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Geografisk Tidsskrift, Bind 48 (1946)

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By Johannes Reumert.

In Denmark, every scientist, and in fact everybody connected with education who has had to do with geography, knows Professor Martin Vahl's climatic and vegetation belts, these being described in Andersen & Vahl's geographies for the middle and secondary schools, and in the large scientific geographical text-book Vahl & Hatt: "Jorden og Menneskelivet" (The Earth and Human Life) (I-IV. Copenhagen 1922—27).

But if we take the text-books, atlases and wall-maps generally used abroad, we find that the climatic divisions employed there are a good deal inferior — in point of clarity, at any rate — to what we are accustomed to in Denmark. Pedagogically, Vahl's climatic divisions are superior to those we know of elsewhere. We shall revert to this point later. On the other hand, the scientific basis of Vahl's divisions is less well known, and we shall endeavour to explain that basis in the following.

First, the main outlines as laid down in the text-book "Jorden og Menneskelivet".

The earth is divided into seven climatic belts which are zonal, i. e. they run right round the earth, but their limits are not confined to definite parallels of latitudes, viz.: the tropical zone, the northern and the southern sub-tropical zones, the northern and the southern temperate zones, and the northern and southern polar zones.

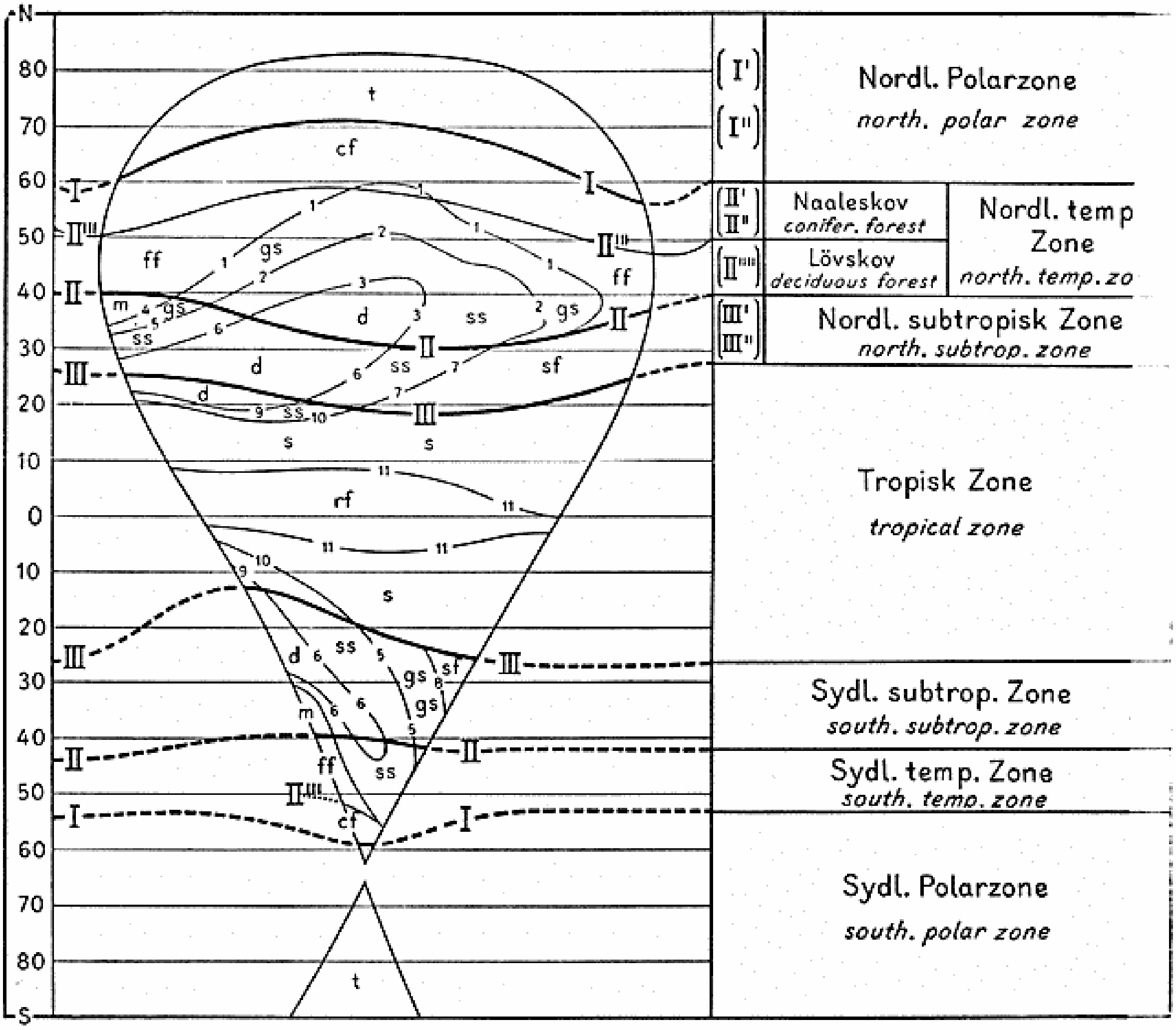
The *tropical zone* is characterized by the fact that the vegetation is never forced to suspend its activities by lack of warmth. One crop after another can be reaped in the fields, and the crop succession may be arbitrary. The boundary to the north and to the south can be drawn where the mean temperature of the coldest month is 14 to 16° C.

The *sub-tropical zones.* The characteristic here is that night frost may occur anywhere. In the cooler parts of the sub-tropics the frost is not confined to night time, but it is not severe and its periods are short. Two crops may be grown, it is true, but cultivation of the thermophilous crops is limited to the summer months.

Vahl describes in broad outlines how the coldest month of the sub-tropical zones has an average temperature of between 5° and 15°, and how the average temperature of the hottest month may be over 35° and go right down to 20°, and from this one might think that the boundary against the temperate zone must lie either at the isotherm of 5° for the coldest month or at the 20° isotherm for the warmest month. It is not so simple as that, however. Vahl himself says that in the southern hemisphere the boundary between the sub-tropical and temperate zones lies at 18 to 19° of mean temperature for the warmest month, because winter there is so mild. On the border between sub-tropical and temperate climates in the northern hemisphere, Vahl writes that it lies at various mean temperatures for the coldest month, from 3° in East Asia to 10° in the southeast regions of the United States. In East Asia the reason for the low temperature limit in the coldest month must be that summer is long and hot and that the brief winter in southern China never brings a destructive frost; in the Gulf regions of the United States, where summer is hot too, the reason for the high mean temperature in the coldest month at the zonal border must be that occasionally there is a possibility of severe and protracted frost far to the south where the January temperature otherwise is usually high. The minimum mean for the year at the zonal border both in East Asia and in the United States lies in the vicinity of —10°, the most severe frost in the various years fluctuating between – 5° and – 10°. As we shall see later, the climatic factors pointed out in "Jorden og Menneskelivet" are not the only ones used by Vahl for delimiting the sub-tropical zone from the temperate zone, for another — and important — factor is the length of winter. The apparent arbitrariness of this delimitation is no doubt explained by the fact that Vahl regards the monthly mean temperatures merely as a practical expedient in drawing the boundary.

The *temperate zones,* whose borders against the sub-tropical zones have just been referred to, are bounded on the north and south by the polar zones.

Fig. 1. Diagram of Vahl's Climate and Vegetation Zones.



Letter symbols for regions in the diagram:

- t tundra
- cf conifer forest, magellanic forest
- ff foliferous forest, temperate rain forest
- gs grassy steppe } in temperate,
- ss scrub steppe } subtropical and
- d desert } tropical zones
- m maqui
- sf subtropical forest and savanna
- s savanna
- rf tropical rain forest

Numerical symbols for boundaries:

(Zonal main boundaries are designated by Roman numerals; except the border between conifer and foliferous forests the boundaries of zonal subdivisions are not shown in the figure (or on the corresponding map), but in the column on the right. They are shown in Roman numerals with one or more".

In the equations employed for placing the zonal vegetation boundaries climatically, the mean temperature for the warmest month is shown as w, and the mean temperature for the coldest month as c).

- I' Boundary between distinctly polar and high-arctic polar climates; w = 0°.
- I'' Boundary between high-arctic polar and low-arctic polar climates; w = 5°.
- I Boundary between polar and temperate zones; w = 9.5 − 1/30 c.
- II' Temperate zone, conifer forest. Cereal limit; w = 10.4 − 0.2 c; (3 mths over 8°).
- II'' Temperate zone, conifer forest. Wheat limit; w = 14.5 − 0.28 c; (4 mths over 10°).
- II''' Temperate zone, boundary between conifer & foliferous belt; w = 16.2 − 0.3 c; (4½ mths over 10°; 155 days over 8°).
- II'''' Temperate zone, foliferous belt. Maize limit; w = 18.7 − 0.3 c.
- II Boundary between temperate and sub-tropical zone; w = 31.8 − 1.5 c.
- III' Sub-tropical zone, orange limit (no equation).
- III'' Sub-tropical zone, banana limit (no equation).
- III Boundary between sub-tropical and tropical zones; c probably = 14°– 16°. (The boundary undoubtedly depends on the mean temperature of a period longer than one month).

(Boundaries of non-zonal sub-divisions marked with Arabic numerals).

Temperate Zone, foliferous belt:

1) Boundary between foliferous forest and grassy steppe: Mean rain probability 0.35 in the four wettest months with mean temperature over 5°. (Climatic limits of conifer and grassy steppe unknown as yet).
2) Boundary between grassy steppe and scrub steppe: Mean rain probability 0.24 in the four wettest months with mean temperatures over 5°.
3) Boundary between scrub steppe and desert. Formation boundary not yet definitely determined climatically.

Sub-tropical zone:

4) Boundary between maqui and grassy steppe. Mean rain probability 0.33 in the four wettest months. (No boundary between maqui and sclerophyll forest yet determined climatically).
5) Boundary between grassy steppe and scrub steppe. Mean rain probability 0.31 to 0.34 in the three wettest months.
6) Boundary between scrub steppe and desert. Not yet definitely determined climatically.
7) and 8) Boundary for forest and savanna against scrub steppe and grassy steppe not yet definitely determined climatically.

Tropical zone:

9) Boundary between scrub steppe and desert not yet definitely determined climatically.
10) Boundary between savanna and scrub steppe not yet definitely determined climatically.
11) Boundary between savanna and rain forest seems to lie where two months each has a precipitation of less than 5 cm.
    (Furthermore, in the Tropical Zone there is also a boundary between genuine rain forest and evergreen thicket at 150 to 180 cm. annual rainfall).

