.

¹⁾ Measurements of soil moisture by the author on May 18th 1997 on a south-facing slope with loessial soil 190 km north of Fairbanks in a depth of 10 cm between sagebrush amounted to a moisture content of 2.5% of the weight resp. 5.5% of the field capacity, which already means a deficit of almost 95%. On a well-drained river terrace with silt and fine sand 50 km north of Fairbanks measurements on May 19th 1997 amounted to 12.2% moisture of the weight resp. 27% of the field capacity, which still means a deficit of 73%. It was about three weeks after snow-melt and it had rained only very little during that time. There was practically no accumulated soil moisture from September 1996 and precipitation was falling only as snow from October to early April. In poorly-drained plains waterlogging from snow-melt occurred.

Table 2: Water deficit regarding the potential evapotranspiration* during the vegetation period
Wasserdefizite gegenüber der potentiellen Evapotranspiration* in der Vegetationszeit

Region	May	June	July	Aug.	Sept.
Tanana Basin	Prec. 17 mm	35 mm	47 mm	55 mm	26 mm
Fairbanks, 133 m, 64°49'N, 147°52'W	-PET 106 mm	130 mm	110 mm	70 mm	43 mm
	Def. -89 mm = 84%	-95 mm = 73%	-63 mm = 57%	-15 mm = 21%	-17 mm = 40%
Central Yukon Basin	Prec. 20 mm	34 mm	55 mm	39 mm	31 mm
Carmacks, 525 m, 62°06'N, 136°18'W	-PET 113 mm	136 mm	119 mm	96 mm	54 mm
	Def. -93 mm = 82%	-102 mm = 75%	-64 mm = 54%	-57 mm = 59%	-23 mm = 43%
Upper Yukon Basin	Prec. 14 mm	31 mm	38 mm	39 mm	35 mm
Whitehorse, 703 m, 60°43'N, 135°04'W	-PET 111 mm	130 mm	115 mm	96 mm	56 mm
	Deficit -97 mm = 87%	-99 mm = 76%	-77 mm = 67%	-57 mm = 59%	-21 mm = 37%

* Calculation of the PET by the PENMAN formula with the correction for high latitudes by MCCULLOCH (1965)

3 Relations to the temperature

Temperature conditions in the semi-arid boreal regions are extremely continental. The low cloudiness hardly impedes irradiation and radiation. There is also the fact that the high number of daily sunshine hours (in summer) often creates temperatures of more than 30°C, with 36°C being the maximum. In winter, when cold air accumulates in the basins, temperatures can drop below -63°C.

The contrast between day and night is only strong in early spring and early autumn when the hours of daily irradiation and nocturnal radiation do not differ significantly. But until the beginning of June, frost can occur during the night after a clear day with temperatures reaching above 20°C.

On the south-facing slopes the temperature on the soil surface is amazingly high in summer and even in spring and autumn. The author measured up to 30°C around March 20th and 42°C in the middle of September on the soil surface north of Whitehorse.

The warm (foehn-like) Chinook occurs as a strong katabatic wind mainly in the southern Yukon Basin. Cold waves from the northwest have an effect mainly in Alaska. However, the showers they cause are mostly light, as the air masses are not very humid.

4 Zoning of semi-arid regions

Four intramontane semi-arid regions can be distinguished in interior Alaska and the Yukon Territory (Fig. 2):

- the small-sized Matanuska Valley-Copper River Basin in the lee of the coast ranges;
- the Tanana River Basin in the lee of the Alaska Range;
- the Upper Yukon River Basin in the lee of the St. Elias Mountains;
- the Central Yukon River Basin in the lee of the Tanana Yukon Uplands.

Another semi-arid region is the northern slope of the Brooks Range and the arctic coastal plain where the climatic dryness is hard to distinguish because of edaphic moisture. This subpolar to polar region is not treated within the framework of this paper, which focusses on the boreal zone.

The most pronounced semi-arid conditions are found in the Yukon Basin, resulting from its screening. They can hardly be distinguished in the Alaskan portion, as the Yukon River is creating large swamps in a tectonic syncline there, the Yukon Flats. Towards the edge of the basin, especially on the lee side of the Tanana Yukon Uplands, the semi-arid climatic situation is clearly noticeable. It is intensified by local climate and edaphic conditions. On the Canadian side open dry forests and forest steppe islands cover some plains as, for example, 130-140 km south of Dawson City on pleistocene gravel or about 100-120 km north of Whitehorse on till-plains, as well as from 50 km west of Whitehorse with interruptions to Aishihik (Photo 1).

Larger south-facing mountain slopes in the Yukon Basin show the entire sequence from forest to dry steppe, in places even to semi-desert (Photos 2-5). In higher elevation a transition to tundra-steppe takes place, as EDWARDS a. ARMBRUSTER (1989) documented

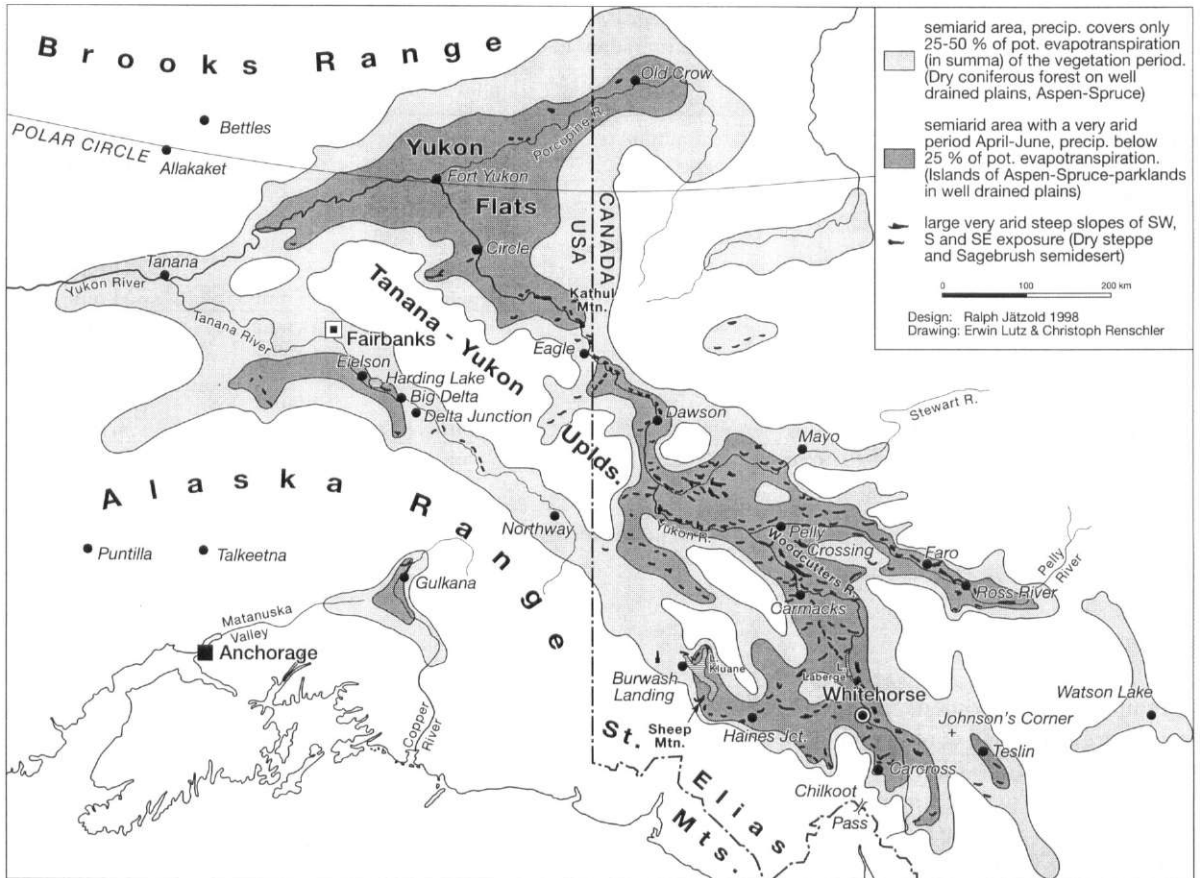


Fig. 2: Semi-arid regions and dry slopes in Central Alaska and in the Yukon Territory
Semi-aride Gebiete und Trockenhänge im zentralen Alaska und im Yukon-Territorium

