Physical Factors on the Sandy Beach. Part I. Tidal, Climatic, and Edaphic.

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With 3 Figures in the Text.

CONTENTS.

INTRODUCTORY.

In no other region of the biosphere does it appear that the purely physical factors of the environment exercise so profound an influence upon living forms as on the seashore, for not only the animals and plants which live upon it to-day, but the various groups of organisms which have passed through it in their evolutionary history, reveal, in their structure, rhythms and reactions, the indelible impress of the littoral discipline. The intertidal zone, in which these special conditions are operative, is very extensive —amounting in the British Isles alone to 620,000 acres—and the investigation of so large and important a region must necessarily be of considerable scientific and economic interest.

While much attention has been given, in recent years, to the physical ecology of the open sea (*vide* Atkins, 1926, for bibliography), and even to the special conditions obtaining in limited or almost land-locked sea-areas (Marshall & Orr, 1927), the study of the seashore itself has progressed on different lines. Much detailed ecological work has been carried out (*vide* Flattely & Walton, 1922, for bibliography), leading to the recognition of definite " zones," both algal and animal, corresponding to the successive levels of the intertidal and subtidal regions, but in no direction has it been found possible to establish those general principles of interdependence which have done so much to clarify our knowledge of the open sea and its inhabitants. This failure is due, partly to the complexity and fluctuating character of the factors involved, but even more to the lack of adequate data, and the failure to utilise existing data, bearing upon the magnitude and incidence of the physical, rather than the biological, agencies which are so evident in the area. In this paper an attempt is made to survey some of the physical conditions obtaining upon the seashore, with special reference to that distinctive region known as the sandy beach.

The outstanding factor, of course, is the tidal ebb and flow, which not only modifies and determines the incidence of all other factors, but is the characteristic and dominant influence of the littoral region. The effect of currents and of wave-impact, also, as other types of water movement, have been considered along with the tide. The climatic factors of temperature, light and wind are of special significance in so exposed an area, though only the first is here given special consideration, since the effects of sunlight upon the shore will form the subject of a separate communication, and wind, so far as it operates upon the intertidal region, does so indirectly, through the action of the water-waves which it induces. The relation of the wind to dune formation does not fall within the scope of the present survey.

Salinity as a factor in the life of beach organisms is as potent an influence as in the sea, and calls for special consideration, in relation to drainage, sand-grade, and tidal movement. Finally, the sand itself, as the permanent factor in the beach environment, enters into those other variables of porosity, evaporation, and capillarity, which stand in such intimate relation to the life-processes of the littoral biota.

THE TIDE.

While the mean tidal range is, of course, the prime factor in determining the extent and development of the fauna and flora of the portion of shore lying between the tide-marks, it is obvious that with any given vertical range, the width of the intertidal zone may vary from a few feet, on a rocky or steeply shelving coast, to hundreds of yards, or in extreme cases miles, on a flat sandy beach. Under the latter conditions there is afforded an opportunity for studying, in their fullest development, those features which depend most intimately upon the tidal ebb and flow.

Ebb and Flow.

For the sake of simplicity and brevity, consider the ideal case—that of a symmetrical tide, of twelve-hour period, rising over a smooth and evenly sloping beach. The course of such a tide can be represented by a simple harmonic expression :—

$$h = \cos 30^\circ\, t$$

where h is the relative height of the tide, above or below mean sea-level, and t is the time-interval after high water. The curve given by this expression (Fig. 1) is similar, in its essentials, to that produced by any

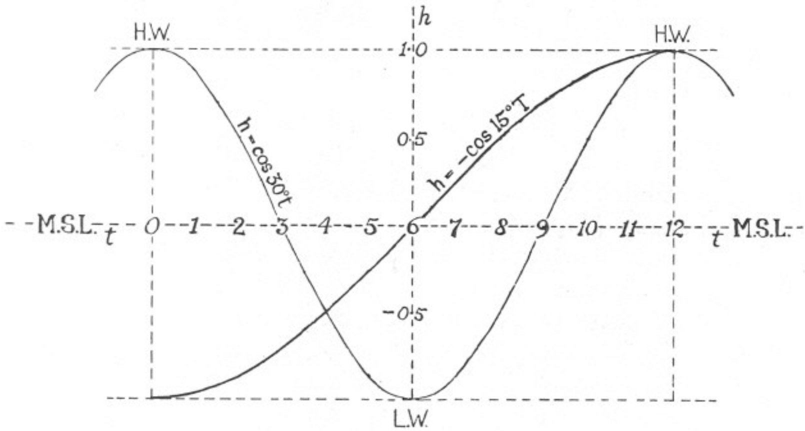

FIG. 1.—Diagram to illustrate the periodic exposure and submersion of the beach. h, Relative height above or below Mean Sea-Level ; t, Time Interval after High Water ; T, Total time of exposure during one tidal oscillation.

