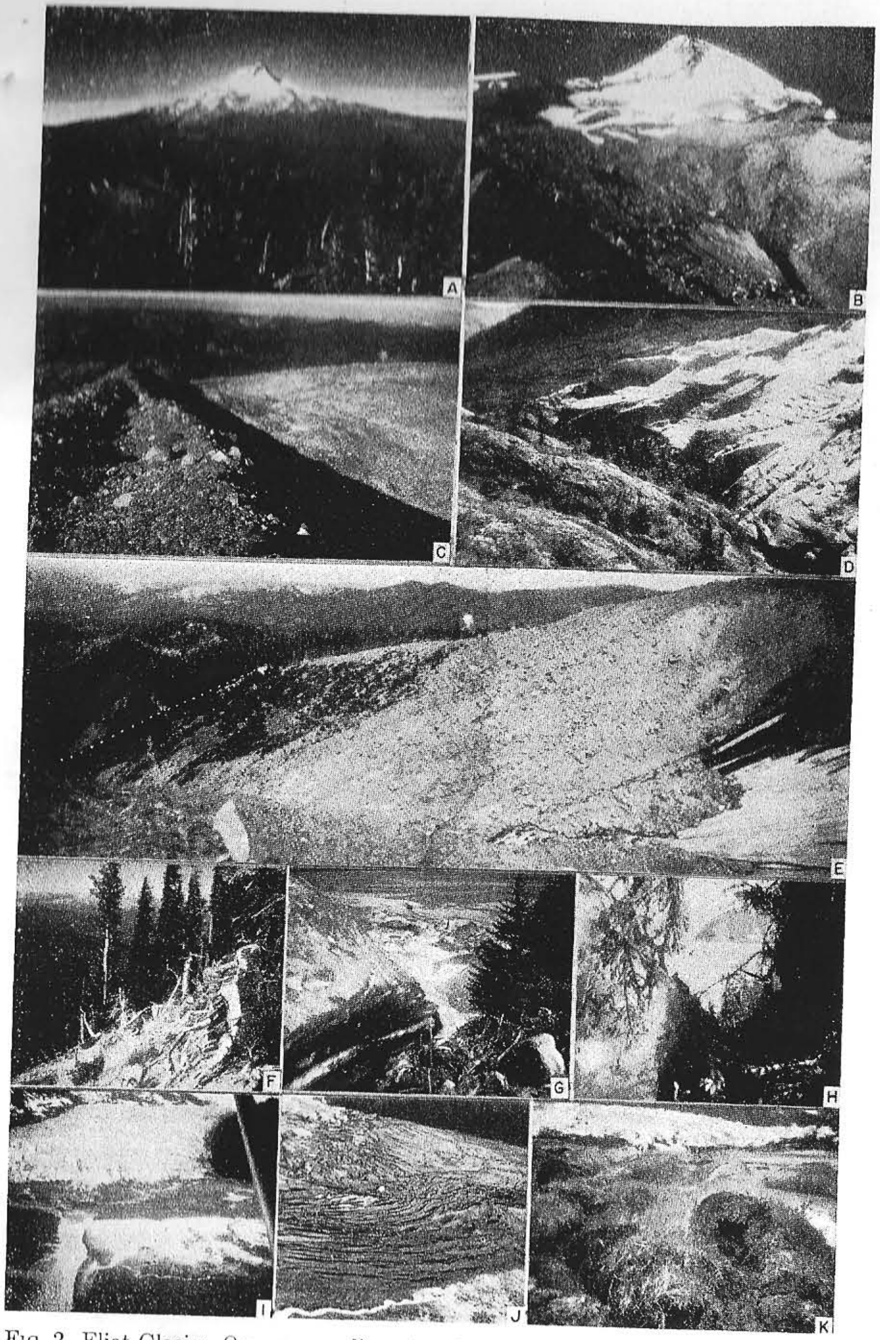

FIG. 2. Eliot Glacier, Oregon, receding, shrunken; Hole-in-the-wall Glacier, Alaska, advancing swollen.

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GLACIERS AND VEGETATION IN SOUTH-EASTERN ALASKA*

By DONALD B. LAWRENCE

GLACIER HISTORY

IN the past decade glaciers have begun to sparkle with new light, a glow born not of sun, moon, or stars, but of new knowledge gathered by fresh searching eyes. This has been particularly true in western North America where man-kept history, so brief and fragmentary, cannot satisfy an inquiring mind. In this new attempt to solve geophysical problems, botanical and geographical evidence has been brought to bear, including detailed study of individual living plants and, in fact, the character of the whole organic mantle of the earth's crust in the periglacial region adjacent to the present ice.

During the present International Geophysical Year (IGY) concerted effort, using many of the new techniques, is being made by twenty cooperating nations on a scale never attempted before and it is expected that results will be obtained whereby old hypotheses of glaciation can be reexamined and perhaps new, more satisfactory ones formulated.

It should be of interest to review briefly, at the outset, available figures on the earth's present ice load. According to the U.S. Navy Hydrographic Office (Anonymous 1956) six per cent of the earth's total surface is covered with ice in the course of a year. Half of this is land ice and this constitutes almost six million square miles. Thorarinsson (1940) pointed out that only 13 per cent of the world's land ice is in the northern hemisphere, and that 86 per cent is in Antarctica. It is very fitting therefore that the major offensive against glaciological problems during the IGY should be in the Antarctic, but precise information on fluctuations in glacier size over the past several centuries is not likely to come from Antarctica because there are no woody plants or peat deposits there from which estimates of time lapse can be readily obtained, and human records are virtually absent. For information on recent glacier

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* A Sigma Xi-RESA National Lecture for 1956–57.

history there is no region of the world as favorable as northwestern North America, and Southeastern Alaska in particular.

I wish to record here my appreciation of the interest shown by many audiences of my Northeast Sigma Xi tour in February and March 1957, and of their penetrating questions which have helped me to understand more clearly the features I was attempting to describe.

It is my main hope in presenting this material to provide an opportunity to become better acquainted with glaciers, and the manner in which plant cover develops after glaciers melt away. Although I could do that photographically with the help of nearly a hundred slides during the lectures, I must rely here largely on verbal imagery and the figures generously allowed me by the editors.

One may gain perspective by comparing, on the glacial map of North America (Flint 1945), the rather minute perennial ice cover of today with the extensive surfaces covered during the Great Ice Age, when glaciers migrated southward as far as northern Kansas and southern Illinois, and when, in the now arid basins of the West, great lakes formed.

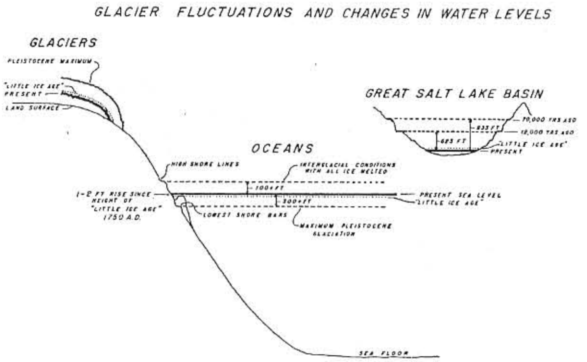


FIG. 1. Glaciers, sea levels (Flint 1957), and pluvial lakes (Durrant 1952).

Review of the modern literature resulting from recent studies of glaciers, vegetation, sedimentary deposits, and sea levels reveals that the prevailing idea of gradual amelioration of climate since recession of continental Ice Age glaciers is a misconception. These studies have shown that the climate has been both less and more favorable to glacier nutrition than at present since the continental ice melted away. Probably it has been more favorable than at present for glacier growth more than once. The latest period of glacier expansion which occurred only two to three centuries ago is close enough to us in time to be susceptible of precise dating and therefore of most accurate comparison with possible causal agencies. A number of scientists have followed the lead of a clever newspaper columnist who, in reporting the early work of Francois Matthes (1940: 398), called this event part of the "little ice age."

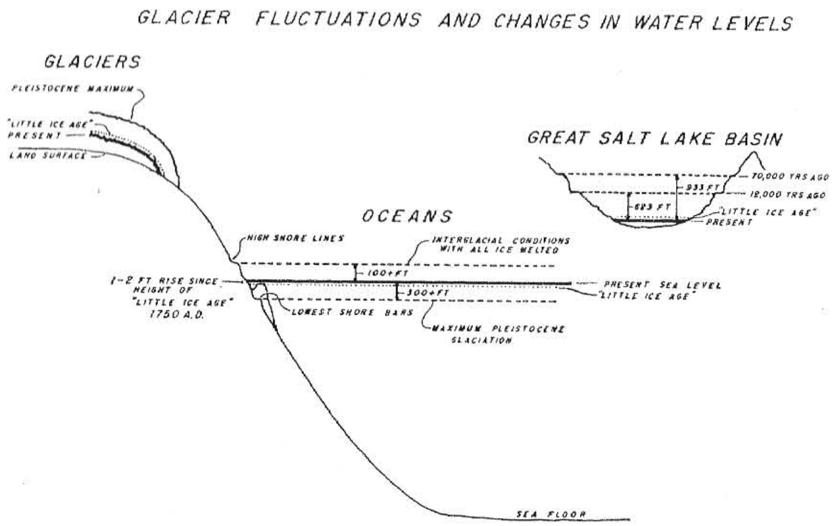
For further evidence as to where our present conditions stand in relation to glacial and interglacial periods let us look at the diagram of Figure 1. During glaciation, to the best of our knowledge, water migrates from oceans to continents, piling up in higher latitudes and altitudes as glaciers, and in undrained basins at middle latitudes and altitudes as lakes, while at the same time sea level is lowered throughout the world. We believe that we stand at present approximately midway between a full glaciation and an interglacial period in which all ice will have returned to the sea, raising its level 100 feet or more, and the inland lakes will have evaporated still more completely than now.

A glacier may be thought of as a complicated meteorological instrument which is a combination of snow gauge, dew gauge, evaporimeter, solar radiation meter, and an instrument which would measure the melting capacity of warm wind and rain. The volume of ice in a glacier at the present time is thus an index of the integrated record of all these instruments, a glacial measure of the present climate. The history of past glacier fluctuations as far back in time as they can be worked out is a record of climatic oscillations of the past, but a record not merely of increases or decreases in temperature or in precipitation, but of the much more complex combination of *caloric heat balance* and the *water balance* of the ice mass.

The Record at Eliot Glacier on Mount Hood, Oregon

In order to gain an understanding of the mechanics of glaciers and the methods by which their recent history can be studied, let us examine the small Eliot Glacier (Fig. 2, A, B, Frontispiece) in the shady northeast slope of Mount Hood, Oregon's highest volcanic peak. This was the first glacier in the United States whose history was worked out in detail (Lawrence 1948). Its whole external anatomy can be seen at once. It is two miles long from the region of major snow accumulation at its head to its debris-laden tip in the valley below. It is nourished mainly in winter by snowfall especially at the 8000 to 10,000 foot level, and it melts and evaporates chiefly in summer. The individual ice crystals are constantly moving down slope in response to gravity, faster at high level than at low, and by the end of the first year some crystals have grown gradually at the expense of others from the minute spicules and plates of the original snow flakes to coarse granular particles called "firn." Ultimately they develop into giant interfingering crystals almost a foot across at the ice terminus. The ice, in passing over rough places in the valley floor, cracks to form deep crevasses and pinnacles. The whole ice mass can be felt to quiver at intervals as it moves ahead not smoothly but in a series of minute jerks. The position of the terminus may advance, remain static, or recede from year to year depending on the net nutritional balance between accumulation and loss, economy being governed by

Illinois, and when, in the now arid basins of the West, great lakes formed.



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coldness and length of winter, warmness and length of summer, precipitation as snow *versus* rain, sunshine *versus* cloudiness, wind *versus* calm, and humid *versus* dry air. Rock debris accumulated on top of the ice and within it is gradually transported to the terminus as by a giant conveyor belt mounted at its lower end upon a bulldozer. When the tip of the glacier stays in one place long enough, a pile or ridge of material accumulates forming an end moraine; and along the sides debris ridges form the lateral moraines. Subsequent advance pushes the ridge ahead, and recession leaves a stable surface upon which plants can become permanently established.

As we walk along the left edge of this simple glacier we see evidence, such as is common throughout the world, of great recent shrinkage, the concave shrunken ice mass heavily covered with rock debris moving along at about four feet per year and lying between high lateral moraine ridges (Fig. 2C). There are even some young trees riding along which are doomed to violent death when they roll off the steep terminal face. Along the left lateral moraine we notice multiple crests representing successive advances or hesitations in progress of recession.