at Kathul Mountain. The large dry slopes start south of Carcross, just 40 km north of Chilkoot Pass, and reach a climax in the landscape about 30 km north of Carmacks at the Yukon bend downstream of the Five Finger Rapids in the Wood Cutters Range and the Tatchun Hills (Photos 3–5). Also some west- and east-facing slopes in this area are free of forest. Pleistocene gravel banks of up to 300 ft., a layer of volcanic ash, local volcanic rock and limestone favour the aridity phenomena. The climate figures at first sight do not appear to support that: Carmacks receives an annual average of 277 mm of precipitation (1961–90), which is not much less than Fairbanks. However, all months of the growing period are at least semi-arid, and the critical beginning of the growing period from April to the end of June is even very arid (Figs. 1 and 3). The percentages of the water deficit on a south-facing slope are of similar scale as those in a semi-desert plain in Mexico (Tab. 3).

5 Meso- and microclimatic and pedologic exceptional features

On south-facing slopes the water balance is more unfavourable due to the steep incidence angle of sun rays, but also because slope winds increase and measured precipitation (in $\text{mm} = 1/\text{m}^2$) is spread over a larger area, which accounts for even 22% on a 35° slope (Tab. 3 and Fig. 3). On the slopes the very arid spring months are not mitigated by an accumulation of soil moisture, as the melt-water runs off or evaporates before it can infiltrate the still deeply frozen soil.

The influence of exposition is most significant in the south of the study area as the incidence angle of sun rays is almost rectangular between April and September on the south-facing slopes. This is why the semi-arid landscape around Carcross is particularly impressive (even badlands can be found there). Further northward where the sun takes a lower position above the horizon and the midnight sun shines in summer, the

Table 3: Comparison of the percentual water deficits at a south-facing slope in the Yukon Basin and in a semi-desert in the Southwest of North-America

Vergleich der prozentualen Wasserdefizite an einem Sonnenhang im Yukonbecken mit einer Halbwüstenstation im Südwesten Nordamerikas

	April	May	June	July	Aug.	Sept.
South facing slope near the Yukon north of Carmacks, 35°angle*	Prec. 5 mm -PET 63 mm	16 mm 150 mm	28 mm 177 mm	45 mm 158 mm	32 mm 130 mm	25 mm 73 mm
525 m, 62°06'N, 136°18'W	Def. -58 mm = 92%	-134 mm = 89%	-149 mm = 84%	-113 mm = 72%	-98 mm = 75%	-48 mm = 66%
Semidesert plain near Ciudad Lerdo, Mexico, 1140 m, 25°32'N, 103°32'W	Prec. 4 mm -PET 171 mm	16 mm 210 mm	27 mm 214 mm	40 mm 195 mm	42 mm 174 mm	57 mm 145 mm
	Def. -167 mm = 98%	-194 mm = 92%	-187 mm = 87%	-155 mm = 77%	-132 mm = 76%	-88 mm = 61%

* As the area on which precipitation falls increases by 22% on a 35° slope, the amount per m² decreases by 18% while the evaporation increases by up to 30% due to the more vertical irradiation and slope winds.

contrast between different expositions decreases. This is already clearly visible north of Dawson City in the Ogilvie Mountains, and in the Brooks Range.

In addition, the influence of wind has to be considered. If a slope becomes bare, which is mostly caused by natural forest fire, the snow is blown away by the wind. Therefore, only a small amount of moisture is gained from snow-melt, and the slope becomes even more barren.

As the water balance of the snow-free season is negative, the soil is not deeply moistened in the fall. Therefore, permafrost ice cannot develop on slopes in these semi-arid areas but only in the plains where the water is poorly drained. If semi-arid conditions occur up to late summer and if forest fires destroy the isolating layer of vegetation and, through the dark ash cause an increase in the amount of absorbed irradiation, the permafrost thaws in places deeply and the surface collapses (thermokarst). The well known thaw lakes develop.

Such thaw lakes are particularly numerous in semi-arid subpolar areas, e.g. in the Porcupine and Yukon Flats, as forest fires occur more frequently there than in humid areas, and due to the negative water balance the lakes do not overflow, and they therefore have no erosive outlets. This also applies to the northern tundra plain, which is characterized by an abundance of thaw lakes in the semi-arid region of North Alaska. If the plains are located in areas covered by (volcanic) sediments rich in minerals, these lakes can become salt pans, as it is the case 50 km west of Whitehorse, an astonishing phenomenon in the boreal coniferous forest zone.

²⁾ In recent forestry maps of northern British Columbia the term "northern dry forest" is already used.

6 About the vegetation of semi-arid boreal regions

6.1 Boreal dry forest

In areas of lower semi-aridity (Fig. 2), this climatic condition is not very evident in the vegetation because they are mostly covered by forests, as around Fairbanks. Therefore it is necessary to examine the effects of this semi-arid climate more closely. During the 12,000 years since the end of the last Ice Age, the dominant tree species, white spruce (*Picea glauca*), has succeeded in adapting to the water deficiency by extremely slow growth, forming a boreal dry forest²⁾. In this way, a "hidden semi-aridity" developed. On the semi-open plains mentioned in the introduction, these spruce trees can even be mixed in with aspen parklands which are more typical of the semi-arid climatic conditions. Coniferous trees are not as threatened by drying-up as deciduous trees. Twelve year old spruce trees there only reach a height of 0.5 m. The average growth rate over the first 25 years is not more than 5 cm per year. This is only partly caused by the short growing season, because in places where additional water is available, growth rates are up to ten times higher. In semi-arid boreal regions it takes spruce trees 200 years to reach full maturity which in humid temperate regions is reached already in 60 years. The stems in old dry forest are thin (only around 10 cm in diameter), the wood is very hard. At the humid coast of Alaska (although characterized by lower amount of irradiation and lower temperatures in summer) the average growth rates of white spruce over the first 25 years are about 30 cm per year, and when 60 years old, the trees are much taller than spruce trees in Central Europe. The second dominant species, black spruce (*Picea mariana*), does not show the effects of the water balance as clearly, because these trees are

