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THE CLIMATOLOGICAL TOOL IN LEPIDOPTERA RESEARCH

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THE PURPOSE OF THIS ARTICLE is to discuss sources of raw climatic data, to acquaint Lepidopterists with climatology, to develop a few procedures that would be useful to research on the Lepidoptera, and to describe briefly some paleoclimatology and automation techniques.

Some illustrative examples are provided that utilize climatic data, though it should be kept in mind that the figures are based on the few local distribution records at my disposal; values would probably vary considerably if a large volume of data from throughout the species range were considered. Being more familiar with species and climatic conditions in Oregon, material treated will primarily concern the Pacific Northwest, but could be applicable on a much broader scale.

DATA SOURCES

The basic data for an involved climatic study may be mostly obtained from three government publications: *Climates of the States, Climatological Data,* and *Climatic Summary.* All are published in sections—a state, territory, or group of states.

Climates of the States. This publication is probably the best general source of climatic data for those not familiar with climatology. The climate of particular sections is generally described, with references and bibliography to indoctrinate the reader with that section's climate. The long-term annual and monthly mean values of precipitation and temperature are listed for several stations within each section's climatic divisions. Freeze data and growing season length are reported also for representative stations. For all U. S. Weather Bureau stations within the section, data concerning snowfall, humidity, wind, and cloudiness are compiled. Five maps are given with isolines for January and July mean maximum and minimum temperatures, and for mean annual precipitation. For a detailed analysis of the climatology of a region, it is found that the material in the publication is insufficient.

Generally unknown to most, the United States is literally blanketed with a network of cooperative climatological stations. The observations at these stations generally consist of a daily reading of maximum and minimum temperatures, precipitation amounts, and snow depths.

Data for the cooperative stations may be found for periods prior to 1955 in the *Climatic Summary.* This publication (actually two, a 1930 edition, and a 1931-1955 supplement) is concerned mostly with precipitation, giving monthly and annual amounts by year. Temperature and snowfall are listed only as a long term normal of that station. A station directory and history is included also.

Climatological Data. This is a monthly and annual publication listing all pertinent climatic data for the month, with an annual summary. Temperatures are here listed by each year. Daily precipitation is also given in this publication.

Of interest also is *Local Climatological Data,* and *Climatological Data National Summary.* The former gives local data, monthly and annually, for each Weather Bureau Station, and the latter a general summary of the U. S.

General background material on most phases of climatology may be obtained from *Climate and Man.* This book covers a very broad range of meterological subjects from flooding to paleclimatology, besides giving a climatic cummary of each state with maps. This information is somewhat dated though, and should be accepted only as a guide

CLIMATIC DISTRIBUTION

Clench, in an earlier (Sept. 1963) issue of this journal, concerning climatic adaptation, stated "The various factors which together make up what we call climate exert a strong control over the distribution of Lepidoptera. . .". This statement, in effect, is very valid, and I should assume that the probable distribution of most species may be determined solely on the basis of climatic limitations. Often, other factors, such as foodplant availability, or geographical barriers may alter the picture somewhat, or in other cases, species are found to inhabit wide climatic zones and be very widly distributed. In all cases though, a species is limited between a maximum and minimum range of climatic factors, and probable distribution may be predicted by comparing collecting sites with climatic data.

