Summer Climatic Gradients and Vegetation near Barrow, Alaska[1]

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ABSTRACT. A general amelioration of climate inland from the northernmost tip of Alaska is accompanied by distinctive changes in vegetation within a few miles, including an increase in the shrubby component of the vegetation, and a decrease in the prominence of the graminoid element. Simple instruments provided periodic values for rainfall, evaporation and evapotranspiration. Sod block evapotranspirometers, weighed at intervals, gave reasonable and consistent estimates of evapotranspiration rates, which increased by more than a third between the ocean and 28 miles inland.

RÉSUMÉ. *Gradients du climat et de la végétation en été, près de Barrow, Alaska.* À l'extrême pointe du nord de l'Alaska, on constate une amélioration générale du climat vers l'intérieur des terres, qui s'accompagne de changements visibles de la végétation en quelques milles seulement, dont une augmentation de l'élément broussailleux et une diminution d'importance de l'élément graminacé. Des instruments très simples ont permis de recueillir des données périodiques sur la pluie, l'évaporation et l'évapotranspiration. Le pesage à intervalles réguliers d'évapotranspiromètres à motte de gazon a donné des estimations raisonnables des taux d'évapotranspiration, qui augmentent de plus du tiers entre l'océan et des lieux situés à 28 milles (45 km) à l'intérieur.

РЕЗЮМЕ. *Летние климатические градиенты и растительный покров в районе Барроу (Аляска).* Общее улучшение климата по мере удаления от наиболее северной оконечности Аляски вглубь страны сопровождается отчетливым изменением в растительном покрове, заметным уже на расстоянии в несколько миль. В частности, роль кустарников возрастает, а роль злаковых понижается. Количество осадков, эвапорация и эвапотранспирация периодически измерялись с помощью простых приборов. Периодическое взвешивание весовых испарителей давало достаточно точные и последовательные оценки скорости эвапотранспирации, которая увеличивалась более чем на треть на расстоянии в 28 миль от побережья океана.

The general influences which large bodies of water exert on the climates of adjacent land masses are well known, but the gradients of the climatic elements over distances of tens of miles from shorelines have been intensively studied in few places. In particular, the relations between climatic and vegetational variations over such distances from coastlines have not been studied in areas where climate appears to dominate other factors in the control of vegetation. An opportunity to make such a study between Point Barrow, Alaska, on the Arctic Ocean, and the village of Meade River, 65 miles to the southwest and 28 miles from the Arctic Ocean (Fig. 1) was provided in the summer of 1956 (Clebsch 1957).

That portion of the Arctic Coastal Plain is relatively flat, with a maximum

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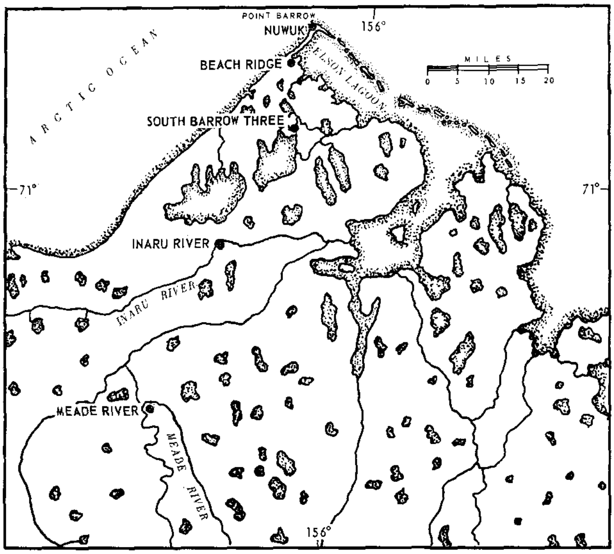

FIG. 1. Map of northern Alaska showing locations of stations used in this study.

local relief of approximately 50 feet developed along major rivers and along some sections of the coastline. Well developed systems of polygonal ground dominate much of the landscape and many of the low centre polygon pools and shallow oriented lakes are filled with water or ice the entire year. Near the coast in the region of Barrow village, there are several well preserved and uplifted ancient beach ridges, now covered with vegetation, which resemble the present day form of Point Barrow.