recording tide-gauge. It is clear that the period of submergence or exposure experienced by any point between the tide-marks is determined by its position relative to the mean levels of high and low water, a point at high-water mark being only touched by the sea once in twelve hours, and another at low-water mark having an equally brief exposure to the air. The expression

$$h = -\cos 15^\circ\, T$$

(h being the height of the point above or below mean sea-level) affords a measure of T, the total time of exposure during one tidal oscillation. The results are relative only, but they may be fixed for any station by the insertion of the appropriate numerical values. This relation is of fundamental importance in the study of the shore, since its periodicity is superimposed upon every other factor operating in the intertidal area, such as temperature and insolation, or chemical and biological changes, whether of themselves periodic or aperiodic.

The relations of tide and temperature are discussed in a subsequent section (p. 540). Among the important biological and chemical factors depending upon the tidal movement, are those associated with the metabolic products and residues of the plankton and larger algæ of the coastal area. These chemical influences, varying from season to season, are borne into shallow water by each returning tide (Atkins, 1922 ; Bruce, 1924 ; Moberg & Allen, 1927) profoundly affecting the onset of successive stages in animal and plant development (Knight, 1923). It is probable, too, that the periodic removal of the products of metabolism of the microflora and -fauna of the beach is a no less important result of the tidal movement. These, however, are chemical problems, with which it is proposed to deal in the second part of this paper.

Currents and Wave-action.

The major problem of coastal erosion and accretion is one that has called for detailed treatment at the hands of the civil engineer and the economic botanist (Royal Commission on Coast Erosion, etc., 1907–11 ; Carey & Oliver, 1918), but it is rather to the local effects of wave-action and water-movements upon beach deposits that attention is now directed.

The mechanical forces which operate upon the sea-beach, leading to the attrition, transport, and segregation of its various materials, are essentially the same as those at work on the sea-bed in shallow seas. On the beach, however, the water-movements are of much greater violence, and, in consequence, erosion and attrition proceed more rapidly, and where separation of the different grades of material occurs, it is on a steeper scale. As Cornish (1910) has pointed out, the breaking waves on the sandy beach, and especially those of the flood-tide, are responsible for a selective transport of the coarser grades in a shoreward direction. This is usually accompanied by a further drift, in a direction parallel to the shore-line, occasioned by the resultant set of the inshore current, whether of wind or tide. Such influences, however, are only of relative permanence, and the construction of sea-walls, revetments, and harbour works, even at considerable distances, may lead to a complete redistribution of inshore and littoral deposits, while the effect of long-continued winds, whether inshore or offshore, in modifying the character of sandy beaches, is well known.

Permanent or temporary, the movements of winds, tide, and currents ultimately determine the contour of the beach, and the grade-distribution of its materials. These, in turn, modify such biologically significant features as the height above the water-table, drainage, exposure, and porosity. At this stage, however, the effects are no longer tidal, but edaphic, and under that heading they are more appropriately considered (p. 543).

Temperature.

The Annual Cycle.

The temperature of the coastal waters passes through an annual cycle which, like the tidal oscillation, is capable of harmonic expression. Numerous observations are available, of both sea and air temperature, made at various offshore stations, lightships, etc., around the British coasts, and these are summarised in the Monthly Weather Reports of the Meteorological Office. A series of observations of greater relevance to the purpose in view, however, are those from Port Erin Bay, made daily at a point close inshore, in one or two fathoms of water. The monthly means of daily readings, at 9 a.m., G.M.T., over a period of 25 years, together with the mean difference between the temperatures of air and sea, are shown in the following table, and graphically in Fig. 2.

Temperature of Sea and Air, at Port Erin, at 9 a.m.
(25-year Means, 1903–27).

Month.	Sea-Temp. ° C.	Air-Temp. ° C.	Excess of Sea- over Air-Temp. ° C.
January	7·78	5·77	2·01
February	7·08	5·28	1·80
March	6·78	5·44	1·34
April	7·43	7·22	0·21
May	8·97	10·71	−1·74
June	10·94	13·14	−2·20
July	12·77	14·77	−2·00
August	13·76	14·43	−0·67
September	13·32	12·73	0·59
October	12·29	10·49	1·80
November	10·44	7·62	2·82
December	8·74	6·44	2·30

Temperature and the Tide.