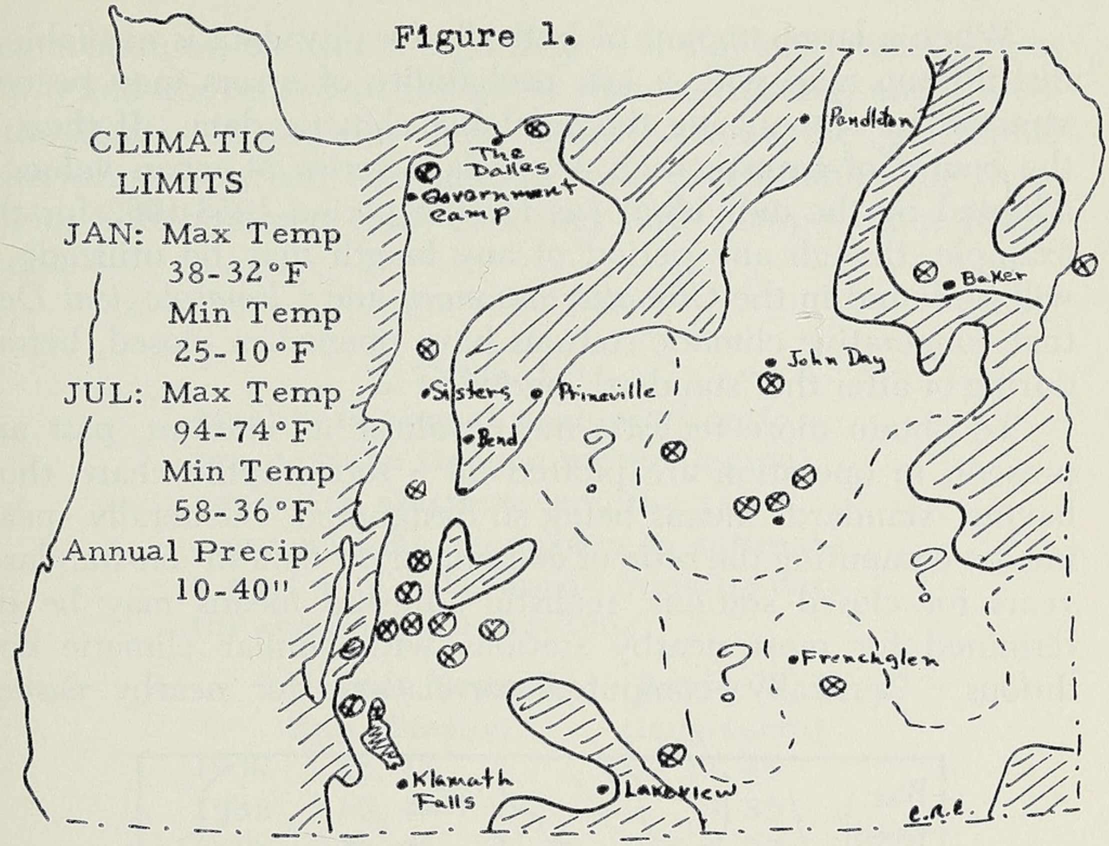

Fig. 1. Probable Distribution of *Callopsyche behrii* in Oregon, based on climatic means. Shaded area presumably unavailable to *behrii*. X indicates locality from which specimens have been reported.

Figure 1 is a sketch of the probable distribution of *Callopsyche behrii* in Oregon, based on an accumulation of some twenty localities. The localities were plotted on each of the five maps in *Climates of the States-Oregon,* and all values outside the maximum and minimum departure were shaded out. This distribution of many species may be determined solely on the basis itation are the primary limiting factors. Elevation (maximum observed 7000′-Steens Mts.) was not plotted due to the small aerial coverage of 7000′ plus values in the unshaded areas. A questioned area of precipitation from 8-10″ may be revised by the discovery of a specimen in these limits. The area is shaded only on the strength of all specimens falling at an annual mean precipitation value in excess of ten inches. In areas of eight inches and under, temperature again becomes a second barrier (in Oregon—maybe different elsewhere, the whole range should be considered).

Clench (Sept. 1963) used a similar approach in constructing a distribution diagram of *Callophrys sheridani* for the Pacific Northwest. Had values from *Climates of the States* been utilized, rather than from *Climate and Man,* perhaps a more realistic distribution pattern might be realized.

When a large amount of butterfly locality data is available, a distribution map with a low probability of errors may be constructed by reanalyzing the available climatic data. If then, in the course of investigation a standard series of mean values is adopted by the individual (as for the period 1953-1962 for this example, though any period of any length may be utilized), it will be found in the *Climatic Summary* and *Climatological Data* that cooperative climatic stations have opened or closed, before, during or after the "standard" period.

To obtain more realistic mean values, all stations, past and present, in operation are plotted on a topographic chart, those having "standard" means being so designated. Generally speaking, by computing the ratio of contemporary data in "on-standard" years for closed stations, realistic adjusted means may be determined for most nearby stations with similar climatic conditions. Generally, computed correlations for nearby eastern