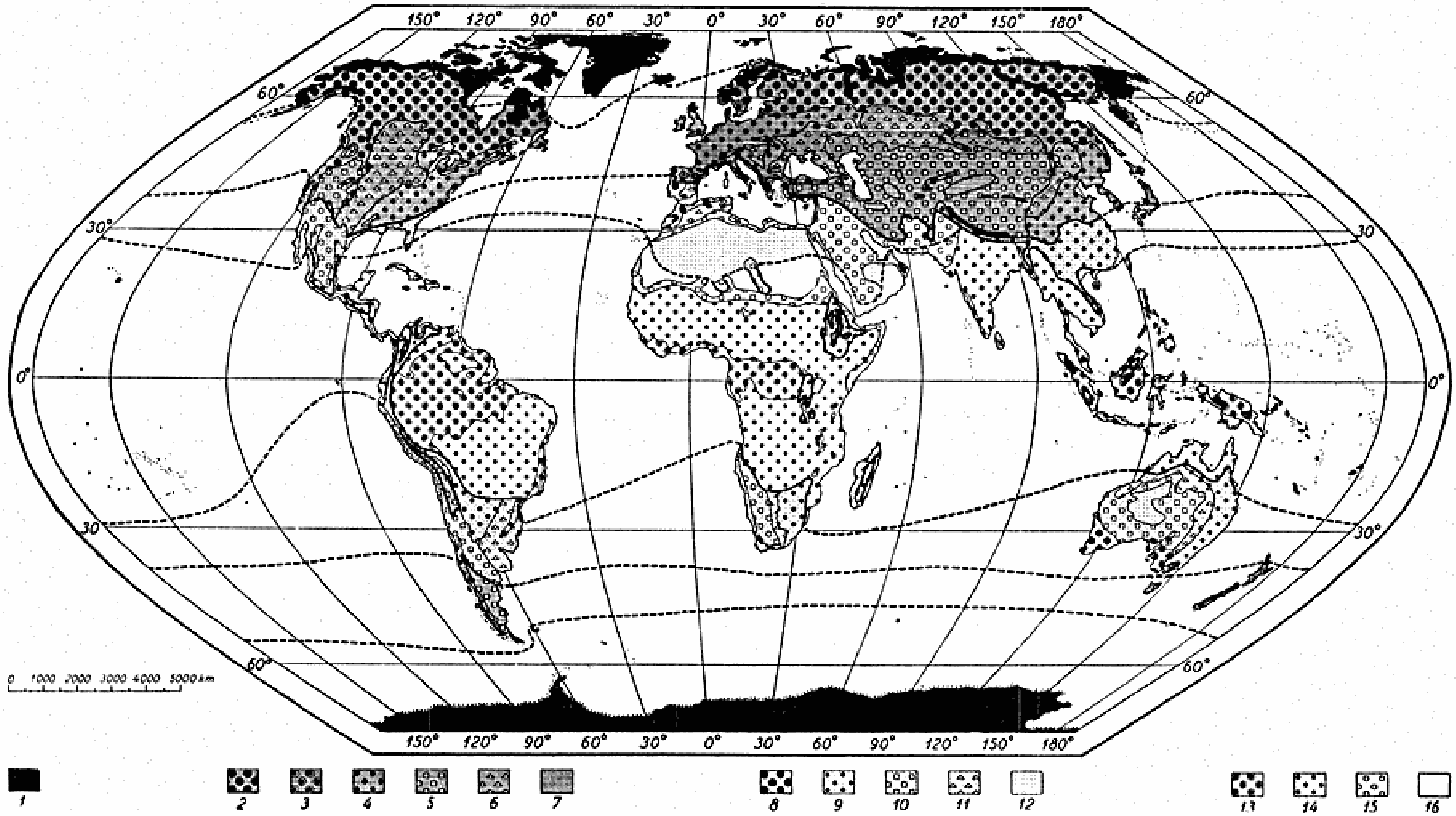


Fig. 2: Vahl's Climate- and Vegetation Zones, drawn by M. Vahl and J. Reumert compiled in cooperation with The Geographical Institute of the University, Copenhagen. (Eckert's equal-area projektion).

1. *Polar zone* (tundra)
Temperate zone
2. conifer forest
3. rain forest
4. Deciduous (foliferous) forest
5. Scrub steppe
6. Grassy steppe
7. Dry desert

Subtropical zone
8. Maqui
9. Forest and savanna
10. Scrub steppe
11. Grassy steppe
12. Dry desert

Tropical zone
13. Rain forest
14. Savanna
15. Scrub steppe
16. Dry desert

The *polar zones,* according to Vahl, have their limits at a mean temperature of 9° to 10° in the warmest month.

These definitions of climatic zones and climatic boundaries can be simplified, as indeed has been done in several of the text-books written by Vahl together with P. Andersen. Most simply of all we can characterize Vahl's climatic zones as follows:

Tropical zone: No frost.

Sub-tropical zone: No severe or protracted frost. Warm summer.

Temperate zone: Possibility of severe and protracted frost in part of the year, or, if not, a cool summer. It must not be too cool, however. It must in any case be "a summer where plants with higher requirements than the most wretched temperature conditions can find a suitable vegetative period."

Polar zone: Possibility of frost all the year round.

These characteristics must be said to be extremely simple and comprehensible. The difficulties begin when we have to work with them. One of the objects of geography at the universities and the schools is not merely to establish certain facts as regards climate, vegetation and human life, but also to support these facts by such visual means as generally lie to hand. A climatic division should be supported by maps or diagrams showing the climatic factors, and it is here the difficulties lie in Vahl's divisions. In the ordinary atlases we have nothing but the isotherm maps to help us with the necessary orientation in temperatures. As a rule the atlas contains the isotherm chart for January and July, these being the most useful charts for giving a rough characteristic of a region's temperature. Several climatic divisions besides Vahl's employ the temperatures in the coldest and the warmest month for drawing the boundaries. In practice one has not much use for the annual isotherm charts, now that we have ceased to follow Supan's ungeographical climate division, the system employed in various text-books for a time but now abandoned. Nor can we ignore the fact that the isotherm chart for January and July is inadequate if we wish to determine the mean temperature of the coldest and the warmest months. In the Faroe Islands, for example, March is the coldest month, and indeed on the whole in the oceanic climates there is a trend towards a shift in the times of the lowest and highest annual temperatures. For the tropical climates the isotherm charts for January and July are not satisfactory either. In Northern India the greatest heat occurs in March-April, and at several places near the equator there are double heat maxima, so that January and July may have almost the lowest mean temperatures of all months. Thus the January and July isotherm charts are also inadequate adjuvants even when the theoretic basis of Vahl's climatic divisions are to be demonstrated, not only for the reasons already given, but also because in actual fact it is not directly the mean temperatures of the coldest and the warmest months that signify most in Vahl's climatic divisions. Nevertheless the charts can be used. On them we can find the 10° isotherm for the warmest month which roughly forms the boundary of the polar zones, and likewise we can define the limit of the tropical zone against the sub-tropical zones by means of the 15° isotherms for the coldest month. All the same, even with these fairly accurate boundaries our determination must be inexact, because we can only judge where a full 10° in mean temperature in the warmest month is not required for including a region within the temperate zone, and where the boundary of the tropical belt is to be placed at the 14° isotherm, and where at the 16° isotherm, or perhaps a still higher mean temperature for the coldest month. It is still more difficult to determine by means of these isotherm charts the boundary between the sub-tropical and the temperate zones. Here it is the temperature boundaries of both the warmest and the coldest months that must be found, and for the warmest month the boundary may fluctuate between 18° and 21—22°, for the coldest month between 3° and 10°. As we see, drawing the boundary here is not merely complicated, but very much subjected to personal judgment. And when we must know in advance which of several possible isotherms we must use for drawing a boundary, the use of isotherm charts on which to base climatic divisions might easily become fallacious.

These imperfections do not lie in Vahl's climatic divisions, for, as already said, he employed the mean monthly temperatures merely as a kind of expedient; to him other factors were more important climatically. Unfortunately, for these more important factors we lack means of visualization. Even if we had atlases containing isotherm charts for all months, we should still lack an adequate map material. We should have no map showing the probability of frost for all countries; we should have no map of the mean extremes of temperature, and no map showing on how many days of the year we can reckon with a temperature of 8° and above, 10° and above, and so on. For most countries we are scarcely likely to have the climatological data necessary for the drawing of such a map. The foundations would first have to be laid.

It is this lack of resources, one that cannot be remedied easily or quickly, that makes Vahl's climatic divisions, apparently so simple and straightforward, really so difficult when the theoretic basis is to be visualized.

We can obtain great assistance from the hydrothermal diagrams with curves showing the mean temperatures and mean precipitations of the various months. (By the way, for pedagogical reasons, instead of Vahl's hydrotherm diagrams it is advisable to use those given in Raunkiær: "Planterigets Livsformer" (Copenhagen 1907) and in Marke: "Meteorologi og Klimatologi" (Copenhagen 1934), because in them temperature is indicated by a continuous curve and precipitation by a stippled one, the opposite of what is the case in Vahl's diagrams.) But even the hydrothermal diagrams do not directly show the most important factor in Vahl's division. They do not give the daily fluctuation or the frost probability; by measurement, however, they can tell the length of a period with more than a certain mean temperature.

No doubt many will ask what this term "periods with more than a certain mean temperature" has to do with Vahl's climatic division, because they are just mentioned in "Jorden og Menneskelivet". Just mentioned; at one place in the Introduction we read that the boundary between conifer climate and deciduous forest climate within the temperate zone lies where 155 days have over 8° in mean temperature. And yet, when one is orientated beforehand, a large number of allusions are to be found here and there, from "Jorden og Menneskelivet" to Vahl's chief theoretical work: "Zones et biochores géographiques", Oversigt over det Kgl. danske Videnskabers Selskabs Forhandlinger 1911, and to the subsequent works "Les types biologiques dans quelques formations végétales en Scandinavie, K.d.V.S.'s F. 1911 and "The Growth Forms of some Plant Formations of Southern Norway", K. d. Vidensk. Selsk. biol. Medd. 1919. But very little of all the knowledge with which these publications are crowded and which represents an enormous amount of work, really emerges from the background, and indeed in the bibliography to "Jorden og Menneskelivet" Vahl neglected to refer to them. So it is not remarkable that few people know of them. Many in Denmark have worked educationally with Vahl's climatic and vegetation zones, but the theoretic basis has been known only in extract form, and in extracts which have totally ignored many essential features. If Vahl did not refer to his main works in his bibliography, the explanation of his modest reticence is probably that he looked upon his division not as a complete system, but more as a precise outline of principles to be brought gradually to greater perfection and temporarily subject to such changes as were required as more knowledge was gained of relevant factors.

In the following we shall give an account of the labour which Vahl put into "Zones et biochores" and "Growth Forms of Plant Formations". Actually, it will be more than an account; we shall endeavour to make the principles more generally accessible than they are in these works.

1) To Vahl, the *central problem of geography* is: *to ascertain in what measure the resources of man depend upon the climate.* In order to solve this problem he will turn to a study of the *vegetation.* The direct physiological influence of climate on man is great, but difficult to determine, whereas the *direct influence of climate on vegetation is evident, and through plant ecology climate has its greatest influence on human activities.*

2) *The boundaries between the zones must be climatic boundaries which coincide with botanic boundaries.* The boundaries of cultivated plants, however, are less suitable for direct application, because they are dependent not only on the climate but also on the level of human civilization as expressed in conditions of cultivation, transport, administrative measures, customs borders, tariffs, plant improvement, etc. In his studies of climatic boundaries, however, Vahl himself has often made use of the distribution of culture plants, because particulars of it were more easily obtainable than of the natural vegetation.

