THE DISTRIBUTION OF LOMAS VEGETATION AND ITS CLIMATIC ENVIRONMENTS ALONG THE PACIFIC COAST OF PERU

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Abstract Lomas vegetation, a seasonal meadow which grows in the coastal desert of Peru and Northern Chile, was investigated. Its distribution area was classified into four zones on the basis of features of the vegetal community. Each zone corresponds to a certain precipitation pattern characterized by its amount and frequency. The lomas vegetation on Loma Ancón was precisely investigated and its distribution related to the climatic conditions in a small study area.

1. Introduction

Under the strong influence of trade wind inversion, a coastal desert develops along the Peruvian Pacific Coast. The desert is well-known as one of the drier ones in the world, the cooling effect of the Peruvian Sea Current increasing air stability. Under the influence of the cool Peruvian Sea Current advancing northward along the Pacific Coast in winter, the coastal desert is covered with a stratus layer (coastal fog) developing below the base of an inversion layer. The extent of this stratus layer depends on the height and strength of the inversion layer and the sea surface temperature.

The peculiar orographic conditions of Peru are responsible for the much greater effect than elsewhere of this coastal fog. The steeply rising slopes of the coastal mountains are called 'Lomas'. On the lomas, the fog produces a characteristic type of vegetation during the winter months, so-called 'fog-oases' (ex. Ellenberg, 1959). We term this vegetation 'Lomas Vegetation' in this paper. When the slopes are covered with lomas vegetation, the landscape changes from that of a brown desert to that of a flower garden. The distribution of this vegetation ought to be clearly controlled by some climatic conditions. This vegetation is classified into five main types by Ferreyra (1953) and Ono (1982), namely herbaceous lomas, shrubby lomas, bromelian lomas, tillandsia lomas and cacti lomas. Attention is paid here to only herbaceous lomas and tillandsia lomas.

The paper presents the summarized results of the authors' investigation of the distribution of lomas vegetation and its climatic environments. The research was conducted from September, 1980 to January, 1981 and was sponsored by Grant-in-Aid for Overseas Scientific Survey, the Ministry of Education, Science and Culture, Japan (No. 504157).

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2. The distribution of lomas vegetation and its climatic environments

The distribution of lomas vegetation

The distribution of some distinctive types of lomas along the Pacific Coast of Peru and Northern Chile is shown in Fig. 1. It includes some lomas cited in previous literature (for instance, Weberbauer, 1945; Ferreyra, 1953; Rauh, 1958; Koepcke, 1961) and investigated by Ogawa in 1971. That is, it does not show the contemporaneous distribution of lomas vegetation, but rather the broadest distribution when the conditions are most suitable for its growth. This vegetation has a narrow landward distribution running in a strip some 10~60 km from the sea coast, and is distributed more than 1000 km from north to south. The uppermost community of the lomas vegetation, which consists of tillandsia, reaches 600~700 m above sea level (a.s.l.) in the middle part of Peru and ca. 1100 m a.s.l. in the southern part. Lower communities are composed of tillandsia in the middle part, and herbaceous in the southern part of Peru. The lower limits of their distribution are not different (Fig. 2). Concerning the distribution pattern of the lomas vegetation, herbaceous and shrubby communities occupy the core of the lomas vegetation, with tillandsia communities being found in peripheral parts. We can point out some distinctive features of the distribution of lomas vegetation. First, four geographic zones can be recognized in the horizontal distribution of the communities, namely 1) ~11°S, 2) 11°S~13.5°S, 3) 13.5°S~15°S, 4) 15°S~. In the second and fourth zones, the lomas have a continuous distribution although the size of individual communities differs. But, in the first and third zones, the communities are very sparse. These four zones can also be distinguished clearly in the vertical distribution shown in Fig. 2.

At time of the author's field work in 1980, the lomas vegetation existed at least in the second zone, but it was not found in other zones except for limited areas. When the Peruvian Coast was affected by one of the most destructive events of 'El Niño' of this century in 1983, it was reported that the vegetation had a very wide distribution in the forth zone despite having a smaller than usual distribution in the second zone. In accordance with the facts mentioned above, it can be said that the lomas vegetation is constantly formed every year in about the same area in the middle part, especially in the second zone, but its distribution exhibits extreme fluctuations year by year in the southern part, especially in the fourth zone.

Climatic environments

Differences in the vegetation pattern among the four zones or between the middle and southern parts of Peru ought to be compared with the characteristics of coastal fog. Regrettably, it is still difficult to obtain meteorological data for coastal fog (stratus layer). In this paper, instead of the direct analysis of the fog data, the inversion of air temperature and the precipitation pattern are investigated in order to clarify the effect of the fog on the lomas vegetation.

Inversion of temperature

It is well-known in Peru that the coastal inversion is much more extreme and visible as a layer of stratus clouds during the winter months. The frequency distribution of this inversion base which must coincide with the upper limit of stratus clouds is illustrated in Fig. 3.