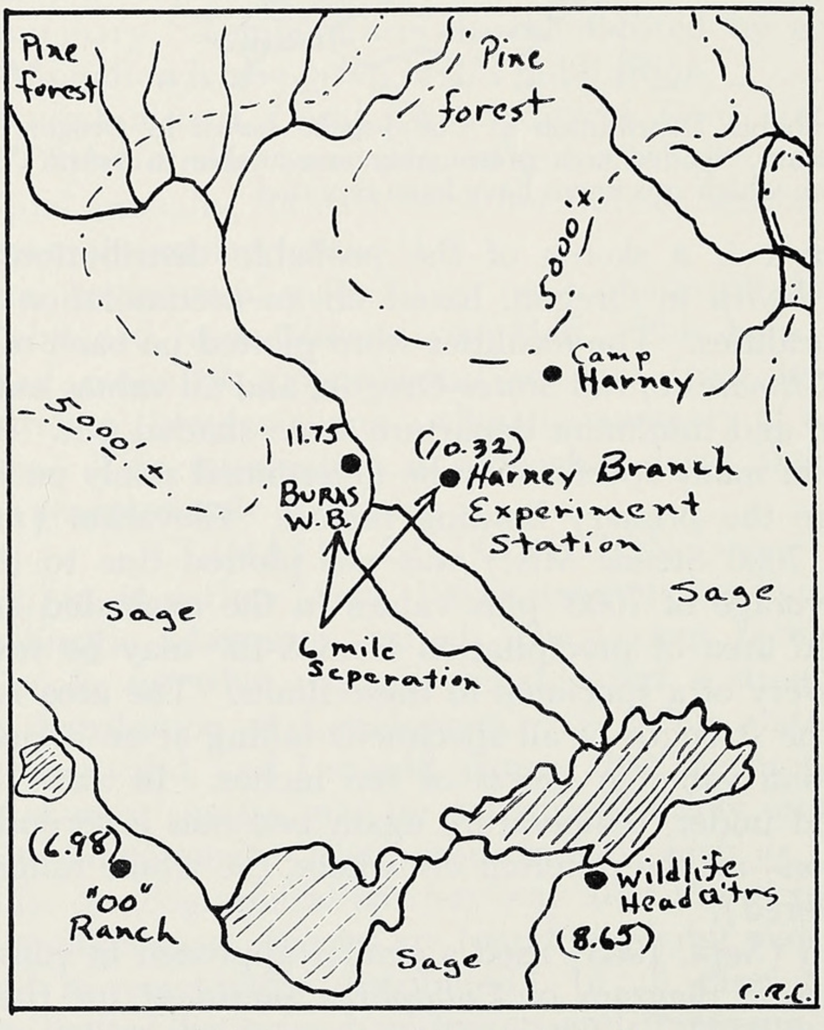

Fig. 2. The geographic relationship of two climate stations with the annual precipitation over a standard period for Burns known, and nearby stations being estimated by ratio.

Oregon stations, indicate a high degree of similarity, with values of 0.75 and above, except for a few stations existing, and closed, in the 1800's. Using this data, figure 2 shows the geographic relationships between two stations, and precipitation for these stations is determined from data and ratio computations found in table 1.

Table 1

Measured annual precipitation for two eastern Oregon meterological reporting stations, and the ratio computations necessary to estimate a period of "standard" missing data for the period 1953-1962.

	Harney Branch Exp. Station				Burns W. B. (long term)	
1937	12. 93				11. 48	
1938	10. 40				9. 55	
1939	5. 82				5. 92	
1940	15. 89				16. 89	
1941	13. 36				14. 92	
1942	13. 13				14. 10	
1943	6. 83				7. 28	
1944	9. 20				10. 17	
1945	12. 75	H'	contemporary period	B'	13. 35	
1946	8. 78				10. 18	
1947	10. 58				12. 36	
1948	10. 93				14. 39	
1949	3. 70				5. 28	
1950	10. 05				11. 54	
1951	9. 32				12. 55	
1952	7. 91				11. 20	
1953	9. 47				13. 63	
1954					7. 51	
1955	$\frac{H'}{n} = 10.06$			$\frac{B'}{n} = 11.45$	12. 14	
1956					12. 65	
1957					13. 45	
1958	Station closed in 1954; H = ?				12. 84	standard mean
1959					9. 64	
1960	$\frac{B}{n} = 11.75$			B	12. 77	
1961					10. 77	
1962					12. 07	

$$\frac{B'}{B} = \frac{H'}{H} \qquad H = 10.32''$$

On occasion computed values will appear that vary from nearby values considerably (as was the case with previously mentioned stations with values in the 1800's), probably due to changing ecology, instrument types, or changes in position of the station locally. If in doubt, correlation coefficients may be computed (0.60 appears to be significant), or the data disregarded. If the latter, one should keep in mind Paul Grey's (1959) suggested formula: m plus t = CS_2.

