but only small-scale experiments along similar lines have so far been carried out in Great Britain.

The synthetic products of the Fischer process consist of 9–10 per cent of gaseous hydrocarbons, 60 per cent 'straight' open-chain paraffinic motor spirit, 28 per cent high-grade Diesel oil fraction and 2–3 per cent wax, but slight modification in processing influences these proportions greatly.

COST PER GALLON

No attempt has been made in the Falmouth Committee report to compare the normal costs per gallon of producing motor spirit by the various processes examined. A fair estimate of the cost for the motor spirit produced by hydrogenation would be approximately 11d. per gallon, remembering that in all new plants it is difficult to assess the amortization figure. The octane rating of this spirit is 70 plus.

The outstanding feature of coal-oil distillation *cum* cracking is that from one ton of coal and one ton of coal-oil make-up there is produced 78 gallons of motor spirit. The approximate cost of this spirit, allowing average price for all other products, is 7·2d. per gallon, and the octane rating is 73–74.

A feature of synthesis is that 5½ tons of coal are required for the production of one ton of synthetic oil product. The yield of finished motor spirit is 40–45 gallons per ton of coal, and the cost may be placed at between 10½d. and 1s. 1½d. per imperial gallon. This range in the estimated price is advisable owing to the fact that in Germany the synthetic industry is very closely associated with the benzole industry and it is not easy to determine the net cost of the synthetic motor spirit. The best octane rating of this spirit is 62.

LIMITATIONS OF THE PROCESSES

Each of the processes considered has its peculiar limitations which must be borne in mind in surveying the economic position.

In the case of hydrogenation, the capital cost is enormous. There are definite limitations to the percentage of coal in the coal-oil paste which it is advisable to treat. There are difficulties in the treatment of the residue and the recovery of the catalyst. It may be that the success of the process will ultimately rest upon the finding of an economic method of separating the catalyst from the residue and the means of handling it.

With coal-oil distillation *cum* cracking an important limitation lies in the supplies of creosote or similar coal-oil products at economic prices. In a state of national necessity the major portion of coal-oil produced would doubtless be made available for the preparation of home-produced motor spirit. If in the interests of the coal industry it were felt wise to make available, unhindered by tax, imported natural petroleum, the field for both hydrogenation and coal-oil distillation would be unlimited.

So far as synthesis is concerned, the motor spirit produced is of low octane rating. It is obvious that there would always have to be available 'upgrading' material at an economic price, such as benzole, alcohol, tetra-ethyl lead, iso-octane, etc. The synthetic process may always be limited by the high cost and availability of the necessary catalyst.

ADVANTAGES

The synthetic process is the only one so far developed which produces from coal a Diesel oil of first quality.

The coal-oil distillation process is the only one of the three under review which produces economically a large quantity of smokeless fuel of high radiant heat value and complete combustibility.

The valuable phenols so essential to the nation's needs in times of peace and war can only be obtained from coal distillation processes and the tar industry, and not from hydrogenation or synthesis.

Plants of the Sand Dune and why they Grow There*

By Prof. E. J. Salisbury, F.R.S.

THE vegetation of a sand dune is unique not only because of the rapidity of the changes that it exhibits but also because, from the manner of dune development, the phases present an arrangement in space corresponding to their sequence in time, so that the plant succession can be ascertained with certainty.

* From a Friday evening discourse delivered at the Royal Institution on February 4.

The embryo dune frequently begins around seedlings of either *Agropyron junceum* or *Ammophila arenaria*. Both are characterized by an important reaction to burial by sand, namely, that they are stimulated to grow through to the new surface. The projecting leaves by reducing wind movement not only shelter the surface from erosion but also bring about further deposition. *Agropyron junceum* can grow normally in 1·5 per

cent of salt and tolerate considerable periods of inundation by sea-water, whereas the marram grass cannot. But *Agropyron*, owing to its drooping habit, as contrasted with the erect habit of marram grass, is not so efficient a collector of sand and has much less capacity for vertical growth. Hence it only forms low dunes at low levels on the beach, whereas the marram grass is the successful pioneer at greater elevations and indeed is always the dominant species on English dunes in their early stages. It not infrequently brings about a rise of more than a foot a year in height, whilst its lateral spread may exceed 36 sq. ft. a year. Other grasses that play a part in the early stages are *Elymus arenarius* and *Festuca arenaria*. All these grasses spread by means of rhizomes from which at intervals tufts of leaves are given off above and roots below.