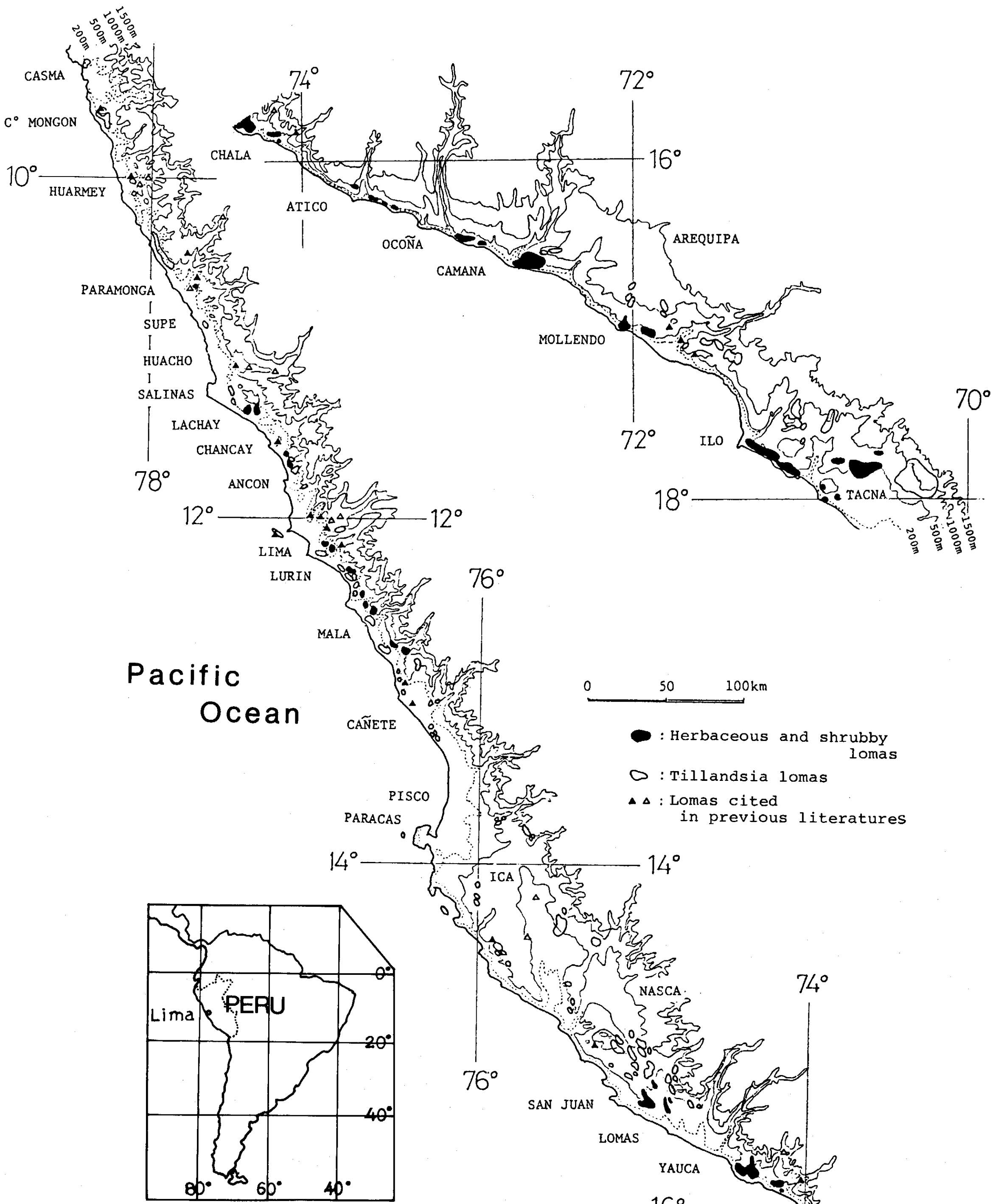

Fig. 1 Distribution of lomas vegetation along the Peruvian Pacific Coast.

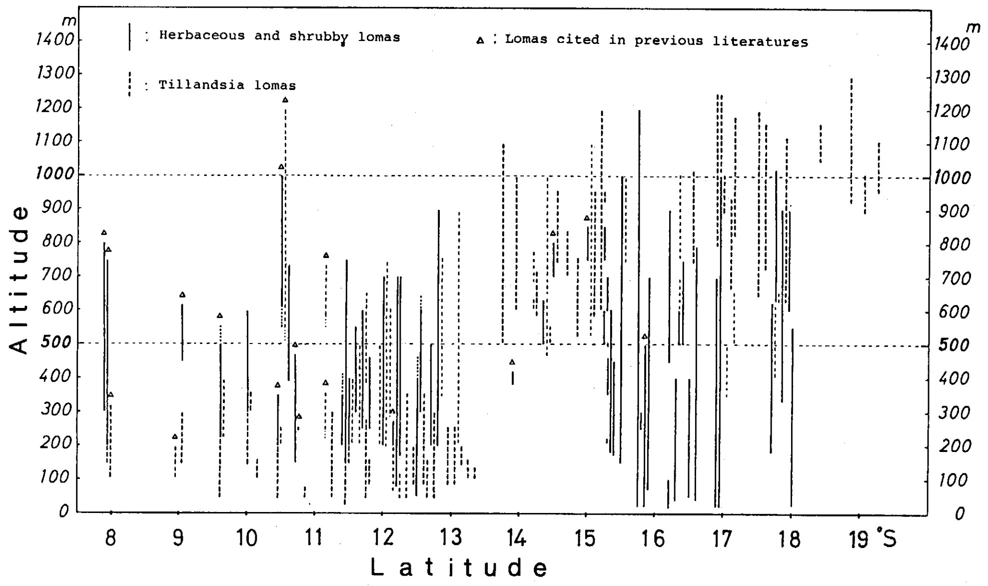

Fig. 2 Vertical distribution of lomas vegetation.