In many cases, a relationship between precipitation and temperature may be expressed graphically. In figure 3 then,

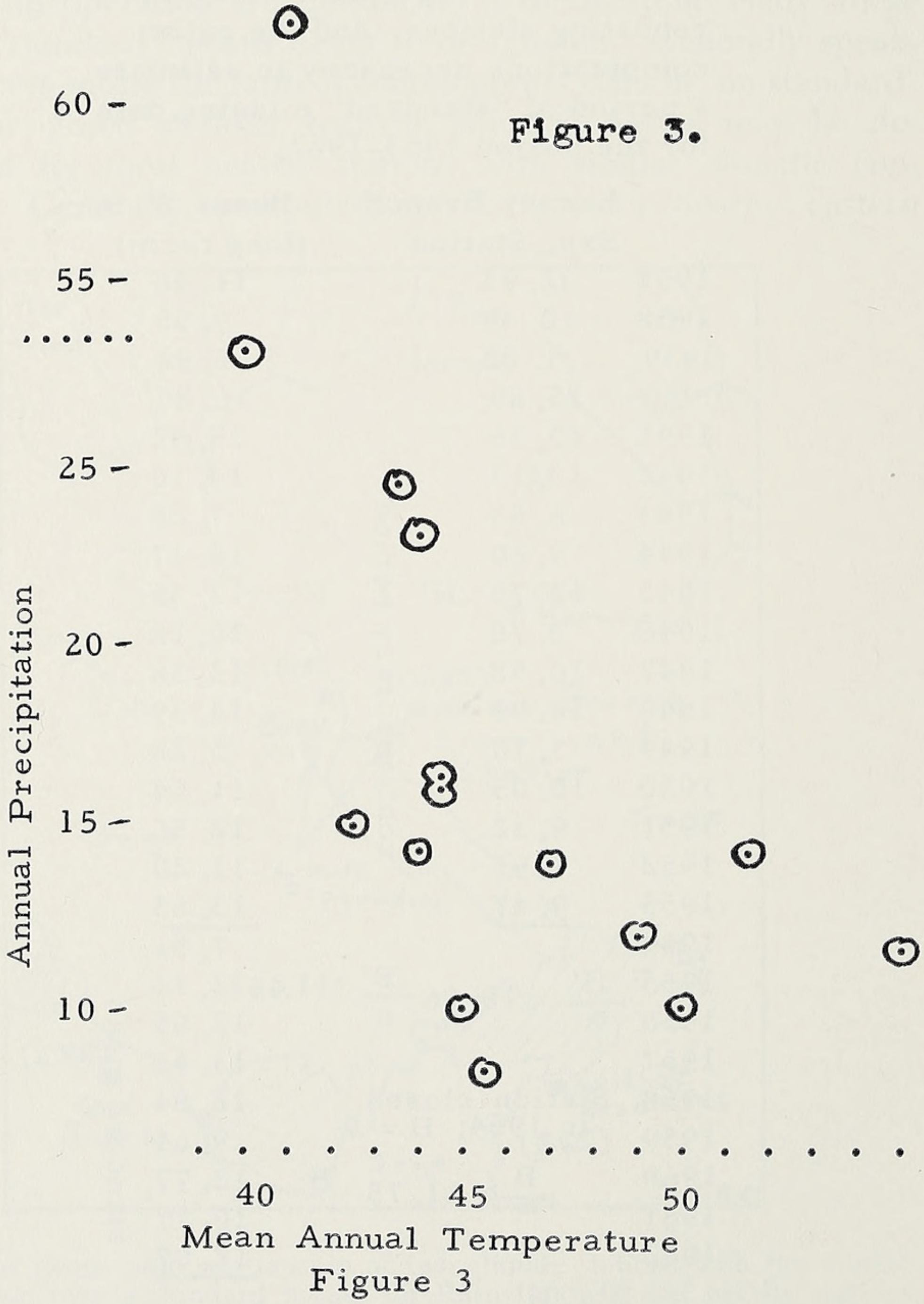

Fig. 3. Scatter diagram of climatic values for year of capture of *Callopsyche behrii.*

data from the year of capture for each locality of *Callopsyche behrii* is plotted. Data is of course insufficient, but generally, from the graph one would expect annual precipitation to decrease as temperature increases, with a rather broad cluster area.

