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The Ecology of Lagos Lagoon. II. The Topography and Physical Features of Lagos Harbour and Lagos Lagoon

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THE ECOLOGY OF LAGOS LAGOON
II. THE TOPOGRAPHY AND PHYSICAL FEATURES OF LAGOS HARBOUR AND LAGOS LAGOON

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(Plate 14)

The waterways associated with Lagos Harbour and Lagos Lagoon and the water movements in them are described.

The salinity changes in the harbour and lagoon for the years 1953–55 have been measured and correlated with the rainfall of the area draining into the lagoon.

The temperatures of the waters in the harbour and lagoon are compared with those of the sea. Sand temperatures in the intertidal zone have been measured at the surface of the beach and at depths down to $7\frac{1}{2}$ in.

A survey of the lagoon, harbour and marine deposits in the Lagos area has been made.

Introduction

The harbour and lagoons at Lagos on the West African coast possess an unusual combination of physical characteristics of particular interest to the ecologist. Lagos Harbour is situated at the centre of a system of marginal lagoons extending 160 miles from Cotonou in Dahomey to the Niger Delta and is the only major outlet for water draining from 40 000 square miles of mostly tropical forest with a strictly seasonal rainfall (see part I). During the rains, therefore, an immense volume of fresh water passes through the harbour and out to sea. On the other hand, in the dry season, the flow of fresh water ceases, the rivers become a series of isolated pools and sea water enters the harbour giving rise to marine conditions near the harbour mouth and to brackish water extending about 20 miles up the lagoons and creeks. Life in these waters is thus subject to a seasonal fluctuation from fresh water to brackish or marine conditions and only species showing a high degree of salinity tolerance are able to survive the full cycle of change from one year to the next. Nevertheless, marine, brackish and freshwater conditions obtain in various parts of the harbour and lagoons at different times of the year for sufficiently long periods to allow temporary colonization by organisms either from the sea or from the permanent fresh water of the rivers and more distant lagoons. The extent to which marine or freshwater species penetrate the brackish zone and the period for which they survive differs largely according to their salinity tolerance.

Apart from salinity, however, many of the physical features of the area are comparatively stable. The water temperatures are high, but relatively constant throughout the year. Light intensity, allowing for differences in cloud cover, is always of the same order and the length of day is also constant, being approximately 12 hours at all times. Lagos is exceptional, even for the Guinea Coast, in having a very low tidal range, never greater than

4 ft. and usually much less. The intertidal region in the creeks and lagoons, therefore, is very narrow and the wide expanses of shallow water in the lagoons never drain to expose sand or mud flats. As a result of the constant temperature, however, there is little vertical circulation in the lagoons. Accumulations of organic remains form in the muddy bottoms, while in the surface waters there is a corresponding depletion of nitrates and phosphates. The lack of vertical circulation is offset to some extent by the influx to the lagoons of turbid river waters rich in mineral salts during the early rains.

Within the harbour and lagoons many different habitats are available for colonization by aquatic animals and plants. The intertidal zone, although narrow, ranges from mangrove swamp to muddy and sandy foreshores with either slight or pronounced wave action according to the degree of protection from the wind and the extent of the open water. A rocky substratum does not occur naturally, but artificial moles and various dock installations provide surfaces for the settlement of sessile animals and algae. As a result of the mode of formation of the lagoon deposits (see part I), a wide variety of sediments occurs throughout the region. These range from coarse sands to muds and clays and provide a large selection of habitats for bottom-living animals.

The lagoons and harbour at Lagos are particularly suitable for the study of salinity tolerance in many species, both of marine and of freshwater animals, without complications arising from gross variation in other factors. Moreover, in these calm shallow waters, observations that would be difficult if not impossible in the sea can be made on the biology of the marine animals entering the harbour. The purpose of this paper is to outline the topography of the Lagos area, to provide data on the salinity and temperature changes of the harbour and lagoon waters and to survey the range and distribution of sediments in preparation for further contributions on the ecology of the region.

The topography of Lagos Harbour and Lagos Lagoon

Lagos Harbour is the only natural break of any size in a continuous barrier beach extending from the Volta River to the Niger and has for centuries been a port of call for shipping. In earlier times the harbour mouth was closed to all but boats of shallow draft by a sand bar formed by the west–east movement of sand along the coast (see Pugh 1954; and part I), but between 1901 and 1930 three artificial moles of stone were built seaward to limit bar formation and a fairway was dredged to permit the entry of larger vessels (see figure 1 and figure 7, plate 14). Although the construction of the moles has preserved the harbour mouth, it has also interrupted the west–east sand movement. In consequence, whereas sand is deposited to the west of the harbour, the supply to the coast immediately east of the harbour has ceased and a rapid erosion of the shore has followed. Thus the sea beach (Lighthouse Beach) to the west of the harbour has become a deposition beach and has been built out far beyond the original line of the coast, while that to the east (Victoria Beach), is a typical erosion beach (see figure 1 and figures 7 and 8, plate 14).

The town of Lagos is built upon an island and lies between Harbour and Lagos Lagoon. Lagos Lagoon is a great expanse of shallow water covering many square miles and in most places is little more than 3 ft. deep (see figure 1). To the east Lagos is separated from Ikoyi Island by an artificial canal while, to the north, it is connected by Carter Bridge to Iddo Island and thence by causeway to the mainland at Ebute Metta. The

