WIND AND VEGETATION IN THE DALE PENINSULA

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ABSTRACT

DATA upon wind directions over large areas of exposed coastal or upland parts of the British Isles are limited, and often unobtainable from the records kept at present. In view of the accepted fact that vegetation in such localities is deformed by the wind, it is argued that detailed field study of the orientation of the growth-form of trees and bushes can go some way to filling the gap. The general shaping wind direction over a whole area can be determined and, in addition, local topographically influenced wind directions can be indicated in a manner which could only be more precisely recorded by a detailed and prolonged investigation by means of a network of wind-vanes. Vegetation gives information on the ecologically significant wind, which is not the same as the meteorological mean wind, but the former is more likely to be the wind influence of most interest to the agriculturalist and ecologist.

To illustrate the general theme an exposed peninsula in Pembrokeshire was surveyed in the field. For comparative purposes the fairly full meteorological record for two stations within the small area has been examined by standard methods of wind-data analysis.

INTRODUCTION

Exposure to strong winds is an important quality of the climate of coastal and upland areas of the British Isles. It is obvious that in such exposed localities the greater strength and frequently more persistent and regular character of the prevailing winds contribute to the ecological habitat as well as limit the agricultural potentialities. The effect of winds is one of the reasons for the lower heights of the tree limit in the British Isles as compared with less exposed parts of Continental Europe (Steven, 1953). The basic data on the mean climate of an area, particularly precipitation, humidity and temperature, can hardly be appreciated adequately without a knowledge of the features of air movement. Mean winter temperatures may well suggest a fertile coastal plain as an ideal situation for the horticultural production of less hardy fruit or vegetables but the exposure factor will be the negative determinant. Sensible temperatures for man and farm stock are strongly influenced by the rate of air movement. The coolness of a coastal summer is accentuated by the greater wind velocities experienced in such areas, whilst the rigours of the lower temperatures of the uplands, in particular those nearer to the coast, can only be assessed correctly if the exposure of higher ground to strong winds is recognized. Evaporative losses of moisture from plants and the soil are related to air movement as well as temperature, sunshine and humidity. Evaporative cooling is affected by the rate of movement as well as by the temperature and humidity of the air.

The need to take the exposure factor into account, when assessing the nature of a climatic environment, has long been recognized. This has lead to a great deal of investigation in the field and in wind-tunnels to find the best ways of using shelter-belts for providing the maximum protection from wind damage. A large body of information has been built up on this subject (Caborn, 1957), but its application in practice must depend upon the data available about regional wind directions and velocities. It is in this respect that the gap between the requirements for detailed quantitative data on a regional basis and available meteorological information upon the winds is most apparent. At the very best, direction and velocity summaries can be derived from the autographic records of one or two stations in the area equipped with self-recording anemometers. At most Agrometeorological Stations cup-counter anemometers, often at 6 feet above ground surface, are operated. These give valuable run-of-wind data, but not directions, and since their number is limited they can contribute only in a restricted way to knowledge of regional variations. More often the records, although perhaps more numerous for a given area, are limited to the 0900 hours G.M.T. measure of wind-direction and estimated wind force according to the Beaufort scale made at a third-order Climatological station. Without any information for the remaining hours of the day there is a strong possibility that the frequencies of stated wind directions derived from a single morning reading will misrepresent the mean wind conditions. In even more instances, especially in upland regions, it is necessary to resort to the records of a station located outside the area being studied as the only source of information.

The almost certain insufficiency of an adequate coverage from the sparse network of observing stations is made worse by the problems of providing some form of statistical average of wind data. The analysis of an anemograph, a lengthy and laborious business when dealing with a long period record, will give the nearest approach to reliable information but, where there are only observations at a fixed hour or for a small number of recording times, the resultant statistical summary can, at best, be only a rough and ready measure of the prevalent wind conditions at the station site. The provision of mean wind data is one of the most difficult requirements to meet from the normally available wind records. It must be emphasized that these records apply, or should do, to a standard height of 33 feet above open level terrain, and that, while this procedure has the advantage of making the different station records more readily comparable, it yields unrealistic records when considering their application to problems of ecology, agriculture and shelter-belts. The type of criticism which is directed at the agricultural or ecological relevance of temperature and humidity values recorded within a Stevenson screen at four feet above the surface of the ground is applicable here. No crops and only the higher trees are affected by the winds at the standard observing height. There are many significant contrasts in wind direction and force at heights between ground level and 33 feet above the surface. A meteorological wind record is very much determined by the details of the station site, and it is difficult or impossible to make allowances for these effects when extending the record to a wider area. The scale of the micro-topography is significant and even if the relief shapes are similar one cannot theorize from one set of observations and apply the findings to another locality (see for example Yoshino, 1957).

