RANDALL - VEGETATION ZONES AND ENVIRONMENT
ON THE BARBADOS COAST

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ABSTRACT

The vegetation pattern in the coastal associations of Barbados is described and related to parameters of the environment. Topography, soils and climate are analyzed and attention is paid to variation of salt-spray intensity inland at each location and as it varies around the island. Methods for collecting salt-spray and evaporation data are described. Samples of the vegetation were examined by means of transects perpendicular to the sea and lines of quadrats at right-angles to the transects.

Three series of zonal patterns are demonstrated associated with coastal cliffs, Windward beaches and Leeward beaches. Each series can be linked with the other by environmental influences. No species are ubiquitous and patterning can only be understood in terms of locative species. Within their ranges of tolerance plants can have individual life-histories which situate them outside their normal pattern location. The vegetation zones described are seral but at present held stable by environmental factors.

VEGETATION ZONES AND ENVIRONMENT

ON THE BARBADOS COAST

by

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CHAPTER 1

INTRODUCTION

Review

Coasts have been described as "the last places on earth God created - and he never quite finished them!" (Fancourt 1961). They are ideal 'laboratory' areas for studying changes in vegetation over short periods of time or short distances in space, so that an understanding may be gained concerning the relations between environment and vegetation distribution. This thesis is an attempt to describe and to interpret some aspects of the coastal environment and its vegetation in Barbados.

Along the seacoasts of the world there is a zone of land that lies above the reach of all but the highest tides, yet is so severe an habitat that in it, normal, unadapted inland vegetation cannot grow. On sheltered coasts this zone narrows to little more than a line, except where lack of relief results in tidal marshes or swamps, but on exposed coasts it broadens to a wide belt within which several sub-zones have been defined, (Tansley 1949). This is the habitat of a specialized vegetation-type dominated by a small number of species adapted to tolerate the harsh conditions that are a result of the close proximity of the sea (Sauer 1959, Tansley and Fritsch 1905). The majority of these species persist on raw sand or bare rock despite constant wind, sand-blast and salt spray. Even occasional poundings by storm-waves or flooding by storm-waters do little permanent damage. These species are true pioneers (Sauer 1959) which survive the continuous siege of the sea only by their repeated colonisation of ephemeral sites.

There is a difference between these plants and those, for example, of an inland hydrosere. The coastal environment is too harsh for it to be modified much by the vegetation; only erosion or accretion appear to trigger vegetational succession. The main environmental modifications brought about by the vegetation cover are a slight increase in soil organic matter, and protection for a less hardy plant such as when a large halophyte grows between it and the sea. Many plants are suited admirably to such a rigorous existence by possessing impermeable seeds and fruits (Guppy 1917) that may float for days, months or even years, according to species, until they arrive at a suitable site for their germination. Others are propagated vegetatively. Parts of plants or even whole specimens are broken off or uprooted by either the action of storm waves or animals and then are carried to a new site where, given suitable conditions, they may survive. Perhaps the best documented of the disseminules is that of the coconut (Cocos nucifera) which was studied by Edmonson (1941). Guppy (1917) discusses the various routes taken by plant propagules and disseminules through the Caribbean Sea.

Behind this pioneer zone there is a buffer zone in which the hardiest of the true land plants survive in association with some pioneer species. Here the effects of the sea are still felt but are less severe. The rooting medium of the buffer zone is similar to the true soils of inland areas except for such things as the heavy concentration of salt. Away from the coast the vegetation of this buffer zone gradually merges with that of the inland locations. Within these two zones (pioneer and buffer) several different bands of vegetation occur. Species ranges are extremely narrow orthogonal to the shore, whereas parallel to it they extend over great distances in irregularly spaced patches.

Borders between bands are fixed not only by distance inland from the sea but also by the elevation of local topographic irregularities. The absolute location of these bands is ephemeral since plant survival is influenced by storms which affect the topography of the beach, the gradual accretion or erosion of beach sediments, and interference by man and his animals. In the long run these affect the absolute location of bands but not their location relative to each other.

Literature

Coasts have been popular areas for study since the early days of ecology. Their vegetation often has been described and many of the interactions between plant and environment have been noted. The late 19th and early 20th century literature contains many descriptions of coastal areas: Schimper (1891) catalogued the beach vegetation of the Indo-Malayan region, Harshberger (1900) studied the strand flora of New Jersey, Hansen (1901) examined the West Frisian Islands and Børgesen (1909) described the beaches of the Danish West Indies. Since then several authorities have published accounts of coastal regions in order to complete the catalogue: for example the work of, Boughey (1927) in West Africa, Bayer (1938) in South Africa, Kurz (1942) in Florida and Sauer on the coastal flora of islands in the Caribbean (1959) and the Indian Ocean (1961, 1965a, 1967a, 1967b).

Coastal ecologists mainly have tackled the problems of identifying relations between plant and habitat in two ways. One group investigated the autecology of certain species while the other examined the effects of particular environmental parameters on whole communities. Examples of the former approach are Beneke (1930), who worked on dune grasses in Germany, Gregor (1939) who investigated sea plantains (Plantago maritima) in Europe and North America, and Clausen et al. (1948) who took plants of Achillea from different climatic regions, propagated them in identical conditions, and examined their varying growth responses. In Britain considerable work has been done by Chapman (1947a, 1947b, 1950), Scott (1963) and others for the 'Biological Flora of the British Isles' programme of the Journal of Ecology.

Effects of several environmental parameters were investigated early this century. The relative importance of salt-spray, wind and sand-blasting were examined by Focke (1871) who concluded that salt-spray is the major factor. Borggreve (1872, 1890) favoured wind action, while Gerhardt (1900) thought sand-blasting the most important, but the ecological significance of these three parameters was in doubt until Boyce (1954) showed that, in New England at least, salt spray was the major factor. Much less work has been done on other habitat factors, although some authors considered certain of them critical: Hill and Hanley (1914) examined the effects of moisture content in, and mobility of, shingle: Scott (1960) discussed the importance of soil particle size, and Gillham (1957a, 1957b) pH and salinity.

Few authors have examined how the large scale banding of coastal vegetation varies with change in the environment. Little research on this has been done outside Europe and North America, the results of which have not been tested in tropical locations. Seldom has an isolated region been studied in which great differences in environment can be examined within a small compass.

Sauer (1961) made a study of the Mauritius coast concentrating on its plant patterns. He related species' presence to such habitat parameters as strength of surf, and nature of substrate, but his only quantitative data were rainfall. Poggie (1963) examined 'Coastal Pioneer Plants and Habitat in the Tampico Region, Mexico'. He discussed soil as the major habitat factor but only made passing reference to regional climate. Neither author discussed aerial salt in detail.

Plant Patterns

Bearing these points in mind the island of Barbados was chosen as a suitable place for the description of the vegetation bands that occur along tropical coastlines and to see if they relate to any factors of the environment. An ideal situation would be an isolated, uninhabited, circular island with its strand composed of homogeneous sand, and a similar climate with onshore winds at every beach. One might expect the coastal vegetation of such an island to show identical bands on all parts of its periphery. That of Barbados, however, departs from this "ideal" because of the factors of topographic irregularities resulting from variations in the island's geology and geomorphic history, a climate which varies between the Leeward and Windward sides of the island, soils which range from cliff to beach soils and from coralline to siliceous soils, and variations in the quantity and effect of salt deposition. Also, European man has been on the island for four centuries during which time he has done much to alter the natural vegetation. These factors are examined to see how they differ from place to place around the island and to see whether they have a pattern which corresponds to that of the vegetation.

The term 'pattern' as used in vegetation studies has several meanings, most of which are related to the scale of enquiry. Scale components in geographical problems are examined in detail by Haggett, Chorley and Stoddart (1965) and Haggett (1965). At the smallest scale usually examined in ecological studies, there is that pattern related to the mean size of individuals (Kershaw 1958) but when a species has an extensive rhizome system several scales of pattern may be recognisable (Phillips 1954, Kershaw 1959). Information on the mean size of the individuals of a species may be useful in assessing their growth performance (Anderson 1961). These 'morphological' patterns (Kershaw 1964) almost certainly occur in the vegetation of the Barbados coast, but they were not examined since their effect upon larger scales of pattern was thought to be negligible.

At a scale larger than the morphological is 'sociological' pattern (Kershaw 1964) which is the result of either intrinsic properties of plants themselves, (such as age (Watt 1955)), or the micro-environment (Zinke 1962). Pattern types of this scale occur within the bands of the coastal vegetation of Barbados. Although they are not the immediate concern of this project, such pattern units are referred to in discussions on the homogeneity of the vegetation bands.

At a still larger scale are the 'environmental' patterns (Kershaw 1964). These are thought to be the effects of major discontinuities in the environment and often they can be recognised by eye. As a rule they show as gross changes in floristic composition (Kershaw 1959) or density (Kershaw 1958) and are especially well developed in tundra vegetation (Billings and Mark 1961, Billings and Mooney 1959, Warren Wilson 1952) and coastal vegetation (Greig-Smith 1961, Sauer 1959, 1961, 1965a, 1965b, 1967a, 1967b). In many papers Sauer attempted to describe the patterns of coastal vegetation both at the island and the site scales. He found that in the coastal vegetation of the tropics regular banding occurs although different species compose these bands in the different environments.

This project is concerned with the geographic distribution of areas within the environmental pattern units of the Barbados coastal vegetation. In the Oxford English Dictionary, pattern is defined as a 'repeating decorative design on surfaces' and as a 'model from which a thing is to be made'. The term geographical pattern, in this thesis is used in both senses: it is a 'decorative design' or arrangement in the vegetation on the surface of the earth which repeats itself in similar locations but is a simplification since boundaries are drawn that do not exist with such precision in nature.

The terms 'white' dune, 'grey' dune and 'sandy field' (Hardy 1934) are attempts to name parts of this pattern. 'White' dunes refer to those zones of the dune area that are for the most part unvegetated mobile sand. 'Grey' dunes are covered with vegetation of olive-green or grey colour, common to many xerophytes. 'Sandy field' is the flat area behind the beaches where the soil has a high sand content and where non-pioneer littoral species grow. Gooding (1947) also described vegetation pattern when he named zones with such dominant species as _Ipomoea pes caprae_ and _Coccoloba uvifera_, or by their situation, for instance, pioneer.

Aims

The aims of this dissertation are the description of plant and environment patterns of selected beaches, the more detailed examination of the relations in the vegetation/environment complex of different beaches on the Barbados coastline, and the examination of major habitat factors for relations between environmental variations and changes in the vegetation.

Analysis of the vegetation distribution patterns was approached on three levels. First, the overall species ranges, relevant to the problems of geographic origins and migrational histories of floristic groups, were established from a review of the literature (chapter 6). Second, the large-scale circumcoastal ranges which presumably are related to gross climatic gradients and regional contrasts in the island's soils and terrain, were obtained from field studies and show in the variety of species distributions along the vegetation bands. Third, similar methods were applied in establishing species ranges across the vegetation bands - which distributions presumably reflect the variety of local environments.

Methods

Several approaches to a study of banding in coastal vegetation are possible. At one extreme is a visual examination of particular beaches. Without doubt, information on banding in the vegetation and on the importance of salt and wind as environmental factors would result, but it was felt that much could be learned from measurements made of some of these parameters. At the other extreme there are the various quantitative methods for pattern recognition (Williams and Lambert 1959, 1960), but in the Barbadian situation, where a lack of homogeneity in both habitat and vegetation is obvious such methods might give a poor return for the effort needed in collecting the data. Stratified sampling within subjectively defined bands is not satisfactory since this would not give any information about zonal boundaries and furthermore, many of the bands are too small to permit collection of a representative sample. Similar objections ruled out regularly spaced samples, leaving only nested sampling (Haggett 1965) or transect sampling along a gradient, as adequate methods for the project. Transect sampling was chosen as the most useful method since, in this situation it gave good returns within the period available for research and also allowed comparison with other coastal studies in which similar methods were used (Gooding 1947, Poggie 1963, Sauer 1959, 1961, 1965a, 1965b, 1967a, 1967b, and Thom 1967).

The method of examining vegetation along an environmental gradient by means of transects was developed by Ramensky (1930) and Gleason (1939) in attempts to disprove the idea that vegetation types were well defined natural units with narrow boundaries. A review of the history, aims and methods of gradient analysis, was made by Whitaker (1967). Despite the fact that the method was used for the collection of data in support of the theory of continuity in vegetation (Curtis and McIntosh 1951, Whitaker 1956), it is equally efficient for revealing the existence of boundaries (Sauer 1965b).

In essence, Whitaker's method of direct gradient analysis is to take a transect along a single topographic or environmental gradient and sample the vegetation in equidistant quadrats (Whitaker 1967). Because change occurs so frequently and so suddenly in coastal vegetation, many workers (Poggie 1963, Sauer 1951, 1961, 1965a, 1965b, 1967a, 1967b) have modified this method by sampling within contiguous quadrats along a transect orthogonal to the shoreline. This modification was used here after a further change was made. Reconnaissance work showed that little was to be gained from more than one transect on a beach but that small cross traverses centred on the single transect give more additional useful information than does a second transect, and provide a measure of the vegetation homogeneity within the bands.

The following techniques were used. A preliminary survey of all beaches on the island was made. This resulted in a division of the island into nine sectors (see chapter 2). Within these subdivisions, 15 beaches were selected as the minimum number required to illustrate the major factors of the environment. From each beach vascular plants were collected and pressed for subsequent identification. The nomenclature of species follows the 'Flora of Barbados' (Gooding, Loveless and Proctor 1965) and all species mentioned previously have been recorded from Barbados.

The beach was chosen as a natural areal unit, since in most instances it had recognizable spatial limits. The position of the transect for each beach was selected in the following way. To avoid edge effects, such as those caused by cliff walls, the furthest quarter of each end of the beach was ignored and the balance of its length was divided into ten equal segments. A card was picked from a pack of playing cards (with court cards removed) and the starting point of the transect taken as the given number of tenths from the right hand side of the beach when facing seaward. Usually one transect per beach was examined, but where the randomly chosen route passed through an environmental anomaly (see Bathsheba 'B') a second transect address was drawn. In the case of Foul Bay 'gully', an obvious variation in environment was seen on the beach but not included within the transect. Here, a second transect was deliberately placed. Transects were started at the estimated high water mark and ran inland, orthogonal to the shore, as far as the nearest cultivated land or road. This transect orientation was chosen because it included the greatest number of vegetation changes in the least distance.

Cross-traverses were run after the transect data had been examined in the office. Their positions were chosen in a manner similar to those of the transects. One quarter of the width of the presumed zone adjacent to each boundary was discounted, and the balance divided into tenths. A card was chosen from a pack, the traverse starting point located, and 20 contiguous yard-square quadrats were run from the starting point on either side of the line of the main transect.

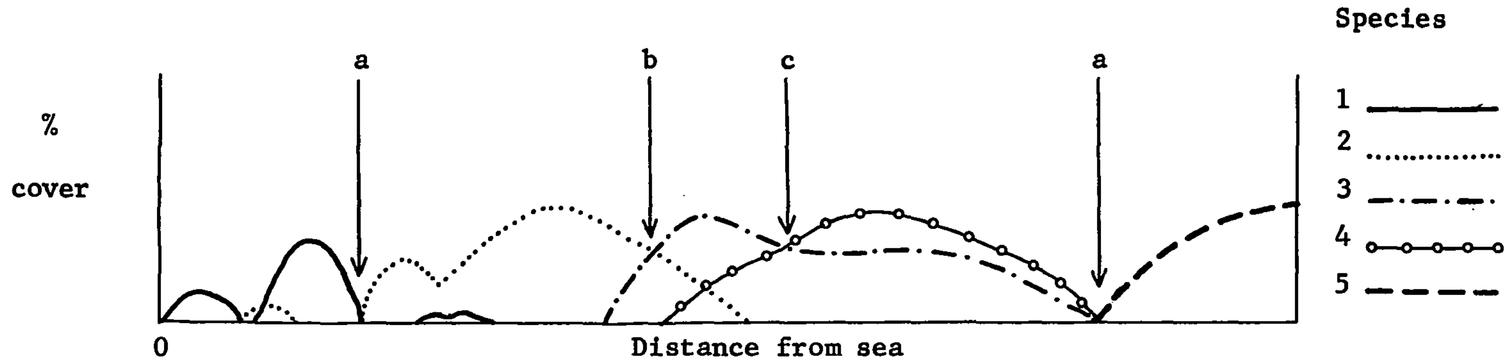
The data collected from each transect are: slope and other topographic features, soil characteristics, climatic parameters, aerial salt and ground surface salt figures, and information about the vegetation. The topographic survey was done with a Cowley level and staff, and efforts were made to minimise errors. Soil samples were taken from points along the transects to cover the range of topographic and textural classes (for detail see chapter 4). Climatic information was obtained from the Seawell meteorological office and the station maintained by McGill University at Waterford. Along each transect, rainfall and evaporation data were collected from instruments (see chapter 3) placed in particular topographic divisions (e.g. back, middle and front of beach). Salt concentrations in the air and on the ground surface were measured adjacent to rain gauges (for further descriptions see chapter 5).

Vegetation data were collected from contiguous yard square quadrats along the transects as estimates of the percentage cover of each species. A yard square quadrat was chosen for the following reasons: it was large enough to obviate edge effects, it included enough area where cover was sparse, yet, was not so large that the vegetation within the centre could not be recorded accurately, and many previous workers examining herbaceous vegetation have used quadrats of similar size. Percentage cover rather than numbers of plants was used as a criterion for dominance since most coastal species reproduce by means of rhizomes and definition of individuals is difficult.

These data were recorded on vegetation charts in the field and later they were analysed by a visual method in the office. Diagrams for each species at each location were drawn as histograms (see Figs. 7.1 - 7.15, chapter 7), and examined for similarities. It can be seen that several species begin and end their ranges, or have their greatest density at, similar places on the beach. If these data concerning the major species are superimposed (see for example Fig. 1.1), the grouping of curves represents groups of these species in the field. Several species show sudden reductions in cover density at similar positions and represent those parts of the beach where a marked change in flora occurs. These positions show on the superimposed histograms (for example Fig. 1.1) as 'V' shapes. The more acute the 'V' the more obvious is the change in the field. The location of a 'V' is taken as the boundary between two bands within which species occur that are not present in any quantity or at such density outside the band. At locations such as points 'a' on Fig. 1.1, the position of the boundary is caused by the rapid decline of one species and equally rapid increase of another. The boundary location at point 'b' is the result of a less rapid decline in density of one species and less rapid increase of the other. The boundary is drawn at that point where the one species reverses the order of density with the other; in this situation the boundary is less definite in the field. The 'V' at point 'c' illustrates a third type of boundary. In this case neither of the species involved die out but the magnitude of density changes. The 'Vs' at points 'a' and 'c' represent the extreme cases experienced in the field.

FIG. 1.1 HYPOTHETICAL SUPERIMPOSITION DIAGRAM

To illustrate the method of determining zonal boundaries



a - Boundary seen by a change in species
b - Boundary seen by change in density and species
c - Boundary seen by change in density but not species

Two methods were used to extend these results from the transect to the beach. The first is by returning to the field and following each boundary along the beach from the appropriate position in the line of transect. In some instances this was quite simple to do in the field. The second was by examination of data from the cross-traverses, (appendix V). These show the consistency of the data drawn from the main transects for a distance of 40 yards. This length was chosen to give enough data to eliminate unrequired micro-patterns within the zones. However, it was not so long that the traverse ran out of the central region of a band if that band was not truly parallel to the shore. The latter is frequently the case with small, almost semicircular bays.

Attempts were made to relate all such pattern units, or bands, from one beach to those of other beaches around the island. The cover diagrams were examined for similarity in numbers of zones per transect and in species present within zones. Any groupings that result were examined for correspondence with factors of physical location, climate, soil, and salt.

Naturally since the beaches are of different width, any one zone will not necessarily compare in size to its related zone at another beach, and in cases of markedly different topography a particular zone may be absent. Similarly, slight differences in aspect and collection of data during periods of different windspeed result in salt data from one beach not being absolutely comparable to that of another. However, the ranking of data of some major environmental characteristics such as salt, pH, or grain size, with distance from the sea enables correspondence between the vegetation pattern units and habitat to be seen.

In a situation like that of the 'ideal' island originally postulated, one transect at one location would provide all the data necessary for this study. With Barbados, however, the complete island was taken as one unit, on which the littoral was studied. The physiography was analysed and the coastline divided into different units (beaches) from which vegetation, climate, soil and salt data were collected. The vegetation was described by means of transects which were visually analysed by means of histograms to discover the composition and number of bands within the vegetation at any one beach. When all the required vegetation studies were completed, the data from each beach were compared to discover what variations occurred and the degree to which they were related to parameters of the environment.

CHAPTER II

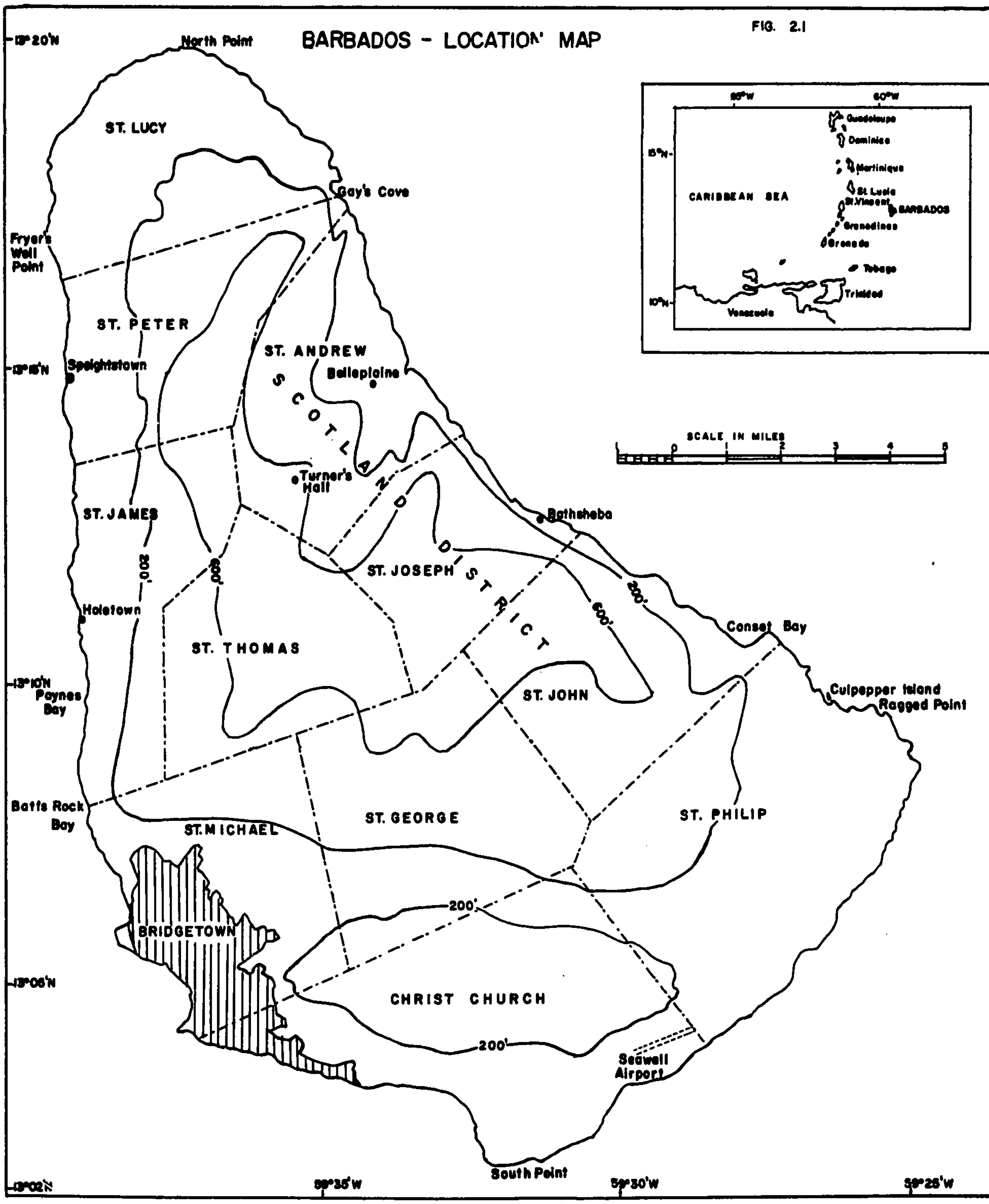
THE ISLAND AND ITS COASTLINE

General Observations

The island of Barbados is situated between 13° 02' N. and 13° 20' N., and 59° 25' W. and 59° 39' W., (Fig. 2.1). It is the easternmost island in the Caribbean, 100 miles east-southeast of St. Lucia and 180 miles northeast of Trinidad. As such it possesses many of the physical features that Wallace (1880) extolled in oceanic islands as excellent field laboratories. From north to south it measures 21 miles and has a maximum east-west width of 18, and its total area is 166 square miles.

The island is dome-like in shape rising from the coast in a series of terraces, (Broecker 1968, Price 1962), to a maximum height of 1,115 feet at Mount Hillaby. The surface is relatively smooth and an upland plateau above the 600 foot contour covers one third of the total area. The greater part of the island is covered by Pleistocene reef limestone which is almost 300 feet thick in places (Senn 1946). However, in the area subtended by an arc from Gays Cove to Conset Bay the terraced reef rock has been eroded away exposing the underlying sedimentary formations of the Scotland District which Schomburgk (1847), Harrison and Jukes-Brown (1890), Trechmann (1925, 1933, 1937) and Senn (1940, 1946) describe in detail.

The climate of Barbados has been described by Skeete (1963) and Tout (1968). At present Seawell Airport, and McGill University at Waterford (Garnier 1968) maintain Class 'A' meteorological stations, and most plantations record rainfall: Barbados lies within the belt of the northeast trade winds which play a major part in the control of its weather. They


BARBADOS - LOCATION MAP
FIG. 2.1
13°20'N
North Point
ST. LUCY
Gay's Cove
Fryer's Well Point
ST. PETER
ST. ANDREW
13°15'N
Speightstown
Belleplaine
SCOTLAND DISTRICT
Turner's Hall
ST. JAMES
Bathsheba
200'
600'
ST. JOSEPH
Holetown
ST. THOMAS
Conset Bay
13°10'N
Paynes Bay
ST. JOHN
Culpepper Island
Ragged Point
Batts Rock Bay
ST. GEORGE
ST. PHILIP
ST. MICHAEL
BRIDGETOWN
13°06'N
CHRIST CHURCH
Seawell Airport
South Point
13°02'N
59°35'W
59°30'W
59°25'W
SCALE IN MILES
0
1
2
3
4
5
65°W
60°W
15°N
10°N
CARIBBEAN SEA
Guadeloupe
Dominica
Martinique
St Lucia
St Vincent
BARBADOS
Grenadines
Grenada
Tobago
Trinidad
Venezuela

are fairly constant, blowing from between east-northeast and east throughout most of the year. There is a dry season from mid-December to late May, and a wet season for the remainder of the year (Skeete 1963). Over 77% of the rain usually falls in the wet season, but variability is extreme so that wet and dry spells occur throughout the year.

In contrast to rainfall, temperatures are relatively constant, and mean daily variation is usually less than 4° F. Average temperatures normally vary between 75° F and 82° F. Daily average sunshine rates are at their lowest in October with 7.3 hours and rise up to 8.8 hours in March and April. Humidity does not vary greatly throughout the year, averaging 71% for the dry season and 76% for the wet season. The island is not within the normal Caribbean hurricane belt and has only been hit once this century, by hurricane Janet in 1955 (Dinger 1962).

Barbados is very heavily populated, with over 232,000 people at the 1960 census. The main population cluster is at Bridgetown, the capital, and numbers per square mile decrease to the north and east, but because of the high density of the road network no area is without people. The island is fully cultivated and only areas like the coastal fringe or bare rock exposures are not planted.

The soils of Barbados have been mapped by Vernon and Carroll (1966). They distinguish 10 associations in the coralline area plus the Scotland District soils. Much of the soil is the weathered residue of bed-rock but Harrison (1920) points out that a percentage of the soil is composed of wind-blown ash from eruptions on the volcanic islands to the east.

Barbados has been fortunate in having a series of botanical floras from Ligon (1657), through Hughes (1750), Maycock (1830), Schomburgk (1848), Grisebach (1864), to that of Gooding, Loveless and Proctor (1965), with which the introduction and disappearance of species can be traced. Relatively little of an ecological or biogeographical nature has been published. Beard's monograph (1949) of the vegetation of the Windward and Leeward Islands includes only a short discussion of the flora of Barbados. Hardy (1934) has produced the only ecological study of the island, but there is also an historical treatment of the vegetation by Watts (1966). Studies were made by Gooding (1944) of Turner's Hall Wood, the only remaining forested area of Barbados, and by Allan (1957) of Barbadian grasses. Gooding (1947) has been the only person to publish an article directly concerned with the Barbados coast. In this he examines the sand dunes of the west and south.

The Coast

Barbados has a regular coastline lacking in deep indentations. There are few separated land areas: off the northeast coast there are some stacks that are devoid of terrestrial vegetation, and in the southeast there is tiny Culpepper Island. McLean (1965) notes that the coast of Barbados is about 57 miles long. It comprises 20 miles of coral limestone cliffs and scarps, 19 miles of coral sand beach, seven miles of silica sand beach, seven miles of sedimentary slopes and four miles of man-made sea defences.

Fringing coral reefs occur around most of the slight promontories along the western, southern and eastern coasts but these are actually growing only in the west. Along the south coast there is a line of dead coral fragments extending nearly a mile offshore while off the east coast there is another bank of remains thinning northwards and almost disappearing off Belleplaine.

Tidal range is quite low, averaging about 2.5 feet, so that the intertidal exposure is small except in areas of low relief. Over a month tidal range may vary from less than 0.5 feet to more than 3.0 feet. The times of high and low tide are strongly influenced from day to day by cyclonic disturbances in the open ocean.

Lewis (1960b) shows that there is great contrast between wave amplitudes on the west and east coast on any one day. With light wave action there is a fourfold difference, with moderate waves sixfold and heavy wave action eightfold. Donn and McGuiness (1959) describe storm swells which alter this pattern when the swell direction is west of north. Rough seas on the west coast from September 6th to 10th 1967 probably originated in the disturbance that resulted in hurricane Beulah which missed Barbados but damaged Martinique and St. Lucia.

Storm swells cause great damage to the vegetation and drastically change the physical environment. During the storm swell that occurred between December 6th-12th 1967, the high tide mark moved 210 feet inland at the point of survey on Lakes Beach, Belleplaine, engulfing some of the Philoxera (Philoxera vermicularis) dunes. Even on the leeward coast damage was great. At Maycocks Bay (Figs. 2.2-2.3), an area of sand 90 feet wide and over one foot deep was lost and the crab grass (Sporobolus virginicus) zone destroyed.

The beaches experience an annual cycle of sand movement. During the dry season reasonably calm weather gives accretionary waves which bring in the sand. During the early part of the wet season storm waves comb the sand back from the beach into the nearshore zone. Superimposed on this cycle is one of longer duration which at present results in accretion on

Fig. 2.2
Maycock's Bay, St. Lucy, view north (site 15). On the sand in the foreground are clumps of crab grass. The beach is backed by a forest of manchineel trees, and some shrubs of sea grape (centre right). Photo taken in August 1967.

Fig. 2.3
View of same beach as Fig. 2.2 after storm swell of December 1967. Note that the beach sand has been eroded as far back (90 feet) as the manchineel trees, exposing their roots.

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Maycock's Bay, St. Lucy, view north (site 15). On the sand in the foreground are clumps of crab grass. The beach is backed by a forest of manchineel trees, and some shrubs of sea grape (centre right). Photo taken in August 1967.

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View of same beach as Fig. 2.2 after storm swell of December 1967. Note that the beach sand has been eroded as far back (90 feet) as the manchineel trees, exposing their roots.

the Scotland Coast and erosion elsewhere. Gooding (1947) mentions the history of erosion and deposition on the south coast.