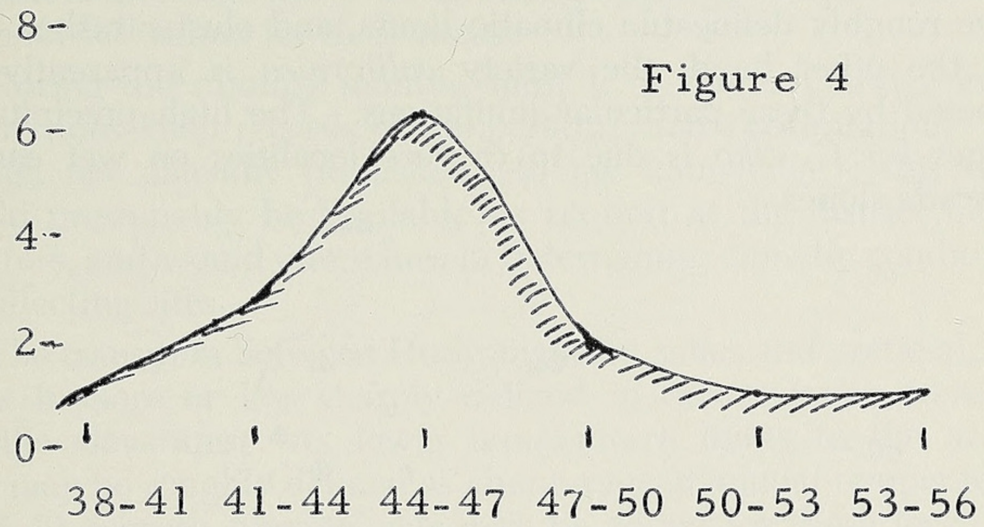

Fig. 4. Frequency diagram of *Callopsyche behrii*, plotted against annual mean temperature of year of capture.

Figure 4 is a frequency polygon for year of capture of *Callopsyche behrii*, with annual temperature as the X-axis, and frequency for the Y-axis. A sharp peak is noted in the 44-47 degree area. Again more data would perhaps make the curve more symmetrical, rather than skewed.

CLIMATIC FACIES VARIABILITY

It is often noted that facies appear to vary with different climatic conditions. In some cases, climate may not be the primary shade limitation factor, but graduation limits may be generally definable by correlation with climatic means.

It is probable then, that when standard methods of measuring variability in facies is determined, that many graduations may be geographically defined by climatic correlation. Probably one of the reasons for the apparent lack of present interest in this area is that if a correlation does exist, it is still difficult to prove that climate is the influencing factor inducing the variation. Many will argue that genetic factors are the primary variational factor (temporarily disregarding topographic barriers), rather than environmental conditions, but it is probable, in either case, that the two are either directly or indirectly linked, depending on the species considered, and results would be similar for environmental or genetic variations.

Subspecies and minor variations are affected in the same manner as general variation, in most instances. In figure 5 I have plotted the mean annual precipitation against the mean January minimum temperature for three northwestern varieties of *Coenonympha.* At once it is noted that *C. elko* and *ampelos* have roughly defineable climatic limits, and cluster rather well. On the other hand, the variety *californica* is apparently not affected by these particular limitations. The high precipitation values for *C. elko* is due to capture localities on wet eastern Cascade slopes.