The climate of the region is well within the boundaries of the tundra climate type of the standard classifications, the average temperature of the warmest month being below 50°F. but above 32°F. The only U.S. Weather Bureau station in the area, within 0.3 miles of the coast at Barrow village and about 4.5 miles from the nearest station used for this study, records a very high fog frequency, a high degree of cloudiness (80, 82, 90, and 92 per cent of the sky covered on the average in the daylight hours of the respective months of June, July, August, and September), and very few entirely clear days during the same period. Over half of the annual average recorded precipitation of 4.2 inches falls as rain during these four months.

The average wind velocities at Barrow were 12.1 and 16.7 miles per hour in the months of July and August, 1956. The prevailing wind directions were WSW., SSW., and SW. in July and were NE. and ENE. in August.

METHODS

Climatic measurements made in the present study were of period maximum and minimum temperatures, period rainfall, evaporation and evapotranspiration. Four points at irregular intervals along a northeast-southwest line were selected as station sites, each of them in the southerly direction being progressively farther removed from the strong influence of the Arctic Ocean. The northernmost of these was established near Nuwuk, the old Eskimo village site on the Point Barrow spit (Fig. 1). The Beach Ridge station was placed on the foreslope of the most northerly of the series of old beach ridges previously mentioned, approximately 6 miles southwest of Nuwuk and 1.5 miles from the Arctic Ocean. The South Barrow Three station was established near South Barrow Test Well Number Three, 11 miles south of the Beach Ridge and 15.5 miles south-southwest of Nuwuk. The Inaru River station, used only for vegetation studies, was 23 miles south-southwest of South Barrow Three and 17.5 miles from the Arctic Ocean. The southernmost station, Meade River, was 30 miles south-southwest of the Inaru River station and 28 miles from the nearest point on the Arctic Ocean.

Temperature measurements were made with Taylor Six's maximum-minimum recording thermometers which were mounted about 4 inches from the soil surface in quonset-shaped shelters designed by Dr. M. E. Britton of the Office of Naval Research and constructed from 2 sheets of aluminum separated by about 0.5 inch. The shelters were oriented in a north-south direction and the thermometers inserted with bulb ends to the north. The dimensions of the shields and the orientation of shields and bulbs were such that the instruments were infrequently exposed to direct solar radiation, and then only at low northerly sun angles.

Precipitation and evaporation gauges were open cans 6 inches in diameter and 7 inches deep, sunk into the soil to the depth at which the lip of the can was slightly above the soil surface. After each reading a thin layer of fuel oil was left in the bottom of the precipitation cans to reduce evaporation. Field readings were volumetric and were converted to depth equivalents.

For the measurement of evapotranspiration, containers of the same kind were used, but with perforated bottoms to allow for drainage. In order to make the evapotranspirometers as uniform as possible, all of the cans were filled with sod plugs of the grass *Dupontia fischeri* cut from the same coastal locality and trimmed to fill the cans exactly. These sod-filled containers were maintained in triplicate at each station in order to increase the precision of measurement and to ensure estimates of evapotranspiration independent of differences in soils and vegetation among the stations.

The vegetation in the evapotranspirometers was observed at the end of the field season for relative stage of development and was then clipped and dried for total net production of aerial parts. Single plots of garden peas were also planted at Nuwuk, South Barrow Three, and Meade River for an attempt at phenological scoring according to Higgins (1952).

CLIMATE

Because of transportation difficulties only the Nuwuk, Beach Ridge, and South Barrow Three stations were visited regularly, and the Meade River station was visited only a few times after its installation. Extreme temperatures were recorded at weekly intervals from the first three stations, and were found to deviate appreciably from the Weather Bureau records at Barrow. However, the weekly-period extreme temperatures provided an inadequate basis for inferences concerning the temperature regime of the region. Deviations of our readings from those of the Weather Bureau were from 1 deg. F. below to 5 deg. F. above their maxima and from 7 deg. F. below to 17.5 deg. F. above their minima during the months of July and August. The magnitude of the deviations and their sign showed no clear pattern (Clebsch 1957).