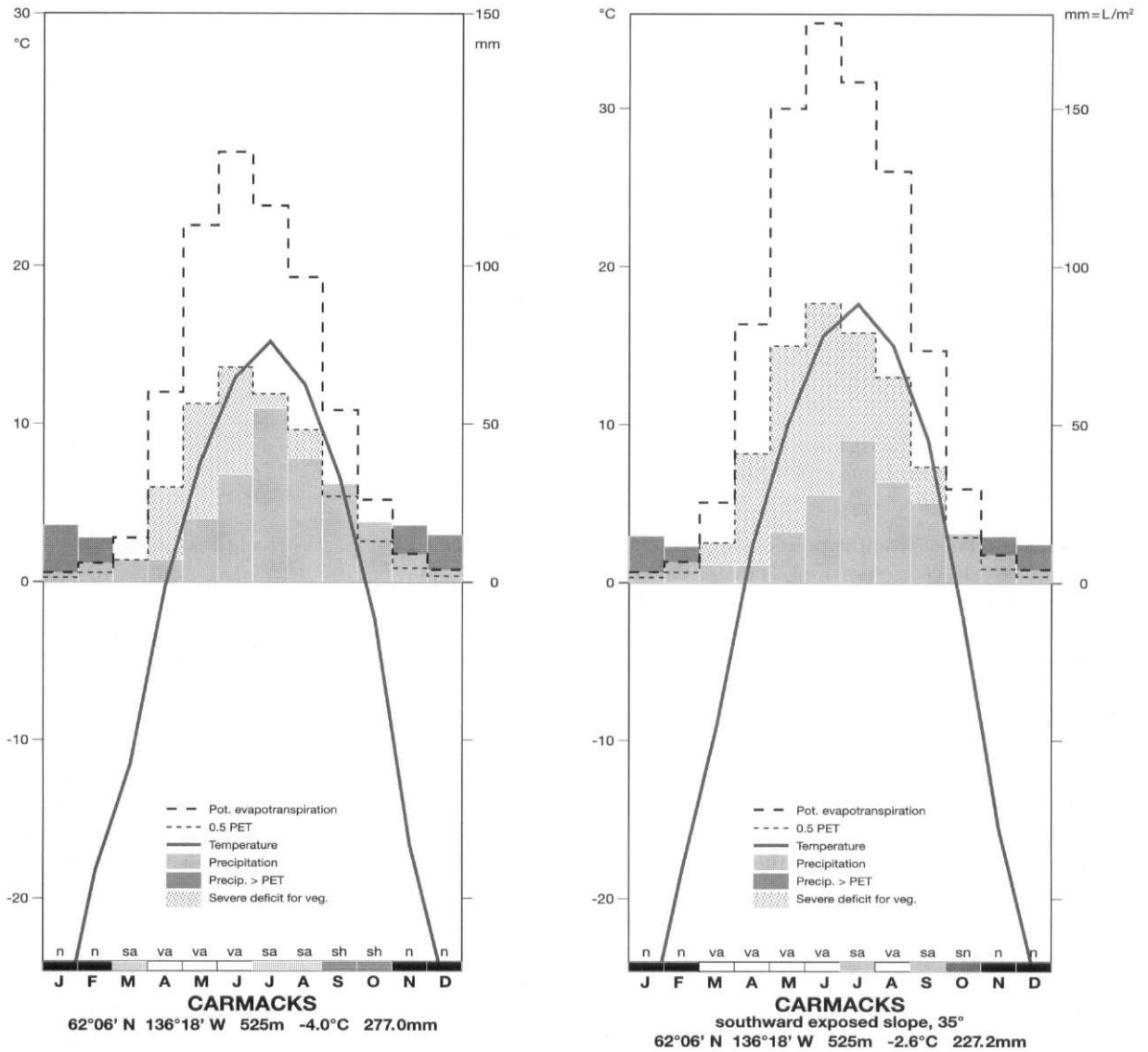


Fig. 3: Climate diagrams of Carmacks/Yukon and an estimated one of a south-facing slope there

The amount of rainfall there is 18% less, if it is counted in liters per m^2 because the 35° steep square is 22% larger. The water deficits are enormous, the sagebrush is a climax vegetation

Klimadiagramme von Carmacks am Yukon und eines dortigen südexponierten, 35° steilen Hanges (berechnet)

Dort sind die Niederschläge um 18% geringer, wenn sie als Liter pro m^2 angegeben werden, weil die schräge Fläche um 22% größer ist. Die Wasserdefizite sind enorm, die Zwerstrauchsteppenvegetation ist klimabedingt

mainly found on poorly drained, wet soils above permafrost. Due to waterlogging it forms such open stands that the formation can be confused with forest steppe in an aerial photograph (e.g. south of Fairbanks).

The adaptation of coniferous trees to dryness can also be seen from the annual rings. The stem growth of white spruce near Fairbanks is more than 1 mm in

radius on moister habitat near the river, on drier habitat just 0.3 mm. The rings in dry years as 1956/57 are even more narrow. The density of the trees on a stand plays an important role in the "struggle for water". In the Forestry Institute of the University of Alaska, Fairbanks, a slice of the stem of a white spruce, which was felled west of Fairbanks in 1977, is displayed. This tree



Photo 1: Forest-steppe and dry slope south of Aishihik, about 140 km west of Whitehorse. The forest-steppe is a climax formation because old conifers dominate (Photo: 20. 3. 1998)

Waldsteppe und Trockenhang südlich Aishihik, ca. 140 km westlich von Whitehorse. Es ist eine Klimaxformation, weil alte Nadelbäume vorherrschen

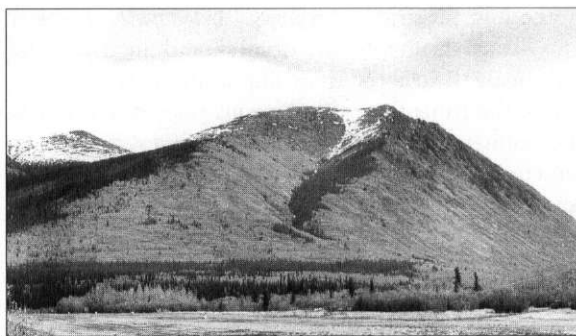


Photo 2: Asymmetric vegetation: treeless southern, forested northern slope, here at Caribou Mountain near Carcross (Photo: 29. 5. 1997)

Asymmetrie der Vegetation mit waldfreiem Südhang und bewaldetem Nordhang, hier am Caribou Mountain bei Carcross

had only reached 11 cm in diameter over 157 years (1760–1917). The surrounding trees were felled then so that it was freed from its water-competitors (in the struggle for light it had already outgrown them), and the tree gained another 63 cm over the last 60 years since then (average distance of annual rings: 5 mm). Its speed of lateral growth was therefore 13 times as high after a better water-supply.

Black spruce, which do not only dominate on water-logged but on poor soils too, can also be well adapted: on dry habitat in dense stands, where water is not sufficient for all trees, their stems remain very thin so that even tall trees only form pole-wood (which economically is almost worthless). A special tenacity of the wood allows this stature. If wind or snow rip a gap into the stand, however, an ugly disorder of the thin, bent stems is caused if the mutual support is lacking.