3) *The basis for climatic division must be the natural vegetation,* not the individual species but that which Humboldt long ago, with the foresight of genius, called "the physiognomy of vegetation". Thanks to works by Grisebach, Warming, Schimper and Raunkiær, modern geography has obtained concrete objects to operate with, viz. "life forms" and "plant formations". As an excellent means of delimiting the plant formations we would single out Raunkiær's formation statistics (Raunkiær: "Forma-

tionsundersøgelser og Formationsstatistik", Bot. Tidsskr., Copenhagen 1909), which Vahl himself made use of in a somewhat modified form when studying formation boundaries in various parts of Scandinavia.

4) *The prime necessity is to determine the limits of the plant formations as climatic formations or biochores.* Here we encounter difficulties: 1) the climatic formation within the same biochore may occur with various floristic compositions; 2) ecological differences may require a sub-division of the formations; 3) plant species may be present secondarily in formations far removed from formations in which they represent the dominant elements, and 4) a formation may occur edaphically, governed by soil conditions, far from the place where it occurs as a climatic formation. Vahl seeks to overcome these difficulties by careful studies of the plant formations, in which he makes use of formation-statistical methods.

5) *When the limits of the climatic formations are finally determined, the time has arrived for ascertaining what climatic factors determine the limits in each case.* Within one biochore there may be great climatic differences to which the climatic formation does not react, whereas small climatic differences at biochore boundaries may favour the preponderance of another climatic formation. Vahl goes deeply into the matter of the climatic factors which determine the boundaries between the biochores.

Here Vahl has made a very important contribution concerning the relation between the mean temperature of the coldest and the warmest months along a vegetation boundary. The procedure is this: After a formation boundary has been determined as exactly as possible in the field with the aid of formation statistics, the largest possible number of stations is found in the literature as near as possible to this boundary line. The mean temperatures for the coldest and warmest months at these stations are listed, beginning with the station with the highest temperature in the coldest month. It has been found in every case that at a biochore boundary a lower temperature in the coldest month has its counterpart in a higher temperature in the warmest; however, the rise of the mean temperature in the warmest month does not necessarily correspond to the decrease of the mean temperature in the coldest month. The further procedure may be illustrated by a simple imaginary example: A mean temperature at Stations I, II, III and IV, which are situated at the biochore boundary determined in the field on the basis of formation statistics, of +3°, +2°, +1° and 0° in the coldest month (c), corresponds to a mean temperature in the warmest month (w) of +12°, +14°, +16° and +18°. Thus the differences for the coldest month (c) are between I and II: −1, between I and III: −2, and between I and IV: −3; the mean of the differences is −2. For the temperatures in the warmest month (w) we get the differences +2, +4 and +6, with a mean of +4. The relation between the difference mean for the warmest month (Dw) and the difference mean for the coldest month (Dc), (in this selected case $\frac{Dw}{Dc}\ \frac{4}{-2} = -2$) is expressed by a constant: b. If the mean temperature of the coldest month is multiplied by the constant b and the product added to another constant: a, the sum along the biochore boundary will be equal to the mean temperature of the warmest month. Thus w = a + bc. The constant a is easily found. After having found the constant b, we merely insert the values for w (mean temperature of warmest month) and c (mean temperature of coldest month) for one of the stations in question in the Vahl equation.

(For Station I the equation will be: 12 = a + (−2 × 3); for Station IV it will be: 18 = a + (−2 × 0). For this imaginary biochore boundary the constant a will thus be 18).

We can now employ the equation for calculating the biochore boundary where we know the mean temperatures of the coldest and warmest months but not the exact extent of the particular plant formation, and its usefulness extends as far as the case where the temperature is the same all the year round. (In the chosen example with a = 18 and b = − 2, there will be a mean temperature af +24° in the warmest month if the temperature in the coldest month is −3°. If the temperature is the same in the coldest and in the warmest months, the equation will be: 6 = 18 + (− 2 × 6)).

For the cultivation limit of wheat Vahl found the constant b = − 0.28 and the constant a = 14.5. Accordingly, the equation is w = 14.5 − 0.28 c. The equation will work out if the place lies at the wheat cultivation limit. In "Zones et biochores" Vahl gives a number of stations lying very close to the wheat limit. The greatest deviation between the observed temperatures and those calculated by means of the equation is ± ½°. If the mean temperature in the coldest month is − 20°, the mean temperature in the warmest month according to Vahl's equation will be about

+ 20°. If the temperature in the coldest month is 0°, the temperature in the warmest month will be between 15° and 14°, which agrees very well with the fact that wheat — if it were a matter of climate alone — can be grown everywhere in Denmark and that Denmark lies near the wheat-growing limit, as we can see in abnormally cold years. If the temperature is the same in the coldest and warmest months, it will be 11°.3, which agrees well with experience in tropical highlands.

If we employ the mean monthly temperatures for plotting temperature curves for all stations along a biochore limit, we shall see that most of the curves intersect one another at two points, whereas at their highest and lowest parts they diverge from one another. Thus this means that a feature common to most of these stations is a period of almost equal length with temperatures over a certain value. It should be pointed out here, however, that there is a certain correlation between the height of the peak of the curve and the course of the curve, a very high temperature in the warmest month corresponding to a slightly shorter period with temperatures over a certain value; in this case the curve will lie within the "junctions". Conversely, a low temperature in the warmest month will give a flat curve lying outside the "junctions".

Coordinately with the equations, when determining the temperature limits of the biochores Vahl made use of a map of Europe which Supan published in Petermann's Mitteilungen in 1887. This map shows by means of curves the duration of the period with temperatures below zero and the duration of the period in which the *daily* mean is over 10° and over 20°. Moreover, Vahl uses duration periods for daily temperatures with other values than those given on Supan's map. Duration periods of this kind were employed by Köppen for delimiting climatic belts. Their theoretic usefulness was discussed by Hult, of Finland. It should be interposed here that Vahl regards this man Hult (Vetenskapel. Medd. af Geogr. Fören. i Finland 1892—93) as the original father of the ideas which he himself put into shape. What is more, Vahl attached some importance to making it clear that as regards his life's work he was not so much the disciple of the Teutons as of the Scandinavians. In recent years too Scandinavian scientists (among them the Swede F. Enquist) have worked on the reasons for the distribution of plant species and plant formations on the basis of the duration period.

Vahl considers these duration periods to be of great value, and in a way they figure in his equations and appear from his hydrothermal diagrams. But, he says, if the duration periods are to be applicable the annual course of the temperature must not vary too much along the border of the biochore, nor is the method effective when the difference between the seasons is too small.

Vahl's equation is less directly distinct as a limitation, but it can be used when the annual temperature range along the biochore boundary varies considerably; without serious inaccuracy it can also be extended to regions where the difference between the seasons disappears. It is an outstanding fact about Vahl's equation that it takes account not only of the duration of a period having more than a certain mean temperature, but also of the entire annual range of temperatures.

It is not only the duration of a warm period that is expressed by the equation, but also the length of a winter. The value of the method lies in the fact that quite empirically we determine what kind of temperature conditions accompany the plant limits that are governed by nature, both for the natural formations and for the cultivated plants.

But if Vahl attaches weight to his temperature equation as the most important of the possible means of finding the boundary of a biochore, he does not overrate the applicability of the method. The life of a plant, he says, is made up of numerous biological processes, each with its minimum, optimum and maximum. It is not only the mean annual temperature range that governs these processes, but also, for example, the mean of the lowest extreme temperatures, the rain probability, the amount of precipitation and the average wind velocity. A plant formation requires a certain vegetation time with temperatures over a certain threshold value; perhaps it cannot tolerate temperatures below a certain value; it requires a special volume and distribution of precipitation. If *one* of these vital conditions is at or below its minimum requirement, it is just this vital condition that determines the boundary. That the other conditions are fulfilled, perhaps in the fullest measure, makes no difference.

Nevertheless, the same climatic factor cannot act as a limit with different values. If for instance the mean temperature of the coldest month has different values along the boundary of a biochore, it cannot be this mean temperature alone that determines the boundary (apart from the curious fact that the mean temperature of an arbitrary period, such as a month, should determine the limit). If the same temperature equation does not apply to the boundary of a biochore as a whole, the course of that boundary must be governed by other factors such as extreme minimum temperatures, probability of rain, or the like.

Temperature, however, must serve as the *primary* limit. Precipitation is secondary. Along rivers running through scrub steppe the same plant formations grow as in rainy regions with the same temperatures. Plant cultivation with artificial warmth can only be regarded as luxury production. It is much easier to make up for lack of rain by artificial watering.

The *limit of the polar zone* ($w = 9.5 - 1/30\ c$) lies at about where Köppen places it, at the 10° isotherm for the warmest month. Vahl's equation, however, corresponds to a period of something more than a month with temperatures above 9°. This conforms better with what we know about the limits of plant formations in Iceland, Greenland and Siberia.

The equation dividing the conifer and foliferous (deciduous forest) belts ($w = 16.2 - 0.3\ c$) shows that the deciding factor here is the length of summer. Examining Supan's map, Vahl finds a period of 4½ months with a mean temperature of over 10° as corresponding almost with the boundary line. This line has since been determined more exactly in the field by the dominance of conifer or foliferous forest on flat terrain and good soil, and it does not coincide with Köppen's boundary for the conifer belt, which was determined by means of the polar limit of scattered oaks. In "The Growth Forms of some Plant Formations of Southern Norway" (Videnskabernes Selskabs biologiske Meddelelser 1919) we find the results of a formation-statistical investigation of conditions on the west coast of Norway, where a narrow strip of deciduous forest as a climatic formation stretches northwards right up to the entrance to Sognefjord. From these investigations Vahl was able, with greater accuracy than before, to draw the line between the climatic formations of conifer and foliferous forests. Leafing in the deciduous forest starts at a time when the daily mean temperature reaches 8°, and Vahl published a map of South Scandinavia showing the number of days with a higher mean temperature than 8°. From this we find that the dividing line runs very close to the curve for 155 days over 8° (Fig. 3).

Vahl drew his map from Swedish and Norwegian temperature records, which then outnumbered the Danish. Since then the Meteorological Institute in Copenhagen has published the tables in "Danmarks Klima" (Copenhagen 1933) accompanied by so much material that it would suffice to draw a map which, as far as Denmark is concerned, would be more accurate as regards the placing of the line for 155 days over 8°. In Vahl's opinion this line would give a result agreeing in the closest possible manner with the biochore boundary. Vahl's equation gives a rougher evaluation, but it is much better for drawing the boundary than Supan's map of 1887. Moreover, the equation is easy to apply, as it involves merely a simple calculation for each station on the basis of the mean temperature for the coldest and the warmest months, whereas the calculation of the number of days with a mean temperature of over 8° presupposes the plotting of temperature curves for every station, whereafter the number of days is measured from the curves. The equation has been used on the map reproduced here, and curves are drawn through the places in Denmark where the equation works out, as well as for certain minus and plus deviations. We see that according to the equation, certain parts of Jutland lie within the conifer biochore. If we apply the 155 day limit for 8° we shall find that only few and small parts of the country come close to having a conifer climate. However, this much is certain, that Denmark, especially the interior of Jutland, lies just on the boundary between the two biochores, conifer and deciduous forest (Fig. 4).