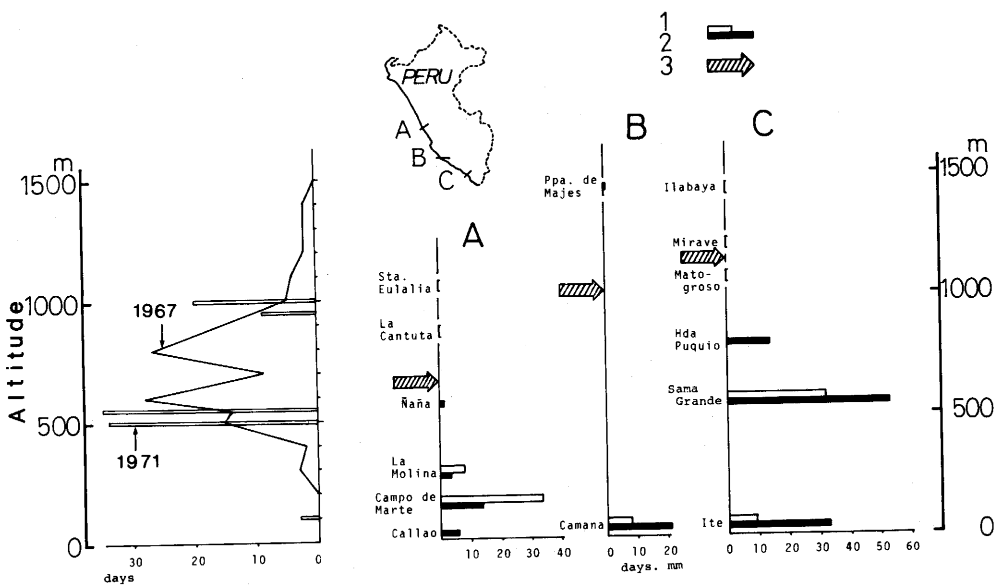

Fig. 3 Frequency distribution of inversion base (left) and vertical distribution of precipitation (right) during the winter, 1: number of days with precipitation (≧0.1mm), 2: amount of precipitation, 3: upper limit of tillandsia community.

During the winter of 1967, the inversion base fluctuated between 300~1400 m a.s.l., with a peak frequency at 600 and 800 m a.s.l. over Lima (Prohaska, 1973). Although we cannot discuss in detail for lack of meteorological data for 1971 at significant points over Lima, the inversion base appeared most frequently between 500 m a.s.l. (ca. 950 mb) and 1000 m a.s.l. (ca. 900 mb) (Fig. 3). Air temperature of the inversion base was most frequently 10 °C and 12 °C.

An increase in instability in the marine air layer below the inversion leads to frequent drizzles, called garúa. This fog precipitation, originated from the stratus clouds, extends upward approximately to the inversion base. The marine air is lifted orographically as it moves inland onto the slopes and hills in the Pacific Coast region. As a result, drizzle falls continuously in the area where the stratus clouds come in contact with the ground surface. The upper limit of this precipitation over Lima is ca. 500 m a.s.l. almost the same as the