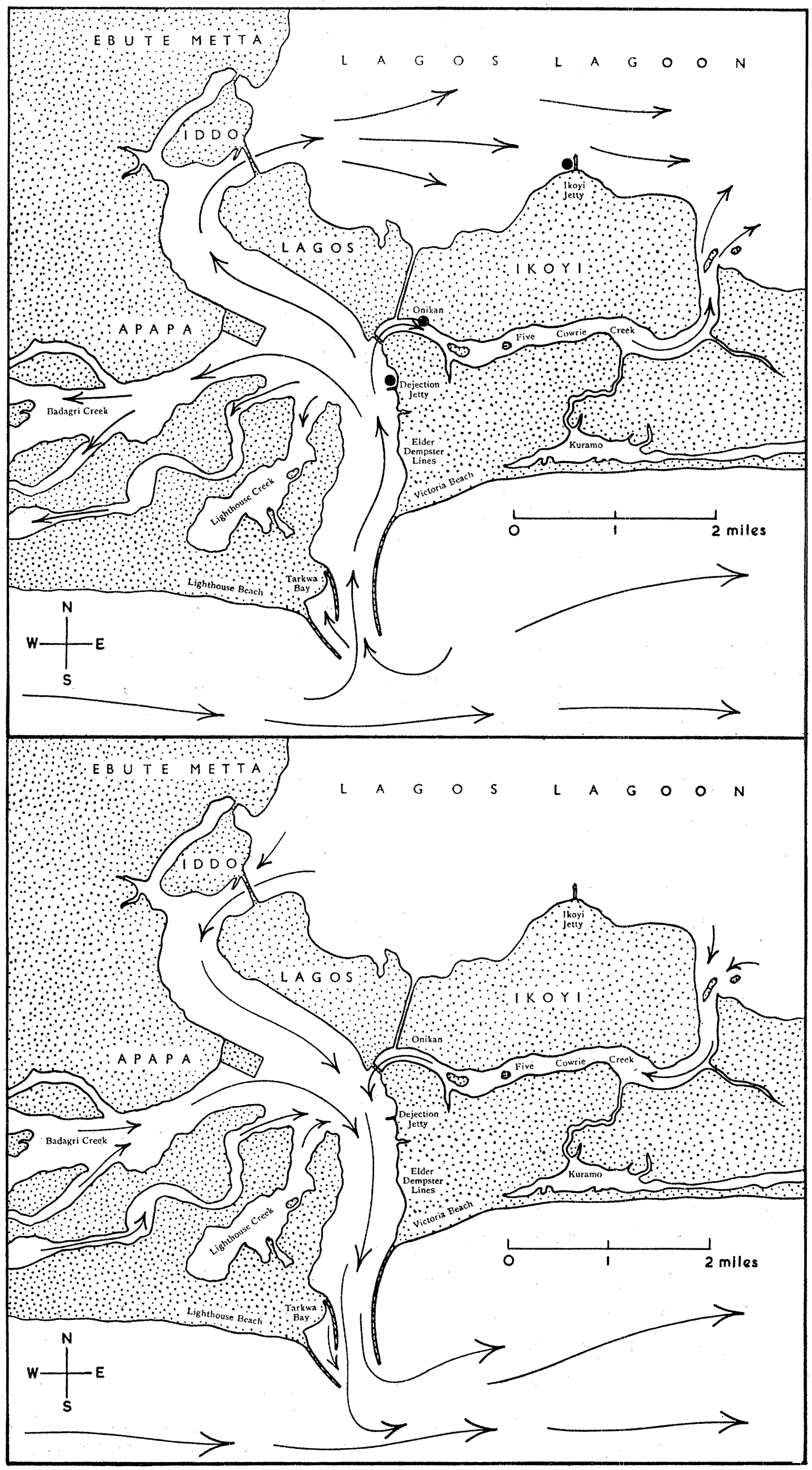

Figure 1. The direction of flow of water in the Lagos area: *a*, on the rising tide; *b*, on the ebb tide.

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southern margin of Lagos and Ikoyi is bounded by Five Cowrie Creek, a waterway connecting the harbour to Lagos Lagoon. Five Cowrie Creek can be crossed at its western extremity by a bridge leading to the barrier beach which is very wide at this point.

Within the harbour mouth, the centre mole of the three, or Training Mole, encloses Tarkwa Bay to the west. The harbour itself is about 5 miles long with a fairway of 5 to 6 fathoms leading to the wharf area of Apapa. Three creeks enter the harbour from the south-west. The most southerly is Lighthouse Creek which is a backwater. Badagari Creek to the north is the main waterway leading to Badagri, Porto Novo and Cotonou (see part I). The creek at the centre joins Badagri Creek a few miles from the harbour (see figure 1). Immediately behind the barrier beach to the east of the harbour lies a long and narrow lagoon known as Kuramo Water. This lagoon is connected to Five Cowrie Creek by a narrow and tortuous channel running through mangroves.

On the falling tide, water flows from the lagoon system into the harbour through Badagri Creek, Five Cowrie Creek and beneath Carter Bridge. With the rising tide the direction of the currents is reversed (see figure 1 *b* and *a*). The influx of salt water from the sea gives rise to brackish conditions in the lagoons and encourages the growth of mangroves which line the edges of many of the waterways and cover those areas of low lying swampy ground which are inundated at the high spring tides. Elsewhere, on the higher ground, the vegetation is typical of a rather arid sandy soil. Much of the region, notably Lagos, Iddo and Ebute Metta and parts of Ikoyi Island and Apapa, is densely populated with habitations extending to the water's edge.

The salinity of the harbour and lagoon waters

As the water in Lagos Harbour and lagoons is derived partly from the sea entering the harbour on the rising tide and partly from rivers entering the lagoons, the salinity shows both a diurnal fluctuation due to tidal effects and much greater seasonal changes caused by the influx of fresh water during the rainy periods. The rains in Western Nigeria begin in March and, except for a short dry period of variable duration in the summer, continue until November. Thereafter, apart from a few isolated storms, no rain falls until the spring. An indication of the extent and periodicity of the rains is given by the precipitation figures for the year 1954 determined by the Geography Department, University College, Ibadan (figure 2). Ibadan is situated near the centre of the watershed draining into the lagoon, so that the precipitation at this meteorological station can be considered as approximately representative of the region as a whole.