One must realize that during glacier advance the ice was piled high above the tops of these ridges. A glance at an advancing ice stream, the Hole-in-the-Wall Glacier (Fig. 2D), a distributary tongue of the Taku Glacier, 20 miles northeast of Juneau, Alaska, will help one visualize the swollen contour and bulldozer action (Figs. 2, I, J, K) of a well-nourished glacier, one of the very few in the world which has advanced consistently through the past half century.

Almost every year since 1925 when measurement of Oregon's Eliot Glacier began, its terminus has been farther and farther up the valley, the ice stream becoming shorter by about 10 feet per year, and also notably thinner. On the valley floor and walls for nearly a half mile below the present ice terminus occurs a young forest grown up recently on the terrain from which the glacier has melted since the time of maximum recent advance. A sharp boundary, the forest trimline (Figs. 2, E, F), marks the limit of forest destruction brought about by advancing ice. One trimline tree scarred and pushed part way over by the ice pressure survived and recorded by a sudden change in symmetry of its growth layers that the time of maximum glacier advance was about 1740 A.D.

Brief return to the rare advancing Hole-in-the-Wall Glacier in Alaska allows us to see how this happened. The glacier has advanced into living forest in winter and has receded from it a little in the following summer revealing newly scarred tree trunks (Figs. 2, G, H). If recession had then continued and had the scarred trees survived, an enduring record of the year of maximum advance would have been made. But this Alaskan glacier did advance to destroy these trees completely the following winter. Possibly this glacier has advanced while others from the same ice field have been receding because the Taku Glacier system is nourished at a somewhat higher altitude than others (Heusser, *et al.*, 1954), or possibly because the great earthquake of 1899 may have altered its bed enough to allow more ice to move through its valley.

The time of maximum advance of Eliot Glacier in Oregon, as worked

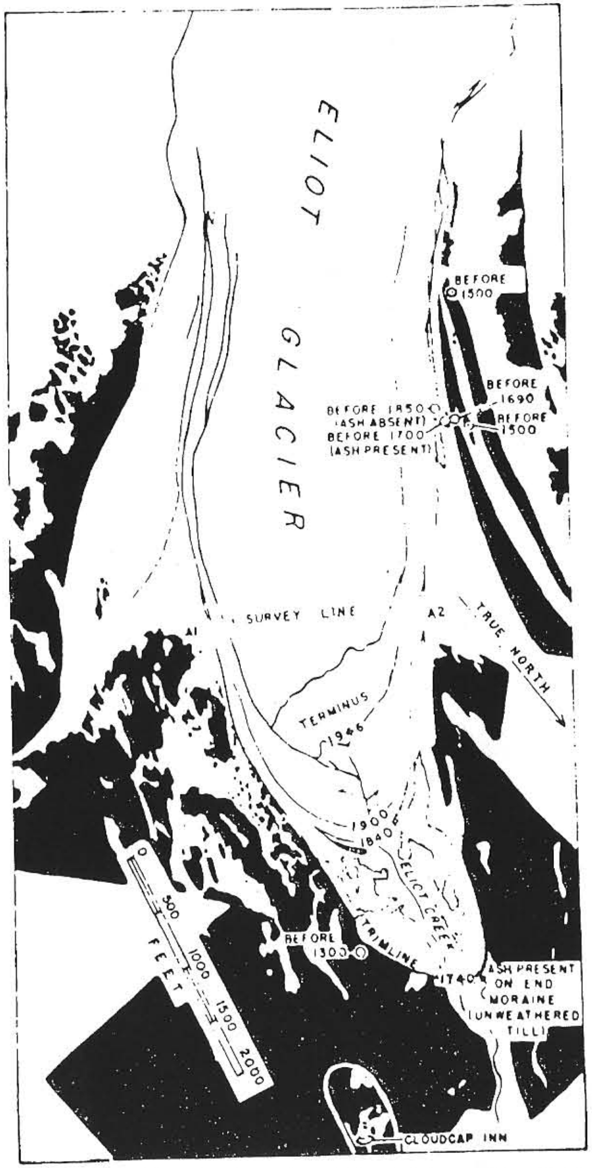


FIG. 3. History of Eliot Glacier, Mount Hood, Oregon (Lawrence 1948).

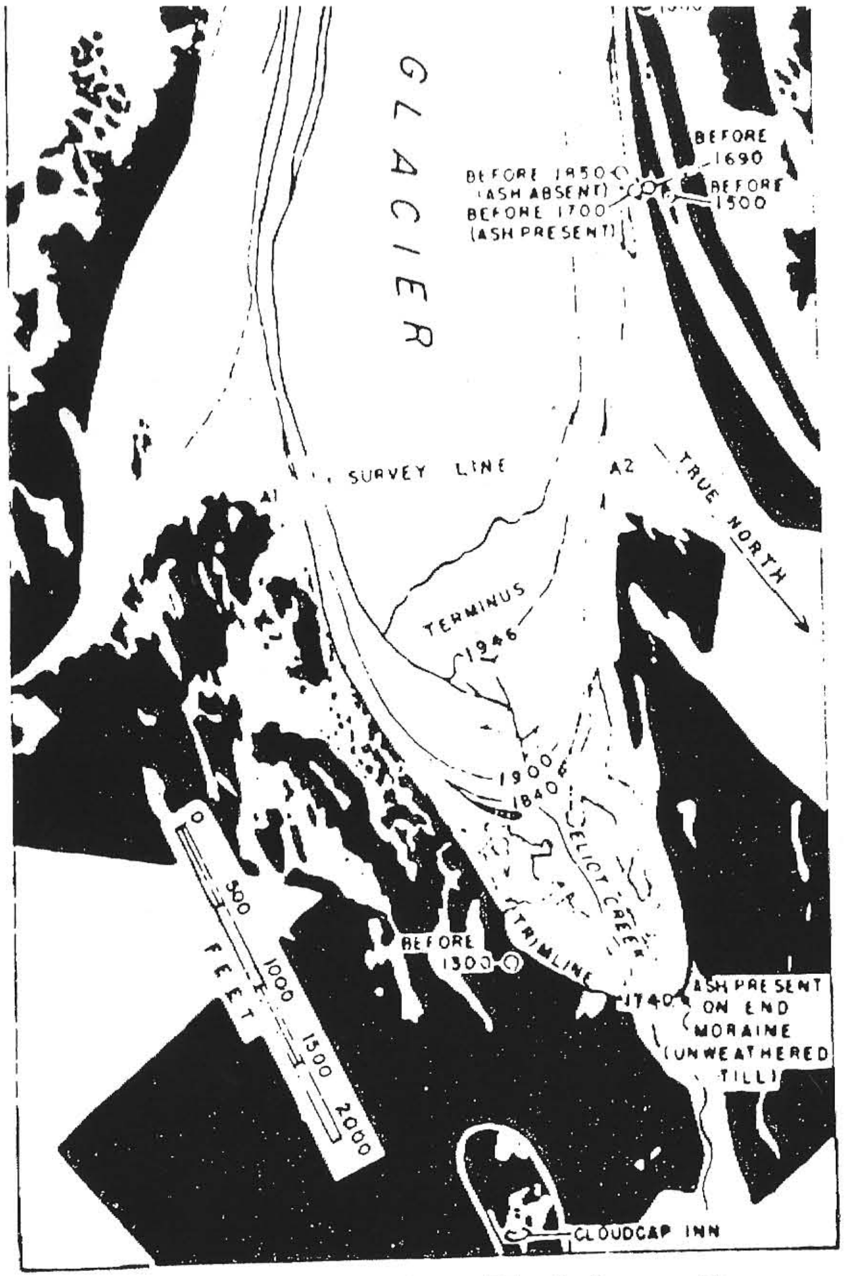


FIG. 3. History of Eliot Glacier, Mount Hood, Oregon (Lawrence 1948).

out from the ice-scarred tree trunk, was confirmed to within a few years by the age of the oldest trees grown up on surfaces left bare by receding ice. The history of recession up the valley (Fig. 3) has been followed by counting growth rings of the oldest trees at various places. Study of ancient trees in the old forest beyond the trimline showed that no more extensive glacier advance had occurred for at least 650 years.

This work on Mount Hood, originally suggested by Francois Matthes, has been supported by grants from the Mazama Hardesty Fund of Portland, Oregon, and would not have been possible without the devoted help in the field of Kenneth N. Phillips and of my wife, Elizabeth. The dating techniques involved have been published in detail (Lawrence 1950a).

The Record at Juneau Ice Field, Alaska

Now let us return to Southeastern Alaska, 1100 miles northwestward, where minute details of glacier behavior have been more completely recorded by the natural vegetation than perhaps anywhere else in the world. The most useful areas of study so far located for working out the latest 250 years of history are the valleys of the Mendenhall and Herbert Glaciers draining westward from the Juneau Ice-Field (Fig. 4).

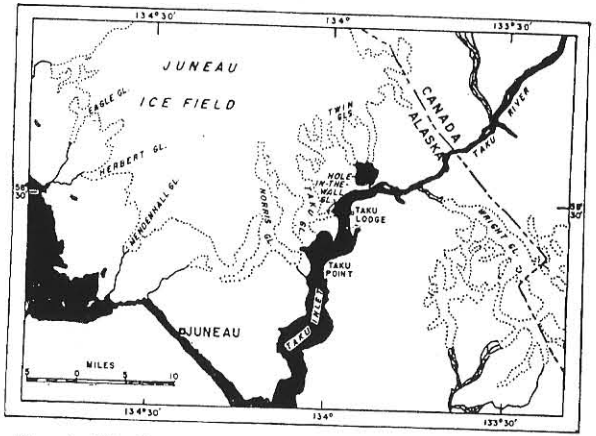


FIG. 4. The Juneau Ice Field, Alaska-British Columbia.

These Alaskan studies have been supported by the American Geographical Society of New York as a part of its Juneau Ice-Field Research Project, the Office of Naval Research, the University of Minnesota Graduate School, the American Philosophical Society, the Arctic Institute of North America, the U.S. Forest Service, and again the Mazama Hardesty Fund. The work has been stimulated and encouraged by William O. Field of the American Geographical Society, and guided in the field during various summers by Malcolm Miller, Calvin Heusser, and Lawrence Nielsen. About two score persons have been members of the high altitude teams studying glacier characteristics, nutrition, and movement. Our smaller teams comprising eight persons in all have concentrated attention in the rain-soaked evergreen conifer forest and peaty muskegs only a few hundred feet above the sea where the history of glacier oscillations for several centuries could be worked out in detail.

Taking off in a small plane from Juneau Airport in midsummer, we may get the bird's-eye view necessary for understanding the relations of glaciers and vegetation in this spectacular region. Close by the airport is the sparkling blue and white Mendenhall Glacier, its broad valley decked in forests of green differing in shade depending on age since ice recession. At the edges of the valley areas of reddish yellow mark open moss-edge muskeg on surfaces of much greater age where no disturbance by ice has occurred for many centuries. The glacier tip, about a mile and a quarter across, ends in beautiful powder-blue Lake Mendenhall in which float icebergs which are harvested to chill beverages in the bars of Juneau.