The periodic inundation of the beach by the incoming tide results in a sudden change of temperature—a change which, while of less extent than the mean diurnal range in summer, introduces, by the abruptness of its incidence, a new and significant factor into the shore environment. From the above table, or from a comparison of the curves in Fig. 2, it will be

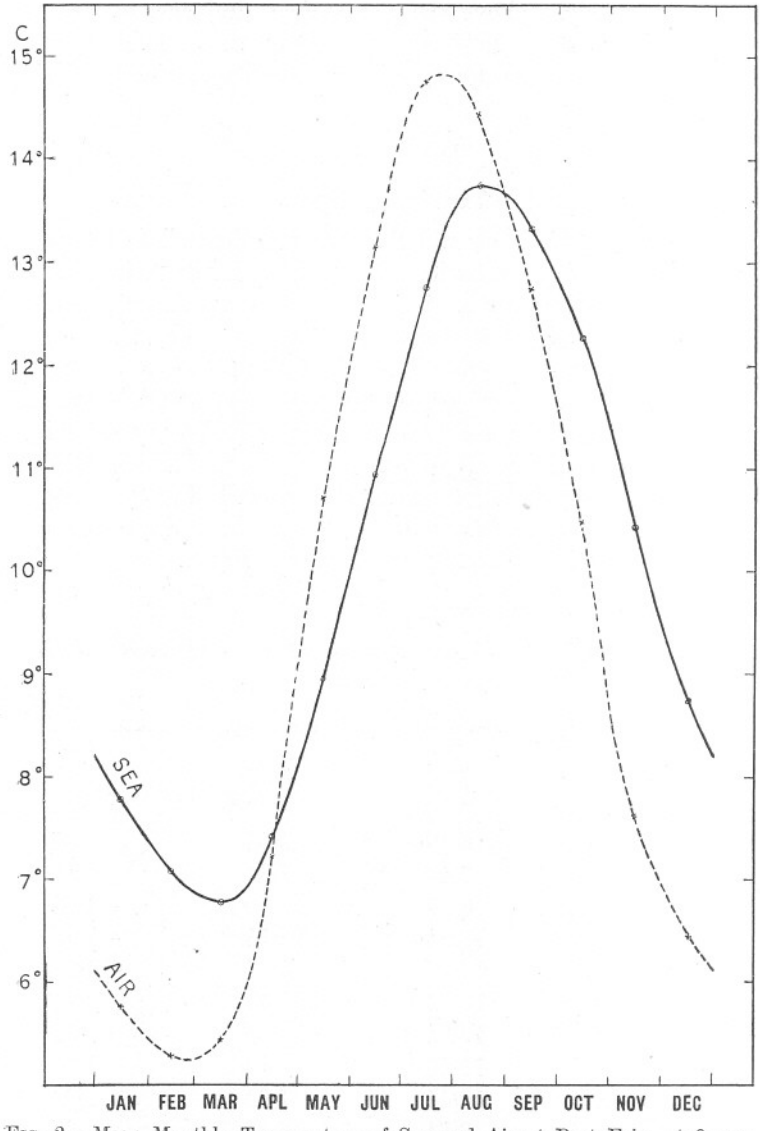

Fig. 2.—Mean Monthly Temperature of Sea and Air at Port Erin, at 9 a.m. G.M.T. during the 25 years, 1903–27.

noted that the disparity is at a maximum at the end of June, and in November, when the temperature of the sea is, in the one case, 2°·4 C. below that of the air, and in the other, 2°·8 above it. These differences are those obtaining at 9 a.m., G.M.T., when the air and the beach-sands are approximately isothermal. At a later hour, when insolation has raised the surface-temperature of the beach, the inequality is greater, but evaporation from the moist surface usually prevents any excessive rise of temperature. The specific heat of the sand *in situ*, itself a function of grade, air- and moisture-content, enters also into the thermal relations.

Surface Temperature of the Beach.

Numerous observations, extending over several years, gave the following mean values for the temperature of the upper 1 cm. of moist sand, between tide-marks, on Port Erin beach :—

June, 16°·5 ; August, 18°·8 ; October, 10°·7.

The highest surface-temperature recorded was 21°·0, in full sunshine, in June. It must be emphasised that these values refer to the intertidal region only, much higher temperatures being attained by the dry blown sand above the reach of the highest tides. No readings of the surface-minima are available, but during the winter months the sand is occasionally coated with snow or hoar-frost.

Subsurface Temperature of the Beach.

A considerable temperature gradient occurs, especially in summer, between the surface of the sand and the deeper layers which, at depths below 20 cm., approximate to the temperature of the sea. The following is a typical depth-range, observed on Port Erin beach, in August :—

Depth, cm.	0	5	10	15	20
Temperature, °C.	18°·8	17°·6	16°·5	15°·6	15°·3

The significance of the subsurface temperature will be apparent in connection with the numerous organisms—molluscs, annelids, echinoderms, etc.—which pass a considerable part of their existence below the surface of the sand, and also as a controlling factor in those chemical and bacteriological processes which take place in the deeper layers.

SALINITY.