Salinity estimations in the neighbourhood of Lagos have been made at both high and low water at each spring tide during the period from November 1953 to June 1955 at the three stations marked by black spots on figure 1 *a*. The first of these, at Dejection Jetty on the east shore of the harbour, gave a measure of the salinity changes in the main stream of water oscillating back and forth along the length of the fairway. The second, at Onikan in Five Cowrie Creek, showed the effect of the mixing of harbour and lagoon waters, while the third, at Ikoyi Jetty on the north shore of Ikoyi Island, represented the water of the lagoon itself. These stations were not, perhaps, located at the most suitable positions to give the information required as Dejection Jetty and Onikan are rather too close together, but their selection was largely determined by ease of access by motor road, as it was essential that the samples from one tide should not differ too widely in the time at which they were collected. The samples were taken from the surface of the water and their salinity, estimated by the usual method of titration against silver nitrate (Harvey 1945), was expressed in parts per thousand of chloride ions. Samples taken at different depths and at the bottom

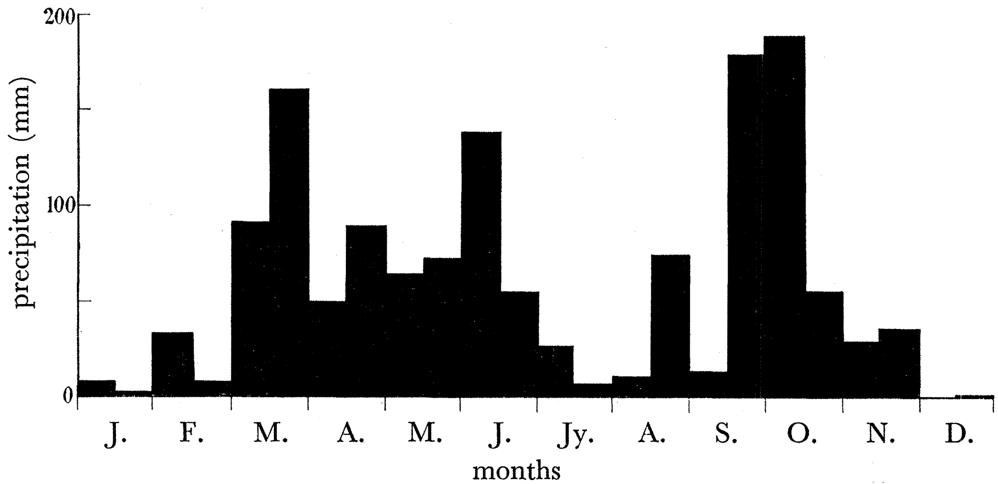

FIGURE 2. The rainfall at Ibadan in the year 1954.

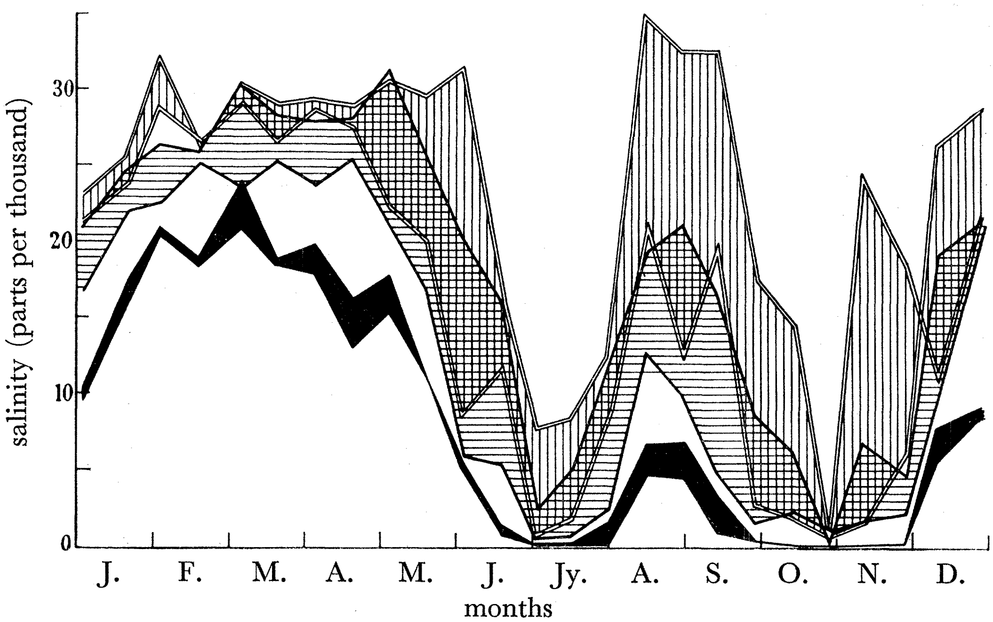

FIGURE 3. Graph showing the seasonal and diurnal fluctuations in salinity at Dejection Jetty, Onikan and Ikoyi Jetty for the year 1954. ▥, High and low tide, Dejection Jetty; ▤, high and low tide, Onikan; ■, high and low tide, Ikoyi Jetty.

showed that, in the lagoon and in Five Cowrie Creek and also at the edge of the harbour where the water was comparatively shallow, there was no salinity gradient with increasing depth, the salinity of the water at the bottom being the same as that at the surface. The salinity changes for the year 1954 are shown in figure 3 in a graph illustrating both the seasonal and the diurnal fluctuation at each of the three stations.

It is seen from figure 3 that the salinities at all three stations were high during the months of January to May. In June and July the salinity fell, but rose again in August

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and September only to fall once more in October and November. When these fluctuations are compared with the rainfall at Ibadan for the same year in figure 2, it is clear that the long period of high salinity at the beginning of the year was a result of the dry season extending from the end of November to the beginning of March. Moreover, the periods of low salinity followed the heavy rainfall of March to June and again of September to November, while the period of drought in July and August also corresponded to the rise in salinity in August and September. There was, therefore, a close correlation between the salinity in the lagoon and harbour at Lagos and the rainfall of the region draining into the lagoons. However, whereas all periods of heavy rainfall at Ibadan were followed in due course by a fall in salinity at Lagos, the time lag between the incidence of the rains and the corresponding rise or fall in salinity was not the same in each case. The onset of rains in March was not followed by a significant fall in salinity until 8 to 10 weeks later, but in August the resumption of rains after the short dry spell caused a fall in salinity in only 2 to 4 weeks, while a cessation of rains was reflected in a salinity rise after 2 weeks. It is clear, therefore, that when the ground was saturated the rain water from the drainage area took an average of 2 to 4 weeks to reach the lagoons. After the dry season, however, much of the early rains was evidently absorbed by the ground and never reached the lagoons, and it was not until sufficient rain had fallen to give an appreciable run-off that the rivers began to flow and the salinity in the lagoons was affected. This phenomenon thus caused a lengthening of the period for which marine conditions prevailed in the harbour, the salinity being continuously high for 5 months from mid-December to mid-May as compared with a dry season of only 3 months.