Aspect and shape are important features of particular beach sites. Those exposed to the northeast receive the full force of waves generated by the "Trades" and suffer from evaporation, sand-blast and salt, throughout. Semi-circular beaches vary in exposure and differ in their soil-type, climatic conditions and plant growth at the sides and in the centre. Beaches where the dominant wind direction is at an angle to the foreshore receive large quantities of salt spray at the front but little reaches the back. Those with leeward exposure have little or no spray effects, throughout most of the year.

Few stretches of the coast are in their natural state. Several coastal species that Watts (1966) describes as present in the 17th and 18th centuries are no longer found; conversely there have been many introductions. Even greater changes have occurred through the direct use of beaches by man and his animals. By law all beaches are common land but in some places there is no immediate public right of access. All the beaches west of South Point and south of Fryer's Well Point are directly accessible by road, and are used by bathers. Some of these, especially near Bridgetown and the luxury hotels are almost devoid of vegetation. Other points, notably River Bay and Bathsheba are 'Excursion' beaches, where Barbadians congregate on national holidays and create havoc with the local vegetation. Several of the sheltered beaches on the east coast are pulling-up points for fishing boats. The topography and vegetation of Skeete's Bay and Foul Bay are changed by this. Many coastal areas not used by tourists have goats, sheep (Fig. 2.4) and occasionally cattle tethered. This results in considerable overgrazing especially in such areas of poor pasture as Animal Flower Bay and River Bay.

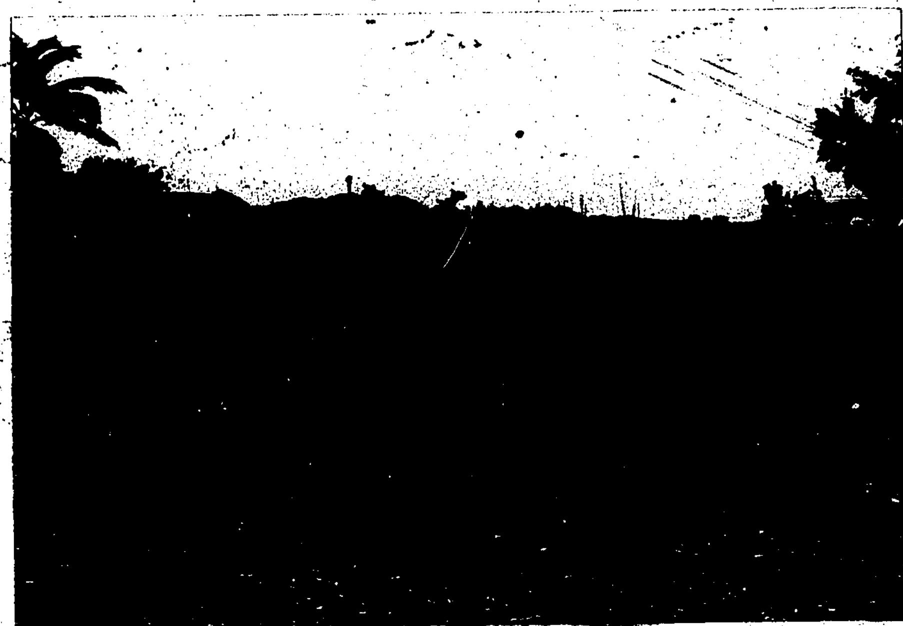

Fig. 2.4
Sheep grazing on the sparse vegetation of the estuary at River Bay. The sheep are usually tethered near a clump of seaside samphire or wild lavender in the morning and taken back to domestic shelter at night.

Domestic animals have eaten out the most palatable species, especially among the grasses, and this has allowed the spread of other species which could not compete previously. Several species are also transported by domestic animals when seeds become entangled in the animals' pelts. Appreciable amounts of organic matter are lost from the nutrient cycle because the animals graze all day on the coastal 'pastures' and are taken away at night. Although animals excrete both at night and in the daytime, they do not feed at night. Lastly overgrazing and the action of cloven hooves lay bare and cut the topsoil so that in the dry season it can be blown away by the wind.

Thus, sections of the coastline of Barbados can be differentiated by siderable overgrazing especially in such areas of poor pasture as Animal Flower Bay and River Bay.

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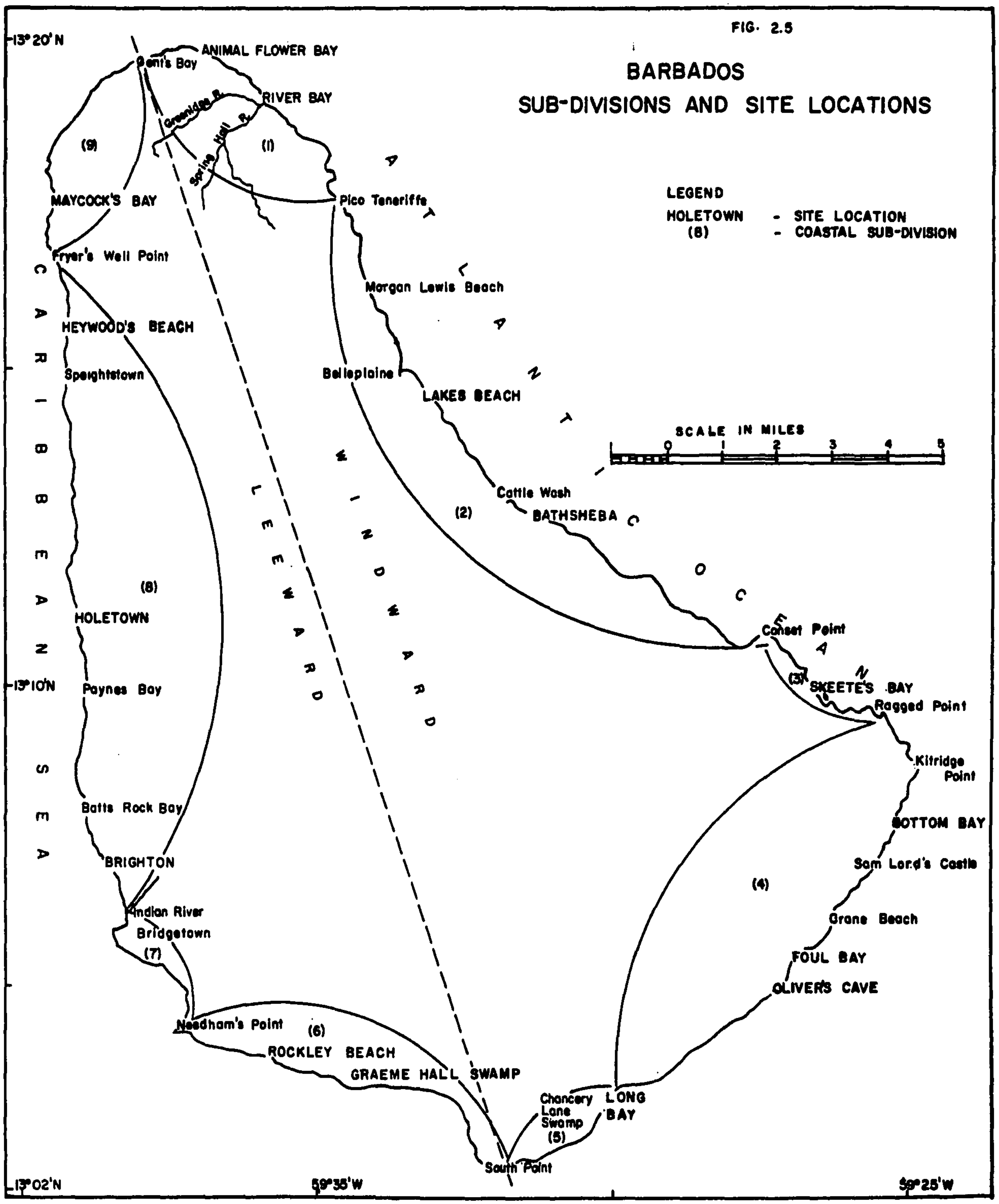
FIG. 2.5



BARBADOS
SUB-DIVISIONS AND SITE LOCATIONS
LEGEND
HOLETOWN - SITE LOCATION
(8) - COASTAL SUB-DIVISION
SCALE IN MILES
0 1 2 3 4 5
13°20'N
13°10'N
13°02'N
59°35'W
59°25'W
ANIMAL FLOWER BAY
Boni's Bay
RIVER BAY
Greenidge R.
Spring Hall R.
(1)
(9)
MAYCOCK'S BAY
Pico Teneriffe
Fryer's Well Point
Morgan Lewis Beach
HEYWOOD'S BEACH
Speightstown
Belleplaine
LAKES BEACH
Cattle Wash
BATHSHEBA
(2)
(8)
HOLETOWN
Paynes Bay
Batts Rock Bay
BRIGHTON
Indian River
Bridgetown
(7)
Needham's Point
(6)
ROCKLEY BEACH
GRAEME HALL SWAMP
Chancery Lane Swamp
(5)
South Point
LONG BAY
(4)
OLIVER'S CAVE
FOUL BAY
Crane Beach
Sam Lord's Castle
BOTTOM BAY
Kitridge Point
Ragged Point
SKEETE'S BAY
(3)
Conset Point
CARIBBEAN SEA
ATLANTIC OCEAN
LEEWARD
WINDWARD

both physical and human factors. The primary division is between east and west or more exactly, Windward and Leeward, but within these two broad categories there are nine topographic subdivisions; five are on the Windward coast and four on the Leeward. Within each of these nine areas some other differences were found which resulted in 15 sites being chosen to typify the Barbadian coastline (Fig. 2.5). It was at these sites that the pattern of coastal vegetation and its relationships with the patterns of the environment was studied.

Beginning in the north at Gent's Bay, and continuing southeast as far as Pico Teneriffe, there is the most indented part of the Barbados coast, with a high cliff-line that drops straight down to the sea. Promontories enclosing small inlets are found within this area.

Fig. 2.6
View south across cliff at Animal Flower Bay, St. Lucy. In the foreground there is considerable fretting of the surface, which consists mainly of exposures of bare rock. In the middleground, right, there is an area of crab grass. Note the exposures of bare rock continuing inland as far as clumps of screw pine and prickly wild coffee. On the horizon, left, is a windbreak of casuarina and middle, the inflorescences of maypole.

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Animal Flower Bay (Fig. 2.6) is an example of this section of coast. Its quaint name is derived from the tube worms that cluster in the tidal pools within the sea-worn caves. It is a desolate, dry, windy coral limestone plateau that terminates with considerable overhang almost 60 feet above the sea. Waves blown by the regular northeast "Trades" strike the ragged cliffs at an angle such that considerable amounts of spray are ejected into the air, blown over the cliff and across the plateau. In some places cave-roofs have collapsed resulting in geos, allowing greater dissemination of salt spray inland. Southwards the land-surface increases 20 feet in height over a distance of nearly 1,000 feet. On this cliff-top a soil has developed which Vernon and Carroll (1966) map as part of the Coastal Association. This soil is 18 inches deep in some places but in others knolls of coralline bedrock are exposed, affording protected locations to the lee. Much of its surface is overlain by limestone particles which vary from the size of small pebbles to large boulders.

Within this cliffed region there are a few lower areas where rivers reach the coast. Here the high cliffs give way to steep, valley-side slopes that have a sparse soil cover. River Bay, (Fig. 2.7) is the estuary of the Greenidge and Spring Hall Rivers[1]. The interior arms of the estuary are protected, only the Greenidge arm being exposed about 13^{o} to the southeast. The outer part of the bay is fully exposed to the east. To the north and south of the estuary is the continuation of the bleak, limestone upland found at Animal Flower Bay. However, the plateau is lower here reaching only 53 feet in the north and 31 feet in the south. The plateau

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[1]Outside the Scotland District, Barbados has no permanent rivers, and all estuaries become stagnant and saline except immediately after a rain and at the peak of the wet season.

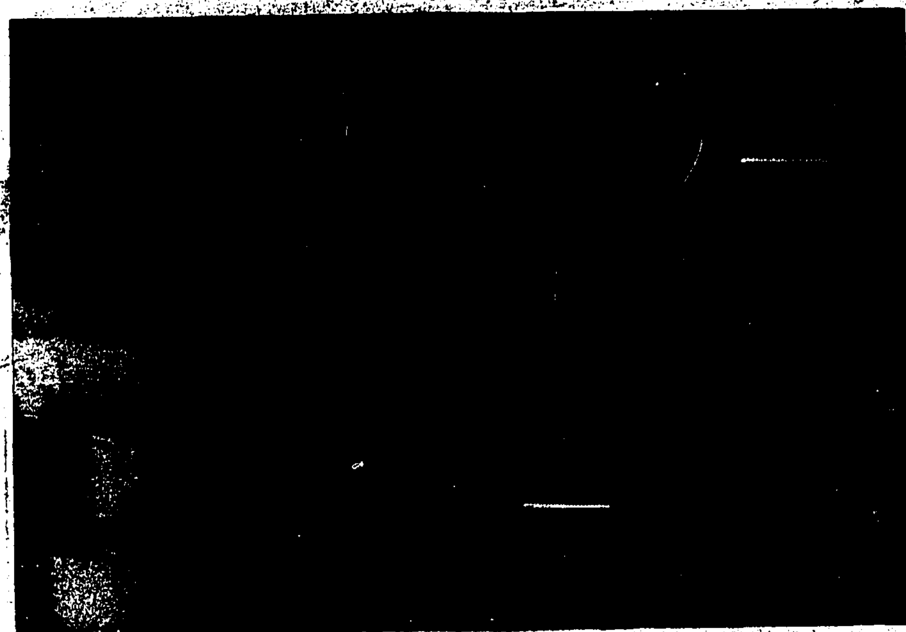

Fig. 2.7
Aerial view of River Bay, St. Lucy, at low tide on 12.11.64. Note the direction from which the waves are coming. None of the beaches in the estuary are exposed to wave action. The cliff-tops mainly have a sparse cover of crab grass with a few bushes of seaside sage. On the south-facing estuary slopes there are casuarinas and prickly wild coffee. (Photo by Hunting Surveys Ltd.)

areas have extremely shallow but fairly well developed soils. Occasionally bedrock is exposed while at other places clint-like formations are filled with soil nine inches deep. The east-facing unprotected beach is 40 feet wide and composed of fairly homogeneous sands. The interior beaches are composed of a coarse sand and pebble mixture. Because of the shape and topography of the estuary these interior beaches are only in contact with the sea-water for a few hours at each high-tide when a small bore brings the salt-water up river. The south and west facing slopes have very little soil, composed only of crushed limestone rock but, are vegetated because of the more protected environment. The interior lowland between the two rivers carries a fully developed soil of the Coastal Association

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South of Pico Teneriffe for about eleven miles to Conset Point is the coastline of the Scotland District. This area differs from the rest of the island because its sands are predominantly siliceous. The central part of the region from Morgan Lewis Beach to Cattle Wash is composed of wide east-northeast facing beaches frequently backed by sand-dunes.

Fig. 2.8
Aerial view of siliceous sand-dunes at Lakes Beach, Belleplaine on 25.11.64. Note the tiny Philoxera dunes at the rear of the beach, then the higher crests of the main ridge with sea grape at the summit. Only the dune crests of the middle, mobile zone are vegetated, with fat pork. Behind the dunes there is manchineel forest. (Photo by Hunting Surveys Ltd.)

The best development of this type of coast is found at Lakes Beach, Belleplaine, (Fig. 2.8). The beach itself is about 180 feet wide but in some places it narrows to 100 feet. Immediately to the rear of the beach, small actively accreting dunes about four feet high are found. Behind these, there is a continuous dune crest about 20 feet high and 100 feet wide which is also active. Between this crest and the high dunes to the and a vegetation cover.

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South of Cattle Wash, as far as Conset Point rough sedimentary slopes reach the sea and only a narrow beach results, which in places is completely lacking. Some remains of the old coralline cap of the Scotland District are found as huge boulders either on or near the beach or just out to sea.

Fig. 2.9
View north over Bathsheba, across the Scotland District. On the siliceous sand beach and just out to sea there are several huge coralline boulders on the lee of which whitewood is growing.

Bathsheba (Fig. 2.9) has a tan-sand beach about 90 feet wide, from the back of which steep hills rise into the interior of the island. The beach is exposed to the northeast and receives continuous heavy surf. However, the presence of a broad coralline platform immediately offshore causes the rear is a series of three intermittent dune-crests four to six feet high which show evidence of instability and blow-out. The crests of the rear dune series are up to 34 feet high and heavily vegetated to the lee. The rooting medium throughout is raw, siliceous sand.

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Between Conset Point and Ragged Point, a distance of only two miles, cliffs, steep slopes and a reasonably lowland coast are to be found. The beaches of this area are a meeting point for the siliceous sand of the Scotland District and the coralline sands of the rest of the island. Skeete's Bay (Fig. 2.10), in the centre of this region is unique in having almost equal amounts of coralline and siliceous sand. There is a beach 60 feet wide, exposed to the northeast, backed by a hillslope that rises over 80 feet. Because of its somewhat semi-circular shape, the full effects of the trade winds are limited to the southern part of the bay at beach level, though considerable amounts of salt are deposited in the soils of the lower part of the hillslope.

Fig. 2.10
Aerial view of Skeete's Bay on 7.12.64. Little vegetation is present on the beach which is used by fishermen. On the hillslope behind there are whitewood and manchineel trees. (Photo by Hunting Surveys Ltd.)

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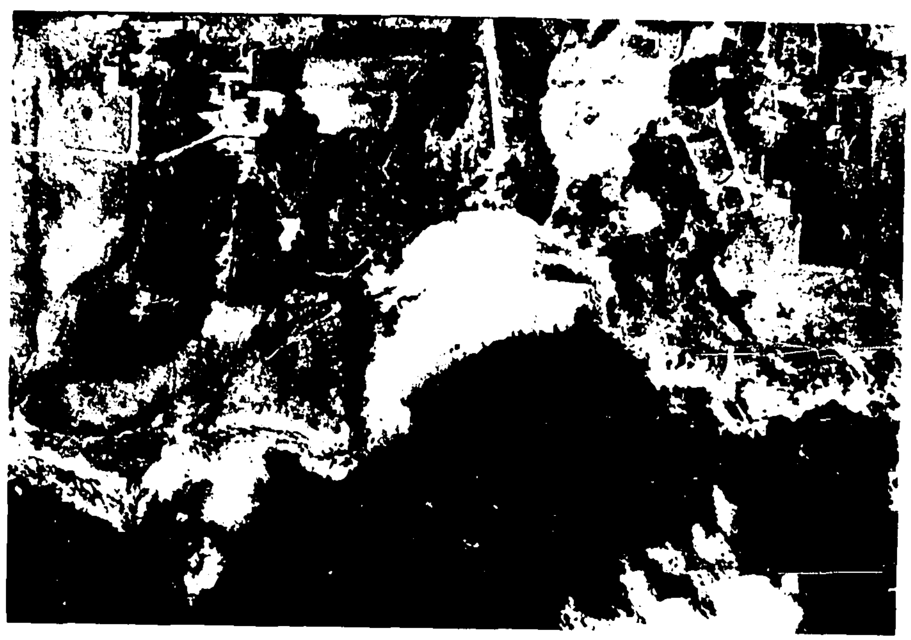

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Aerial view of Skeete's Bay on 7.12.64. Little vegetation is present on the beach which is used by fishermen. On the hillslope behind there are whitewood and manchineel trees. (Photo by Hunting Surveys Ltd.)

From Ragged Point to Kitridge Point the coast continues in a south-easterly direction, then turns southwest. An almost continuous line of cliffs is found from Ragged Point to the northwestern corner of Long Bay. The northern part of this sector as far as Crane Beach is typified by small semi-circular bays encompassed by steep or sheer cliff-walls, 20-40 feet high.

Fig. 2.11
Aerial view of Palmetto Bay (left) and Bottom Bay (right) on 13.12.64. Note how the vegetation changes in type and species between the protected areas near the cliffs and the exposed areas in the centre of the bays. The seaward edge of the cliff-top is rocky and poorly vegetated but further inland there is good sour grass pasture. (Photo by Hunting Surveys Ltd.)

Bottom Bay, (Fig. 2.11) is one of three contiguous cliff-backed bays that face due east. The beach sand is coralline and built up in the form of a large dune some 180 feet wide and 7-10 feet high. To the south of the dune there is a channel which at times of high seas allows water to flow into the bay and around the rear of the dune where land level is 2.5 feet below high tide mark. The cliff-face is considerably broken at the

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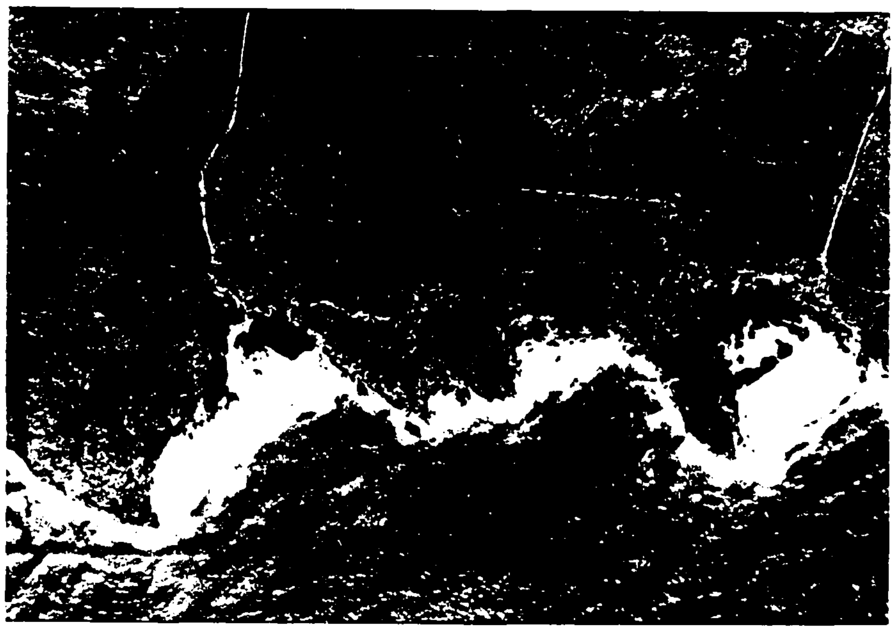

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In a few places along this coast, primarily at Sam Lord's Castle Hotel, The Crane Hotel and at Foul Bay the cliff is broken and replaced by sedimentary slopes, on which gullying has occurred. At each of these points a beach has developed.

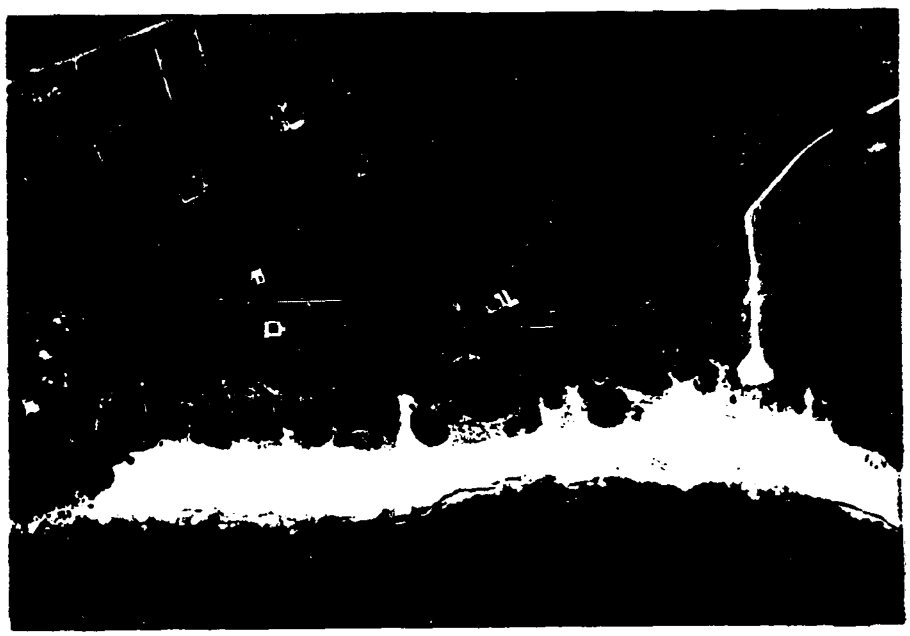

Fig. 2.12
Aerial view of Foul Bay, on 5.12.64. The dune summits are covered with sea grape as at Belleplaine. No vegetation occurs in front of the roadway where fishermen bring in and sell their catch. Immediately left of the roadway is a gully which has seaside samphire in it (centre front) and manchineel trees on the slopes. (Photo by Hunting Surveys Ltd.)

Foul Bay, (Fig. 2.12), contains a beach about 130 feet wide which is composed of two low dune series about five and three feet high respectively. Behind the beach, rough slopes rise over fifty feet to a plateau. In the rear, allowing a number of plant species to gain a foothold where little or no soil exists. Immediately at the cliff-top, 25 feet above, conditions are extremely harsh, and soil is shallow. On the plateau behind a true soil of the Coastal Association has developed on which good pasture is found.

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Foul Bay, (Fig. 2.12), contains a beach about 130 feet wide which is composed of two low dune series about five and three feet high respectively. Behind the beach, rough slopes rise over fifty feet to a plateau. In the northeast sector of the bay a large gully has been cut into the hillslope. The beach is almost pure coral sand but up the gully an admixture of finer material from the hillslope occurs. Foul Bay is exposed to the south-southeast so that although the front of the beach receives the full fury of the sea very little spray reaches the rear of the first dune. However, the front part of the gully is extremely saline because of seepage and evaporation of sea-water which flows in at times of high seas.

Fig. 2.13
The broken cliff-slope at Oliver's Cave. Much of the ground surface is covered with mobile rubble, but most of the boulders are colonized by seaside samphire. On the more gentle upper slope where there is more soil there is a cover of duckweed and Egletes prostrata.

Immediately southeast of Foul Bay, at Oliver's Cave (Fig. 2.13), the coastal cliffs rise to their highest point on the island, and there are sheer drops of 100 feet to the sea. Because erosion at the base of the cliff has resulted in overhang, there has been some slumping of soil that has allowed certain hardy species of vegetation to gain a foothold. The fall at Oliver's Cave has resulted in a semi-circular amphitheatre with sheer walls 30 feet high at the top and a 50 feet slope of rock, cobbles and earth below. At the base of the cliff there is a tiny beach, only 6 feet wide at high tide. There is a dry, windy plateau at the top of the cliff, similar to the one at Animal Flower Bay in the north.

From Long Bay to South Point is the final stretch of the Windward coast of Barbados. In this region the cliffs are several hundred yards inland and the actual coast is an area of very low relief with enclosed and now-drained swamps.

Fig. 2.14
View east over Long Bay dunes, Chancery Lane, towards a coconut grove. In the foreground are clumps of crab grass, with seaside spurge and trailing stems of seaside yam. In the middleground is a bush of seaside lavender.

Long Bay, Chancery Lane, is a southeast-facing beach about a mile long and 180 feet wide with two parallel dune series behind, (Fig. 2.14). The front crest reaches 14 feet and the rear about 12 feet above sea level. The foot of the front dune approaches or actually reaches high-tide mark along most of the beach. The sand is almost entirely composed of quite large coral fragments. Behind the dunes there is a flat area of pasture that was once Chancery Lane Swamp.

West of South Point through to Needham's Point, the coast faces south-southwest. This six mile stretch is the main holiday and tourist region of Barbados and as such has a very limited number of areas that can be examined from a biogeographical point of view. Most of the coast is at present subject to considerable erosion. In several places artificial shore defences have been built while in others the seas beat hard against the footings of hotels and houses.

Fig. 2.15
View south at Rockley Beach. Most of the trees on this beach have been cut (middle and right) and only one casuarina is left standing. Ground vegetation is dominated by crab grass and seaside yam.

However, at Rockley (Fig. 2.15), there is a beach that stretches 120 feet from high tide mark to the main road and appears to be the remnants of two dune series, though now the crests are only 3 feet above high tide mark. Due to erosion of the old foreshore the present front beach has an anomalously high cover of vegetation.

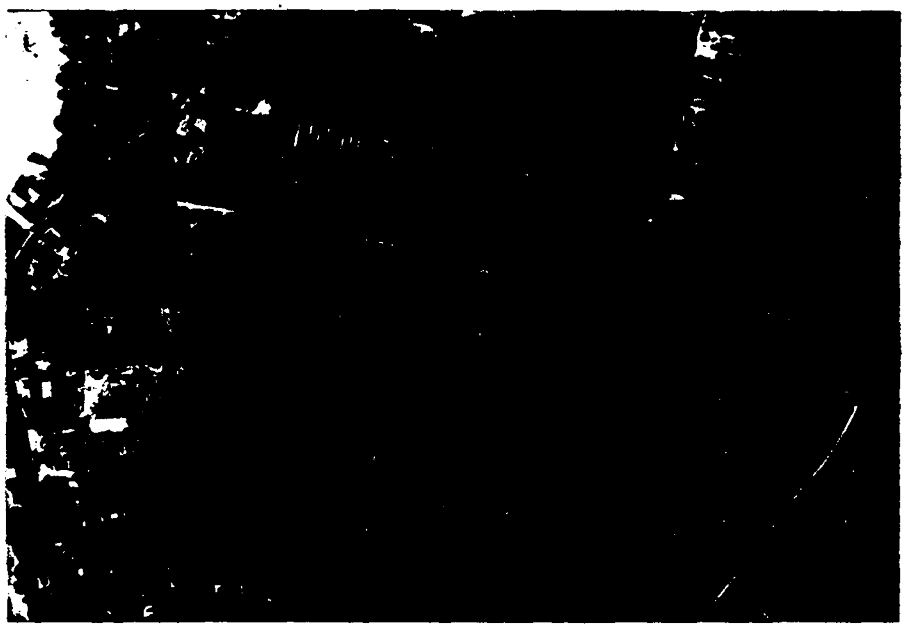

Fig. 2.16
Aerial view of Graeme Hall Swamp, on 23.11.64. Most of this swamp is artificially maintained. Note the development of mangroves along the drainage channel parallel with the road that divides the swamp. At top left corner is the beach. (Photo by Hunting Surveys Ltd.)

One unique factor about this coast is that it contains the only remaining area of true mangrove swamp in Barbados. Graeme Hall Swamp (Fig. 2.16), begins about 150 feet inland from high water mark and is about half a mile square. At present it is being encroached on and filled in. The land surface is about a foot above high-tide level, and is drained by a small creek. The beach is about 50 feet wide but only reaches 9 inches above sea-level. The sand is composed of very fine coral particles. The area between the beach and the swamp has been built up and contains houses and a highway.

The sector from Needham Point to Indian River is almost entirely made up of Bridgetown's sea defences and was not examined. Beyond Indian River for more than eleven miles north to Fryer's Well Bay is the west coast of the island. This is made up of a series of gentle promontories and embayments with quiet water breaking over coral reefs. The whole length of the coast is followed by Highway 1. Most of the beaches are much narrower on this coast and the vegetation grades more quickly into interior associations.

Fig. 2.17
View west of a small beach at Brighton. Large quantities of casuarina needles at rear of beach hinder vegetation growth. Seaside yam is common over all the beach but an extremely large number of species are present. Immediately behind the mobile area of the beach manchineel occurs (left and right).

Along much of the west coast south of Paynes Bay the beaches are under ten feet wide and are immediately backed by gardens. However, near the West India Rum Refinery at Brighton (Fig. 2.17), a strip of beach occurs that is about 75 feet wide. Like the majority of beach sites south of Batts Rock Bay, it faces southwest. The beach rises in two gentle swales to a maximum height of five feet. At the front it is composed of almost pure coralline sand but behind this grades into a sandy soil.