The two available records of daily precipitation in the area are those of the U.S. Weather Bureau at Barrow and of Mather and Thornthwaite (1956 and 1958). Precipitation measurements were made by the latter in cans 10.6 cm. (4.17 inches) in diameter and 17.4 cm. (6.85 inches) high; these were sunk into the soil with the lip of the can protruding about 1 cm. After they had made precipitation measurements in several of these instruments in a very small area and had found their results to be highly variable, they concluded that the method did not give an adequate sample of the precipitation falling on the area. They then reverted to the use of a standard instrument. The site at which they made their measurements [*Britton Manor*, the site of earlier microclimate studies (Britton 1957)] was approximately 2 miles northeast of the Weather Bureau station, within 300 yards of the ocean and in an area of high centre polygons with considerable microrelief, the individual polygons being up to 3 ft. high. Since much of the summer precipitation in the region is in the form of wind-driven drizzle and mist which may be moved laterally over long distances even near the ground, the effects of microrelief on turbulence may be in large part responsible for the disparate measurements of Mather and Thornthwaite. Proximity of the ocean and accompanying onshore winds may be related to the small total amount of precipitation caught by their instruments, and they made no attempt to minimize evaporation from them.

In Table 1 records from the stations used in this study are compared with official records and those of Mather and Thornthwaite (1956). It is apparent from the total precipitation figures that there was an increase in summer season precipitation southward and inland from Nuwuk. Apparently the highest rate of increase was very near the coast, with the rate of increase dropping off farther inland. It is significant that some precipitation fell on a high proportion of the days during the summer months, at least at Barrow, and that on many of these days the amounts recorded as traces by USWB personnel were large enough to be measured in our instruments. Mather and Thornthwaite (1958) discounted the possibility of an increase in precipitation inland from the coast, but their conclusions were based only on rain gauges as near the coast as the Beach Ridge station. Their several stations did catch higher amounts than those also reported for the USWB gauge at Barrow in 1957 and 1958.

Conover (1953, as quoted by Tedrow and Hill 1955) stated that precipitation during the three summer months averaged less than 1 inch per month, that there was an annual water deficiency of 3.3 inches at Barrow, and concluded that the climate should, therefore, be classed as semiarid. We question the appropriateness of this designation in the absence of evidence of actual moisture stress on the vegetation, and find it difficult to conceive of a semiarid climate with as much of the landscape covered with water or marsh as is the case in the Barrow area. Mather and Thornthwaite (1958) properly concluded that "The figures obtained in all these years indicate a virtual balance between the precipitation and the

TABLE 1. Deviations of Period Accumulations of Precipitation (cm.) from U.S. Weather Bureau (Barrow Station) Records of June, July, and August 1956.

Date		*Barrow Station*	"Britton Manor"*	*Nuwuk*	*Beach Ridge*	*South Barrow Three*	*Meade River*
June	29	0.20	–0.20		start		
	30	T					
July	1	0					
	2	0					start
	3	0.08	–0.08				+0.40
	4	0.53	–0.53				
	5	T					–0.11
	6	0.66	–0.66	start			
	7	T					
	8	T					
	9	T					
	10	T			+0.34		
	11	T				start	
	12	0.66	–0.28				
	13	T					
	14	T		–0.77			
	15	T					
	16	T					
	17	0.74	+0.70	+0.70	+1.20		
	18	T					+0.48
	19	T					
	20	0					
	21	0					
	22	0					
	23	T					
	24	T		+0.02	+0.01		
	25	T					
	26	0.10	**				
	27	0.48	–0.17				
	28	T	**				
	29	0.15	–0.02				
	30	0.23	–0.23				
	31	T		–0.04	+0.58		
Aug.	1	T	**			+1.35	
	2	T	+0.28				
	3	0.11	–0.11				
	4	T					
	5	T	**				
	6	1.30	–0.24				
	7	0.23	–0.04	+0.29	+0.57		
	8	0.02	**			+0.51	
	9	0.05	+0.10				
	10	0.05	–0.05				
	11	T					
	12	T					
	13	T					
	14	T		+0.50	+0.47		
	15	0				+0.75	
	16	0					
	17	0					
	18	0					
	19	T					
	20	0.58	**				
	21	0.15	+0.02	0	+0.04		+2.80
	22	T					
	23	T					+0.04
	24	T					
	25	T					
	26	T					
	27	T					
	28	T		+0.01	+0.05		
	29	T				+0.67	
Total		6.32	–1.88	+0.71	+3.26	+3.28	+3.61
Miles from coast		0.3	0	0	1.4	8.8	28

*Data of Mather and Thornthwaite (1956).
**Not measured. Next deviation figure is for sum of this and following day.

evapotranspiration during the summer period in the Barrow area."