In comparing the salinities at each of the three sampling stations, it is seen from figure 3 that, except following very heavy rains when the water at each station was practically fresh (as in October 1954), the salinity in the harbour (Dejection Jetty) was always slightly higher than in Five Cowrie Creek (Onikan), and at Onikan it was again always distinctly higher than in the Lagos Lagoon (Ikoyi Jetty). During November, December and January the salinity rose until, in the harbour in February, it reached that of the open sea and remained at this figure with very little fluctuation until the middle of April. In Five Cowrie Creek during this period the salinity at high tide was equivalent to that of the harbour, but, by low tide, the salinity had fallen several parts per thousand. There was, therefore, appreciable diurnal fluctuation in this creek. In the Lagos Lagoon north of Ikoyi Island from mid-January to mid-April, the salinity was about 20 parts per thousand and diurnal fluctuation was comparatively slight. From the end of April until early July the salinity fell rapidly at low tide at all stations but more slowly at high tide in the harbour and in Five Cowrie Creek. Thus, while the diurnal fluctuation in the lagoon was negligible, that in the harbour and at Onikan was at times very great and tended to remain so throughout the period of the rains except when the flow of fresh water was so great that influx of salt or brackish water from the sea at high tide was prevented. As would be expected, both the absolute salinity and the fluctuation in salinity became less and less with increasing distance from the harbour mouth until lagoon water fresh at all times was reached about 20 miles from the sea.

Although the salinity of the shallow waters was uniform at all depths, in the centre of the harbour, where there is a channel about 30 ft. deep, a vertical salinity gradient was found to exist at certain times of the year (see figure 4). During the dry season, although the salinity at low tide was slightly less than at high tide, there was little or no vertical salinity gradient. From May onward, in the rains, however, at high tide the surface waters were brackish in the harbour and the deeper layers salt, while at low tide the surface waters were practically fresh and the deeper layers brackish. The extent of the vertical gradient, therefore, varied not only with the state of the tide but also with the rainfall of the region draining into the lagoon. Toward the end of the rains in October the salinity began to rise and the vertical gradient in the harbour was reduced until, in November and December, although there was a considerable difference between the salinity at high tide and at low tide, the gradient at any one time was slight. It seems, therefore, that the deep water of the harbour, at least in the region toward the sea, is never entirely fresh.

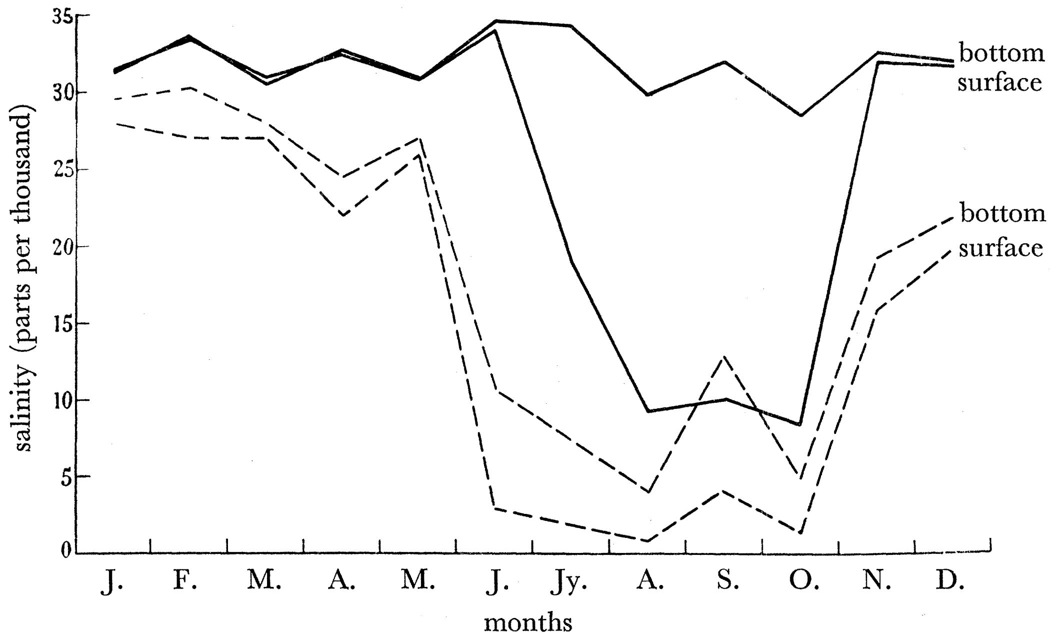

FIGURE 4. Vertical salinity gradients at high (—) and low (– – –) tide in Lagos Harbour in the year 1954.

Estimations of salinity have also been made in Kuramo Water (see figure 1). It has already been mentioned that this lagoon is connected with Five Cowrie Creek by a long and narrow channel through which water flow is strictly limited. The tidal movements in this lagoon, therefore, are greatly reduced and the salinity changes very gradual. Monthly readings showed that the salinity ranged from a minimum of 15 parts per thousand in October to a maximum of 24 parts per thousand in April. It is evident, however, that the salinity changes in Kuramo Water are due in part to causes other than tidal water. The barrier beach separating Kuramo Water from the sea is in places very narrow and in rough weather at high tide waves occasionally break over the beach and salt water flows into the lagoon thus raising the salinity. It is also possible that some salt water may find its way into the lagoon from the sea by seepage through the beach sands. Evaporation from the surface of the lagoon in the dry season must also contribute to a rise in salinity. On the other hand, the drainage of rain water from local storms will reduce salinity in the lagoon during the wet season.

The temperatures of the water in the harbour and lagoon and of the sand in the intertidal region

The temperature of the water in the harbour at Lagos, although comparatively constant, is less uniform than that of the sea. Measurements made in the harbour at different depths and at different times of the year have shown that the temperature of the surface water rises from a minimum of a little under 25 °C in August to a maximum of 29 °C in March and April, while the temperatures of the deep waters were found to be not more than 0·5 deg. less than that at the surface. In the open sea the temperatures show a comparable range throughout the year from 25 to 27 °C, but are practically uniform down to depths of 30 m. It is clear, however, that, since the harbour water is a mixture of sea water and lagoon water, its temperature will be governed not only by that of the sea, but also by temperatures in the lagoon.