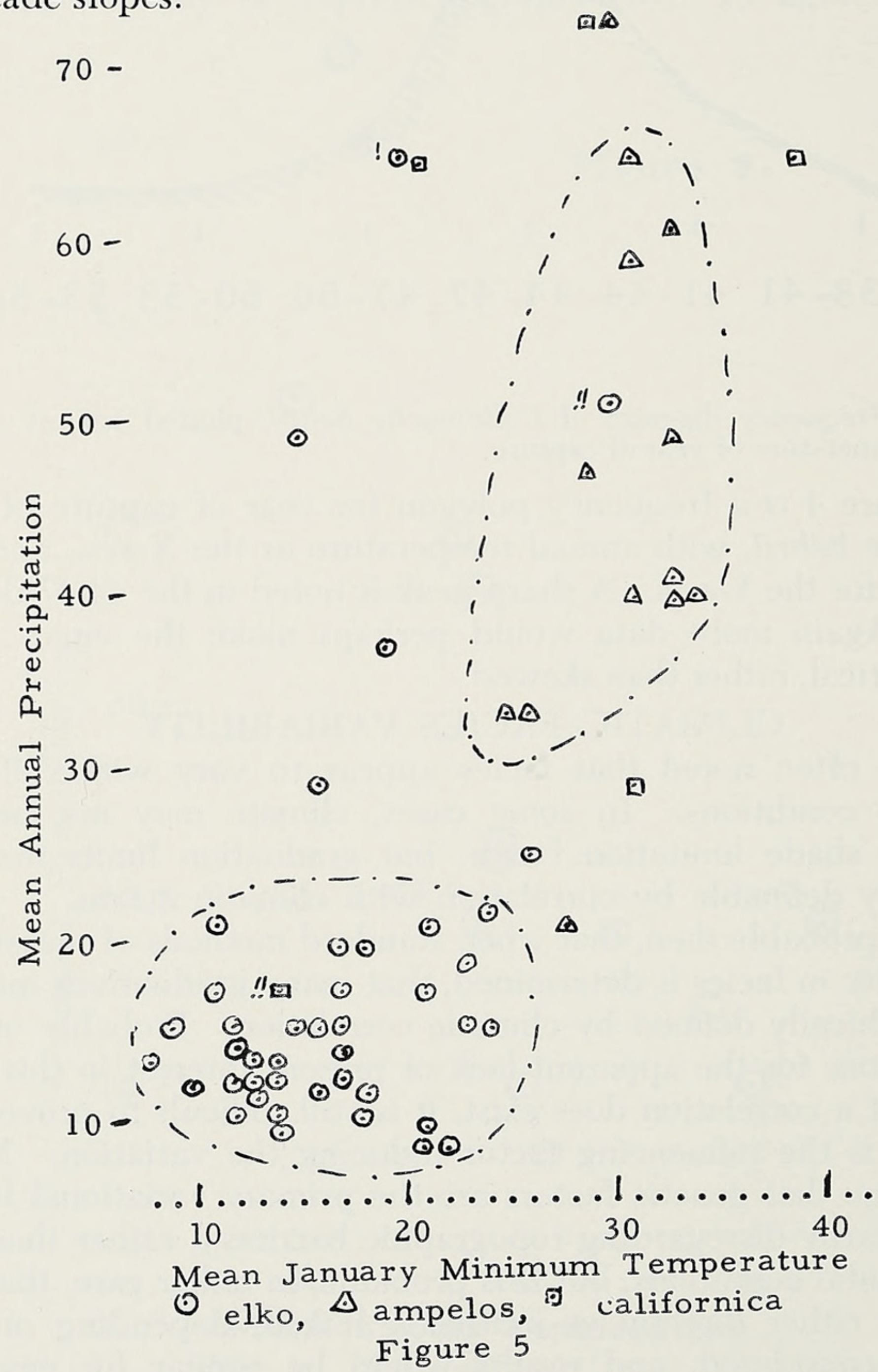

Fig. 5. *Coenonympha* scatter diagram, based on long term climatic means.

OTHER DATA OF INTEREST

Most mountainous areas have snow courses in which measurements of depth and water equivalent are taken during the winter months, for water supply forecasting. This data is published and offers information for determining approximate precipitation and snowfall values for these areas.

During the summer months, most U. S. Forest Service lookout stations keep records of temperature and precipitation. Although not officially published (to my knowledge), this data would presumably be available on request at the district headquarters, and would offer clues in determining climatic conditions at collecting sites.

The transition between Hudsonian life zones and arctic-alpine areas is more or less sharply defined in mountainous areas at specific elevations. As lower temperature limits to the arctic area may be roughly defined as about a mean annual temperature of 35-40 degrees, another clue may be added for those localities in mountainous areas. By comparing temperatures with a climatic station at the base of the mountain then, a graduated temperature diagram by altitude may be used as an estimate for temperatures about the perhipicy of the mountain and on the slopes. Standard lapse rates are rather unreliable due to changes in local topography, storm patterns, solar insolation, and elevational differences in foilage cover.

A definite correlation has been found to exist between annual precipitation (also temperature to some extent), and the thickness of annual tree rings. At some future date then, collectors might be asked to bring cuttings from specified collecting localities. In mountainous areas, this may prove to be the only reliable method of obtaining precipitation values for that site.

Besides temperature and precipitation, many other climatic factors exist that should be of interest to collectors. Areas like solar radiation, cloud cover, growing season and freeze dates, snowfall, winds, humidity, pressure and storm patterns, extreme temperatures, and the like are relatively uninvestigated, in relation to butterflies.

The interested reader is urged to obtain free of cost from the Superintendent of Documents, Government Printing Office, Washington 25, D. C., price list number 48, titled *Weather, Astronomy and Meterology.* This describes the earlier mentioned publications, besides other pertinent material available concerning meterology and climatology.

PALEOCLIMATOLOGY

In recent years, authors are becoming increasingly more aware of the significance of paleoclimatological events, as concerns present subspeciation and distribution. Phrases such as "refugia" are being considered with significance during Pleistocene (Ice Age) ice advances, as are "mass population movements", retreating or advancing in rhythm with thrust stages of glacial ice.