In the immediate foreground seaward and toward the airport from the lake one sees a set of concentric moraine ridges lying across the valley (Fig. 5A). The moraine ridge, farthest down the valley from the present ice-front, and closest to us in our plane, marks the position of maximum modern ice advance; ring counts of the oldest trees of its first generation forest reveal that the ice had begun to melt away from that advanced position by 1765 A.D. Beyond the limits of modern ice advance stand ancient living trees 600 years old, themselves rooted on the logs of a previous generation now imbedded in saturated peat, making it clear that at least a thousand years must have elapsed, and very likely several thousand, since the ice had advanced farther than its position of two centuries ago. Between the terminal moraine of the mid-eighteenth century and the ice are at least 20 ridges, recessional moraines, all more or less parallel to one another, marking positions of hesitation or slight advance in the two century period of general recession. The oldest ridges are covered with stands of towering Sitka spruce. Between the ridges are troughs marking intervening years when the ice melted back so rapidly across the landscape that almost no rock debris was deposited. Many of these troughs contain long narrow ponds, some with water so darkly stained that few submerged green plants can survive; over others rise the green pads and golden cups of the yellow water lily. Information gained from this Mendenhall Glacier valley (Lawrence 1950b) has served as an important bridge joining the recent past with prehistoric events. Detailed Forest Service maps made by the late Charles Forward are available to show positions of the ice-front every few years since 1931; thus the years between ice-melt and establishment of the time-keeping woody plants could be precisely ascertained. The Sitka spruces,

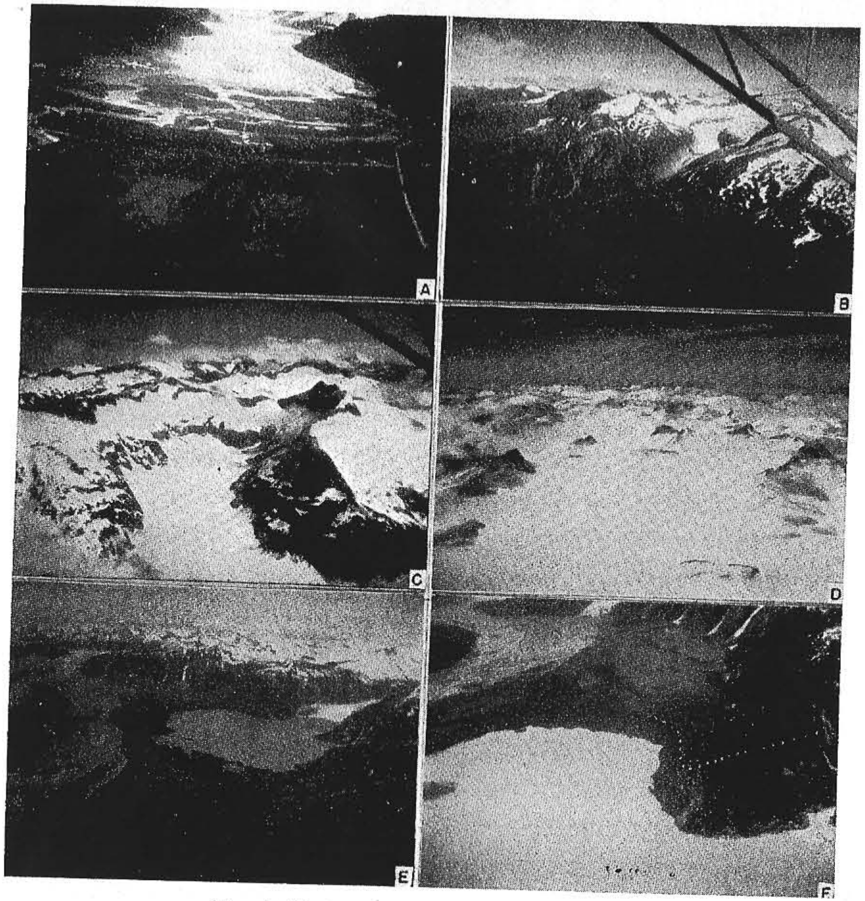


FIG. 5. Features of the Juneau Ice Field.

most useful in these studies because of their long life span, were found to require usually only five years for successful germination and establishment following melting of the ice, sources of seed being never more than a few hundred yards away. As a further check, dates derived from tree rings have been validated along lines of position of two ice fronts mapped by geologists in 1910.

As our little plane climbs in ever widening spiral over the sea to gain altitude for crossing the ice field, we glimpse occasionally some of the other glaciers which drain from the great 700 square mile Juneau Ice Field. Studies on six of these other glaciers have confirmed the conclusion reached at Eliot Glacier in Oregon, that maximum advances occurred in early or middle 18th Century. But, instead of receding only 2000 feet, these glaciers have receded about five times that distance, half of it since 1910.

Other evidences of recent climatic conditions more favorable to glacier growth than at present also greet the eye. Between the valley ice tongues and the youngest vegetation is a gray barren zone so recently exposed that vegetation has not yet had time to become established (Fig. 5B). Higher on slopes facing the sea and completely isolated from present glacier systems are saucer shaped basins (Fig. 5B, lower right) until a few decades ago perennially filled with snow. More recently, reduced snowfall and extended summer growing seasons have allowed meadow vegetation and then shrubs and now a few trees to grow, their youthfulness giving mute testimony to this recent climatic change. Above a sharp line on the walls of these basins stand gnarled elfin forests that have stood above the drifted snows for many centuries.

Sufficient altitude having been reached, our plane may follow upward from the jagged ice-front for ten miles along the winding glacier, its surface studded with ice pinnacles, and inlaid with pools of clearest blue. Back among the hills are ice cliffs and entering tributary ice streams bearing curving trains of rock debris scrubbed from confining walls. Farther back at the head walls where forces of erosion have been gnawing most fiercely at the bed rock are the symmetrical cirques, not single as one might expect, but in pairs one within another (Fig. 5C), which W. S. Cooper has suggested orally may represent two periods of glaciation, the outer, larger cirque carved during the Great Ice Age, the inner, smaller, subsequently carved during the "little ice age," which, however, he considers far too little to be a geological "age."

Finally, before we can draw our eyes from the features of the valley glaciers carrying their load toward the sea, we are flying over the smooth level surface of the ice-field where, should engine fail, a safe landing could be made at about 4000-feet altitude. Not all the surface is smooth, for we see protruding from the bright ice-field dark peaks sharply chiseled (Fig. 5D). Some had been completely submerged by increase in thickness of ice in recent centuries, scrubbed clean of vegetation, and are just now emerging with summers' increased length and warmth to provide space again for slow growing lichens, mosses, and hardy alpine seed plants. Other taller peaks had been only partly buried by ice and they reveal clearly by their dark green sedge-heath alpine turf, scraped off squarely from below, the maximum height to which the thickened ice field rose. The trend of climatic change is thus revealed as a long period favorable for alpine plant growth, followed by a period of increased snowfall and decreased snow wastage, and now the present phase during which the ice-field's surface has been lowered by 500 to 600 feet as shown by Heusser and his mountaineering teams (1954: 234), but the exact timing of these events has not been found possible there because of lack of woody time-keeping plants of sufficient age. For more exact information on timing we must return to near sea level where ice tongues forced their way into deep forests wreaking havoc, then withdrew leaving sharp forest boundaries or trimlines, some clearly visible to this day (Fig. 5, E, F), along which the tree ring record of contact with ice can be read.

The Record at Glacier Bay, Alaska

Off to the westward 50 to 100 miles from Juneau lies the Glacier Bay National Monument preserved since 1924 as part of our National Park system through efforts of foresighted scientists lead by Cooper (1956). There, records of the little ice age are more completely preserved than anywhere else known, and glacier recession is most exaggerated, the trunk tidewater glaciers having wasted away 15 times more rapidly than anywhere else in the world. This region is perhaps the most interesting portion of the earth's surface for the study of glacier history and the development of forests following the recession of the ice. This is true because of the extraordinary rate of recession that has taken place since the maximum advance was reached about two centuries ago. Since then there has been a recession of 61 miles to the faces of Grand Pacific Glacier and Johns Hopkins Glacier at the heads of the west arm of the Bay, and of 43 miles to the Muir-Riggs ice-front at the head of the east arm. Beautiful U-shaped valleys and new fiord systems have been thus exposed, whose waters are in places over a thousand feet deep, and whose surface on a clear day reflects, between large icebergs, the images of many peaks over 5000 feet and one, Mount Fairweather, 15,320 feet high.

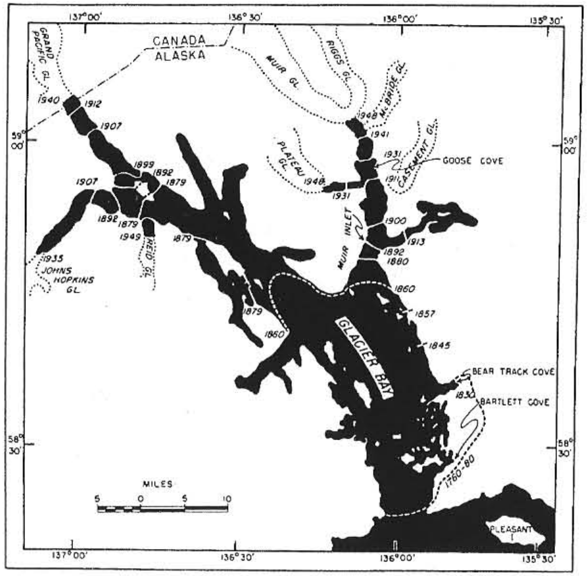


Fig. 6. History of ice recession at Glacier Bay, Alaska.

The map of Glacier Bay (Fig. 6) shows known positions of the ice-fronts (solid lines), and supposed positions (broken lines) based on a variety of sources. We are greatly indebted to Cooper (1937) for estimating, from the rings of trees growing on a portion of the terminal moraine, the time of beginning recession of the ice in the middle 1700's when the bay was filled completely to its mouth. To Captain Vancouver we owe our knowledge of the 1794 position when there were *two* great bays bordered on the north by ice-fronts. The 1860 position is again based on tree rings. Our detailed knowledge of positions begins with 1879 when John Muir visited the area. Later positions have been mapped by others, including especially Field (1947) who has brought together all available data on the history of the Muir Inlet side of the bay.

At the head of the arms of the bay are great ice-fronts in contact with the sea whose tides fluctuate daily through a range as great as twenty feet. At high tide the relatively warm salt water melts the ice faces with which it is in contact more rapidly than does the air so that the face becomes undercut, and, as the tide recedes, the upper ice-face, less well supported than before, breaks off in great masses (Fig. 7C), beginning slowly enough with widening crevasses so that cameras can be finally adjusted before the climactic crash into the sea raises plumes of spray and giant rolling swells which move slowly, distorting reflections of adjacent mountains as they expand in ever widening circles down the bay. Then, when activity has appeared to be over, a new phase is discovered in progress at the base of the ice-cliff as pale blue pinnacles of ice begin to rise from the water, the buoyancy bringing upward sections of the ice-cliff which had just previously fallen so tumultuously from above. Occasionally another kind of berg appears, of clear deep blue ice with rounded surfaces, for which the smaller white berg fragments make way as it emerges from below like a whale coming up to spout. These are chunks of underwater ice broken off from submerged parts of the glacier tip. After passage of summer days with frequent caving, icebergs accumulate at the head of the bay, especially when southerly winds keep them from moving toward the more open sea, and the surface waters become so choked with bergs (Fig. 7D) that it is difficult for motor vessels to traverse the inlets. When tides recede many small bergs stranded on shore reveal by blue rounded form below and rough white angular parts above that about nine tenths of their depth had been submerged (Fig. 7E). Close observation of the stranded bergs reveals that they are made up of giant crystals of ice, irregular in surface configuration, and interfingering with each other like a three-dimensional picture puzzle. It is at the interfaces between these crystals that melting by the salt water and sun begins, and by grasping a delicate projecting

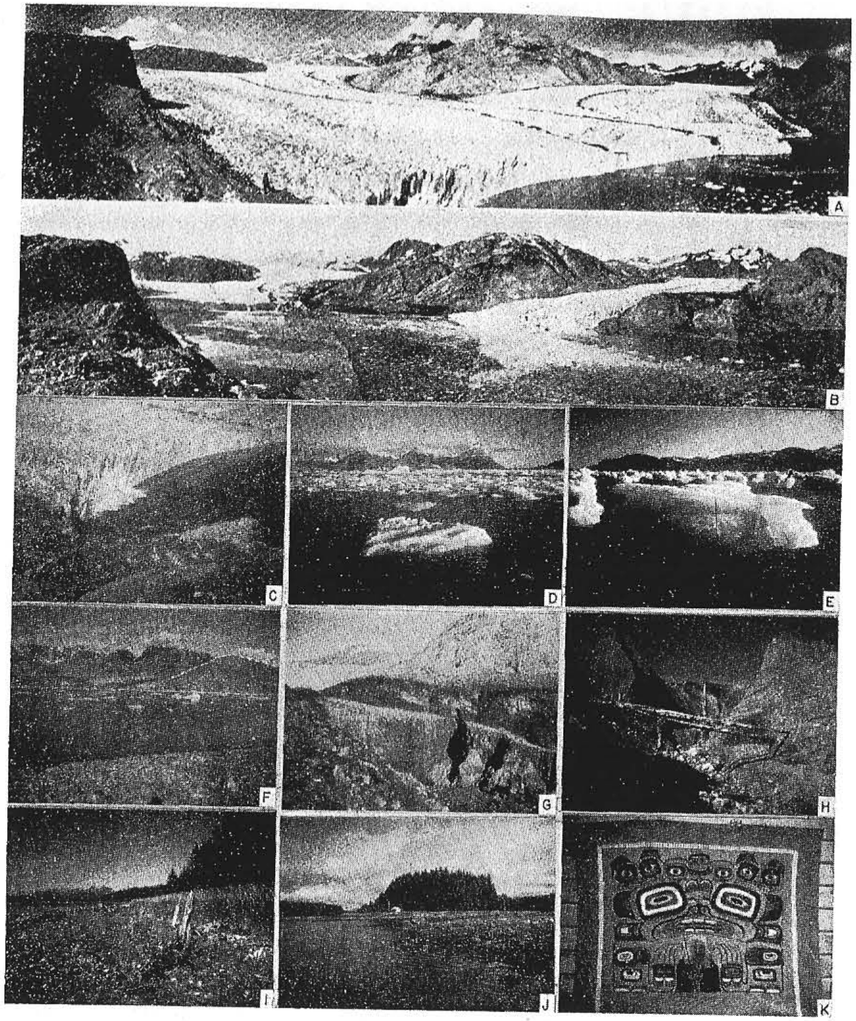


FIG. 7. Features of Glacier Bay, Alaska.

portion of a berg, one discovers that the ice structure has become flexible, movable with squeaking sounds along the junctions of the crystals.