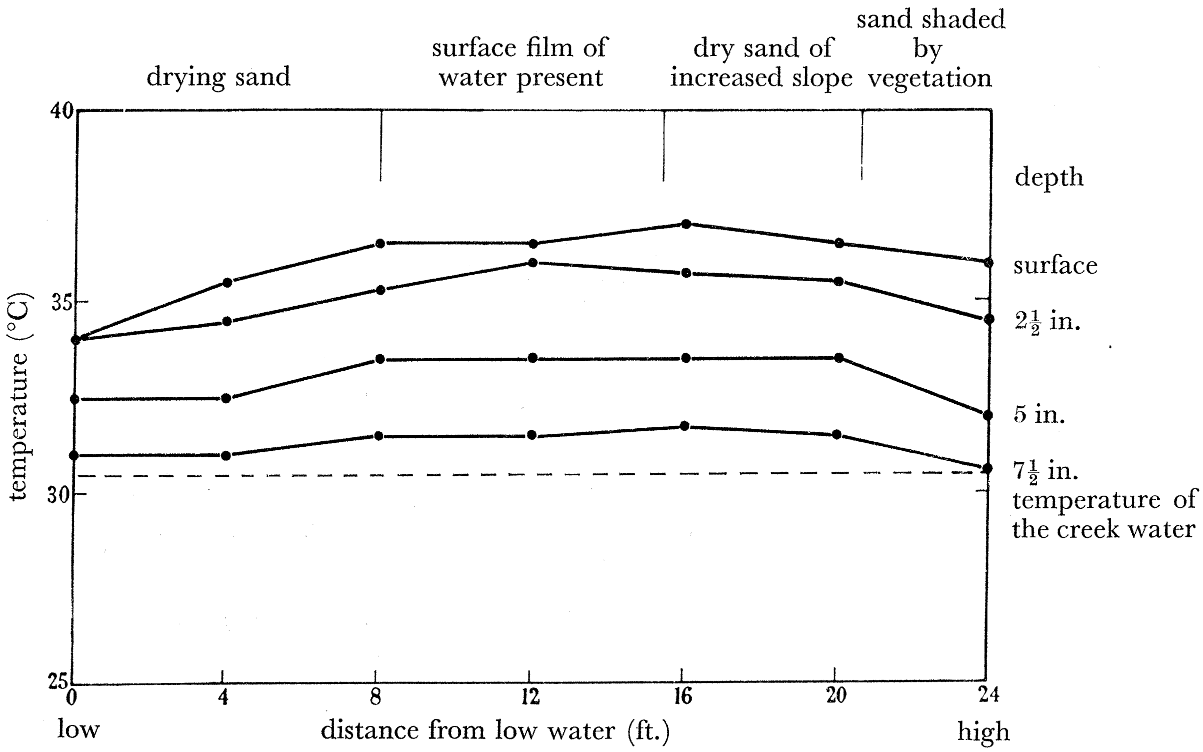

Figure 5. Sand temperatures in March in the intertidal region at low spring tide at Onikan.

In the lagoon during the dry season the shallow water is largely static as the rivers have ceased to flow. At this time the temperature of the water rises through insolation and reaches a maximum of a little above 31 °C in March. The flow of this warm water into the harbour raises the temperature of the harbour water above that of the sea and gives rise to the peak harbour temperatures of March and April. With the replacement of warm lagoon water by cooler river water during the rainy season, the temperature of the harbour water gradually falls until, in August, it is a little lower than that of the sea. The gradual decrease in the rate of flow of the rivers from October to December, at the end of the rains, causes a rise in the temperature of the harbour water to that of the sea and above as the lagoon, no longer fed by the rivers, is warmed by the sun.

Although the water temperatures at Lagos are high, the temperature of the sand in the intertidal zone exposed to the sun may be considerably higher. To assess the extent of the temperature rise on these shores due to insolation, readings were taken along a line traversing the intertidal zone at Onikan at the surface of the sand and at depths of $2\frac{1}{2}$, 5 and $7\frac{1}{2}$ in. at intervals of 1 ft. from low- to high-water level of the spring tides. The readings were taken on an average day in March with a slight wind and light cloud and therefore would not be quite as high as on a cloudless day. Low spring tide at this time was at 1.0 p.m. so that the entire period of ebb was during the hours of daylight. Thus a maximum area of shore had been exposed to the heat of the sun for a maximum period. A selection of these readings at intervals of 4 ft. is given in figure 5.

As would be expected, the highest temperatures and the greatest temperature range were obtained at the surface of the sand. Here temperatures rose from 34 °C at the low-water mark to a peak of 37 °C 16 ft. up the beach and fell to 36 °C at the high-water mark. The temperatures did not rise and fall uniformly, as the surface of the beach itself was not uniform. The line along which readings were taken passed through an area of water-logged sand, up a more or less sharp rise to a sloping beach partly shaded by vegetation at the high-water level. Figure 5 shows that the temperature at the centre of the zone was lower than would be expected since the sand was wet with a film of surface water, and again at the high-tide mark where the beach shelved more steeply and vegetation was present. Temperatures taken below the surface followed the same general trend as those at the surface, except that they were unaffected by the surface film of water and became less extreme in range with increasing depth. However, even at a depth of $7\frac{1}{2}$ in., the temperatures were the same as or slightly above that of the water in the creek.

It is of interest to compare these figures with those obtained by Bruce (1928) for a sandy beach at Port Erin in the Isle of Man. He found that the maximum surface temperature of the beach in the intertidal zone was 21 °C in full sun in June, while at a depth of $7\frac{1}{2}$ to 8 in. the temperature was 15·3 °C. Thus the fall in temperature with increasing depth at Port Erin was comparable to that found at Onikan, although the maximum temperature of this tropical beach was 16 deg. higher.