The boundary between the temperate and the sub-tropical zone according to Vahl's equation is determined by the length of winter. As already said, an exception is formed by North America, where the boundary is determined by the lowest temperature normally recorded in winter over a period of several years, more exactly the annual mean minimum of –10°. In "Zones et biochores" Vahl makes use of the equation $w = 34.3 - 10/3\ c$, an equation corresponding more or less to a mean temperature of under 8° for four months. According to Vahl's later vegetation map and the information he gives in "Jorden og Menneskelivet", this boundary is too low.

Originally, Vahl placed New Zealand, Tasmania, South Chile between lat. 37° S and 45° S, the Biscay region, Southwest Ireland and a belt stretching in to the south coast of the Crimea, the Caucasus and the Pontine mountains, within the sub-tropical zone. In the southern hemisphere the dominant vegetation within these regions is the evergreen foliferous forest, but in the northern hemisphere deciduous forest with the closest possible association with the vegetation in the temperate deciduous forest formation. Already in "Zones et biochores" he describes this region in the northern hemisphere as a transitional belt, and says that several sub-tropical growths capable of having a rich vegetative development there, have not the opportunity to ripen their fruits in the cool summer. In the same work he finds that the association with the sub-tropical plant formations is due to the occurrence of certain evergreens such as Quercus Ilex, Erica scoparia and Ulex europaeus. The fact that there is no rain forest in Western Europe as in New Zealand and South Chile he explains as the result of the hard fate of the arctotertiary flora in glacial-age Europe; but Vahl is correct in saying that the temperature conditions in themselves permit of the presence of evergreen forest.

By means of the equation $w = 34.3 - 10/3\ c$ and that for the conifer boundary $w = 16.2 - 0.3\ c$, Vahl demonstrates that evergreen foliferous forest and conifer forest (or corresponding small-leaved forest) can verge on each other without a transitional belt of deciduous forest at places where the difference between the seasons is very small, i. e. where the coldest month has a mean temperature of 6° and the warmest a mean temperature of 14.4°. This is the case on the west coasts of New Zealand and South America, and it is easy to prove that both equations almost work out when the aforesaid monthly mean temperatures are inserted.

The delimitation of the sub-tropical region in "Zones et biochores" by means of the equation $w = 34.3 - 10/3\ c$, whereby the "winter-mild mixed region" is included in the sub-tropics, was dropped, however, as already stated. Already on some of his first vegetation maps in Andersen & Vahl: "Geografi for Mellemskolen 1904" (Fig. 5), he included the transitional belt in Europe in the deciduous forest belts, though without stating whether they belonged to the sub-tropical or the temperate zone; Chile, south of lat. 37° S. and New Zealand are there reckoned in the temperate zone. Later, in "Jorden og Menneskelivet", he says clearly that the transitional region belongs to the temperate zone, and the vegetation maps in that book and in his subsequent text-books include New Zealand in the temperate zone. On a vegetation map of South America in "Jorden og

Menneskelivet", with more detail than his earlier vegetation maps of this continent, temperate rain forest is shown on the west coast of Chile between lat. 37° and 45° S. bounded on the north by sub-tropical maqui, on the south by the small-leaved forest region of Magallanes, and in the interior by a narrow strip of deciduous temperate forest (Fig. 6).

This altered boundary means that Vahl's equation in "Zones et biochorees" no longer applies, and in a letter of 11th July 1942 to the present author he set up a new equation for the boundary between sub-tropical and temperate zones: $w = 31.8 - 15\ c$, whereby "the winter-mild mixed region" becomes included in the temperate Zone. He did so, however, with the reservation that the equation would undoubtedly be better with the use of more material than that at his disposal then, the summer of 1942. According to the equation in "Zones et biochores", there was the culture-geographical curiosity of a sub-tropical region where maize growing was impossible for reasons of temperature. According to the new equation the maize boundary everywhere runs through the temperate zone and northern New-Zealand north of Hauraki gulf belongs to the sub-tropical zone. In "Zones et biochores" the "winter-mild transition region" was not bordered by what is now left of the sub-tropical zone except by means of the rainfall.

The boundary between the sub-tropical and the tropical Zones, by Köppen laid at a mean temperature for the coldest month of 18°, is determined by Vahl at the 16° isotherm for the coldest month, with the reservation that the decisive factor is probably the temperature over a longer period than one month. In "Zones et biochores" Vahl says that 16° is too low a value in the oceanic regions, too high in the continental; this statement, by the way, does not agree with "Jorden og Menneskelivet", where in continental climates the tropical boundary is moved nearer the equator on account of the heavy daily temperature fluctuations and the consequent greater chance of frost, even with a high monthly mean temperature. The latter must be regarded as being more consistent, so that the tropical boundary lies in the vicinity of 14° mean temperature in the coldest month in oceanic regions, whereas in continental climates there must be a higher monthly mean temperature (16°), or perhaps higher still, if the possibility of frost is to be precluded.

The zonal sub-divisions of the various zones are shown in the diagrams published in these pages, so that these sub-divisions, most of them based upon the distribution of culture plants (the cereal limit, the wheat limit, the maize limit, the olive limit, the orange limit, the banana limit) need not be discussed here. We should perhaps refer to the map of various plant limits published by Vahl in Andersen & Vahl: "Geografiske Tabeller" and later in the same authors' "Erhvervsgeografi" (commercial geography). By this means the map comes into its true perspective (Fig. 7).

On the other hand, some few words on the non-zonal division are necessary.

All the zones except the polar zone, and in part the conifer zone, are sub-divided according to precipitation.

That parts of the grass steppe, scrub steppe and the desert must be regarded as sub-divisions of the temperate foliferous belt is proved, Vahl considers, by the presence of foliferous forest along the watercourses in these regions. It is difficult to trace the boundary for these plant formations, because edaphic conditions are so apt to conceal the climatic. In time, Vahl thinks, formation-statistical investigations will provide greater certainty in determining the formation limits and thus in determining their climatic prerequisites. All the same, his provisional boundaries no doubt represent progress as compared with those hitherto postulated. Whereas Köppen (1901) places the climatic border between foliferous forest and grass steppe at a rain probability of 0.36 for the rainiest month, Vahl puts it at a rain probability of 0.35 for the four months representing the rainiest period in the season when the mean temperature is above 5°. One indication that Vahl's criterion must be better than Köppen's is that, according to the latter, the Hungarian steppe and the steppes along the lower Danube should be timbered, which they are not and which they should not be if we apply Vahl's boundary.

As a border in the sub-tropical zone between regions with winter rain and regions with whole-year rain, Köppen indicates a rain probability of 0.20 in the driest month, a border which, Vahl says, cannot be determined better from the information available. For the present, this is all that can be said of the climatic boundary beetween winter rain vegetation and rain forest. We lack the information as to quantity and distribution of rainfall necessary to draw the line between maqui and sclerophyll forest. The boundaries in sub-tropical zones for grass steppe and scrub steppe (see diagram p. 224) are not definitive, but they are probable, judging from Vahl's own studies in Madeira and the Canary Islands.

In agreement with Raunkiær, Vahl places the boundary for whole-year rain, and with it for rain forest, at the place where two months have a precipitation of less than 5 cm. Köppen's corresponding boundary lies at 3 cm. for the driest month. In the tropical region with whole-year rain a boundary between evergreen thicket and true rain forest lies at 150—180 cm. annual rainfall.

Vahl's vegetation maps (separate maps of the continents), were first published in 1904 in Andersen & Vahl's "Geografi for Mellemskolen". It was only seven years later that, in "Zones et biochores", he published the theory on which they were based, and this theoretic work was not accompanied by any map as Köppen's works had been. This perhaps is the reason why Vahl's climatic divisions have never gained a real footing abroad, and why divisions inferior to Vahl's have dominated in foreign literature.

That his divisions are the best of those hitherto known will appear from the following:

1) They aim at a clear division into zones according to temperature.

2) They follow the chief climatic indicators, the plant formations.

3) They accordingly provide the best possible basis for comprehending the conditions governing human activities in the various parts of the globe.

Vahl's climate and vegetation maps have been altered several times since they appeared, due partly to the aforesaid change in Vahl's conception of the boundary of the sub-tropical zone, partly to the enormous work he put into procuring a steady stream of more exact information on the boundaries of the plant formations. He himself never dared to draw definite boundaries for the tropical zone, and inter alia did not distinguish between the scrub steppe in the tropical and sub-tropical zones — not because he did not think that such a boundary could be found, but because there was a hiatus in the information as to the vegetation of the scrub steppe on which to draw the exact boundary. The present author, however, has had the temerity to do so, because for pedagogic reasons it was reasonable to carry the zonal division to completion. The vegetation map in Johs. Reumert: "Skoleatlas" 1928, a map of the world in Hammer's projection, is based throughout on Vahl's vegetation maps in "Jorden og Menneskelivet". But it includes more details, accounted for in the text of that publication, and the zonal division is completed, as already stated. Since then other Danish geographical school-books have published maps which also show the zonal division.

Köppen's system is the one mostly used abroad. Since it first appeared in 1884 it has been radically altered twice, in 1901 and in 1918; but even when the latest improvements are taken into consideration, it must be obvious to everybody that the map provided by this division gives a very unclear picture, compared with Vahl's. The principal reason is that he wrestles with the zonal division according to the temperatures and coordinates the arid climatic region with the climatic zones that are determined by temperature. All dry climates are put together, no matter to which climatic zone they ought to belong according to the temperatures. Moreover, the many subdivisions make a kaleidoscopic picture whose lack of clarity is not helped by the many letter symbols. His wall maps are useful as a kind of handbook in climatic types, not as pedagogic illustrations. Nevertheless, there is sense in several of Köppen's climatic boundaries, because he uses the mean temperatures for the warmest and coldest months as boundaries, and in his sub-divisions also makes use of periods with mean temperatures over a certain height (for example four months over 10°). Furthermore, Köppen has gradually adjusted his climatic boundaries to the vegetation. On the other hand, his boundaries do not, like Vahl's, build primarily on the plant formations, nor will they tolerate close criticism as far as many details are concerned. In fact, in "Zones et biochores" Vahl criticized several points in Köppen's climatic division of 1901, and much of that criticism is valid today.

The divisions made by both Martonne (E. de Martonne: "Traité de géographie physique") and Thornthwaite (C. W. Thornthwaite: "The Climates of North America". Geographical Review 1931) are based more on meteorological speculation than on the actual climatic conditions all over the world as shown by the vegetation. Martonne, who as a writer of textbooks differs favourably from Supan by virtue of his Gallic clarity, has not separated himself so far from the latter in the matter of climatic division as to liberate himself from employing the annual mean temperature for delimiting the climatic zones; yet it must be admitted that his system is better. The American Thornthwaite has not succeeded in adapting his division so that its boundaries, in Europe for example, coincide even fairly well with those of the plant formations, which after all must be the chief climatic indicators.