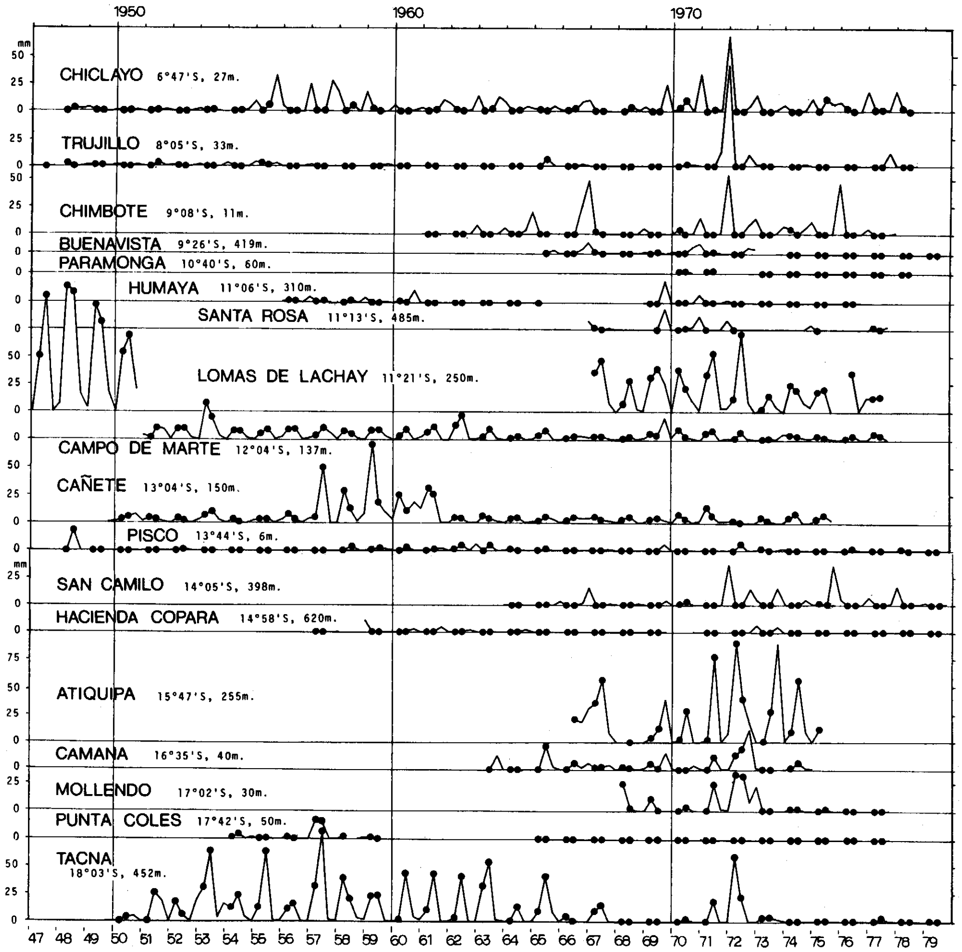

Fig. 4 Inter-annual variation of precipitation at every three month intervals at stations along the Peruvian Coast; black spots indicate the value during the winter months (May ~ July, Aug. ~ Oct.)

height of the inversion base and corresponds to the upper limit of the lomas vegetation consisting of tillandsia community as shown in Fig. 3. The upper limit of precipitation is higher in the southern part of Peru (at least ca. 800 m a.s.l.) than in the middle part. It corresponds to the fact that the upper limit of the lomas vegetation is higher in the southern part. Accordingly, it is expected that the inversion base frequently becomes higher in the southern part of Peru than in the middle part and the stratus develops upward at least to 1200~1300 m a.s.l. in the southern part.

Precipitation

Fig. 4 shows inter-annual variation of precipitation for every three months (Feb.~Apr., May~July, Aug.~Oct., Nov.~Jan.) at some stations below ca. 500 m a.s.l. along the Peruvian Coast. Some distinctive features from north to south are shown as follows: 1) summer precipitation predominates over winter one and changes markedly year by year in the northern part of Peru (Chiclayo, Trujillo and Chimbote), 2) there is rarely precipitation through the year near Paramonga, 3) amount of precipitation increases during the winter and its yearly variation is not conspicuous in the middle part of Peru (Lomas de Lachay, Campo de Marte and Cañete), 4) as one gets near Pisco, precipitation decreases in amount again, and 5) beyond 15° south latitude, amount of precipitation increases strikingly, but winter precipitation is variable year by year. Characteristics of winter precipitation only particularly correspond to the four geographic zones of lomas vegetation mentioned previously. For example, Paramonga and Pisco situated in the first and third zones of lomas vegetation respectively have almost never had precipitation. On the other hand, Campo de Marte and Cañete situated in the second zone and Camana and Mollendo in the fourth zone, experience some precipitation every year. However, because the total amount of precipitation decreased in the late 1970s in the fourth zone including Camana and Mollendo, recent formation of lomas vegetation in this zone has been poor.

Climatic diagrams based on Walter's method (Walter, 1964) are illustrated in Fig. 5. Higher stations, Lomas de Lachay and Atiquipa, differ from lower stations in having several humid months during which the precipitation curve lines above the temperature one. We can see that the relationship between the amount and frequency of precipitation in the second zone differs from that in the fourth zone. Actually, the precipitation records of August 1971, when the lomas vegetation was relatively well-developed, indicated the total Amount of 6.4 mm for 17 days at Campo de Marte in the second zone. In contrast, the total amount of precipitation for only 4 days was 23.6 mm at Mollendo in the fourth zone. The more altitude increases, the more the contrast strengthens; compare, for instance, Lomas de Lachay (250 m a.s.l.) having a total amount of 34.7 mm for 29 days with Atiquipa's (255 m a.s.l.) 71.8 mm for only 4 days. This characteristic of the precipitation pattern is shown in another way in Fig. 6.

We can recognize differences not only in amount of precipitation but also in precipitation intensity or frequency among the four vegetation zones, especially between the second and fourth zones in Fig. 6. Furthermore, when the 'El Niño' effect clearly occurred as in 1965 and 1972, it can be seen that precipitation decreases both in amount and frequency in the second zone of the middle part of Peru, but increases in amount in the fourth zone of the southern part (Fig. 6). These observations lead to the following questions: what makes the precipitation more intensive in the fourth zone than in the second zone? When the "El Niño'