Further north, from Paynes Bay to Speightstown, the beaches become wider and human habitations are often set further back from the sea. All beaches in this sector face due west and have a less adverse habitat. At Holetown there is a beach about 180 feet wide from high water mark to the highway, (Fig. 2.18). The first 45 feet is nearly pure coral sand rising

Fig. 2.18
View south along beach at Holetown. Some manchineel trees occur at the front of the beach (front and rear right) but more usual is the pioneer zone of crab grass with manchineel development behind (middleground).

to a maximum height of three feet. Behind the beach, the land falls to only one foot high but rises again to five feet before reaching the highway. North of Speightstown to Fryer's Well Bay the distance between the sea and the highway narrows again. At Heywood's Beach, (Fig. 2.19), the sand is almost pure coral. The land rises gently up to four feet above sea level and supports dense cover of vegetation.

From Fryer's Well Bay around to Gent's Bay, the cliff line again approaches within 200-300 feet of the coast. Below the cliff there is a "sandy field" area composed of eroded coralline rock fragments and soil with an admixture of sand. In front of this is the beach. At Maycock's Bay, (see Fig. 2.2), there is a coastal strip about 200 feet wide with the beach exposed directly to the west. For 90 feet inland from high-water mark there is pure coral sand rising to a height of eight feet. Quite abruptly this is replaced by a soil of the Black Association (Vernon and Carroll 1966), with only a slightly sandy surface cover, which continues inland to the cliff face.

Fig. 2.19
Manchineel trees in the pioneer zone at Heywood's Beach. At high spring tides these trees have their exposed roots awash. Note that the branches that are touched by seawater have no leaves. At bottom right there is a ground cover of wild jasmine.

The foregoing descriptions of the 15 sites show that topography varies considerably around Barbados. There are coastal cliffs 100 feet high and almost flat swamps; there are sand-dunes and flat cliff-tops. These variations are enough to explain some of the vegetational types such as mangrove, but other differences in the vegetation are the result of other environmental factors. Those that appear to change most markedly are soils and salt-spray.

However, on further examination it was found that, despite the small size of the island there are varying climatic parameters which may both directly and indirectly influence the vegetation, through their effects on soil chemistry and aerial-salt content. For these reasons the climatic variations will be described next.

CHAPTER 3

THE COASTAL CLIMATE

Barbados lies within the 'humid tropics' as delimited by both Garnier and Küchler, (Fosberg, Garnier and Küchler 1961). Nevertheless large areas of the coast, especially in the north and south do not satisfy Küchler's vegetation criteria and in certain years climatic records place the coastal areas in the least humid of Garnier's divisions.

Rainfall and evaporation were observed at coastal sites during the period of study, since both were known to vary considerably from place to place. Local wind information would also have been useful but instrumentation was not available. The methods used to collect rainfall and evaporation data are as follows.

Ten wooden boxes were constructed (Fig. 3.1) each 3'x2'x2', with the front side a hinged door. Two holes were cut in the top of the box, and in each hole a metal funnel was placed with a surface area of 112 sq. cms. Coconut matting was laid on top of the box to simulate a ground surface, so that the funnel tops were level with the surface. A lighthouse wick was placed in one funnel with its lower end projecting through, and surrounded with cotton wool to give a level surface. Inside the box a jar was placed below the empty funnel to collect the rain, and a metal canister on a stand below the full one to hold the projecting part of the wick. An overflow pipe connected the metal cannister to an overflow jar. When placed in position the evaporimeter canister was filled with water to overflowing and once in equilibrium the excess discarded. Every three days (or other known period) the water in the rainfall jar was poured off into a

Fig. 3.1
One of the rainfall/evaporation/salinity gauges at River Bay. For explanation see text.

TABLE 3.6 RAINFALL AT WATERFORD 8-19.6.67, 21.6-5.7.67, 12-30.7.67 (in cms.)
(Data modified from McGill University Climatic Observations , 1967)

Date	Rainfall	Date	Rainfall	Date	Rainfall
8-11	0.03	21-24	0.42	12-16	0.33
11-14	0.07	21-26	0.47	16-20	0.58
14-17	0.00	24-30	0.28	20-28	1.32
17-19	2.01	26-30	0.22	28-30	0.30
		30- 5	2.92		

Fig. 3.1
One of the rainfall/evaporation/salinity gauges at River Bay. For explanation see text.

TABLE 3.6 RAINFALL AT WATERFORD 8-19.6.67, 21.6-5.7.67, 12-30.7.67 (in cms.)
(Data modified from McGill University Climatic Observations , 1967)

Date	Rainfall	Date	Rainfall	Date	Rainfall
8-11	0.03	21-24	0.42	12-16	0.33
11-14	0.07	21-26	0.47	16-20	0.58
14-17	0.00	24-30	0.28	20-28	1.32
17-19	2.01	26-30	0.22	28-30	0.30
		30- 5	2.92		

measuring cylinder calibrated with the size of the funnel-top and the figure noted. The amount of water (if any) in the overflow jar was also noted. The evaporimeter canister was then topped up from a known volume of water till overflow occurred. The amount of rainfall was added to the latter figure and any overflow (excess rain over evaporation) subtracted. The result, divided by the amount of days since the last measurement, gave the average daily evaporation.

Three circuits were devised to measure the variation in rainfall and evaporation around Barbados, each approximately covering $\frac{1}{3}$ of the island's coast, and each including selected Windward and Leeward points. The first circuit covered the northern part of the island, the second the central part both east and west and the third was along the south coast (Fig. 3.2). Circuits 2 and 3 included a control station at Edgehill. At each coastal location two or more instruments were set up in line at a known distance from high water mark in order to measure any changes that occurred inland. The exact height and distance from the sea of each instrument is shown in Table 3.1. Readings were maintained for 12 or more days on each circuit and a variety of weather conditions were included.

Skeete (1963) gives an average precipitation figure of 60 inches for the period 1847-1960 but since variation is great both from year to year and from place to place over the island, this has little meaning. Fig. 3.3 shows the average rainfall 1908-1961 from stations nearest the coastal locations examined and includes Rouse's (1966) 65 inch isohyet. Deviations of rainfall of up to 70% from the mean annual values have occurred this century (Rouse 1966). Similarly in a single year one station on the island may record up to 35 inches more rain than another. Much of the precipitation

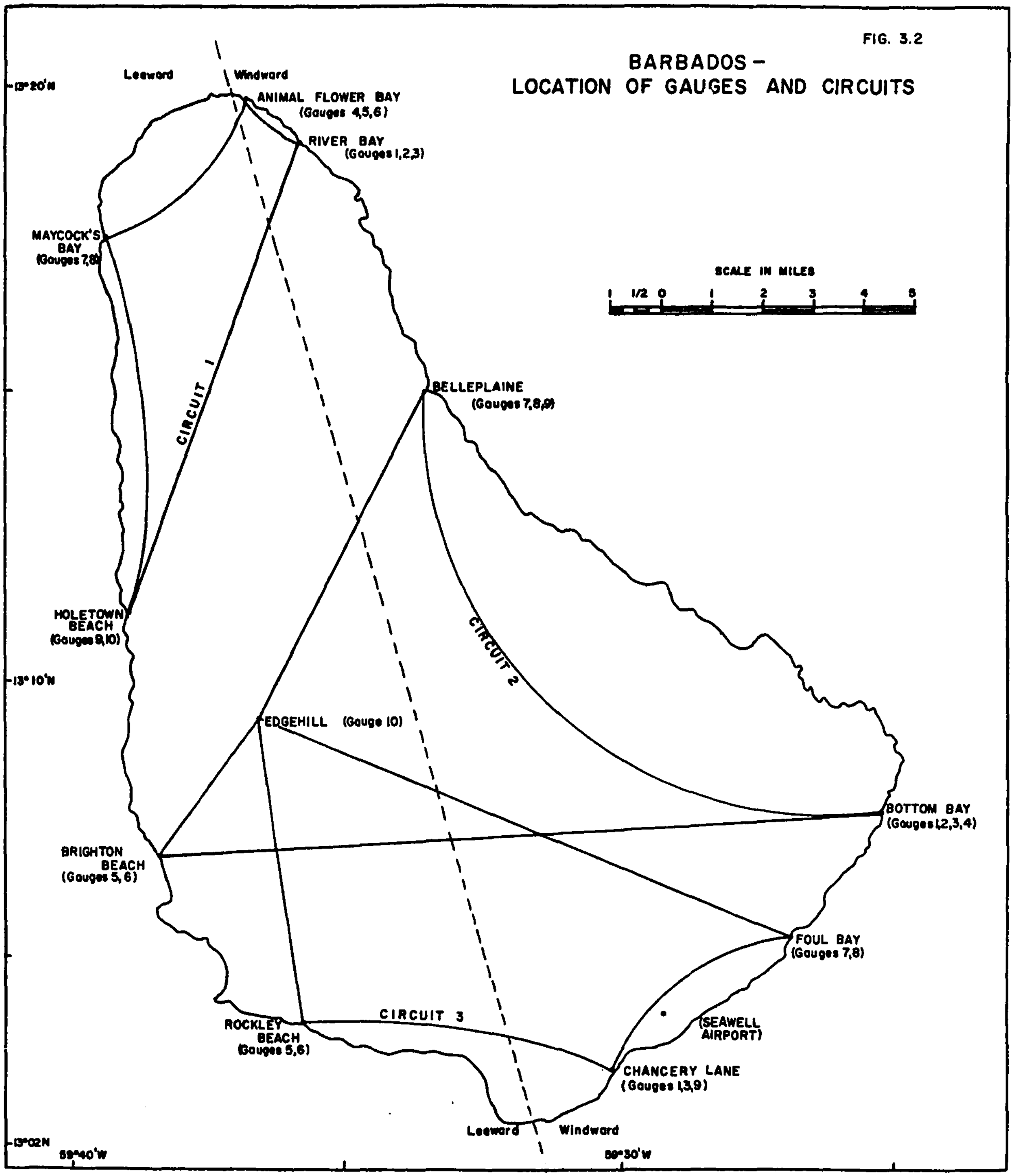
FIG. 3.2
BARBADOS -
LOCATION OF GAUGES AND CIRCUITS
Leeward
Windward
ANIMAL FLOWER BAY
(Gauges 4,5,6)
RIVER BAY
(Gauges 1,2,3)
MAYCOCK'S
BAY
(Gauges 7,8)
SCALE IN MILES
1 1/2 0 1 2 3 4 5
CIRCUIT 1
BELLEPLAINE
(Gauges 7,8,9)
HOLETOWN
BEACH
(Gauges 9,10)
CIRCUIT 2
EDGEHILL (Gauge 10)
BOTTOM BAY
(Gauges 1,2,3,4)
BRIGHTON
BEACH
(Gauges 5,6)
FOUL BAY
(Gauges 7,8)
CIRCUIT 3
(SEAWELL
AIRPORT)
ROCKLEY
BEACH
(Gauges 5,6)
CHANCERY LANE
(Gauges 1,3,9)
Leeward
Windward
13°20'N
13°10'N
13°02N
59°40'W
59°30'W

TABLE 3.1 LOCATION OF EVAPORATION/AERIAL SALINITY INSTRUMENTS

	Gauge No.	Distance From Sea (feet)	Distance Above Sea (feet)
Circuit 1			
River Bay	1	10	1
	2	65	54
	3	30	1
Animal Flower Bay	4	900	78
	5	500	61
	6	110	58
Maycock's Bay	7	35	7
	8	130	9
Holetown	9	72	1
	10	12	2
Circuit 2			
Bottom Bay	1	50	7
	2	190	-3
	3	255	25
	4	475	31
Brighton	5	12	3
	6	78	5
Belleplaine	7	315	20
	8	495	7
	9	750	10
Edgehill	10	inland	
Circuit 3			
Chancery Lane	1	42	6
	3	260	6
	9	148	9
Rockley Beach	5	3	2
	6	90	2
Foul Bay	7	135	-5
	8	35	2
Edgehill	10	inland	

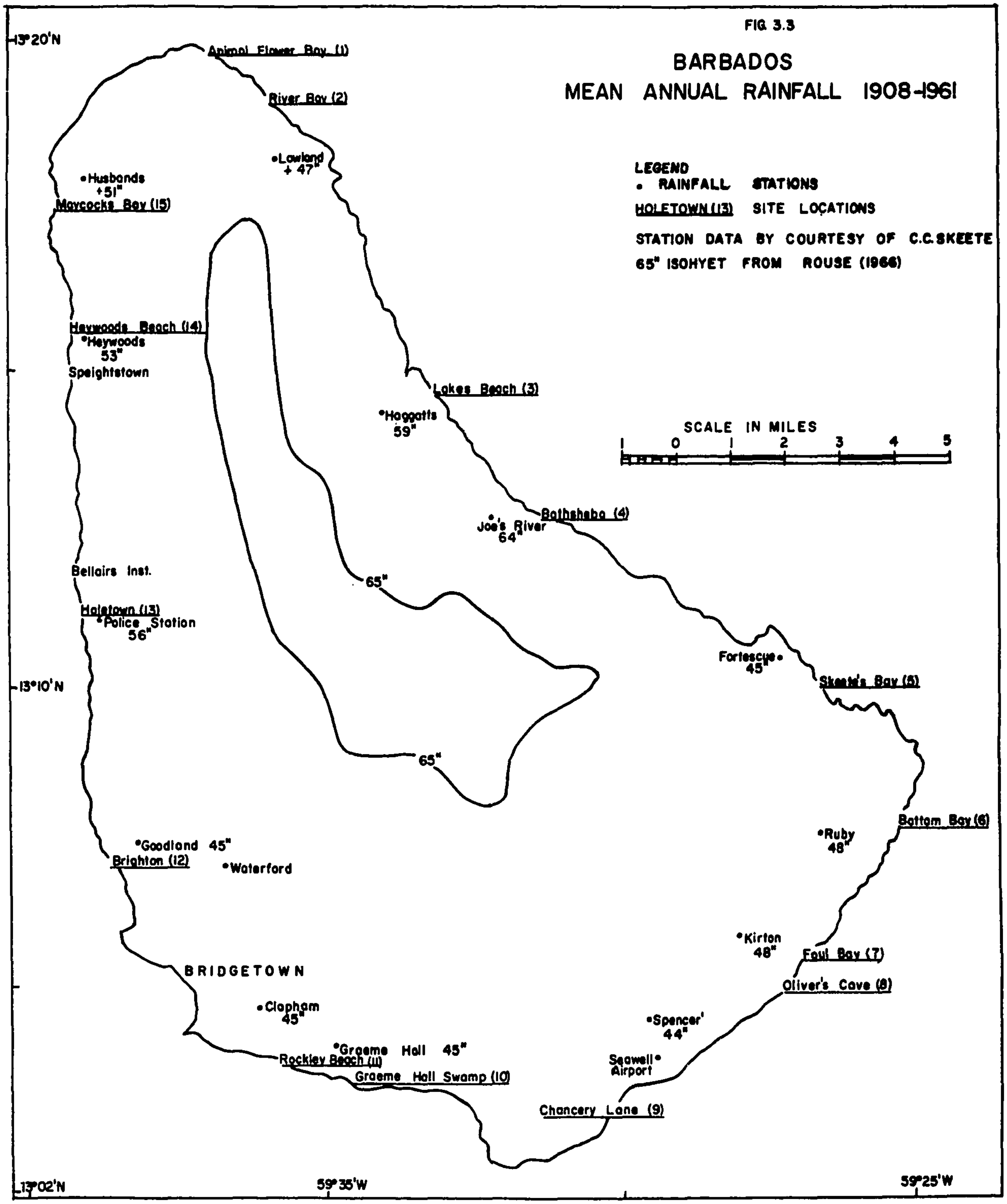
FIG 3.3
BARBADOS
MEAN ANNUAL RAINFALL 1908-1961
LEGEND
• RAINFALL STATIONS
HOLETOWN (13) SITE LOCATIONS
STATION DATA BY COURTESY OF C.C.SKEETE
65" ISOHYET FROM ROUSE (1966)
SCALE IN MILES
1 0 1 2 3 4 5
13°20'N
13°10'N
13°02'N
59°35'W
59°25'W
Animal Flower Bay (1)
River Bay (2)
Lowland + 47"
Husbands +51"
Maycocks Bay (15)
Heywoods Beach (14)
Heywoods 53"
Speightstown
Lakes Beach (3)
Haggatts 59"
Bathsheba (4)
Joe's River 64"
65"
Bellairs Inst.
Holetown (13)
Police Station 56"
Fortescue 45"
Skeete's Bay (5)
65"
Bottom Bay (6)
Ruby 48"
Goodland 45"
Brighton (12)
Waterford
Kirton 48"
Foul Bay (7)
Oliver's Cove (8)
BRIDGETOWN
Clapham 45"
Spencer' 44"
Graeme Hall 45"
Rockley Beach (11)
Graeme Hall Swamp (10)
Seawell Airport
Chancery Lane (9)

falls as heavy showers that last for less than half an hour but may give more than half an inch of rain. Of the 44 inches recorded in 1965, 49% fell in 19 days, each day with over half an inch (Table 3.2). These showers occur locally over the island when narrow belts of rain-clouds blow across. As a result a particular location will be deluged occasionally, then left a virtual desert. Usually rainfall occurs over the whole island only during cyclonic rain in the wet season.

The 1965 records from Waterford (McGill Univ. 1965) show (Table 3.2) that, in the wet season, periods of a week passed without appreciable rainfall, while during the dry season in May/June, 33 days passed with only one shower giving more than 0.1 inches. Such conditions are accentuated at the coast by the lower relief and by the porous nature of the sands, and sandy soils of the Coastal Association. On the other hand, when rain does fall, it is likely to occur on several consecutive days and thus be of use to the vegetation before evaporating.

The results of the rainfall observations made around the island in connection with evaporation studies during June and July 1967 are shown in Tables 3.3, 3.4, 3.5. By comparison the rainfall at Waterford over the same period is shown in Table 3.6. Considerable differences in rainfall were recorded from place to place over the same period. As an example, between June 17th and 19th, 0.4 cm. were recorded from Animal Flower Bay, 0.7 cm. from River Bay, one and a half miles away and 2.5 cms. from Holetown, 11 miles away. Before June 17th, seven days passed without rain at Animal Flower Bay and River Bay but at Holetown only two dry days were recorded.

Reference to Tables 3.3, 3.4, 3.5 and Table 3.1 shows that rainfall also varies with microtopography and exposure. At Belleplaine between

TABLE 3.2 RAINFALL FROM WATERFORD, January-December 1965, (in inches)

(Data modified from McGill University Climatic Observations Nos.18-20, 1965)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	0.20	x	x	0.15	x	x	x	x	x	x	0.11	x
2	x	0.40	x	x	x	x	x	x	x	x	x	x
3	x	x	x	x	x	0.30	x	x	x	x	0.15	x
4	x	x	x	x	x	0.25	x	0.12	x	x	0.82	x
5	x	x	x	0.26	x	0.12	x	x	x	x	x	x
6	x	0.28	x	x	x	x	0.22	x	x	x	x	x
7	x	x	x	x	x	x	x	x	x	x	x	0.46
8	0.12	x	x	x	x	x	0.53	x	0.16	0.19	x	0.25
9	0.59	x	x	x	x	x	0.23	0.55	0.36	0.41	x	x
10	x	x	x	x	x	x	0.19	0.10	0.15	x	x	0.12
11	x	x	x	1.09	x	x	0.33	x	2.00	x	0.30	0.20
12	0.14	x	x	x	x	x	0.75	x	0.19	0.72	x	0.10
13	0.15	x	x	0.31	x	x	0.29	x	0.74	x	x	0.57
14	0.13	0.15	x	x	x	x	0.41	0.23	0.40	x	x	x
15	x	x	x	0.10	0.13	x	x	0.29	x	x	x	x
16	0.44	x	x	1.41	x	x	x	0.32	x	0.21	x	x
17	0.21	x	x	0.92	x	0.10	0.34	0.10	0.19	0.68	x	x
18	x	x	0.36	x	x	0.36	x	0.25	x	x	x	x
19	x	x	x	x	x	x	x	x	x	x	x	x
20	x	x	x	x	x	x	0.10	x	x	x	x	x
21	x	x	x	x	x	x	x	0.13	x	x	x	x
22	x	x	x	x	x	x	0.11	0.14	x	x	x	0.70
23	x	x	0.14	x	x	x	x	x	x	x	x	0.11
24	x	x	0.15	x	x	x	x	x	x	0.66	x	x
25	0.15	x	0.38	x	x	x	x	0.13	0.48	x	x	2.45
26	0.21	x	0.14	0.18	x	x	0.12	x	x	0.24	0.47	3.35
27	0.22	x	x	0.17	x	x	0.26	x	0.30	x	x	x
28	x	0.15	x	x	x	x	x	x	0.30	2.05	x	0.29
29	x		x	0.11	x	0.48	0.22	x	0.86	x	x	x
30	x		0.24	x	x	0.11	0.22	x	x	0.16	x	x
31	x		x		x		x	x		0.24		x

x = under 0.1 inches rainfall.

TABLE 3.3 RAINFALL AT COASTAL SITES 8-19.6.67 (in cms.)

	1	2	3	4	5	6	7	8	9	10
8-11	0.3	0.3	0.3	0.2	0.2	0.2	0.4	0.4	0.1	0.1
11-14	0.0	0.0	0.0	0.0	0.0	0.0	0.05	0.05	0.2	0.2
14-17	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1
17-19	0.7	0.6	x	x	0.4	0.4	x	x	1.9	2.5
	River Bay			Animal Flower Bay			Maycock's Bay		Holetown	

TABLE 3.4 RAINFALL AT COASTAL SITES 21.6-5.7.67 (in cms.)

	1	2	3	4	5	6	7	8	9	10
21-24	0.3	0.3	0.3	0.5	0.2	0.2	x	x	x	x
21-26	x	x	x	x	x	x	0.2	0.2	0.15	0.2
24-30	0.1	0.1	0.1	0.1	0.2	0.1	x	x	x	x
26-30	x	x	x	x	x	x	0.3	0.3	0.25	0.2
30-5	1.7	1.7	1.6	2.0	3.6	2.0	1.0	1.9	1.5	4.0
	Bottom Bay				Brighton		Belleplaine			Edgehill

TABLE 3.5 RAINFALL AT COASTAL SITES 12-30.7.67 (in cms.)

	1	3	9	5	6	7	8	10
12-16	1.6	1.5	1.5	0.9	0.8	1.2	1.2	0.8
16-20	0.8	0.8	0.9	0.5	0.4	0.2	0.2	1.9
20-28	2.0	2.5	1.9	1.5	1.5	x	1.9	2.4
28-30	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.1
	Chancery Lane			Rockley		Foul Bay		Edgehill

June 30th and July 5th much more rain was collected Leeward of the front dune ridge than at the crest of the windswept dunes. At Holetown between June 17th and 19th more rain was collected on the foreshore than in the Manchineel (Hippomane mancinella) grove behind. But on the Animal Flower Bay plateau, no difference in precipitation was recorded by any gauge during the period of observation.

Records of evaporation at coastal locations (Tables 3.7, 3.8, 3.9) were compared with values computed using the Penman equation[1] and it was found that although correlation occurred, the coastal figures were consistently higher. Part of this increase is explained by the 'oasis' effect that occurs at the Coast (Garnier 1968). The greatest differences were between east and west coast sites. The former range between 0.80 cm. and 1.01 cms. per day and the latter range between 0.52 cm. and 0.64 cm. per day. In a study of the moisture balance of Barbados, Rouse (1966) shows a moisture deficit of over 20 inches in some coastal areas but in the extreme north and south where evaporation is high and rainfall is low this may be an underestimation.

Exposure to the wind seems to be the main factor that causes variation in evaporation from place to place. Figures from Bottom Bay (Table 3.8) illustrate this very well. Gauges 1, 3, and 4 are at exposed points, the former on the foreshore and the latter two on the cliff-top, and each has an evaporation loss of just under 1.0 cm. per day. Gauge 2 is in the protected valley between the rear of the beach dune and the cliff face and loses only 0.64 cm. per day. At Bottom Bay and Belleplaine (Table 3.8) and

[1]Data for the Penman equation were taken from Waterford (McGill Univ. 1967)

TABLE 3.7 EVAPORATION AT COASTAL SITES 8-19.6.67 (in cms.)

	1	2	3	4	5	6	7	8	9	10
8-11	3.1	3.0	3.0	2.8	2.9	2.8	1.8	1.5	1.7	2.1
av.	1.03	1.00	1.00	0.93	0.97	0.93	0.60	0.50	0.57	0.70
11-14	2.7	3.0	2.8	2.7	2.9	2.7	1.85	1.85	1.4	1.6
av.	0.90	1.00	0.93	0.90	0.97	0.90	0.62	0.62	0.53	0.60
14-17	2.9	2.9	2.8	2.5	2.8	2.7	1.9	2.0	1.6	1.9
av.	0.97	0.97	0.93	0.83	0.93	0.90	0.63	0.66	0.53	0.63
17-19	1.8	1.8	x	x	1.9	1.9	x	x	1.0	1.2
av.	0.90	0.90	x	x	0.95	0.95	x	x	0.50	0.60
Period av.	0.95	0.97	0.96	0.89	0.92	0.92	0.61	0.59	0.54	0.64
	River Bay			Animal Flower Bay			Maycock's Bay		Holetown	

TABLE 3.8 EVAPORATION AT COASTAL SITES 21.6.67-5.7.67 (in cms.)

	1	2	3	4	5	6	7	8	9	10
21-24	3.1	1.8	3.0	3.1	1.5	1.6	x	x	x	x
21-26	x	x	x	x	x	x	5.4	4.2	5.05	2.65
av.	1.03	0.60	1.00	1.03	0.50	0.53	1.08	0.84	1.01	0.53
24-30	5.1	4.4	5.6	5.5	3.4	3.6	x	x	x	x
26-30	x	x	x	x	x	x	3.8	2.6	3.05	2.15
av.	0.85	0.73	0.93	0.92	0.57	0.60	0.95	0.65	0.76	0.54
30- 5	4.2	2.5	4.8	5.0	2.4	2.6	5.0	3.9	4.3	2.7
av.	0.84	0.54	0.96	1.00	0.48	0.52	1.00	0.78	0.86	0.54
Period av.	0.89	0.64	0.96	0.97	0.52	0.56	1.01	0.76	0.89	0.54
	Bottom Bay				Brighton		Belleplaine			Edgehill

TABLE 3.9 EVAPORATION AT COASTAL SITES 12-30.7.67 (in cms.)

	1	3	9	5	6	7	8	10
12-16	3.3	3.9	3.3	2.3	2.3	3.1	3.4	2.2
av.	0.83	0.98	0.83	0.58	0.58	0.78	0.85	0.55
16-20	3.4	4.3	3.5	2.3	2.5	3.6	4.3	2.5
av.	0.85	1.08	0.88	0.58	0.63	0.90	1.08	0.63
20-28	6.7	6.8	6.0	4.5	5.7	x	7.5	4.8
av.	0.84	0.85	0.75	0.56	0.71	x	0.94	0.60
28-30	1.9	2.4	1.7	1.1	1.2	1.8	2.3	x
av.	0.84	1.20	0.85	0.55	0.60	0.90	1.15	x
Period av.	0.84	0.97	0.81	0.57	0.65	0.85	0.97	0.59
	Chancery Lane			Rockley Beach		Foul Bay		Edgehill

at Foul Bay (Table 3.9) the highest losses were observed at those gauges (3 and 4, 7, 8, respectively) situated at the highest elevations (Table 3.1). It will be seen from Table 3.9 that the highest gauge (9) at Chancery Lane records the smallest loss: this is because it is situated in the vale between two well-vegetated dune crests and is therefore considerably protected. The greatest evaporation occurs at gauge 3 which is inland from the dunes but exposed to the winds blowing across the now-drained Chancery Lane Swamps.

Gauges nearest high-tide mark lose less moisture than those further inland, where no other factors such as altitude or exposure influence evaporation. This point which is illustrated by gauges 4 (Table 3.7), 1 and 5 (Table 3.8) and 5 (Table 3.9), is a result of increased moisture content in the air caused by extreme proximity to the sea.

The northeast trade winds are dominant throughout the year blowing within an arc from east-southeast to northeast, but at certain periods winds may originate from north-northeast or even south, and in times of cyclonic disturbance, from west of north or south. Despite the fact that the latter occur only occasionally they are important to the vegetation of the Leeward coast.

Wind speeds show a cyclonic regime rising from a mean of 7.3 m.p.h. in October to a high of 12.6 m.p.h. in June, after which they decline, (Skeete 1963). Table 3.10 shows the mean monthly variation in wind speed but also illustrates that a daily cycle occurs with a high around mid-day and a low in the early hours.

Soil temperatures are high particularly on the beach and dune sands, but also on the poorly vegetated soils of cliff tops. Soil temperatures

TABLE 3.10 MEAN WIND SPEED 1963-66
(Based on 3-hourly readings from Seawell)

	0200	0500	0800	1100	1400	1700	2000	2300
Jan	9.1	9.1	10.0	12.5	12.5	10.8	11.8	10.1
Feb	10.7	11.0	11.6	12.9	12.5	11.9	10.3	10.2
Mar	11.8	11.4	11.8	14.1	13.7	12.0	10.9	11.7
Apr	11.0	10.9	11.7	13.3	12.9	11.1	10.7	11.2
May	13.4	12.6	13.6	14.7	14.4	12.7	12.7	12.8
Jun	11.2	12.5	13.7	14.5	14.0	13.0	12.4	12.8
Jul	10.9	10.1	11.0	12.5	12.4	10.7	10.0	9.9
Aug	8.1	8.1	9.6	10.5	10.5	9.3	7.9	8.0
Sep	7.3	7.1	8.8	10.3	10.3	8.5	7.8	8.5
Oct	6.7	6.2	7.8	9.5	8.0	9.2	6.9	7.0
Nov	8.6	8.1	9.3	11.4	10.5	9.1	8.1	8.7
Dec	9.1	8.7	9.4	11.3	11.6	9.9	8.5	9.2

TABLE 3.11 MEAN BARE SOIL TEMPERATURES MAY/SEPTEMBER 1967 (in ^{o}F)

	May		June		July		August		Sept.	
	08	17	08	17	08	17	08	17	08	17
<u>Surface</u>										
Animal Flower Bay	87	95	87	96	87	96	88	98	87	97
Belleplaine	88	118	88	118	90	124	90	129	90	120
<u>2" Depth</u>										
Animal Flower Bay	84	92	85	92	84	92	85	95	85	93
Belleplaine	86	104	86	105	87	109	87	113	87	109
<u>4" Depth</u>										
Animal Flower Bay	81	88	80	87	80	88	81	89	82	89
Belleplaine	82	96	82	98	81	100	82	101	84	100

were recorded at Animal Flower Bay and at Belleplaine Dunes during the period May to September 1967. The results are shown in Table 3.11. Soil temperatures at Animal Flower Bay compare favourably with those in bare soil at Waterford (McGill Univ. 1959-65), but they are much higher in the sands at Belleplaine. This is particularly true for observations from the surface and at two inches depth.

The difference between temperatures observed in the air and those within bushes or below mat plants is remarkable. A variation of over 20°F was found between the temperature immediately above a mat of seaside samphire and that below it, at midday in July and August. Similarly there was a 14°F difference in temperature between the air around, and that in the centre of a seaside lavender bush (Mallotonia gnaphlodes).

The climate of Barbados varies considerably both in terms of rainfall and evaporation. These two differ regionally around the island. In the north and south there is relatively low rainfall and high evaporation, resulting in the driest climates of the island. On the Windward coast rainfall is higher but evaporation is extremely high also. The Leeward coast has the most rainfall but the least evaporation. It is obvious that this will be of importance to the vegetation. But climate is also important to soils since the variable grain-size of the soil-types will cause differences in rainfall effectiveness while extremes of wind, salt and rainfall intensity are important factors of soil genesis.

CHAPTER 4

COASTAL SOIL SERIES

The soils of Barbados were mapped by Vernon and Carroll (1966). They divided them by parent material into two major groups: those of the Scotland District and those of the Coral Region (Fig. 4.1). However, since this study is concerned primarily with the coastal areas, the majority of 'soils' analyzed are composed of beach sands or coral rock fragments and only two of Vernon and Carroll's soil associations were examined.

