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# INDICATIONS AS TO CLIMATIC CHANGES FROM THE TIMBERLINE OF MOUNT WASHINGTON[1]

By Dr. ROBERT F. GRIGGS

NATIONAL RESEARCH COUNCIL

WE stand on historic ground. The arctic plants of the Alpine Garden, here isolated on Mount Washington, played a decisive role in establishing Plant Geography as a science; and this science was the crucial point on which turned the acceptance of the doctrine of Evolution. In the years before 1859 progressive naturalists were seeking an answer to the riddle of the Origin of Species. No aspect of this problem was so vexing in those days as the question raised by species with disjunct distribution. Had there been two acts of creation resulting in identical species, one in each of the separate ranges? or was the present dispersal the result of immigration from a single original center? It was the answer to this question which finally disposed of the doctrine of special creation in the minds of Darwin and his associates. Feeling the need of additional data on this question, Darwin asked his friend, Asa Gray, to discuss the relationships of our eastern flora. Gray did so under the unpretentious title of "Statistics of the Flora of the Northern States."[2] In a second paper, still antedating the "Origin" he amplified and strengthened the theoretical opinions cautiously expressed in the first.[3]

[1] Address given at the Symposium on Alpine Ecology, Ecological Society of America, Mount Washington, June 26, 1941.

[2] *Am. Jour. Sci.*, Ser. 2, 22: 23, 1856–57.

[3] "On the Botany of Japan." Mem. Am. Acad. Arts and Sciences, 6: 443 *et seq.* (Read December 14, 1858,

YOU will wonder how the isolated occurrence of a few arctic species here could have any great significance. We in this generation, indeed, expect as a matter of course to find arctic species in alpine habitats. It is hard for us to see the point of view of the naturalists of 85 years ago. The theoretical spectacles through which pre-Darwinian scientists had to look at the world, however, made it more difficult to understand small outlying stations far from the main body of the range of common species than the occurrence of distinct endemic species limited to single stations.

The scientists of those days were struggling with the belief not only that species were created as they now are but where they now are, *i.e.,* confined to their present habitats and in substantially the same numbers as they are to-day. Listen to Gray[3] on the difficulty of this question:

> The fundamental and most difficult question remaining in Natural History is here presented:—The question whether this actual geographical association of congeneric and other nearly related species is primordial and, therefore, beyond all scientific explanation, or whether this may be *to a certain extent* (ital. mine) a natural result. The only noteworthy attempt at a scientific solution of the problems, aiming to bring the variety as well as the geographical association of existing species more within the domain of cause and effect, is that of Mr. Darwin and (later) of Mr. Wallace—partially sketched in their short papers, "On the tendency of Species to form varieties and on the perpetuation of Varieties and Species by means of Selection, in the *Journal of the Linnaean Society,* Vol. 3 (Zoology), page 45." . . .
>
> Professor Agassiz maintains, substantially, that each species originated where it now occurs, probably in as great a number of individuals occupying as large an area, and generally the same area, or the same discontinuous areas as at the present time.

But, as Gray pictured the situation:

> . . . At length—the glacier epoch came slowly on—The change was so gradual that it did not destroy the temperate flora, which . . . must have been pushed on the lower latitudes as the cold advanced; and between them and the ice there was doubtless a band of subarctic and arctic vegetation—portions of which retreating up the mountains as the climate ameliorated and the ice receded, still scantily survive upon our highest Alleghanies and, more abundantly upon the colder summits of the mountains of New York and New England:—demonstrating the existence of the present arctic-alpine vegetation during the glacial era.

That is to say, before Gray's challenge, men felt that they had to believe that the many arctic species which are found in the alpine zone of the Presidential Range required an especial visit of the Creator to produce them, there! Outlying colonies of plants and animals far from the main body of their ranges are among the common phenomena of nature. No two outlying stations preserve exactly the same set of relicts. So it is easier to understand how confusing, not to say irrational, the acts of the Creator appeared to would-be interpreters of nature before Gray boldly declared:[3]

> I cannot resist the conclusion that the extant vegetable kingdom has a long and eventful history, and that the explanation of apparent anomalies in geographical distribution of species may be found in the various and prolonged climatic or other physical vicissitudes to which they have been subject in earlier times.

I need hardly add that, though we are now convinced that an adequate knowledge of the history of such cases would bring complete understanding of them, we are still very far from having unravelled the tangled events involved. We are assembled here to-day, largely to take stock of the progress of that quest from the angles represented by the workers in different fields here present. We know that we shall learn of notable things that others have accomplished, each in his own specialty. Perhaps, from this day's exchange of information and ideas, we can to advantage map our future efforts.