6.2 Forest steppe

In some dry places forests are interspersed with gaps (Photo 1), or even grassland is found (named “dry fescue” by VIERECK et al. 1992, 161, with *Festuca altaica*, *F. rubra* and *Elymus innovatus*). Aspen (*Populus tremuloides*) become dominant if conditions are more semi-arid than in the boreal dry forest, forming aspen parklands as around the prairie zone of Canada. They should not be confused with the early stages of succession following forest fires, which are dominated by deciduous trees in the first 50 years, before coniferous trees, which grow more slowly but reach greater height, outgrow them. In this way, a coniferous forest can be found on semi-arid habitat, e.g. around Whitehorse. Due to the warmer,

continental summer, pine trees (lodgepole pine, *Pinus contorta* var. *latifolia*) also grow there after forest fires. In the old-growth dry coniferous forests hardly any ground cover exists, as it is too dry even for moss. These “senile” forests offer almost no food for large animals and therefore a natural forest fire is not a catastrophe but the birth of a new, diverse forest³⁾ which offers plenty of food. Every 100 to 200 years a forest burns down after lightning. This is most critical when the first thunderstorms of summer occur after the dry period in May and June, and lightning sets in before it starts raining. Such a typical thunderstorm moved over Central Alaska from July 1st to the morning of July 2nd 1990. 2812 flashes of lightning were counted by the meteorological service, of which some caused extensive forest fires as the particular one which threatened the community of Tok.

At the beginning of succession grass and balsam poplar (*Populus balsamifera*) come up, followed by paper birch (*Betula papyrifera*) and aspen (FOOTE 1983). After five years (in distinct semi-arid or in cool conditions after seven to eight years) succession enters a stage in which food is abundant (for animals) and which lasts for about half a century. This stage, dominated by aspen, can be distinguished from natural aspen parklands by the abundance of grass and the diversity of tree species.

³⁾ At the former site of a coniferous forest in the Takhini Basin about 50 km northwest of Whitehorse, which had survived as a relict from the moister and cooler climatic period before 1860, not even aspen parklands have come up 40 years after the big forest fire of 1958, due to the climate with very arid conditions in spring and early summer.

The ground of the semi-arid aspen stands is covered by the low, prostrate bearberry (*Arctostaphylos uva-ursi*). This dwarf shrub tolerates dryness, and the fruit is dry and mealy. Bearberry is an important food for bears, as also the fruits from the previous year which remain after snow-melt. The dryness also becomes apparent by "crocus pasquale" (*Pulsatilla patens*), the first blooming flower in April, which got its name (lat. pasqua = Easter) from Franco-Canadian voyagers. Botanically it is not a crocus but a *ranunculaceae*, of course, and the English name pasque flower is therefore more correct.

6.3 Xerophytic slope vegetation

The most conspicuous vegetation formations of the semi-arid regions there are the forest-free dry slopes mentioned before (Fig. 4 and Photos 1–6) in which many botanists (HULTÉN 1961 and later; YOUNG 1976; YURTSEV 1972 and 1984; MURRAY et al. 1983 and 1995; LAXTON et al. 1996) have taken an interest. In a profile from the coast, the first dry slopes occur on the leeward side of the Coast Range and in the Copper River Basin, in particular on the south-facing scarps of high glacial terraces. Further north in the Fairbanks area and around Eielson Air Force Base they disappear as aridity is mitigated there by frequent thunderstorms in summer with moisture coming in from the Bering Sea. Only from May until the middle of June does it fall below the the critical threshold value of a deficit of 75%, which means very strong aridity, but a bit more than one very arid month can be tolerated by the trees, especially by the aspen. Further northeast, in the Yukon Basin, the forest-free slopes dominate the landscape (Fig. 2–3 and Photos 3–5).

The tenacious, undemanding dwarf shrub of the genus *Artemisia*, the sagebrush, is dominant on the dry slopes there. Sagebrush is the well known characteristic vegetation of the dwarf shrub-desert steppe and semi-desert of western North America. Comparing the percentages of water deficit, some slopes indeed show semi-desert climate (see Tab. 3). Two species are of special significance – the taller, endemic Alaska sagebrush (*Artemisia alaskana*) and the smaller, more herbaceous Fringed sagebrush or Prairie sagewort (*A. frigida*, Photo 6) which is found from east Siberia to Texas (VIERECK a. LITTLE 1994, 252). According to HULTÉN (1968) 20 species of the genus *Artemisia* are found there (map also in CODY 1966). Some that are even typical of Arizona as *Artemisia michauxiqua* and *A. ludoviciana* (HULTÉN 1968) occur in the Carcross area (where the south-facing slopes microclimatically show a semi-desert water deficiency, Photo 2). As the cover of sagebrush is sparse and more than 50% of the ground is bare on



Photo 3: Slope with dry steppe and forest patches at the Tatchun Hills northeast of Carmacks/Yukon. The forest is confined to favourable spots, but there it is a boreal dry forest with extremely low growth rates, recognizable by the very short distances of the annual twig sets (Photo: 15. 9. 1997)

Trockensteppenhang mit Waldinseln in den Tatchun Hills nordöstlich von Carmacks/Yukon. Der Wald ist auf Gunststellen beschränkt, aber dort ist er ein borealer Trockenwald mit extrem geringen Zuwachsraten, wie an den sehr kurzen Abständen der Jahreswirtel erkennbar ist

some sun-facing slopes in the Yukon Basin, semi-desert spots can be defined there. Usually they are found in a formation which reminds of desert steppe, in these northern latitudes of course not in the plains but on heated slopes (Photos 4–6). In areas with an annual precipitation of less than 270 mm, sagebrush covers not only south-facing but also west- or east-facing slopes, as, for example, around the Five Finger Rapids of the Yukon River. The smell of sage on hot summer days is one of the pleasant sensory impressions in these semi-arid areas. In spring the sagebrush vegetation is coloured by many blooms, as those of the yellow Arnica (*Arnica frigida*), the light blue Jacobs ladder (*Polemonium pulcherrimum*) or, towards the north, the purple lousewort (*Pedicularis verticillata*) and others. In the Yukon Basin there are also very rare, endemic species (see DOUGLAS et al. 1981), such as *Cryptantha shaklettiana* which was first collected by SHACKLETTE (1968) near Eagle but not yet distinguished as a separate species, and which was later discovered in another place by BATTEN a. PARKER (1996). Its closest relatives are found in the dry areas of Idaho and Montana.

The sagebrush is surrounded by associations of the dry bunch grass steppe. In dry spring-time, the long roots of bunch grass reach the eventually accumulated moisture from thunderstorms of the previous summer. In Alaska, fescue (*Festuca ovina* ssp. *alaskana*, as well as the Siberian species *Festuca altaica*, HANSON 1951) is dominant in western cooler regions and eastward in higher



Photo 4: In late winter the south exposed slopes of Woodcutters Range and the terraces of the Yukon are free of snow and dried up, while there are still 50 cm of snow in the plain and the river is still frozen (Photo: 28.3.1998, northwestern continuation of Photo 5)

Im Spätwinter bereits schneefreie und abgetrocknete Süd- hänge der Woodcutters Range und der Terrassen am Yukon, während in der Ebene noch 50 cm Schnee liegen und der Fluß noch gefroren ist (Aufnahme: 28.3.1998, nord- westliche Fortsetzung von Photo 5)

elevations. In the eastern part of Alaska *Bromus pumpel- lianus* (VIERECK et al. 1992, 33 and 144) is found, in the Canadian Yukon Basin bentgrass (*Agrostis scabra*, OSWALD and SENYK 1977, 99), blue-joint grass (*Calamagrostis purpurascens*), an endemic wheat grass species (*Agropyron yukonense*) and various sedges (in particular *Carex filifolia*, HOEFS 1984, 143). Only the knee-high prickly rose (*Rosa acicularis*) or a prostrate juniper variety (*Juniperus communis* var. *depressa* Pursh) are found in asso- ciation with the dry bunch grass steppe at the edge of the formation (Photo 6, more species in ZOLADESKI et al. 1996).