It is unlikely in most areas that the standard observations available at present can give an adequate representation of regional wind patterns. Whilst detailed investigations of small areas by a close network of airmeters or anemometers have been carried on in a number of specially chosen localities, these are unlikely to fill the gap in the conventional wind records. They extend over much too short a period to enable mean wind data to be derived and their scope is limited by the problems of observers and of instrumental expense. In practice they are further limited since they can deal only with restricted areas and can be made only at one or a small number of low heights above the surface.

The evidence of the regional plant cover

Faced with severe limitations in the meteorological data on wind direction, other sources of information must be sought. In the more windswept coastal and upland areas of the British Isles, the regional distribution of trees and bushes, and even more their individual shaping, reveal the results of exposure to the wind.

Taller plants, more especially trees and bushes, take on a flag or pennant-like growth-form in areas exposed to regular, strong winds. It is very plausibly assumed that physical damage and desiccation lead to retardation or inhibition of growth on the windward side. Lateral growing shoots can develop more easily on the leeward side with the result that the bush or tree is deformed so as to take on an asymmetrical shape, the greatest growth being downwind along the line of the dominant shaping wind. In coastal areas on-shore winds sweeping in salt-spray have an even greater scorching effect, but the relative influence of salt-spray as compared with other wind effects is a debated question (Boodle, 1920). The effect of increased transpiration by drying winds is more severe if low temperatures or dry soils restrict water absorption by the roots (Salisbury, 1939). Cold, dry winds can have a disastrous effect. The precise meaning of the evidence afforded by deformed vegetation must depend upon the effectiveness of particular winds as shaping agents. Since this will be related to their direction, strength, persistence and their characteristic temperatures and humidities over long periods, an understanding of the general climate and its seasonal variations is a necessary preliminary to the interpretation of plant forms in terms of wind-exposure. In an oceanic climate the emphasis is more on wind strength than upon the occurrence of cold, dry winds.

The form of bushes and trees in an area may be supposed therefore to provide a natural summary of the ecologically significant or dominant wind. This information for a whole area is more realistic for the agriculturalist or ecologist than a meteorologically determined mean derived from a single wind-vane, which is then adopted as the wind over the entire area. Although the information is not as precise as one could wish for, tree deformation suggests regional variations of wind direction which could otherwise only be shown by an elaborate scheme of instrumental readings. On wind force the evidence of vegetation is less valuable and highly subjective. Although the degree of shaping of the tree from the vertical may give some indication of the mean wind strength, too much depends upon the varying conditions and habits of growth of different species. Even for a single species the contrasting amounts of shaping are hard to interpret in anything but the broadest terms. The age of the hedgerow bushes or woodland trees, and the extent to which they have been modified by hedge trimming or laying, further complicate the use of vegetation as an index of wind direction or force.

In using the evidence of shaped vegetation, it is clearly important to discover when the wind has its greatest influence upon plants in our climate. The most marked effects for most species will be during the growth periods, which can be considered approximately as from April to September, and especially in April and May. Drying winds associated with low temperatures in winter can cause the death even of fairly hardy deciduous plants. It has been stated that cold, dry winds determine the polar tree limit and that spring grown shoots will die in a succeeding severe winter (Lundegårdh, 1931), but, in general, more knowledge is needed before it is possible to give a precise estimate of the relative deforming effects of winds during different months and at different stages of the growth cycle.