Fifty soil samples were taken at various distances from the sea along the profile transects around Barbados. Samples were taken from between 1 cm. and 15 cms. below the surface. Each sample was analyzed for calcium carbonate, carbon, moisture, organic matter, pH and salt, and a grain-size analysis was also made. The methods used in these analyses are: calcium carbonate - Collin's Calcimeter; carbon - wet combustion; organic matter - per cent carbon x 1.72; pH - Metrohm mains pH meter; salt - Lock Conductivity Bridge; and grain size - sands by electrical shaker and silts and clays by hydrometer. A complete analysis of all samples is found in Table 4.1.

At Maycock's Bay, inland of the beach sand an example of the 'Very Shallow Associate' (shallower than 10 inches) of the Black Association is found. This is an immature smectoid clay soil which at this point[1] (Table 4.1, samples 49 and 50) has a large admixture of coral fragments from the cliff, and beach sand. The black colour of the soils of the association may be due (Singh 1956) to sorption[2] of organic matter upon montmorillonitic

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[1]The location of each soil sample is shown on the appropriate profile in Chapter 7, Figs. 7.1-7.15.

[2]See Vernon and Carroll (1966), page 21.

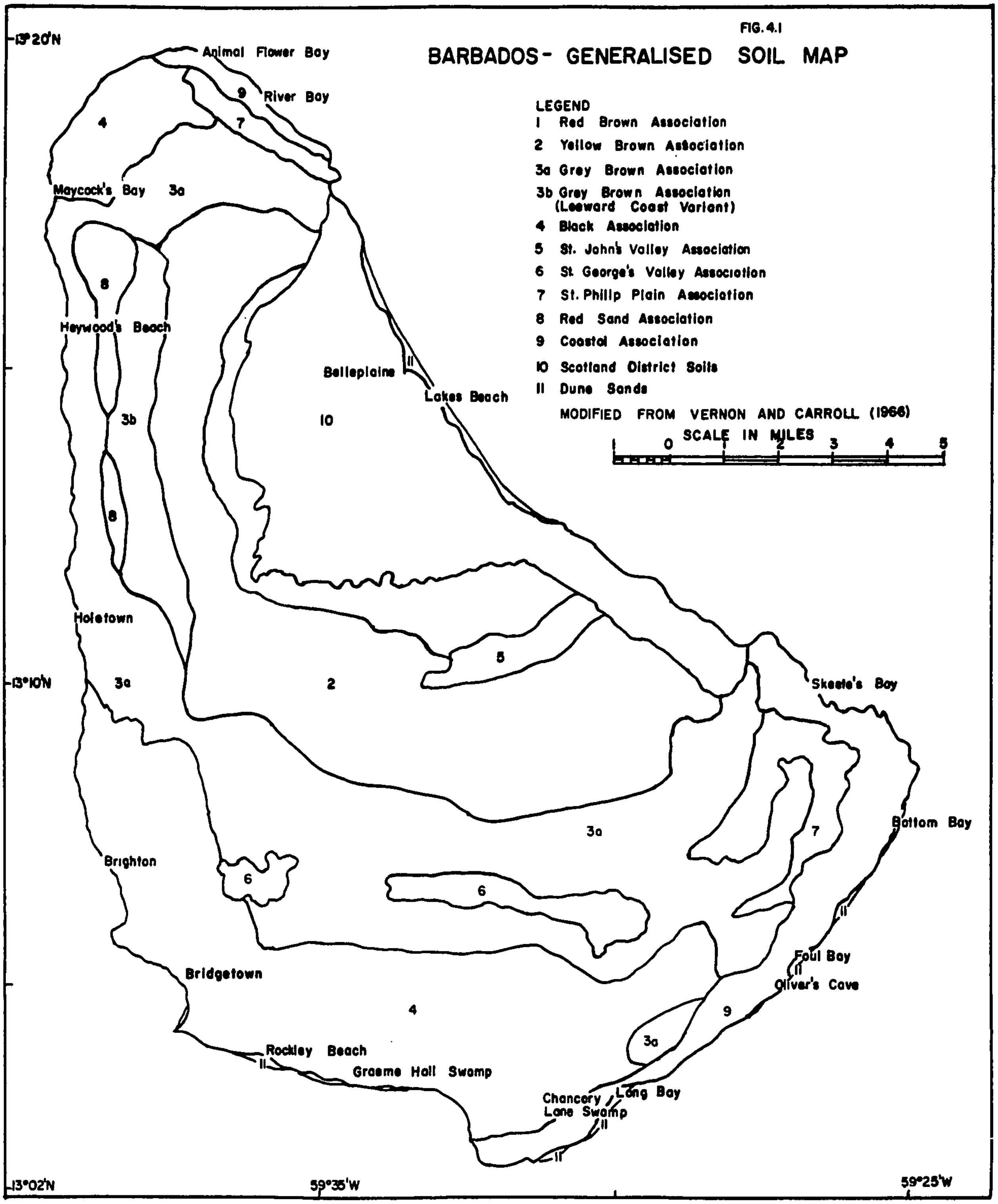
FIG. 4.1
BARBADOS - GENERALISED SOIL MAP
LEGEND
1 Red Brown Association
2 Yellow Brown Association
3a Grey Brown Association
3b Grey Brown Association (Leeward Coast Variant)
4 Black Association
5 St. John's Valley Association
6 St. George's Valley Association
7 St. Philip Plain Association
8 Red Sand Association
9 Coastal Association
10 Scotland District Soils
11 Dune Sands
MODIFIED FROM VERNON AND CARROLL (1966)
SCALE IN MILES
1 0 1 2 3 4 5
13°20'N
13°10'N
13°02'N
59°35'W
59°25'W
Animal Flower Bay
River Bay
Maycock's Bay
Heywood's Beach
Belleplaine
Lakes Beach
Holetown
Skeete's Bay
Bottom Bay
Brighton
Bridgetown
Foul Bay
Oliver's Cove
Rockley Beach
Graeme Hall Swamp
Chancery Lane Swamp
Long Bay

TABLE 4.1

ANALYSES OF BARBADOS COASTAL SOILS

Location	Sample number	Distance from sea feet	Height above sea feet	Gravel + >18	Coarse sand 18-35	Medium sand 35-60	Fine sand 60-120	Very fine sand 120-200	Silt 200-.005	Clay <.005	Moisture %	pH	Salt μ mhos per cm	$CaCO_3$ %	Carbon %	Organic matter %
ANIMAL	1	33	57.5	1.20	2.20	32.20	16.40	13.20	13.00	22.20	9.05	7.8	8836	36.5	0.73	1.26
FLOWER	2	100	58.2	0.00	1.30	26.10	15.50	14.90	16.00	26.20	4.82	7.6	6956	6.2	1.35	2.32
BAY	3	500	64.6	4.00	4.20	30.60	12.10	9.80	9.80	29.70	4.55	7.5	705	4.5	0.35	0.60
	4	765	75.2	3.00	3.80	25.00	13.30	11.70	14.30	28.90	4.31	7.1	268	7.7	2.21	3.80
RIVER	5	113	51.3	10.00	6.30	18.30	10.90	14.60	13.70	26.20	10.17	7.7	1880	8.0	1.95	3.35
BAY	6	90	24.6	66.90	6.00	7.90	4.20	5.30	5.95	3.75	9.35	7.9	1598	47.8	0.90	1.55
	7	33	0.9	55.95	19.15	22.40	1.50	0.55	0.20	0.25	4.81	8.0	508	66.4	0.15	0.26
	8	60	6.8	0.00	1.60	26.00	14.10	12.20	15.40	30.70	7.00	7.1	3807	5.1	1.95	3.35
	9	30	4.1	6.00	27.10	66.05	0.45	0.10	0.10	0.20	3.22	7.9	789	68.0	0.11	0.19
	10	18	8.2	45.60	14.45	15.35	5.60	4.80	6.10	8.10	1.87	7.7	517	63.6	0.76	1.30
	11	36	6.6	21.40	11.10	25.50	10.80	9.10	11.10	11.00	6.80	7.6	696	61.4	1.95	3.35
BELLEPLAINE	12	210	3.8	0.05	2.40	79.05	17.30	1.10	0.00	0.10	0.02	8.0	376	9.5	0.02	0.03
	13	315	20.0	0.00	1.10	67.95	27.65	3.00	0.20	0.10	0.03	8.0	136	10.9	0.04	0.07
	14	495	7.8	0.10	0.20	55.75	32.95	3.85	1.20	5.95	0.01	8.1	451	12.7	0.17	0.29
	15	650	13.6	0.85	0.55	52.95	38.40	6.00	0.70	0.55	0.01	7.9	188	12.9	0.28	0.48
	16	975	31.9	0.00	1.00	52.75	41.35	4.20	0.40	0.30	0.02	7.8	155	15.1	0.29	0.50
BATHSHEBA	17	6	0.3	0.15	7.30	89.20	3.05	0.10	0.00	0.20	0.03	7.9	268	19.4	0.02	0.03
	18	80	3.9	0.70	4.65	82.55	7.95	1.20	1.20	1.75	0.80	7.7	259	14.7	0.53	0.91
SKEETE'S	19	55	1.4	1.30	0.30	3.45	46.45	44.30	4.05	0.15	0.82	7.9	343	57.6	0.08	0.14
BAY	20	105	23.0	2.00	9.10	31.60	11.80	8.90	8.20	28.40	3.80	7.4	3102	34.7	0.64	1.10
BOTTOM	21	18	7.0	1.00	20.40	66.80	9.80	1.80	0.10	0.10	1.18	7.9	348	81.6	0.10	0.17
BAY	22	150	3.2	0.75	4.95	59.60	25.65	6.55	1.30	1.20	0.82	7.9	208	78.7	0.54	0.93
	23	190	-2.5	42.95	11.10	28.80	11.40	4.10	1.00	0.65	2.45	7.9	263	68.8	0.29	0.49
	24	255	24.9	4.70	24.60	45.65	11.95	6.10	3.85	3.15	8.60	7.8	376	32.3	2.71	4.67
	25	475	30.8	0.10	3.00	27.00	15.90	15.10	12.20	26.70	11.06	7.9	375	10.1	1.85	3.18
FOUL	26	36	0.8	2.50	31.15	40.85	19.10	6.10	0.20	0.10	0.08	7.9	188	99.0	0.12	0.21
BAY	27	70	0.5	0.90	15.90	58.40	18.70	4.70	0.70	0.70	0.08	7.9	134	92.5	0.50	0.86
	28	135	-5.0	4.60	18.00	54.50	13.20	5.10	2.40	2.20	9.20	7.1	7802	59.6	0.81	1.39
	29	285	-1.2	11.20	17.60	48.15	11.25	5.40	3.50	2.90	10.26	7.1	338	50.4	1.95	3.35
OLIVER'S	30	12	8.6	25.80	55.55	11.15	2.50	1.05	0.40	0.55	0.74	7.8	752	82.0	0.22	0.38
CAVE	31	105	41.8	41.60	21.90	18.45	5.70	8.50	4.20	3.85	6.80	7.7	409	34.2	1.42	2.44
	32	180	82.0	0.00	9.10	28.40	11.90	9.00	13.60	28.00	10.01	7.8	400	5.0	1.60	2.75
CHANCERY	33	1	0.5	0.40	14.10	65.10	14.90	5.05	0.35	0.10	1.16	8.6	338	98.8	0.12	0.21
LANE	34	42	6.1	0.40	9.50	60.00	18.85	10.05	0.90	0.30	2.03	7.8	235	98.8	0.26	0.45
	35	78	14.0	0.35	13.15	75.90	5.50	3.60	0.80	0.70	0.12	7.9	155	98.0	0.62	1.07
	36	147	11.6	0.30	1.10	25.40	40.55	26.40	4.50	1.75	2.05	8.2	127	86.4	0.35	0.60
	37	261	6.1	4.70	22.10	42.40	12.90	7.80	4.90	5.20	8.74	7.9	564	33.8	1.22	2.10
GRAEME HALL	38	39	1.8	0.05	0.75	3.30	20.50	54.85	20.40	0.15	4.40	7.9	221	99.0	0.11	0.19
SWAMP	39	207	0.9	2.95	16.65	28.05	21.35	19.95	7.60	3.45	14.91	7.6	6760	80.4	0.80	1.38
ROCKLEY	40	3	1.9	4.40	28.95	42.65	13.10	9.10	1.60	0.20	0.41	7.9	169	73.2	0.61	1.05
BEACH	41	92	2.0	0.85	5.20	17.65	28.95	36.20	8.70	2.45	0.90	7.9	174	69.7	0.80	1.38
BRIGHTON	42	12	3.0	4.40	18.45	44.90	25.25	6.30	0.40	0.30	0.05	7.9	202	92.0	0.17	0.29
	43	78	5.0	10.10	8.35	53.15	21.45	4.00	1.30	1.65	1.25	7.9	118	75.3	0.61	1.05
HOLETOWN	44	12	2.2	1.00	9.50	66.90	19.60	2.70	0.10	0.20	0.02	7.9	212	87.2	0.08	0.14
	45	72	1.7	7.20	7.25	50.75	26.65	6.40	0.90	0.75	0.49	7.8	155	81.6	0.36	0.62
	46	165	3.5	4.70	8.25	52.25	20.85	5.90	3.70	4.35	0.16	7.8	110	72.4	0.62	1.07
HEYWOOD'S	47	9	1.7	1.50	13.70	72.00	11.50	1.20	0.10	0.10	0.43	8.8	291	92.4	0.11	0.19
MAYCOCK'S	48	36	5.6	4.35	38.20	57.20	0.20	0.00	0.00	0.05	1.11	7.9	212	90.4	0.04	0.07
BAY	49	100	7.5	0.00	15.00	44.10	9.10	8.20	8.00	15.60	7.11	7.8	179	45.8	1.95	3.35
	50	125	8.8	25.00	8.70	15.80	7.40	9.10	11.90	22.10	7.80	7.6	127	16.5	1.95	3.35

clay.

Saint (1934) made a mechanical analysis of this soil, which usefully compares with sample 50 from Maycock's Bay (Table 4.2).

TABLE 4.2 COMPARATIVE ANALYSES OF SURFACE HORIZONS OF BLACK ASSOCIATION

Saint (1934)	%	Sample 50	%
Coarse sand	2.51	Coral fragments	19.00
		Coarse/medium sand	19.45
Fine sand	11.24	Fine/very fine sand	13.20
Silt	9.16	Silt	9.60
Clay	59.52	Clay	17.60
Moisture	8.80	Moisture	7.80
$CaCO_3$	7.08	$CaCO_3$	10.30
Loss in solution	2.19	Organic matter	3.35
Total	100.50	Total	100.30

Soils of the Coastal Association are found in the north, and southeast of Barbados (Fig. 4.1). These are shallow, immature soils which occur wherever rainfall is low and irregularly distributed and where soils are exposed to strong winds and salt blast. These soils are dark brown clays with an admixture of sand and coral fragments.

At Animal Flower Bay, River Bay, Skeete's Bay, Bottom Bay and Oliver's Cave there are examples of the 'Very Shallow Associate' (shallower than 10 inches) on the cliff-slopes and cliff-tops. (Samples 1, 2, 3, 5, 8, 20, 25, 32). At Animal Flower Bay an example (sample 4) of the 'Shallow Associate' (between 10-18 inches) is found, though this is not mapped by Vernon and Carroll(1966).

There are two other coastal soils that are not strictly members of the

Coastal Association but are included with it by Vernon and Carroll (1966) for convenience. These are the South Coast Member which occurs behind the dunes at Chancery Lane (sample 37) and the East Coast Member which is found inland from the beach at Holetown (sample 46), and possibly behind the beach at Heywood's (not sampled). The former has developed over the marly parent material of Chancery Lane Swamp and is imperfectly drained, but contains a high proportion of coral grit and sand. The latter has formed over calcareous sandy material and is similar to the Grey-Brown Association within which it occurs. The main difference is a higher proportion of coral grit throughout the profile.

Little quantitative data on the Coastal Association soils have been published. The samples examined had between 22.2% and 30.7% clay content, which, with a considerable quantity of sodium chloride present was deflocculated and impermeable in times of torrential rain, (Fig. 4.2). Sand content is high in most cases giving friability and weak structure. In times of drought the soils desiccate, large polygonal cracks occur on the surface (Fig. 4.3) and much of the vegetation dies. Even though its moisture-supplying capacity is low, the moisture content of these soils is often high (samples 25, 32).

On many of the coastal cliff-slopes soils have been unable to develop because of topography. The rooting medium is mainly weathered and crushed coral fragments one to three inches deep situated immediately above unweathered coral bedrock. Examples of this are found at River Bay (samples 6, 10, 11), Oliver's Cave (sample 31), and Bottom Bay (samples 23, 24). Often these samples are markedly bimodal in grain-size distribution. There are quantities of large irregularly shaped coral fragments, little inter-

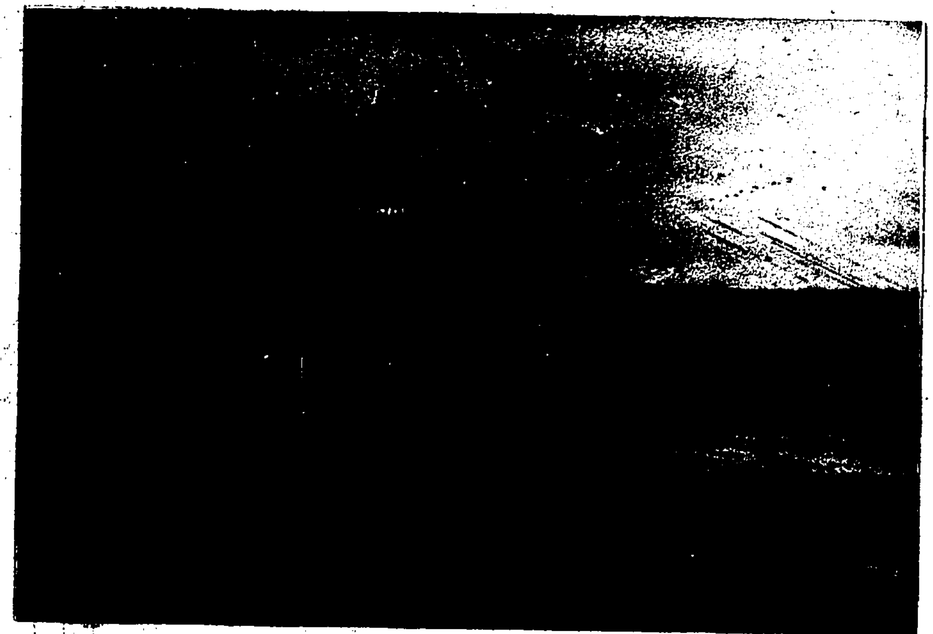

Fig. 4.2
Coastal Association soils at Animal Flower Bay showing impermeability after heavy rainfall, causing flooding in lower areas.

Fig. 4.3
Similar soils to Fig. 4.2 in dry season, showing polygonal cracking and desiccation. These soils have quite a large sand content and separate into crumb structures which are easily blown by the wind. Most of the vegetation is small seaside lavender but left front is seaside samphire.

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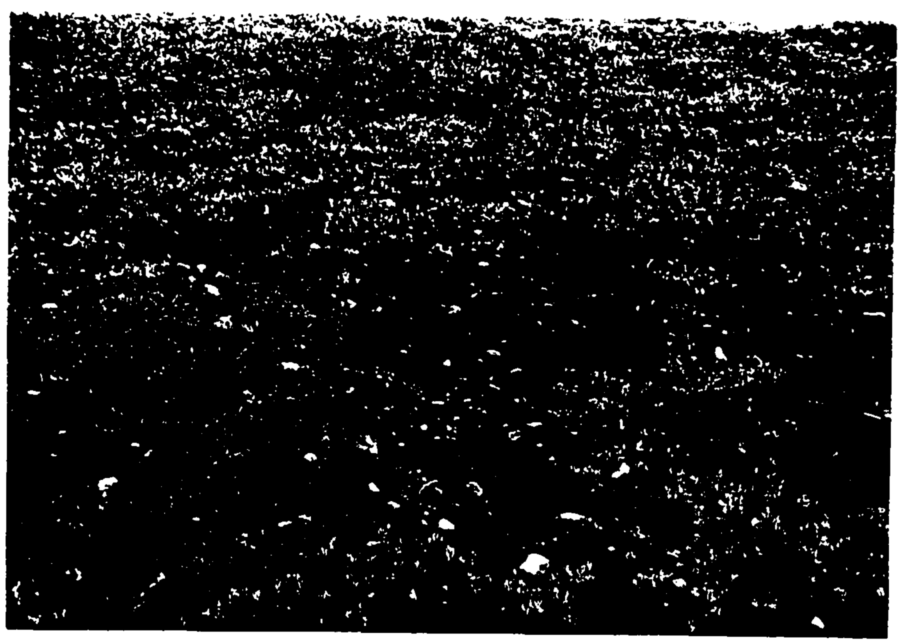
Coastal Association soils at Animal Flower Bay showing impermeability after heavy rainfall, causing flooding in lower areas.



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mediate-sized material and a considerable amount of coral dust. Extractable calcium content is high, around 50%, carbon content is also quite high - up to 3.5%, and pH is alkaline between 7.6 and 7.8.

All 31 other samples taken were beach sand. There is a basic division between the siliceous sands of the Scotland District (samples 12-18) and the coral sands of the rest of the island, which is illustrated by their $CaCO_3$ content. In the former this ranges between 9.5% and 19.4% and in the latter between 66.4% and 99.0%. Gooding (1947) suggests 20-25% $CaCO_3$ at Belleplaine but no sample was recorded in 1967 with concentrations of that level. The beach sand at Skeete's Bay (sample 19) has 57% $CaCO_3$ and is a mixture of sands from the two areas.

All beach sands have a carbon content below 0.5% and all are alkaline in reaction. Around most of the island foreshore sands with a pH of 7.9 occur though at Belleplaine, Chancery Lane and Heywood's Beach the pH is more alkaline. Gooding (1947) found a regular decrease inland at Belleplaine from pH 8.5 to pH 7.5 but a much smaller range occurs at present. Most beach sands record a moisture content of under 1%, since any rain that falls passes through very quickly. Where samples were taken close to high tide mark, higher moisture figures were obtained because of the influence of spray.

All parameters of the soil samples were normalized with the 'Normstand' computer programme (see Appendix IV) and subjected to a simple correlation and regression analysis with the 'COR-DP' programme (see Appendix IV), in order to discover where the closest relationships occur. In order to normalize the data the following transformations were used:-

Log for: clay, salt, carbon and organic matter

Square root for: coarse sand, fine sand, silt and moisture

Cube root for: distance, height, gravel and very fine sand

No transformations were necessary for medium sand, pH or $CaCO_3$. Of the 105 correlations theoretically possible, 56 proved significant at greater than the 10% level. Since the primary pattern found in the coastal vegetation of Barbados is a zonation parallel to the sea, those parameters of the soil that correlate with distance from the sea are the most useful to describe.

Quantities of coarse sand were found to decrease significantly with distance from the sea. Conversely quantities of fine sand, silt and clay increased significantly with distance (silt was significant at the 10% level, the others at the 1% level). This means that there is a regular decrease in the size of soil particles away from the sea. Quantities of $CaCO_3$ also decreased significantly with distance except at Belleplaine (samples 12-16) where there is an increase in calcium carbonate with increase in distance from the sea. This is at variance both with the norm found in Barbados and with that described by Salisbury (1952) but may possibly be explained by the decrease in importance with time, of the dead coral reef offshore, for supplying parent material to the beach and dunes. If this is true the difference should be greater than that shown by the figures (Table 4.1) since chemical weathering and loss in solution would work in the opposite direction. At Bathsheba, the other beach sampled within the siliceous district (samples 17-18), the $CaCO_3$ content, although still low, is higher than at Belleplaine because of the influence of large coralline boulders decomposing on the beach and just offshore. The latter mask any effect of offshore coral and the usual negative relationship of $CaCO_3$ with distance is maintained.

These relationships of grain-size and calcium with distance are associated with two other factors, pH and carbon content, which also significantly correlate with distance. The quantity of carbon increases with distance because the smaller soil particles can retain more humus. Furthermore increasing distance from the sea results in a less adverse habitat and thus a greater plant biomass. The soil becomes more acid in reaction as it is less affected by saline salts and as decaying plant matter increases in quantity.

Increasing height results in a similar set of relationships to increasing distance. Amounts of coarse sand, medium sand and $CaCO_3$ decrease with increasing height above sea level while those of silt, clay, carbon and moisture increase. Since height of land always increases with distance from the sea, the majority of these relationships would be expected. The correlation between increasing moisture and height is, like pH and carbon, associated with increasing quantities of small particles in the soil. The reason this does not show as varying significantly with distance is because there are several high-moisture soils at high altitudes quite close to the sea, as at Animal Flower Bay, River Bay and Oliver's Cave.

Another factor is that quantities of $CaCO_3$ have a positive relationship with those of coarse sand and a negative one with those of silt and clay. This shows that the coral sand grains are predominantly coarse in size. Nevertheless there are anomalies in this relationship. At the mouth of Greame Hall Swamp the beach sand (sample 38) is coral but is also very fine, while at Oliver's Cave (sample 30) some of the coral grains were the size of gravel. The siliceous sands on the other hand are predominantly

TABLE 4.3 CORRELATION COEFFICIENT MATRIX: FACTORS OF BARBADOS COASTAL SOILS

Legend:
< 0.1680 - not significant at 10% level
0.1680-0.2010 - significant at 10% level
0.2010-0.2680 - significant at 5% level
> 0.2680 - significant at 1% level

ROW	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	1.0000														
2	0.4112	1.0000													
3	-0.1862	-0.1406	1.0000												
4	-0.4664	-0.2971	0.4665	1.0000											
5	-0.0834	-0.2970	-0.4147	0.0755	1.0000										
6	0.3891	-0.0126	-0.4728	-0.6327	-0.0341	1.0000									
7	0.1942	0.1947	-0.1851	-0.4702	-0.6476	0.5898	1.0000								
8	0.2500	0.5054	-0.0319	-0.3570	-0.7093	0.0763	0.7297	1.0000							
9	0.4005	0.5655	0.0774	-0.2489	-0.4783	-0.0314	0.3993	0.8137	1.0000						
10	0.1664	0.2921	0.2641	0.0835	-0.5435	-0.2992	0.3476	0.7110	0.6596	1.0000					
11	-0.3326	-0.1677	-0.1201	0.0195	0.2933	0.1161	-0.1906	-0.4801	-0.5627	-0.4657	1.0000				
12	-0.0347	0.2224	0.0755	-0.0223	-0.2997	-0.2016	0.1394	0.4299	0.4538	0.5972	-0.4159	1.0000			
13	-0.6116	-0.5923	0.1880	0.4842	0.1041	-0.0314	-0.0458	-0.4055	-0.5744	-0.2944	0.3902	-0.2814	1.0000		
14	0.3123	0.3770	0.2044	0.0110	-0.4705	-0.0299	0.4347	0.7097	0.8298	0.6854	-0.5266	0.2828	-0.2937	1.0000	
15	0.3100	0.3767	0.2056	0.0141	-0.4743	-0.0270	0.4374	0.7085	0.8256	0.6841	-0.5229	0.2808	-0.2848	0.9998	1.0000

medium in size and no sample had under 50% by weight medium sand, including those at Belleplaine with coralline additions. A complete breakdown of the relationships between the soil factors is given in the correlation coefficient matrix, Table 4.3.

The analysis of the climate of Barbados showed that there was little variation of any factor at any one site, but a considerable difference occurred between certain areas. Soil parameters, conversely, have shown a distinct distribution pattern at each locality, even within regional soil-types. Certain factors increase regularly with distance from, or height above the sea, while others decrease.

Thus an idea of the coastal environment is developed in which topography and climate have a broad regional pattern and soils a locative pattern. Superimposed upon this and affected by all three factors is a fourth major environmental influence, salt, which is blown from the sea in spray. Salt is important both in the soil and in the air and its deposition is affected by topography. Therefore, although in all its various forms it is possibly the predominant factor of the coastal environment, it is described last because of its interactions with those parameters previously described.

CHAPTER 5

SALT

Although salt has not been mentioned at length earlier, it is one of the most important factors of the coastal environment and as such deserves a separate chapter. Salt is present in the air, in the soil, on the ground and on the aerial parts of plants.

The source of the salt is spray blown inland from breaking waves. The salt is primarily sodium chloride but includes small quantities of other salts[1]. The methods by which droplets of sea water detach themselves from the main body of the sea were shown by Stuhlman (1932). Some salt is sent a few yards inland by the detachment of foam from the caps of breaking waves, but most of the salt-spray comes from a jet of water which occurs when bubbles, formed by the meeting of incoming waves and backwash, burst. This jet rises into the air, becomes an unstable column and breaks into drops. With rougher seas, larger bubbles are produced and consequently there are larger jets and more droplets. These droplets are small enough to be carried inland by winds of low speeds which occur at the sea-air interface. With high winds the larger drops that form when surf breaks on the land may also be carried inland. Thus the primary factors that cause variation in quantities of salt in the area of coastal vegetation are wind speed and direction, and wave amplitude. Since high wave amplitudes (Lewis 1960) most commonly occur on the Windward coast of Barbados the factor of salt-spray is almost important there.

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[1]The composition of ocean salts is described by Odum (1959) p. 331

The importance of soil salt as a control of littoral plants has often been questioned. Some authors consider that most coastal vegetation is halophytic, but Kearney (1904) and others found extremely low concentrations of dissolved salts within dune soils, which suggests that saline soil-water is not a limiting factor for psammophytes. To measure soil-salt content, 6 gms. soil was mixed with 50ccs. of distilled water and the conductivity read, in micromhos per cm.[1], from a Lock Conductivity Bridge. It was found that in the sands analysed there were no concentrations of salts higher than the maximum present in the cultivated soils of the island. The reason for the low concentrations of salt within the sand soils is that with the large pore-space and high permeability of the medium, most salts are leached through by even small amounts of rain. Thus a negligible quantity of chloride is absorbed by the roots of dune plants.

On the other hand many of the non-sand soils examined had very high salt contents. In fact the quantity of salts in the soil appears to have an inverse relationship to distance from high water mark and a positive relationship to increase in silt and clay content of the soil. Almost every group of soil samples shows this (Table 4.1) but data from Animal Flower Bay (samples 1-4), Lakes Beach, Belleplaine (samples 12-16) and Skeete's Bay (samples 19-20) are particularly illustrative (Table 5.1).

When the factors of distance, soil-salt and clay (Table 4.1) were normalized and subjected to a simple correlation and regression analysis, it was found that there was a 1% significant relationship between the log of soil-salt and the log of clay content. When samples containing more than

[1]For conversion of electrical conductivity to other measures of salt content see Appendix 1.

10% clay were deleted and the analysis repeated, a similar relationship was found between the cube root of distance and the log of soil-salt.

TABLE 5.1 CLAY-SALT-DISTANCE RELATIONSHIPS AT THREE LOCATIONS

Location	Sample Number	Clay (%)	Salt in μ/mhos/cm. 6gms. soil in 50ccs. H_2O	Distance from sea in feet
Animal Flower Bay	1	22.20	8836	33
	2	26.20	6956	100
	3	29.70	705	500
	4	28.90	268	765
Belleplaine	12	0.10	376	210
	13	0.10	136	315
	14	5.95	451	495
	15	0.55	188	650
	16	0.30	155	975
Skeete's Bay	19	0.15	343	55
	20	28.40	3102	105

At Animal Flower Bay four Coastal Association soils with basically similar physical characteristics were examined. The sample nearest the sea had the greatest quantity of sand and lowest of clay; pH and soil moisture decreased with distance from the sea. The soil-salt content near the sea was 8836 μ mhos/cm., (much higher than for the sand soils), but it decreased to 268 μmhos/cm. 765 feet inland. At Belleplaine the soil medium is siliceous sand so that although the quantity of aerial salt received is similar, the amount retained in the soil is much less. Nevertheless a reduction in quantity with distance from the sea still occurs. Within the _Philoxera vermicularis_ dunes 376 μmhos/cm. were recorded and at 975 feet inland the figure was 155 μ mhos/cm. The effect of topography is seen in samples 13 and 14. A low salt content occurred at the dune crest (13) where particle removal is constantly taking place. In the lee of the fore-

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For any given soil type concentrations of soil salts are much higher on the east coast than on the west. Nowhere on the west coast was salt concentration greater than 300 μmhos/cm. The highest, 291 μmhos/cm. was recorded at Heywood's Beach only nine feet from high-tide mark. Both at Holetown and at Maycock's Bay, concentrations decreased away from the sea despite the increase of clay in the soil. This shows how small a part the trade winds play in salt dissemination on the west coast and also the importance of foam derived particles in the near-sea regions.