A survey of the deposits in the Lagos area

The nature of sediments depends chiefly on the movements of the water from which they have been deposited and the range of water-borne particles available for deposition. In a current of water of constant rate of flow, well-sorted deposits occur along the path of the current according to the time taken for the particles of different mass to settle. Where the direction of the current is periodically reversed, however, as in tidal basins, the rate of flow is not constant and, at the point of reversal, is nil. Under these circumstances mixed deposits occur containing particles of a wide range in size, the proportions of each grade of particle present depending on the maximum rate of flow of the current. The currents in the creeks and harbour at Lagos are reversed at each tide as shown in figure 1*a* and *b*, but their velocity differs widely according to their location and the depth of the water. As the lagoon area as a whole is a complex of sand bars of marine origin interspersed with muddy hollows (see part I) and silt from the rivers periodically enters the lagoon in large quantities, it is clear there is no limitation on the composition of the deposits due to lack of sand or silt particles of any particular size. Thus a wide variety of mixed deposits containing different proportions of coarse sand, fine sand and silt may be expected to occur.

Samples of the deposits were collected at the locations shown in figure 6 in Lagos Lagoon, in the creeks and both inside and outside the harbour and were analyzed by the following method. Each sample was first placed in a bowl and repeatedly washed to remove the silt which was then recovered by filtration. The silt-free sand was sieved under water through a series of sieves of mesh sizes 30-, 60- and 90-mesh to the inch, thus giving the following four grades of sand: (*a*) grains retained by the 30-mesh sieve (2·0 to 0·6 mm

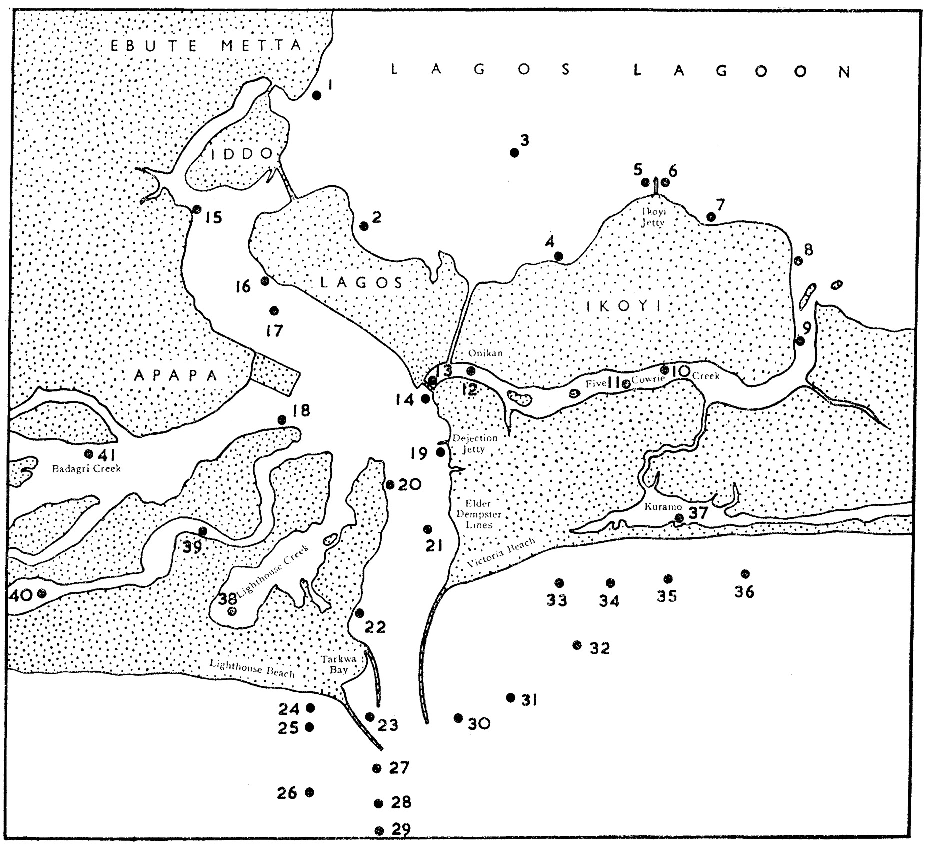

FIGURE 6. The distribution of the samples taken in the survey of the bottom deposits of the Lagos area. Samples 42, 43 and 44 were taken 12 miles E.S.E. of Lagos Harbour.

in diameter), (*b*) grains passing the 30-mesh but retained by the 60-mesh sieve (0·6 to 0·3 mm in diameter), (*c*) grains passing the 60-mesh but retained by the 90-mesh sieve (0·3 to 0·2 mm in diameter), and (*d*) grains passing the 90-mesh sieve (<0·2 mm in diameter). Pieces of shell larger than 2·0 mm in diameter, when present in the first of these fractions, were removed and treated as a separate fraction. The silt and the various sand fractions were dried and weighed, the weight of each being expressed as a percentage of the total dry weight of the sample. The silt in certain of the samples was calcined and the difference in weight assumed to be that of the organic content of the fraction. The organic content was expressed as a percentage of the dry weight of the silt. The results of these analyses are given in table 1.

The deposits of Lagos Lagoon and Five Cowrie Creek

In the lagoon to the north of Ikoyi Island the currents are rather different from those in the creeks. On the rising tide, water enters the harbour from the sea and flows into Lagos Lagoon mostly beneath Carter Bridge, although there is a small influx through Five Cowrie Creek (see figure 1 *a*). There is, therefore, a flow of water from west to east across