Measurements of a number of plants over a period of years indicates that both the pioneers *Agropyron junceum* and *Ammophila arenaria* have a remarkable capacity for rapid spread in their early stages of growth, which must render them peculiarly fitted for the occupation of a mobile habitat. The average areas occupied by twenty plants of *A. junceum* in the first few years of their development were: 1 sq. ft.; 5.7 sq. ft.; 18.4 sq. ft.; and 37.4 sq. ft.; the maximum annual increment, amounting to about 600 per cent, being exhibited during the second year's growth. The rate of radial extension gradually rises during the first three years to about a foot a year. The marram grass, though spreading at a slightly slower rate, namely, about 0.7 ft. per year, exhibits a maximum radial extension in the second year of growth which, in the plants studied, amounted to an average increase of area of no less than seventeen times. *Agropyron junceum*, through its greater toleration of sea water, can not only colonize at lower levels but also tends to occupy sand that is normally moister and hence firmer than that higher up where the marram grass is the dominant pioneer. The remarkable initial capacity for rapid spread of the latter may therefore be of some significance in its more mobile station.

The sand dune, though it may receive as much precipitation in the form of rain and dew as an inland situation, can be aptly described as an edaphic desert—a desert that is due, not to climatic but to soil conditions, since the coarse texture and very low organic content render sand a very poor retainer of water.

Data that I have obtained respecting the actual natural water content of dunes from a number of different localities around our coasts, shows that even after heavy rainfall the supply at the surface of a young dune rarely exceeds 10 per cent. Normally, however, the amount of water available to the plant is less than 4 per cent and frequently

much less. For example, if there is a spell of dry, cold, windy weather the amount of water in the first two inches may fall to below 1 per cent, of which only a small part is available to the plant. On the other hand, the water content at six inches is normally between 4 and 5 per cent, and in warm sunny weather, which tends to promote rapid water-loss from the plant, there is an important compensatory phenomenon which plays a fundamental part in maintaining a fairly constant, if low, supply of water for these dune species. Owing to the large size of the sand particles and the dryness of the surface grains, these constitute a very bad conductor of heat. Hence the heat of the sun received by the superficial layers is not conducted downwards, as in normally moist soil, but results in very high surface temperatures being attained.

Excessive heating of the surface grains raises the temperature of the air in the interstices and the rising convection currents draw in warm moist air, from over the sea and adjacent tidal lands, into the interior of the dune. Here the moisture-laden air impinges upon the cooler sand grains and brings about a phenomenon known as internal dew-formation. Just because this is most pronounced in conditions of prolonged sunshine, internal dew-formation takes a most important role in stabilizing the moisture supply at a time when it might be expected to attain a minimum.

Compared with the shortage of water, the other factors adverse to plant growth, such as the mobility of the substratum, the changing level and the poverty in nutrients, are less inimical to plant life. Further, it must be emphasized that the high temperature attained by dune surfaces accentuates the effect of the small water content. We are not surprised that the number of these pioneer species is very few, but rather that these few can withstand the rigours of the habitat and even flourish despite them. In what way are these pioneer species equipped so that they can endure these very specialized conditions?

Owing to their extensive rhizomes, the risks consequent upon the mobile habitat are minimized. Further, a single plant thus exploits by its roots a very large volume of sand. Penetration of the sand by the rhizomes is facilitated by the structure of their apices, which are woody with a sharp point well suited for piercing the sand and capable of withstanding the inevitable abrasion. But the feature which more than any other fits these pioneers for growth on a dune is that they all possess leaves which automatically flatten out when their water content is high and curl into a cylinder when their water supply is low. On a dry windy day the leaves of the grasses appear

like narrow tubes split along one side, and this split widens or narrows in exact relation to the increase or diminution of the ratio between water absorption and water loss. This feature is of most importance when conditions are most extreme, but some idea of the efficiency of the mechanism can be gained from the fact that experiments with *Elymus* have shown that even under slight air movement the rolled leaves transpire only about a tenth of the water lost by the leaves when flat.