The orientation of wind-shaped trees and bushes can be determined in the field by compass readings. The absolute accuracy depends upon the degree of exposure and the species of tree or bush. In many exposed environments in the British Isles trees are absent, but stunted, hardy hawthorn and other bushes often give a good indication of the dominant, shaping wind. Whilst different species in a single locality may respond differently in the extent to which they are wind-shaped, they all give the same orientation. In many cases bearings to plus or minus five degrees are the most accurate which can be obtained, but very strongly deformed bushes can give values to the accuracy of a degree. By plotting the bearings on a large scale map a picture of regional patterns of dominant winds can be obtained. This reveals not only the general streaming of air across an area but also some permanent eddies and subsidiary local directions due to the influence of minor relief features (Sekiguti, 1951). Vegetation can, therefore, in many areas be used as a measure of the "ecological wind factor". The directions obtained cannot be expected to be the same as those derived from instrumental recording. Vegetation provides an integrated record of the effects of shaping winds, and not of those winds of which the influence is slight. In exposed localities the dominant shaping wind direction and that of the prevailing wind are closest to each other. The vegetation record reflects the sum total of shaping over the life period of the plant. The tree or bush as seen today may have responded differently at various stages of its growth to the same wind, and, where climatic fluctuations have occurred during its life, the eventual form is an expression of a complex pattern of combined wind direction and force effects.

Hawthorns shaped by winds blowing from the north up the cliff-face of Dale Point.

Windswept hawthorn on the plateau surface of the Dale Peninsula.

Photos by Martin George

View across Haygardhay Wood showing shaping of the hedgerow hawthorns and the pruning of the trees of the wood to the level of the plateau surface either side of the valley. The shaping winds are from directions slightly south of west.

The Plantation on the western side of Blue Anchor Wood showing the effect of west-south-west winds along Dale Valley upon hawthorn, larch and sycamore.

Photos by Martin George

An example of the evidence in a sample region in Pembrokeshire

In conjunction with an analysis of the local climates of the parish of Dale, Pembrokeshire (Oliver, 1959), a detailed measurement of the orientation of all available wind-shaped vegetation was made. The south projecting peninsula of Dale affords a good example of an area in which wind exposure is highly significant for the plant ecology and agriculture (in particular the early potato crop) and it provides a good opportunity to employ the method described.

The peninsula is characterized by an extensive development of an area of low relief of about 200 feet above sea level. This surface, which represents the 200-foot marine abrasion platform so well displayed in other parts of South Wales, has been dissected in Dale by minor rejuvenated streams which have eroded relatively deep, incised valley notches. These valleys open out either to the Bristol Channel to the south-east or into the entrance of Milford Haven or Dale Roads on the east. Hook Vale is the only minor valley which drains to the west coast. The west and south coasts of Dale, therefore, present a steep cliff face towards the prevailing wind with little variation in height between the cliff-top and the interior parts of the peninsula. Coastal erosion has sought out structural and lithological differences in the Upper Palaeozoic rocks to give a varied cliff-line which locally produces "funnels" such as the Vomit near St. Ann's Head or steeply inclined coves up which the wind is canalized. Complex eddies must occur up the western cliff-face and at its top, but this is only a subjective statement since no tree or bush vegetation exists on or near these cliffs to give guidance.

The stream valleys facing towards the south-east or east are sheltered from the main air-flow from the south-west. The stream which rises in the marshy boulder clay area immediately to the south of Moorland Cottage, and then flows north through Haygardhay Wood until it swings east down the main Dale valley, has incised itself in its middle course. This deep valley section is set athwart the prevailing wind and the shelter provided permits the growth of one of the few areas of woodland in the parish. The trees of Haygardhay Wood are not deformed on the floor of the valley but are increasingly wind-pruned as they grow higher up the valley slopes. The crown surface of the trees has been shaped so that it presents a continuation of the level of the plateau either side of the valley. The col-like valley of Dale permits a canalization of westerly winds down from the higher Westdale Bay end towards Dale village. In its more sheltered eastern part woodland manages to survive under wind-swept conditions around and east of Dale Castle, whilst—hugging the sheltered south side of the valley—Blue Anchor Wood presents a wedge-shaped profile. The apex of the wedge points west and the height of the trees increases eastward. The trees on the east provide an increasingly effective shelter for their neighbours growing to their leeward. A similar wedge-shaped woodland shelters in the deep valley leading east to Castlebeach Bay. The low scrub around Maryborough Farm gives way to larger trees as one goes towards the east. The only other tree growth in the parish is the narrow fringe of woodland either side of the Dale to Haverfordwest road along the west side of Dale Roads and under the shelter of Dale Hill. Elsewhere in the exposed areas of the parish there is no large tree growth although over the plateau surface in minor hollows and in the hedgerows grow stunted and mis-shapen hawthorn, blackthorn and an occasional elder bush. It is doubtful whether agricultural clearance is entirely responsible for the lack of tree growth, but the removal of field banks in the areas of the Royal Navy training station at Kete and of the wartime Dale aerodrome probably explains the complete lack of any bushes in these exposed western cliff-top areas. However, south of Kete and between Kete