Equally with the inhabitants of rock-pools or the open sea, the animals and plants of the sandy beach require water for the essential acts of their physiology. During the ebb-tide period of exposure to the air, the supply may be derived from the film held around the sand-grains by surface-forces, or else, by capillary rise in the interstices, from the permanent water-table at some depth below the surface. In either case, renewal of the source, usually with a change of salinity, will accompany every rising tide. The study of the salinity of the sandy beach and its changes is thus of great importance from a biological point of view.

Salinity of Beach Waters.

In the simplest possible case, the interstitial waters of the beach are isohaline with those of the adjacent sea, except for the purely surface concentration resulting from evaporation, or the dilution resulting from local rainfall. Numerous factors, however, notably the presence of superficial or subterranean streams of fresh water, lead to a departure from the ideal conditions. Such streams, carrying away the sea-salts, give rise to regions of greatly diminished salinity. In the case of subsurface waters, the salinity of the uppermost layers of the beach is determined by the capillary lift of the pore-spaces between the grains, and this, in turn, as shown in the following section, is a function of grade. Thus it comes about that isolated areas of low salinity may occur upon a level beach, at some distance from any visible source of fresh water. and this fact has been associated with the remarkable distribution of certain sand-living dinoflagellates, which require a definite range of salinity for their optimum metabolism (Bruce, 1925).

Under these circumstances the actual rate at which the salinity falls, at any given point on the beach, under the influence of fresh-water streams, will depend more upon the washing effect of such streams, than upon any mutual exclusion of the fresh and salt waters. The rate and completeness of washing is limited by the volume of fresh water poured upon the beach, the porosity and retentive capacity of the sand, and the rapidity of escape of the surface-water. Such factors are difficult to evaluate, and it is generally necessary to determine the rate of change of salinity by actual trial, in any given case. The following example, from a point at about three-quarter flood level, on the smoothly-sloping surface of Port Erin beach, may be typical :—

Time.	State of Tide.	Salinity. Sea. ‰	Salinity. Beach. ‰	Remarks.
5.30 a.m.	H.W.	–	–	Observation station submerged.
9.0 a.m.	Half-ebb	32·9	–	——
11.0 a.m.	Nearly L.W.	–	23·0	Sand-surface damp, but not streaming. Sunny. E. wind. 10° C.
12.45 p.m.	Rising	–	19·4	,, 11° C.
2.30 p.m.	Half-flood	–	18·2	,, 12° C.
3.45 p.m.	⅝-flood	–	15·1	,, 11°5 C.
4.30 p.m.	¾-flood	33·0	20·3	Edge of advancing tide 1 foot from station. 11° C.
6.0 p.m.	H.W.	–	–	Observation station submerged.

It is evident, from the above figures, that there is a progressive fall in salinity, from the time the beach is uncovered, until the advancing tide has nearly reached the point of observation, when the salinity rapidly rises to the full sea-value. Under these conditions, the diminution of salinity occurring at any point on the shore, between successive tides, is proportional to the distance of the point above low-water mark.

The Beach Sands.

Under this heading, it is proposed to include those factors which, in an ecological study of a land-area, would be termed "edaphic." Such factors are associated with the solid medium of the "ground," as distinct from the fluctuating conditions of tide, temperature, and salinity.

Chemically and lithologically, the shore-sands from various points around our coasts are not greatly dissimilar; they consist, for the most part, of more or less rounded grains of quartz, with a coating of iron oxide, and a greater or less admixture of calcareous matter, in the form of fragments of chalk, limestone, or comminuted shells. Important differences between beach sands become apparent, however, when they are subjected to mechanical analysis, either by sieving, or elutriation.

Distribution of Grade on the Beach.

It is a matter of common observation that differences of "grade," or grain-size, occur at different points on the sandy beach. The distribution of grade upon the beach, as indicated in a previous section (p. 538), seems largely to be due to local currents, and to the deflection or obstruction of the tidal flow by rocks, groynes, or harbour-works, while winds may also exert a selective influence, especially on beaches which quickly become dry. The sorting effected by these agencies is naturally far from perfect, on account of turbulence, and fluctuating velocities. Nevertheless, the long-continued incidence of currents and wave-action on the shore has led to the elimination of both the finest and coarsest grades, with the result that most beach-sands contain a high proportion of medium-sized grains, and under special local conditions may be almost perfectly graded (Boswell, 1918).

On a small scale, the varying distribution of grades can be seen in the bed of the numerous runnels which traverse the flat surface of any sandy beach, while on a more extended scale it is found that samples of sand, taken from different parts of the beach, reveal, on elutriation or sifting, a marked difference of grade-composition.

Effect of Local Conditions.