It has been the contention of some workers that precipitation in the Barrow area is much greater than recorded. Black (1954) stated that soil pore space amounted to 20-40 per cent of the soil volume, and the thawed portion of the profile could thus hold 1.6 to 6 inches of water at saturation. He estimated that during each of the summers of 1946, 1947, and 1950, 6 to 9 inches of rain would have been necessary to saturate the soil to the degree observed. He also reported that on the basis of his own snow measurements in the area, the annual precipitation is between 2 and 4 times as great as is recorded by the Weather Bureau station. It is also possible that condensation of water vapour and deposition of fog droplets on plant and soil surfaces contribute appreciably to the total moisture received by the land, but this contribution would probably not be recorded in ordinary precipitation gauges.

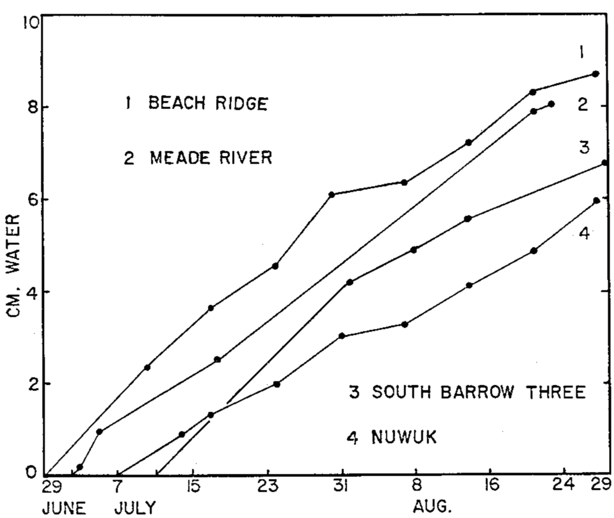

FIG. 2. Accumulated evapotranspiration losses (average of 3 cans per station).

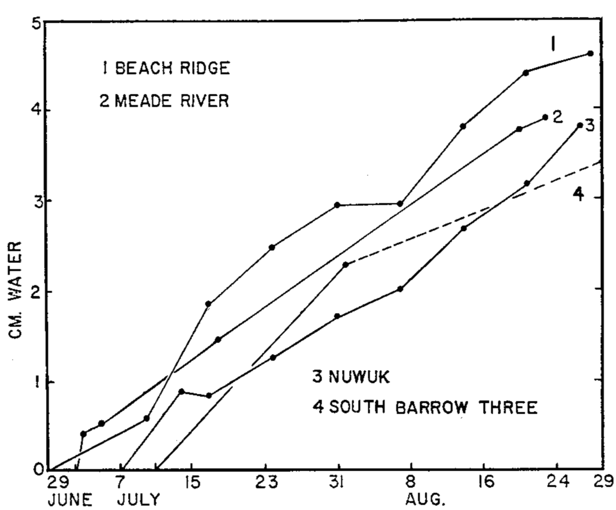

FIG. 3. Accumulated evaporation losses.

In order to compare average daily rates of evaporation and evapotranspiration for the 43-day period 11 July to 23 August, common to all the stations, values for the beginning and end of the period must be interpolated on the cumulative graphs (Figs. 2 and 3) and the difference in the two figures divided by the length of the period. These computations reveal that the average daily rate of evapotranspirational water loss at Nuwuk was 0.108 cm. (0.42 inches), at the Beach Ridge was 0.137 cm. (0.054 inches), at South Barrow Three was 0.145 cm. (0.057 inches), and at Meade River was 0.149 cm. (0.059 inches), a relatively smooth increase with distance from the ocean.

If it is assumed that evaporation from the open cans was approximately equal to the evaporation from the relatively moist soil surface in the evapotranspirometers, the difference in the rates of evaporation and evapotranspiration will provide some estimate of the average daily rate at which water was lost by transpiration. These differences are: Nuwuk, 0.042 cm. (0.016 inches); Beach Ridge, 0.050 cm. (0.020 inches); South Barrow Three, 0.073 cm. (0.029 inches); Meade River, 0.079 cm. (0.031 inches). Evaporation accounts for nearly two thirds of the water loss from the evapotranspirometers at Nuwuk and the Beach Ridge, half at South Barrow Three, and about half at Meade River. Conversely, transpiration accounts for more of the water loss at the two inland stations and for less at the coastal stations. The same conclusions may be drawn from a comparison of the evaporation and evapotranspiration data as presented in Figs. 2 and 3 for the entire period of observation.

