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ON THE SEASONALITY OF DROUGHTS IN THE LOWLANDS OF SARAWAK (BORNEO)

With 5 figures and 2 tables

EBERHARD F. BRUNIG

Zusammenfassung: Über das jahreszeitliche Auftreten von Dürren im Tiefland von Sarawak (Borneo)

Die langjährigen Mittel der monatlichen Niederschläge, Temperatur und Humidität kennzeichnen das Klima des Tieflandes von Sarawak als immerfeuchtes äquatoriales Regenwaldklima. Ein Vergleich von gleitenden 30-Tages-Summen des Niederschlages von Juli 1963 bis Juli 1965 an fünf Beobachtungsstationen mit den Verteilungen der Niederschlagshöhe in den entsprechenden Monaten an drei Beobachtungsstationen zeigt, daß auch in diesem Klimatyp Dürrezustände jahreszeitlich regelmäßig auftreten. Für die Waldvegetation bedeutet dies nicht nur eine Verringerung der Nettoproduktion organischer Substanz, sondern auch eine Förderung von morphologischen und phänologischen Merkmalen, die an diese Trockenzustände angepaßt sind.

Die Zweifel an der tatsächlichen Existenz eines immerfeuchten äquatorialen Regenwaldklimas im tropischen Tiefland werden für Sarawak bestätigt.

Acknowledgements

The author thanks the Public Works Department, Government of Sarawak, for unpublished records of daily precipitation and evaporation at various stations in Sarawak. Thanks are also due to Dr. A. S. RAND, Smithonian Tropical Research Institute, Panama Canal Zone, for a first comment on the basic data and for encouraging me to make this information more widely known by speculating that "adapting to these conditions in a rain forest climate 'preadapts' a species to invade a more seasonal climate".

1. Introduction

Within the region of tropical rain forest the lowlands of parts of the northern half of Borneo possess the most uniform climate. In the lowlands of Sarawak temperatures are even with annual variation around 2° C (tab. 1, Tm) and diurnal ranges around 5–7° C (fig. 1), wind speeds are generally low, high winds are localized (ASHTON, 1964, p. 11), and annual rainfall exceeds 3000 mm and shows only a small seasonal variation. The peak of rainfall during December–February is more marked in southwest Sarawak (fig. 2 and 3).

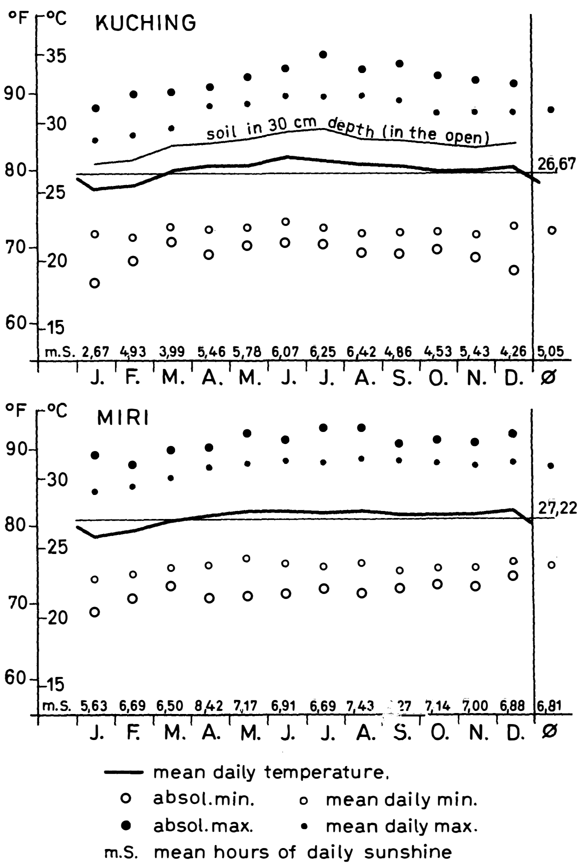

Fig. 1: Mean Daily Temperature and Sunshine

The values for the MARTONNE Index (LAUER, 1952, p. 23–24) exceed 60 for any month of the year (tab. 1, last column to the right). The climatic type corresponds to KOEPPEN's Afi, isotherm, Continuously wet with average monthly rainfall above 60 mm throughout the year, but a rainfall peak in early winter (w'), and LAUER's Taefd, tropical equatorial continuously wet climate with 12 humid months. (KOEPPEN, 1923; LAUER, 1952.)