Through comparison of photographs (Fig. 7, A, B) taken from the same spot in 1941 and 1949 it is possible to gain a visual impression of the recession of over two miles at the head of Muir Inlet in those eight years. Similar comparison of photos taken in 1910 and 1941, and soundings of the fiord, have revealed a vertical wastage of about 2175 feet of ice in that 31-year interval. The 1175-foot hilltop at the right in the 1941 photograph of Figure 7F was just beginning to emerge from the ice in 1910. The water there is over 1000 feet deep. At the 18th century maximum the ice stood here 3000 feet above present sea level. With the progress of this catastrophic melting, extreme erosion by meltwater streams has occurred in gravel beds previously overlain by the ice (Fig. 7G), and groves of unpetrified stumps of fossil forests have thus been brought to light. The oldest at the head of the bay (Fig. 7H) was alive about 7000 years ago according to radiocarbon dating by Preston, Person, and Deevey (1955: stump Y 132–81); the species in the groves include spruces, hemlocks, cottonwoods, willows, and alders, the same tree and shrub species which clothe the walls of older fiords beyond the mouth of the bay today. Other of the fossil forests are apparently of as many as 14 different younger ages, but we do not yet know how many of these succumbed to glacial advances, and how many to other physiographic events; careful stratigraphic studies are needed. John Muir in his early visits used the wood of these fossil trees to heat water for his tea, because there was no other fuel available then. On the shores of Bartlett Cove near the mouth of the Bay stand the youngest fossil groves of all, the wood well preserved even with bark still in place below the surface of the beach from which the stumps protrude (Fig. 7I). Excavation revealed that some were rooted on horizontal logs of a previous forest, indicating that several centuries had elapsed since a previous glaciation had reached this far down the bay. Radiocarbon dating of this forest also by Preston, *et al.* (1955: stumps Y 132–83 and Y 132–86) and by Barendsen, Deevey, and Gralenski (1957: stump Y-308) shows that these erect stumps were living trees less than 300 years ago; they were dated "modern." But they stand at a level where trees could not possibly grow now. Some are indeed rooted among seaweeds between the tides at levels at least 20 feet below the most venturesome young spruces living along the adjacent shore today. Less than 300 years ago when the fossil stumps were living trees the ice advanced from some unknown line of retreat to the mouth of the bay, overwhelming the forests as it moved ahead and depressing the land as the load of ice increased where none had been immediately before. This action is of course similar to the measured depression of the earth's crust by Lake Mead's water load impounded behind Hoover Dam on the Colorado River (Carder and Small 1948). Though the ice has been gone now from the mouth of the bay for about two centuries, the land surface has not yet rebounded to the level at which it stood in relation to sea surface before the ice advanced. But the land is rising rapidly as surveyors have shown (Twenhoffel 1952) from one half to one inch per year in this general vicinity. Even without the testimony of surveyors one can tell from vegetation evidence alone that the land is rising rapidly along the shores of Bartlett Cove at the mouth of the bay, for the forest of young spruces is migrating out on strands (Fig. 7J) which a few years ago were covered only with salt-tolerant shore plants. It may take another 250 years before the land can rebound from the depression produced by the load of the latest glacier extension. And even then rebound may not be complete because previously unconsolidated strata have very likely been permanently compressed and because of the heavy mineral deposits left by the ice, and meanwhile the sea level is rising because of the world-wide trend of glacier melting. Some of the rising of the land in this general region has not been gradual but sudden and catastrophic as in the Yakutat Bay earthquake in 1899 when land rose almost 50 feet and many glaciers were badly shaken up (Tarr and Martin 1912).

It is interesting to examine the tradition of the local Indians regarding these events in Glacier Bay as it has been handed down orally by rote in a carefully memorized chanted story from Tlingit mother to daughter at the town of Hoonah, across Icy Strait from the mouth of the bay. This story told in 1952 by Mrs. Lonnie Houston and recorded by Mrs. James Seitz (personal communication 1955) tells of the rapid advance of ice down the river valley destroying villages and causing the Indians except one old woman "Kostine" to flee, while she alone remained to be overwhelmed by the ice. The story relates the surprise of natives returning after ice recession to find that terrain from which they had been evicted by the glacier was, after the ice had eroded and depressed the valley floor, a bay rather than the river valley known before ice advance. This event of the little ice age is commemorated in a modern Indian blanket designed by John Lawson and owned by Mrs. Helen Clements of Hoonah and Elfin Cove. In the blanket (Fig. 7K) the ice claws of the animal glacier spirit are about to overwhelm old Kostine. Similar Indian stories have been recorded along a 600 mile stretch of coast from Icy Bay (Miller 1948) in the northwest at Latitude 60° N to Queen Charlotte Island (Deans 1899: 3) at Latitude 53° N to the southeast, but unfortunately they provide no real clue as to when the ice advance occurred.

The Record at Nigardsbre, Norway

Information on histories of North American glaciers immediately prior to 1700 A.D., that is, during the period of advance, is still lacking except for radiocarbon dating which shows that the stumps of trees overridden by the latest ice advance were alive less than 300 years ago, their C^{14} content being similar to that of living trees. For detailed history of the glacier advance one must go to the most similar region one can find where man-recorded history is sufficiently long. That region is southwestern Norway. The Nigard Glacier located near latitude 61°40′N, longitude 7°15′E, which drains out from the Jostedalsbre, largest ice-field in continental Europe, provides a favorable comparison (Fig. 8A, view westward). The history of ice advance there has been carefully studied by Faegri (1948) who has reported these events as follows: "Some time during the late 17th century a very strong glacial advance

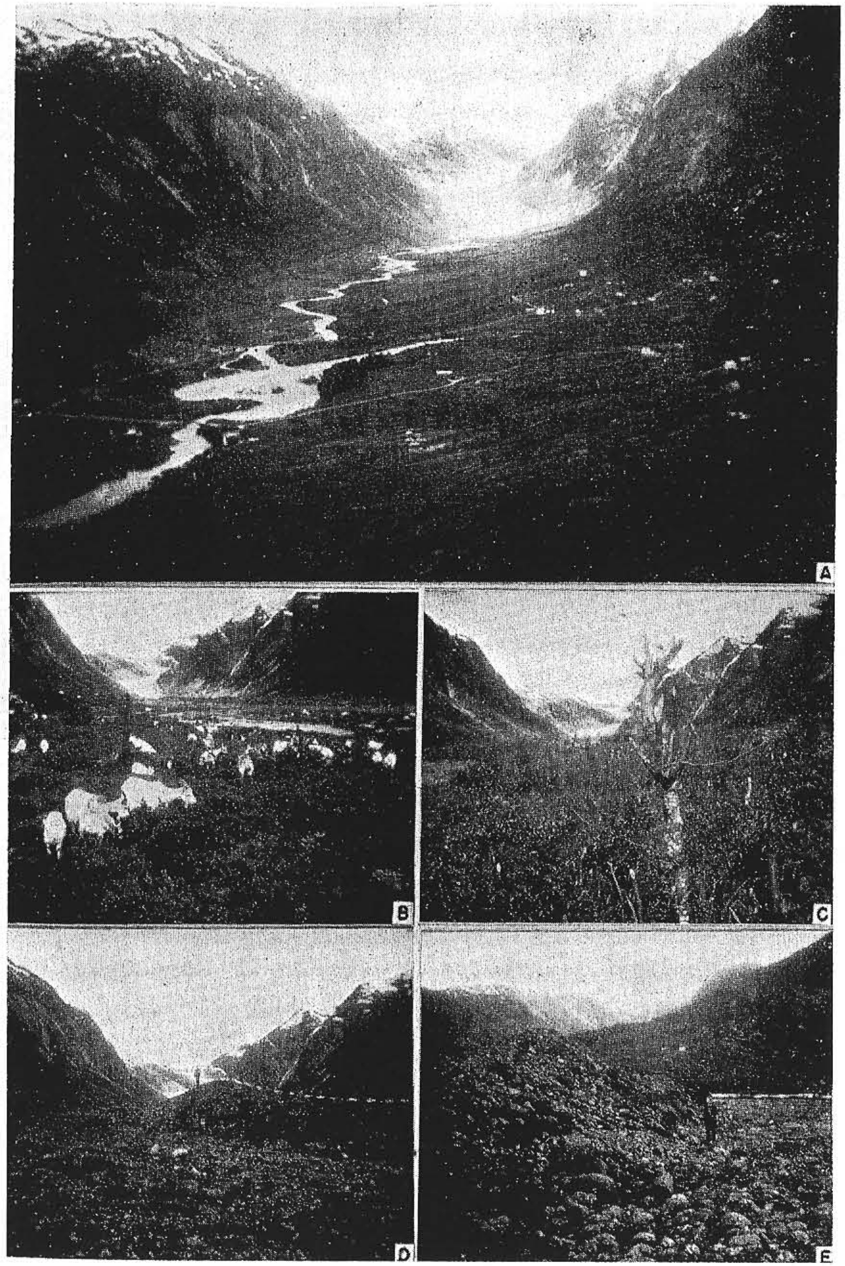


Fig. 8. Nigard Glacier, Norway.

made itself felt: the glaciers came down into the valleys, covered previous pasturages, and even destroyed farms and houses. Thanks to this last-mentioned effect we possess some evidence of the extent of the damages as land-taxation protocols reflect the diminishing value of the affected farms. It is, of course, very difficult to establish the extent of the glaciers before the advance. Probably they were of about the same order as today. They then advanced some kilometers during the former half of the century [18th]. In 1750 the vicar of Jostedal, Foss, wrote that the Nigardsbre had receded since 1748. Obviously the glaciers were oscillating for some time about the maximum stage before effective recession started, as is shown by the highly complex character of the 1750 moraines in front of Nigardsbre and other Jostedalsbre glaciers."

Mrs. Lawrence and I consider ourselves most fortunate to have visited the Nigardsbre with the kind help of Professor Faegri in the summer of 1956, spending three days comparing the features left in its valley below the present tip of the glacier with those we have come to know so well in Southeastern Alaska. We found that the valley below the Nigardsbre from which the ice had begun to melt in 1748, and even the older surfaces farther down the valley were still unforested for the reason that, throughout this period of over two hundred years, goats have been let out to browse each suitable morning and all the most palatable plants have been eliminated. Now even the most unpalatable elements of the vegetation are held within a few inches of the ground by constant nibbling (Fig. 8B) so there is in effect a goat-desert at least on the southerly side of the formidable river which drains away from the ice. On the north side, to which access by goats is prevented by a gate on the bridge, the farmers go with knives and hatchets to cut off the tops of young birches and willows (Fig. 8C), tie them in bundles, and carry them off to the barns for winter goat feed. So it has come to pass that no woody time-keepers have survived to tell the story of ice recession. This would be very sad indeed were it not that the man-kept record tells the story for which in Alaska we have had to depend on trees up to four feet thick to reveal. The barren 18th century terminal moraine is visible in Figure 8, D, E.