It appears that, on the sandy beaches and dunes, quantities of salt in the air and on the plant/ground surface are more important ecologically than the amount of salt in the soil. Aerial salinity was measured in some parts of the island by Hudson (1963) who produced a generalized contour map showing the approximate amount of salt present over the whole island, but no measurements were made at the coast.

Aerial salinity was measured as follows. Ten instruments were constructed (see Fig. 3.1) to fit on to the evaporimeter boxes. From the top of each box a piece of 'Glasslite' measuring 2 ft. x 2 ft. was fixed, held secure at its outer edge by a cord joined to a weight on the ground. This cover was large enough to act as protection from the rain but not so large as to interfere with the wind. Under the 'Glasslite', and also joined to the evaporimeter box was a wooden supporting strip into which two hooks were screwed. A piece of washed towelling, one foot square with tabs at each corner, was suspended from these hooks and kept vertical by a heavy wooden strip also containing two hooks, suspended below. The towelling was between one and two feet above ground level. The instrument was exposed directly into the face of the prevailing trade winds and towels were replaced every 24 or 48 hours. The replacement was made at the same time for each station and took place between 4.30 p.m. and 5.30 p.m. when the wind speed tends to be lower than during the day. The amount of salt present on exposed towels was discovered by placing them separately in jars containing 300ccs. of distilled water and pummelling thoroughly to force out the salt particles. The resistance of the solution was then read on a Conductivity Bridge, (Randall 1968).

In order to discover the variation in aerial salt around Barbados, the same circuits, locations, and gauge numbers, were used as for the collection of rainfall/evaporation data (see Fig. 3.2). On each circuit readings were maintained for more than a week and a variety of weather conditions were included. During the time records were being taken, windspeeds from the anemometer at Seawell Airport were calculated for the same 24 and 48 hour periods, (Table 5.2-5.4). This anemometer is situated 10 meters above ground level and is thus free from ground interference. Also each day during the experiment wave amplitude in relation to windspeed was noted. The results of this work are given in Tables 5.5-5.7.

There is a decrease in salinity with increase in distance away from the sea, in almost all cases, suggesting that the roughness of the ground caused a decrease in windspeed at lower levels and a consequent loss of

TABLE 5.2 WINDS AT SEAWELL DURING SALINITY MEASUREMENTS - CIRCUIT 1
6-17.6.67

Date	Wind Speed	Rank	Percent from 'Trade' Quadrants	Wave Amplitude in relation to Wind Speed
6- 7	14.87	1	100	High
7- 8	14.04	3	100	High
8- 9	12.92	4	100	Low
9-10	9.08	7	100	Medium
10-11	8.92	8	92	High
11-12	14.50	2	100	Low
12-13	12.63	5	100	Medium
13-14	9.21	6	100	High
14-15	7.42	9	83	Medium
15-16	4.71	11	50	Medium
16-17	6.04	10	92	High

TABLE 5.3 WINDS AT SEAWELL DURING SALINITY MEASUREMENTS - CIRCUIT 2
21.6.67-5.7.67

Date	Wind Speed	Rank	Percent from 'Trade' Quadrants	Wave Amplitude in relation to Wind Speed
21-23	12.85	4	100	Low
24-26	12.93	3	100	Medium
26-28	10.95	5	100	Medium
28-30	14.20	1	100	High
3- 5	13.08	2	100	Medium

TABLE 5.4 WINDS AT SEAWELL DURING SALINITY MEASUREMENTS - CIRCUIT 3
12-30.7.67

Date	Wind Speed	Rank	Percent from 'Trade' Quadrants	Wave Amplitude in relation to Wind Speed
12-14	7.72	5	62	Low
14-16	12.45	2	100	Medium
16-18	10.27	4	100	Medium
18-20	14.91	1	100	Low
28-30	11.00	3	100	Medium

airborne salt particles. This relationship does not hold true at Bottom Bay, Circuit 2, where excessively low readings were recorded for Gauge 2, (Table 5.6). This is because the gauge was situated in a protected pocket at the foot of a cliff behind a dune. However, the average daily salt deposition, in Tables 5.5-5.7, and the locations of the instruments, (Table 3.1), show the usual situation. On the Leeward coast, as illustrated by the values for Brighton, Holetown, Maycock's Bay and Rockley Beach, the aerial salt levels are considerably lower than to Windward and the fall-off rate inland is much less. This shows, as with soil salinity, that the major source of salt over Barbados is from the trade winds which blow from the windward side of the island. This point is emphasized further by the small difference in salt levels between Edgehill in the centre of the island and the gauges on the Leeward coast. However, local salt from foam-derived particles is just enough to give a higher reading from the seaward gauge at all stations on the Leeward coast. At certain times, particularly during winds associated with hurricane disturbances, such as Beulah, September 1967, and during storm swells, such as in late November and early December 1967, the Leeward coast may receive amounts of locally derived salt particles equivalent to or greater than those normally received on the Windward coast. Naturally this has considerable effect upon the vegetation.

A second important factor is the extremely close relationship between changes in windspeed and changes in salt present at any one location. If the ranked windspeeds are correlated with the ranked salt quantities they are seen to be in a similar order. These data are summarized graphically in Figs. 5.1-5.4, which show that a logarithmic increase in aerial salt occurs as windspeed increases. This relationship is not apparent at the

TABLE 5.5 AIR SALINITY, 1 foot squares, 9-17.6.67
(in micromhos per cm. - in solution of 300ccs. H_2O)

Date	1	2	3	4	5	6	7	8	9	10
9th	3713	3102	1551	498	1175	4653	204	193	146	174
10th	1344	1109	582	291	658	2491	169	159	160	197
11th	2444	1974	1316	517	940	3478	183	150	131	150
12th	6110	4600	2444	743	2444	11186	202	130	95	134
13th	5546	4136	2068	568	2350	7332	141	117	80	128
14th	1715	1580	709	282	696	2491	157	129	113	120
15th	799	465	385	212	273	1029	131	81	91	103
16th	259	207	202	124	139	282	122	65	70	75
17th	437	265	204	124	183	583	115	113	125	126
Daily av.	2485	1938	1051	373	984	3725	158	126	112	134
	River Bay			Animal Flower Bay			Maycock's Bay		Holetown	

TABLE 5.6 AIR SALINITY, 1 foot squares, 21.6.67-5.7.67
(in micromhos per cm. - in solution of 300ccs. H_2O)

Date	1	2	3	4	5	6	7	8	9	10
21-23	7708	395	2786	961	x	136	6005	4290	808	150
24-26	8178	479	3431	1175	113	136	6900	4700	x	160
26-28	6862	325	x	921	315	x	4136	3008	569	164
28-30	9776	873	x	2068	221	268	8570	7614	1301	240
3- 5	8460	790	4275	1927	x	508	x	5170	1097	x
Daily av.	4098	286	1915	705	108	131	3201	2478	401	89
	Bottom Bay				Brighton		Belleplaine			Edgehill

TABLE 5.7 AIR SALINITY, 1 foot squares, 12-30.7.67
(in micromhos per cm. - in solution of 300ccs. H_2O)

Date									
12-14	1316	7614	912		508	249	1974	4888	249
14-16	2773	15745	1326		306	228	3431	7332	308
16-18	1287	6486	761		202	124	1786	3901	x
18-20	4089	25380	3290		348	263	5557	17426	235
28-30	1410	8554	846		508	268	2773	5625	114
Daily av.	1092	6378	714		187	113	1552	3917	113
	Chancery Lane				Rockley Beach		Foul Bay		Edgehill

RELATIONSHIP BETWEEN AERIAL SALT AND WINDSPEED - CIRCUIT 1

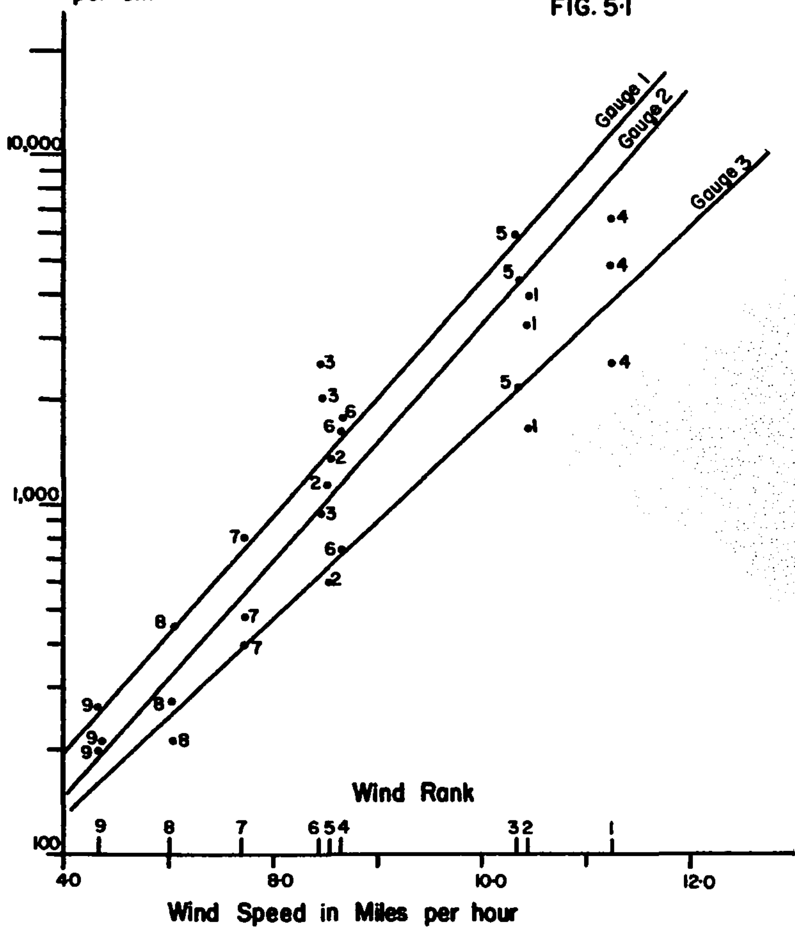


FIG. 5·1

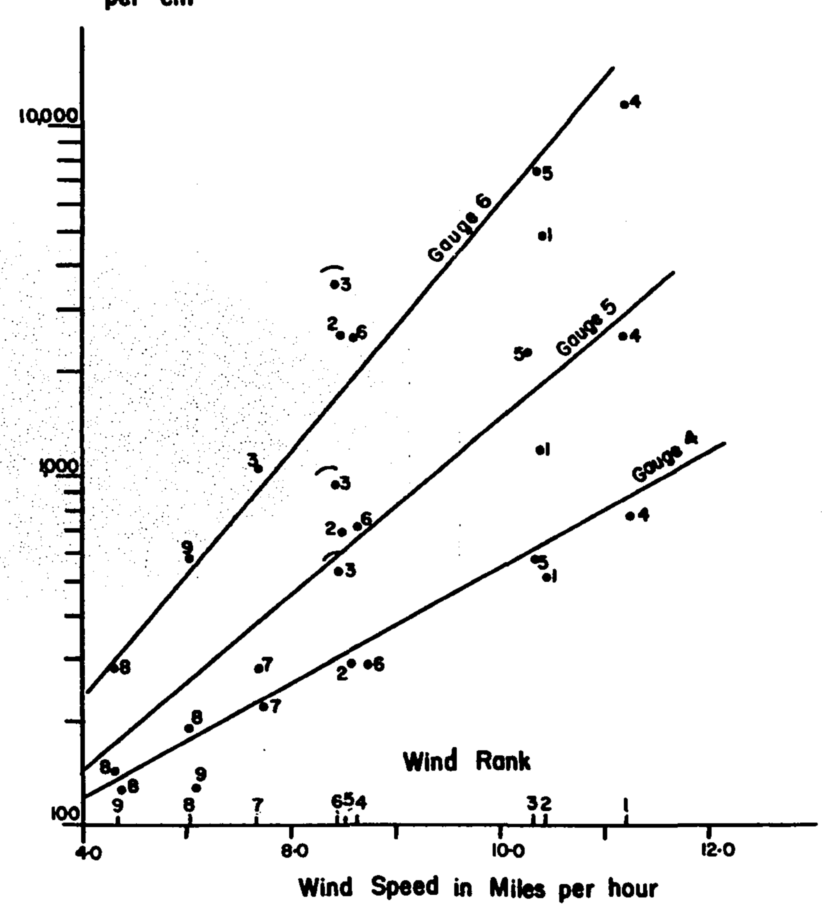
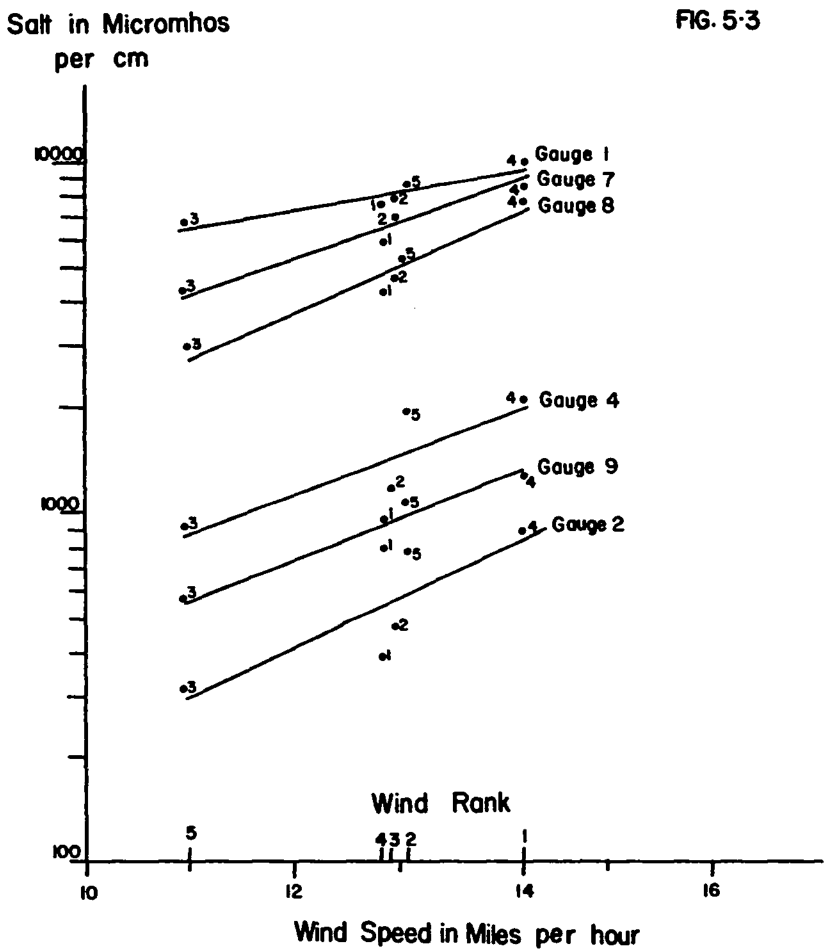
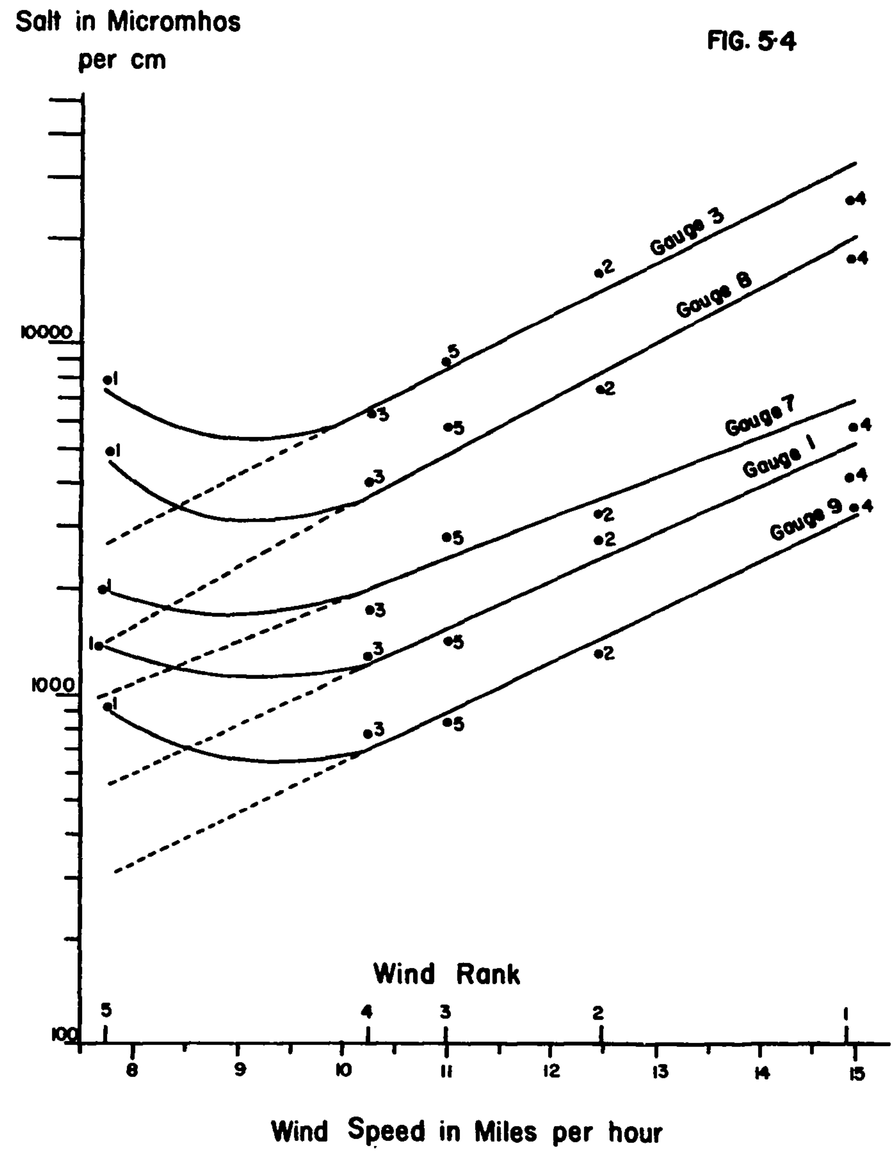


FIG. 5·2

Leeward coast stations since there are so many interference factors that the true windspeed for each station is not comparable with that at Seawell. Furthermore the trade winds are offshore and would not be expected to produce the same results. There are also particular anomalies that occur throughout the Windward coast stations. Good examples are at Foul Bay and Long Bay, Chancery Lane, Circuit 3, (Fig. 5.4). At these two points much higher salt readings occurred on 12-14.7.1967 than would have been expected by examining the windspeeds. However, during these two days the wind only blew from the "Trade" quadrant 62% of the time, the rest coming from the southerly quadrants, thereby giving higher readings on the South coast despite the lower windspeeds and low seas; hence the rise on the left side of the graph. Readings from the gauges at Rockley Beach (also on the South coast) were relatively high (Table 5.7) over the same period. The masking effect of wave amplitude is illustrated in Circuit 1, Figs. 5.1-5.2. From June 10th to 11th (points 3) high seas kept up as the wind died down and high salt figures were recorded despite low windspeeds and some periods of adverse wind direction.

Ground-surface salt figures were measured by placing a ¼ square foot circle of towelling in a black-painted metal tray seven inches in diameter and ½ inch deep, near each aerial salinity collector. This depth allowed readings to be taken even when small amounts of rain had fallen. The towels were immersed in 75ccs. of distilled water so that the results were comparable with those for aerial salt. It was found, Tables 5.8-5.10, that the average amount of salt deposited on the ground is related approximately to that trapped in the air. At high windspeeds and in exposed situations ground salinity is about $\frac{1}{6}$ air salinity at that location. With





RELATIONSHIP BETWEEN AERIAL SALT AND WINDSPEED

CIRCUIT 2

CIRCUIT 3

TABLE 5.8 GROUND SALINITY, ½ foot circles, 7-14.6.67
(in micromhos per cm. - in solution of 75ccs. H_2O)

Date	1	2	3	4	5	6	7	8	9	10
7th	1320	930	744	410	424	2004	150	125	127	165
8th	1240	894	554	376	408	1316	164	136	140	141
9th	646	610	470	208	328	902	169	141	132	164
10th	428	412	272	192	220	498	131	122	139	160
11th	790	752	509	220	322	1090	107	98	73	75
12th	846	794	530	318	330	1674	68	54	69	114
14th	418	394	268	156	160	460	61	57	57	66
Daily av.	811	684	478	269	313	1135	122	105	105	127
	River Bay			Animal Flower Bay			Maycock's Bay		Holetown	

TABLE 5.9 GROUND SALINITY, ½ foot circles, 21.6.67-5.7.67
(in micromhos per cm. - in solution of 75ccs. H_2O)

Date	1	2	3	4	5	6	7	8	9	10
21-23	1457	365	780	267	57	x	749	940	451	110
24-26	1504	390	893	270	119	126	820	1108	508	100
26-28	1222	310	564	127	87	x	454	602	414	108
28-30	2021	432	1457	418	122	250	1203	1692	743	122
3- 5	1692	410	902	306	x	150	830	1128	628	x
Daily av.	790	191	460	139	48	88	406	547	274	55
	Bottom Bay				Brighton		Belleplaine			Edgehill

TABLE 5.10 GROUND SALINITY, ½ foot circles, 12-30.7.67
(in micromhos per cm. - in solution of 75ccs. H_2O)

Date								
12-14	345	771	387	221	210	706	1833	146
14-16	470	1786	564	254	176	980	2021	118
16-18	357	912	424	150	124	x	x	250
18-20	507	1880	598	282	216	989	2115	134
28-30	395	1372	464	302	282	978	1889	188
Daily av.	207	672	244	121	101	457	982	84
	Chancery Lane			Rockley Beach		Foul Bay		Edgehill

medium windspeeds and more sheltered locations it is approximately $\frac{1}{3}$ while well inland, or on the Leeward coast, or at very low windspeeds it is $\frac{2}{3}$ the air salinity. Other relationships such as decrease in quantity with distance from the sea and increase in quantity with increasing windspeeds apply equally to ground surface salt and to aerial salt, as the graphs (Figs. 5.5-5.7) indicate.

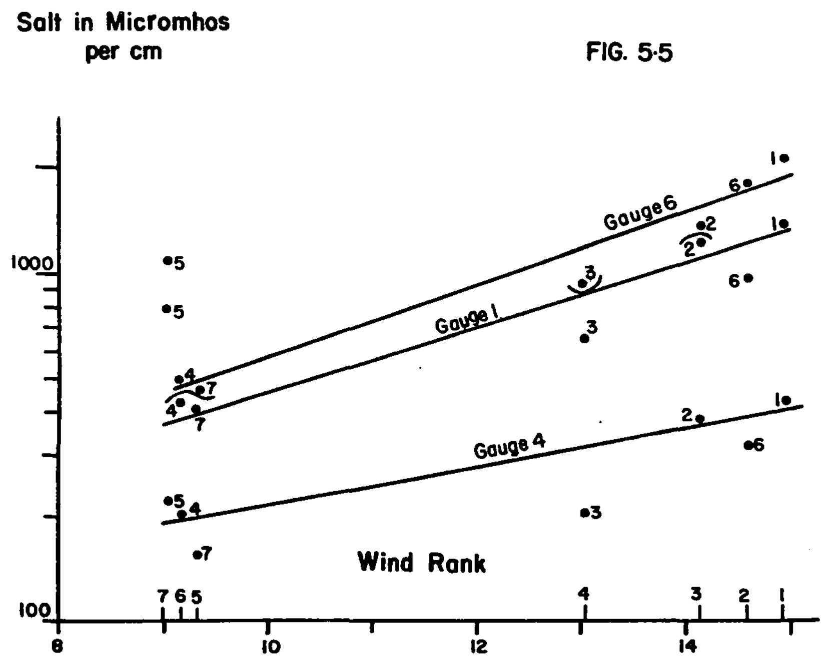
The efficiency of deposition of salt-spray particles on these types of collectors is known (Boyce 1954) to be lower than that on leaves and twigs per unit time. Data from Chancery Lane demonstrate this. Between the cessation of morning rain at 7.30 a.m. and a collection made at 5.30 p.m. on 11.12.1967 salt was deposited on the lowest sea grape leaves, (*Coccoloba uvifera*), at over twice the average rate for the ground salt collectors (Table 5.11). Nevertheless the measurements are indicative of the relative intensity of spray at different stations.

TABLE 5.11 COMPARISONS OF GROUND AND LEAF SALT AT CHANCERY LANE

Position	Ground Salt (24 hours)	Leaf Salt (10 hours)
Front Dune	546	672
Rear Dune	180	207

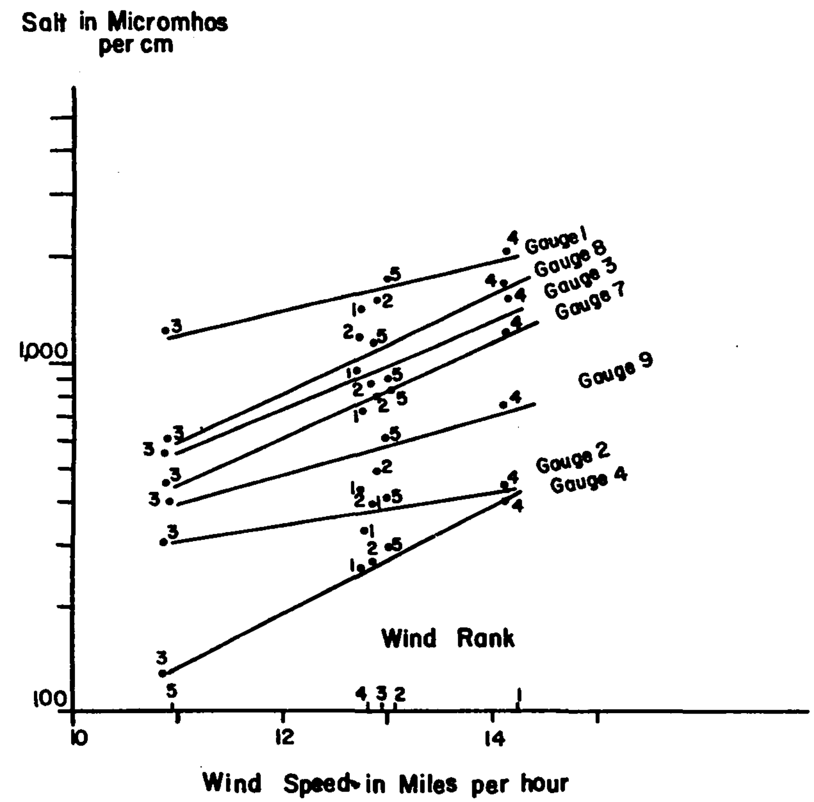
In order to gain a closer idea of the relationship between ground salt deposition and topography, a series of ten collectors were placed at 50 foot intervals inland on the flat cliff top of Animal Flower Bay, and ten were placed at topographically significant points on the dunes at Lakes Beach, Belleplaine. Data collection took place during the massive storm swell of early December 1967 when waves over 40 feet high were breaking on the Animal Flower cliffs. With each wave a drenching cloud of spray was