In less exposed areas of the slope, aspen parklands form a frame around the dry bunch grass steppe, comparable to the forest-steppe, consisting of aspen (*Populus tremuloides*), pasque flower (*Pulsatilla patens*) and a carpet of bearberry (*Arctostaphylos uva-ursi*) mentioned above. On slopes which have not been affected by forest fire for a long time, some slow-growing coniferous trees, especially white spruce (*Picea glauca*), can be found on favourable spots and characterize these small forest steppe areas too (Photo 3). Grass is not able to with- stand the competition of trees in the long run there, as the monthly distribution of precipitation is not favourable for grass species. In order to do so, May and June would have to be the most humid months so that exuberantly growing grass suppresses tree seedlings. Grass can only spread during the first years after forest fires before it is outgrown in the shadow of taller-

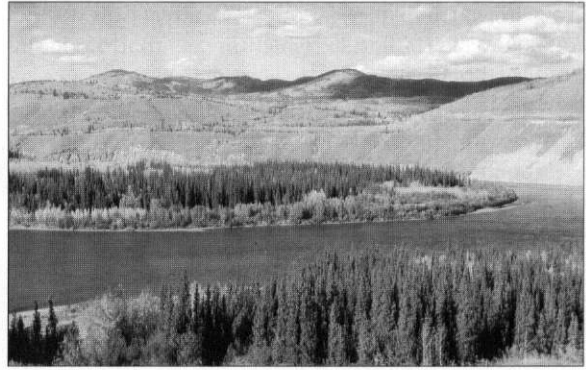


Photo 5: Sagebrush desert-steppe at Woodcutters Range and glacial terraces of the Yukon below the Five Finger Rapids (Photo: 18.9.1997, eastern continuation of Photo 4)

Sagebrush-Wüstensteppenvegetation an Woodcutters Range und glazialen Terrassen des Yukon unterhalb der Five Finger Rapids, östliche Fortsetzung von Photo 4

growing trees and by their water consumption. There- fore only very few and small places of real forest steppe exist.

During the Ice Ages the unglaciated semi-arid areas in the interior of Alaska and the eastern Yukon Basin were characterized by tundra steppe, which was connected over the almost 1500 km-wide Bering land bridge with east Siberia, as floristic relations prove (YURTSEV 1972 and 1984). There are critical voices concerning the steppe idea because of pollen analysis showing much willow pollen (*Salix* spp.) (CWYNAR a. RITCHIE 1980) but their samples were taken on moister spots.

In the currently forest-free semi-arid areas (as well as in the semi-arid transition zone to the northern tundra) relicts of this tundra steppe can still be found. YOUNG (1976 a, 124–146) floristically analysed this “arctic steppe biome”, which was assumed before to exist by YURTSEV (1972) and others, and pointed out the positive result (YOUNG 1976 b).

The relict situation is also manifested by the occur- rence of the same steppe species east and west of Bering Strait, as for example, the Prairie sagewort (*Artemisia frigida*) (VIERECK a. LITTLE 1992, 252). EDWARDS a. ARMBRUSTER (1989) studied the vegetation at Kathul Mountain (see Fig. 2) in the central Yukon Basin. Steppe taxa such as *Agropyron spicatum* grow in elevations of up to 900 m on the south-, southwest- and southeast-facing slopes before a transition to dry tundra takes place. During the last Ice Age steppe was found there up to 350 m, tundra up to 550 m (op. cit., 303).

The depression of average temperatures was not so strong that no more trees would have been able to

grow in warm places (about 4°C after EDWARDS a. ARMBRUSTER 1989, 296, which means that the basins would still have had an average temperature of 10–13°C in July). The increasing continentality caused by the wide Bering land bridge partly compensated the cooling during the Ice Age by a stronger contrast of temperatures between summer and winter. The dryness, which then was stronger than today, was decisive for the treelessness, except for some places with edaphic moisture, but which also mostly had a cooler microclimate because of the moisture. The dryness was more intense than it currently is because, on the one hand, the heavy glaciation of the coast ranges intensified the lee effect as a result of the cooling of the passing air masses, which soon warmed on the leeward side as foehn-like katabatic winds though. On the other hand, the land mass of the Beringia sub-continent eliminated the Bering Sea as a source of moisture for thunderstorms in summer. But the Yukon Flats, which were flooded by snow-melt water, were the main source of moisture and this was the reason why the maximum of precipitation was shifted more toward the early summer and therefore made it more favourable for grassland. In addition there was loess drift from the fans in front of glaciers and from the bare frost-withered ground, which created a favourable friable soil for grass.

Geo- and palaeobotanists are fascinated by the pleistocene steppe issue and have hardly turned to the current climatic conditions. Regarded economically, forest is more important than open land. Therefore, the government was and is more interested in forest than in open country. Even in the detailed official vegetation classification of Alaska by VIREECK et al. (1992, 33) the sagebrush-juniper-association (see Photo 6) is only mentioned but not yet described. In “Ecoregions of the Yukon” (BURN, FULLER et al. 1998) CATHERINE KENNEDY concentrates on the forest associations even within the semi-arid regions, as forests are of greater importance as resources. An impressive vegetation analysis of a semi-arid slope was conducted by wildlife biologists (HOEFS et al. 1975, 1979 and 1984, see below).

7 Relations to the fauna

The low amount of winter precipitation, which is particularly affected by the leeward situation, is essential for the survival of caribou and today again as well for bison and elk. Where the snow is blown away on forest-free slopes, nourishing plants can be reached easily. On south-facing slopes the early thawing of the



Photo 6: Fringed sagebrush (= Prairie sagewort, *Artemisia frigida*) and extremely low mountain Juniper (*Juniperus communis*, var. *depressa* Pursh) in a dwarf shrub-steppe near Kluane Lake. The capsule measures 6 cm (Photo: 5.6.1997)

Fringed Sagebrush (= Prairie sagewort, *Artemisia frigida*) und extrem niedriger Wacholder (*Juniperus communis*, var. *depressa* Pursh) in einer Zwerstrauchgruppe am Kluane Lake. Die Maßbandkapsel mißt 6 cm

snow also allows easy access to food. This is especially important for wild sheep, particularly Dall sheep (*Ovis dalli dalli*). The large southwest-facing slope of Sheep Mountain near Kluane Lake, which is free of forest and covered by dwarf shrub steppe (sagebrush with *Artemisia frigida* dominant), is a well-known example (HOEFS, COWAN a. KRAJINA 1975; HOEFS 1979 and 1984). The southern variety, the Stone sheep (*Ovis dalli stonoi*), are found in the Tintina Trench up to Faro, where the snow free southwest-facing slopes are their pasture in winter (pers. comm. C. KENNEDY). Mustangs (HOEFS 1984, 142) and the northernmost occurrence of coyotes, which immigrated from the south after 1920, are found in these semi-arid regions too.