Climatic events prior to the Pleistocene, over the arid Pliocene and damp Miocene, probably are of little significance to our present biological situation, even though fossil evidences shows butterfly existance much earlier. The climatic pattern assumes probable importance at the beginning of the Pleistocene then, some 1,000,000 years ago, and marked the end of some 12,000,000 years of relatively consistant dry climate.

The arctic ground far south, invading the northern U. S. and dropping temperatures considerably from the present normal. Those areas not covered by ice suffered pluvial rains of long and heavy duration (estimated to be 2-3 times the present normal). In my own area, lobes of the great Cordillian Ice Sheet, of British Columbia, pushed as far south as Spokane, and the Vashon sheet past Olympia in Washington. Mountain glaciers were carving moraines in the Steens and Wallowas of Oregon, while extensions of inland seas filled the low eastern basin areas, forming Lake Lahontan. Volcanoes were covering millions of acres in the Cascades and eastern Oregon with sterile pumice, besides leaving thick successive layers of basalt and andesite.

With drastic Quaternary events, the butterfly populations undoubtably suffered greatly, and the collector is tempted to speculate on conditions affecting certain species. In some instances this speculation has been fruitful, as with Clench's (Dec. 1963) treatment of west Indian *Lycaenidae* during the Wisconsin maximum.

Figure 6 is an Oregon-Washington map of the Wisconsin maximum around 14,000 years ago. As is noted at the present, the Oregon Cascades north of Crater Lake are relatively poor in butterfly fauna. As can be seen from the Pleistocene volcanic activity (not necessarily contemporious) the bulk of the Cascades would be rendered unfiit for arctic species following the ice south, while sterile pumice areas would prevent a northern movement of southern species during inter glaiceral times. A