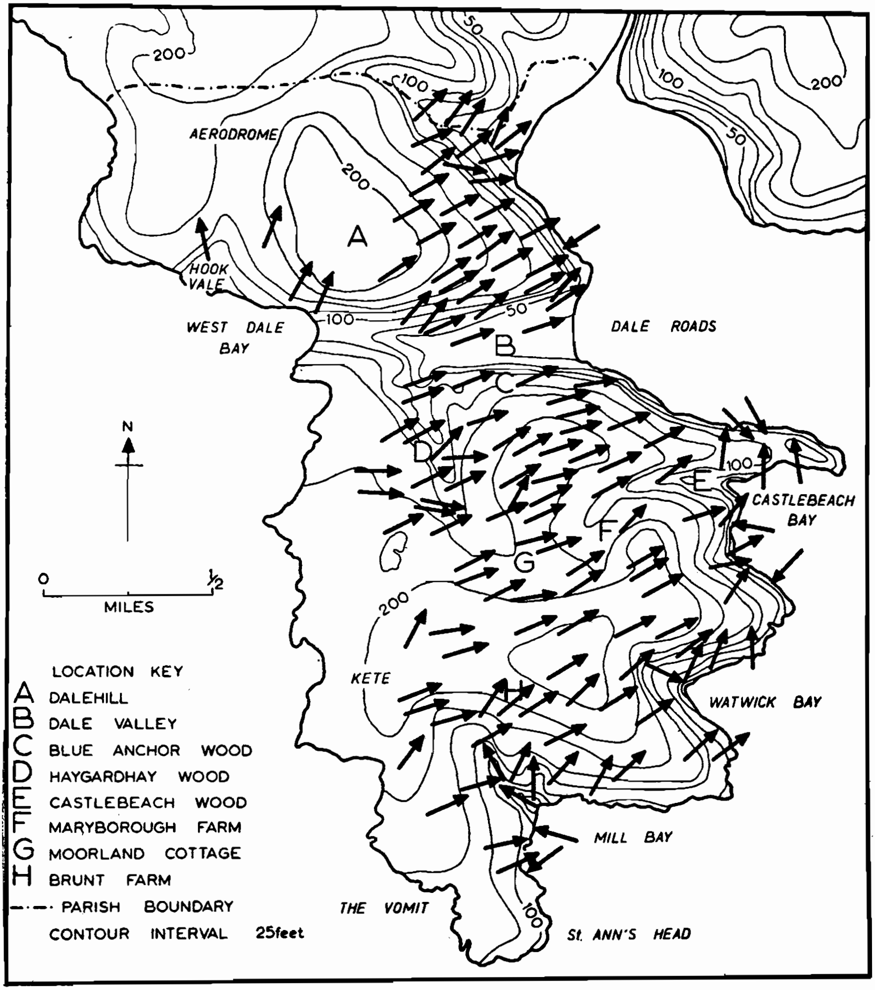

FIG. 1

Orientation of tree and bush deformation in the Parish of Dale, Pembrokeshire. Arrows show directions of elongation with reference to true-north.

and the Aerodrome in areas not touched by such clearance there are very few hedgerow bushes nearer to the west coast, and this suggests that exposure is the main explanation for the general sparsity of trees and even of bushes in the west.