Bison were reintroduced to Alaska in 1923, south of the town of Delta Junction, in an area which is comparatively dry and therefore partly free of forest. But as the area is covered by xeromorphic grassland or dry tundra, which does not provide much food for bison, and the adjoining meadows near the river are very small, it was not surprising that the rapidly growing bison population (which had already reached a number of about 500 animals in 1980) moves in summer to the fields of the adjacent Delta agricultural project. This causes conflicts which are dealt with in a management plan (RUTLEDGE 1995). Efforts are also being made to resettle small herds to other semi-arid areas of Alaska, for example in the Copper River Basin (in the Chitina Valley). Licences for bison hunting are already a lucrative source of income. Up to one third of the animals' population can be “harvested” each year. Bison were

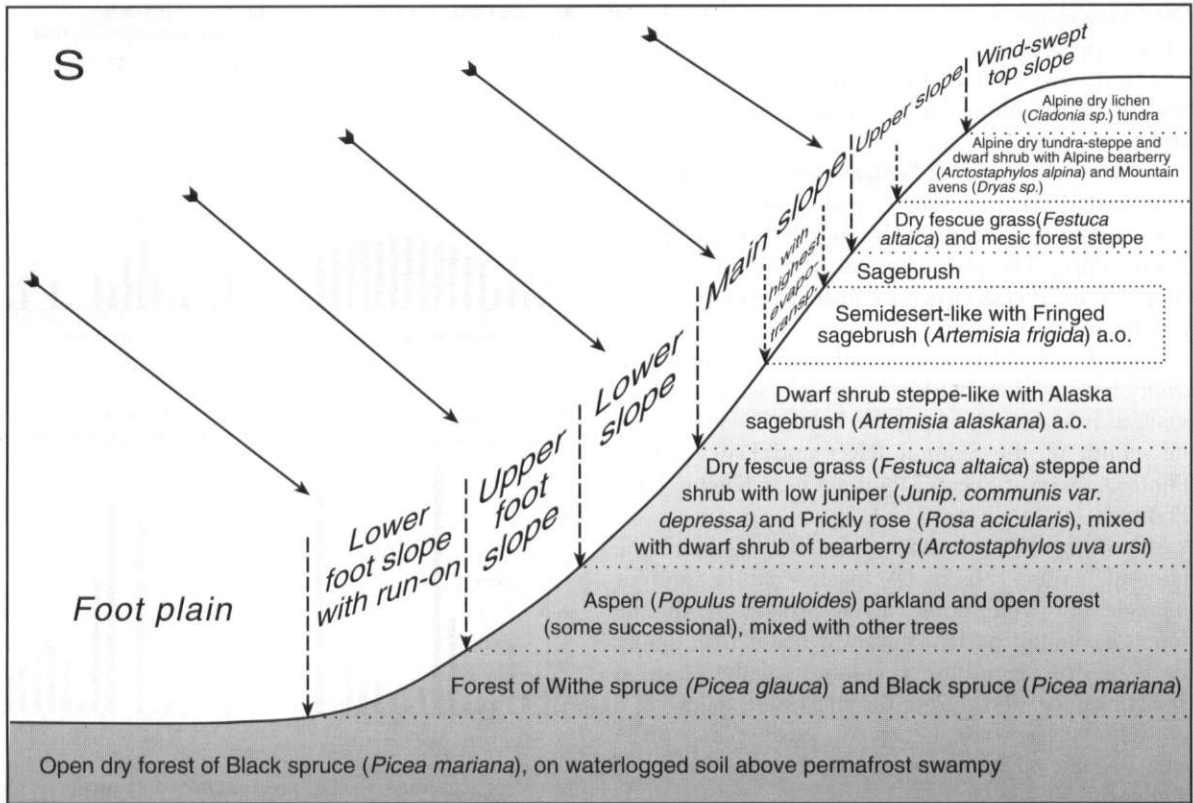


Fig. 4: Schematic generalized profile of vegetation on a south-facing slope in the semi-arid part of the Yukon Basin
Schematisches generalisiertes Vegetationsprofil an einem südexponierten Hang im semiariden Teil des Yukonbeckens

also re-introduced to the most semi-arid part of the Yukon Territory south of Lake Aishihik where natural forest steppe is found (Photo 1). The population has grown to 300 animals there (pers. comm. HOEFS 1998).

Through the knowledge of semi-aridity and steppe distribution, the issue of the abundant wildlife in Interior Alaska and the Canadian Yukon Basin during the Ice Age is resolved. Loess deposition contributed to a very nutritious pasture which formed, according to LAXTON et al. (1996), the basis for the abundance of wildlife, as proved in an analogous study at Kluane Lake where loess is still deposited today and relicts of the "tundra-steppe" can be found. Typical grassland animals: Saiga antelopes (*Saiga tatarica*), still roaming the dry steppe of Kasachstan today, a lion subspecies (*Panthera leo americanus*) and the big scimitar cat (*Homotherium serene*), wild horses (*Equus lambei*) and donkeys, mule deer (*Odocoileus hemionus*), and the large-horned steppe bison (*Bison priscus*) were numerous and attracted Indians who were migrating from Asia. The occurrence of typical ice age animals like mammoth, cave bear (*Ursus spelaeus*), caribou (*Rangifer tarandus*) and muskoxen

(*Ovibos moschatus*) is also evident in numerous fossils (HOPKINS et al. 1982).

8 Zoning of arid regions in the landscape

The first four of ten intensity levels of aridity⁴⁾ are represented in the Yukon and Tanana Basin:

Intensity level 1: South-facing slopes show open forest formations (woodlands and parklands), the plains show semi-moist forests.

Intensity level 2: South-facing slopes show steppe-like formations (dry steppe to dwarf shrub steppe), west- and east-facing slopes show woodlands and parklands, the plains are covered by dry forests.

Intensity level 3: South-facing slopes are (mostly) covered by dwarf shrub and desert steppe, west- and

⁴⁾ Except for the four levels mentioned in this paper, the fifth with dry steppe, the sixth with desert steppe, the seventh with semi-desert, the eighth with brim desert, the ninth with core desert and the tenth with extreme desert can be found in drier zones.

east-facing slopes are covered by dry steppe and dwarf shrub steppe, the plains by woodlands and parklands, at least by dry forests in mixture with little steppe patches. Shallow lakes without outlet become salt pans during summer.

Intensity level 4: South-facing slopes are characterized by semidesert-like patches with sparse vegetation, west- and east-facing slopes by dwarf shrub steppe to desert steppe. The plains are partly covered by forest steppe. This level occurs only in fragments in Alaska and the Yukon.

From the third level on, the phenomena caused by aridity become dominant in landscapes with a distinct relief, as it is the case along the Yukon River between the mouth of the Salmon River and Dawson City (Photos 4–5) or at Sheep Mountain near Kluane Lake (Photo 6).

Of course, there is a number of variations within the different levels, caused by local, edaphic and/or microclimatic conditions, in accordance with the slope's inclination and the thickness of soil. In addition, the poor drainage above permafrost in the plains is of significance, and during the succession following a forest fire a transitional stage of aspen parklands is likely to come up before spruce trees become dominant after about 50 years.