The closing remark in Vahl's "Zones et biochores" reads as follows:

> "The interesting part of a general survey of zones and biochores such as that just given, lies above all in the fact that it throws light upon what is still lacking to enable us to solve the central problem of geography (viz. to what measure human resources depend upon the climate). We see, for instance, in what regions we must first gather information on the cultivated plants, on methods of cultivation, on the wild vegetation and on the climate. Foremost among the tasks lying before us at the moment is this: accurately to delimit the natural plant formations so that they may form the foundation for the study of the cultural conditions. This vital limitation can only be carried out with the help of formation statistics."

Thus it is nothing like a fully complete system he presents, but the guiding principles for future work. Of that work much has been done by Vahl and others. As we have stated, Vahl tackled the problems in the field, and from the plant-geographical literature he continued to bring up to date the climatic and vegetation maps which still appear in his and Andersen's textbooks, the last occasion in Andersen & Vahl: "Lærebog i Geografi for Seminarier", 1938 (see the coloured accompanying maps). In that publication the biochore boundaries were altered somewhat, particularly in the light of the recent Russian and American plant-geographical literature. But even with these corrections the vegetation maps give only a summary rendering of many plant limits. Moreover, there must be a certain contradiction between the generalization which makes the maps clearer and the passion for detail, which demands the presence of as many details as possible, for example the markedly different vegetation in mountainous countries. Even with the best aids and the most logical principles a certain arbitrariness is inevitable when drawing a vegetation map. But still, with all its imperfections, which will doubtless be remedied in time, Vahl's climatic division is the clearest and therefore the most useful pedagogically.

We can by no means say even now that the possibilities to which the road was opened by Vahl's principles, as outlined in "Zones et biochores", have been utilized. Modern plant geography and its allied subject climatology began with Hult and continued with Vahl's great work. Botanists and geographers still have enough to do, and it requires collaboration. Here is one of the many points on which we shall see that a separation of the biological and the geographical studies at the universities will be ill-advised.

There is most certainly what may be called a Scandinavian trend in this branch of the science of geography, and we hope and believe that a continuation of that trend and the investigations associated with it will endow the world with a richer knowledge of the conditions of human life. It will mean the continuation of the work to which Martin Vahl devoted his great labours.

The map of the world showing the climatic and vegetation belts in Eckert's projection, now published with this explanation, was drawn by M. Vahl and J. Reumert. It was compiled from Vahl's climatic and vegetation maps of the various parts of the world in the textbook "Jorden og Menneskelivet" compared with the information imparted by Vahl in the text of that book. Due consideration was given to the corrections of the biochore boundaries made by Vahl in his last cartographic publications ("Geografi for Seminarier", 1938). Contrasting with his earlier maps, this one shows some of the mountainous countries where the climate is different as a result of the heights, for example the northern parts of the Cordilleras de los Andes and Abyssinia. In addition, the symbols, which on Vahl's earlier maps were not quite uniform in the various regions, were revised in one respect, necessitating a correction in a biochore boundary in Australia.

All these corrections and all the details were gone through by Vahl and the present author a month before his death in the summer of 1946. At that juncture we had a map on which the biochore boundaries were outlined and the various biochores symbolized by letters. Unfortunately, Professor Vahl did not live long enough to see the finished map.

Postscript.

The above article was ready for the press in November 1943, but various circumstances prevented the accompanying maps from being worked out until the spring of 1946. The opportunity was taken then to make certain additions to the article, the printing of which, together with the map, has not been possible until now in 1948.

In a way it is fortunate that there has been this delay, for I am now able in this Postscript to show precisely how necessary it is that Vahl's climate and vegetation belts should be explained in a world language, not merely in Danish. It happens that a large part of the geographical literature published in countries not occupied by the Germans became accessible to Danish geographers during the past year; and from that literature one gains the impression that the subject of "climatic division" is extremely topical.

Edward A. Ackerman: The Köppen classification of climates in North America (Geographical Review 1941), says of Köppen's classification that it is justly criticized by some because it is too theoretical and "now and then shows pronounced discrepancies from phenomena of the natural and cultural landscapes", by others because it is too empirical. On Thornthwaite's classification Ackerman writes: "Although the only serious competitor of the Köppen system, Thornthwaite's classification, corrects one deficiency, it is just as empirial as Köppen's at critical points, and much more complicated". The determination of "adequate" and "deficient" precipitation and of the "T/E" boundaries are arbitrary, and ..."the application to the world of a P/T ratio calculated from American data only makes the accuracy of Thornthwaite's system more apparent than real". "Thornthwaite's system is a step farther than Köppen's in the development of a purely quantitative classification, but it is greatly handicapped by the incompleteness of the data on which it must be based". Ackerman then explains his preference for Köppen's system in spite of its shortcomings by saying that those who criticize it for its emphasis of the quantitative actually approve of it, as nearly all the purely empirical divisions are based upon Köppen's. "Its simplicity makes it preëminent among the quantitative systems ...". "Thornthwaite's effort has been the only notable attempt at an entirely new classification since Hettner and Supan, and even it is built on the ideas that Köppen has set forth."

The climatic map of North America published by Ackerman in his paper makes several alterations to Köppen's classification. One of these is the application of the 0° isotherm for January instead of the −3° January isotherm for limiting the so-called D-climates from the C-climates, which undoubtedly is an improvement but, in the opinion of Thornthwaite, not sufficiently radical. In "Problems of the classification of climates" (Geographical Review 1943) Thornthwaite asks why Ackerman does not make use of the 40° F-isotherm (about 4.5° C.) for January as the border when marking a boundary line between the grey-brown and the red-yellow soils. Another of Ackerman's corrections to Köppen's map involves the appearance of a small area in the Fraser valley with steppe climate "for the first time", says Ackerman. This steppe area, however, is to be seen clearly on Vahl's much earlier map of climate and vegetation belts. Furthermore, in agreement with Russell and Van Royen, Ackerman advocates that the temperature limits applied in the wet climates should be extended to the dry B-climates. This idea was adopted and developed by Kesseli in "The climates of California according to the Köppen classification" (Geographical Review 1942). The tendency towards a zonal arrangement of the climate belts is unmistakable.

In his 1943 article just referred to, Thornthwaite brings a quantity of data concerning the basis of Köppen's climatic classification. For example, he writes: "De Candolle's designation of the Xerophiles with the symbol B and the insertion of this group into a series based on thermal conditions was not illogical, because he considered the groups to be parallel belts or zones arranged consecutively from the equator both north and south to the two poles." His purpose was to help palaeontologists to understand the distribution of land, sea and organisms of the past. Gradually as we knew more about these things we must recognize that the B regions were not zonal. Nevertheless, Köppen made use of De Candolle's "physiological" classification of the vegetation as the basis for his climatic classification, which Thornthwaite describes as "a great misfortune". He considers it would have been much better to utilize Schimper's "physiognomic" classification of the vegetation as a basis; Köppen's classification would then have been "very different and very much better". After a discussion of Köppen's many changing indicators for humidity and a thorough criticism of them, he proceeds to pass judgment on Köppen's temperature indicators. Here Thornthwaite in his dissatisfaction with Köppen's classification goes so far as to say that "variations in the heat factor of climate do not generally result in the development of sharply defined boundaries between vegetation formations." He points out that there is a gradual transition in the vegetation from the equator to the poles, and goes on: "Thus the boundaries separating tropical, mesothermal, microthermal and subpolar climates are vague and ill-defined, and there is no present indication that it will ever be possible to locate them with much precision. Perhaps the lack of definition of the boundaries is due the indefiniteness of the climates themselves." At the close of his article Thornthwaite writes: "Geographers have concerned themselves with climate because they have believed that there are on the earth's surface natural climatic regions that are reasonably homogeneous and that have boundaries which can be identified in terms of limits of plant communities, soil groups, and land-form types and can be defined in terms of numerical climatic data. Too often, umfortunately, they have failed to recognize that the first step is to discover the individual climatic regions and locate their approximate boundaries through study of the distribution of vegetation and soils. The value of any climatic classification depends, first, on the accuracy with which the climatic regions are identified and their boundaries located, and second, on the skill with which numerical data are selected to match these boundaries. A climatic scheme can be evaluated by these two tests and by them alone."

Having regard to these remarks, one would expect Thornthwaite to advocate a careful investigation of plant communities and soil forms and, on that basis, to make a climatic classification that was zonal, or mainly zonal. He rejects Köppen's system, saying: "As a matter of fact, Köppen's system is not simple; it is unneccessarily difficult and complicated because it is so unsystematic, using such a miscellany of definitions." "It would be a calamity if any current climatic classification were adopted as a standard". "The primary climatic factors relate to moisture and heat. If the classification employs the concept of favorability for plant life, then both hygrometric and thermic conditions should be expressed through scales of progressive values to accord with the characteristic progression in nature. Indices expressing the total effectiveness of precipitation and efficiency of temperature for the year are basic. Other important climatic factors relate to the distribution of moisture and heat throughout the year". "The scheme should not only differentiate between the various types, it should also show the relationships that exist among them. It should be able to characterize the climates of the whole earth. At the same time, it should supply the framework for a differentiation of the innumerable microclimates that make up a climatic type." "The result is a classification of climate, not one of vegetation climatically explained, as has sometimes been asserted."

With this Thornthwaite indicates the chief principles of the climatic classification which he presents in the paper "An approach toward a rational classification of climate" (Geographical Review 1948).

In this scheme he makes use of four characterizing factors for the purpose of obtaining a complete description of a climate. All four factors include a component which he calls "the potential evapotranspiration", which is defined as the maximum quantity of water that *would* evaporate from soil and vegetation if the precipitation were adequate and if there were the most luxuriant vegetation possible under the given conditions of temperature. Whereas the actual evapotranspiration can be measured by a method "not easy either to understand or to use", the potential evapotranspiration must be calculated. Here his presupposition is that "as long as the root zone of the soil is well supplied with water, the amount of water transpired from a completely covered area will depend more on the amount of solar energy received by the surface than on the kind of plants". It is a condition that there is not an excess of water in the soil to inhibit the supply of oxygen to the roots and thereby their work. By means of the mean monthly temperatures, the latitude of the locality and a rather complicated equation, whose mathematic clarification Thornthwaite signifies as "far from satisfactory" and quite useless without the help of tables and nomograms, he has calculated the monthly potential evapotranspiration in centimetres for 3500 weather bureau stations in the United States. By adding together these monthly values he has procured the basis for a map of the annual average potential evapotranspiration in the United States. For the rest of the world he says that "actual determinations are so few that it would be impossible to make a map of any area by means of them". Despite these deficiencies, however, Thornthwaite considers that there is no way of avoiding the use of evapotranspiration as the principal means of determing climate types; and, as already stated, it forms a part of all the four factors he employs in climate descriptions.

The first factor is a moisture index, in which the excess of precipitation over the potential evapotranspiration outweighs the deficit of precipitation in the course of the year in the proportions of 10 to 6. This moisture index, which has numerical values from 100 to – 60, is used for characterizing nine types of climate from "perhumid" through "humid" and "subhumid" to "arid".

The second factor is simply the value indicating the potential evapotranspiration, this being taken as an expression of the effect of temperature. Thus the boundary between the "megathermal" and the "mesothermal" climates is placed at an annual evapotranspiration of 114 cm., and between the latter type and "microthermal" climate at 57 cm. A distinction is also made between "tundra climate" and "frost climate". As there are four mesothermal and two microthermal sub-divisions, the result here too is nine types of climate.

