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A TEST OF THE HOLDRIDGE SYSTEM AT SUBARCTIC TIMBERLINES

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ABSTRACT. The system developed by Holdridge in tropical mountains, whereby climate and vegetation are considered predictable one from the other, fails to predict the decline of timberline from the interior of Alaska and the Yukon south and west to the coast of the Gulf of Alaska. However, the same system does predict that decline, and may be expected to perform well at arctic and alpine timberlines, as well as to improve demonstration of climate-vegetation correlation throughout middle and high latitudes and altitudes, if its bio-temperature values are reckoned as a function of the sum of observed temperatures above 10° C, rather than above freezing.

IN the summer of 1967 a visit to the Yukon and Alaska, involving observations in parts of the Saint Elias, Chugach, and Wrangell Ranges, provided a good chance to test in the subarctic the system developed in tropical mountains by Holdridge (1964), whereby climate and vegetation are considered predictable one from the other. The test was limited to the thermal aspect of the system, because the wet coastal forest and the much less moist interior forest, (which stands on ground with highly variable drainage), do not make good contact in the coastal mountains at any point which has been climatologically documented. Furthermore, their margins in the mountainous contact zone have been greatly disturbed by glaciers (Griggs, 1934).

On the other hand, Alaskan alpine timberlines seem to be in reasonable equilibrium with climate, and thus have permitted a test of the thermal assumptions underlying the Holdridge system. Coniferous timberlines have indeed been disturbed by ice quite recently in many Alaskan localities, but their restoration usually requires only short migrations of the species involved. Also, the level eventually reached by conifers when they are undisturbed is reached much more promptly by willows and other successional species, but is apparently not exceeded by them.

Holdridge's diagram for classification of life zones places timberline at the 3 C° biotemperature level (Holdridge, 1964, 20). His measure of biotemperature is arrived at by dividing by twelve the sum of all positive mean monthly Celsius temperatures. Negative Celsius means are ignored as having no effect on plant growth.

A rule of thumb used by Koeppen (Hare attributes it to Supan) was also tested for comparative purposes. Koeppen considers that mean July temperature at arctic timberline approximates 10°C (50°F) (Koeppen, 1936, part C; Hare, 1951). Such information as is available suggests that the rule may be a reliable guide to most alpine and arctic thermal timberlines, subject only to the ordinary deficiencies in accuracy and representativeness characteristic of climatic data. Hopkins has found that Koeppen's rule is supported by climatic records at stations near Alaskan lowland timberlines in the Arctic and close to the Bering Sea (Hopkins, 1959, 213–220).

OBSERVATIONS

Holdridge biotemperatures were mapped for all available Alaskan climatic stations before going into the field. Although summers are warmer in the interior of Alaska than on its Pacific coast, and timberlines decline southward in that direction in accord with the Koeppen rule, biotemperatures were found to increase in that direction because stations there have more months above freezing. As a matter of fact, timberline declines from continental to maritime climatic regions everywhere on the Pacific Coast north of California.

It was therefore apparent initially that the Holdridge system did not predict Alaskan timberlines satisfactorily. It remained to determine whether timberlines actually approximate a July isotherm of 10°C near the coast, and if possible, why the Holdridge approximation fails there.

Some interesting, though not vital, observations were made during the summer. Most significant was the discovery that timberlines along the Alaska Highway near Snag, in Yukon Territory, Canada, lie at 4,500 feet, a level not attained on slopes facing the Pacific at any point north of Vancouver Island, more than 20 degrees of latitude to the south. From Snag, similarly high timberlines extend south into the mountains as far as Skolai Pass, on the Yukon-Pacific divide. South of Skolai, they descend to about 3,000 feet on the margins of the extensive Chitina Lowland, but are still 2,000 feet higher than on the coast facing the Gulf of Alaska, still further south beyond the Chugach Mountains.