The steepness of the slope of any segment of these curves is an indication of the average rate of the process considered. The changes in steepness in segments of these curves are thought to be due to short period fluctuations in weather, but supporting data could only be provided by more elaborate instrumentation or more frequent observations.

Mather and Thornthwaite (1956) used a battery of soil-filled cans of the type previously mentioned (that is 4.17 inches in diameter and 6.85 inches high), to measure *potential evapotranspiration* at sites near the Arctic Research Laboratory, at *Britton Manor,* and on the crest of the Beach Ridge near one station used in our study. [Potential evapotranspiration, the basic parameter of the Thornthwaite (1948) climatic system, is the amount of water lost by evaporation from the surface of soil in which the moisture level is maintained at or above field capacity plus that lost by transpiration from plants rooted in that soil.] At their Arctic Research Laboratory station the mean total water loss from 8 cans between 18 July and 6 September was 5.01 cm. (1.97 inches), an average daily rate of 0.050 cm. (0.020 inches).

At their *Britton Manor* station the mean loss from 14 cans between 30 June and 31 August was 5.75 cm. (2.26 inches): an average daily rate of 0.093 cm. (0.037 inches). The mean loss from 10 cans at their Beach Ridge station between 3 July and 4 September was 5.61 cm. (2.209 inches): an average daily rate of 0.089 cm. (0.035 inches). The total mean loss at their Beach Ridge station was 2.09 cm. (0.823 inches) less than the total mean loss at our Beach Ridge station from 29 June to 28 August.

Water loss varied widely among their sets of cans at all stations, and it is

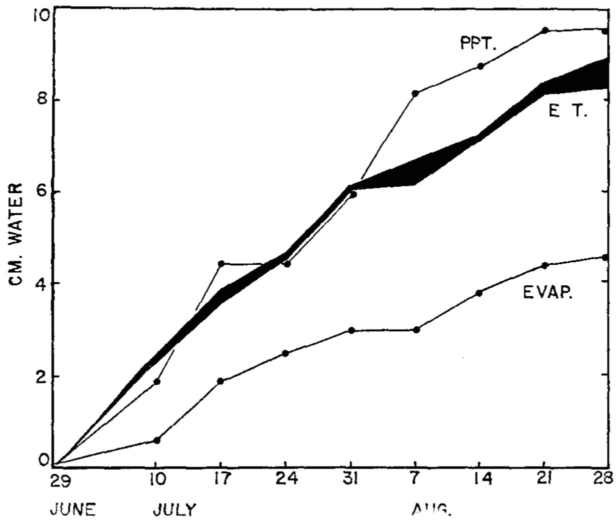

FIG. 4. Accumulated precipitation, evapotranspiration (extremes among 3 cans), and evaporation, Beach Ridge Station.

felt that the variability was in large part due to their use of highly variable soil materials containing highly variable vegetation cover. Statistics indicating variation among sets of cans were not provided in the 1957 and 1958 studies (Mather and Thornthwaite 1958). The close uniformity among the cans used in the present investigation at the Beach Ridge station is illustrated graphically in Fig. 4. The range of observations at each sampling date is shown in black.

The excess of precipitation over evapotranspiration for the entire period of measurement at each of the 4 stations of the present study was as follows: Nuwuk, 7 July to 28 August: 0.13 cm. (0.051 inches); Beach Ridge, 29 June to 28 August: 0.88 cm. (0.346 inches); South Barrow Three, 11 July to 1 August: 1.37 cm. (0.539 inches); Meade River, 2 July to 23 August: 1.59 cm. (0.626 inches).

If the *Britton Manor* precipitation data of Mather and Thornthwaite (1956) are compared to their evapotranspiration data, moisture *deficiencies* are as follows: Arctic Research Laboratory station between 18 July and 6 September: 1.92 cm. (0.756 inches); Britton Manor station between 30 June and 31 August: 1.33 cm. (0.523 inches); Beach Ridge station between 3 July and 4 September: 1.70 cm. (0.669 inches). If, on the other hand, their evapotranspiration data are compared to records of the Weather Bureau station, precipitation excesses are indicated at all of their stations. We infer from our data that there was no moisture deficiency during the season; and, therefore, actual evapotranspiration should have closely approached potential evapotranspiration.