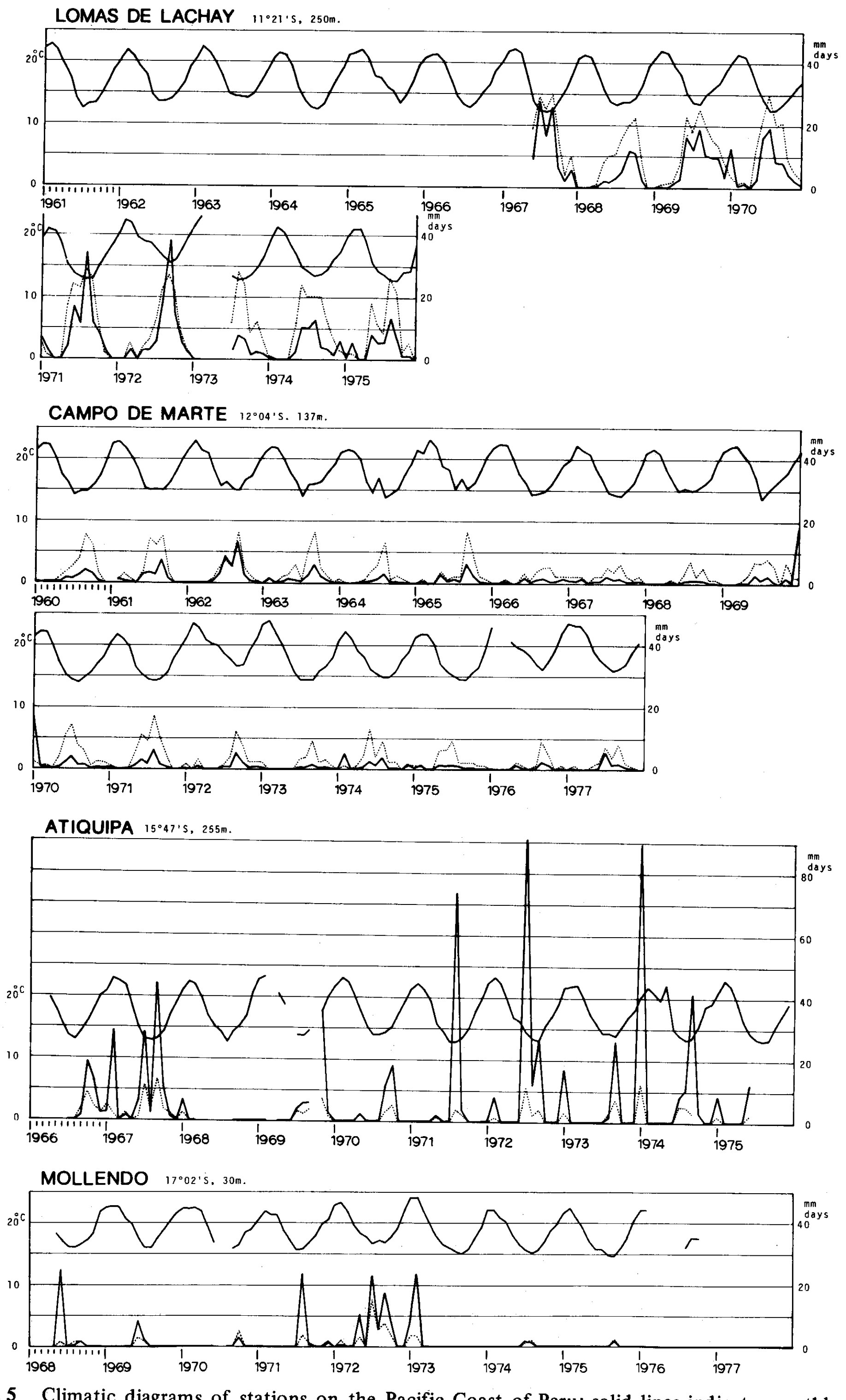

Fig. 5 Climatic diagrams of stations on the Pacific Coast of Peru; solid lines indicate monthly mean temperature and monthly total precipitation, dotted lines indicate number of days with precipitation.

effect occurs, why does the second zone experience lower amount and less frequency of precipitation than usual, as against the fourth zone with a higher total amount than usual? We do not have enough meteorological data for a detailed discussion of these problems. But, at least it seems to be sure that the inversion base controlling the height of stratus layer is lower in the middle part of Peru than in the southern part. If the inversion base is lower, the stratus layer is thinner and its activity is weakened, but the fog clouds come in contact with the ground surface during the winter and continuously supply enough moisture to produce the lomas vegetation. If the inversion base is higher, the thickness of the stratus layer exhibits extreme fluctuation in accordance with the strength of instability of the