It has seemed best, however, not to rely too heavily on such relatively local observations, especially since climatic data are sparse in the region visited, as in most other parts of Alaska. Observation of timberline levels elsewhere in Alaska during past field seasons helped, but greater reliance was placed on topographic map coverage showing forest limits. Such coverage, published since World War II, has been found to define timberline reasonably accurately wherever it has been checked against field observations. Values accepted here are the highest indicated forest levels which recur often enough in a given locality to give assurance that they are not cartographic errors. 1/250,000 map coverage was used to determine the regional trends and normal elevation of timberline, and 1/63,360 maps were then consulted to be sure that accuracy was not lost because of the generalization necessary on smaller-scale maps.

If a complete map of timberline in the Alaskan area had been attempted, the topographic map coverage required would have been roughly three times the considerable amount actually obtained. The general trend of timberline in that part of the world is well known to many residents and biologists, however, and present findings are in accord with it. Map data were not obtained for Chignik, the Alaska Peninsula station. Timberline there is known to be substantially lower than at localities further northeast on the peninsula which are familiar to me from past field studies, and which have treelines at about 1,000 feet.

Maps of mean monthly temperatures at numerous Alaskan stations were already on hand, and a map of Holdridge biotemperature, using the same stations, had been compiled (U.S. Weather Bureau, 1943). Nine stations were selected as representative of the area to be considered, including Snag in the Yukon and eight stations on or south of the Yukon-Pacific watershed in Alaska (Fig. 1). Little Port Walter, the station included from Southeastern Alaska, is of exceptional interest. Because of its mild winter, it has the highest Holdridge biotemperature in Alaska, 9.19 C°. That circumstance, and the low timberlines nearby, both seem related to its maritime site and large mean annual precipitation, which is 230 inches. A number of other stations in Southeastern Alaska which have heavy precipitation also have high biotemperatures.

FINDINGS

Stations are ranked by latitude in Table 1, and the general decline southward of Alaskan timberlines between the 63[d] and 56[th] meridians can be clearly seen there. A difference in timberline level is seen not only between interior and coastal stations, but also between coastal stations differently exposed to maritime and continental air masses. Mean July temperatures show a similar distribution, but biotemperatures increase southward in general.

The situation is even more clearly seen in Figure 1, on the vertical axis of which the altitude of timberline above each climatic station is shown, rather than that above sea level. Both Holdridge biotemperature and July mean temperature are plotted against those altitude values, which relate in a simpler way to the altitudinal thermal gradients existing at each site than altitudes above sea level do.

The distribution of points relating July mean temperature to altitude above climatic stations supports the Koeppen rule of thumb (Fig. 1). That is, a line of best fit so drawn as to have the least possible standard error (1.55 F°) predicts timberline at the 51.4°F level, as compared to Koeppen's prediction of 50°F (10°C). (Climatic data used were initially in Fahrenheit degrees, and that system was used in the diagram for ease of plotting,