Recapitulation

If we examine a map of the northern hemisphere we may review at a glance what we have learned thus far about the recent history of glaciers, starting as we did with the Eliot Glacier on Mount Hood where the ice advanced to a maximum extent about 1740 A.D., then withdrew up the valley 2000 feet; the glacier had not advanced farther than its 1740 position since 1300 A.D. at the latest. Then we moved 1100 miles northwestward to Southeastern Alaska, to the Juneau Ice Field, where the history was similar but available in much greater detail. There the earliest recession from positions of maximum advance thus far discovered was 1700 A.D. Ancient undisturbed forest and deep muskeg peat on undisturbed terrain attest that the ice had not been beyond that trimline since the year 1000 A.D., and quite possibly for several thousand years before that. Recessions of two miles are common. Then we viewed the history of Glacier Bay where maximum advance occurred less than 300 years ago, and recession began in the middle of the 18th century, with horizontal recession as much as 61 miles, and vertical dissipation as much as 4000 feet since then. Then we moved to southwestern Norway where we found the same history with the added detail recorded by human beings that advance *began* as recently as the latter part of the 17th century. Literature review reveals that the history has been similar in Iceland (Thorarinsson 1956), East Greenland (Koch 1945), and in the Canadian Rockies (Field and Heusser 1954) and the Coast Range of British Columbia (Mathews 1951). Thus, we have found in our work and in that of others, except in Switzerland where some maxima occurred a century earlier (Matthes 1942), a broad geographical synchronism in time of maximum glacier extent in the 17th and 18th centuries which was greater than it had been for at least four to nine centuries previous to that time and possibly for much longer.

Glaciers and Solar Activity

Why did the glaciers advance when they did? It has seemed to us that events of such broad geographical concordance cannot have been purely coincidental. Unfortunately, there are no weather records extending far enough back to reveal the causes of this widespread though minor glaciation. The only data which we have thought might be useful are the sunspot records which go back to 1610 when Galileo built his first telescope. Figure 9A (Menzel 1949) shows the heavily spotted sun on Aug. 14, 1947 as an example. In a survey of these records, the British astronomer Maunder (1921–22) discovered a great sunspot dearth period from 1645 to 1715 A.D.; during those 70 years only a very few spots were observed (all in the sun's southern hemisphere). In southwestern United States astronomer Douglass (1919) had independently noted in the tree ring patterns of Ponderosa pines, in which the wide rings of wet years are related to solar activity, a failure of the "11-year" sunspot cycle over essentially the same period. Discovery of the synchronism of this great sunspot dearth period with the time of maximum recent glacier extension suggested the stimulating hypothesis that glacier growth in these particular regions may have been brought on by decreased solar energy. How the conditions in the sun, varying as they do between sunspot high and low, can influence the climate of the earth is at present a controversial issue. As a matter of fact, so many terrestrial phenomena have been blamed on sunspots that many people have come to discredit

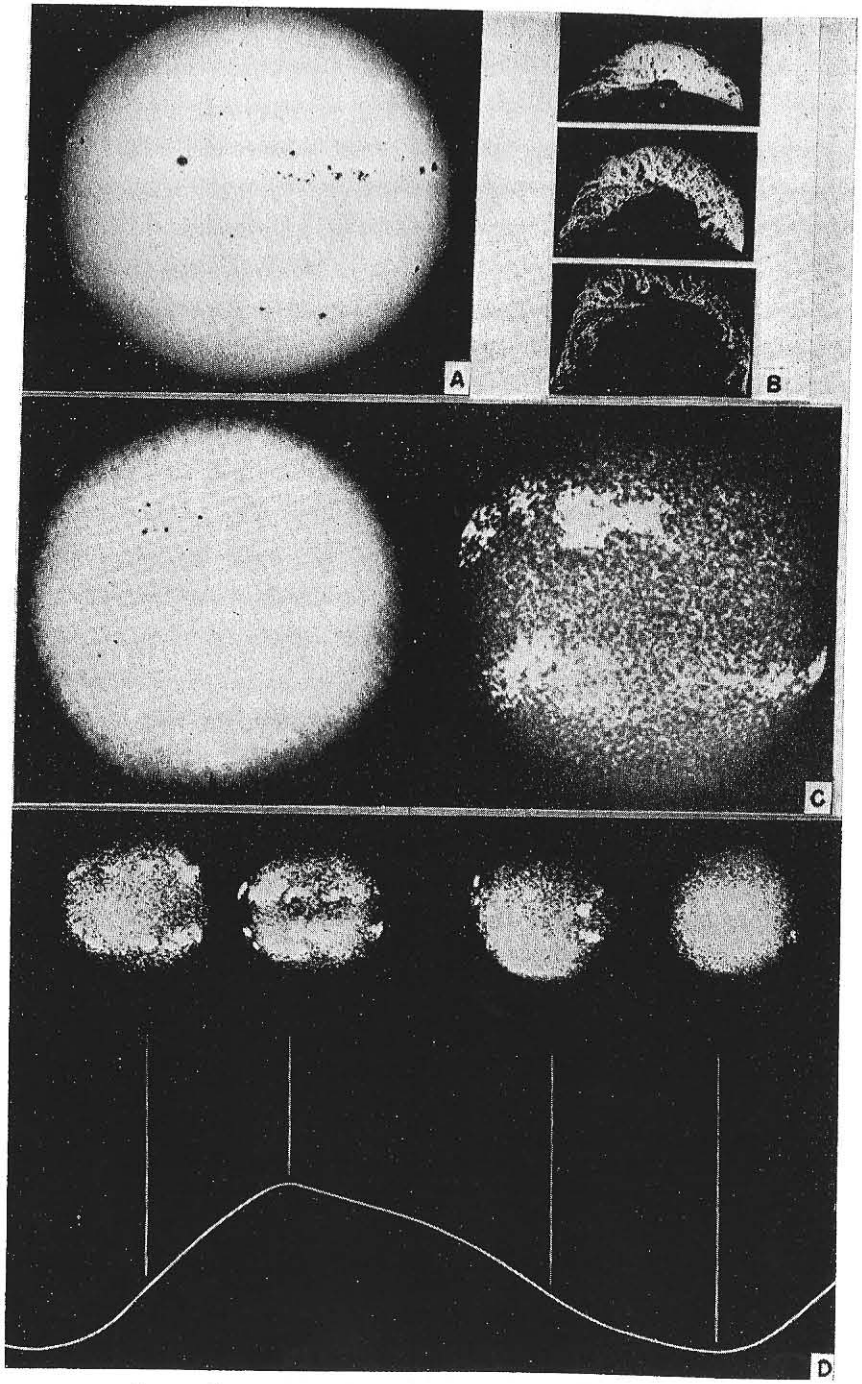


FIG. 9. Sunspots and the sunspot cycle (really half-cycle).

their effects entirely. It seems to be the present consensus that the sunspots themselves are not so important, but they may be considered rather as symptoms of disturbances of very great magnitude when the sun is more excited than usual and is giving off more energy. Most of us are familiar with some electronic effects of solar excitation as when radio reception fades. One visible form of solar excitement is revealed by photographs of the edge of the sun taken with a coronagraph which produces essentially a continuous eclipse by keeping a black disc over the luminous portion of the sun. Thus at Climax, Colorado, for example, Roberts (1952) on 4 June, 1946 photographed an intense eruption of hydrogen. Figure 9B, taken from Menzel (1949) shows three stages of this flare within 48 minutes; the white dot indicates the size of the earth. These hydrogen prominences develop most commonly in the vicinity of sunspots, and most frequently at the high portion of the sunspot cycle. If we now compare ordinary photos of the sun (Fig. 9C, from Menzel 1949, left) with spectroheliograms (right) taken at the same time but using only the light of glowing calcium, we note that there are large areas of the sun's surface adjacent to the sunspots which are covered with glowing clouds of calcium called flocculi. Study of these calcium heliograms taken at different stages of the sunspot cycle (Fig. 9D, from Clayton 1943) reveal that, at the trough of the cycle, there are almost none of these glowing clouds of calcium drifting in the atmosphere of the sun, whereas at the peak of the cycle there are many glowing clouds surrounding the much smaller sunspots. Thus far, in the investigation of the total amount of energy in sunlight, it has been impossible to demonstrate more than a very low per cent of gain in energy received at the earth's surface between sunspot low and high. In the ultraviolet portion of the spectrum the intensity may increase as much as 100 per cent (Stetson 1947: 180), and showers of cosmic rays from the direction of the sun sometimes accompany solar outbursts (Korff 1957: 288).

In order to learn what relation may exist between solar activity and glacier nutrition, we may return to the Juneau Ice Field and examine the record left by two of the glaciers draining from its western edge. The area most carefully studied in this regard (Lawrence and Elson 1953) is located about 25 miles north of Juneau. It is the portion of the valley freed from the ice since the Herbert Glacier began to recede in 1700 A.D. Here a series of about 20 more or less parallel crescentic morainal ridges separated from one another by troughs has been more beautifully preserved than at any other place yet discovered (Fig. 10, A, B). Study of many ridges including those seen in front of the Mendenhall Glacier (Fig. 10,C,D), by the technique of aging the oldest tree that could be found on each and correcting for time required from ice-melt to seedling establishment as described earlier, has revealed the strong tendency for moraine formation to occur with low sunspot number intervals of

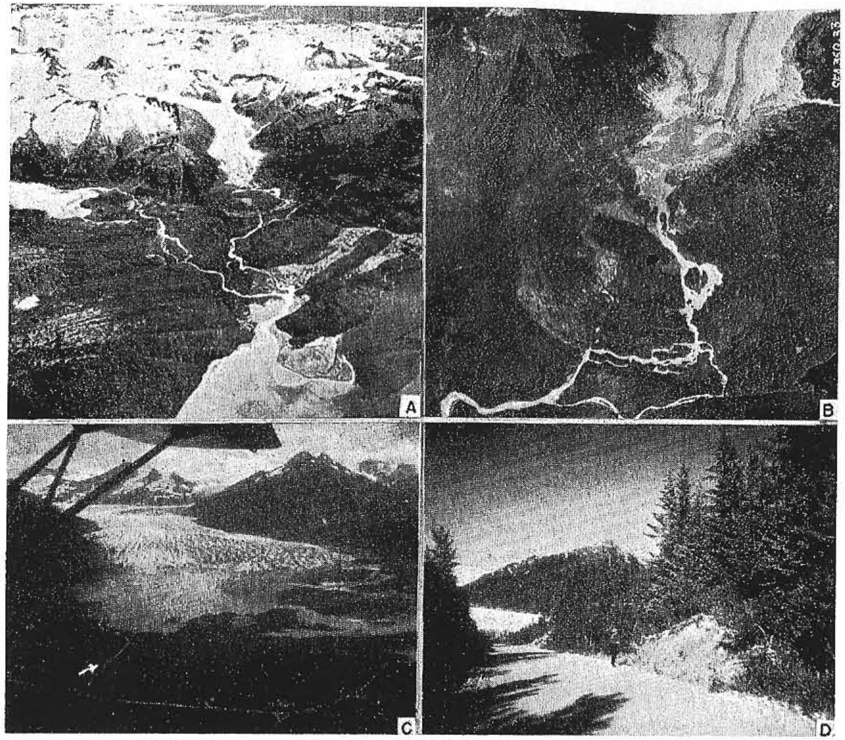


FIG. 10. Herbert (A, B) and Mendenhall (C, D) Glaciers and recessional moraines.

about 11 years, suggesting that favorable glacier nutrition existed then, and unfavorable nutrition at high sunspot number. Of course, the tree-age method used in this study is not precise enough to enable us to be sure that the glacier tip stood at a certain place in a given year. Nor can we be certain yet that the glacier tip is in equilibrium with the whole mass of the glacier. But, I believe now that there is normally no lag between a climatic change affecting glacier nutrition and the response at the tip, at least during glacier advance and early recession in glaciers whose region of nutrition is very large and of uniform altitude as is the general situation for the Juneau Ice Field of Alaska and the Jostedalsbre of Norway. The observations on the Nigardsbre outlet of the Jostedalsbre by Faegri (1948) showing the position of glacier tip each month in relation to monthly temperature, showed no lag in response. The winter advance and summer recession of the terminus of the Hole-in-the-Wall Glacier in Alaska also suggests absence of lag. Future studies of annual photos and measurements in regions of nutrition and at glacier tips should eventually reveal whether lag occurs or not.