The results of synecological studies in the Mixed

Dipterocarp forests (Ashton, 1964) and in the Heath or Kerangas forests (Brüning, 1967) lead one to suspect that the water regime might be a limiting factor for the formation of vegetation types even on normal soils, and that water supply might not be as adequate throughout the year as meterological data and climate diagrams (Walter and Lieth, 1966, p. 27) indicate.

2. The Pattern of Rainfall

The Department of Civil Aviation and Meterological Services has published the monthly rainfall for a number of Stations in Sarawak for the period 1876–1957. The data have been summarized for 4 stations in fig. 2. The stations represent inland and coastal climate respectively for south (Kuching and Talang-T.) and north Sarawak (Miri and Marudi). The distribution of minima shows that months with less than 100 mm precipitation may occur at any season of the year except from October to February in the heavy winter-rainfall area around Kuching.

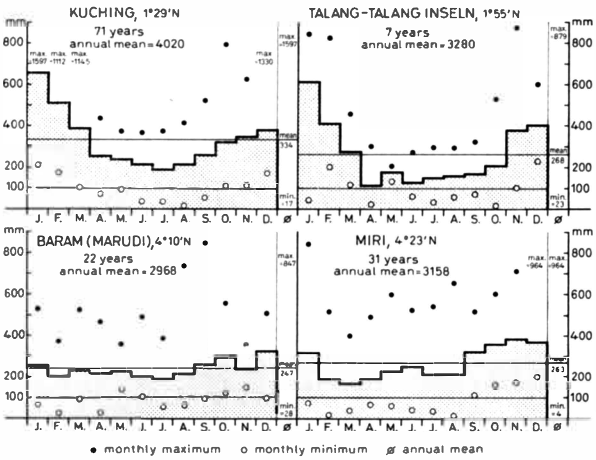

Fig. 2: Monthly and Annual Means of Precipitation

The frequency of months with less than 51 mm and 51 to 101 mm precipitation during the periods of observation is shown in tab. 1. 4 months with less than 51 mm rainfall occurred during 71 recorded years at Kuching, 10 months during 31 years at Miri and 4 months during 22 years at Baram-Marudi.

The frequency distribution of months with certain amounts of rainfall is as expected more strictly seasonal in Kuching than in the northern stations. The frequency of dry months is greater in the north and is somewhat more widely spread over the period January to August with a weak depression of dry-months frequencies during May–June when south pacific trades bring more constant rains (fig. 3). The mean annual frequency of months with less than 101 mm rainfall is 0.4 in Kuching, 1.4 at Miri (coastal) and 0.9 at Baram Marudi (inland).