Table 1. Table of analyses of the samples of deposits taken from the localities shown in figure 6

number of sample	analysis of samples							depth of water (ft.)
	% shell	% > 30-mesh grains	% 30- to 60-mesh grains	% 60- to 90-mesh grains	% < 90-mesh grains	% silt	organic matter as % of silt	
1	2·2	25·2	21·6	14·3	16·9	19·8	—	4
2	—	2·2	3·3	3·6	17·3	73·6	—	1·5
3	—	4·1	39·0	32·5	23·5	0·9	—	3
4	0·6	10·1	36·8	13·4	30·6	8·5	—	1
5 (1954)	—	3·0	32·0	54·4	9·5	1·1	23·0	2·5
5 (1955)	1·2	5·6	31·8	51·2	9·4	0·8	13·5	2·5
6	—	14·9	33·0	30·6	17·8	3·7	15·5	2·5
7	—	14·9	70·6	8·6	5·1	0·8	—	1·5
8	0·5	13·8	62·7	13·9	7·9	1·2	—	2
9	—	14·7	59·3	11·3	5·5	9·2	—	1
10	—	11·7	57·8	15·0	13·5	2·0	—	3
11	—	3·5	33·1	29·9	29·0	4·5	—	3
12 (1954)	—	28·75	46·0	12·75	11·0	1·5	20·0	2
12 (1955)	—	13·5	40·5	17·9	25·0	3·1	19·0	2
13	1·8	6·3	34·0	24·0	33·6	0·3	—	1
14	3·1	0·9	39·3	30·0	26·4	0·3	—	2
15	—	7·9	40·4	14·4	16·3	21·0	—	5
16	—	8·0	12·0	10·9	60·7	8·4	—	4
17	—	0·2	5·6	14·0	78·9	1·3	—	5
18	—	—	—	0·7	18·3	81·0	8·9	6
19	—	8·4	77·75	13·0	0·75	< 0·1	—	3
20	—	< 0·1	6·5	77·8	15·5	< 0·1	—	2
21	—	40·5	51·6	6·9	0·8	0·2	—	25
22	—	19·8	20·1	16·8	11·2	32·1	—	2
23	—	—	5·0	23·5	64·0	7·5	—	30
24	—	—	4·2	21·3	74·5	—	—	18
25	—	—	2·6	19·5	77·9	—	—	18
26	—	—	—	0·8	32·1	67·1	—	27
27	—	3·4	5·3	36·1	53·9	1·3	—	36
28	—	—	0·9	29·9	69·2	—	—	36
29	—	—	—	—	14·3	85·7	—	42
30	—	7·2	36·6	45·0	11·2	—	—	18
31	—	8·9	46·2	1·8	14·9	28·2	—	30
32	—	3·6	61·6	23·6	11·2	—	—	18
33	—	2·6	39·2	32·6	25·2	0·4	—	18
34	—	8·8	57·5	19·7	14·0	—	—	18
35	—	14·6	66·7	12·6	6·1	—	—	20
36	—	1·0	22·0	25·0	51·7	0·3	—	20
37	—	10·8	78·7	7·6	1·5	1·4	—	2
38	—	2·3	8·4	15·8	68·0	5·5	25·0	2
39	—	17·0	51·5	14·2	3·9	13·4	—	4
40	—	7·2	68·7	16·4	6·2	1·5	—	2
41	—	7·6	19·0	13·3	58·2	1·9	10·4	4
42	—	1·5	35·1	34·0	28·9	0·5	—	45
43	18·7	40·0	34·5	3·8	2·3	0·7	—	45
44	7·2	21·5	48·9	9·4	9·8	3·2	—	45

the shallow lagoon of sufficient magnitude to keep fine sand and silt particles in suspension. Thus an extensive area of rather coarse sand is formed. With the falling tide, however, the currents in the creeks are reversed, but the rate of flow of the current in the lagoon itself, by virtue of the size of the water mass, becomes so greatly reduced as to be negligible (see figure 1*b*). During the period of ebb, therefore, a comparatively small amount of fine sand and silt is deposited from this standing water. Regions not in the direct line of the water flow across the lagoon on the rising tide, or in the few places where the water is deep, become very muddy with deposited silt. Thus, at locations 3, 4 and 5 in figure 6, the bottom consists of relatively coarse sand with a low percentage of fine grains and very little silt (see table 1). At the most northerly point of Ikoyi Island, Ikoyi Jetty projects into the lagoon for a distance of 200 to 300 yards and protects the region to the east of the jetty from the west–east current. In consequence, at location 6, the deposits contain a higher proportion of fine sand and silt than those on the western side of the jetty. At locations 7 and 8 the protective effect of the jetty is lost and currents due to the tidal flow from the east end of Five Cowrie Creek keep the silt in suspension so that the deposits here are sandy and relatively silt-free. At locations 1 and 2 on the west side of the lagoon the water is protected by the land masses, there are no water currents and a very high percentage of silt is present in the deposits.

In Five Cowrie Creek on the west bank at location 9 there is slack water and the sand is muddy. This is also true of the south bank at the centre of the creek, location 11, while on the north bank, locations 10 and 12, a more rapid flow of water gives a sandy deposit with little silt. At Onikan conditions are changing (location 12) as this point has become a mooring for small boats since samples were first taken in 1954. The mooring of boats has had the effect of reducing the flow of water and in consequence there has been an increase in the deposition of silt and the finer grades of sand. This effect can be seen by comparing the analysis of the 1954 sample with that of a second taken in 1955 (see table 1). At locations 13 and 14 on the south bank at the point of junction of Five Cowrie Creek with the harbour, there is a high proportion of fine sand but very little silt. The water here is comparatively slack and shallow at low tide, the main flow of water into and out of the creek following the north bank, while on the rising tide this area tends to be protected from the main harbour currents by Dejection Jetty.

The harbour deposits

The most rapid currents of the area occur in Lagos Harbour (see figure 1*a* and *b*). The greatest flow of water is in the region from Five Cowrie Creek to the harbour mouth and is reversed with each tide. The water follows the east bank of the harbour and here there is considerable scour as shown by samples 19 and 21 which contained very little fine sand and virtually no silt. On the west side of the harbour the water is shallow and there is a deposit of fine, silt-free sand at location 20, while in the more protected areas, as for example location 22, a heavy deposit of silt occurs. In Tarkwa Bay there is calm water with a reduced tidal flow, so that deposits here (location 23) consist largely of fine sands with a moderately high proportion of silt.

In the innermost reaches of the harbour the current is reduced, the deposits at the edge contain high proportions of silt and fine sand (locations 15 and 16) and those in the centre (location 17) large amounts of fine sand with few coarse grains and very little silt. The deposits of the fairway are disturbed coarse sands as dredging operations take place throughout the length of the harbour.