I may begin by stating, what is familiar to all of you, that the very general terms of Asa Gray's original *Glacial Relict Theory* are by no means detailed enough to satisfy the scientific curiosity of those who have later sought to interpret the plant geography of northeastern America. Relict species have, rather, continued to be a matter of discussion down to the present day. The most extensive expression of that interest is to be found in the many papers of Professor Fernald and others, elaborating and discussing the "Nunatak hypothesis."

In addition to such arctic plants as those growing around us here in the "Alpine Garden," there are isolated in northeastern America tiny outliers of many other species, the main body of whose ranges lie elsewhere, often not at all in the arctic. The "Nunatak hypothesis" supposes (1) that these species survived the last (Wisconsin) glaciation by persisting on areas which, though surrounded by the continental glacier, were not covered by ice, like the nunataks standing above the Greenland ice-sheet of to-day; and (2) that since the Wisconsin glaciation they have for the most part remained confined to their nunatak refuges. The existence of a notable collection of such plants is taken as prima facie evidence according to this view that their habitat was free from ice and otherwise favorable for plant life through Wisconsin times, *e.g.,* the Keewanaw Peninsula of upper Michigan.[4]

An essential feature of these relict theories is that

and January 11, 1859.) ("The Origin of Species" was published on November 24, 1859.)

[4] M. L. Fernald, *Rhodora,* 37: 197–228, 1935.

they envisage conditions as static. To be sure, they do recognize that the invasion of the ice sheet had caused readjustments of the flora in the dim geologic past. But they take little specific account of plant migrations since the glaciation.

Until the last decade or two there has been a great gulf fixed in men's minds between geological time and historical time. Changes in climate since the last ice age were discussed at the International Geological Congress at Stockholm in 1910, the opinion was then expressed that the deterioration of climate in Scandinavia shown by late Pleistocene deposits might likely be continuing into the present. But no means were discovered of testing this opinion by evidence.[5] Since 1910, however, notable progress has been made in connecting the geological past with the historical past.

We should look at these arctic plants here hanging on and at these trees here stretching up the mountain slopes as mute indicators of climatic trends and we should seek to unravel their story. The tension zone between subalpine forest and alpine tundra ought to be one of the most favorable of all places to discover what is going on. Specifically, are these dwarfed and crippled trees, in whose shelter you crouch as you listen, advancing up the mountains under conditions still improving since Wisconsin times or are they being beaten back by a worsening climate?

This timberline differs markedly from those of Western America. On the arctic timberline in Alaska the trees are not deformed in any way but, as studied especially at Kodiak,[6] are normal spire-shaped conifers and maintain a reproduction and rate of growth comparable with that of the same species a thousand miles inside the arctic border. Here there is conclusive evidence, botanical and historical, that the trees are advancing into the tundra. We conclude that climate is improving in Alaska.

In the Northern Rocky Mountains the uppermost trees are recumbent and their growth is reduced, but very old trees, erect and undwarfed, occur close to extreme tree line, and the trees commonly retain their full size up to or beyond the point where the forest begins to thin out and give way to open meadow so that one may usually walk with ease through the forest at timberline in any direction. Conditions here convinced me that in this area timberlines have been static for a number of centuries.[7]

In the White Mountains the forest begins to be stunted 2,000 feet below the timberline. The trees become shorter and denser with ascent until, still retaining the erect arborescent form, they form a compact level-topped elfin forest over the top of which you may sometimes walk but which you can penetrate only by chopping your way. Above this scrub, the trees, still further dwarfed, form in places extensive carpets close-clipped by wind and snow blast. These appear from a little distance like well-kept lawns. In the most extreme of these, all tendency to form upright leaders is suppressed and only lateral branches are produced.

Second, the trees on the exposed portions of the Presidential Range and to a considerable extent elsewhere in the White Mountains are confined to specially protected situations such as the lee of a bowlder. Old trees come finally exactly to fill a streamlined outline matching the flow lines of the prevailing wind around the projecting bowlder. The winds at Kodiak do not deform the trees at all, and in the western mountains such excessive wind action is rare and local. There clumps of trees may, indeed, be differentially dwarfed and wind-shorn on the windward side (see photographs[7]), but they often stand in the open without protection.

Third, seedlings or young trees of the conifers are rare near tree line in the White Mountains. But on the western mountains seedlings of fir and spruce are readily found up to and beyond the last of the established trees. Most of these, as would be expected, grow a few years and then succumb. At Kodiak seedlings are not only common, but vigorous and persistent, providing the means for the active migration into the Arctic. The absence of seedlings on the heights of the Presidential Range is not due to any scarcity of seed—every bank at favorable levels in the forest and well into the zone of dwarfing is covered with seedlings. Nor is it due to lack of wind to scatter the seed over the alpine zone—the winds on Mount Washington are second to none.

The seeds of fir and spruce which lodge in the alpine zone of the White Mountains must, with rare exceptions, be killed as they germinate.