The question now posed is: how can changes in solar activity as indicated by sunspot number bring about variations in size of these glaciers? By what meteorological mechanics is the nutritional balance of glaciers regulated? To the best of my knowledge the first person to study the relation of solar activity to terrestrial weather was H. H. Clayton (1943). He selected for special analysis the relation of sunspot number to barometric pressure, probably because there were more and better data available on pressure than on any other element of weather, but also because he reasoned that if changes in atmospheric pressure patterns were found to be associated with changes in solar activity, other characteristics of weather would surely be related also. One might dismiss as unimportant Clayton's studies on barometric pressure and sunspot number because the correlations are weak, ranging from plus 0.4 to minus 0.3. When plotted geographically as in Figure 11, they make, however, a sensible pattern and give one a hunch about relationships. Highest correlations he discovered between these two occur on the north Pacific coast of North America and central Alaska in the winter season; other regions of recognizable correlations are in south Greenland, southwest Norway, east Asia, and the Hawaiian Islands. Some of the correlations are positive, some are negative, some are related to winter and some to summer season. In many regions of the world he found no correlation whatsoever. Subsequent detailed study of Alaskan data by Bodurtha (1952) has substantiated Clayton's discovery; higher than normal barometric pressure had occurred in winters of high solar activ-

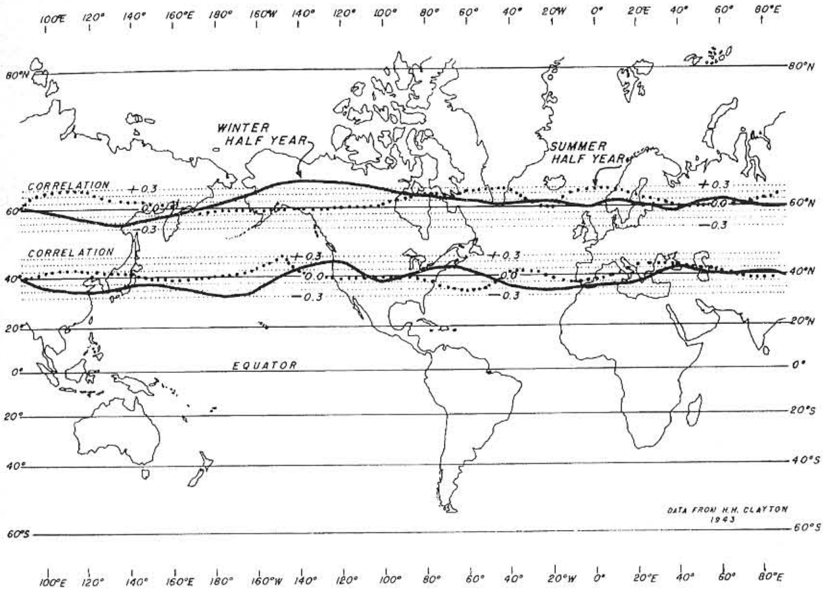
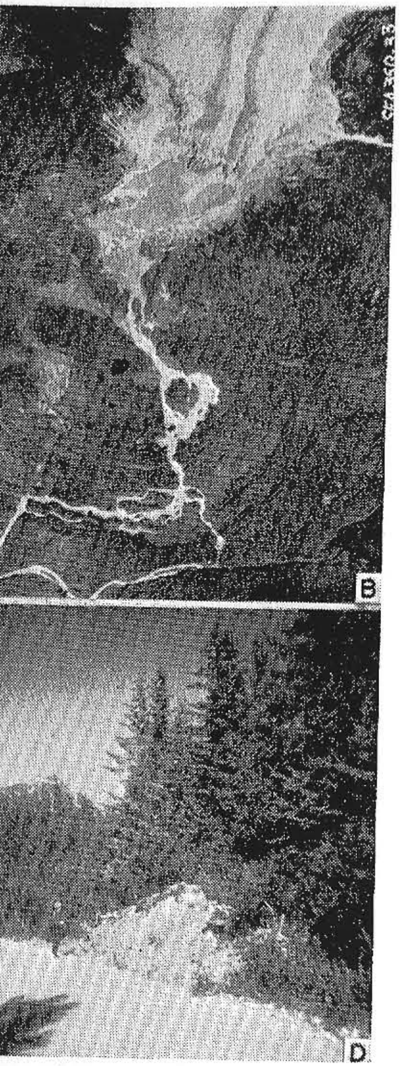


FIG. 11. Correlation of barometric pressure with sunspot number, after Clayton (1943).



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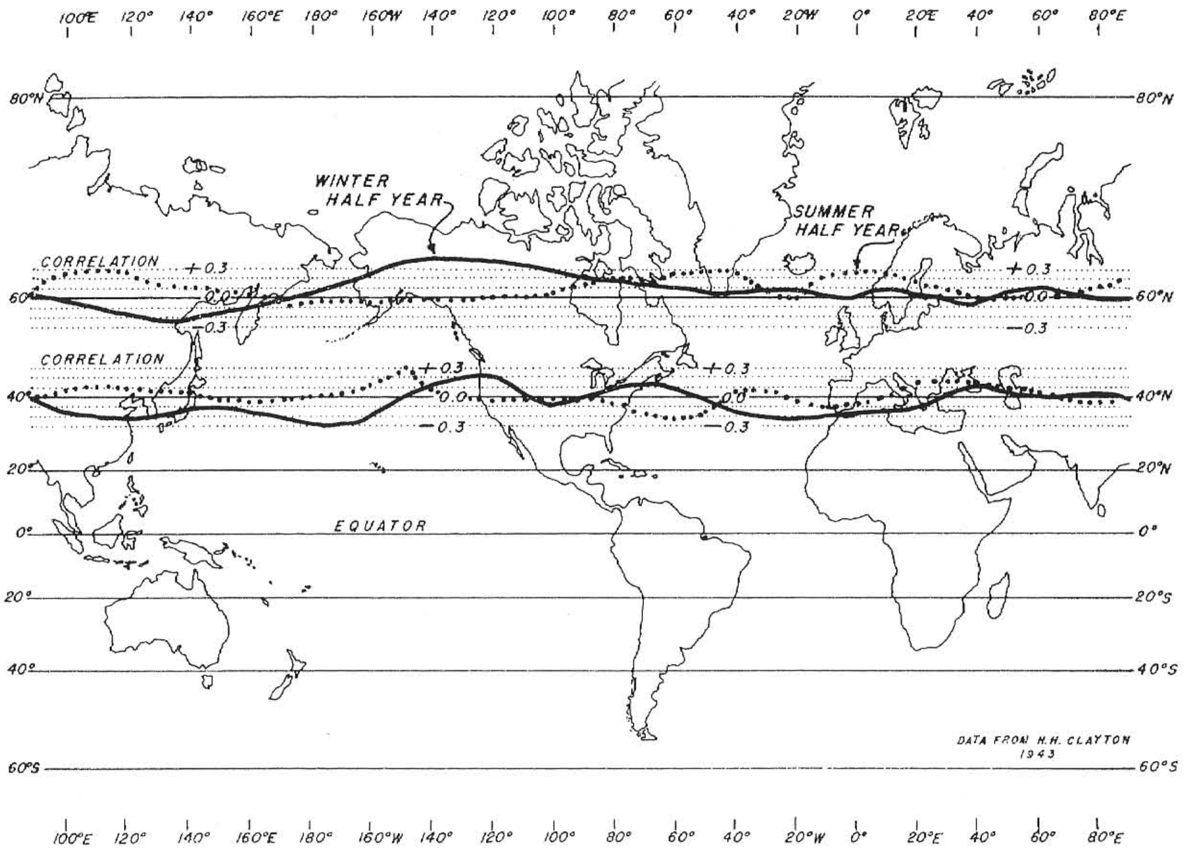

FIG. 11. Correlation of barometric pressure with sunspot number, after Clayton (1943).

ity, amounting to more than twice as many anticyclones per winter and a mean increase of 5.1 millibars (Fig. 12). Located on a knife edge between maritime climate to the west and continental climate to the east as is the Juneau Ice Field, and receiving a large portion of its precipitation in the winter, any significant changes in regional barometric pressure could strongly influence the local weather. Barometic pressure shifts may change paths of storm tracks, precipitation, temperature, wind, sunshine, and cloudiness, and these, in turn, can strongly influence glacier nutrition especially in glaciers nourished over snow-fields as broad and relatively level as are the ones here discussed which have behaved so sensitively. A very fragmentary preliminary study of the Juneau weather record suggests that high sunspot number is associated with unusually cold, calm, dry winters, and low sunspot number is accompanied by warm, windy, and wet winters, but we do not yet know how this would act to influence glacier nutrition. Regarding summer ice wastage near Juneau, we have definitely learned from Hubley (1957) that it depends very largely upon the number of warm storms passing over the glacier.

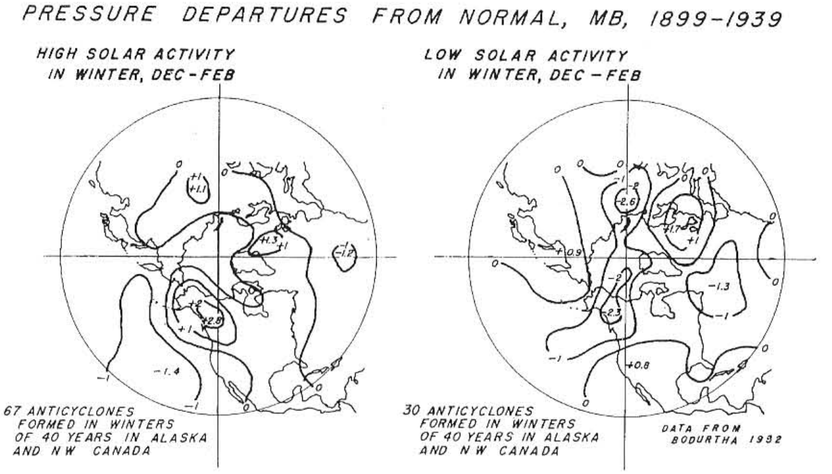

FIG. 12. Barometric pressure departures from normal in relation to solar activity, after Bodurtha (1952).

There is a growing literature on the relation of our weather to solar activity beginning with Huntington and Visher (1922) and Visher (1925), and to which Willett (1951) and Arakawa (1955) have been recent major contributors. The detailed studies of glacier nutrition and weather being carried on during the IGY, purposely centered astride the crest of the sunspot cycle, will surely help provide additional data for understanding this and other cosmic-terrestrial relationships.

Within the past 40 years it has been discovered that sunspots tend to occur in pairs (Fig. 13A) with definite positive and negative magnetic polarity (Stetson 1947: 122). Changes in polarization and splitting of spectral lines of the light from the spots show that the magnetic sign of leading and following members of a pair become reversed in succeeding 11-year periods (Menzel 1949: 123). This has led astronomers to realize that the 11-year average period between peaks of the "sunspot cycle" is really just a half-cycle and that the two adjacent half-cycles should be plotted graphically above and below a zero line as one would plot the curve of alternating current (Anderson 1939). When one examines the graph of whole 22-year sunspot cycles plotted as they should be (Fig. 13B, after Anderson 1939), new relationships not before discovered become evident, and there appear strong suggestions of periodicities of even longer term than the 22-year cycle. The dotted line as shown in Figure 13B was added by Anderson from component harmonics of a 312-year period. When one compares these theoretical curves of solar activity, based on mathematical analysis of the past record, with the actual record, especially for recent years, one realizes how poorly qualified we still are to predict even when the next peak of solar activity will come and what degree of activity will be attained. We may conclude that our knowledge of the variability of our own sun is still at a low level. Here again we may be sure that the studies being carried on during the

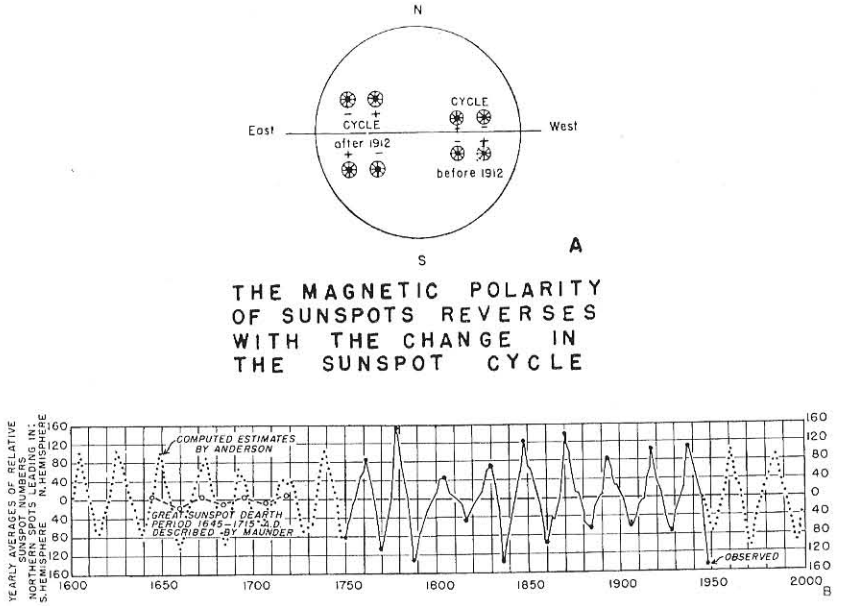

FIG. 13. Sunspot pairs and the full sunspot cycle (sometimes called the double Hale solar cycle).