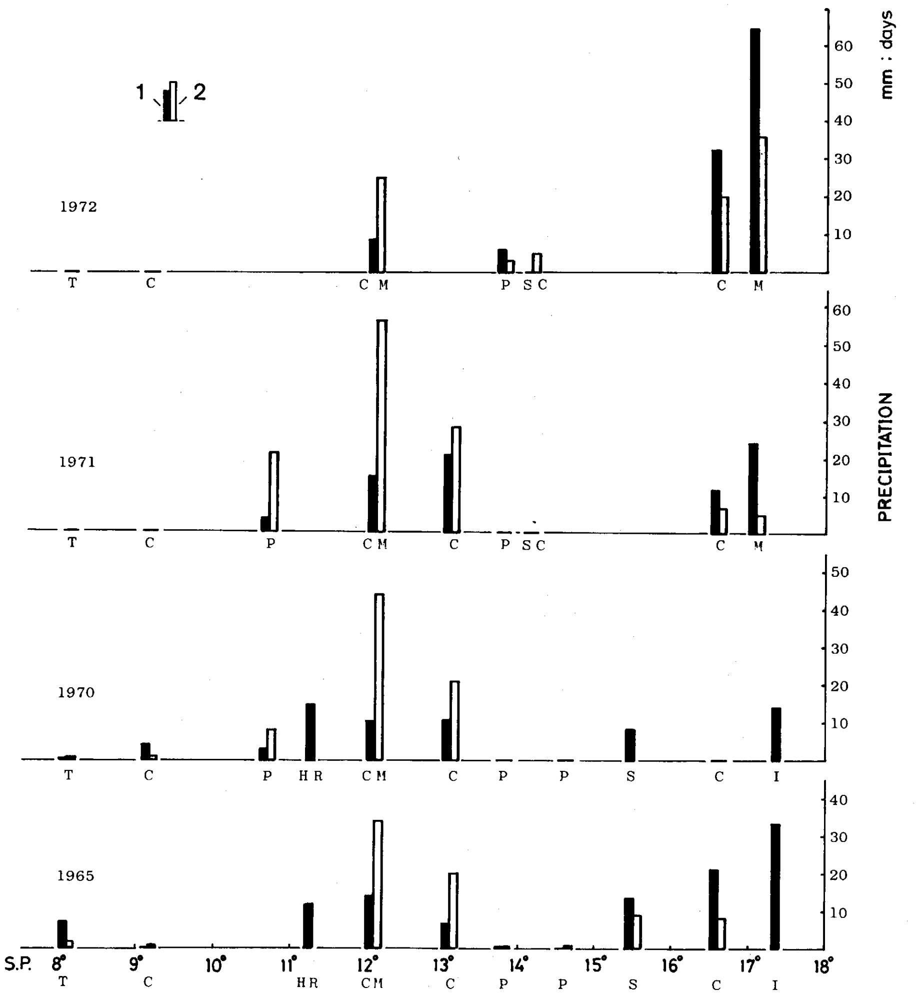

Fig. 6 Latitudinal distribution of precipitation during the winter along the Pacific Coast of Peru. 1: amount of precipitation, 2: number of days with precipitation (≥0.1mm), T: Trujillo (33 masl), C: Chimbote (11 masl), P: Paramonga (60 masl), HR: Hda Retes (182 masl), CM: Campo de Marte (137 masl), C: Cañete (150 masl), P: Pisco (6 masl), SC: San Camilo (398 masl), P: Palpa (357 masl), S: San Juan (30 masl), C: Camana (40 masl), M: Mollendo (30 masl), I: Ite (30 masl).

marine air layer. Whether the amount of precipitation increases or decreases depends on the rise and fall of the stratus layer. As a result, the lomas vegetation will appear or disappear.

3. Lomas Vegetation on Loma Ancón in 1961 and 1980

Lomas vegetation

Loma Ancón ca. 60 km north of Lima is one of the coastal hills in Peru, ca. 700 m a.s.l. It has a well-known road sign 'Zona de Neblina' meaning 'fog zone'. Although only small

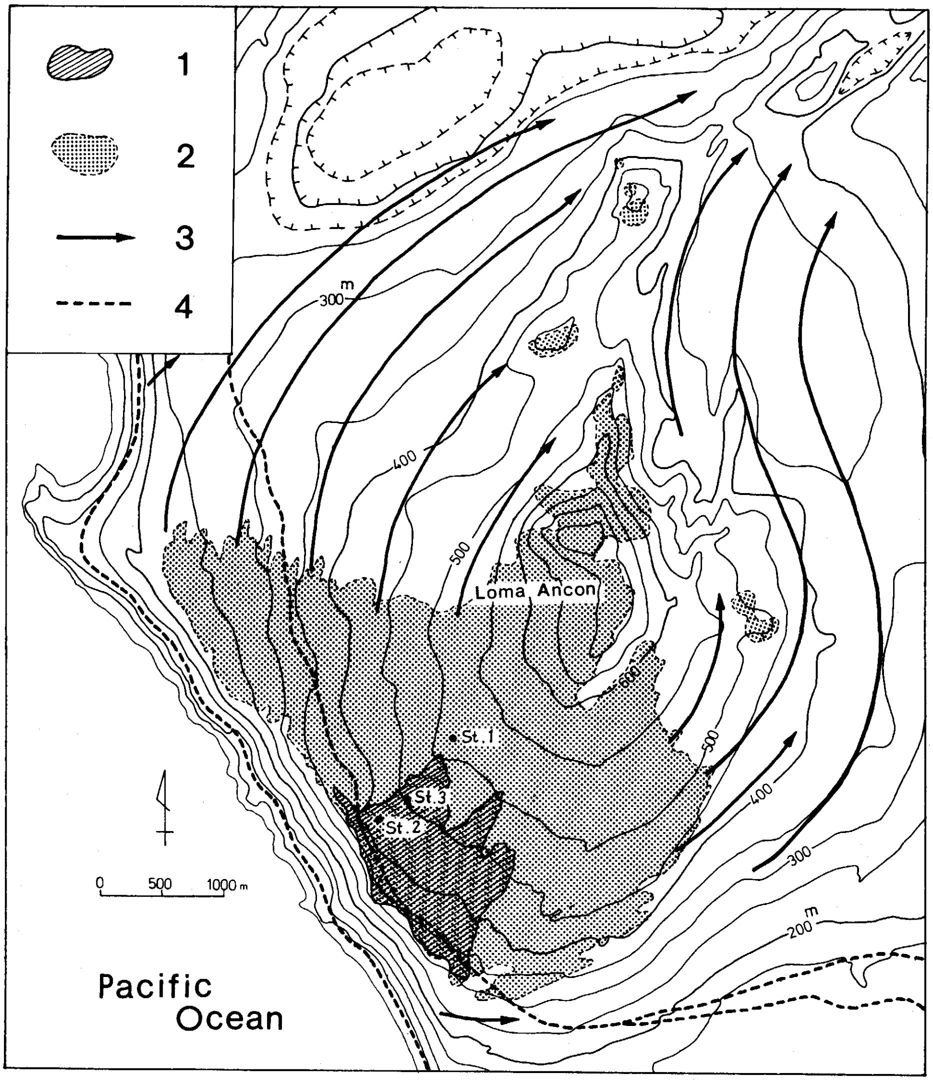

Fig. 7 Distribution of lomas vegetation on Loma Ancón
1: herbaceous lomas in 1980, 2: herbaceous lomas in 1961, 3: direction of arrangement of longitudinal dune, 4: Pan-American high way