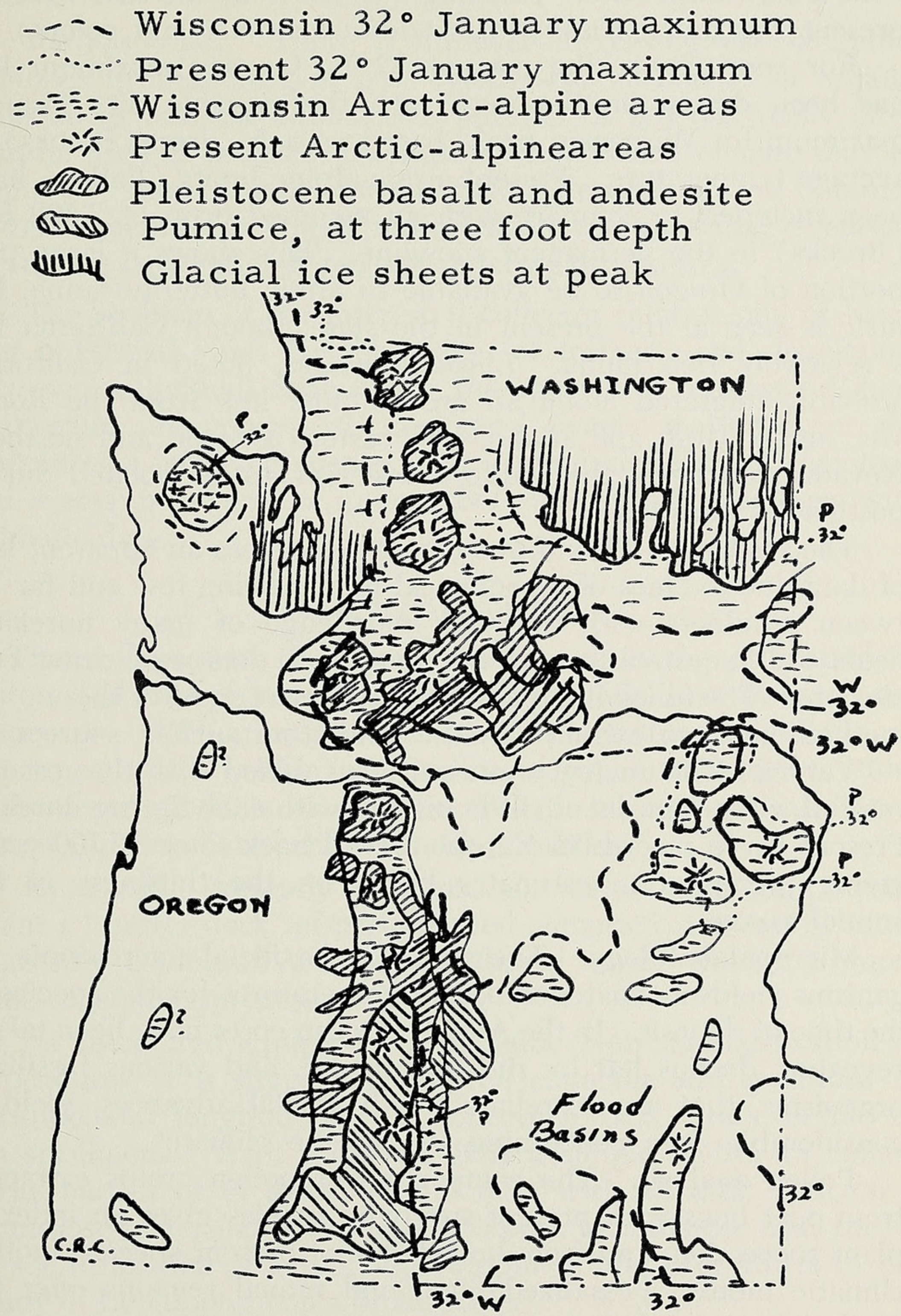

Fig. 6. Oregon-Washington Pleiostocene Events.

species trapped between, and efficiently isolated, would probably, with time, subspeciate. This might prove to be the case with the present Cascadian *Euphydryas editha lawrenci* and *colonia.*

For comparison, the present 32°F. January maximum line has been drawn on the map with the possible 32° January maximum for Wisconsin peak, based on a 5° drop (Brooks) in average temperature. Present arctic-alpine limits (Bailey) have been included to compare with an assumed drop of 2,500 feet (Brooks) in the permanent snowline. This shows a large proportion of Oregon to be available to arctic butterfly fauna, but little is seen at the present in the state, though California has a relatively rich fauna. *Lycaena phlaes,* noted in California probably migrated along an arctic-alpine link from the Rocky Mts. across Utah and Idaho, into eastern Oregon and northern Nevada, and down the California Sierras, to be isolated during postglacial warming.

The student of Pleistocene climatology faces an apparent lack of data due to clues of a geological nature being few and far between. Students with a broad knowledge of many unrelated fields are required to sort the minimual data and draw conclusions. The following is a brief summary of some of the methods used to extract climatic data from ancient sources.

Varves. The ancient shores of lakes varied with the seasonal rainfall, with deposits of silt being left with each Spring flooding. Present varve records in Europe extend back some 13,700 years, giving precipitation estimates based on the thickness of the annual varves.

Micropaleontology. The study of fossilized microscopic organisms yields estimates of ocean temperatures for the species at the time of deposit. In the Atlantic Ocean cores have been taken, revealing detrius left by the oceanic ice, and various fossilized organisms, that are correliated with glacial advances, yielding considerable data concerning Pleistocene climates.

Pollen analysis. The comparison of pollen grains extracted from peat bogs with present surviving species gives an index of plant succession, and from knowledge of prssent species another climatic index. Fossalized floral and faunal remains offer the same index.

Tree rings. The analysis of tree rings has given us a climatic record extending back some 3,000 years or so in North America. It is possible that at some future date this method of analysis will overlap fossilized tree species, and the limit will be extended far into the Pleistocene. Comparison of rings of fossil species with modern counterparts will yield approximate precipitation values for the period of growth.

Radioisotopes. There is an ever increasing use of radioisotopes in measuring of past events—the carbon 14 of organic substances and the radioactive fluorine of igneous rocks often can be used as prehistoric signposts from which climate may be indirectly established. The increasing dependency on obtained dates from these methods indicates a trend that may eventually replace conventional geological dating procedures.

The problem of the interested collector then, is one of locating published clues for the region of interest, and developing his own individual analysis for the species of interest. Where butterflies are concerned, geological events may prevent the spread of a localized species, and a familarization with geological events in the area of interest becomes equally necessary with climatic data.

AUTOMATION

There at present is a "landslide" trend in the utilization of automated data processing equipment in all fields of research and endeavor. With greatly increased computer storage facilities, as on tape, it falls within economic and practical limits to store voluminous amounts of climatic data to be automatically compared and correliated with butterfly localities.

Even with, presently common, automated tabulating equipment a "master deck" of pre-punched climatic cards can be automatically compared with distributional cards, though a more time consuming process.

As automated equipment is dependent on standardization of procedures, it is suggested that the collector add notations of latitude and longitude to his collecting data, either in file or on specimens. With this data, it is a simple matter to collate large masses of of distributional data with climatic data on a grandiose scale, and we have but to peek towards the near future to see utilization of automated equipment and procedures in the study of Lepidoptera on a broad scale.

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