On the sandy beach at Port Erin, where the onset of the flood tide, the prevailing run of the sea, and the protection of a pier and breakwater on the south side of the bay, all combine to bring about a surface-drift in a southerly direction, a series of surface-samples were taken, at low water mark. The samples were separated into their constituent grades by sieving. The sieves used were of woven brass wire, square mesh, and as the sand was perfectly "free-running," they were used dry. While the best modern practice requires the use of round-meshed sieves for coarse material (down to 0·5 mm.), and elutriation for the finer grades (Borley, 1923), neither of which methods were at the time available, the sieves used were carefully measured, and in view of the fact that the sand-grains were not very angular, and were free from flaky material, it is felt that the results are comparable with other and more standardised work.

Calibration of Square-meshed Sieves.

Meshes per linear inch.	Measured width of square holes. mm.	Standard I.M.M. square-mesh sie mm.
30	0·54	0·421
60	0·28	0·211
90	0·16	0·139
120	0·12	0·107
150	0·09	0·084

The sieves used differed considerably in mesh, as will be seen, from the standard I.M.M. sieves of corresponding number. Sample A was taken at the south end of the beach, and the successive stations were about 200 feet apart, E being close to the rocks at the north. The sequence showed the following grade-composition :—

Sample.	Percentage by Weight retained by Sieves. Mesh *60*	*90*	*120*	*150*	(Passing *150*)	Representative Number.
A	1·7	53·7	42·0	0·7	1·8	0·14
B	30·3	52·2	15·3	0·8	1·4	0·19
C	15·6	62·0	19·8	0·8	2·0	0·17
D	26·5	62·7	8·6	0·8	1·5	0·19
E	21·7	48·4	27·7	0·6	1·6	0·17

The individual values vary irregularly, but the "representative numbers" (Borley, *loc. cit.*)—obtained by multiplying the minimum diameter of each selected grade by the weight percentage of that grade in the sample, and dividing the sum of the products by 100—indicate a tendency for the finer grades to segregate at the southern extremity of the beach, a complementary residuum of coarser material remaining at the north. Not the least important aspect of such surface-drift is the indication it affords that the organic detritus of the beach, lighter than the finest grades, will tend to advance in the same direction.

Grade, Pore-space, and Surface.

The most important quantities associated with grade, so far as that quality affects the sandy beach, are—

(i) the volume of the " pores," or interstitial spaces, in relation to the volume occupied by the grains, and

(ii) the aggregate surface presented by the grains in unit volume of the sand.

These values are familiar to the agriculturist, in connection with the texture of the soil, and they are no less significant to the marine biologist, if in a slightly different direction. The importance of the interstitial space, whether occupied by water or air, lies in the fact that the animals and plants inhabiting the sandy beach are practically limited to that volume for their life-processes during the periods when the beach is uncovered by the tide. It is also a measure of the resistance of the beach to overheating and desiccation during prolonged periods of sunshine, since the specific heat of the damp sand varies from one-tenth to one-third that of pure water, according to the relative volumes occupied by sand, air, and water (p. 541). The width of the capillary interspaces is also one of the factors which determine the availability of the subsurface water, and, where such is fresh, the salinity of the surface-layers of the beach.

The aggregate surface-area presented by the grains determines the capacity of a sand for retaining moisture in the form of a liquid film around its particles, and it is in this film, confluent from grain to grain, and more or less filling the interstitial space, that dinoflagellates and other minute but teeming organisms of the sandy beach find their habitat. The extent of the surface is also to be associated with solubility and several chemical reactions which take place at the interfaces in this complex system of sand, air, and water (*vide* Part II of this paper, *Journ. Mar. Biol. Assoc.*, Vol. XV, No. 2, p. 553). Finally, it has been shown by Stowell (1927) that positive adsorption of the ions of sea-water takes place on the surface of the sand-grains, giving rise to a film of higher salinity. At the same time, calcium ions are liberated from the sand, in exchange for those of magnesium and sodium.

Pore-space and its Influence.

It has been calculated that in a system of equal spheres, in the closest possible contact—a condition attained when each sphere touches twelve others—the aggregate volume of the spheres is 74·04% of the total space occupied, the pores therefore accounting for 25·96%. It will be evident, upon consideration, that these values are quite independent of the absolute size of the spheres. In nature, however, these ideal conditions are never realised, since the sand grains depart from the spherical shape, and in most cases large and small grains are present side by side, the smaller filling the interstices between the larger. Under these conditions, it becomes necessary to make empirical determinations of the relative volumes of sand and pore-space.

Determination of Pore-space.