The only plants of these early phases which have not such automatic transpiration checks are those of the drift line on the dune face. These species are able to survive during periods of shortage by storing up copious internal water reserves, the presence of which renders the leaves succulent. The two most frequent are the sea rocket (*Cakile maritima*) and the prickly saltwort (*Salsola kali*). Both are very tolerant of sea water.

By the activity of the pioneer species, three main changes result. The embryo dunes rise in height, extend laterally and the hummocks coalesce to form a definite ridge, which may attain to heights of from sixty to one hundred feet in Great Britain. The decaying leaves, rhizomes and roots add organic material to the sand mass. Thus the dune becomes not only less mobile but also its capacity to retain the water that either falls upon its surface or condenses within is continually being augmented. So the extreme conditions become ameliorated and sooner or later, on advancing shores, the establishment of new dune ridges seawards of those already formed gives some protection both from sand removal and from rapid accretion.

The less specialized conditions which thus ensue are marked by the advent of other perennial species only slightly less specialized than the grasses. Of these the most characteristic are the sand sedge (*Carex arenaria*), the convolvulus (*Convolvulus soldanella*), sea spurge (*Euphorbia paralias*), sea holly (*Eryngium maritimum*) and rest harrow (*Ononis arvensis*). The sand sedge is remarkable for the rapidity of its growth and the extent of its rhizomes. From the parent plant the rhizomes radiate out like the spokes of a gigantic wheel and grow horizontally a few inches below the surface of the sand, sending up tufts of leaves at intervals of about four to six inches throughout their length. With the passage of time some of these tufts form the centres of origin of further radiating rhizomes, thus in a few years the sand is occupied by a sort of network bearing tussocks that constitute an efficient wind-break so that this species is an important stabilizer. The sea spurge and sea holly, not being rhizomatous species, have little capacity for lateral growth and

so are more susceptible to sand removal, but they both exhibit rapid response, by new growth, to burial. In common with the other dune perennials, they meet the low water supply by means of a deeply penetrating and extensive root system (in the sea holly this may penetrate 2.7 m.); also they both possess leaves with a thick protective cuticle.

Up to this stage of dune development, a considerable area of bare sand is still obvious between the tufted growths. This implies great vulnerability to high winds and consequent risk of rapid erosion or accretion, thus precluding the development of species incapable of rapid growth. However, with the passage of usually about half a century, conditions have become sufficiently stabilized and the rate of accretion sufficiently diminished to permit the growth of dune annuals. These dune annuals are all characterized by germinating in the autumn, and passing through their life-history during the winter months, flowering in the spring and perishing with the surface drought of summer. They evade the adverse period in the seed state. The capacity of the dune annual to grow during the colder months of the year is enhanced by the warmth of the surface sand in sunshine. This brings about a rise in temperature of the air just above the sand. As a consequence, the leaves of these annuals are sufficiently warm to carry on active photosynthesis when this would be quite impossible for plants on other soils with a more normal capacity for heat conduction. Readings taken on the Norfolk dunes in April indicate that the temperature immediately surrounding the dune annuals may frequently be 10°–15° C. higher than the air generally.

All these dune annuals afford a striking contrast to the dune perennial by reason of their shallow roots, which only penetrate to an average depth of about four centimetres. They are enabled to flourish partly because of the frequent rains and high average humidity of the winter months, but even more because by the time of their arrival the pioneer species have added to the surface sand sufficient organic matter to augment appreciably the water-retaining capacity. Moreover, all these dune annuals are rosette species with foliage close to the ground, thus occupying the most humid layers of the air and a level least exposed to wind action.

It has been possible to obtain data as to the water loss by various species when in sand of a normal water content. Such data show that a plant of *Cerastium semidecandrum* may, on a sunny day, lose water at the rate of more than two grams per 100 sq. cm. of surface per hour. If we allow for the normal volume of soil exploited and the average water content, this rate of loss

involves complete removable of the available water supply within about a day. Since this species will survive a period of more than a week without rain, it is evident that it must depend on internal dew formation and upon the movement of water from beyond the immediate vicinity of the root system. The maintenance of such a flow requires some motive force, but this is supplied by the osmotic suction of the roots, which in various dune plants has been found to range from 9 to 20 atmospheres, or a force of from about 130 lb. to 290 lb. per sq. inch. Much higher osmotic pressures equivalent to 630 lb. to the sq. inch have been observed in dune plants of Algeria and California.

