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BIOCLIMATIC APPROACH TO THE ANALYSIS OF DROUGHT IN THE MEDITERRANEAN REGION OF CHILE (x)

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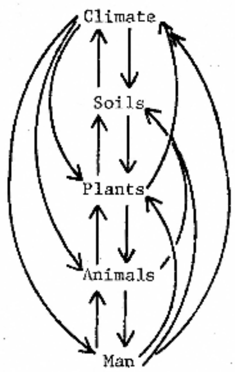
"The desert is advancing" has been an observation postulated in Chile for a long time. The reasons have been diverse. Sometimes it has been the unrestricted action of Man, with his different ways of influencing the natural ecosystems, other times there have been reasons of a physical nature (mainly climatic) and in the majority of the cases, the action is mixed.

It is necessary to remember the close relationships existing between climate and the other components of ecosystems (physical and biological):



(di Castri & Hajek 1961a, modified)

(x) Report on a research carried out by the author with M. Pacheco and A. Passalacqua.

It is important to point out that Climate and Man are the main elements of modeling or demolishing the natural situations.

Climate would be the main conditioner of the regions of aridity in the world and climatic variations the principal determinants of the periodic phenomena of drought.

In Chile, several investigators have been concerned with the problem of the drought, from meteorological, climatological, economical, or other points of view. These studies are carried out, unfortunately, with the same periodicity of the drought phenomena, without continuously observing these aspects and their evolution, so that it might be possible to formulate some models for predicting future situations, based on the tendency that these phenomena show.

It is also of a certain meaning to analyze these phenomena in their biological implications. The integration of climatic elements is a very useful resource. Many times, the joint action of climatic elements is of a greater importance than the isolated study of one or the other climatic factor. In several previous papers (di Castri & Hajek, 1961b, 1962, 1970), with a bioclimatic approach, the necessity was stressed to analyze jointly the effect of climatic elements on the organisms, concerning the areas in which they thrive and live. Thus, it has been possible to obtain a very complete picture of the bioclimatic situation of Chile and to divide the country in 5 main zones: desertic, tropical, mediterranean, oceanic and continental. The detailed characteristics of these zones can be found elsewhere (di Castri 1968; di Castri & Hajek 1970); therefore, it will not be necessary to repeat them here.

Based on previous bioclimatic studies, which were made under the "normal situation", this research was carried out with an eminent bioclimatic approach on some aspects of the drought in Chile. We have considered only the drought of the last years, due to the presence of a greater amount of meteorological stations with reliable data. The previous “historic” droughts in Chile (1924 and 1886) unfortunately could only be evaluated on the basis of limited information because meteorological stations were lacking at the time.

This drought analysis deals mainly with the Chilean mediterranean zones in order to keep it within the scope of the “Structure of Ecosystems” Project. Some stations of the oceanic zone were also taken in account, but only for measuring the displacement northward of this region.

Methods

Data of temperatures (mean, maximum and minimum), relative humidity and rainfall were obtained directly from the files of the "Oficina Meteorológica de Chile" for the years 1965-1969 and for 30 stations (Table 1) from Chañaral (26°20') to Puerto Montt (41°28').

For the integrated analysis, two mechanisms have been used: 1. Bioclimatic indices and 2. Bioclimatic graphical representations. For bioclimatic indices, only the monthly index of de Martonne was used because of its wide acceptance, and its use in defining normal situations in previous research in this field, in our country. For the index, monthly mean temperatures and rainfall data are used. The equation is:

$$\frac{P}{T + 10} \times 12$$

where P is monthly rainfall (mm) and T the mean monthly temperature (°C). According to this index, a month is considered arid with an index below 10; semiarid, between 10 and 20, and humid above 20. Within this, we have also used the concept of cold months (di Castri et al. 1962) in which a month is considered cold when the mean temperature is below 5 °C, semi-cold between 5 °C and 10 °C, and warm, above 10 °C.

The summation of the conditions of aridity and cold gives us a series of situations which can be defined as favorable, semi-favorable and unfavorable.

For graphical representations, we have used the Gaussen-Walter diagram with a system of coordinates with two scales of ordinates (left, temperature; right, rainfall) and the months on the abscissa. When the curve of rainfall is below that of temperature, a month is qualified arid, being the opposite humid.