Sand from Port Erin beach was separated by sieving (p. 544) into a number of grades. Samples of the different grades were dried at 100°, and after cooling, 50 g. of each grade were placed in a wide, dry, measuring cylinder. Sea-water, at 10°, was then added, from a second cylinder, which originally contained 100 c.c. After thoroughly incorporating the sand and water, "excess" of the latter being present, the cylinder was allowed to stand until, after slight tapping, the sand was level and well-packed. The supernatant water was poured back into the original cylinder, allowing one minute for draining of the final drops. The volume of the wet sand was read off, and, by difference from the other cylinder, the volume of sea-water it had absorbed. The results are expressed in volumes of water per 100 volumes of wet sand, this being the most significant relation from the biological standpoint.

WATER CONTENT, AT SATURATION, OF DIFFERENT GRADES OF SAND.

Grade. Meshes per inch.	Mm.	Vols. of water present in 100 vols. of wet sand.
Greater than 30	> 0·54	35·8
30– 60	0·53–0·28	39·0
60– 90	0·27–0·16	42·0
90–120	0·15–0·12	42·2
120–150	0·11–0·09	44·7
Passing 150	< 0·09	43·4
Ungraded, natural sample		20·0

It is at once observed that the volume of the pore-space, in all the graded samples, is strikingly higher than the theoretically deduced value of 26%. This is in part to be accounted for by the fact that the sand-grains, very light in weight, and somewhat irregular in outline, do not readily fall into the position of closest contact, but rather into stable arcades, a condition enhanced by the imperfection of grading. It is noticeable that the departure from the ideal value becomes greater in the case of the smaller and lighter grains, while the ungraded, natural sample, containing a fair proportion of fine material, shows a very low pore-space, for reasons already indicated.

Grade and Rate of Evaporation.

The rate of evaporation from the surface of the sandy beach is obviously a factor of some importance, since it affects not only the temperature of the surface, but its availability as a habitat for those organisms which live in the water-film around the sand-grains, at or near that level. To determine the effect of grade upon the rate of evaporation from a surface of wet sand, a number of dishes were exposed, containing graded samples of sand, saturated with sea-water, but in a fully drained condition. The dishes (11·5 cm. petri dishes) contained their quota of wet sand (approx. 120 g.) in a layer 5 mm. thick, and each exposed to evaporation a surface-area of 100 sq. cm., this factor being regarded as of greater importance than the absolute weight of sand taken. The dishes were placed in the open air, under identical conditions, and the loss in weight ascertained periodically. The results obtained, expressed as the absolute loss of water, in grammes, per 100 sq. cm. of surface, at successive stages of drying, are given below :—

EFFECT OF GRADE UPON RATE OF EVAPORATION FROM THE SURFACE OF WET SAND.

Grade (meshes per inch).	Loss of Water, in grammes per 100 sq. cm., at 11°·5–14°·5 C. (Progressive Totals.)					
	1 hr.	*4 hrs.*	*15½ hrs.*	*21 hrs.*	*29½ hrs.*	"*Air-dried.*"
30– 60	5·2	12·4	15·6	20·7	25·1	(25·3)
60– 90	5·6	14·3	17·5	23·0	25·9	(26·1)
90–120	5·3	13·8	15·7	20·5	22·2	(22·4)
Ungraded	5·5	12·0	17·5	20·0	–	–

It is evident from these figures that grade has but little influence in determining the rate of evaporation under the conditions described. It is somewhat remarkable that the initial rate of loss from a saturated sandy surface is not appreciably different from that of an equal area of sea-water. It would appear that the internal surface, as it may be called, of the damp sand, contributes but little to the total evaporation loss, the actual escape of water molecules being limited by the rate of diffusion through the narrow interstices. Another factor tending to reduce the rate of evaporation, especially in the case of the finer grades, is the diminished vapour pressure exerted by the concave liquid menisci at the ends of the capillary channels.

Rate of Capillary Rise.

On the beach, as upon the land, evaporation from the surface is usually compensated for, in whole or in part, by accessions of water from neighbouring sources. These may be either pools upon the surface or, more usually, the subsurface layers in which the pores are fully occupied by water, and which correspond to the " water-table " of cultivated lands. These subsurface reserves may consist of sea-water, infiltrated from the margin of the tide, or, as at Port Erin and elsewhere, of fresh water derived from streamlets which, sinking through the sand where they reach the shore at high-water mark, are arrested by an impervious layer at some little depth below the surface. In either case, the availability of these supplies for surface requirements depends upon (*a*) their depth and amount and (*b*) the rate of capillary rise through the overlying sandy layers. As to the slight depth of the water-table, and the abundance of its reserves, no one who has dug between tide marks on the sandy beach can be in doubt, and it would seem that the rate at which the water is able to rise through the capillary channels is the more significant factor.

Determination of Capillary Rise.