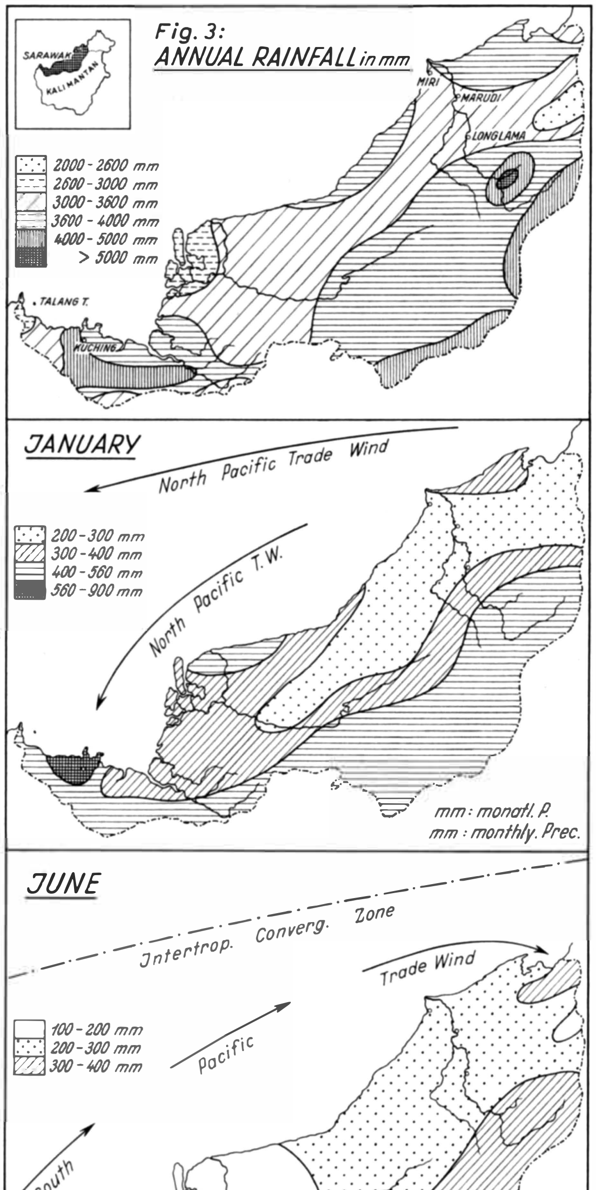

Fig. 3: ANNUAL RAINFALL in mm

Monthly records are not very efficient indicators of rainfall pattern because dry and wet periods overlap the arbitrary calendar divisions. Schulz (1960) has shown for the somewhat more seasonal climate of North Surinam that sliding 30-days totals have an advantage over monthly records for ecological interpretation of rainfall patterns.

Daily rainfall records for the period July 1963 to June, resp. May, 1965 were supplied by the Public

Table 1

	Monthly Rainfall											De Martonne-Index		
	—51	—101	—151	—203	—254	—305	—355	—406	—457	—508	>508	P_m mm	T_m C°	M.I.
	Frequency of Months													
KUCHING (71)														
J					1	3	4	4	6	6	47	655	25.4	222
F			1	3	6	7	2	12	5	5	30	505	25.7	170
M		1	6	7	9	8	12	8	6	2	12	385	26.4	127
A		1	7	12	12	18	13	3	5			257	26.9	84
M		2	5	24	10	12	10	7	1			241	27.0	79
J	1	2	15	19	12	10	8	3		1		214	27.6	68
J	1	5	17	24	11	5	6	2				192	27.3	62
A	2	3	10	16	18	15	2	4	1			216	27.0	70
S		3	6	18	13	11	7	8	3	1	1	258	26.9	84
O		1	5	17	13	10	10	9	3	2	1	324	26.5	107
N			1	4	12	12	12	11	8	6	5	344	26.5	113
D				4	4	6	6	8	13	6	24	380	26.7	216
S	4	18	73	148	121	117	92	79	51	29	120	4,020		
p.a.	0.06	0.3	1.0	2.1	1.7	1.6	1.3	1.1	0.7	0.4	1.7		26.6	110
MIRI (31)														
J		2	3	1	5	5	7	3		2	3	314	26.0	105
F	5	7	5	1	3	2	5			2	1	187	26.3	62
M	1	8	7	6	5		3	1				164	26.9	55
A	1	6	5	5	9	2	1		1	1		189	27.4	61
M		1	7	5	9	4	2	1		1	1	229	27.7	73
J	1	1	4	7	5	6	4	2	1		1	246	27.7	78
J	1	4	4	8	5	4	4				1	204	27.5	65
A	1	4	7	8	2	5	1		1	1	1	207	27.7	68
S			4	1	2	8	4	3	7	1	1	319	27.3	103
O				1	6	5	7	4	2	1	5	352	27.3	113
N				1	6	4	2	8	2	2	6	378	27.2	122
D				2	5	6	6	2	2	3	4	365	27.6	116
S	10	33	46	46	62	51	46	24	16	14	24	3,158		
p.a.	0.32	1.1	1.5	1.5	2.0	1.6	1.5	0.8	0.5	0.5	0.8		27.2	85
BARAM (22)														
J		1	6	3	3	3	2			1	3	259	25.8	87
F	2	1	4	4	2	4	4	1				206	26.0	69
M		1	6	4	2	3	4		1		1	237	26.6	78
A	2	2	2	3	5	4	1	1	1	1		220	27.0	72
M			2	9	5	3	2	1				221	27.3	71
J		1	8	4	5	2		1		1		198	27.6	64
J		5	3	5	4	2	1	2				188	27.7	60
A		3	3	8	3	3				1	1	212	27.4	68
S		1	2	8	2	6	1		1		1	261	27.0	85
O			1	2	6	5	5	1	1		1	296	27.0	96
N			1	7	6	4	3	1				240	26.9	78
D			2	1	5	1	4	3	4	2		324	26.5	106
S	4	15	40	58	48	40	27	11	8	6	7	2,960		
p.a.	0.16	0.7	1.8	2.6	2.2	1.8	1.2	0.5	0.4	0.3	0.3		26.9	80