By their carpeting of the dune surface during the season of frequent high winds, the annuals materially diminish the risk of surface erosion, and they in turn add further to the humus in the soil. Their protective action, which ceases when they shrivel in summer, is augmented by certain mosses, of which *Tortula ruraliformis* is the most important, which endure periods of severe drought quite unharmed.

The prevalence of lichens also on the more advanced stages of stabilized dunes has given rise to the name of 'grey dune' in contrast to the younger 'yellow dune'. The vegetation carpet is quite efficient so long as unbreached by the tracks of man or the activities of the ubiquitous rabbit. The latter is often the source of exposure that permits wind entry and erosion, leading to a so-called 'blow-out', that either results in complete removal or initiates a secondary succession.

A striking feature of earlier dune phases is the frequency of comminuted shell fragments among the sand grains. The proportion of calcium carbonate thus furnished varies greatly from one dune system to another. Some in Dorset contain practically none, and heather appears quite early in the dune succession, whilst other dunes contain a high proportion (up to 17 per cent at Bundoran in Ireland). In Portuguese dune samples from Comporta I found up to 27 per cent CaCO_3 in the young dunes and 0.2–0.4 per cent in the leached sands of the old. According to J. A. Van Steijn, the dunes of Holland show a similar range to those of Britain; he gives 0–18 per cent as the range of lime content. Where the calcium content is high, for example Tenby dunes, there are usually a number of calcicole species.

Before passing to the final stages of dune development, we may pause to consider a feature that will in most dune systems have already appeared. We shall note that dunes tend to develop as ridges parallel to one another. This usually intermittent formation is partly due to

the presence of the main dune ridge, which by upward deflection of the on-shore wind produces a relatively calm condition at the ground-level immediately in front, so that embryo dunes starting here would exhibit little accretion. Still more, perhaps, it is due to the fact that the sloping sand in front of the ridge has the effect of pushing the main drift line farther out, and it is usually in relation to the buried drift that the new dunes begin to form. Thus the marram grass seedlings which arise along the drift line exhibit rapid growth and rapid accretion, and so form a young dune ridge separated from the pre-existing one by an interval. The parallel ridges often rest on a relatively impermeable substratum, and the water, of which the dune ridges are the catchment area, drains into the intervening hollows and sometimes forms what are known as 'dune slacks'. They naturally exhibit a marsh and aquatic vegetation which is beyond the scope of our present treatment, but there are a few special features to which attention must be directed. These slacks are the especial home of the creeping willow (*Salix repens*), which by its mode of growth and extensive root system (it will form roots more than 25 ft. in length) is able to spread into the dunes proper and can even grow successfully in mobile sand, but its apparent role as a pioneer is probably illusory, despite all statements to the contrary.

Into these slacks the drainage water from the dune ridges brings the nutrients, particularly the calcium salts leached from above, and to this fact we must, I think, attribute the presence of species that we more particularly associate with dry chalky soil. Such plants as *Chlora perfoliata*, *Linum catharticum*, *Gentiana campestris*, even *Carlina vulgaris* and the lady's tresses (*Spiranthes autumnalis*) are to be found growing even in free water. In such a 'slack' the soil contained 3.0–3.7 per cent calcium carbonate and the reaction was pH 7.5. The dune ridges on either side of the 'slack' contained about 0.3 per cent of carbonates and were appreciably acid (pH 6.8).

The dune slacks are the especial home of the bog pimpernel (*Anagallis tenella*) and the brookweed (*Samolus valerandi*). Here too in the southwest grows the giant spiked rush (*Juncus acutus*), whilst in similar situations in the Southport dunes occurs a remarkable habitat form of the grass of Parnassus (*Parnassia palustris* f. *condensata*) and also a sand form of the beautiful *Pyrola rotundifolia*. There are also certain liverworts which are peculiar to this situation, notably the rare *Petalophyllum Ralfsii*, which exhibits perennation by means of tubers. The shallower slacks often become dry during the summer months and here occur remarkable depauperate forms of many species.