Some 850 compass readings of the orientation of the shaping of individual hedgerow bushes were taken in addition to the recording of the direction of shaping of woodlands as a whole. Where both sides of a bush were accessible, readings from both the windward and leeward sides were obtained and these provided a valuable check on the reliance which could be placed on the readings. The most reliable indicators were hawthorn bushes, but blackthorn provided a reasonably good guide, whilst elder bushes were the least valuable. These readings were plotted on 6 inch to 1 mile maps. Figure 1 shows the general orientation of wind-shaped bushes. This map is based upon the detailed plotting which could not be reproduced on a small scale. The lack of any major deflecting relief feature on the plateau permits a remarkably uniform streaming of the prevailing wind over the whole surface. On the south side of the slightly higher ground on which Brunt Farm is situated the wind direction is slightly backed from the directions apparent further north in the parish. The winds sweeping up the northern side of Dale valley and around the eastern flanks of Dale Hill also showed a tendency to back as compared with those in the centre of the parish. The interesting features of the map are the well-marked effects of minor relief features. The shaping wind along the east coast has orientated the bush growth in an up-cliff direction so that the bearings observed are controlled by the alignment of the individual stretches of coastline. In such cliff situations the height of the trees, where these occur, decreases up-slope as the plateau surface is approached. The forms of vegetation along the valleys show the complex interaction of two shaping forces. At the heads of the valleys and on the upper parts of the slopes the effective shaping force is that which characterizes the plateau surface. In the valley leading down to Mill Bay the dominant wind on the lower slopes and on the valley floor is up the valley from the east coast. In the valley to Watwick Bay the trees and bushes suggest that the wind is actually swung round by the west facing side of the valley so that the shaping wind is effectively down the axis of the valley from the west-north-west. In each case the valley wind directions are imprinted upon the bushes and near the heads of the valleys the individual bushes often show the two directions of shaping involved, i.e. the valley direction and the main plateau direction. The bushes on the headland on which Dale Fort is situated are shaped by winds from the south. Two factors are involved here. There is shelter from the west and also a greater development of winds with a southerly component which blow more easily through the wide water opening of Dale Roads and Milford Haven (Table 1). Between Dale Village and the parish boundary some of the trees immediately on the coast show a shaping effect from a northerly quarter but the cliff-line is degraded here and fronted by a narrow coastal flat and the general plateau direction from the west-south-west generally influences even the east coastal strip. The corridor of Dale valley appears to cause the west-south-west winds to veer slightly and to blow more directly west to east along the valley. This tentative suggestion cannot be strongly supported, however, by the evidence of vegetation, since, except near Dale village at the eastern end there are no bushes on the valley floor. On the northern side of the valley the wind sweeps up the slope in a north-easterly direction as is spectacularly demonstrated by the profile of the wood north of Dale Castle and the church.

The permanent effects of topographic features upon wind directions are frequently indicated on the map. It was observed in the field that hedgerow lines often influenced the shaping directions in detail but this cannot be shown cartographically. Where hedges were oriented nearly along the line of the dominant wind of the area in which they were situated, the bushes were aligned exactly with the hedge direction and this did not appear to be due to artificial pruning or laying of the hedges. In the angles of the banks at the corners of fields a funnel-like effect could be seen on the shape of individual bushes.

RELATIONSHIP OF VEGETATION EVIDENCE AND METEOROLOGICAL RECORDS

Until June, 1951 a telegraphic, first-order Meteorological Station was maintained at St. Ann's Head. Here the anemometer was set up at 70 feet above ground level. Commencing in 1950, the Dale Fort Field Centre has continued the record as a third-order Climatological station. For the period 1921-1950 the wind directions recorded at 0100, 0700, 1300 and 1900 hours G.M.T. have been extracted from the Monthly Weather Report, and percentage wind frequency values for eight points of the compass are tabulated in Table 1. The mean wind roses for the year and for the period April to

Table 1. *Percentage frequencies of wind at St. Ann's Head.* 1921-50 (*based on readings at* 0100, 0700, 1300 *and* 1900 *hours* G.M.T.), *and Dale Fort,* 1950-58, *at* 0900 *hours* G.M.T.