The rate of rise, through sands of different grade, was determined in the following way. A series of glass tubes, 13 mm. in internal diameter, were fixed in a frame, their lower ends resting in a shallow dish, their upper ends open, and a centimetre scale affixed at the back. The tubes were filled, each with a particular grade of sand, and water was poured to form a shallow layer in the dish. The water was absorbed by the sand, and the height of the saturated column was read from time to time. Fresh water, sea-water, and sea-water drained from the black layer in the beach, were used. The temperature throughout was between 17° and 19° C. ; results obtained at other temperatures would be different, owing to the changing viscosity, but the effect should be calculable. The values given are the means of several determinations in each case, with a view to minimising errors due to differences of packing.

Time-Interval.		Height of Capillary Rise (cm.). 60–90 mesh.	90–120 mesh.	120–150 mesh.	Ungraded.
10 mins.	A.	5·0	9·2	9·5	18·5
	B.	7·5	8·9	10·0	18·2
	C.	7·7	10·0	10·5	17·0
30 mins.	A.	7·0	10·2	11·6	23·0
	B.	8·1	10·4	11·7	22·3
	C.	8·6	11·4	12·5	20·5
1 hr.	A.	7·8	11·1	13·0	25·5
	B.	8·6	11·3	13·0	23·5
	C.	9·2	12·2	13·8	22·8
2 hrs.	A.	8·9	12·4	14·5	28·0
	B.	9·2	12·2	14·3	26·8
	C.	10·0	12·9	14·8	26·0
3 hrs.	A.	9·6	13·3	15·5	–
	B.	9·7	12·6	15·0	–
	C.	10·5	13·2	15·4	–
5 hrs.	A.	10·6	14·3	16·9	–
	B.	10·3	13·3	15·7	–
	C.	11·1	13·7	16·3	–
8 hrs.	A.	11·5	15·4	17·9	–
	B.	10·8	15·4	17·9	–
	C.	11·5	14·1	17·2	–
20 hrs.	A.	13·2	18·2	20·4	–
	B.	12·0	15·1	17·9	–
	C.	12·8	15·2	18·9	–

(A. Fresh water; B. Sea-water; C. Sea-water from the black layer in the beach.)

From Fig. 3, in which the results are represented graphically, it will be observed that the height to which the liquid column rises in a given time is a function of grade or, more strictly, of the width of the capillary channels between the grains, since this, irrespective of the total volume of the pore-space, becomes less as the grains decrease in size. The mean height attained after 12 hours, in the case of 60 mesh material, is 11·8 cm.; with 90 mesh, 15·1 cm.; with 120 mesh, 17·9; and in an ungraded sample, 35·0 cm., this being an extrapolated value. It is not apparent that the differences of surface-tension between fresh water and sea-water, or between the two samples of the latter, from different sources, result in any constant or significant difference of capillary rise, under the conditions of the experiment.

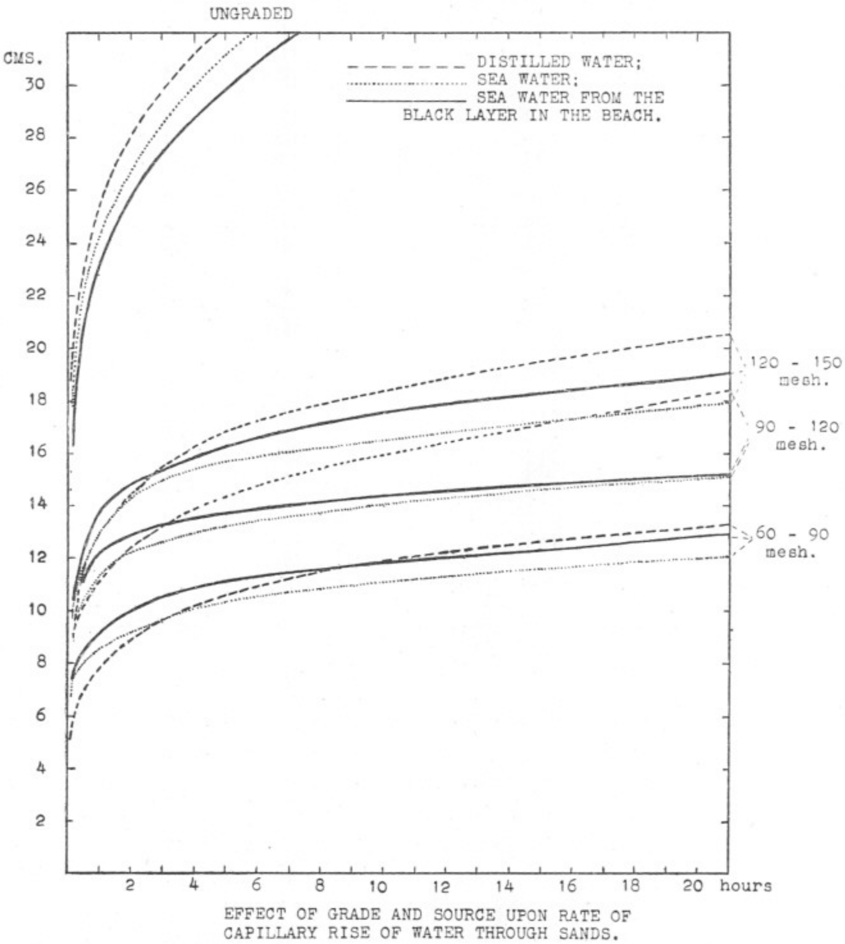
UNGRADED
CMS.
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
DISTILLED WATER;
SEA WATER;
SEA WATER FROM THE BLACK LAYER IN THE BEACH.
120 - 150 mesh.
90 - 120 mesh.
60 - 90 mesh.
2
4
6
8
10
12
14
16
18
20
hours
EFFECT OF GRADE AND SOURCE UPON RATE OF CAPILLARY RISE OF WATER THROUGH SANDS.