P_m = mean monthly precipitation
T_m = mean monthly temperature

Works Department, Sarawak for the Stations Kuching Airport (I), Kuching Semengoh Forest Reserve (II), Bako National Park (III), Miri (IV) and Long Lama (V). Sliding 30-days sums were calculated from these data and are reproduced in fig. 5. The calendar monthly rainfall figures for this period are lowest at Station I in July, 1963 (108 mm), in Station II in May (101 mm) and July, 1964 (102 mm), at Station III in August, 1963 (112 mm) and at Station IV in March, 1964 (93 mm). The Stations II and V have generally a more even and higher monthly rainfall than Station I, III and IV during the southwest monsoon. This may be due to their inland situation which reduces the effect of seabreezes, and to the thickly forested environment and also to the proximity of high hills which increases the frequency of convectional showers during low-rainfall periods. Both stations are new and there are no long term data for average annual and monthly rainfall. While the recorded monthly rainfall is below the 100 mm margin only in one instance (Miri, March 1964, 93 mm) the 30-days sliding totals go below this level at Kuching Airport in June 1964 (9 days duration), August 1964 (3 days), at Kuching Semengoh in Sept. 1964 (2 days), at Bako National Park in Sept., 1963 (10 days), Oct. 1963 (2 days), June 1964 (4 days), July 1964 (3 days), Aug. 1964 (2 days), April 1965 (7 days), May 1965 (2 days) and May/June 1965 for one period of 24 days with a minimum of 69 mm on 20th June. At Miri the sum falls below the 100 mm level in Aug. 1963 (1 day), Sept. 1963 (12 days), Nov. 1963 (4 days), March 1964 (7 days), June 1964 (3 days), April 1965 (7 days) and June 1965 (1 day).

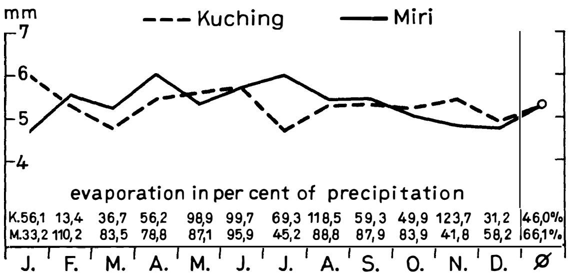

Fig. 4: Monthly and Annual Mean Daily Evaporation J. 1963–J. 1965

The occurrence of 30 days-sums below 100 mm is restricted to the period March to November in the north-east and May to October in the more strongly seasonal southwest.

Tab. 2 gives the frequency of 30-days sums below 100 mm with the lengths of dry periods in brackets, per month in monthly recorded rainfall classes according to the standard meteorological records for the period August 1963 to June 1965. Calendar months with a recorded rainfall below 150 mm have practically all at least one day on which the sum of the rainfall during the preceeding 30 days falls below 100 mm. If this period is sufficiently long, as in Bako National Park in June, 1965 (tab. 2 and fig. 5), even the 60 mm-margin is approached during a month with a recorded rainfall of 145 mm (121–150 mm class). In months with heavier rainfall the frequency decreases to less than one quarter of the months between 151 and 300 mm and to nil above 300 mm.

Comparing the frequencies in tab. 2 with the dry periods in fig. 5 we can conclude that in all recorded stations in the lowlands in any year at least once or twice the 30-days sum of precipitation falls below 100 mm in heavy rainfall areas, but that this may happen 3 to 4 times a year in areas with lower annual rainfall around 3000 mm in coastal areas. The annual frequency of periods with 30-days sums below 60 mm may in these areas be near 1 (tab. 1, Miri). The Martonne-Index during such periods will be below 20 (margins are 64 mm at 28° C, 62 mm at 27° C and 60 mm at 26° C) which indicates arid conditions. We can further conclude that the distribution of these dry or arid periods exhibits a seasonal pattern in all stations, even in those stations with an apparently extreme evenness of rainfall throughout the year.