	N	N.E.	E	S.E.	S	S.W.	W	N.W.
St. Ann's Head								
Jan.	5·9	8·2	8·9	10·0	11·7	21·2	20·1	14·0
Feb.	8·1	11·5	11·8	13·0	8·7	16·7	17·6	12·6
Mar.	8·8	12·9	13·2	15·4	9·2	16·9	13·6	10·0
April	13·6	12·2	8·9	9·5	8·7	15·7	16·8	14·6
May	13·6	13·0	8·9	10·7	10·9	16·8	14·2	11·9
June	13·0	8·6	5·6	7·2	8·4	19·6	22·7	14·9
July	10·6	4·7	3·4	6·4	9·7	22·2	26·0	17·0
Aug.	9·4	7·2	5·6	6·7	9·7	21·6	25·0	14·9
Sept.	10·3	11·2	7·4	7·3	9·4	19·8	20·8	13·8
Oct.	8·0	12·1	10·3	8·5	8·9	18·9	20·8	12·5
Nov.	8·2	14·3	11·1	8·0	9·8	17·7	17·8	13·1
Dec.	7·5	9·9	10·0	8·4	9·7	19·3	18·7	16·5
April-Sept.	11·7	9·5	6·6	8·0	9·5	19·3	20·9	14·5
Year	10·1	10·4	8·8	9·2	9·5	18·7	19·5	13·8
Dale Fort								
April-Sept.	11·8	7·4	7·4	9·1	12·9	26·7	7·6	17·1
Year	10·7	10·8	8·7	9·9	12·0	25·5	7·2	15·2

September are shown in Figure 2. Comparable values and wind roses for Dale Fort are also given. A combined force and direction wind rose would have been more valuable but the published data in the *Monthly Weather Report* do not permit this. In the *Climatological Atlas of the British Isles* (pages

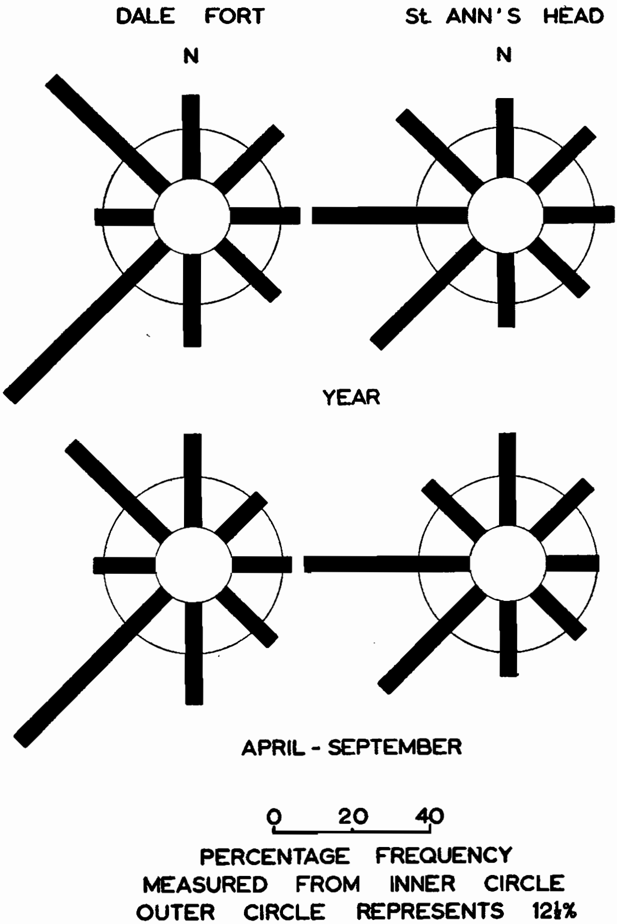

FIG. 2

Wind roses showing the percentage frequency of winds from eight points of the compass for St. Ann's Head (4 readings per day, 1921-50) and Dale Fort (0900 hours G.M.T. 1950-58) during the year and for the months April to September.

21-27) monthly and annual wind force and direction diagrams, corrected to an effective height of 33 feet above the surface level, are presented for St. Ann's Head for a short period 1935-1943. During this period 21·3 per cent. of the total duration of all the winds had a mean speed of over 21 knots. Winds from the south-west, west-south-west and west together made up two fifths of such winds. Some interesting points are worth indicating in the frequency data presented. The St. Ann's Head record reveals a moderately circular distribution of wind directions with a predominance, however, of winds from between south-west and north-west. Westerly winds have a slightly higher percentage frequency than south-west winds. The April to September rose shows little difference from the annual pattern, but there is in these months a slightly greater development of westerly winds and an increased frequency of south-west and north-west winds. Perhaps rather unexpectedly winds from between north-east and south-east are less frequent in the April to September months. The east winds of Spring are noticeably absent. Table 1 indicates that April and May, at which time desiccating and cold easterly winds would do much harm to new shoots and leaves, are not months when such winds are much above average. Only in the months of January, March, May and December do south-west winds exceed in frequency the west winds.