IGY will be of great value. Karlstrom (1956) has assembled data from a variety of sources which he feels point toward "a fundamental climatic cycle with a base periodicity of about 500–600 (550) years, strong recurrences every 1000–1200 (1100) years, and major recurrences every 3000-4000 (3400) years." He made no suggestion as to possible cause.

Although many hypotheses of the causes of climatic change and of glacial epochs have been proposed, they were developed for periods so remote from the present that the time element was very inadequately known. It has seemed to us that we are most likely to arrive at valid solutions to the problems of why glaciation has occurred in the past by studying with extreme care the glaciation, though it was rather minute, which occurred so close to us in time, only two and a half to three centuries ago, that it has been rather precisely dated. Though our weather and cosmic-terrestrial data have many exasperating gaps, it is possible to find in the record some well documented years and sets of years in which there are extraordinary aberrations from the normal. Faegri (1950) has recently expressed the opinion that periods of glaciation were similar to these historic aberrations but extended much longer. If we can find out the causes of these we shall stand in a much sounder position for testing the various hypotheses as to causes of glaciation.

Critical testing in the light of historical or recently dated events has been begun on some hypotheses, namely: atmospheric carbon dioxide by Plass (1956), volcanic dust by Wexler (1956), meteoric dust by Bowen (1953), and solar variation by Clayton (1943), Kullmer (1943), Willett (1951), Abbot (1952), Bodurtha (1952), and Lawrence and Elson (1953). It is hoped that the present paper may provide additional facts for testing. Other new hypotheses are sure to appear as our understanding of the universe improves and as new minds focus their attention on the problem. For example, following my lecture at Cornell University, an astronomer, Professor S. L. Boothroyd, proposed one which he believed to be new, the possibility that the earth in passing through regions of space richer in hydrogen would by combination of the hydrogen with the oxygen of our atomosphere gain water vapor and hence increased precipitation.

VEGETATION DEVELOPMENT FOLLOWING ICE RECESSION

Pioneer Stage

We have discovered by observation that plants, at least green plants, cannot survive beneath glaciers through even a "little ice age." The process of vegetation development must begin with migration of mobile seeds and spores from adjacent undisturbed areas. The situation at Glacier Bay gives us a better idea, we feel, than we can get anywhere else in the world today of what probably happens following a continental glaciation. This is true because the great speed and distance of recession of ice there in the past two centuries has resulted in a gap of many miles between the newly deglaciated ground and the mature vegetation from which seeds and spores must migrate. As a result, the establishment of forest on the shores of Glacier Bay has required 50 to 100 years instead of the 5 to 10 years required along the margins of the Juneau Ice Field as we have seen in the valleys of the Mendenhall and Herbert Glaciers near Juneau. At Glacier Bay, the many square miles of new glacial till surface exposed even in the past decade, provide great stretches of raw parent soil material lacking in nutrients necessary for rapid plant growth. The pioneer plants, small and slow growing, have apparently without exception entered as seeds or spores blown in by wind or carried by birds and mammals in their digestive tracts or attached to the surfaces of their bodies. The first shrubs and trees, mainly species of willows and cottonwood, even those capable of growing erect in later life, grow there prostrate, with sickly yellowish leaves. These characteristics of unhealthy growth are largely symptoms of soil nitrogen deficiency, as has been demonstrated by the marked stimulation of growth and the appearance of healthy blue-green foliage color where experimental applications of ammonium nitrate have been made, and where small natural additions of nitrogenous matter occur, such as animal bones, fecal matter, and exposures of fossil soil layers. The seed of Dryas, a conspicuous plant which can grow only as a prostrate mat, arrives early as a feathery parachute transported by the gentlest breeze; it germinates promptly and rapidly covers the ground with a carpet, deep green in spring, yellow when in flower, gray in fruit, and red-bronze in fall, which acts effectively to reduce soil erosion. Dwarf fireweed, willows, and cottonwood arrive in the same way. Occasionally, the less mobile winged seeds of alder, spruce, and hemlock arrive from the more mature vegetation on older terrain down-valley from the ice, sliding along the crusted winter snow, or shaken from the back of some roving bear, wolf, or mountain goat as he unburdens his pelt of the load of water accumulated in the frequent rainy autumn days. By following the establishment and later development of the pioneer plants in detail on permanently marked plots established by Cooper in 1916, on surfaces left free by the ice on known dates as early as 1879, it has been possible to learn many things about the manner and rate of forest development in the first seventy five years following recession of the ice at Glacier Bay (Cooper 1939 and earlier).

Alder Thicket Stage and Nitrogen Fixation

In the early developmental process the rate of growth of two plants is outstanding. One of these is Drummond's Dryas which covers great areas by rapidly spreading horizontal evergreen mats. The other is Sitka alder (*Alnus*), a rapidly growing upright deciduous shrub capable of

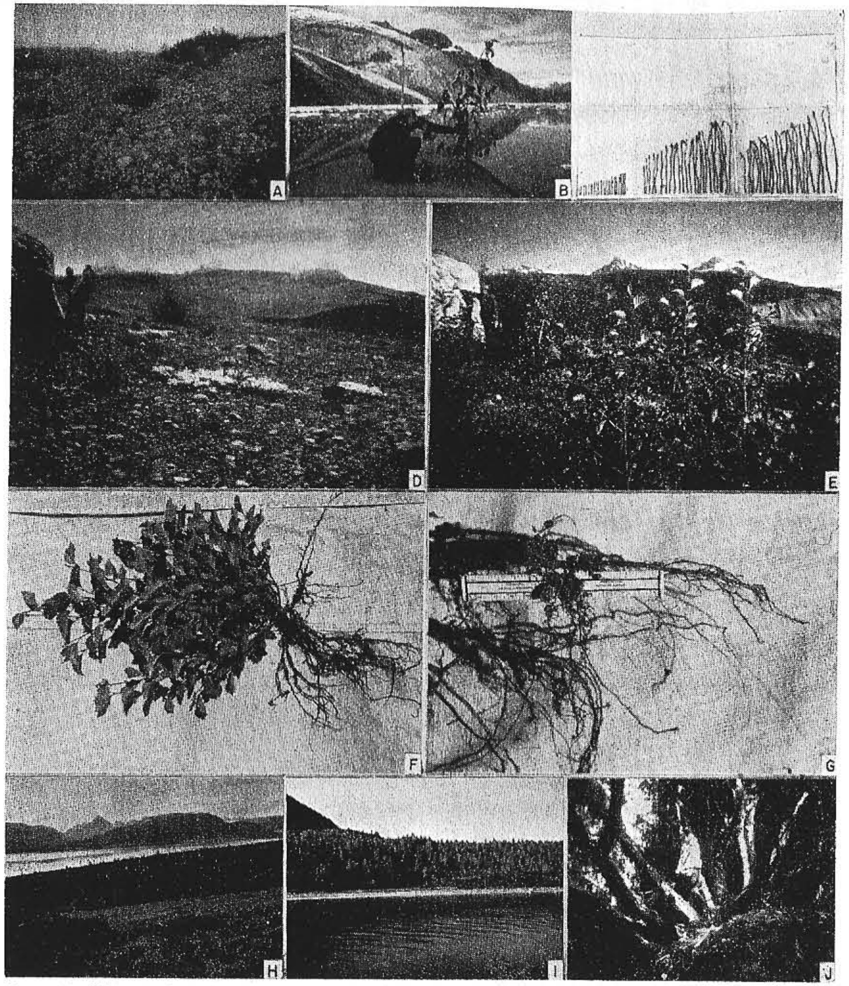

Fig. 14. Vegetation development and the importance of alder in nitrogen fixation at Glacier Bay.

attaining a height of 11 feet and of reproducing abundantly by seed within seven years, and of attaining maximum heights of 25 to 35 feet in a few decades. These two plants, to some extent Dryas (Schoenike, in press), but especially the alder have the ability not only to grow rapidly themselves, but also to stimulate to vigorous erect growth adjacent shrubs and trees which were previously groveling as semiprostrate individuals. Figure 14A shows tall cottonwood saplings bursting up through stimulating alder thicket. In Figure 14B three years of height growth of cottonwood from within an alder thicket (right) are compared with a growth equivalent of one grown away from alders; the one was 22.5 times the weight of the other. Figure 14C compares single year

leader growths of cottonwood away from alder (left) with alder (middle), and cottonwood surrounded by alder (right); the longest stems are 20 inches. Through the process of change the landscape becomes mantled with a brilliant blue-green shrub thicket of rapidly growing alder and willows within 10 years after the alder first appears. Comparison of Figures 14, D and E taken from the same spot 11 years apart makes it possible to visualize this process. The reason for the tremendous burst of growth is found on the roots of the alder shrubs (Figs. 14 F, G with 6-inch rule) and Dryas mats. Close examination reveals clusters of golden brown fleshy nodules, some clusters attaining the size of golf balls, which contain within their cells delicate filaments of an organism quite surely not a bacterium, but some actinomycete or fungus as yet not identified (Uemura 1952, Quispel 1954), which has now been demonstrated in alder (Virtanen *et al.*, 1955, Bond 1955) and is strongly suspected in Dryas (Crocker and Major 1955) to fix atmospheric nitrogen. The nitrogen compounds fixed in the alder root nodules leak out in slight amount into the soil directly (Virtanen 1957), but mainly they move up the stems as amino acids including the unusual citrulline (Virtanen and Miettinen 1952), building blocks of the proteins to be formed later in the leaves. There, nitrogen accumulates by the latter part of the growing season in mid-August to a concentration of almost 3 per cent of the dry weight of the leaf. This is a nitrogen level as high as that which develops in alfalfa and other legumes long used in agriculture for adding nitrogen to the soil. But neither the alder nor the Dryas is a legume; they belong to the birch and the rose families. We have found that young alder thickets five years of age and five feet tall are adding to the soil through their fallen leaves each autumn 140 pounds of nitrogen per acre; as the thickets get older the annual rate probably increases greatly. Because this process of nitrogen fixation continues year after year in the naturally developing soil, and because of the cool moist climate, nitrogen is not used as rapidly as it is fixed. Crocker and Major (1955) and Crocker and Dickson (1957) have shown that over a ton of nitrogen per acre has been stored in the uppermost eighteen inches of soil and leafmold by the end of the first 70 years following recession of the ice. This amounts to an accumulation of nitrogen never before realized. In legume crop rotation systems used in agriculture, if the whole plant is plowed in, we can expect with efficient nitrogen fixers such as horse bean, alfalfa, lupines, and clovers to add about 150 to 200 pounds of nitrogen per acre each year and if we harvest the tops and plow in only the roots we gain 10 to 45 pounds of nitrogen (Fred, *et al.*, 1932). But, in crop rotation in agriculture, we use up in non-nitrogen fixing crop production the following year practically all the nitrogen added by the legumes so that agricultural soil at any one time does not contain any great reserve bank of nitrogen. Unfortunately, in forestry as it has been practiced in this country, with its great rush to harvest the bounteous production of natural forests, little thought has been given to the long term nitrogen needs of the forest crop produced slowly over periods of forty, sixty, or even a hundred or more years. The lesson provided by nature in Southeastern Alaska should open our eyes to what has long been known in northern Europe and Japan (Kohnke 1941), and Korea (Wilson 1920) where, for over seventy years, alders have been used to add nitrogen to the soil in amounts suitable for the periods of long term forest and crop rotations.