Trees are now occupying a rather wide zone on these mountains which they could not colonize under present conditions. They hang on by virtue of the freedom with which they spread by putting out roots along their prostrate trunks. Because of this habit trees can persist indefinitely without reseeding, continuously rejuvenating the tips while dying behind. It is not at all uncommon to find a prostrate tree whose distal, younger portion is larger than the proximal, older part by reason of growth supported by adventitious roots. Thus there may be more rings in the younger portion of a trunk than in the older. The real age of such a "tree" can by no means be ascertained from the number of rings in its trunk. Some of these prostrate cripples have probably persisted for centuries.

[5] Gunnar Andersson, "Veränderungen des Klimas seit dem Maximum der Letzen Eiszeit," 11th Int. Geol. Cong. Stockholm, p. 292, 1910.

[6] R. F. Griggs, *Ecology*, 15: 80–96, 1934.

[7] *Idem*, *Ecology*, 19: 548–564, 1939.

We must ask ourselves now how the trees above the zone of seedlings ever became established. The simplest explanation and, I believe, the true one is that the upper trees on Mount Washington are hold-overs from a time of more hospitable climate when seedlings could start in places where they are now killed off.

The next question is whether the highest trees under these conditions are holding their own in spite of the lack of reinforcement, so to speak, by new seedlings. To answer, the differences in reproductive condition between this and normal forest must be brought out. In normal forests, even in many of the patches of upright trees high up on the Presidential Range, all stages occur: seedlings, saplings, mature trees, dead stubs, decaying logs; some are vigorously adding new wood year by year, others are standing nearly still, others, at the limit of their life span, slipping backward and the proportion of dead wood to live, increasing.

But among these crippled trees distinctions between youthful vigor and decrepit age appear more between the parts of a single tree than between different trees. Prostrate branches covered with snow through the winter and rooting freely maintain indefinitely the condition of youth and, barring accident, can spread for long periods. But, whenever these snow-covered mats send up vertical shoots, they begin to suffer. The upright trunks in the transition zone between forest and prostrate carpets are the best indicators which way the balance is tipping.

On most of these trees the branches of the live uprights have been slowly diminishing for a number of years. This does not mean that upright growth is stopped. Supported by the large mat of recumbent branches at the base, the leaders of a timberline tree will often make strong growth year after year—I have measured 17 inches. But on balance, winterkilling nearly always exceeds growth. For example, one tree on Osgood Ridge had a dead trunk about six feet tall. Directly to lee of this was a second leader which, though sheltered by the older trunk, had attained a height only about four fifths as great. Yet it had reached its limit and was on the point of death, only a few small twigs remaining alive. Further to lee was a shorter oblique shoot about two feet high which remained healthy.

Such a tree presents a diagrammatic picture of what appears to be happening generally: The trees seem to be in process of being forced into more and more recumbent positions.

In a few places, where the old forest was killed back half a century or more ago by some catastrophe, probably fire, there remain stumps of old trees larger than any that now grow on the sites. The new trunks that have come up since have now reached their limits and are held at sizes somewhat less than half the originals.

One of these is on the lee side of Osgood Ridge, where a narrow tongue of trees reaches up from the forest into the alpine zone. At the tip of this tongue are two picturesque repeater trunks, standing above the subprostrate snow mat. The largest of these measures 5 inches in diameter. It has made 20 successive attempts to push up a leader. Immediately in front of it stands a shell of a predecessor trunk which was 12 inches thick.[8]

These large old stumps again are difficult to interpret except as indicators that the climate on Mount Washington has grown worse for trees within the last century.

But changes in climate are regional rather than local. Before we can draw conclusions from the retreating timberline of Mount Washington, we must look further afield. Scattered through the literature is a good deal of evidence that the climate of northeastern America has changed considerably during the last thousand years. Fortunately these have been brought together by Raup,[9] first for New England and New York and later as a part of a more general review.[10] Evidence from many sources indicates a very definite worsening of climate during the latest centuries over all northeastern America from New York northward. Perhaps the best-attested and certainly the best-dated of these evidences is the gradual freezing out of the old Norse Colonists of Greenland. Accounts indicate that the new Green land, discovered by Lief Ericson in the tenth century, offered considerable advantages over Iceland as a home for European colonists. The Norse colony in Greenland, supported by dairy farming and exports of cheese to the mother country, had a prosperous existence until the latter part of the twelfth century. The Norsemen hung on in Greenland until the fifteenth century, but increasing rigor of climate caused a pitiful decline and final extinction. The recent excavation of this colony has brought to light physical facts which abundantly corroborate the old records of increasing ice in the sea and similar difficulties. Perhaps the most significant of these physical evidences is the fact that the colonists lie buried in soil which is now perpetually frozen. Yet their coffins and even the marrow of their bones are permeated by tree roots. Since tree roots can not penetrate frozen soil, these must have grown before the ground froze up, *i.e.*, in a period with a milder climate than the present.[11]

[8] These and other features of timberline on Mount Washington will be described in detail in another place.