9 Land use in the semi-arid boreal regions of Alaska and in the Canadian Yukon Basin

The dry forests can hardly be used as their timber is too thin for boards and too hard for producing chipboards. Therefore, timber is mainly harvested in riparian forests. The very arid spring and semi-arid summer also show predominantly negative effects on agricultural land use. At the beginning of the 20th century, some settlers started keeping cows because the prospectors paid well for fresh milk, butter and cheese. Creamers Dairy in Fairbanks was the largest business. But aridity is highest during the main grass-growing period in May and June, and during hay harvest in July and August the hay can be ruined by thunderstorms. As the Creamers Dairy farm was located in a favourable area with aqueous loessial soils and several ponds, it was able to survive until 1960. From then on, it was cheaper to have milk delivered from the west coast of the USA.

The agronomists of the Agricultural College, which was founded in 1922 (and later incorporated into the new university), soon realized that water is a limiting factor for many cultures. Vegetables – which grow especially large under the long-lasting irradiation of the summer days – have to be irrigated in Central Alaska,

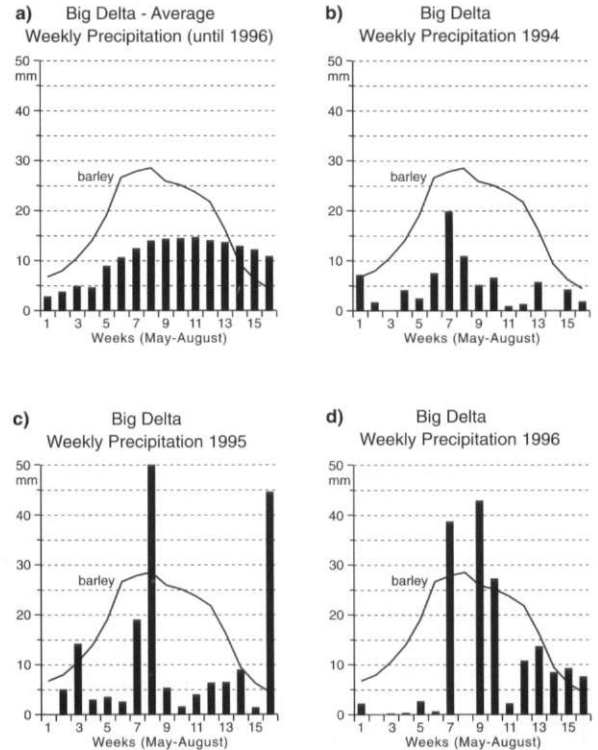


Fig. 5 a–d: Average weekly precipitation and mean water requirement of barley (calculated by Kc factors of the FAO) in the agricultural area of Big Delta, compared with the actual rainfall in three different years

Durchschnittlicher wöchentlicher Niederschlag im Landwirtschaftsgebiet Big Delta und mittlerer Wasserbedarf von Gerste (berechnet nach Kc-Werten der FAO), verglichen mit den tatsächlichen Niederschlägen in drei unterschiedlichen Jahren

while in the Matanuska Valley, the farming area near Anchorage, most of the time additional irrigation is not needed, although a certain rain shadow effect of the coast range exists.

Despite the scientific knowledge about insufficient precipitation in Central Alaska, the US Department of Agriculture took a political decision⁵⁾ when allocating 100,000 acres (= 40,000 ha) of land, about 1000 ha per applicant, between 1978 and 1982 near Delta Junction (Delta Junction is located at the end of the Alaska Highway, 157 km east of Fairbanks) in a dry part of the Tanana Basin (285 mm annual precipitation). The area, located between the Tanana and Delta rivers, is a gravel plain slightly covered with loess and fine sand. Semi-arid climatic conditions are “hidden” by a spruce forest; the extremely slow growth of the relatively small

⁵⁾ Besides the “winning of laurels” for development, a basic food supply of the local Air Force Base was expected.

trees, of which many are already 200 years old, was not taken into consideration. This slow growth is not so much caused by cool summers, as the region is one of the warmest in Alaska (with a mean temperature in July of about 17°C), but rather by dryness. About two thirds of precipitation actually falls during the warmer season (May until September) but disregarding years with lower amounts of precipitation only a few varieties of cultivated plants are able to flourish with only 200 mm during their growing period. Among the cereals and oilseed rape attention was soon focussed on an undemanding type of barley for the fattening of cattle and pigs although oats and certain short-cycle varieties of wheat are suited to the temperature if they could get more water. But even the cultivation of barley is not profitable with these low amounts of precipitation (Fig. 5). Its average yield is 0.8 t/ha, in good years 1.1 t/ha, in bad ones 0.6 t/ha or less (average yield in the USA is 3.1 t/ha, in Germany 5.5 t/ha). In 1996 barley only covered 7% of the farm area within the Delta project. Cattle grazing (number of cattle in 1997: 1440) and hay production dominate. In 1996, for example, the late spring and the early summer as the main grass-growing period were too dry for hay production with only 4 mm of rainfall in May and 40 mm in June (Fig. 5 d). Only 0.7 t/ha could be brought in which are just 60% of the relatively low average of 1.1 t/ha. The five dairies had to import forage (soybeans). Vegetables (cabbage, broccoli, cauliflower, onions, peas, Brussel sprouts, carrots) are irrigated but they only cover 0.14% of the area. For the past five years the irrigation of grass is also increasing as the spring is too dry in 4–5 out of 6 years. Some farmers have started to produce grass seeds but only on 0.25% of the area (1997).

The cultivation of potatoes on 200 ha (0.5% of the area) at an average yield of 13 t/ha is of greater importance. The yields do not react as sensitively to the rainfall curve but correspond very close to the total sum of rainfall during their growing period, as long as killing frost does not occur between the middle of May and the middle of September. According to the records of the Agricultural Office in Delta Junction, the season of 1994 started with 50 mm of plant-available soil moisture and 104 mm of rainfall were received until harvest, resulting in a yield of 8.3 t/ha. In 1995 283 mm altogether yielded 17.2 t/ha, and in 1996 the total of 202 mm 12.9 t/ha. Compared to the average yield of 34 t/ha in Germany and of 36 t/ha in the USA it is still low. But because of the high cost of transportation in regard to the low price per ton, the cultivation is still economic. Imported barley, however, is often cheaper than the locally produced grain.

Many farms are located too far from the river for additional irrigation and water can only be drilled through the permafrost from great depth. The farmers also often do not have the necessary capital. Although the government gives loans at a reasonable interest rate, irrigation is relatively very expensive for the short summer season, as the pipes need to be totally emptied before the beginning of winter in order to avoid frost damage. Early and late frost, as well as severe thunderstorms, can cause unforeseen loss to yield. Finally, the damage caused by game is considerable. The bison of the Bison Range migrate into the farm area in July and August. In spring sandhill cranes and wild geese eat the seedlings, and vegetables are a preferred food for moose. It is not permitted to kill the animals at springtime and summer as it is closed season, and fences that would keep moose and bison out would be too expensive.

Today the financially most favourable "land use" is the ten year-fallow of the US Program for the reduction of agricultural surplus and for the restoration of nature. 30 \$ per acre per year are paid (75 \$ per ha). In 1997 an average of about 300 ha per farm (30% of the farm area) lay fallow. The 22,500 \$ which are paid for that guarantee the basic maintenance of the farmer. But it is a disappointing final stage of the Delta Agricultural Project which had begun with great effort. It would indeed be most reasonable to leave most of the cleared space to the bison. Many farmers already get a considerable extra income by selling hunting licences (200 \$ per hunting trip).