Richards (1952, p. 136) remarks that drought years are by no means unknown even far into the equatorial forest belt (approx. ± 3° on either side of the climatic equator), but considers drought condition in this belt as an exceptional event. The climate in the equatorial belt is classified by him as non-seasonal (e. g. the hythergraph for Singapore in fig. 20 opposite page 136), but Richards cautions later (l. c., p. 139) that "there are probably no land surfaces within the tropics with a completely non-seasonal rainfall". The most non-seasonal rainfall pattern within the equatorial belt in his table 12, p. 141 have Pontianak (Kalimantan) and Sandakan (Sabah) which have similar climates as Kuching and Miri respectively. Similarly, Blumenstock (1958) commenting on the prevailing seasonality of climate in much of Southeast Asia, cites the climate of most of Sumatra and Indonesian Borneo as examples of truly humid climate and Singapore as "a good wet location" with only two single months with less than 100 mm of rainfall between 1931 and 1939.

3. *The Ecological Significance*

The importance of adequate, non-excessive but sufficient water supply to trees for the assimilation and respiration rates and for the growth of trees is well known. Assimilation is reduced and respiration up to a point increased by water-stress within the plant (Müllerstael, 1968). In trees water-stress reduces the net production of organic matter, induces the formation of late wood type of tissue in growth

Table 2 : Frequency of Periods with a 30 Days Sum of P below 100 mm

Monthly rainfall recorded	Number of months recorded	KA I	KS II	BN III	M IV	LL V	Total I–V
below 100	1				1(7)		1(7)
101–120	4	1(2)		4(1,2,2,3)	1(1)		6(11)
121–150	9	2(2,9)		1(20)	3(2,3,10)		6(46)
151–200	11			3(2,3,7)	2(1,4)		5(17)
201–300	36	1(1)	1(2)	1(2)	3(1,2,7)		6(15)
above 300	53						
Total months	113	23	22	23	23	22	
Frequencies		4	1	9	10	0	24(96)

2(2,9) means 2 events of 30-days sums of *P* below 100 mm with 2 days duration in the one event and 9 days in the other.

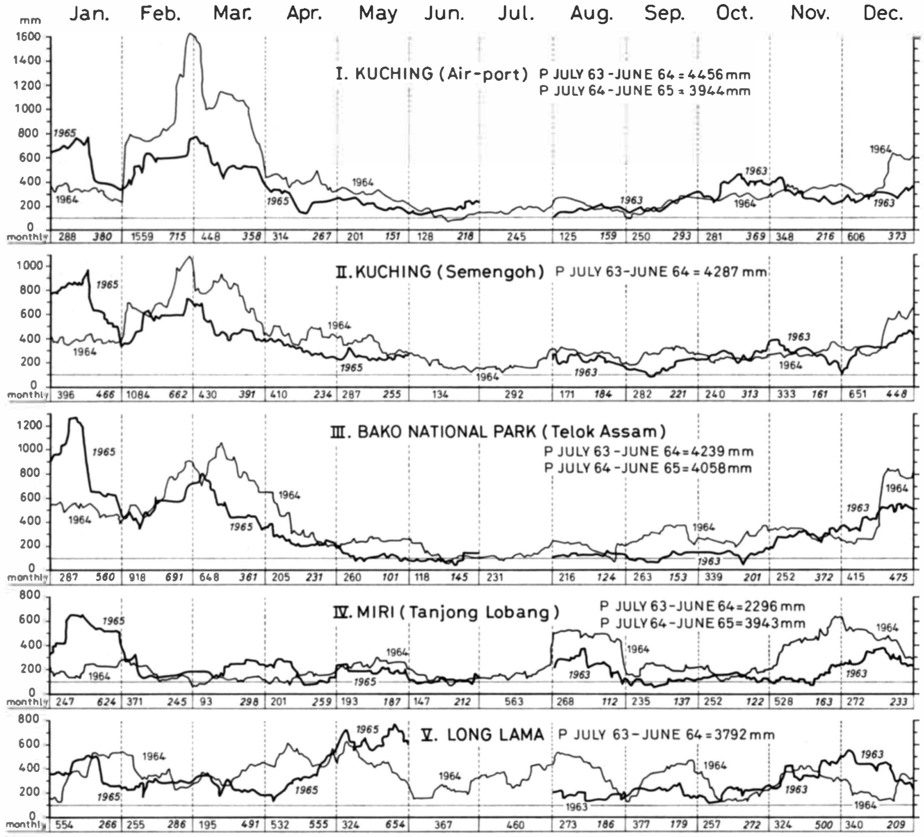

Fig. 5: 30 Days Sliding Sums of Precipitation

rings of the wood, and generally leads to a slowing-down of diameter and height increment.

The seasonal occurrence of water-stress in vegetation favours morphological and phenological adaptations by the plants, especially in those species which are as main storey trees particularly strongly exposed to the effects of variation in the water balance and humidity gradients.