[9] Hugh M. Raup, *Jour. Arnold Arboretum*, 18: 79–117, 1937.

[10] *Bot. Rev.*, 7: 209–248, 1941.

Fitting in with these human records is the fact, commented on by many botanists, that plants of Greenland seldom ripen seed under present climatic conditions, though the same species are fully fertile in more hospitable climates.

Several observers[10] report that the arctic timberline in northeastern America is retreating, *viz.*, "West of Hudson's Bay," by Sir John Richardson and Johannsen,[10] "East of Hudson's Bay," by Abbe.

The situation on the north shore of the Gulf of St. Lawrence is discussed by Marie Victorin.[12] The record of Jacques Cartier indicates a wider extension of forest near the Straits of Belle Isle in 1534 than at present, but the geographical reference is rather vague. However, Fernald[13] has recorded stumps a foot in diameter at Blanc-Sablon, where to-day is only moss and bog. Likewise there are a number of puzzling relicts of southern plants in this region which point to a former period of warmer climate. These facts caused Marie Victorin to remark, "One could perhaps go further and ask himself if the present spruce forest of the north coast, of Anticosti and elsewhere is not irretrievably doomed, maintaining itself only by virtue of the mutual protection the trees give each other and whether if once destroyed over a large area this forest would be able to reconstitute itself."

It has been suggested, not infrequently, by those considering the evidence of deteriorating climate that another glacial period may be coming on. The evidence in our possession does not justify so strong a statement. All that is proved is that climate in our part of the earth is undergoing a prolonged deterioration in terms of human history. We do not yet know enough of climatic change to distinguish variations of merely historical importance from those of geological consequence.

The geological implications of the worsening of climate being experienced in northeastern America lie rather in another direction—in their bearing on the problem of the correlation of ice ages. Were the Pleistocene glaciations of the northern hemisphere simultaneous throughout, or did the centers of the ice-sheets shift about so that first one area was glaciated, then another? It is the current belief of geologists that the Wisconsin glaciation of America and the Würm of Europe were synchronous. But it should be remembered that, despite the remarkable work that has been done in following the retreat of the ice year by year through study of the varves, there are in America breaks in the varved record which prevent the assignment of definite dates. The character of the gaps in the sequence and the irregularities in the rate of melting of the ice over the area where the sequence is complete preclude any estimate of the time periods covered by the breaks in the record and so of any definite correlation with events in Europe. Kirk Bryan[14] has recently remarked in this matter:

> Unfortunately, there is no absolute proof that glaciation was synchronous over the earth. The synchroneity is at best a doctrine supported by: . . . These arguments when set down seem weak indeed. On the other hand, there is no valid argument to the contrary. . . .

On the principle that the simplest hypothesis possible should be invoked to explain any phenomenon, a theory of alternative continental glaciation is preferable to one of total hemispheric refrigeration. The latter requires some drastic change in the amount of radiation supplied to the earth. But local glaciations covering merely parts of continents such as that of Greenland to-day require merely shifts in the positions of present climatic provinces.

It is indeed a matter of primary importance for the interpretation of glaciation to remember that the Pleistocene ice sheets were always largely restricted to western Europe and northeastern America. In neither northwestern America nor northern Asia was glaciation so well developed as in the lands on both sides of the Atlantic.

As a matter of fact the Wisconsin glaciers throughout their various stages were always of limited and regional rather than of truly continental extent. The Islands of the Arctic Archipelago lying north of the ice sheets were never glaciated. Neither was the interior of Alaska.

The center of Wisconsin glaciation moreover moved from Labrador to Keewatin during the epoch. What sort of climatic changes could produce these shifts in the center of ice accumulation? Who can imagine a shift in present climate that would produce a continental glacier on the Arctic Archipelago while allowing that of Greenland to dwindle away? Yet something very like that happened in Wisconsin Time when the glacial center moved westward across Hudson's Bay from Labrador to Keewatin.

The evidence of the timberlines shows, however, that climatic changes of that type are occurring to-day. The climate in Alaska has recently become more favorable for trees and that of the northeastern portion of the continent less favorable. Everything indicates these changes are still going forward. When we come to understand their causes, it may be that we shall be set forward also in an understanding of the causes of ice ages.

[11] Poul Norlund, "Viking Settlers in Greenland and their Descendents during 500 Years." Cambridge University Press, 1936.

[12] Frére Marie Victorin, Cont. Bot. Lab. University of Montreal, No. 131, p. 77 *seq.*, 1929.

[13] M. L. Fernald, *Rhodora*, 13: 109–62, 1911.

[14] SCIENCE, 93: 509, 1941.