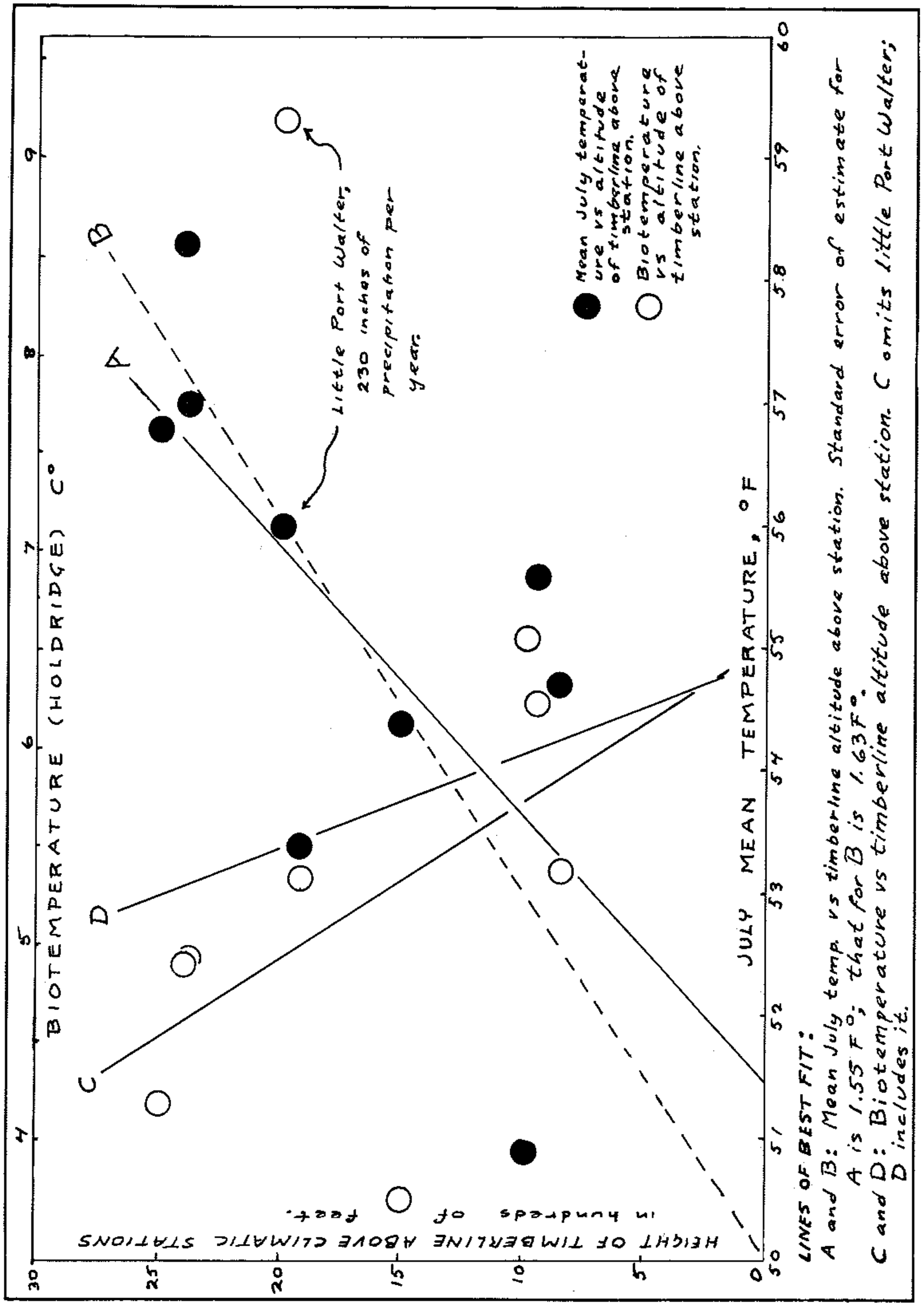
BIOTEMPERATURE (HOLDRIDGE) C°
JULY MEAN TEMPERATURE, °F
HEIGHT OF TIMBERLINE ABOVE CLIMATIC STATIONS in hundreds of feet.
Little Port Walter, 230 inches of precipitation per year.
Mean July temperature vs altitude of timberline above station.
Biotemperature vs altitude of timberline above station.
A
B
C
D
LINES OF BEST FIT:
A and B: Mean July temp. vs timberline altitude above station. Standard error of estimate for A is 1.55 F°; that for B is 1.63F°.
C and D: Biotemperature vs timberline altitude above station. C omits Little Port Walter; D includes it.