The third factor is the annual variation of the moisture. The moist climates (perhumid, humid and wet subhumid) are thereby divided into five categories, and the dry climates (dry subhumid, semiarid and arid) also into five sub-divisions.

The fourth factor is summer's share in the temperature effect, expressed as the potential evapotranspiration of the three summer months as a percentage of the evapotranspiration for the year. In equatorial climates it is about 25 %, and in frost climates it reaches up to 100 %. This gives eight sub-divisions.

By this means, each meteorological station can be characterized by the four factors, which are expressed by letter symbols. San Francisco, for example, is signified by $C_I B'_I s_2 a^1$, which shows that the climate type is subhumid, mesothermal of the first order, with a large winter excess of moisture and with a summer temperature effect corresponding to megathermal, because the difference between the summer and winter temperatures is so small.

Four factors of a similar kind are employed in Thornthwaite's earlier classification: a moisture factor, a temperature factor and the annual variations of these two factors (Thornthwaite: The climates of North America, Geographical Review 1931, and Thornthwaite: The climates of the earth, Geographical Review 1933). The resemblance, however, is merely superficial; actually the two classifications are fundamentally different. In the 1931 classification the climate types were signified and the boundaries determined empirically by studying the distribution of vegetation, soil, drainage, etc. In the 1948 classification the plants are not regarded as meteorological instruments combining the various climatic fectors and read like a thermometer or a rain-gauge; they are regarded merely as instruments of evaporation, as the clouds are instruments of precipitation. "The subdivisions of the older classification were justly criticized as being vegetation regions climatically determined. The present climatic regions are not open to this criticism, since they come from a study of the climatic data themselves and not a study of vegetation."

However, Thornthwaite takes the natural reservation that his classification is capable of improvement. Better methods can be evolved for determining the potential evapotranspiration. Further observations are required, especially in the tropics and the polar regions. A truly rational manner of determining the regions of temperature effect may perhaps be based on a relation between the temperature factor and the moisture factor, which no doubt exists but has not yet been found.

"There is an encouraging prospect that this climatic classification, which is developed independently of other geographical factors such as vegetation, soils, and land use, may provide the key to their geographical distribution."

On the basis of this summary with quotations from articles in American journals published during the war years it is now possible to draw up some outlines of the discussion on climate classifications, and also to set up the American views on the background of — and bring them in relation to — the subdivision into climate and vegetation belts arranged by Martin Vahl.

Köppen's system is not simple in Thornthwaite's opinion, in which he is undoubtedly right. But according to Ackerman, Thornthwaite's system of 1931 is more complicated even than Köppen's. What is more, the brief summary attempted in the foregoing cannot but give the impression that Thornthwaite's 1948 system is in no way less complicated than the one which Ackerman criticizes. Vahl's classification seems to be far superior to both Köppen's and Thornthwaite's as regards simplicity and clarity.

Köppen's system is criticized by both Ackerman and Thornthwaite because it does not agree with the known facts of the effect of climate on plant formations and soils. For this reason, those who nevertheless have tried to use Köppen's system have had to revise it incessantly. Thornthwaite's new, revised system is formed without regard to geographic phenomena other than the climatic, but may perhaps be useful in time for, e.g., the delimiting of plant formations when the numerical values have been found for the climatic conditions prevailing along the formation boundaries. Vahl's system is built up in conformity with the plant formations, whose boundaries Vahl was able to evaluate better than most by virtue of his enormous knowledge on this point. And he initiated a study of the climatic factors along the formation boundaries, inter alia by means of the Vahl equation, which comprises the temperature values for the coldest and warmest months. These equations may perhaps have to be modified somewhat, and several biochore boundaries have not yet been climatically determined; but hitherto I have seen no evidence to show that the line taken by Vahl is not the right one.

It is characteristic that the above-quoted suggestions for improving Köppen's system tend towards closer conformity with Vahl's climate and vegetation zones. This is true of less important matters like the steppe climate in the Fraser valley, and it is also true of more important factors such as the prolongation of the zonal C—D boundaries into the dry B climates. And finally, it applies to Ackerman's removal of the C—D boundary southwards and Thornthwaite's question of whether, after the criteria employed, it should not be laid still more to the south. From there it is not far to the acceptance of Vahl's boundary between temperate and sub-tropical climates in North America.

Thornthwaite points out that de Candolle's classification, which unfortunately Köppen followed instead of Schimper's, was originally intended as a zonal division. Vahl's division is zonal and has important contacts with Schimper's plant formations.

Thornthwaite is right in saying that in nature there are gradual transitions between the plant formations; but if we ignore the broader or narrower transitional belts, the plant formations as a whole are uniform over great distances. As a general rule, one is in no doubt as to whether the belt of vegetation in which one happens to be is grassy steppe, scrub steppe or temperate deciduous forest, etc. If they have no sharply defined boundaries, it does not mean that there are gradual transitions *everywhere;* nor does it mean that between the plant formations and the climatic regions corresponding to them there are no very definite boundaries corresponding to numerical climatic values. This is quite compatible with the fact that there are boundary belts in which in some years there is one, in others the other sharply defined type of climate (cf. Russell: Climatic years, Geographical Review 1934). For this reason, Thornthwaite's idea of a gradual progression of the climatic conditions corresponding to a supposed gradual transition in the character of the vegetation should be taken up for renewed examination.

Thornthwaite's complaint against geographers in general that they omit to study first the limits of plant formations etc., and then facts expressed by climatic numerical values to fit into these limits, does not apply to Martin Vahl's work.

In his classifications Thornthwaite always places the temperature factor last and the moisture factor first, and he actually expresses the temperature requirement by means of the term "water need", for which he uses the values of the potential evapotranspiration. The distrust which he thus seems to betray of temperature as a direct climatic factor is, I think, unwarranted and at any rate should be better motivated. It is not enough to refer to Köppen's rather erratic use of temperature factors and to the assumption of gradual transitions in nature. It would be well if geographers in various countries would make a serious test of the applicability of Vahl's temperature equations before compiling new systems.

Thornthwaite's 1948 classification will not be easier to apply than his 1931 system. It is based on factors difficult to work with, and, if full use is made of all four kinds of symbols, it will lead to a climate map of the world even more mosaic-like than Köppen's. Although Thornthwaite says that a scientific classification "cannot be based on the needs of a classroom", no harm would be done if it were a little perspicuous.

Thornthwaite himself has a feeling that his latest climate classification needs further improvement. Köppen and Vahl also worked on improving their systems. Vahl admitted that his delimitation of the tropical zone and the finer subdivision of this and other belts were temporary, because of the lack of data regarding plant formations and climates. No existing climate classification is complete. But the question is whether Vahl's classification after all is not the best of all existing systems as a basis for further development. On the whole his biochore boundaries are fixed; it is perhaps their climatic motivation that must be altered and developed. For this reason a world map of Vahl's climate and vegetation belts will suffer but little change in appearance.

In considering Thornthwaite's 1943 and 1948 articles there seems to be something illogical in his first reproaching Köppen and others for not basing their climate classifications on observations in nature of factors such as plant formations etc., and then himself contriving a system on a purely climatic basis in the hope that some day it will provide an explanation of the limitation of other geographical phenomena.

All the work put by Thornthwaite into the estimation of evapotranspiration may very well acquire significance for climate classifications primarily built on another foundation, for instance in support of the non-zonal boundaries between deciduous forest, grassy steppe and scrub steppe. Vahl's boundaries by means of the rain probability in the months of vegatation growth are undoubtedly better than Köppen's, and they are easier to judge than Thornthwaite's. A discussion on this point would, howevér, be profitable.

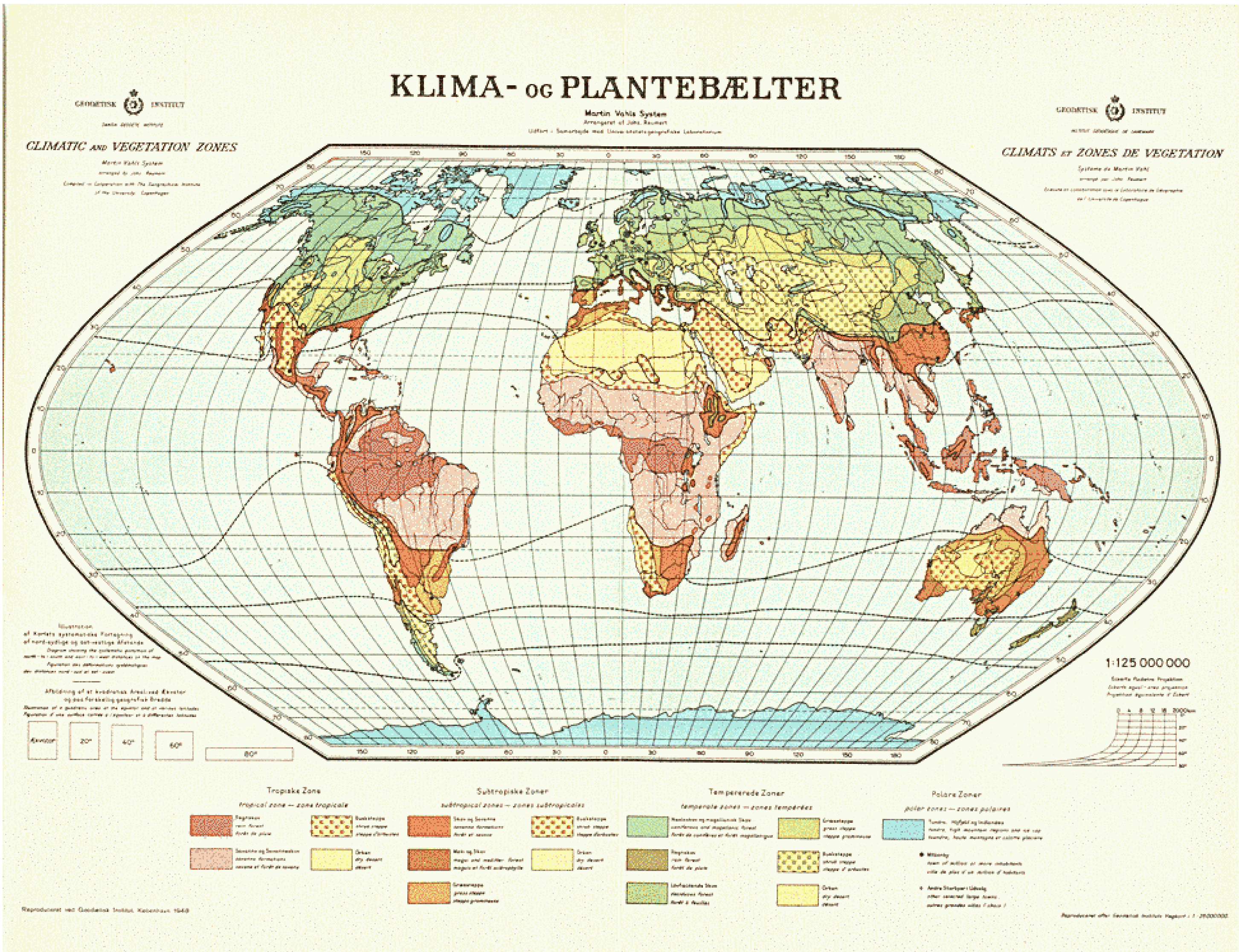
The most important of the facts established by a perusal of the Americal climatological literature is that the American geographers are ignorant of Vahl's classification. Had they known of it, they would perhaps have omitted to attempt to modify Köppen's system or to put new systems in its place. An article by A. W. Küchler: A geographic system of vegetation, makes no mention of Vahl but of another Dane who accomplished much in the sphere of plant geography: C. Raunkiær. Küchler, who appears not to know of Raunkiær's formation statistics, offhandedly dismisses the geographical importance of his "life forms".