The current aspect of the agricultural area provides evidence of the semi-arid climate. In order to increase soil moisture and to decrease the wind erosion, strip cultivation is dominant on the fields which are still cultivated. The planted windbreaks appear miserable. Trees grow poorly and many have died because of dryness. The wind blows through the open forest strips.

In the Canadian Yukon Territory larger agricultural projects have been avoided. The limited possibilities are clearly recognized (SMITH 1994). Some farms around Whitehorse and Dawson City focus on supplying the towns with fresh milk and vegetables. Sprinklers were installed in order to balance the water deficit. Where the forest opens to forest steppe due to semi-aridity or is burnt or cut down respectively, there are attempts to do some ranching. Problems of salinization can also occur on delicate soil due to the negative water balance.

The current increase of global temperatures is significant for agriculture. In Mayo (Fig. 2) the sum of the average daily temperatures above 5°C increased from 870 to 1010 over the last seven decades (Yukon Dept. of Renew. Res. 1996, 8). This tendency enables a north-

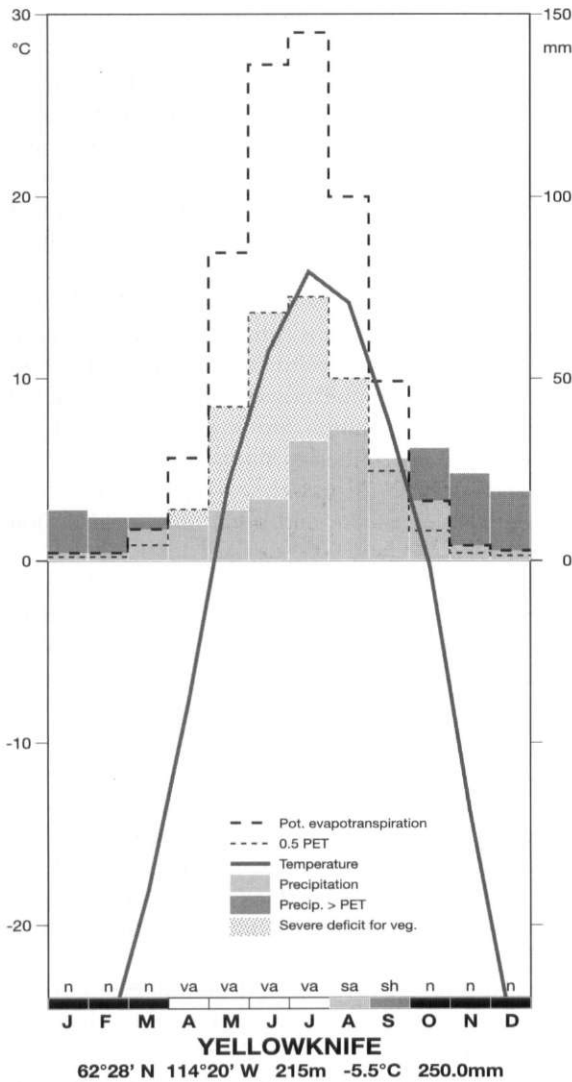


Fig. 6: Yellowknife at the east shore of the Great Slave Lake represents the semi-arid interior of North Canada
Yellowknife am Ostufer des Großen Sklavensees repräsentiert das halbtrockene Innere von Nordkanada

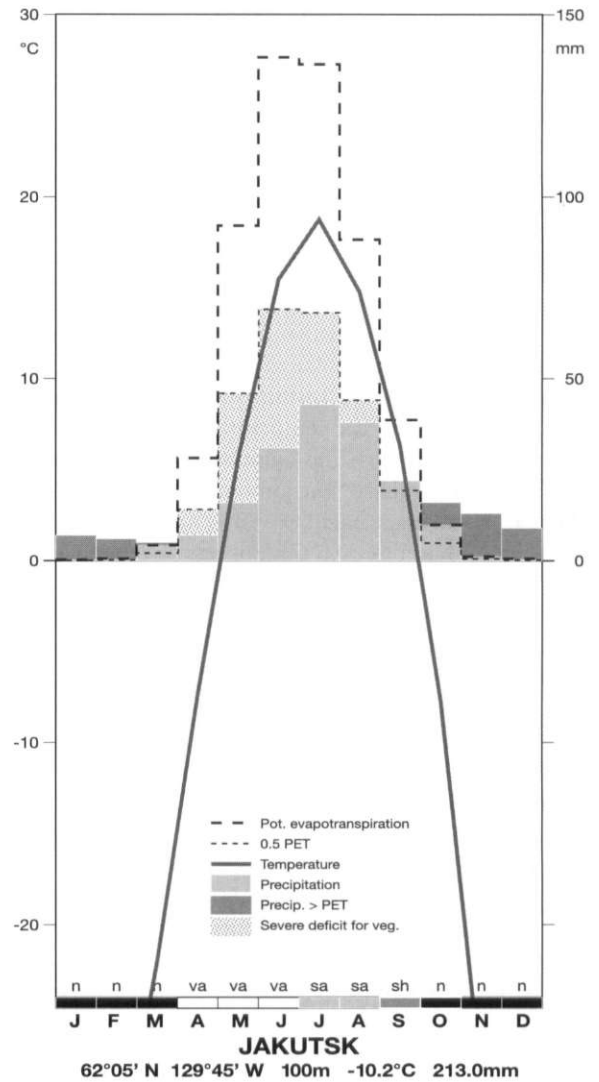


Fig. 7: Yakutsk is typical for the semi-arid East Siberia with visible similarity also to the Yukon basin
Jakutsk ist typisch für das halbtrockene Ostsibirien mit auffälliger Ähnlichkeit auch zum Yukonbecken

ward shifting of the thermal limit of cultivation (cf. EHLERS 1984).

10 Boreal semi-arid regions: are they azonal exceptions or a regular intrazonal sequence?

According to the appearance of the dry slopes, one tends to consider the semi-arid regions in the interior of Alaska and in the Canadian Yukon Territory as azonal exceptions. Taking into account the extensive boreal dry forests, however, the intrazonal sequence of regions

by different hydroclimates within the boreal zone becomes clear: The humid oceanic coniferous forests on the west side of the continents are followed eastward over transition stages by a type of climatic region characterized by continental dry coniferous forests, as TROLL (in TROLL a. PAFFEN 1964) already demonstrated. On the base of the precipitation curve he considered dryness to occur during the winter months but it actually occurs in spring and early summer, as the comparison with potential evapotranspiration shows. He also did not yet mention the inclusion of steppe areas. Towards the ocean in the southeast, conditions become

more humid again, but with strong contrasts of temperature.

In Eurasia this sequence of regions is clearly visible as a change of vegetation from the west to the east. The first semi-arid months in the boreal zone set in east of Moscow, and Yakutsk is characterized by three very arid spring months and three semi-arid summer months. In North America the aridity is significantly shifted westward due to the high mountain ranges in the west and northwest and the southward bend of the warm ocean current, and can therefore be considered as an azonal variant of the intrazonal regionality.

Further east in boreal Canada it is not as dry as in eastern Siberia but six arid months are still attained (from the eastern shore of the Great Slave Lake, Fig. 6, to the Thelon River, JÄTZOLD 1961). Due to the widespread edaphic moisture and to the water logging above permafrost, the dry forests, however, only locally show there.

Acknowledgements

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