Drought conditions exist for the vegetation if evapotranspiration has exhausted the available water supply from precipitation and soil and tissue moisture. Evaporation from "class A pans" in the open has been high throughout the years 1963–65 (fig. 4) but shows a low peak in the summer season corresponding to the rainfall and sunshine distribution pattern, with unexplained deviations in January and July at Kuching. The mean annual evaporation at the two stations is 1970 mm. This figure appears high but reflects the high daily saturation deficits (Brunig, 1968, p. 6–7) and high amount of incoming radiation. On the basis of mean annual sunshine hours to which evaporation rates are closely correlated (Nieuwolt, 1965) the evaporation at Kuching (5.1 hrs) would be calculated as 1740 mm and at Miri (6.8 hrs) as 2016 mm, if the regression for Singapore is used (l. c., fig. 3). The differences are surprisingly small.

Little is yet known about the effect of tropical rain forest on the water regime of the site. The few data which exist indicate that the combined evapotranspiration rate may approach the evaporation from open water surfaces as long as water supply is ample (Brunig, 1968, p. 6–7). Thermodynamic conditions are probably different in the environ of the evaporation pan on a lawn and in the forest canopy (Ashton, in litt.). But an increase in dryness and turbulence of the air above the grass during mid-day may well be balanced by an increased turbulence within the very heterogeneous rain forest canopy particularly during early afternoon breezes. Until more information becomes available it may be safe to assume that the potential annual evapotranspiration is between 1500 and 2000 mm. The rate is probably considerably lower in Heath forests and some peat swamp forest types with a more strongly sclerophytic, often microphyllous, and generally more uniform and even canopy with high albedo particularly in the red fraction (Brunig, in print).

During a 30-days period of bright weather (more than 7 hrs sunshine per day) between 160 and 200 mm water would be used for evapotranspiration. The water-holding capacity within the rooting zone of normal Red Yellow Podzolic and Lateritic loamy soils may be between 100 and 150 mm for plant-available water, but less in sandy soils, physiologically shallow soils and lithosols. Consequently water-stress may gradually develop as water from the soil and from plant tissue is used up if during this fine weather period the 30-days sum of precipitation falls below 100 mm. It certainly will develop and may become severe even on normal soils if the sum falls below the Martonne-Index margin of about 60 mm. Water deficits, and consequently reduced transpiration and production, will occur much earlier on soils with low water capacity such as Heath forest soils (Brunig, 1968 b) and on some limestone habitats. It is also known to occur in the more developed phases of peatswamp forest with raised peat several meters thick and a highly reflecting vegetation surface of *Shorea albida* Sym. trees (Anderson, 1961; Brunig, in print).

4. Conclusion

The rainfall pattern in the equatorial wet climate of the lowlands is inadequately represented by monthly means which obscure the regular and seasonal occurrence of periods in which drought conditions are approached. In four stations representing average lowland conditions the annual frequency of 30-days periods with rainfall less than 60 and 100 mm is around 1 and 3–4 respectively. These dry periods are regularly of sufficient duration to be of ecological significance. They also have been shown to be restricted to certain parts of the year with seasonal peaks of frequencies.

Some morphological features of the Malaysian equatorial lowland rain forests, such as the predominance of relatively small- and thick-leaved and thick-barked top-storey trees and the high albedo from reflecting leaf-surfaces particularly on sites with precarious water supply, may in part be an adaptation to seasonally regular drought conditions. Also phenological features, such as the seasonal fruiting of Dipterocarps and many of the common fruit trees of the region, may in part be controlled by the regular occurrence of water-stress during seasonal droughts. The ecological importance of this seasonal feature in the equatorial lowland climate is enhanced if we assume, as we may, that intense speciation phases must have occurred under similar climatic conditions when newly emergent land surfaces in the area became available to plant colonization during the tertiary and pleistocene. In any case the present phylogenetic development in this area is subject to the effects of seasonal droughts.

Concluding, the warning of Richards (l. c.) that a completely non-seasonal tropical climate does not exist can be amended by the statement, that it is highly probable that in all equatorial lowland rainforest climates sufficient seasonality of the water regime exists to favour corresponding adaptation in trees. The reality of the "Singapore type" of climate where sufficient water supply prevails throughout the year (Nieuwolt, 1965) as an equatorial lowland climate is more than doubtful. Not only occur occasional exceptionally dry years in this climate, as Nieuwolt himself later reports (Nieuwolt, 1966, fig. 5), but shorter or longer dry periods of sufficient severity to create water-stress in the vegetation are an annual and seasonal characteristic feature of this climate. This characteristic is, however, obscured by the usual manner of meteorological recording.