The best climate classification I have found in American geographical literature is Van Royen's, as formulated in Bengtsson & Van Royen: Fundamentals of economic geography, New York 1946. This system, which is a modification of Köppen's, in many ways approaches Vahl's zonal climate division, but without being as good.

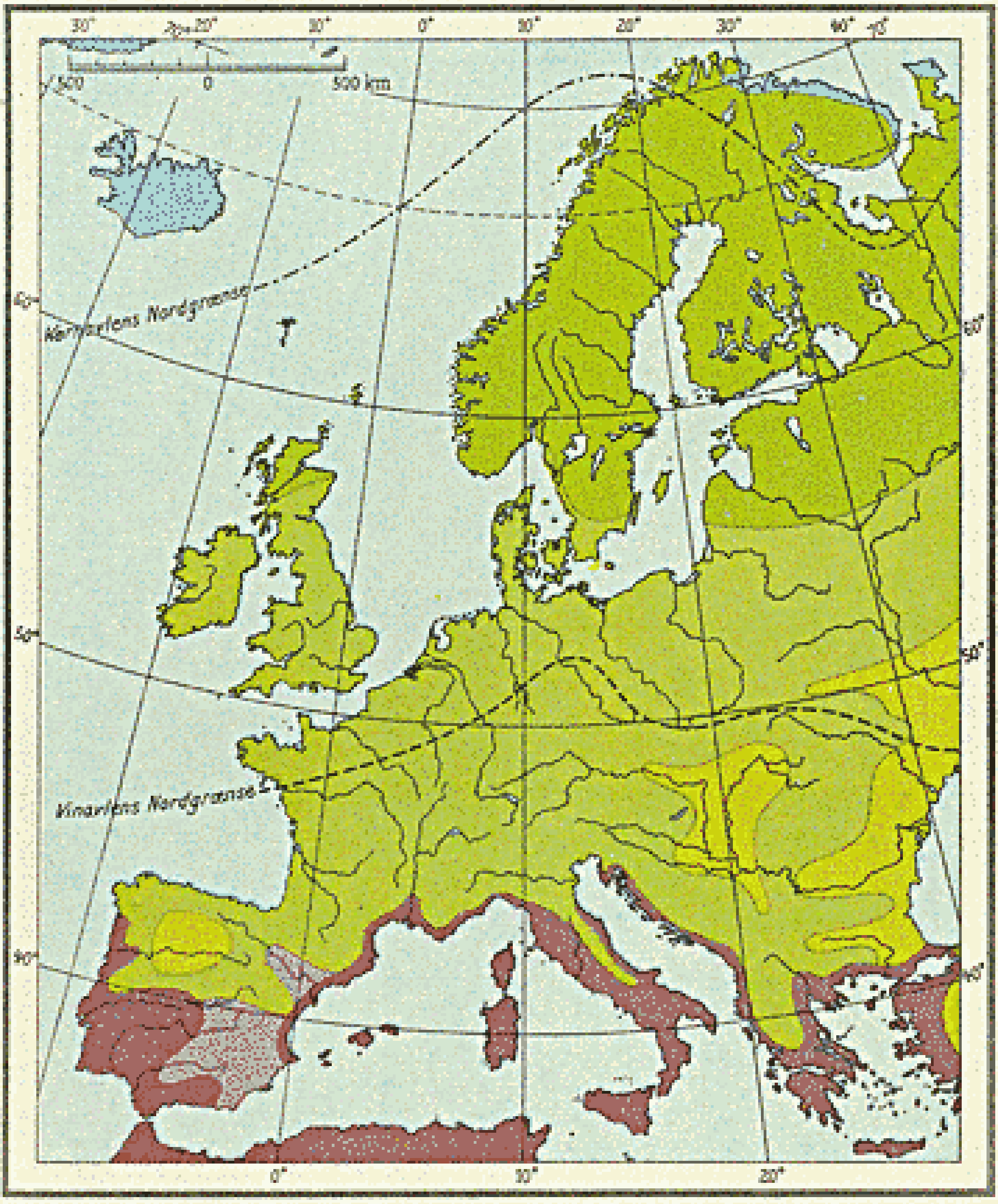
All of which goes to show that it is time Vahl's classification into climatic and vegetation zones became known and discussed.

In conclusion, Vahl's climatic and vegetation zones have now been plublished as a wall map, scale 1:25,000,000, in Eckert's projection, compiled by the Geodetic Institute, Copenhagen, with explanations in Danish, English and French.

A diminished reproduction of the wall map, scale 1:125,000,000, is subjoined to this paper.



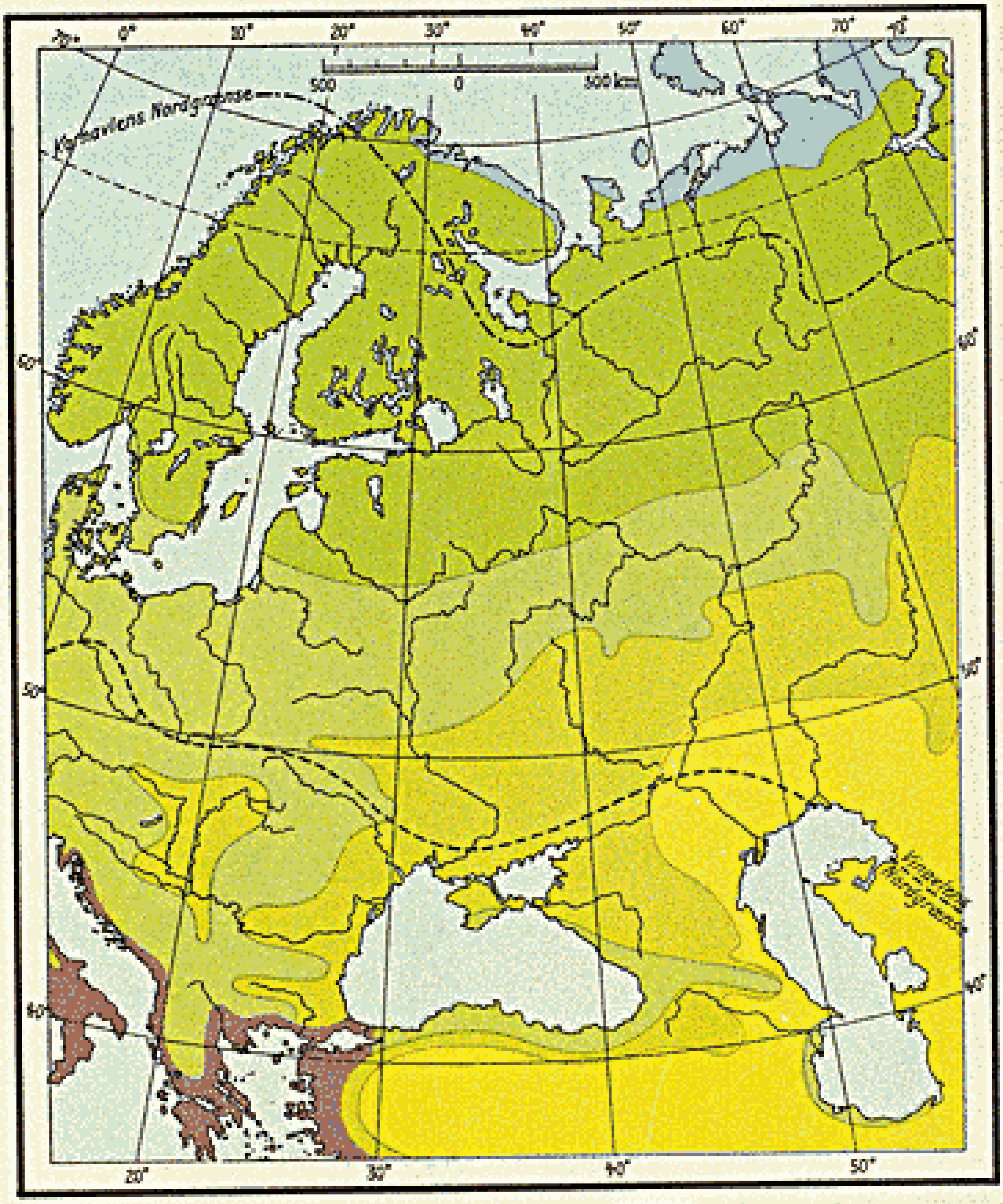
KLIMA- OG PLANTEBÆLTER
Martin Vahls System
GEODÆTISK INSTITUT
CLIMATIC AND VEGETATION ZONES
CLIMATS ET ZONES DE VEGETATION
1:125 000 000
Tropiske Zone
tropical zone — zone tropicale
Subtropiske Zoner
subtropical zones — zones subtropicales
Tempererede Zoner
temperate zones — zones tempérées
Polare Zoner
polar zones — zones polaires



Tundraregion. *tundra.*	Græssteppe i temp. Zone. *grassy steppe, temperate zone.*
Naaleskovsregion. *coniferous forest.*	Subtrop. Maki og Skov. *sub-trop. maqui and forest.*
Løvfældende Skovregion. *deciduous forest.*	Græssteppe i subtrop. Zone. *grassy steppe, subtropical zone.*

Plantebælterne i det vestlige Europa (tegnet af M. Vahl).
Bjærgenes Plantebælter er ikke angivne.

The vegetation zones in western Europe. (M. Vahl).
The vegetation zones in mountains not shown.



Tundraregion.
tundra.

Naaleskovsregion.
coniferous forest.

Løvfældende Skovregion.
deciduous forest.

Græssteppe i temp. Zone.
grassy steppe, temperate zone.

Buskssteppe i temp. Zone.
shrub steppe, temperate zone.