The Dale Fort readings show some marked features of contrast. It must be remembered that these are for a different and much shorter period than the record for St. Ann's Head, and that they represent only single readings at 0900 hours G.M.T. It seems, however, that the difference in the sites of St. Ann's Head and Dale Fort partly explains the different patterns of wind distribution. Dale Fort shows a striking decrease in westerly winds and a much more frequent development of south-west winds and, to a lesser degree, of those from the north-west. The explanation seems to be in the fact that Dale Fort is relatively sheltered from the west but almost as open as St. Ann's Head to the south-west and south. The south winds at the Fort show a slightly greater frequency than those at St. Ann's Head. The evidence of the few bushes on the Dale Fort headland suggests a greater dominance, closer to the surface level, of southerly winds. It is interesting to observe that the small contrasts between the Dale Fort annual and April to September conditions are very similar in sign to the differences between the same periods observed at St. Ann's Head.

From the frequency record for St. Ann's Head resultant winds have been calculated. These have been based on the methods given by Conrad (1950) and Brooks and Carruthers (1953), the latter method making an allowance for assumed variations in velocity with frequency. The mean annual frequencies for St. Ann's Head over the period 1921-50 give the values of 265° and 267° respectively for the two methods. The comparable April to September values are 270° and 273°. The difference between these values computed from the wind record and those derived from the vegetation record is noticeable. This discrepancy arises from the fact that the shaping winds do not include all those which enter into a meteorological summary. There may also be a limitation in the extent to which the St. Ann's Head readings, based on values at four times in the day over the period 1921-50, truly represent the sum total of winds which have contributed to the form of the vegetation. Winds of a light character which contribute little to the exposure of an area, although perhaps otherwise climatically significant, will not be reflected in the vegetation. On the other hand, very strong winds will probably have an effect on plants out of all proportion to their frequency (Goodman and Gillham, 1954). In this respect, however, it has also been stated (Boodle, 1920) that the leaves are often killed by the drying effects of long-continued winds of ordinary strength rather than by gales. Neither wind-vanes nor vegetation can give a reliable measure of turbulent conditions.

In Figure 3 an attempt has been made to obtain a quantitative expression of the wind directions derived from vegetation. The peninsula has been divided into squares of ¼-mile side, and in each are shown the average wind direction in degrees from true north as determined from the indicated number of compass readings of tree and bush form. Where two or more distinct directions are involved it was thought better to give these as separate mean values rather than to produce a meaningless composite figure by averaging the whole set