in extent, a typical lomas vegetation is constantly formed there during winter when the stratus layer is well developed. However, a detail investigation of this area revealed that the extent of the community fluctuates year by year. The distribution of herbaceous lomas only in 1961 and 1980 is shown in Fig. 7. The delineation of the 1961 community was observed by aerial photograph analysis and that of 1980 was obtained by an on-the-spot survey. The vegetation had a wide vertical distribution from ca. 250 m a.s.l. to the hill-top in 1961, but only a small one from ca. 250 m a.s.l. to 500 m a.s.l. in 1980. The former is about six times as large as the latter. In both cases, the community is formed on the southwestern slope of Loma Ancón.

Climatic conditions

Analysis of the aerial photographs of Loma Ancón taken in 1961 revealed that longitudinal dunes of clear arrangement existed in a peripheral area of the lomas vegetation. Wind direction was able to be deduced from the arrangement of dunes and it was clarified that the lomas vegetation occupies just the windward slope. Direction of prevailing wind at Lima was southwest as shown in Fig. 8. It is not consistent with the direction of the streamline deduced from the arrangement of dunes. Comparing the wind direction data at Lima in 1971 with those in 1980, the former is more concentrated on the southwest than the latter. In addition, the direction of the prevailing wind in 1961 was almost the same as that of the former (1971), for it indicated southwest or south-southwest direction in January and July. Considering the fact that the distribution area of the vegetation just corresponds to the zone called 'Zona de Neblina', it can be concluded that the wind brings enough moisture to produce the lomas vegetation on the southwestern slope.

Why did the size of the lomas community differ between 1961 and 1980? In order to answer this question, the inter-annual change in amount of precipitation at Campo de Marte (Lima) were examined (Fig. 9). According to the inter-annual trend, the mean annual precipitation was mostly supplied by the winter precipitation, which was about 20 mm during the 1950s and 10 mm from the 60s to the 70s. Considering the value of 30 mm during the 1940s, this decreasing trend is most conspicuous. A small amount of precipitation means there is a low activity of stratus clouds in the region. Consequently, total water supply for the lomas vegetation is not sufficient to produce a large community.

We made observations of air temperature at three stations on the southwestern slope of Loma Ancón on 27~28 Oct., 17~18 Nov., and 2~4 Dec. 1980. The isopleths of air temperature are illustrated in Fig. 10 on the basis of observation records. Some remarks on the inversion of temperature can be made: the inversion occurs at least both in the evening and morning in October, its occurrence was limited to 3 or 4 hours before sunrise in November, and in December it occurs only for a couple of hours after mid-day. As mentioned above, we can see clear seasonal changes in the occurrence of the inversion in such a small area. As summer approaches, the inversion layer becomes poorer and consequently only a slight stratus layer develops. As the fog precipitation decreases from October to December together with the disappearance of the inversion and stratus layers, the vegetation slowly fades away and the landscape reverts to a brown desert.

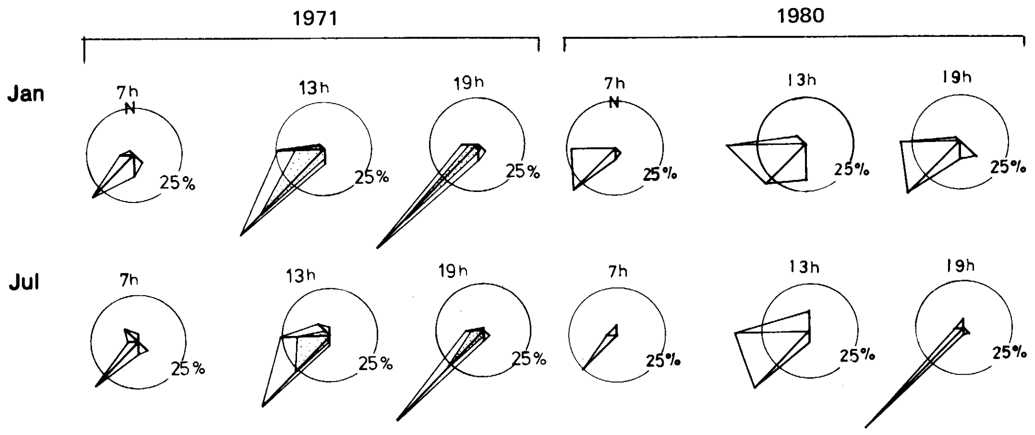

Fig. 8 Windroses for 1971 and 1980, Campo de Marte (Lima)