Throughout the dune development, certain continuous changes have been going on apart from the diminishing mobility and increasing water-retaining capacity to which I have especially directed attention. These are the progressive leaching out of the soil carbonates and the augmentation of the acid products of organic decay, and so it is that we find that the prevailing alkaline condition of the young dune passes gradually into an acid state of the old. In the regions of higher rainfall, peat accumulation leads to the development of heather moor as on the old dunes of the Culbin Sands on the Moray Firth.

The progressive changes in the character of the dune soil with the passage of time are shown by the two series of data summarized below. These show the increasing acidity (diminishing pH value), increasing organic content, and decreasing content of calcium carbonate, in two dune systems. One (Blakeney) with an initially low carbonate content, and the other (Southport) in which the initial carbonate content is comparatively high.

SOUTHPORT DUNE SYSTEM			
Approximate age of dunes in years	CaCO ₃ %	Organic content %	Reaction
2	6.3	0.53	8.2
6	4.15	0.33	8.2
14	3.17	0.68	8.15
25-55	2.6	0.74	7.8
100	1.14	4.0	7.2
200-280	0.28	5.9	6.4
BLAKENEY POINT DUNE SYSTEM			
5	0.42	0.36	7.2
80	0.34	0.5	7.0
160	0.03	0.86	6.9
235	0.01	1.15	6.4
340	0.01	2.7	6.2

Whereas the young yellow dunes only possess a flora of about ten species, the later yellow dunes can support between fifty and sixty different kinds of flowering plants, and the comparatively stable grey dunes have a flora of more than a hundred, exclusive of those confined to the 'slacks'.

The specialization imposed by the physical attributes of the habitat itself have been permanently modified; but the final occupants may themselves create specialized physical conditions which once more restrict the supportive capacity of the habitat.

Landscape at the Royal Academy

IN considering pictures from the point of view of science, one is glad to subscribe to what appears to be Ruskin's central doctrine, which may be put thus: a creative artist in portraying natural subjects, whether figure or landscape, should base his work, except in so far as it is meant to be symbolic, on a scientific realism expressing the love of Nature, and should carefully restrict the selection of particular effects to the suppression of others where this is rendered necessary by the limitations of the medium.

There can be no question but that both scientific realism and the love of Nature are apparent in the pure landscape work which has figured so prominently in British art since the time of Constable, and that the annual exhibitions of the Royal Academy reflect this tradition. The 1938 exhibition has the usual large proportion of landscapes amid figures, portraits, historical scenes and coronation pageantry, and in this short notice attention may be directed to a few of the landscape canvases, leaving out of account the quite strong representation in water-colour.

Mr. Sydney Lee's "Lulworth Cove" (274) well suggests location in the midst of a stretch of the Dorset coast-line, as high, rugged and fierce as any in England. The rock-contortions about the cove should please geologists, but the general alignment of the cove in relation to the open sea will

certainly force attention on the laws of perspective.

Another pleasing Dorset scene is that in a small picture by Major C. E. Phillips, secretary of the Royal Institution, entitled "On the Purbeck Hills" (76). The general conformation of the land, as well as the line of stone walls in the background, would place this scene, not in the range of chalk downs that sweep round by Corfe Castle, but in the limestone ridge the upturned edge of which forms the splendid high coast between Swanage Bay and St. Aldhelm's Head.

In "Bibury Bridge" (26), Miss Kathleen M. Pearson presents a typical Cotswold scene: the delightful oolite stone, ever dominant, never out of harmony with other elements, the backing of stately elms gloriously grouped, and the foreground touch of animation given to the precincts of the village by two lads with a dog. The "Sutherland" (314) of Mr. Borlase Smart shows an inlet of the sea overlooked by mountains; but the whole power of the picture to the present writer lies in its suggestion of the wild tract of the Northern Highlands that lies behind the scene depicted. The grand simplicity of the title hints, indeed, that this is precisely the reaction the artist intends. "On the Moors, Skye" (760), by Mr. Arthur T. Nowell, is a skilful rendering of the beautiful lighting effects so typical of showery weather in the wild hills of the Western Highlands.