FIG. 5·5



Wind Speed in Miles per hour

FIG. 5·6

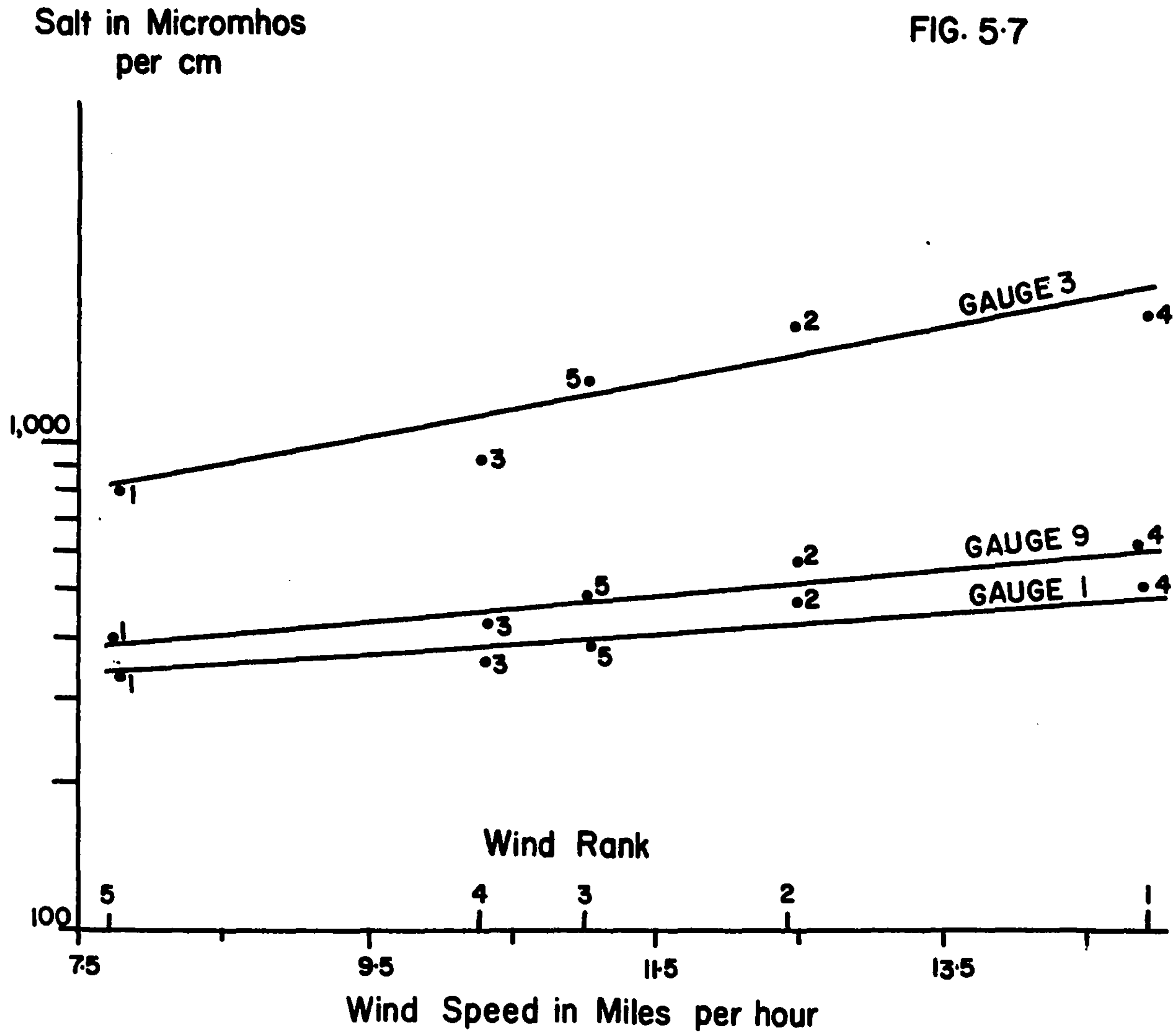


RELATIONSHIP BETWEEN GROUND SURFACE SALT AND WINDSPEED

CIRCUIT 1

CIRCUIT 2

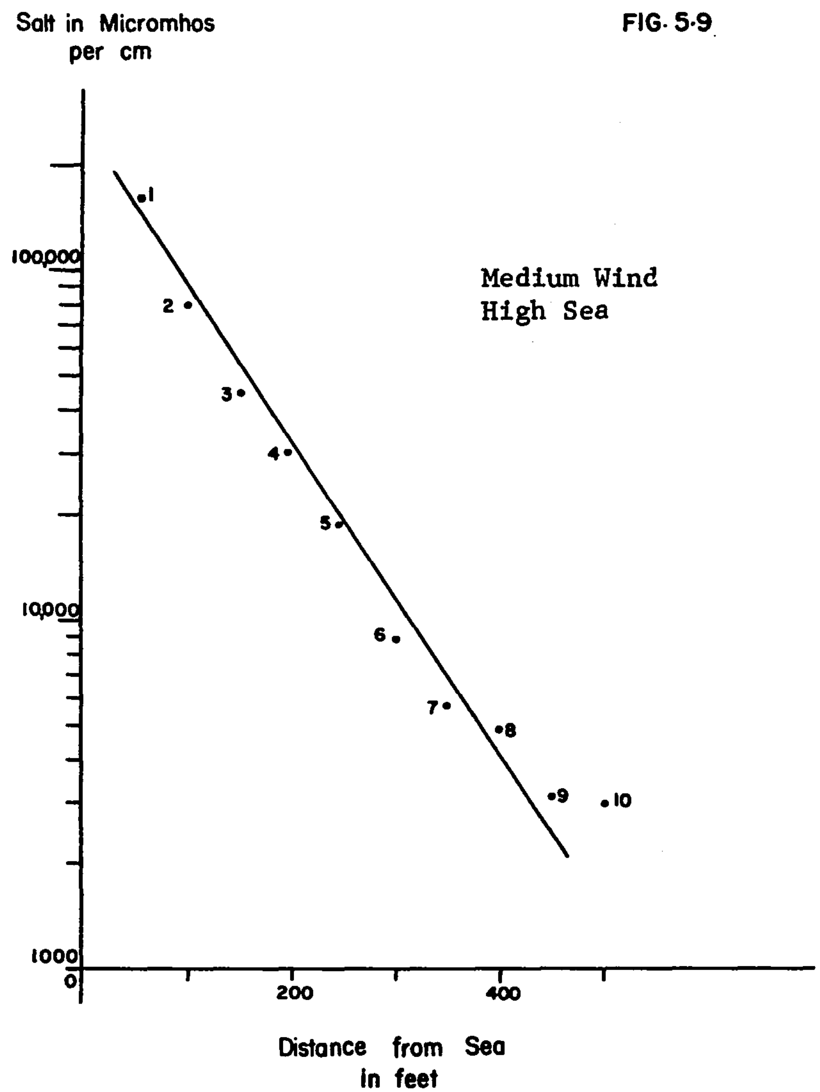
FIG. 5·7

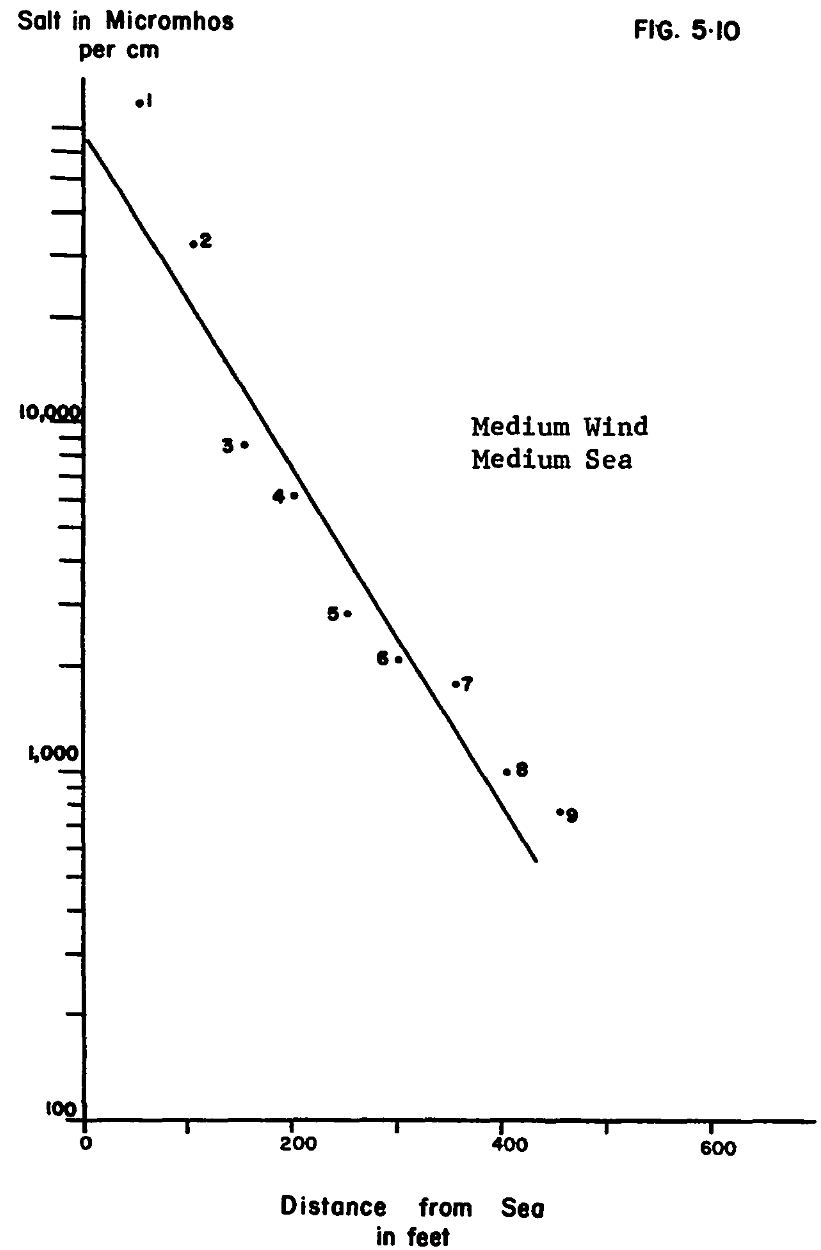


RELATIONSHIP BETWEEN GROUND SURFACE SALT AND WINDSPEED - CIRCUIT 3 felt 200 feet from the cliff-edge and spouts over 50 feet in height issued from the geos (Fig. 5.8). The maximum value of 162,000 mhos recorded at 50 feet from the cliff-edge is approximately equivalent to 15 gms./ square foot/24 hours!

At Animal Flower Bay the expected log relationship was found (Figs. 5.9-5.10) between distance from the sea and salt deposition, but at Belle-plaine major variations occurred, (Fig. 5.11). Salt deposition increased with distance inland as height increased as far as the top of the foredune but increased still more in the immediate lee of the dune. The latter can be explained by the eddying effect in the air which causes salt fall-out as forward speeds decrease. This phenomena also explains why in Table 5.6 the average air salinity is higher for gauge 7 than for 8 than for 9 but the ground salinity (Table 5.9) is higher for gauge 8 than for 7 than for 9. Behind the foredune salt-values continued to fall until another eddy effect behind the main fat pork (Chrysobalanus icaco) dune caused an increase in salt fall-out. Again there was a fall in values with distance until the great height of the rear dune caused a major increase in salt deposition. Thus topography is an important factor in ground-salt deposition because of the effect it has on the lower strata of the wind, but the effect does not seem to be exhibited in the higher regions of the air that were sampled by the aerial salt collectors.

Nevertheless it can be seen from these results that very large amounts of salt are deposited regularly on the east coast of Barbados. These large amounts decrease quickly inland but cover an area wide enough to be of considerable importance to the coastal vegetation. Although the Leeward coast does not receive such large amounts of salt throughout most of the





RELATIONSHIP BETWEEN GROUND SURFACE SALT AND DISTANCE - ANIMAL FLOWER BAY

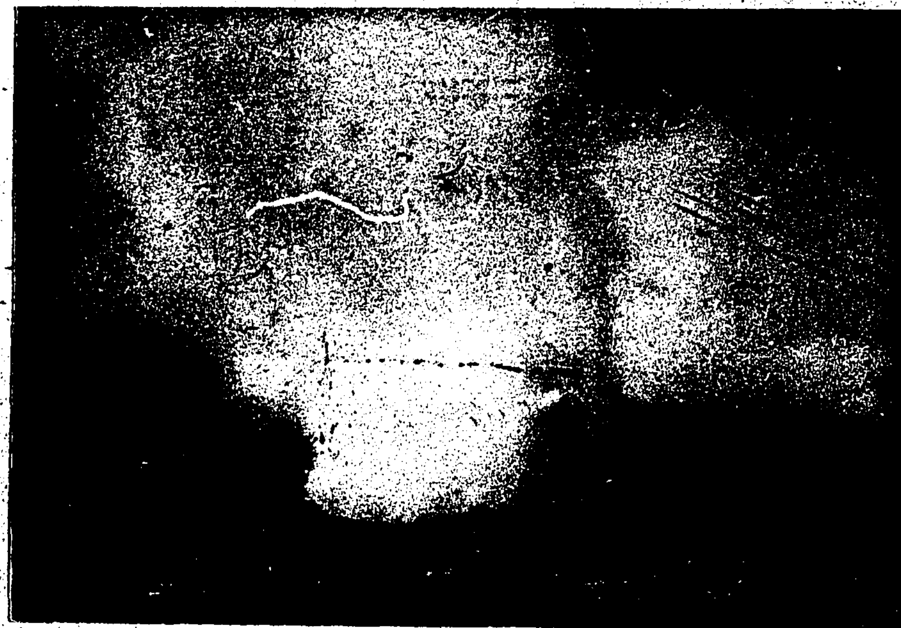


Fig. 5.8
Salt-spray being forced through a geo 80 ft. from the cliff-edge at Animal Flower Bay. This is common during high seas and greatly increases the quantity of salt on the cliff-top.

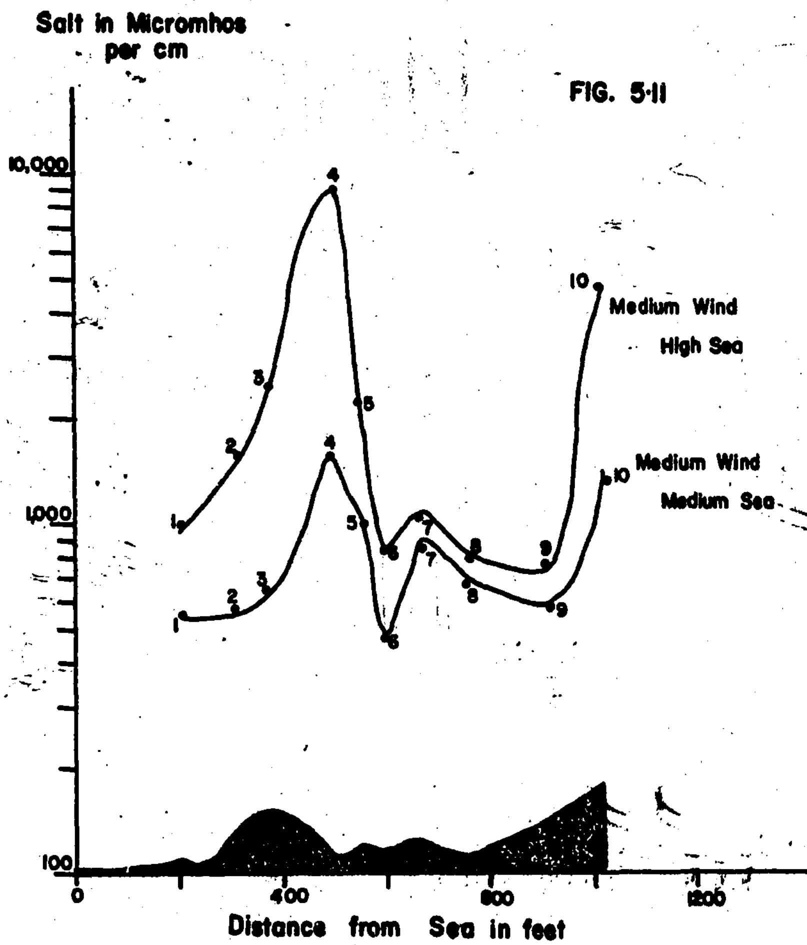
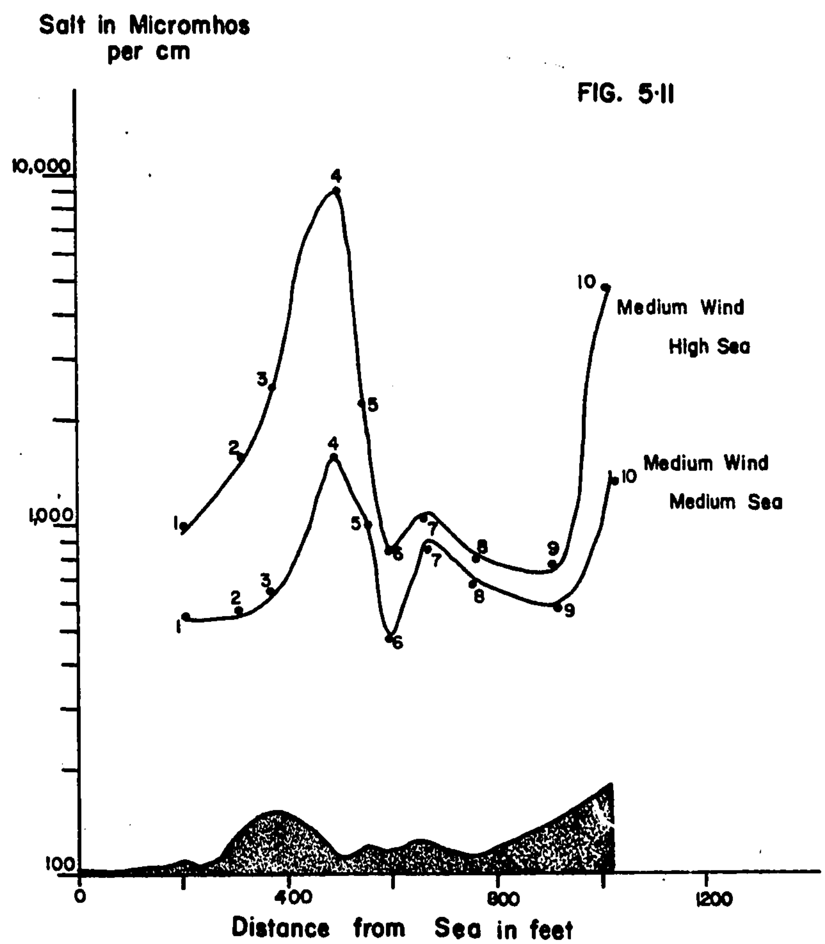


FIG. 5·11

RELATIONSHIP BETWEEN GROUND SURFACE SALT AND DISTANCE - BELLEPLAINE

Fig. 5.8
Salt-spray being forced through a geo 80 ft. from the cliff-edge at Animal Flower Bay. This is common during high seas and greatly increases the quantity of salt on the cliff-top.



RELATIONSHIP BETWEEN GROUND SURFACE SALT AND DISTANCE - BELLEPLAINE year, irregularities in the weather are common enough to make salt deposition important within the Leeward coastal vegetation. The precise injuries that salt causes to vegetation do not concern this thesis and are described by Boyce (1954). However, as will be seen in chapters 6 and 7, salt affects the vegetation pattern by limiting the species growing in any location, by causing die back of certain species especially in times of drought and by causing variations in growth-form.

CHAPTER 6

THE HISTORICAL SETTING

There are no descriptions in existence of the vegetation of Barbados before the 17th century but one can infer from the lack of its agricultural use and from later records that the present pattern of the littoral vegetation is the most similar of all contemporary vegetation-types to that present before 1627. Watts (1963, 1966) describes changes in Barbadian vegetation from 1625 to 1830. The earliest description of the coastal vegetation (Anon 1629) is one that is still valid for the west coast of the island.

> 'La Barbade est la premiѐre a l'ѐst des Iles du Péru, habitée des Anglois ... elle est toute pleyne de bois ... il y a grande quantité des mançanilles.'

This reference to the manchineel (Hippomane mancinella) is the first identification of a species from Barbados. Colt (1631) identified the sea grape[1] as;

> 'a tree that bears bunches like green grapes, but much bigger, the leaf round, thick and great.'

Today the sea grape is still common on sand dunes and in 'sandy fields' of the littoral.

Ligon (1657) examines mangrove-swamp, a type of vegetation that is now quite rare but at one time must have been present along all river estuaries and low-lying areas of the Leeward coast. Describing an estuary that is most likely to be that of the Constitution River at Bridgetown, he says;

> 'it has not been often that ... fish or any other, have been taken in that place, by reason the whole lake is filled with trees and roots.'

---

[1]A list of the common names of species with the Latin equivalents is shown in Appendix III.

In addition to the mangrove, Ligon (1657) records several other coastal species that still occur: the bearded fig (Ficus citrifolia), growing inland and in rocky coastal districts, the spider lily (Hymenocallis caribbea), and fat pork.

By the time the work of Sloane (1707) was published, much of the natural vegetation had been removed except for some parts of the inland forest and the littoral. Manuscripts collected by Sloane in the period 1684-1700 and his book (1707), provide descriptions of more species of the original littoral vegetation: the whitewood (Tabebuia pallida), the white sage (Lantana involucrata), the West Indian tea (Capraria biflora), and the wild olive (Bontia daphnoides). The seaside laurel was also mentioned as a colonizer of dune coasts and horse nicker (Caesalpinia bonduc) as a species to be found immediately inland from the coast. During the 18th century four mangrove species were identified. The red mangrove (Rhizophora mangle) was seen 'widely distributed along coasts and estuaries, and intermingled in places with the white mangrove, (Avicennia schauerana)' (Watts 1966). A broad-leaved mangrove (Laguncularia racemosa (L.) Gaertn.) was also identified by Sloane (1707), and Hughes (1750) described a dwarf mangrove (Avicennia germinans (L.) L.).

Thus evidence suggests that, along the west coast where the rainfall is highest, the pre-European coastal vegetation was a dense xerophytic forest dominated by manchineel and whitewood. In the drier parts, particularly St. Lucy and the south coast, there was more open xerophytic forest and scrub, including species like horse nicker, white sage, West Indian tea and two endemics, the maypole (Agave barbadensis) and the columnar cactus (Cephalocereus barbadensis). On sand dunes seaside grape and seaside laurel were found. Most of the estuaries and lowland coasts were covered with dense mangrove swamp.

The period from 1627 to the present day has been one of ever increasing clearance of the natural vegetation for most of Barbados. However, the littoral flora has increased continually with garden escapes, officially introduced littoral species and introduced inland species that since have run wild. Losses of species have also occurred. Draining of swamps led to the disappearance of two major trees, the broad-leaved and the dwarf mangrove; overgrazing caused the eradication of part of the open xerophytic forest which has become scrub; and much of the manchineel and whitewood forest has been cut for fuel. The latter have resulted in the absence today of the palmitto ([illegible] sp) and the bully tree (Manilkara bidentata (DC.) A. Chev.), both recorded by Colt (1631).

Some of the earliest recorded introductions are grasses. Hughes (1750) mentions dog's grass (Egragrostis ciliaris), Dutch grass (Eleusine indica), plush grass (Chloris radiata), nut grass (Cyperus rotundus) and the bulrush (Eleocharis mutata). The bulrush and plush grass were already native to the West Indies and were probably introduced accidentally to Barbados. Dutch grass is a good pasture species and was most likely brought deliberately into the Americas. Dog's grass is a very poor pasture type and its introduction may have been accidental or deliberate. Hughes (1750) describes the first introduction of nut grass. It was;

> '... brought here in a pot of flowers sent from England to Mr. Lillington in St. Thomas parish: from thence it hath been more or less unluckily propogated throughout the whole island.'

Many larger plant species were almost certainly deliberate introductions. Schomburgk (1848) mentions that mahogany (Swietenia mahagoni) was introduced between 1750, (the time of Hughes' publication) and 1806, when he visited the island. This species was originally brought in as a windbreak, but now is thriving in the pre-European littoral forest on the west coast of the island. The coconut was not recorded in Barbados at the time of first settlement but was almost certainly an early introduction. It is a species whose origin has long been under dispute (Beccari 1917) but throughout tropical America there are similar varieties to the Barbadian one. Like the coconut, purslane (Portulaca oleracea) is a pantropical coastal species that was not present in Barbados in 1627. However it has been a popular garden and pot-plant for a long time and must early have escaped.

Gooding, Loveless and Proctor (1965) describe several deliberate introductions that occurred after 1848. Casuarina (Casuarina equisitifolia) was introduced around 1870 from Australia and is used as a windbreak, a hedge plant, and for fuel. It is widespread both in coastal and inland areas. The clammy cherry (Cordia obliqua) was introduced into the West Indies from India in the late 18th century. Initially it was a cultivated species but now is common in waste places and particularly in 'sandy field' areas immediately behind the coast. The flamboyant (Delonix regia) was also introduced into Barbados as an ornamental about the same time. Like the clammy cherry, the Barbados almond (Terminalia catappa) was introduced from India, and has now become naturalized near the sea.

Many of the other introduced species are those that one would expect to arrive in a period of world-wide human movement. There is wild jasmine (Jasminum fluminense) from tropical Africa, seed-under-leaf (Phyllanthus fraternus) from India, the red thistle (Emilia coccinea) from Europe, and Conyza canadensis from North America. But some species have surprising origins, especially the periwinkle (Catharanthus roseus) and love leaf (Bryophyllum pinnatum), both of which are natives of Madagascar but now are wide-spread in the tropics.

Seeing the remarkable ranges of many coastal species, several authors have studied the suitability of their seeds for oceanic dispersal. The most useful research on this subject is the pioneer study by Guppy (1917). Later Ridley (1930) described other widely distributed coastal species. Most pantropical plants are capable of long-range oceanic dissemination. The seeds of horse-nicker, sea bean (Canavalia maritima), mahoe (Thespesia populnea), and seaside yam (Ipomoea pes-caprae) can all withstand flotation in sea water for many months. Seaside samphire has non-buoyant seeds but the plant itself remains alive after very long periods floating in the sea. Conversely, few American coastal species are suited to long migrations. The seeds of seaside lavender have the greatest viability, remaining fertile after six months in sea water, but it is more common for seeds to die after a few weeks as those of sea grape.

Even when the seeds do not float, other means of oceanic dispersal occur. Desmodium canum has buoyant seed-pods, even though the seeds themselves will sink, so that it is possible for the seeds to be transported while still attached to the pod. Both Guppy (1917) and Ridley (1930) observed seedlings including purslane and seaside samphire that had germinated and were growing on rafts of floating pummice or in 'teredo' holes on drift logs. Many of the Caribbean species could be dispersed in this way. Less is known about the dispersal mechanisms of the coastal grasses and sedges but most likely many of them are eaten by migrating birds and either pass through their systems undamaged or are regurgitated.

Despite the fact that the historical literature concerning the present littoral vegetation contains exact detail only for a few species, it seems certain that most of the plants that comprise the seaward part of the coastal pattern are part of the original vegetation of the island, whereas the present distribution pattern of the inland zones are to a large extent the product of post-European times. Little change in species occurs either in the outpost or inland coastal vegetation at the present time since replacement after storms usually results in the same colonizers in the former, while sour grass and casuarina dominate the latter. Thus the pattern described in the next chapter may be relatively permanent.

CHAPTER 7

THE VEGETATION

During the period of research 100 species belonging to 41 families were recorded growing on the Barbados littoral (Appendix II), and of the 100, 91 were recorded within the quadrats. The grass, legume (senna, mimosa, bean), and spurge families were best represented with 15, 13 and 12 species respectively. Of the 100 species, 62 were recorded at more than one location (see Appendix II), 20 grow on beaches throughout the tropics and 23 are relatively recent introductions. Despite the island's geographically isolated position only two species are endemic, (Table 7.1).

TABLE 7.1 THE ORIGINAL DISTRIBUTION OF THE BARBADOS COASTAL VEGETATION

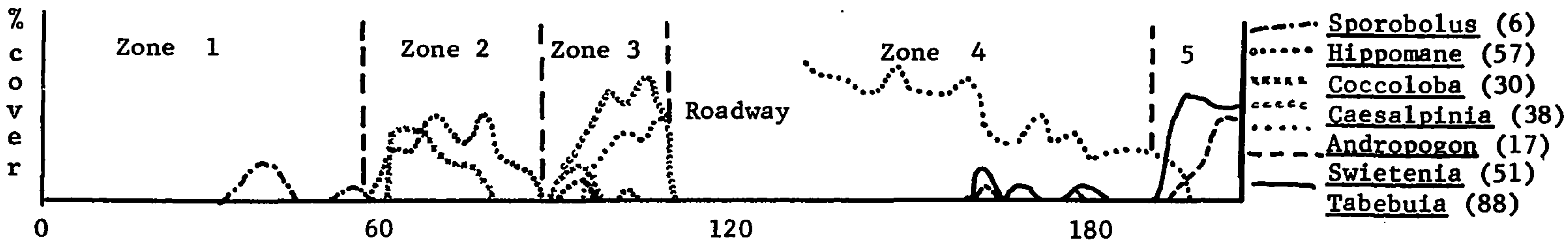
Original Distribution	Number of species
Pantropical	20
Panamerican tropics	14
Caribbean	12
Caribbean and central America	9
Caribbean, central and South America	7
Tropical Atlantic	6
Caribbean and South America	5
Caribbean, central and North America	2
Endemic	2
Introduced after 1627	23
Total	100

This heterogeneous collection of endemic, native and introduced species, can be divided (Sauer 1959, 1961) into 'outpost' species, which dominate the vegetation near the sea, and 'inner littoral' species, which are commoner where the influence of the sea is less severe. On many Leeward coasts, as at Maycock's Bay (Fig. 7.15), and on some Windward coasts, where the beach sands give way to soil these two groups meet in a sharp contact zone. At other locations where soil and topographic changes are gradual, as at Animal Flower Bay (Fig. 7.1) the decrease in effects of the sea with distance is also gradual and outpost species occur within the inner littoral vegetation. On the whole however, outpost species act as pioneers, existing in high-light intensity, mobile habitats, and they mostly are incapable of competing with the plants of the inland vegetation. These species (e.g. crab grass and seaside samphire) are xerophytic and thrive despite the long dry periods, the large particle size of their rooting medium and the presence of saline soil water and spray. The inner littoral species, which grow in a less severe habitat, are not well adapted to growth in outpost locations and such member species as casuarina and prickly pear compete successfully in dry, rocky, inland areas.

However, examination of the 15 transects through the coastal vegetation of Barbados (Figs. 7.1 - 7.15) shows that changes in the vegetation pattern are both more numerous and less definite than this broad generalization suggests. The positions of boundaries between zones were determined by the methods described in chapter 1. Histograms of the cover percentage of each species in each quadrat were plotted separately then superimposed. Fig. 7.16 gives an example from the Leeward coast (Maycock's Bay) and one from a cliffed section of the Windward south coast (Oliver's Cave). It can be seen (Fig. 7.16) that when the major species, first occur, or die out or are replaced by other species, the fitted lines plunge toward the base line. This marks a zone boundary (see, for example, divisions between zones 2 and 3 at Maycock's Bay or 1 and 2 at Oliver's Cave). In some cases a species does not die out but instead covers a smaller percentage of the area and another species becomes dominant. When this happens the plunge of the lines is less marked but is still obvious enough for a boundary to be drawn (see, for

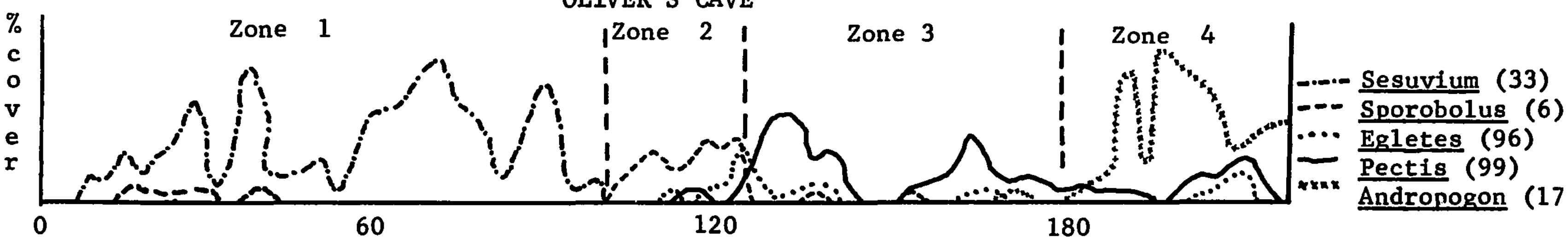
FIG. 7.16 SAMPLES OF SUPERIMPOSITION OF COVER DIAGRAMS TO OBTAIN ZONES

MAYCOCK'S BAY



DISTANCE FROM SEA IN FEET

OLIVER'S CAVE



DISTANCE FROM SEA IN FEET

example, divisions between zones 4 and 5 at Maycock's Bay or 2 and 3 at Oliver's Cave).

When boundaries had been drawn on all transects (Figs. 7.1 - 7.15) using this technique, it was seen that some had a few, wide zones, others had more, narrower zones while a third group had a few, narrow zones. Changes in the species composition of bands reflects this tripartite division. It was found that the few, wide zones occurred on coastal cliffs of the north, east and south of the island, where the quantity of salt spray in the air decreases slowly with distance inland, that the many narrow zones were present on the Windward coast and dunes where topography varies considerably over short distances, and that the few, narrow zones occurred on the Leeward coast where environmental influence of the sea is least. On coastal cliffs, a maximum of four zones occurs, on Leeward coasts five and Windward coasts and dunes, seven.

The reality of these zones, that were discovered from analyses of the transect data was tested with further field work. At sample beaches, cross-traverses of 40 contiguous, one metre square quadrats were located by the methods described in chapter 1 and placed within the zones at right angles to the line of transect. Examination of the data from these cross-traverses (see Appendix V) and visual examination of the beaches showed that the zones of the transects are present as distinct pattern units on the beach. Since no two of the 15 locations are identical physically, as chapters 3, 4, and 5 show, no two have exactly the same complement of species, and even the most common plants are not ubiquitous. Each beach has a few rare species which are not part of the usual zonal pattern since they result from individual plant life-histories caused by such factors as human interference, climatic accidents or chance seed dispersal. But the majority of species repeatedly recur, reflecting external influences by their location and create plant patterns of the scale discussed in this dissertation.