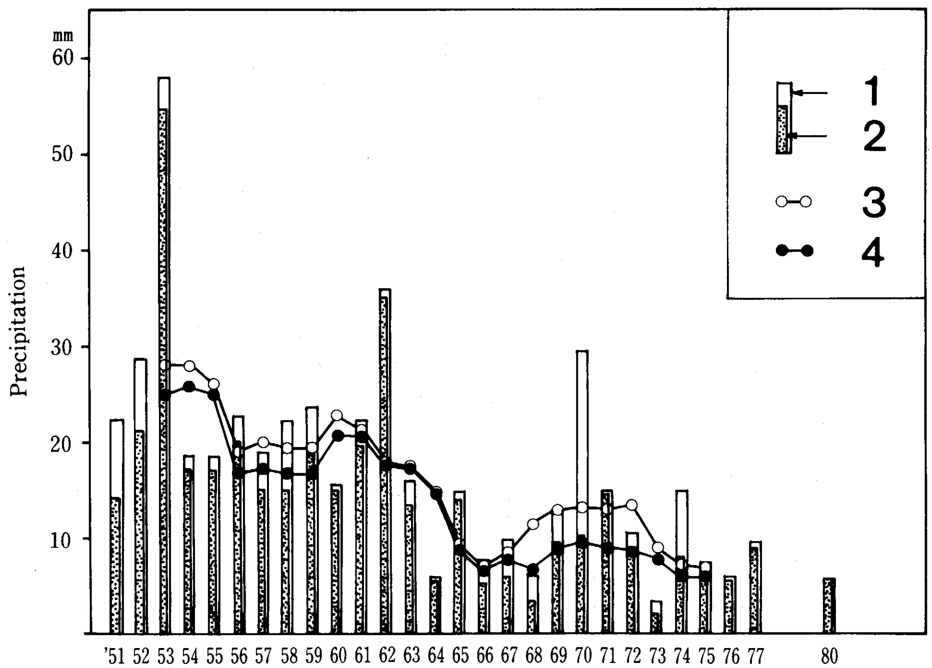

Fig. 9 Inter-annual trend in amount of precipitation at Campo de Marte
1: annual amount of precipitation,
2: amount of precipitation during the winter,
3: 5 year running means of annual precipitation,
4: 5 year running means of winter precipitation (May ~ Oct.)

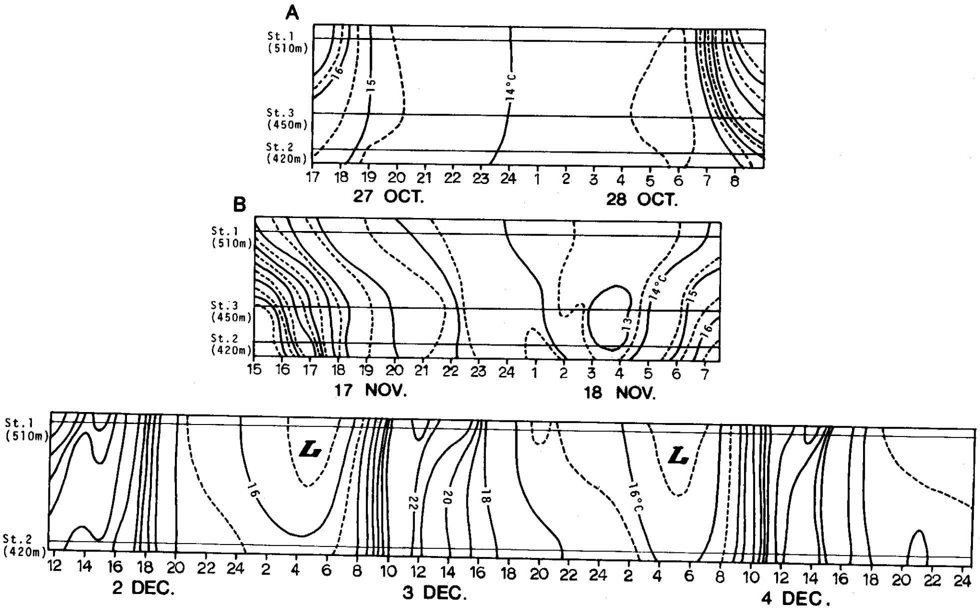

Fig. 10 Isopleths of air temperature on the southwestern slope of Loma Ancón; stations are as shown in Fig. 7.

4. Conclusion

As the lomas vegetation is sustained by the moisture supplied from the stratus layer, its formation is limited to the coastal region. Although the distribution of the lomas vegetation has not been fully explained yet, this paper has, it is hoped, clarified some of its characteristics. In order to explain its distribution more fully, it is necessary to examine other factors such as characteristics of the plant itself, edaphic control, grazing and water conditions.

In this paper, precipitation characteristics were examined as one of the indicators of water conditions and it is concluded that they yield a fairly good explanation of the distribution of lomas vegetation. For a more complete understanding an examination is needed of how much water is needed for the plants and how the water is supplied to the plants. Also, it is necessary to investigate the relationship between water supply and the life cycle of the plants comprising the lomas vegetation.

Distribution of the lomas vegetation in a small area such as Loma Ancón was related to the prevailing wind bringing the moisture. The authors' observation of air temperatures on Loma Ancón proved the existence of seasonal changes in the inversion layer at such a small scale. More investigations in small areas would yield valuable data necessary for a fuller understanding of the development of the lomas vegetation.

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