FIGURE 1

TABLE 1: — TIMBERLINES, MIDSUMMER TEMPERATURES AND BIOTEMPERATURES, AT NINE STATIONS IN ALASKA AND THE YUKON

CLIMATIC SITE	TIMBERLINE DATA SOURCE: (A and B represent topographic maps at 1/250,000 and 1/63,360 respectively)	TIMBERLINE HEIGHT (feet above sea level)	JULY MEAN TEMPERATURE °F.	BIO-TEMPERATURE C°
McKinley Park Station, Alaska, 63° 25′N. 2,098 feet	Healy quadrangle, A&B	3,500 feet at numerous separate places	54.4	3.75
Snag, Yukon Territory 62° 26′N. 2,000 feet	Observations in flight nearby, 1967, checked by map elevations	4,500 feet	56.8	4.18
Chitina, Alaska, 61° 32′N. 600 feet	Valdez quadrangle B. (C1, B1, B2, B3 sheets) Also, observations in flight	3,000 feet in general, 3,500 feet locally	58.3	4.97
Anchorage, Alaska 61° 12′N. 118 feet	Anchorage quadrangle A&B, visits to the area	2,500 feet NE of town, rising to 3,000 feet on the Matanuska River	57.0	4.92
Cordova, Alaska 60° 33′N. 83 feet	Cordova quadrangle A&B	2,000 feet	53.4	5.32
Cape St. Elias, Alaska, 59° 47′N. 55 feet	Middleton Is. quadrangle B. (D1-D2 sheet)	1,000 feet on the lee slope of the cape	55.6	6.21
Kodiak, Alaska 57° 50′N. 152 feet	Kodiak quadrangle A&B, port visited	1,000 feet on Whale and Spruce islands. Under 200 feet on south coast of island	54.7	5.37
Little Port Walter, Alaska, 56° 23′ N. 14 feet	Port Alexander quadrangle, A&B	Less than 2,000 feet	56.0	9.19
Chignik, Alaska 56° 20′N. 10 feet	Timberlines decline almost to sea level (alder only). No map data.	Below 1,000 feet	50.9	6.62

since Celsius mean monthly temperatures are not directly comparable with biotemperature in any case). Only a very slight increase in the standard error of the line of best fit, to 1.63F°, is produced by constraining it to pass through the intersection of the axes representing 50°F July mean temperature and zero altitude (station at timberline).

On the other hand, the distribution of Holdridge biotemperature versus altitude above climatic stations indicates an inverse correlation corresponding to the inverse geographical relationship cited above. The point representing biotemperature and timberline level at Little Port Walter shows so little agreement with those of stations with less precipitation that lines of best fit for biotemperature were calculated both with and without considering it.

It is a matter of considerable interest, and has some bearing on the basic assumptions of the Holdridge system, that if 10° C were used as a base for calculation of biotemperature, rather than 0° C, the zero isoline of biotemperature would become identical with that of 10° C in the warmest month, which is July at most high altitude stations. If the zero rather than the 3° C biotemperature were used, the Holdridge system would then predict accurately not only Alaskan timberlines, but perhaps also thermal timberlines throughout the northern hemisphere, at least.

From the biological point of view, the freezing point is especially significant because it causes plant growth to start and stop, yet it seems probable that the efficiency of utilization of thermal energy by plants does not increase arithmetically as temperature rises above that level. Thus a precise calculation of biotemperature might have to be made on a geometrical rather than an arithmetical basis. However, it seems possible that even an arithmetical estimate of biotemperature similar to that now used by Holdridge, but based on 10° rather than 0° C, might do quite well for all vegetation other than tundra and that of alpine levels, which in any case are differentiated by Holdridge only according to their moisture relationships.

In tropical mapping, Holdridge and his associates have found it convenient that mean annual Celsius temperatures have been equivalent to biotemperature below the frost line. However, map distributions of biotemperature in regions having no months averaging below 10° C would not change if the value plotted for each station were simply reduced by ten degrees. Where mean monthly temperatures below 10° C occur, some improvement in correlation of vegetation and climate might be possible if the revised measure of biotemperature were used. It seems unlikely that the real virtues of the Holdridge system would be obscured by the change.

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