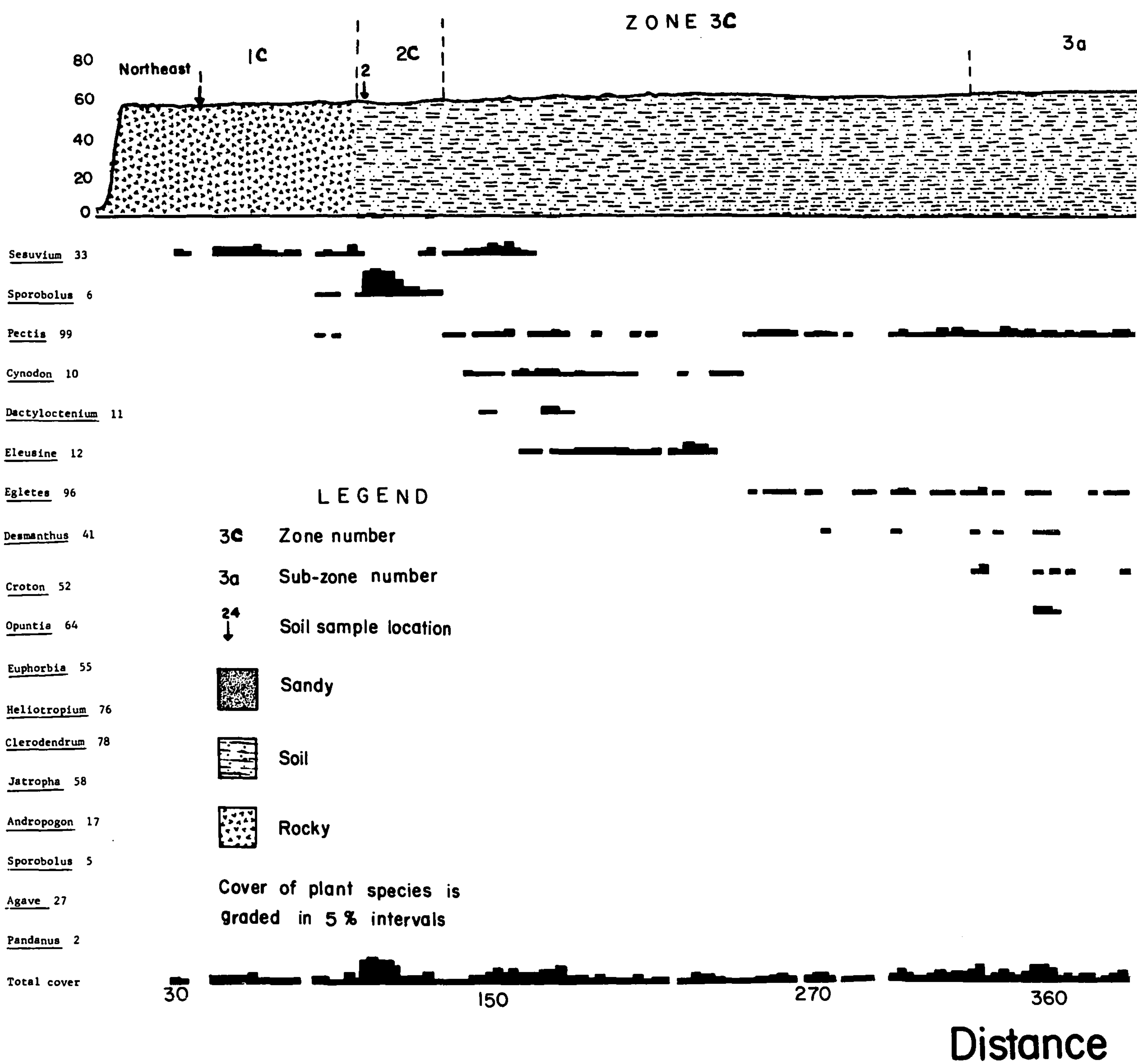
The beaches in each of the environment types (coastal cliff, Windward beaches and dunes, and Leeward beaches) are discussed as a group, using the following conventions. The zone nearest the sea is labelled '1' and all others inland number from it. Cliff zones have the letter 'C' attached (1C, 2C, ...), those on Windward beaches 'W' and those on Leeward beaches 'L'. In a later chapter the zone numbers of each beach are related.

Coastal Cliff Pattern

This pattern is seen only on the Windward coast because cliffs are not found close to the Leeward shore. Such vegetation was examined at Animal Flower Bay (Fig. 7.1), River Bay (Fig. 7.2), Skeete's Bay (Fig. 7.5) Bottom Bay (Fig. 7.6), and Oliver's Cave (Fig. 7.8). Because the cliff-top at Animal Flower Bay extends inland without topographic change for a great distance, a complete range of four vegetation zones occurs (Fig. 7.1).

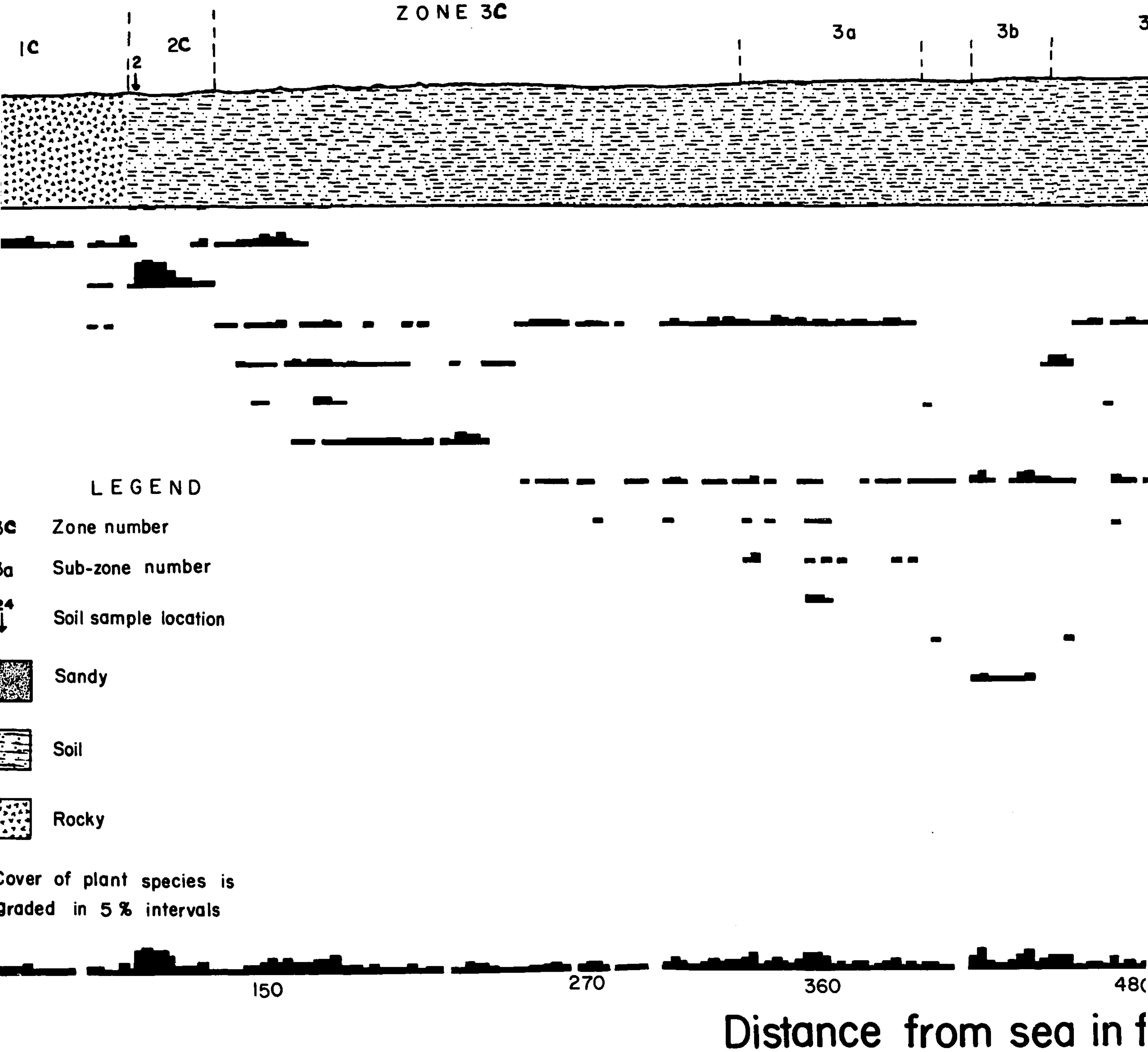
The first zone extends from the cliff-edge to about 100 feet inland. This is the most severe of the coastal-cliff habitats and for the first 30 feet, and more in places, there is no vegetation. Most of the surface of zone 1 has been fretted greatly by the action of the sea. In the seaward 50 feet there is no soil, but some hollows in the rock are partly filled with sand carried up in the spray; others just have a salt encrustation. Seaside samphire, grows in the small quantities of soil in these hollows (Fig. 7.17). It is the only species present and does not spread over the bare rock. The disadvantage of its calmer situation is that it is often submerged by spray which drains to the lowest points. During a dry spell after heavy seas, seaside samphire thrived in pools of water 50% more saline than normal sea

ANIMA



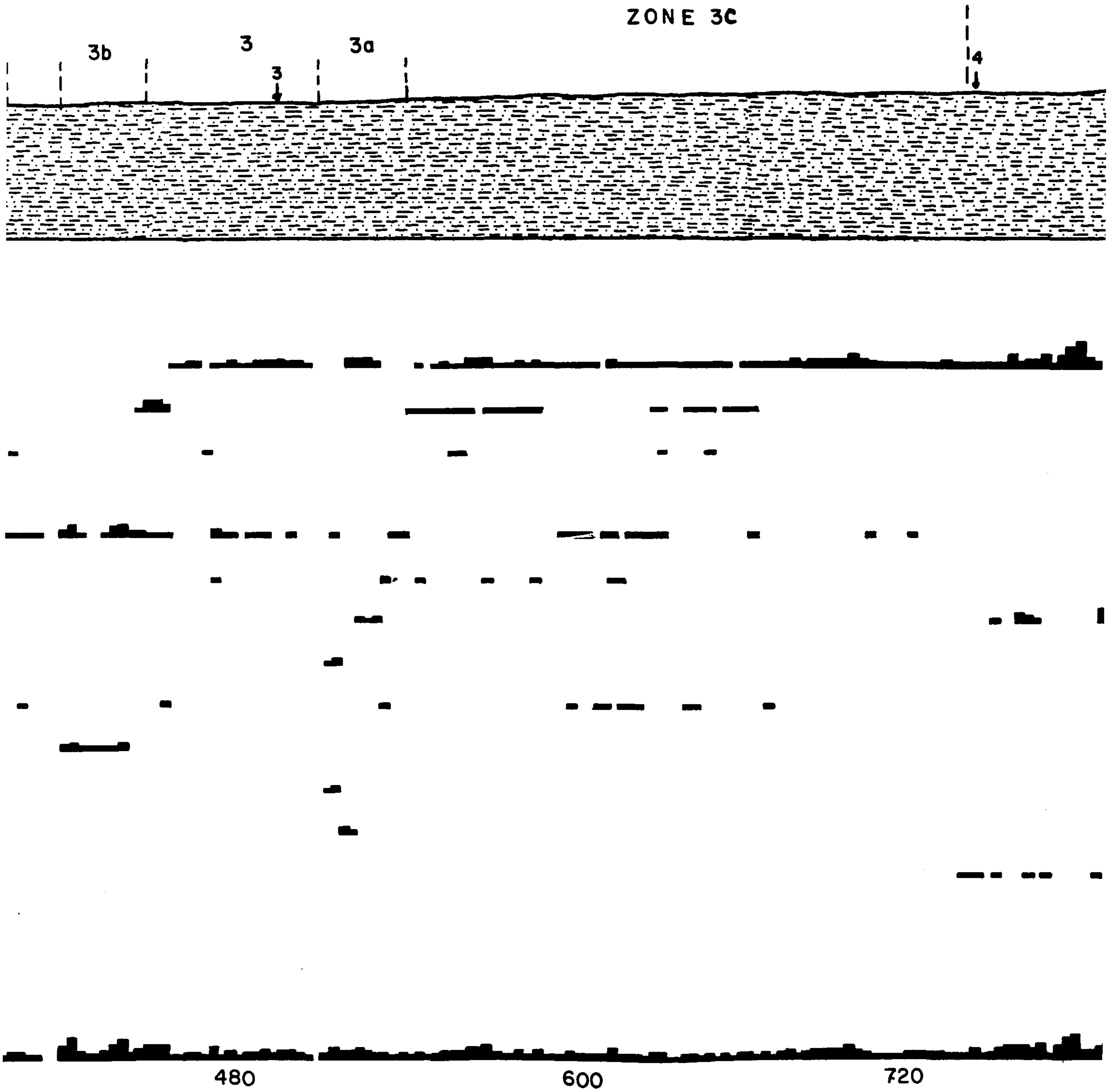
ZONE 3C
80
60
40
20
0
Northeast
1C
2
2C
3a
Sesuvium 33
Sporobolus 6
Pectis 99
Cynodon 10
Dactyloctenium 11
Eleusine 12
Egletes 96
Desmanthus 41
Croton 52
Opuntia 64
Euphorbia 55
Heliotropium 76
Clerodendrum 78
Jatropha 58
Andropogon 17
Sporobolus 5
Agave 27
Pandanus 2
Total cover
LEGEND
3C Zone number
3a Sub-zone number
24 Soil sample location
Sandy
Soil
Rocky
Cover of plant species is graded in 5 % intervals
30
150
270
360
Distance

ANIMAL FLOWER



_ FLOWER BAY

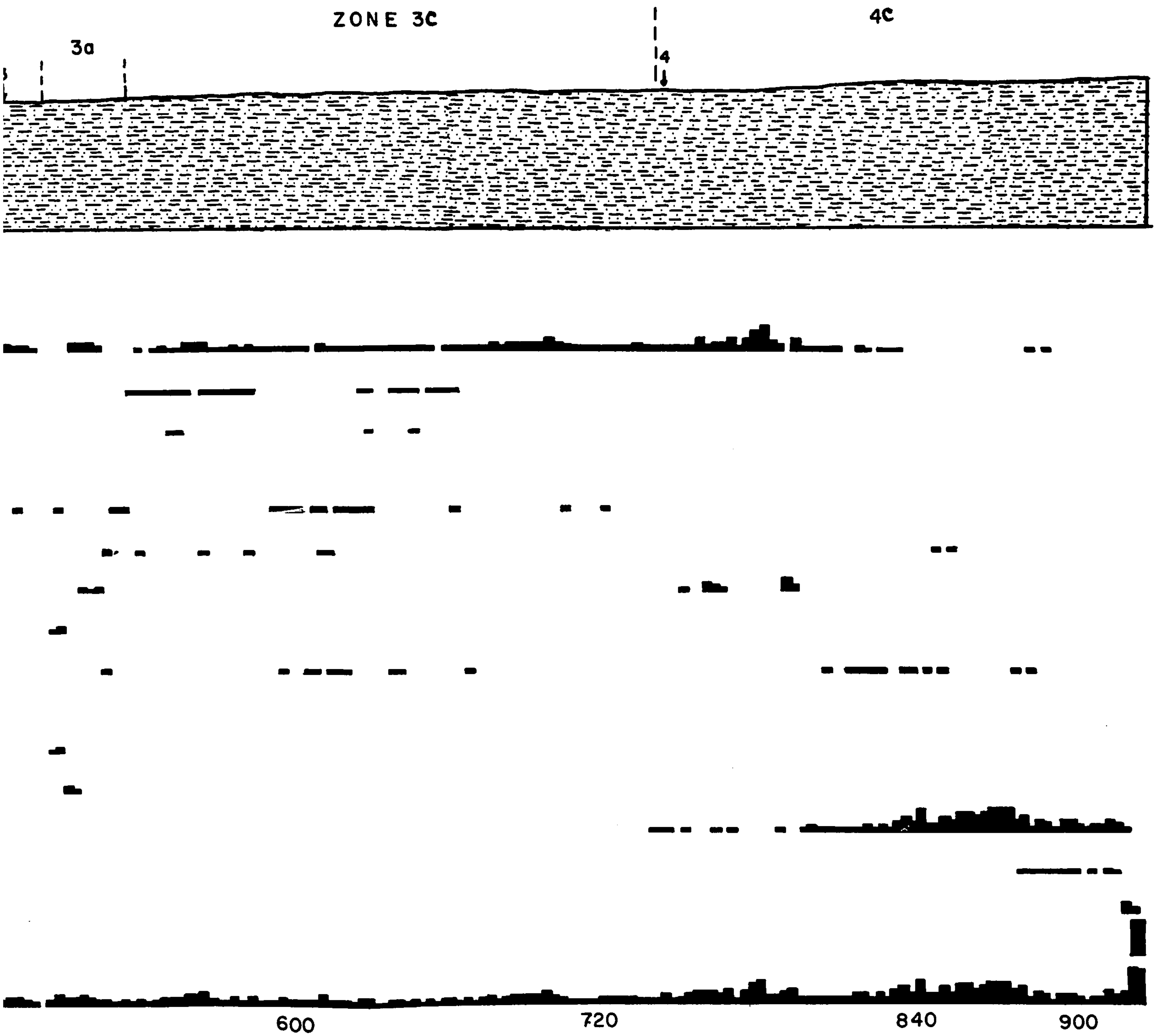
FIG



rom sea in feet

BAY

FIG. 7·1



et

water. In the main part of the zone more of the rock surface is covered with a sandy soil and occasional specimens of duckweed (Pectis humifusa) and crab grass also occur. Total plant cover for this zone averaged 5% though some quadrats containing seaside samphire had 60% cover. The frequency figures for the zone are:-

TABLE 7.2 SPECIES FREQUENCIES - ZONE 1 - ANIMAL FLOWER BAY

Species	Growth form	Frequency per 100 quadrats
Sesuvium portulacastrum	Ch	70
no plant rooted	--	30
Sporobolus virginicus	H	10
Pectis humifusa	Ch	5

Growth forms after Raunkaier (1934)
Ch - Chaemephyte
H - Hemicryptophyte
P - Phanerophyte

Fig. 7.17
Seaside samphire growing in a hollow in Zone 1 at Animal Flower Bay. Similar sheltered locations enable this species to grow up to 100 feet nearer the sea than other plants. After heavy seas these hollows become full of very salt water but the plant does not appear to suffer.

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Seaside samphire growing in a hollow in Zone 1 at Animal Flower Bay. Similar sheltered locations enable this species to grow up to 100 feet nearer the sea than other plants. After heavy seas these hollows become full of very salt water but the plant does not appear to suffer.

Zone 2 is variable in width at Animal Flower Bay and may be over 100 feet wide where deep soil is present. If the soil is excessively shallow, the species found in zone 1 persist further inland with the same frequencies and are replaced by species of zone 3. Where the transect crossed zone 2 it was 33 feet wide, (Fig. 7.1). Zone 2 does not contain any species that are not present in zone 1. However, its presence can be defined by an abrupt change in the relative frequency and density of these species. The frequency ratings are:-

TABLE 7.3 SPECIES FREQUENCIES - ZONE 2 - ANIMAL FLOWER BAY

Species	Growth form	Frequency per 100 quadrats
Sporobolus virginicus	H	100
Sesuvium portulacastrum	Ch	44
Pectis humifusa	Ch	16
no plant rooted	--	-

As can be seen in Figs. 7.1 and 7.18 crab grass generally has a very high density as well as high frequency in this habitat but this is dependent upon depth of soil. Where the soil is thin and bedrock projects the density is under 10%. At these locations duckweed and seaside samphire also occur and have a low density. In this zone there is a seasonal change in density for although all the species are perennial, crab grass suffers from die-back in the dry-season, and cover is reduced by half (Fig. 7.19). It is unlikely that this die-back is caused by drought, since crab grass growing on sand does not suffer similarly. Three causes for die-back appear likely: one is damage to the root hairs caused by soil desiccation (see Fig. 4.3) another is damage to aerial parts caused by the deposition of large quantities of salt particles which are not washed off by rains,

Fig. 7.18
Crab grass sward in Zone 2, at Animal Flower Bay. This photo was taken in the rainy season when growth is good.

Fig. 7.19
Photo taken at same point as Fig. 7.18 in dry season. Note the dieback of the crab grass presumably caused by salt damage to the aerial parts.

Fig. 7.18
Crab grass sward in Zone 2, at Animal Flower Bay. This photo was taken in the rainy season when growth is good.

Fig. 7.19
Photo taken at same point as Fig. 7.18 in dry season. Note the dieback of the crab grass presumably caused by salt damage to the aerial parts.

and the third is brought about by the extremely high soil salinity found in dry [illegible] clayey soils.

Fig. 7.20
An island of shrubs on deeper soil within Zone 3 at Animal Flower Bay. In the foreground is prickly pear and behind it prickly wild coffee; to the left is seaside sage. Note how the prickly wild coffee is 'planed' by salt spray in the direction of the wind: more leaves are missing from the windward (left) side of the bush and growth is higher to leeward (right).

Neither zone 1 nor 2 contain palatable species and neither is grazed, but the zones further inland are subject to intense overgrazing. In zone 3 this has resulted in many of the most palatable species being eaten out and replaced by many small weeds of which duckweed and Egletes prostrata are dominant. At animal Flower Bay this zone is very wide stretching from approximately 130 feet to 740 feet inland, and within it several variations of the standard pattern can be seen. In the lower areas, which are prone to inundation for considerable periods of the wet season, Egletes prostrata and wild lavender (Heliotropium curassavicum) occur (Fig. 4.2).

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An island of shrubs on deeper soil within Zone 3 at Animal Flower Bay. In the foreground is prickly pear and behind it prickly wild coffee; to the left is seaside sage. Note how the prickly wild coffee is 'planed' by salt spray in the direction of the wind: more leaves are missing from the windward (left) side of the bush and growth is higher to leeward (right).

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In areas of deeper soil scrubby vegetation dominated by prickly pear (Opuntia dillenii), prickly wild coffee (Clerodendrum aculeatum), screw pine (Pandanus utilis) and seaside sage (Croton balsamifer) grows (Fig. 7.20). Since these species are present also on the thinner soils of zone 4, they represent an intermediate zone which is similar to the xerophytic coastal scrub suggested as the pre-European vegetation-type of the driest parts of the coast. In the main part of zone 3 besides the two dominants, seven other species were recorded with the following frequencies:-

TABLE 7.4 SPECIES FREQUENCIES - ZONE 3 - ANIMAL FLOWER BAY

Species	Growth form	Frequency per 100 quadrats
Pectis humifusa	Ch	45
Dactyloctenium aegyptum	H	40
Egletes prostrata	Ch	35
Eleusine indica	H	20
Desmanthus depressus	Ch	15
Cynodon dactylon	H	10
Sesuvium portulacastrum	Ch	10
Euphorbia prostrata	Ch	5
Lithophila muscoides	Ch	5
no plant rooted	--	-

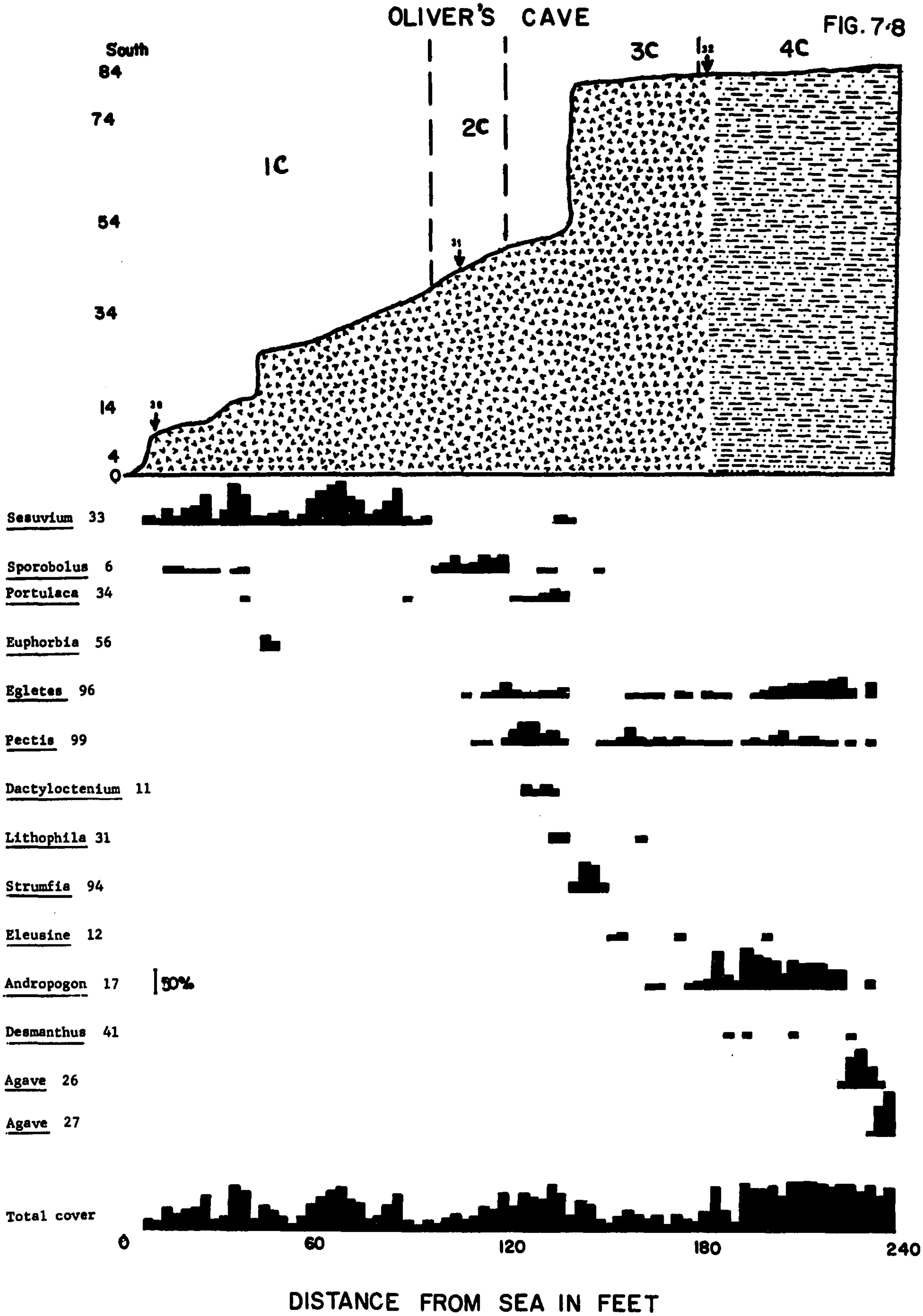
Because Egyptian grass (Dactyloctenium aegyptum) and Dutch grass are both grazed annuals, the dry season cover density of this zone is extremely low, averaging under 20%. However in the wet season the cover rises to about 40%.

The fourth zone is recognized by the presence of sour grass (Andropogon intermedius var. acidulus). This cultivated species, common in the West Indies, was planted in the early part of this century in areas of Barbados unsuited to sugar cane production. On many cliff-tops this species grows wild and has become the zonal dominant. Usually the zone ends inland at the line of cultivation but at Animal Flower Bay the transect analysis was stopped at 930 feet from the sea before cane fields were reached. Although sour grass is the dominant species in this zone, its palatability has lead to heavy grazing and in many quadrats duckweed or Euphorbia serpens have a greater density. Seaside sage becomes the dominant species in those parts of the zone where soil is shallow and grasses from zone 3, (Dutch grass and Egyptian grass), occur with it. The endemic maypole and screw pine are also present. In the main part of the fourth zone the species frequencies are as follows:-

TABLE 7.5 SPECIES FREQUENCIES - ZONE 4 - ANIMAL FLOWER BAY

Species	Growth form	Frequency per 100 quadrats
Andropogon intermedius	H	90
Pectis humifusa	Ch	55
Euphorbia serpens	Ch	35
Euphorbia prostrata	Ch	30
Desmanthus depressus	Ch	25
Egletes prostrata	Ch	10
Sporobolus tenuissimus	H	10
Egragrostis ciliaris	H	5

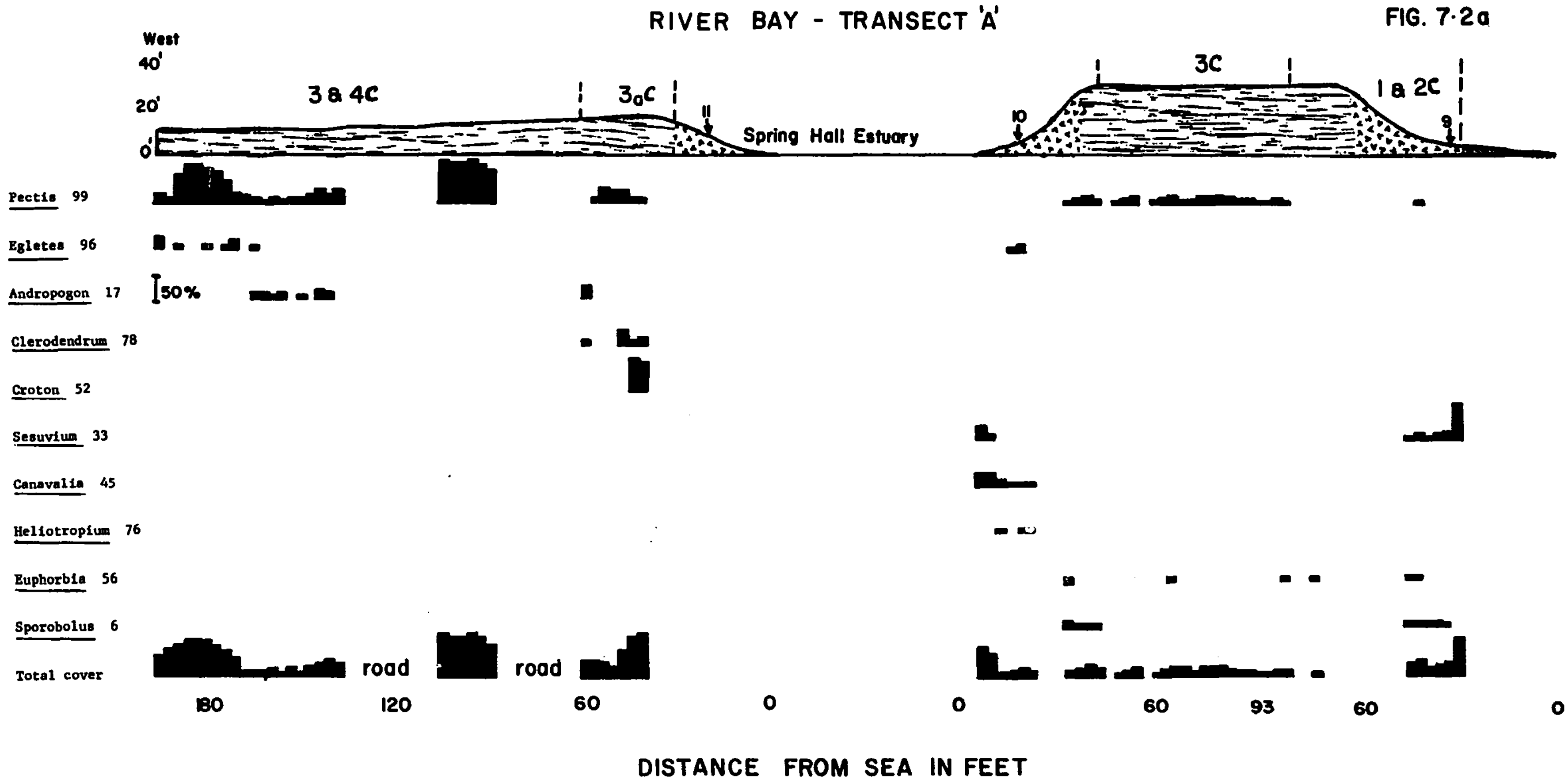
This zonal pattern is repeated at Oliver's Cave (Fig. 7.8), but because the location faces south rather than northeast the habitat is not so severe and cover is correspondingly greater. Furthermore slumping of material from the cliff-top has provided more soil on the flatter parts of the slope than is present in the zones at Animal Flower Bay. Considerably fewer species grow at Oliver's Cave, perhaps because the cliff slope has been available for colonization for a shorter period of time. Two fresh species are present that were observed only at this location. One is Strumfia maritima, an uncommon shrub of Caribbean sea cliffs, which colonizes the shallow soils and cracks in the rocks at the cliff-face in zone 3,


OLIVER'S CAVE
FIG. 7·8
South
84
74
54
34
14
4
0
1C
2C
3C
4C
Sesuvium 33
Sporobolus 6
Portulaca 34
Euphorbia 56
Egletes 96
Pectis 99
Dactyloctenium 11
Lithophila 31
Strumfia 94
Eleusine 12
Andropogon 17
50%
Desmanthus 41
Agave 26
Agave 27
Total cover
0
60
120
180
240
DISTANCE FROM SEA IN FEET

and the other is Spanish needle (Agave angustifolia), an introduced species that occurs with the maypole in zone 4. The latter appear to have been planted as hedgerow species to separate sour grass pastures.