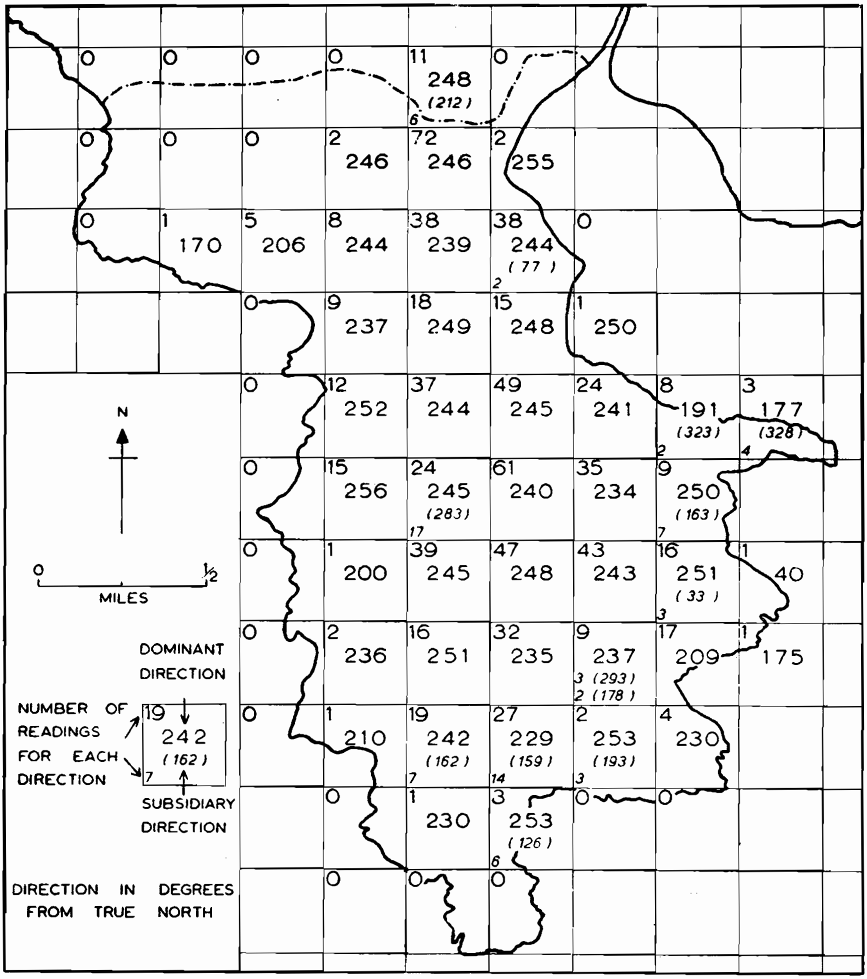

FIG. 3

Record of the direction of elongation of wind-shaped bushes and trees in Dale. The values represent the mean of the number of individual observations made in ¼-mile squares and are bearings from true-north.

of observations. Though this procedure might be criticized as subjective, in that it involves deciding into which category each observation should be put, it was found in the field that usually the different directions of shaping were clearly distinct from each other.

The determination of regional wind directions by field observation in areas exposed to strong wind effects offers a simple but useful method of meeting present deficiencies in our knowledge of this important element of climate. Such information is not without its practical application since the establishment of shelter belts or protective hedgerows, in order to get maximum advantage, must be related not to broad regional wind directions but to local topographically determined winds. The arrangement of field boundaries within the parish suggest that the Dale farmer has already made use of his own observations over the generations to plan the division of his fields by banks and hedges so as to give the best shelter. It is noticeable that field boundaries follow more or less continuous lines with a north-west–south-east orientation whereas the less critical south-west to north-east divisions are by no means so consistently continuous across the peninsula. Until the time when self-recording instruments can be established for long enough periods and in a sufficiently dense network to provide accurate data, empirical field evidence must remain the best possible guide for many regions.

REFERENCES

BOODLE, L. A. (1920). The Scorching of Foliage by Sea Winds. *J. Minist. Agri.*, **27**, 479-486.

BROOKS, C. E. P., and CARRUTHERS, N. (1953). *Handbook of Statistical Methods in Meteorology* (M.O. no. 538). H.M.S.O. London.

CABORN, J. M. (1957). *Shelterbelts and Microclimate* (Forest. Comm. no. 29). H.M.S.O. London.

CONRAD, V., and POLLAK, L. W. (1950). *Methods in Climatology*. Harvard University Press, Cambridge, Mass.

GOODMAN, G. T., and GILLHAM, M. E. (1954). Ecology of the Pembrokeshire Islands, II: Skokholm, Environment and Vegetation. *J. Ecol.*, **42**, 296-327.

LUNDEGÅRDH, H. (1931). *Environment and Plant Development*. Arnold, London.

OLIVER, J. (1959). The Climate of the Dale Peninsula, Pembrokeshire. *Field Studies*, **1** (1), 40-56

SALISBURY, E. J. (1939). Ecological Aspects of Meteorology. *Quart. J. Roy. met. Soc.*, **65**, 354-57.

SEKIGUTI, T. (1951). Studies in Local Climatology, III, on the Prevailing Wind in Early Summer Judged by Bending Shapes of Top-twigs of persimmon trees. *Paps. Met., Geoph.*, **2**, 168-179, Tokyo.

STEVEN, H. M. (1953). Wind and the Forest. *Weather*, **8**, 169-174.

YOSHINO, M. (1957a). Local characteristics of surface winds in a small valley. *Reps. Sci.* (*Sect. C*), *Tokyo University*, **5** (46), 479-486.

YOSHINO, M. (1957b). The Structure of surface winds crossing over a small valley. *J. met. Soc. Japan*, II, **35**(3), 34-45.