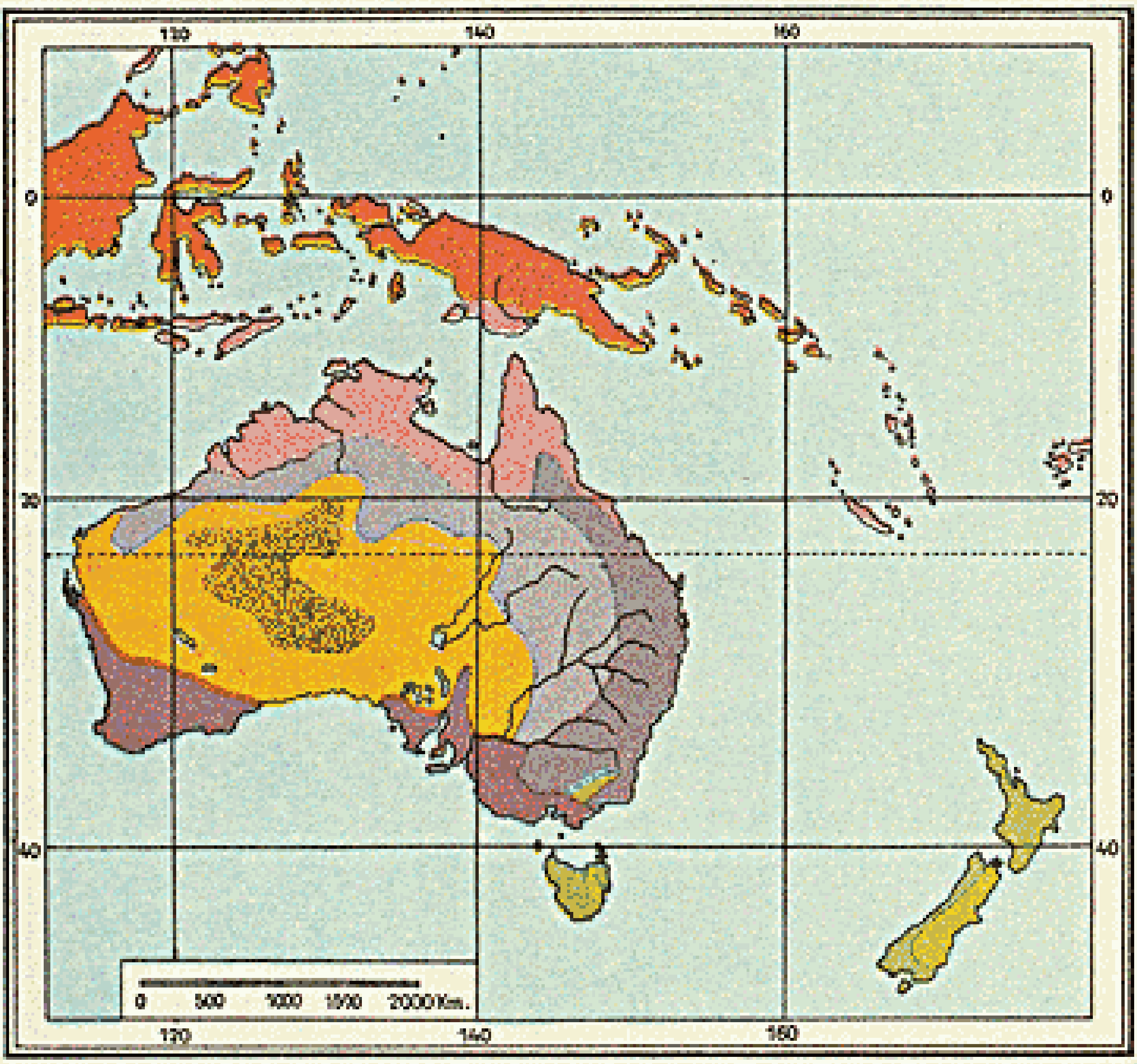
Subtrop. Maki og Skov.
sub-trop. maqui and forest.

Plantebælterne i Rusland (tegnet af M. Vahl).

Kortet fremstiller Ruslands naturlige Plantevækst. Alle de Forandringer deri, som Menneskene har foraarsaget ved f. Eks. at rydde Skov eller opdyrke Steppe, viser Kortet derimod ikke.

The vegetation zones in Russia (M. Vahl).

The map represents the natural vegetation. Alterations through human agency not indicated.



Skov i temp. Zone.
forest, temperate zone.

Græssteppe i temp. Zone.
grassy steppe, temperate zone.

Subtrop. Maki og Skov.
sub-trop. maqui and forest.

Subtrop. Skov og Skovsavanne.
sub-trop. forest and woodland savanna.

Busksteppe i subtr. Zone.
shrub steppe, subtropical zone.

Ørken i subtr. Zone.
dry desert, subtropical zone.

Trop. Regnskov.
rain forest, tropical zone.

Trop. Savanne og løvfældende Skov.
trop. savanna and deciduous forest.

Subtrop. Savanne og Græssteppe.
sub-trop. savanna and grassy steppe.

Plantebælterne i Australien (tegnet af M. Vahl).

The vegetation zones in Australia. (M. Vahl).

Tundraregion.
tundra.

Naaleskovsregion.
coniferous forest.

Løvfældende Skovregion.
deciduous forest.

Græssteppe i temp. Zone.
grassy steppe, temperate zone.

Busksteppe i temp. Zone.
shrub steppe, temperate zone.

Subtrop. Maki og Skov.
sub-trop. maqui and forest.

Subtrop. Skov og Savanne.
sub-trop. forest and savanna.

Græssteppe i subtr. Zone.
grassy steppe, subtropical zone.

Busksteppe i subtr. Zone.
shrub steppe, subtropical zone.

Trop. Regnskov.
rain forest, tropical zone.

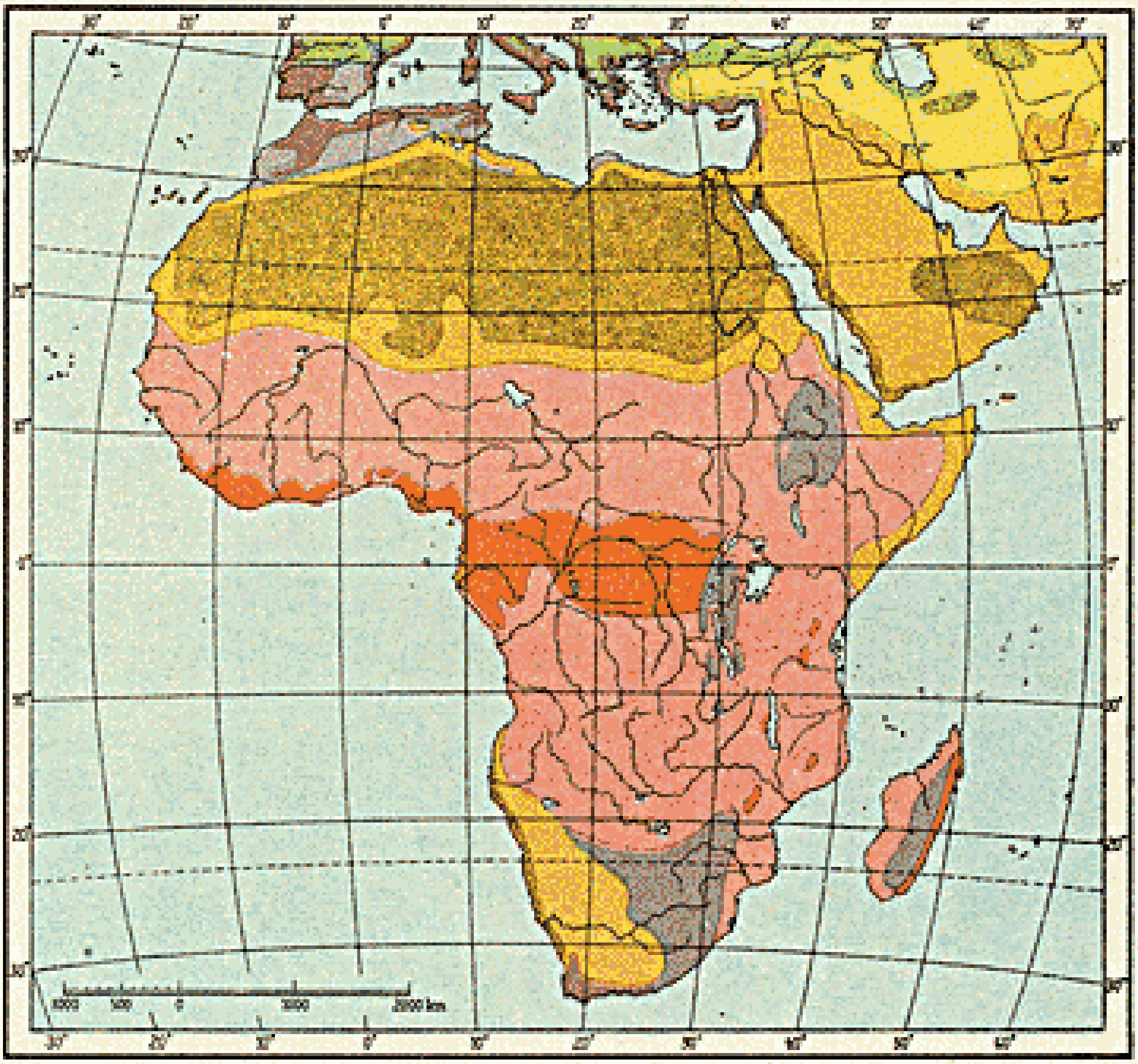
Trop. Savanne og løvfældende Skov.
trop. savanna and deciduous forest.

Plantebælterne i Nordamerika (tegnet af *M.* Vahl).

The vegetation zones in North America. (M. Vahl).

Plantebælterne i Sydamerika (tegnet af M. Vahl).

The vegation zones in South America. (M. Vahl).



Løvfældende Skovregion,
deciduous forest.

Buskstoppe i temp. Zone.
shrub steppe, temperate zone.

Ørken i temp. Zone.
dry desert, temperate zone.

Subtrop. Maki og Skov.
sub-trop. maqui and forest.

Subtrop. Skov og Savanne.
sub-trop. forest and savanna.

Græssteppe i subtr. Zone.
grassy steppe, subtropical zone.

Buskstoppe i trop. og subtr. Zone.
shrub steppe, tropical and subtropical zone.

Ørken i trop. og subtr. Zone.
dry desert, tropical and subtropical zone.

Trop. Regnskov.
rain forest, tropical zone.

Trop. Savanne og løvfældende Skov.
trop. savanna and deciduous forest.

Plantebælterne i Afrika (tegnet af M. Vahl).

The vegation zones in Africa. (M. Vahl).

- Tundraregion. tundra.
- Naaleskovsregion. coniferous forest.
- Løvfældende Skovregion. deciduous forest.
- Græssteppe i temp. Zone. grassy steppe, temperate zone.
- Busksteppe i temp. Zone. shrub steppe, temperate zone.
- Ørken i temp. Zone. dry desert, temperate zone.
- Suptrop. Maki og Skov. sub-trop. maqui and forest.
- Subtrop. Skov og Savanne. sub-trop. forest and savanna.
- Busksteppe i trop. og subtr. Zone. shrub steppe, tropical and subtropical zone.
- Ørken i trop. og subtr. Zone. dry desert, tropical and subtropical zone.
- Trop. Regnskov. rain forest, tropical zone.
- Trop. Savanne og løvfældende Skov. trop. savanna and deciduous forest.

Plantebælterne i Asien (tegnet af M. Vahl).

Kortet fremstiller Asiens naturlige Plantevækst. Alle de Forandringer deri, som Menneskene har foraarsaget ved f. Eks. at rydde Skov eller opdyrke Steppe, viser Kortet derimod ikke.

The vegetation zones in Asia. (M. Vahl).

The map represents the natural vegetation. Alterations through human agency not indicated.