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BERICHTE UND KLEINE MITTEILUNGEN

DIE LANDSCHAFT VON PONTRESINA (OBERENGADIN) IM LUFTBILD

Mit 1 Luftbild, 6 Abbildungen und 3 Bildern

Friedrich-Karl Holtmeier [1]

Summary: The Landscape of Pontresina (Upper Engadine) on an air photograph

Using an air photograph, the author seeks to convey an impression of Nature and, above all, the reciprocal relationships between Nature and Man in the central Alpine high-valley region of Pontresina. The high-mountain climate, the great altitude of the valley-floors and the glacially-moulded relief conditions of this area do not leave Man much room for maneouvre in the vertical plane and force him to adjust as best he can to natural factors. On the steep, partly rocky trough walls stretch woodland areas, opened up by avalanches, mud-streams and rockfalls. Where the terrain is suitable for alpine meadows on the flatter sloping trough shoulders and terraces, Man has cleared the woodland. The altitude of the upper woodland limit is, in the area shown on this air photograph, mostly orographically, but sometimes anthropogenically, determined. Pontresina, which formerly lived from alpine grazing, arable farming and, above all, traffic on the pass, lies on the south-west exposed slope of the Bernina Valley somewhat above the valley floor, which is made climatically unfavourable by frequent formation of cold air layers. In addition the insolation duration is substantially greater in the valley widening which begins here than in the upper part of the Valley. The lowest valley section has the largest amount of sunshine but was, like the still distinguishable gaps between the old village cores, never built on because of the avalanche danger. Tourism, today the basis of existence for the population nevertheless necessitates expansion of the village, houses have been built in these places, and some of them have already been buried by various small avalanches. A winter of avalanches, such as occurred in 1951, would bring catastrophe to these new village areas. A danger for the village which should not be underestimated is posed by the increasing amount of climbing damage on the slopes of the Schafberg and Piz Albris, caused by the immense population of ibexes *(Capra ibex)* in this area. The destruction of plant cover in the alpine region by these animals is followed by solifluction, initiated by needle ice (Kammeis, pipkrake, ice-filaments), at nearly all those places, which favour the formation of mud-streams („Rüfen", „Muren") on these slopes.

[1]) Die Beobachtungen wurden zum großen Teil während der Geländearbeiten zu einer vergleichenden Geographie der Waldgrenze gesammelt. Herrn Prof. Dr. Dr. h. c. Joachim Blüthgen (Münster), der diese Unternehmung leitet, und der Deutschen Forschungsgemeinschaft, die die Kosten trägt, bin ich zutiefst zu Dank verpflichtet.

I

Von einer Geländebegehung abgesehen, ist nichts besser geeignet, einen Eindruck von der Raumnatur eines Gebietes zu vermitteln, als ein gutes Luftbild. Wenn dann noch Photos und Skizzen aus der Erdsicht ergänzend zur Verfügung stehen, wie in diesem Falle,

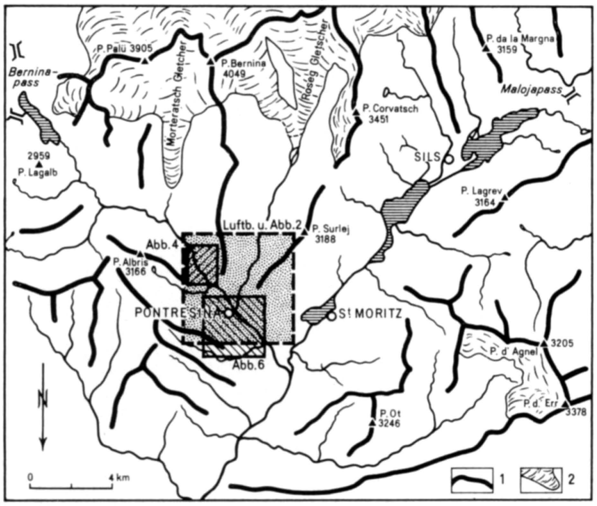

Abb. 1: Übersichtsskizze mit Lage des Luftbildes und der Abbildungen 2, 4 und 6