Fig. 3.

SUMMARY.

1. The distribution and activities of animals and plants upon the sandy beach are largely influenced by the special physical factors operating in that environment. The paper is a contribution to the knowledge of these factors.

2. The tidal ebb and flow, and the resulting alternations of exposure, are the outstanding factors. The extent to which other factors may be operative upon the beach, during the period of ebb-tide, depends upon the vertical distance of the point in question above or below mean sea-level.

3. Tidal and other currents, and wave-action, lead, on the larger scale, to coastal erosion and accretion, but their biological significance lies rather in their local translocation of beach material, with partial separation into its constituent grades.

4. The surface temperature of the beach varies with insolation, grade, and moisture-content, and, under the influence of the recurring tide, alternates twice daily between that of the air and the sea. The temperature of air and sea, in turn, passes through an annual cycle. There is a marked temperature gradient throughout the upper 20 cm. of the beach.

5. The salinity of the interstitial waters of the beach depends upon the volume of fresh water flowing from the land, the effectiveness of the washing being determined by its duration, the grade of the sand, and the local conditions of contour and drainage.

6. The differences between beach sands are largely those of grade, since, chemically and lithologically, sands from various points on the coast are not greatly dissimilar. Grade determines the water-retentive and absorptive capacity of a sand, as well as its capillary lifting power and its porosity to water and gases.

REFERENCES.

Atkins, W. R. G. (1922). The Hydrogen Ion Concentration of Sea Water in its Biological Relations. Journ. Mar. Biol. Assoc., N.S. **12**, 717–771.

Atkins, W. R. G. (1926). A Quantitative Consideration of some Factors concerned in Plant Growth in Water. Part I, Some Physical Factors. Journ. du Conseil Intern. Explor. Mer, **1**, 99–126.

Atkins, W. R. G. (1926). Ditto. Part II, Some Chemical Factors. Journ. du Conseil Intern. Explor. Mer, **1**, 197–226.

Borley, J. O. (1923). The Marine Deposits of the Southern North Sea. Fish. Investigs., Ser. ii, **4**, No. 6.

Boswell, P. G. H. (1918). British Resources of Refractory Sands, Part I. London (Taylor and Francis).

Bruce, J. R. (1924). Seasonal and Tidal pH Variations in the Water of Port Erin Bay. Ann. Rept. Oceanography Dept. Univ. Liverpool (for 1923), 35–39.

Bruce, J. R. (1925). The Metabolism of the Shore-living Dinoflagellates, I. Brit. Journ. Exp. Biol., **2**, 413–426.

Carey, A. E., and Oliver, F. W. (1918). Tidal Lands. London (Blackie).

Cornish, V. (1910). Waves of the Sea, and other Water Waves. (London).

Flattely, F. W., and Walton, C. L. (1922). The Biology of the Sea-shore. London (Sidgwick and Jackson).

Knight, M. (1923). Studies in the Ectocarpaceae, I. Trans. Roy. Soc., Edin., **53**, ii, 343–360.

Marshall, S. M., and Orr, A. P. (1927). The Relation of the Plankton to some Chemical and Physical Factors in the Clyde Sea Area. Journ. Mar. Biol. Assoc., N.S., **14**, 837–868.

Moberg, E. G., and Allen, W. E. (1927). Effect of Tidal Changes on Physical, Chemical, and Biological Conditions in the Sea-water of the San Diego Region. Bull. Scripps Inst. Oceanog. (Tech. Ser.), **1**, 1–17.

Royal Commission on Coast Erosion, etc. (1907–09–11). Repts. I, II, III.

Stowell, F. P. (1927). The Adsorption of Ions from Sea-water by Sand. Journ. Mar. Biol. Assoc., N.S., **14**, 955–966.