Results and discussion

Considering the total amount of rainfall, 1965 showed surplus for all of the stations, except Potrerillos, Copiapó and Puerto Montt. In 1966, the situation is irregular, some stations beginning to show a deficit of rainfall and a surplus which is less than in 1965. In 1967, the phenomenon of drought begins strongly with deficits in 90% of the analyzed stations; the most severe drought was detected in 1968, in which all stations show deficits, exception made of Osorno (+8%). If we consider all the analyzed stations, we find a sequence from north to south with a gradual decrease of the percentages of deficits: from -100% in the north to -6% in Valdivia.

The drought was worse in 1969 only in La Serena and Ovalle (-94% and -87%, resp.). In other localities a recovery was seen, which was variable, remaining some areas still with a certain degree of deficit in relation to the normal year.

A global view of our analysis tells us that the drought in this period affected strongly the zone of the "Norte Chico" and the Central Valley and it can be seen (as far as this study reaches) that the problem is still aggravated in La Serena and Ovalle, while the rest of the northern part remains stationary. With respect to the south zone, the drought was not detected so strongly between Concepción and Puerto Montt, due to abundant rainfall, which was present in years with rain deficiency.

Although rainfall is an important element to be considered when studying drought phenomena, it is also relevant to take into account pairs of elements. Using climatic pairs, especially temperature and rainfall, we obtained a picture rather different than when we analyzed only the precipitations. Analyzing these elements together, we can define better the limits of the displacement of the Chilean bioclimatic regions, compared with the normal situation. In Table 2 and Fig. 1, the correspondence of the stations to each of the bioclimatic zones of the country (in normal years) is shown and also which is the situation produced in the different years with drought.

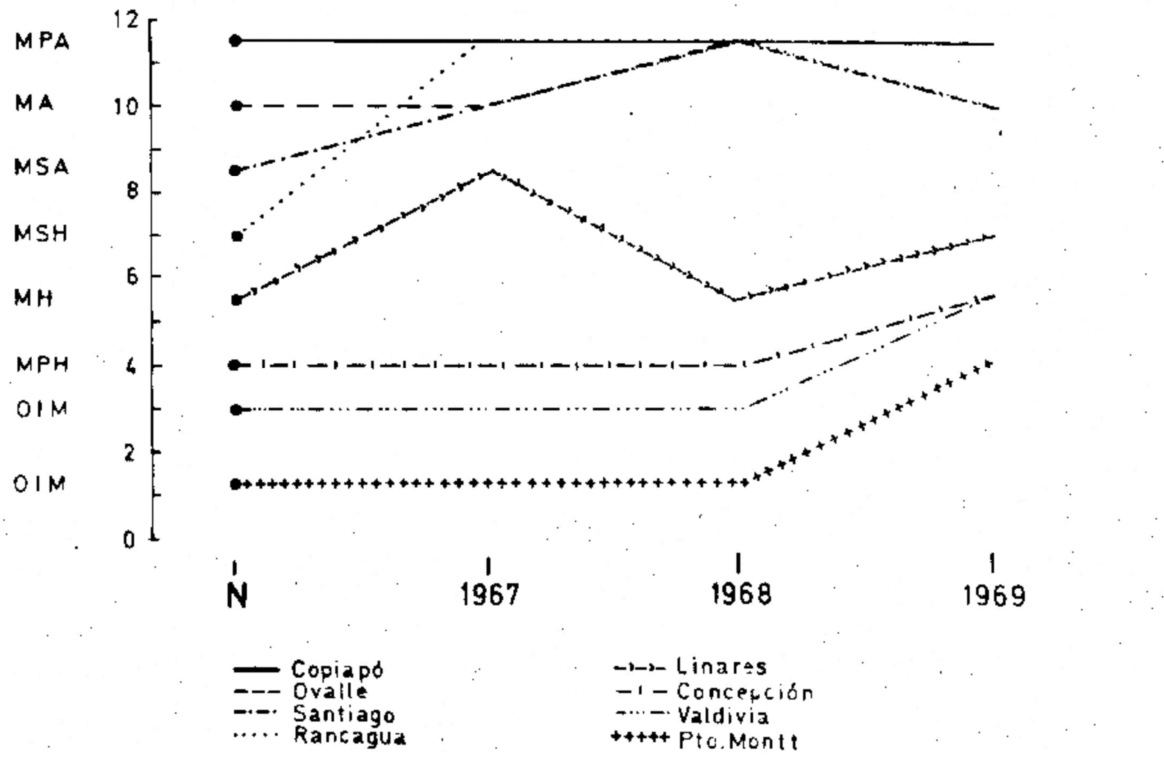


Fig. 1. Location of stations and displacement during the drought years.
O - 12, scale of unfavorable months. (Explanation for abbreviations can be seen in Table 2.)