PHENOLOGY

The Thornthwaite Laboratory of Climatology has sponsored the use of *Early Alaska* variety garden peas in standardized phenological observations because development of the plants is remarkably uniform in a given environment and is rapid enough to produce observable daily changes. Higgins (1952) states, "In southern New Jersey four days or more are required in the cool months (for the development of one complete node) and only two to four days in the warm months." Phenological observations on peas were made at intervals during the 1956 season at Nuwuk, South Barrow Three, and Meade River, but growth rates were so slow that comparative phenological scoring during the season as recommended by Higgins was not warranted. By the end of the season the sets of plants were progressively taller from the coastal station inland, but only those which grew at Meade River produced any fully developed nodes and internodes during the entire period of observation. The net dry matter production of the native vegetation growing in the evapotranspirometers at Meade River was nearly double that at Nuwuk.

VEGETATION

The Coastal Plain province is in aspect a grassland, most of the prominent species being grasses or sedges. It grades from a nearly unbroken ankle-deep grassy sward in coastal areas toward taller tussock meadow farther inland. The polygonal pattern of the land surface is accented by the brighter green vegetation of shallow lake basins, troughs between polygons, and small valleys now containing infrequent sluggish streams. The proportion of woody plants also increases inland, finding local expression as a dwarf shrub heath type after the first few miles (cf. Britton 1957).

The Nuwuk area is unique in the region in the combination of ocean proximity, relatively recent elevation above sea level, and coarse gravelly substrata in a poorly drained position underlying thin sedge peat. The thin peat is densely covered by vascular plants, and mosses and lichens occupy much of the space between stems. *Dupontia fischeri* was by far the most abundant grass in the sampled area and was clearly dominant.

The vegetation of the Beach Ridge has been described in detail by Koranda (1954) and Drew *et al.* (1958). The Beach Ridge is topographically and pedologically unusual enough in the area for its uniqueness to be reflected in the vegetation which covers it. The mat-forming shrubs *Dryas integrifolia* and *Vaccinium vitis-idaea* ssp. *minus* occur there and are known only from similar habitats near Barrow. The sample data indicate that the grass *Poa arctica* and the sedge *Carex aquatilis* are the dominant plants in the sampled area in general despite the local importance on the more exposed spots of prostrate willows with associated mosses and lichens.

Observable changes in the vegetation during overland travel to the interior from the Beach Ridge seem very gradual and slight, but the considerable change over the 11-mile distance to South Barrow Three would be quite obvious if one were to fly there directly from the coast. Woody plants become progressively more prominent southward in certain of the better-drained situations, there is an increase in the abundance of tussock-forming plants such as the cottongrass *Eriophorum vaginatum* ssp. *spissum,* and the number of heath species in the vegetation is greater. The habitat sampled at South Barrow Three was a high centre polygon on an upland between lake basins.

At the Inaru River the sedge *Carex aquatilis* and the dwarf willows *Salix* *pulchra* and *S. phlebophylla* were the dominants in a sample made across a polygon at the outer (river) edge of a high terrace.

The vegetation at Meade River, sampled across a low centre polygon at the edge of a lake basin, assumes an aspect still different from that at the Inaru River. The shallow central pans of the low centre polygons contain a great deal of *Carex aquatilis,* as do the troughs between the ridges of the polygons. The ridges themselves are covered by a mixture of the shrubs *Vaccinium vitis-idaea* ssp. *minus, Ledum palustre* ssp. *decumbens, Rubus chamaemorus, Betula glandulosa* and *Cassiope tetragona,* and the tussock-forming cottongrass *Eriophorum vaginatum* ssp. *spissum.*

Complete species lists (Clebsch 1957) indicate that the floras of the Inaru River and Meade River localities are considerably richer than those of the more coastal stations. The increased richness appears to be due to an increase in the variety of habitats as well as to a climatic shift.

SUMMARY

Four stations between the coast and a point 28 miles inland were established for the measurement of selected climatic elements during the summer of 1956, and the vegetation was studied at each of these and one additional station. Precipitation increased away from the coast, as did evaporation and evapotranspiration. Native vegetation in evapotranspirometers showed greater total growth at inland stations than at the coast, as did planted peas. There was an increase in general height and in the shrubby component in the natural vegetation and a decrease in the prominence of graminoid species.

ACKNOWLEDGEMENTS

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