Transition to Forest

As the Alaskan alder thicket becomes mature and can grow no taller about 60 years after ice recession, the vegetation mantle at Glacier Bay begins to take on a "lumpy" texture when seen from a distance (Fig. 14H). This results through the rapid emergence from beneath the thicket into full light of the rounded canopies of cottonwood and the narrow crowns of spruces and a few hemlocks stimulated by the tremendous supply of available nitrogen provided by the alders. In the early decades which follow, the forest canopy rapidly closes (Fig. 14I) reducing the light available to the alders below. Inside a forest at this stage the alders are seen to have reached their maximum size with sagging stems six to eight inches thick (Fig. 14J).

Spruce and Hemlock Forest Stages

By 170 years after ice-melt, the alder is gone, even its wood mainly incorporated in the organic litter of the forest floor, and a dense evergreen Sitka spruce forest has formed, with trunks up to 110 feet tall (Fig. 15A), three to four feet thick, and with many of the individual annual growth layers 0.3 to 0.4 inch wide. Inside this forest a second generation of smaller trees is now made up of hemlocks of much slower growth rate as light intensity has been greatly reduced and soil nitrogen reserves have been reduced presumably through root absorption by the rapidly growing spruces. A carpet of mosses and litter six to twelve inches deep has formed; this is at first composed of a number of kinds of the ordinary forest mosses typical of the coastal forest. But, rather suddenly in specific spots and for reasons still unknown, a new kind, the bog moss, sphagnum, appears, paler and more yellowish green, at first in small circular patches (Fig. 15B), possibly where other mosses have been killed by fungi or by the urine of bear or wolf, and expanding from there across other mosses, shading them out as their discs enlarge. This unique genus of mosses of which there are about a score of species in North America and at least eight species in Southeastern Alaska, is so water absorbent that Indians after drying it on trees pack their papooses in it instead of using diapers.

Forest Deterioration and Muskeg Development

Gradually, through the growth of the sphagnum layer the forest floor becomes soggy and the trees grow less rapidly for want of aeration to the roots. Tree crowns grown to enormous size before the moss blanket became so soggy now find themselves too large to be nourished by receding root systems. Crown retrenchment then occurs so that the ancient forest of hemlocks and cedars on terrain not disturbed since the latest

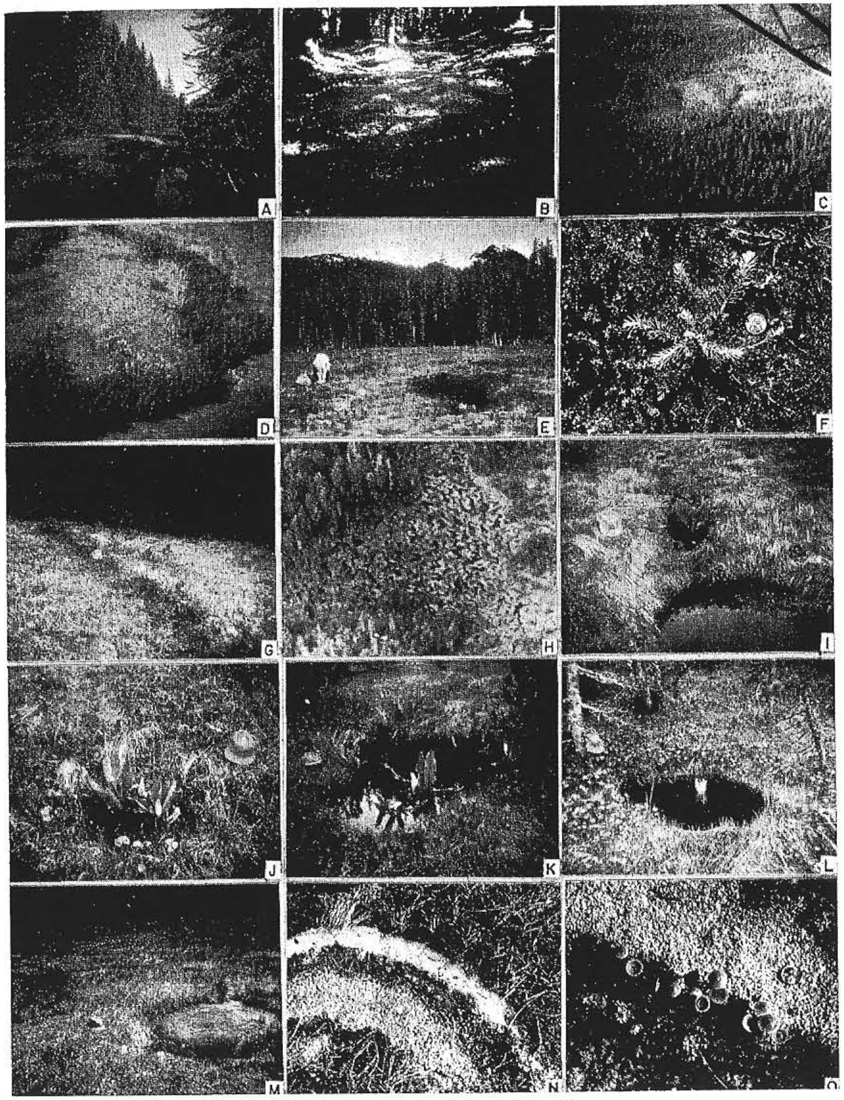

FIG. 15. Forest deterioration, muskeg development, and the origin of pit ponds.

stages of the Great Ice Age has become dotted with silver-gray trees, the upper crowns of which are dead. This sight is often a cause of bewilderment to the observant tourists who travel each summer along the inland passage by boat and who guess that the region is too moist for crown fires to be the cause. The tourist traveling by air has a better chance to understand what is going on, for he can see in the low more poorly drained areas of land not recently glaciated, that the forest has opened up (Fig. 15C) revealing yellowish brown blotches of muskeg surrounded by zones of dead and dying trees. In the 6000 to 10,000 years since the terrain became available for land plants here, extensive areas of the level and gently sloping land have lost their forest, the remains buried as stumps and logs beneath a deep blanket of peat (Dachnowski-Stokes 1941). As sphagnum mosses succeed one another, species of the forest giving way to species that can grow only in the open, and because of their usually saturated condition and inadequate aeration, the older trees gradually die and become bleached and stand as a border between forest and muskeg (Figs. 15, D, E). The forest lives on only on the steeper slopes from which water drains more rapidly (Zach 1950), or on level surfaces at the mouths of valleys where it is exposed to the frequent winter storms of hurricane force, in some years increased in effectiveness by glaze deposited during freezing rain. Trees thus exposed are thrown over and more than half their root systems are pulled up, thereby rejuvenating the drainage of excess water into the gravels left long before by Ice Age glaciers.

The seeds of spruce and hemlock trees which fall in myriads in autumn upon the muskeg germinate in profusion the following spring and they may grow for a few years, very slowly because of the acid products of the sphagnum mosses and inadequate root aeration and nutrient supply. Their vertical growth is in fact slower than that of the surrounding mosses so that in a few years they become overwhelmed (Fig. 15F). Although the climate is generally very moist even in summer, there are in some summers brief periods of drought lasting a few weeks during which the surface few inches of the mosses may become so dry that the tree seedlings can die of drought (Godman 1953), and then the following year the muskeg is dotted with tiny red corpses of conifer seedlings. If fire starts under these circumstances it is most likely to sweep across the dehydrated muskeg surface and stop at the forest boundary where the shaded surfaces stay moist all summer. The only tree species capable of growing rapidly enough to keep above the mosses and develop tree form is the Pacific coast pine, *Pinus contorta,* and some muskegs are spotted with their dark green pyramidal forms. Some of the mountain hemlocks continue growth slowly over many years and I have pulled up little vase-shaped specimens only a foot tall whose basal stems though just a half inch thick had 75 annual growth layers visible under a microscope. Tree seedlings are able to survive on the logs of tree trunks fallen over on the muskeg, for there aeration and nutrition are more favorable for them and water supply more constant during drought; they occur in straight lines as though planted (Fig. 15G).

Pit Pond Development

In a late muskeg stage on the level and even on slopes up to 12 degrees, pit ponds develop as shown by Zach (1950). In some areas the ponds have come to occupy about half the surface with the other half consisting of a continuous network of soggy muskeg (Fig. 15H). In order to understand the origin of these ponds it is helpful to visit the earlier hemlock and coast pine forest stage and see the western skunk cabbage, *Lysichitum americanum,* a magnificent plant with leaves up to four feet long and a foot wide and with a life span estimated by Rosendahl (1911) at 25 to 75 years, and perhaps even much longer. This plant survives into the subsequent muskeg stage and when its fleshy leaves are frosted in autumn they turn black and kill by shading during the winter and following spring the adjacent bog mosses and sedges (Figs. 15,I, J). Experiments done over 40 years ago (Turesson 1916) demonstrated that it was shading and not some leaf toxin which killed the near-by plants and caused the pits to form. Also the skunk cabbage has contractile roots which keep pulling the upward elongating stem down into the peat each year and so the pits gradually deepen, fill with water, and enlarge as other skunk cabbage crowns arise along the pond edge by offshoot from single parent plants (Fig. 15K). Perhaps new skunk cabbages become established from seed on the muskeg also. Occasionally an old skunk cabbage finds itself isolated in the center of a pond where it gets sick and dies (Fig. 15L). Some ponds become drained; others fill with organic debris washed in from the muskeg surface (Fig. 15M). Ponds may be formed without the aid of skunk cabbages here in Southeastern Alaska as they are in some regions of the world where no skunk cabbages grow. But, in these other cases, it is very likely that members of the plant kingdom are responsible for death of the sphagnum mosses and for initiation of the pit. Eriksson (1912) pointed out that pit ponds develop in central Sweden around spruce trees which also kill the bog moss by shading. Another plant surely capable of pit initiation is a lowly fungus which grows outward in ever widening circles, raising above itself, when growth conditions are suitable, telltale "fairy rings" of toadstool fruiting bodies (Figs. 15, N, O,), and killing the moss in ever widening ring shaped patterns, as fungi were shown to kill prairie grasses of the Colorado plains by Shantz and Piemeisel (1917).

Future Research Needs

In the complicated processes of glacier nutrition, plant colonization, nitrogen accumulation, muskeg development and pit pond formation lie countless problems, the solutions of which are open to coming generations of scientists who will find the magnificent scenery and congenial residents of Alaska added attractions in an already pleasant and stimulating research atmosphere. For such work however, a field biological laboratory in the vicinity of Juneau and mobile floating laboratories in Glacier Bay are greatly needed, and it is fervently hoped that the University of Alaska and federal and other agencies may soon combine efforts to provide these facilities.

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THE PLACE OF AGING IN WILDLIFE MANAGEMENT

By Maurice M. Alexander

WILDLIFE Management, because of its comparative newness in science, has been given varying definitions and has made many different impressions on the general public. It can be compared to Farm Management or Forest Management inasmuch as it is involved with a product of the land—on that land. Wildlife is a product of the land just as much as corn or white pine. The older expression of "*Game Management*" is giving way to the more inclusive term "*Wildlife Management.*" The fact is recognized that no animal species stands alone in its natural habitat. Instead, it is a component part of a living community and the changing of a single species in that community or the changing of a single factor in the habitat affects, not one, but all. This gives the Wildlife Manager in many cases the task of working with all species of animals existing on an area at the same time. It is truly then a science of Applied Ecology.

Biologists, therefore, are not only interested in the species of animals that man pursues and calls game, but also the other members of the community that provide such relationships as food, competition, and enemies. The farm manager too is concerned not only with the corn and cabbage, but the management of the weeds and insects as well.

Wildlife management has been described as a science, an art and a philosophy. It is truly all three. The science is naturally the basis and the art the application. Like all sciences dealing with a natural resource, a philosophy based on scientific information must be developed to assist in understanding the phenomena of nature.

Wildlife Management Techniques

The success of the art of Wildlife Management is dependent upon our basic knowledge of the animals and their environments, and the quantity and quality of the management techniques available. In this two-sided problem of wildlife and habitats, the manager is faced with many questions. What species of wildlife does he have? Where is it located? How much does he have? What is needed? What can he do? These questions have to be answered more or less in order by the manager for both the wildlife and the habitat (King, 1941). This involves the use of several techniques even before actual management can be started.

Any science, then, that is the basis for management must provide new and improved techniques. These techniques must be of a practical nature; not of the type that only research men can use. Any wildlife management technique, if it is to be considered practical, must be workable by the managers in the field.