As a distinctive element, we have considered the concept of "unfavorable months", that is, the integration of drought and cold. It is noticeable to observe, as an example, the station of Rancagua, which, according to the characteristics it shows in the different years, would belong to the medíterranean per-arid zone ín 1967 and to the mediterranean-arid in 1969. Also Linares "jumps" to more arid regions in 1967, is normal in 1968 and goes up in 1969.

It is impossible in this brief report to analyze in detail all the changes that are produced in the bioclimatic regions in Chile, due to the drought. Many aspects, such as humidity and extreme temperatures are still under analysis and all the results together will be published elsewhere.

If we make a global analysis of the situation of displacement of the regions during the drought years, it is possible to conclude that in general there exists a movement toward more unfavorable regions with only a slight recovery in 1969. It is necessary yet to resolve which is the situation in 1970, which still shows deficits ín some regions and 1971 in which apparently there has been a greater recovery than in the prevíous year.

As seen in Fig. 1, a second drought wave is also starting in southern regions in 1969, adopting the region some characteristics of more northern areas.

In Fig. 2, we show, summarized, the integration of limiting factors, the drought and cold, as a sequence from north to south (in black, unfavorable months; striped, semifavorable; white, favorable months). It is necessary to point out here that in general 1967 shows a more intense distribution of "black" in the different months, which is due to lower temperatures; so, this year, previous to the drought, must be considered a cold year, since many months show a temperature under 5 °C. It is necessary to test if a cold year precedes a drought year or if this is just an anomaly with no relation to the drought.

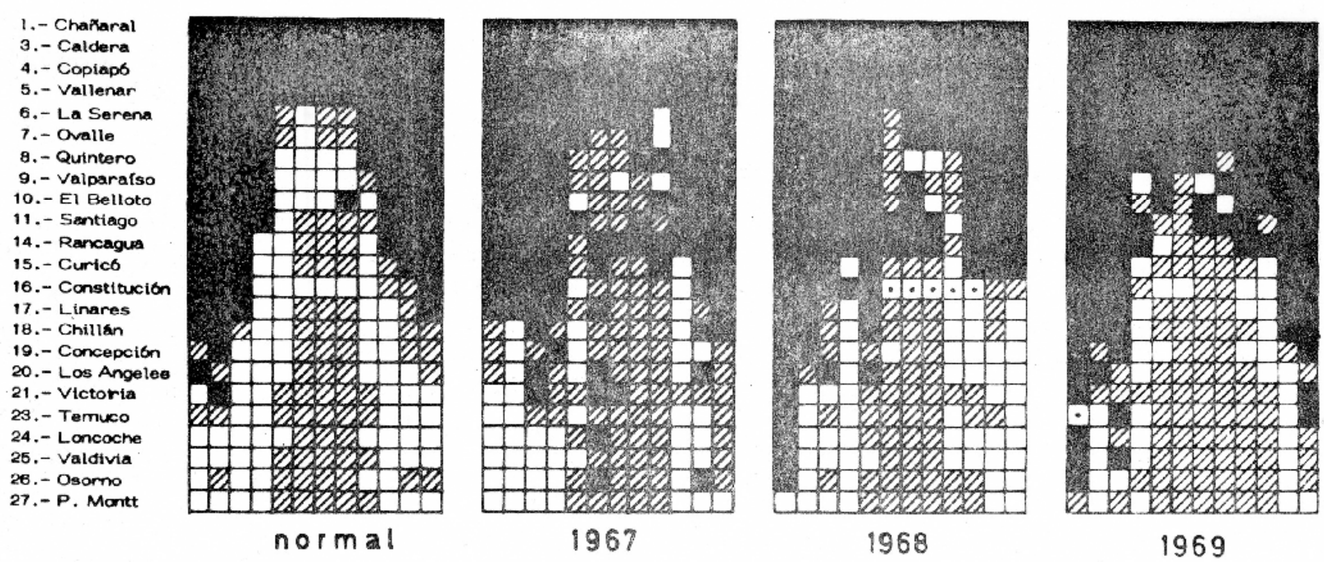


Fig. 2. Representation of unfavorable months, beginning January. (black = unfavorable; striped = semi favorable; white = favorable months).

Stations 2, 12, 13 and 22 have not been included in this sequence. (.... means incomplete data.)