The deposits of Badagri and Lighthouse Creeks and Kuramo Water

At the mouth of Badagri Creek the water is deeper than in most of the region except the harbour and the rate of flow of the current is correspondingly reduced. This is the main outlet of the lagoon system to the west of Lagos, and in consequence there are heavy deposits of silt derived from the rivers in the rainy season as shown in the sample taken from location 18. At location 41 on this creek the water is shallower and the rate of flow more rapid. Here the deposits are mixed, but still with a high proportion of fine sand. Similar conditions obtain in the creek to the south of Badagri Creek where there is also an uninterrupted flow of water from the lagoon system to the west. The water is comparatively deep in the region adjoining the harbour (location 39) and thus the deposits, although of mixed grades of sand, also contain a fairly high proportion of silt. At location 40 the creek widens and becomes very shallow. Here there is a more rapid flow of water and deposits of moderately coarse sand with a low proportion of fine sand and silt occur.

Lighthouse Creek is a backwater connected to the harbour by a broad neck of shallow water. Water movements in the inner regions of the creek are comparatively slight and the creek itself merges into mangrove swamp. At location 38 the deposit is chiefly of fine sand with moderate amounts of silt rich in organic matter. The absence of large amounts of silt in this region can be attributed to the fact that Lighthouse Creek has no continuous water flow from the lagoon and derives its deposits chiefly from the inner side of the barrier beach.

A condition similar to that in Lighthouse Creek is found in Kuramo Water situated behind the beach to the east of the harbour. On the seaward side of this lagoon (location 37) the deposits are generally of relatively coarse sand with small proportions of fine sand and silt. These deposits, like those of Lighthouse Creek, are also derived from the barrier beach. To the landward side, however, the deposits contain more silt as the lagoon merges with mangrove swamp and receives a restricted flow of water from Five Cowrie Creek.

The marine deposits near Lagos Harbour

The marine deposits grade from silt-free sands on the beaches to a blue clay almost devoid of sand grains beyond the offshore zone of turbulence caused by wave action in shallow waters. Immediately behind the surf on Lighthouse Beach (locations 24 and 25) the deposits are chiefly of fine sand with no silt, the proportions of coarse sand present decreasing with increasing distance from the beach. At location 26, however, a short distance beyond the level of the harbour mouth and in a line with locations 24 and 25, the deposit is chiefly of silt, although there is still a fairly high proportion of fine sand present. This region is influenced by the west–east Guinea Current which deflects the tidal water from the harbour to the east (see figure 1*b*). Locations 24 to 26 are outside the normal western limit of flow of harbour water which has been determined by differences in water colour. Locations 27 to 29, on the other hand, are within that limit and thus provide a comparison with the previous series. The deposit at location 27, although considerably further seaward than that at location 24, contains a higher proportion of coarse sand, less fine sand, and in addition, a measurable amount of silt evidently deposited from the harbour water. The mixed nature of this deposit thus indicates diurnal changes in rate of water flow which do not occur at location 24. The deposit at location 28, as compared with that at location 26, is sand of fine and medium grades free from silt showing that here there is a continuous though reduced water movement. At location 29 the deposit does not appear to have been modified by the tidal flow of harbour water and is predominantly silt with a comparatively small proportion of fine sand present. At location 30 the harbour dredger deposits sand from the fairway so that the deposit at this point consists mostly of coarse and medium sands without silt. The water behind the East Mole of the harbour is rather turbulent and is affected by the diurnal flow from the harbour mouth thus giving rise at location 31 to mixed deposits with high proportions of both coarse sand and silt. Nearer the shore at location 33 the deposits are of a similar character but with a more even gradation of sand grains and very little silt. In the turbulent water behind the surf at locations 32, 34 and 35, deposits of coarse sands with a low percentage of fine grains and no silt are formed. Further to the east, at location 36, the deposit is still mixed but contains a high proportion of fine sand and a little silt.

Samples of three other deposits have been taken from a sand bank 12 miles E.S.E. of Lagos Harbour as an indication of the composition of an offshore bank on this coast. The bank is formed mostly of coarse sand and shell, but small proportions of fine sand and silt are present as shown by the analysis of sample 43 in table 1. At the edge of the bank there is a progressive decrease in the proportions of shell and coarse sand and a corresponding increase in fine sand and silt, as shown by samples 42 and 44, until blue clay is reached. The bank appears to be relatively small and isolated and at a depth of between 7 and 8 fathoms.

Summary

1. The topography of Lagos Harbour and the system of lagoons and creeks associated with it is described.

2. Measurements of salinity in the harbour, in the lagoon north of Lagos and in a creek connecting them have been made at intervals of 2 weeks for a period of 18 months. The salinity has been found to show diurnal fluctuation due to tidal effects and a much greater seasonal fluctuation correlated with the rainfall of the area draining into the lagoon system. During the dry season, from November to March, the salinity in the harbour is high and brackish conditions extend up the creeks, lagoons and rivers for a distance of 20 miles from Lagos. From April to October, the period of the rains, the salinity falls first in the lagoons and then in the harbour until freshwater conditions prevail in the lagoons and brackish water extends from the harbour out to sea. There are no vertical salinity gradients in the shallow waters of the lagoons and creeks, but in the deep water of the harbour a considerable vertical gradient obtains during the rainy season from May to November. The salinity of Kuramo Water, a lagoon connected to the main system by a long and narrow channel, has been measured and the waters found to be brackish at all times with a comparatively small degree of seasonal fluctuation.

3. The temperature of the water in the harbour ranges from 25 °C in August to 29 °C in March and April as compared with a range of sea temperatures of 25 to 27 °C. The temperature of the shallow lagoon rises to 31 °C due to insolation during the dry season.

4. Sand temperatures in the intertidal zone were taken at the surface and at depths down to $7\frac{1}{2}$ in. Temperatures up to 37 °C were recorded at the surface and even at a depth of $7\frac{1}{2}$ in. the temperature was slightly above that of the low-tide water.

5. A survey of the lagoon, harbour and marine deposits in the Lagos area has been made. Harbour and lagoon deposits ranging from mud through various grades of sandy mud and muddy sand to coarse sand have been found with a distribution related to the water movements. The marine deposits have been shown to range from clean sand in the turbulent waters behind the surf, through a narrow belt of fine sand and clay, to blue clay in the quiet waters offshore.

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