It will be impossible, due to the character of this report, to make an exhaustive discussion and also to publish all the graphs which could permit a clarification of the picture. Also some other elements, such as extreme temperatures and some parameters of humidity are under study, which will permit us to add new elements to the bioclimatic analysis of the drought.

Finally, it is again necessary to recall the fact that a maximum of elements should be studied together, since out of hydrologic, also thermal conditions seem to be modified. For a full view, a continuous study is necessary, since many species have different tolerances and depend basically on the long range climate for their production and survival. Unfortunately, there is a lack of data on the tolerance to drought for most Chilean species, thus a full measure of the impact that the climatic changes produce on vegetation is unknown; therefore, it will be difficult to evaluate, based on current knowledge, the effects that the changes of climate have on the organisms in this country.

Acknowledgements

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Table 1

Meteorological Stations used for this study

No.	Name	Latitude S deg – min	Longitude W deg - min	Altitude m
1.	Chañaral	26 - 20	70 – 37	9
2.	Potrerillos	26 - 30	70 – 37	2850
3.	Caldera	27 - 03	70 - 58	28
4.	Copiapó	27 - 21	70 - 24	370
5.	Vallenar	28 - 35	70 - 46	470
6.	La Serena	29 - 54	71 - 15	32
7.	Ovalle	30 - 36	71 - 12	220
8.	Quintero	32 - 47	71 - 32	2
9.	Valparaíso	33 - 01	71 - 38	41
10.	El Belloto	33 - 03	71 - 24	121
11.	Santiago	33 - 27	70 - 42	520
12.	I. R. Crusoe	33 - 37	78 - 52	6
13.	Sewell	34 - 06	70 - 22	2134
14.	Rancaqua	34 - 10	70 - 45	500
15.	Curicó	34 - 58	71 - 13	225
16.	Constitución	35 - 20	72 - 56	7
17.	Linares	35 - 51	71 - 36	157
18.	Chillán	36 - 36	72 - 02	118
19.	Concepción	36 - 50	73 - 02	15
20.	Los Angeles	37 - 28	72 - 21	130
21.	Victoria	38 - 13	72 - 21	360
22.	Lonquimay	38 - 26	71 - 15	900
23.	Temuco	38 - 45	72 - 35	114
24.	Loncoche	39 - 23	72 - 38	112
25.	Valdivia	39 - 48	73 - 14	9
26.	Osorno	40 - 35	73 - 09	24
27.	P. Montt	41 - 28	72 - 57	5

Table 2

Distribution of Regions according to index of unfavorable months

Regions	Normal	1967	1968	1969
Mediterranean Per-arid 11 - 12	Chañaral Potrerillos Caldera Copiapó	Chañaral Potrerillos Caldera Copiapó Vallenar Sewell Rancagua	Chañaral Potrerillos Caldera Copiapó Vallenar La Serena Ovalle Santiago Rancagua	Chañaral Potrerillos Caldera Vallenar La Serena Ovalle Quintero
Mediterranean Arid 9.5 – 10.5	La Serena Ovalle	Ovalle Quintero El Belloto Santiago Curicó	Valparaíso El Belloto Sewell	Valparaíso El Belloto Santiago Rancagua
Mediterranean Semi-arid 8 - 9	Santiago Quintero Sewell	Valparaíso Linares	Quintero Curicó	-----------
Mediterranean Sub-humid 6.5 – 7.5	Valparaíso El Belloto Rancagua Curicó	Constitución Victoria	Lonquimay	Sewell Curicó Constitución Linares Chillán Victoria
Mediterranean Humid 5 – 6	Constitución Linares Chillán Lonquimay	R. Crusoe Chillán Los Angeles Lonquimay	Linares Chillán Los Angeles	Concepción Los Angeles Temuco Loncoche Valdivia Osorno
Mediterranean Per-humid 3.5 – 4.5	Concepción Los Angeles Victoria Temuco Osorno	Concepción Temuco Loncoche Osorno	Concepción Victoria Temuco Osorno	R. Crusoe P. Montt
Oceanic with mediterranean influence 2.5 - 3.5	Loncoche Valdivia	Valdivia	R. Crusoe Loncoche Valdivia	-----------
Oceanic with mediterranean influence 0 - 2.5	P. Montt R. Crusoe	P. Montt	P. Montt	-----------

(x) Advances of a research carried out by the author with M. Pacheco & A. Passalacqua