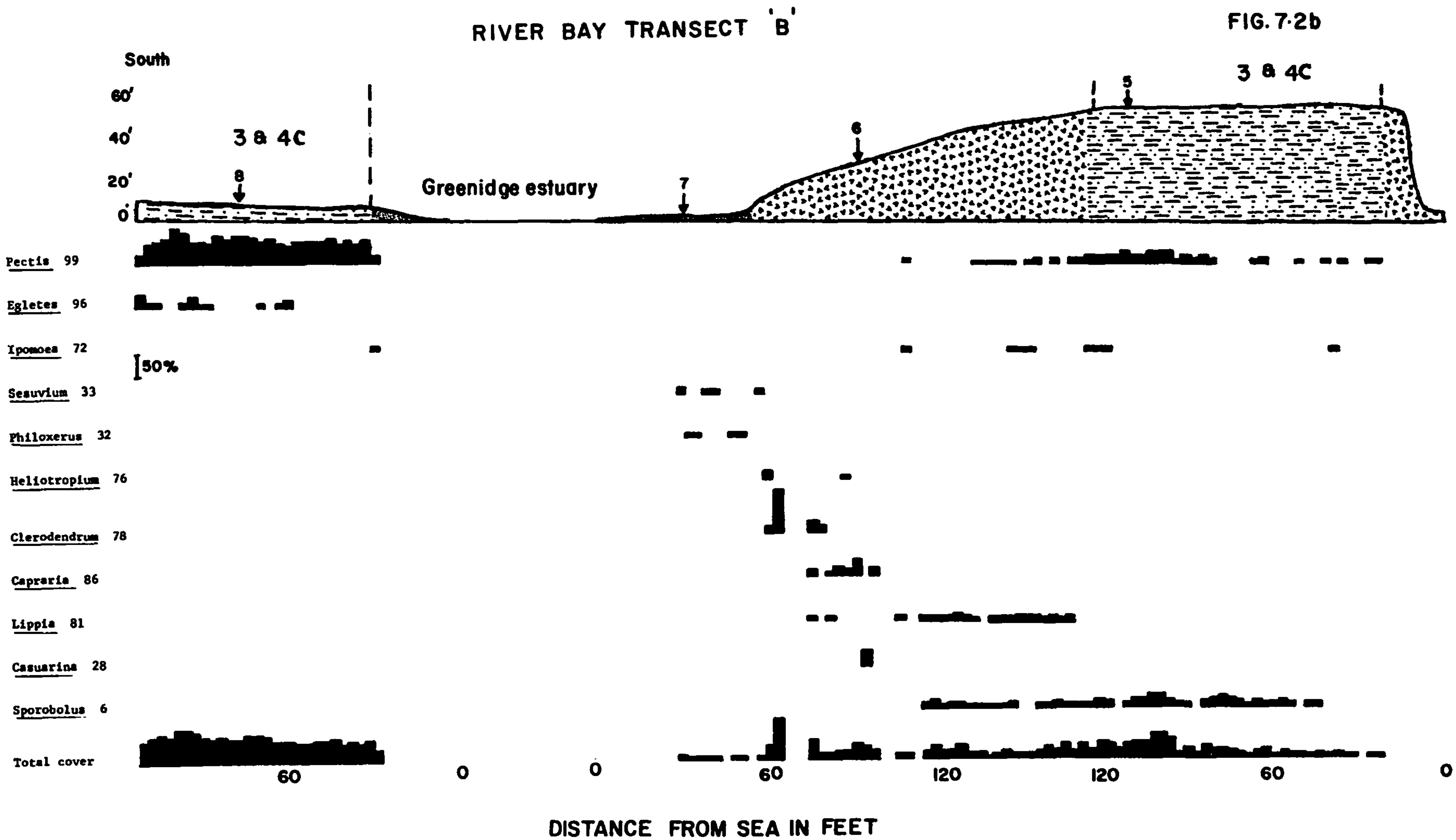
At River Bay, Skeete's Bay and Bottom Bay, coastal cliff vegetation is also present, but for various reasons the complete series of zones does not exist. Two transects were made at River Bay, one running east-west (Fig. 7.2a) and one north-south (Fig. 7.2b), to include the estuaries of both rivers. The two transects met at right angles on a low area of land between the two estuaries. This area was equivalent to a mixture of zones 3 and 4 of coastal cliff vegetation depsite its lower elevation. It is heavily overgrazed and the dominant species are duckweed and Egletes prostrata, with sour grass present in some quadrats. Seaside sage grows on the shallow soils of the estuarine edge, while in the deeper soils of the duckweed 'grassland' the endemic columnar cactus is present. On the upland plateaux that are a continuation of the cliffs at Animal Flower Bay, the more seaward zones occur. The east-west transect (Fig. 7.2a) has a steep slope down to the sea which is mostly devoid of vegetation at its eastern end, but at the base of the slope there is a cover of seaside samphire and crab grass, equivalent to zones 1 and 2 at Animal Flower Bay. The absence of a wide zone 1 may be the result of protection by the sandy beach and the absence of the huge waves associated with the deeper water immediately offshore at Animal Flower Bay. The cliff-tops of both transects have species associated with zone 3, dominated by duckweed but with crab grass also present.

The two inland facing cliff slopes have several different species, and with their different soil and climatic conditions possess a virtually



RIVER BAY - TRANSECT 'A'
FIG. 7·2a
West
40'
20'
0'
3 & 4C
3aC
11
Spring Hall Estuary
10
3C
1 & 2C
9
Pectis 99
Egletes 96
Andropogon 17
50%
Clerodendrum 78
Croton 52
Sesuvium 33
Canavalia 45
Heliotropium 76
Euphorbia 56
Sporobolus 6
Total cover
road
road
180
120
60
0
0
60
93
60
0
DISTANCE FROM SEA IN FEET

FIG. 7·2b


RIVER BAY TRANSECT 'B'
South
60'
40'
20'
0
3 a 4C
8
Greenidge estuary
7
6
5
3 a 4C
Pectis 99
Egletes 96
Ipomoea 72
50%
Sesuvium 33
Philoxerus 32
Heliotropium 76
Clerodendrum 78
Capraria 86
Lippia 81
Casuarina 28
Sporobolus 6
Total cover
60
0
0
60
120
120
60
0
DISTANCE FROM SEA IN FEET

distinct vegetation pattern that might be called 'the estuarine cliff-slope' vegetation (Fig. 7.21). This is dominated by woody species, particularly casuarina, prickly wild-coffee, and West Indian tea, but there is also a variation in prostrate species that includes <u>Lippia strigulosa</u>, wild lavender and two species more commonly associated with sandy beaches, the seaside yam and the sea bean.

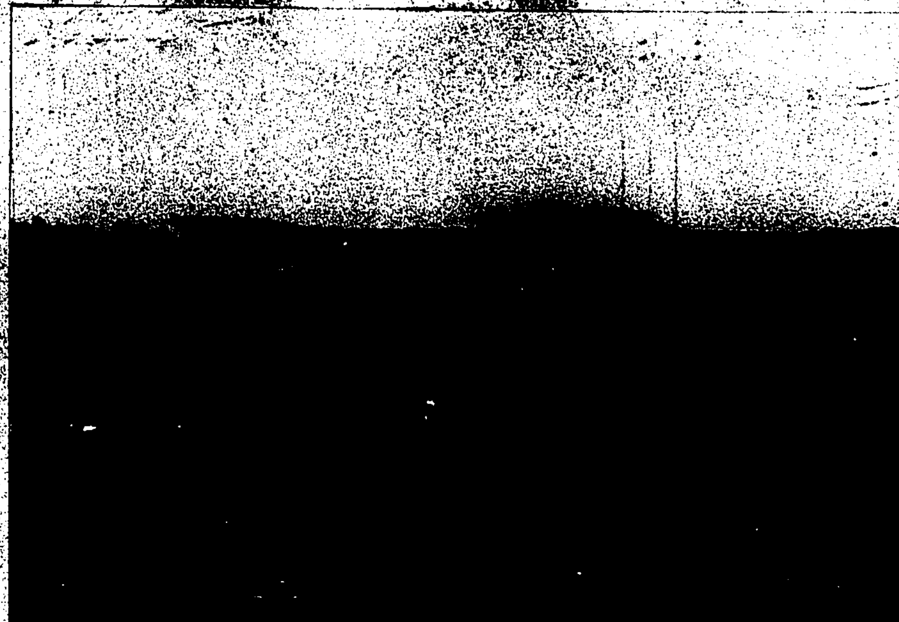


Fig. 7.21
The south-facing estuarine cliff at River Bay. In the foreground is the bed of the river at low-tide. At lower levels on the slope there is prickly wild coffee and higher up to the right shrubs of seaside sage. In the centre of the photo the prostrate vegetation is <u>Lippia strigulosa</u>. The trees are all casuarina; note how the ones growing further up the slope are planed off level with the surface of the plateau by the wind blowing from the northeast, carrying large amounts of salt spray.

Zones 3 and 4 only are present at Skeete's Bay (Fig. 7.5) and Bottom Bay (Fig. 7.6) since beaches are present between them and the sea, where zones 1 and 2 might be expected to occur. On the higher parts of the hill-slope at Skeete's Bay, a forested zone occurs between zone 4 and inland distinct vegetation pattern that might be called 'the estuarine cliff-slope' vegetation (Fig. 7.21). This is dominated by woody species, particularly casuarina, prickly wild coffee, and West Indian tea, but there is also a variation in prostrate species that includes Lippia strigulosa, wild lavender and two species more commonly associated with sandy beaches, the seaside yam and the sea bean.

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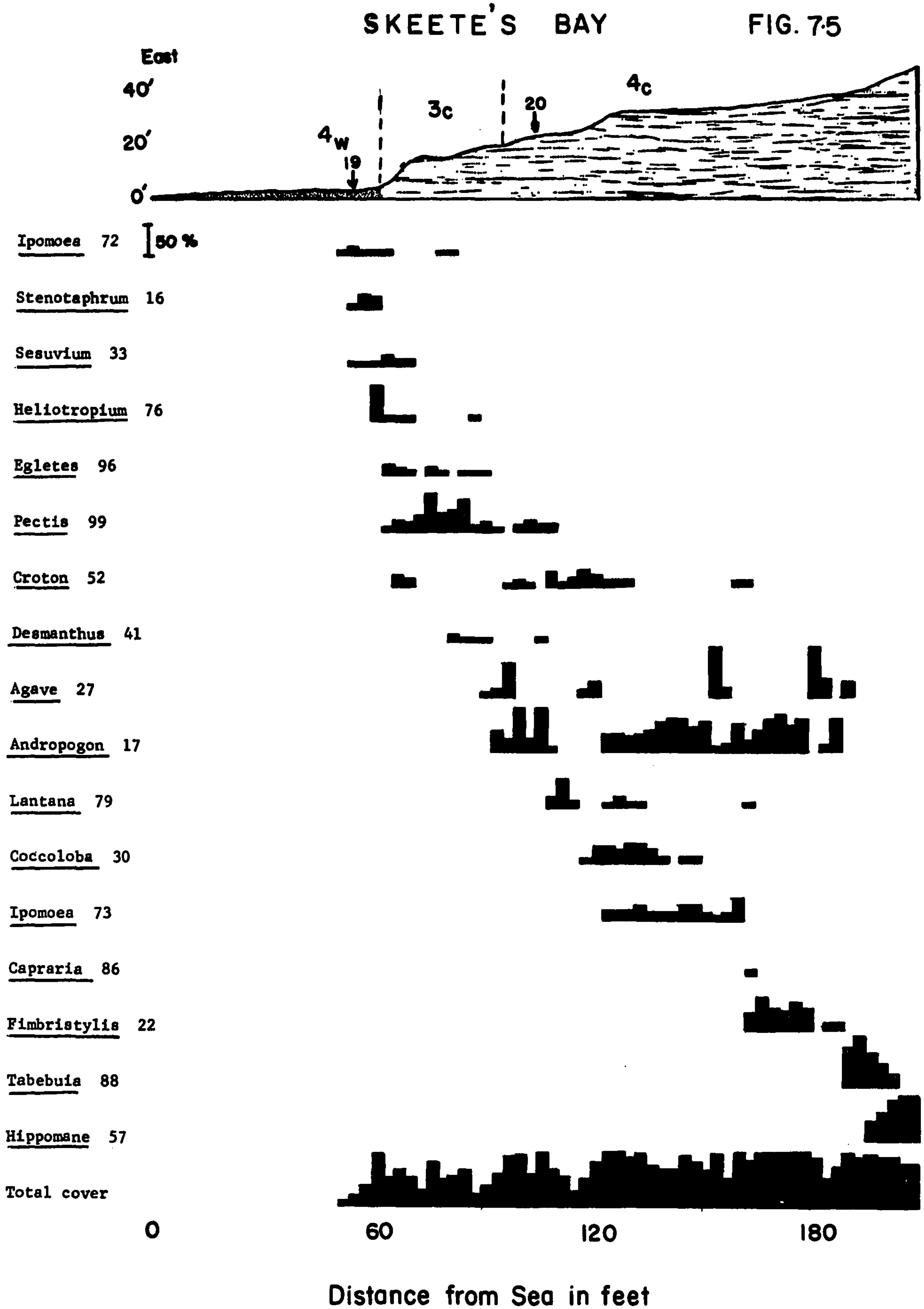
The south-facing estuarine cliff at River Bay. In the foreground is the bed of the river at low-tide. At lower levels on the slope there is prickly wild coffee and higher up to the right shrubs of seaside sage. In the centre of the photo the prostrate vegetation is Lippia strigulosa. The trees are all casuarina; note how the ones growing further up the slope are planed off level with the surface of the plateau by the wind blowing from the northeast, carrying large amounts of salt spray.

Zones 3 and 4 only are present at Skeete's Bay (Fig. 7.5) and Bottom Bay (Fig. 7.6) since beaches are present between them and the sea, where zones 1 and 2 might be expected to occur. On the higher parts of the hill-slope at Skeete's Bay, a forested zone occurs between zone 4 and inland


SKEETE'S BAY
FIG. 7·5
East
40'
20'
0'
4w
19
3c
20
4c
Ipomoea 72
50 %
Stenotaphrum 16
Sesuvium 33
Heliotropium 76
Egletes 96
Pectis 99
Croton 52
Desmanthus 41
Agave 27
Andropogon 17
Lantana 79
Coccoloba 30
Ipomoea 73
Capraria 86
Fimbristylis 22
Tabebuia 88
Hippomane 57
Total cover
0
60
120
180
Distance from Sea in feet

areas of cultivation. This is dominated nearest the sea by whitewood, and then by manchineel. The extremely weathered and broken cliff-edge at Bottom Bay has led to zone 3 being primarily a rocky variant where seaside sage, white sage and seaside laurel grow.

Fig. 7.22
One of the large coralline boulders at Bathsheba which is reached by the sea at high tide. Small specimens of the shrubby variety of whitewood and plants of seaside spurge are growing in the holes eroded on the surface of the lee side. Duckweed and seaside spurge are growing in the solution hollow at the top.

A remarkable feature of the weathered cliff-edge at Bottom Bay and other similar situations is the presence of a variety of whitewood that grows as a small woody shrub in cracks within the rock. This variety often dominates the vegetation, as in the protected location between 210 and 240 feet inland (Fig. 7.6). Whitewood will grow in extremely exposed conditions on rock faces, even on boulders projecting from the sea as at Bathsheba (Figs. 7.4 and 7.22). Krause (1891) described this variety as a separate species, Bignonia cranalis, which he found on coastal rocks areas of cultivation. This is dominated nearest the sea by whitewood, and then by manchineel. The extremely weathered and broken cliff-edge at Bottom Bay has led to zone 3 being primarily a rocky variant where seaside sage, white sage and seaside laurel grow.

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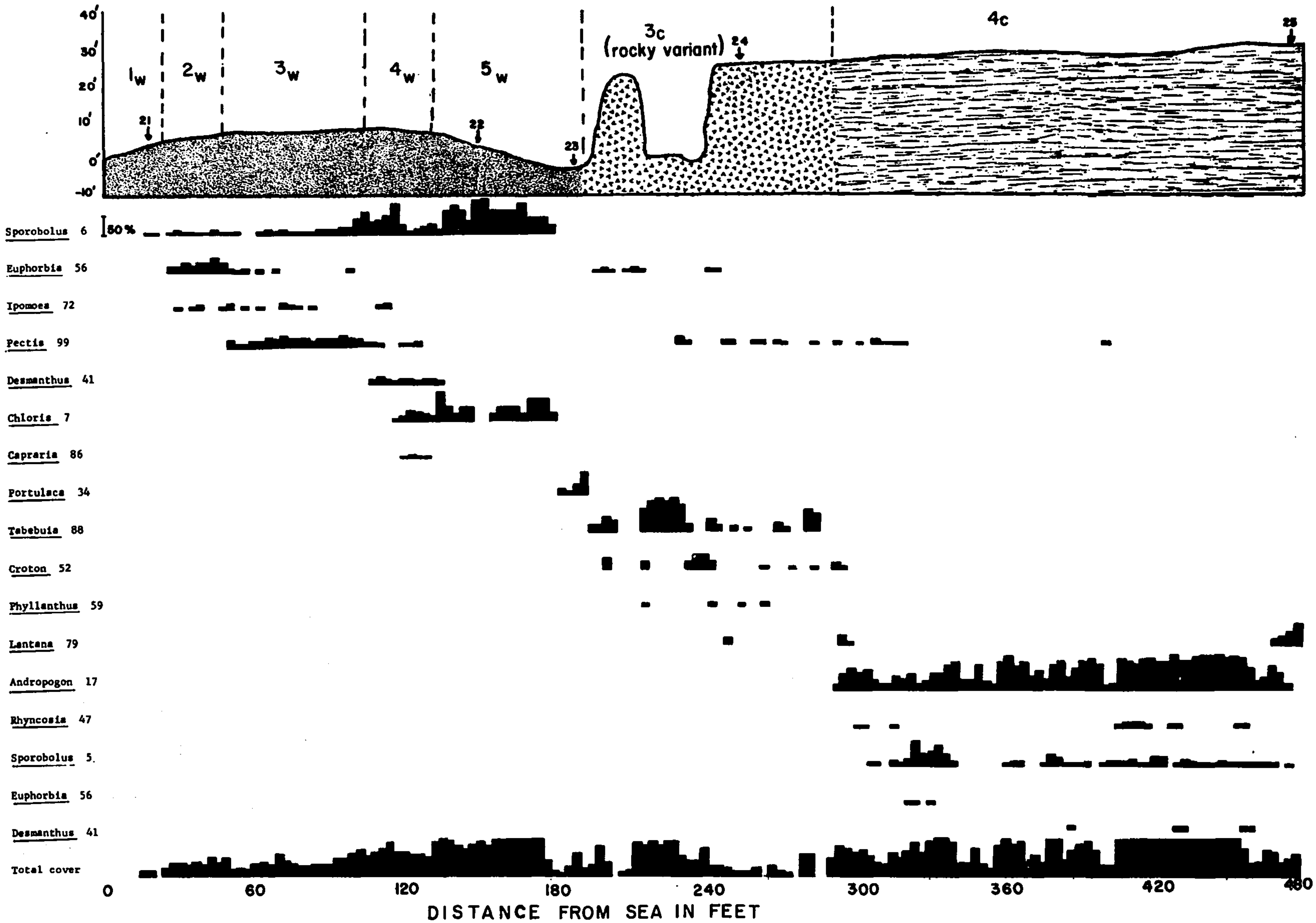
FIG. 7·6

BOTTOM BAY

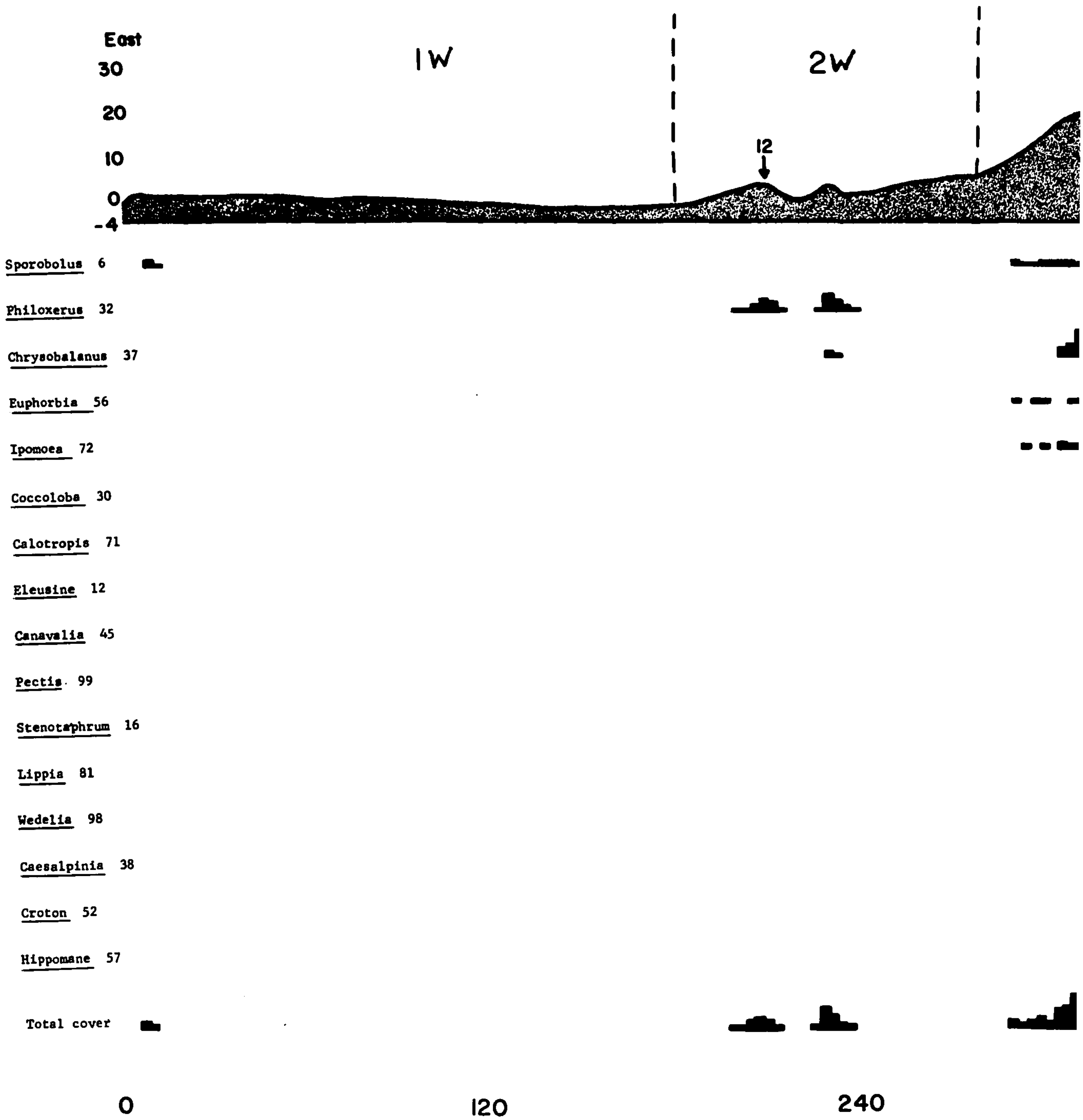


near Crane Beach (Fig. 2.5) but Gooding, Loveless and Proctor (1965) classify it as a variety of Tabebuia pallida.

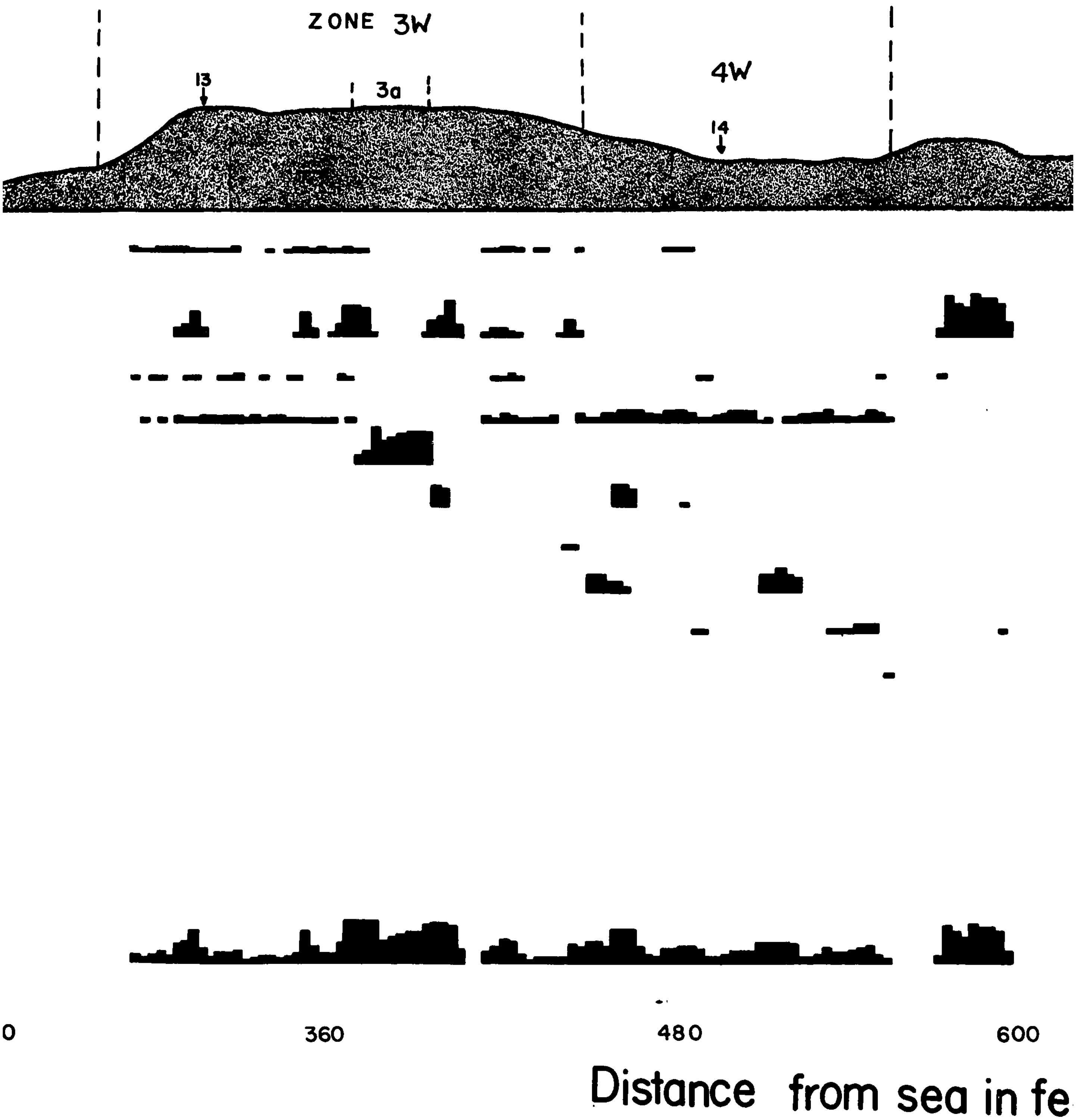
Windward coast beaches and dunes

The pattern of vegetation on coastal cliffs was composed of four quite wide zones. Zonal boundaries were not the result of abrupt changes in species but rather a change in species frequency. The gradients of the variable parameters of the environment, soil salt and aerial salt were also gradual and regular. These facts can be related to the level topography of cliff-tops. Windward coast beaches and dunes have much greater topographical variation over shorter distances and therefore more zones result. The more sudden changes in environment result in some species such as Philoxerus vermicularis having extremely constrained distributions, but others, like seaside grape recur in similar situations in different zones (Fig. 7.3). Vegetation of this type was examined at Lakes Beach, Belleplaine (Fig. 7.3), Bathsheba (Fig. 7.4), Skeete's Bay (Fig. 7.5), Bottom Bay (Fig. 7.6), Foul Bay (Fig.7.7) and Long Bay, Chancery Lane (Fig. 7.9). Although a similar zonal pattern occurs at all these sites, the zones are expressed by some different species at those beaches that are composed mainly of siliceous sand.

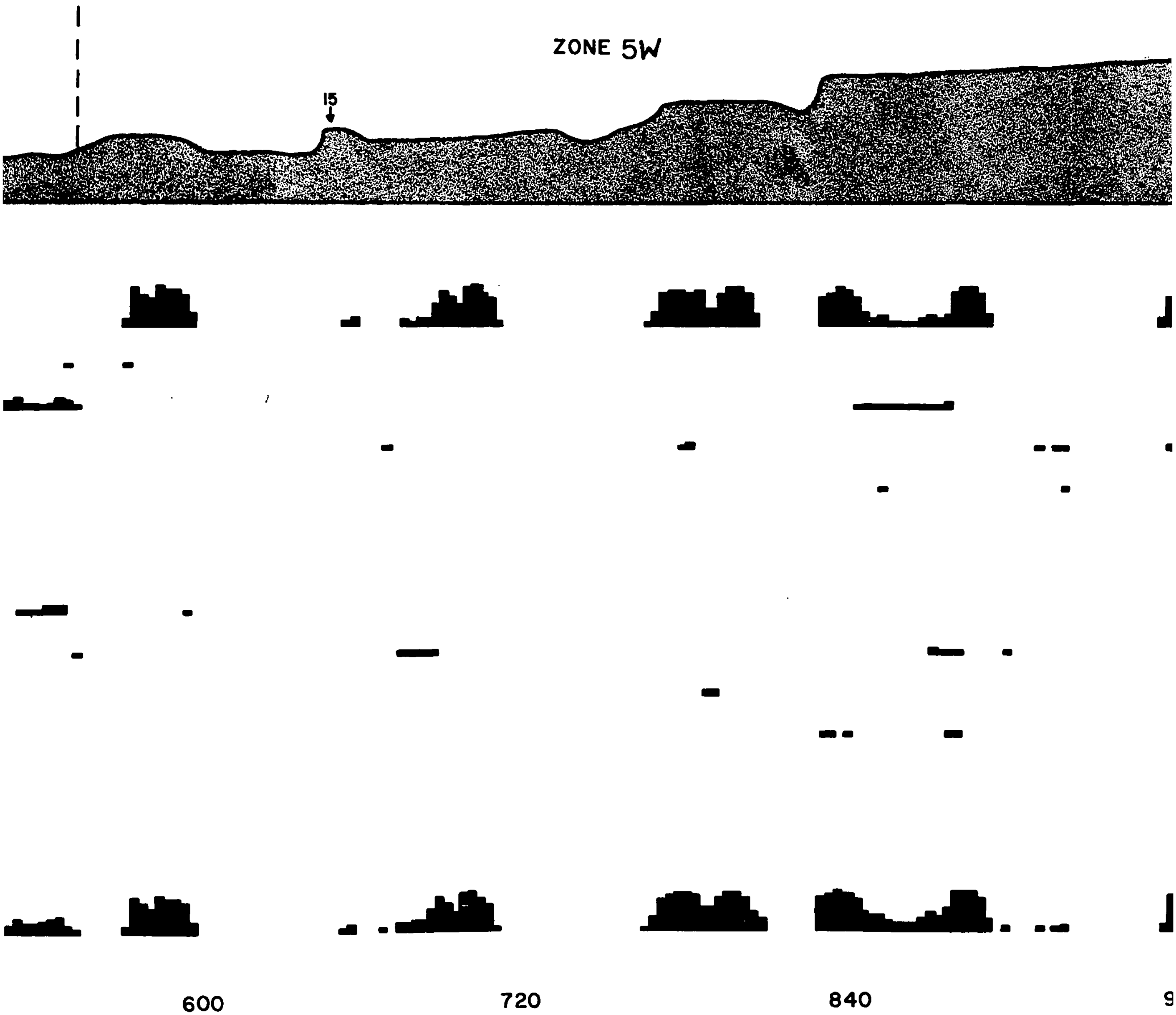
The dunes at Lakes Beach, Belleplaine show the most complete series of zones. In front of the dunes themselves there is a beach about 180 feet wide which comprises zone 1. The whole zone is less than two feet above high water mark and much of the rear beach is below. It is an area of long-term accretion but often liable to flooding and cyclic erosion. During the summer of 1967 only the highest part near the front of the beach was colonized by vegetation. One species, crab grass grew within the zone,


East
30
20
10
0
-4
1W
2W
12
Sporobolus 6
Philoxerus 32
Chrysobalanus 37
Euphorbia 56
Ipomoea 72
Coccoloba 30
Calotropis 71
Eleusine 12
Canavalia 45
Pectis 99
Stenotaphrum 16
Lippia 81
Wedelia 98
Caesalpinia 38
Croton 52
Hippomane 57
Total cover
0
120
240

LAKES BEACH.



BEACH, CHANCERY LANE

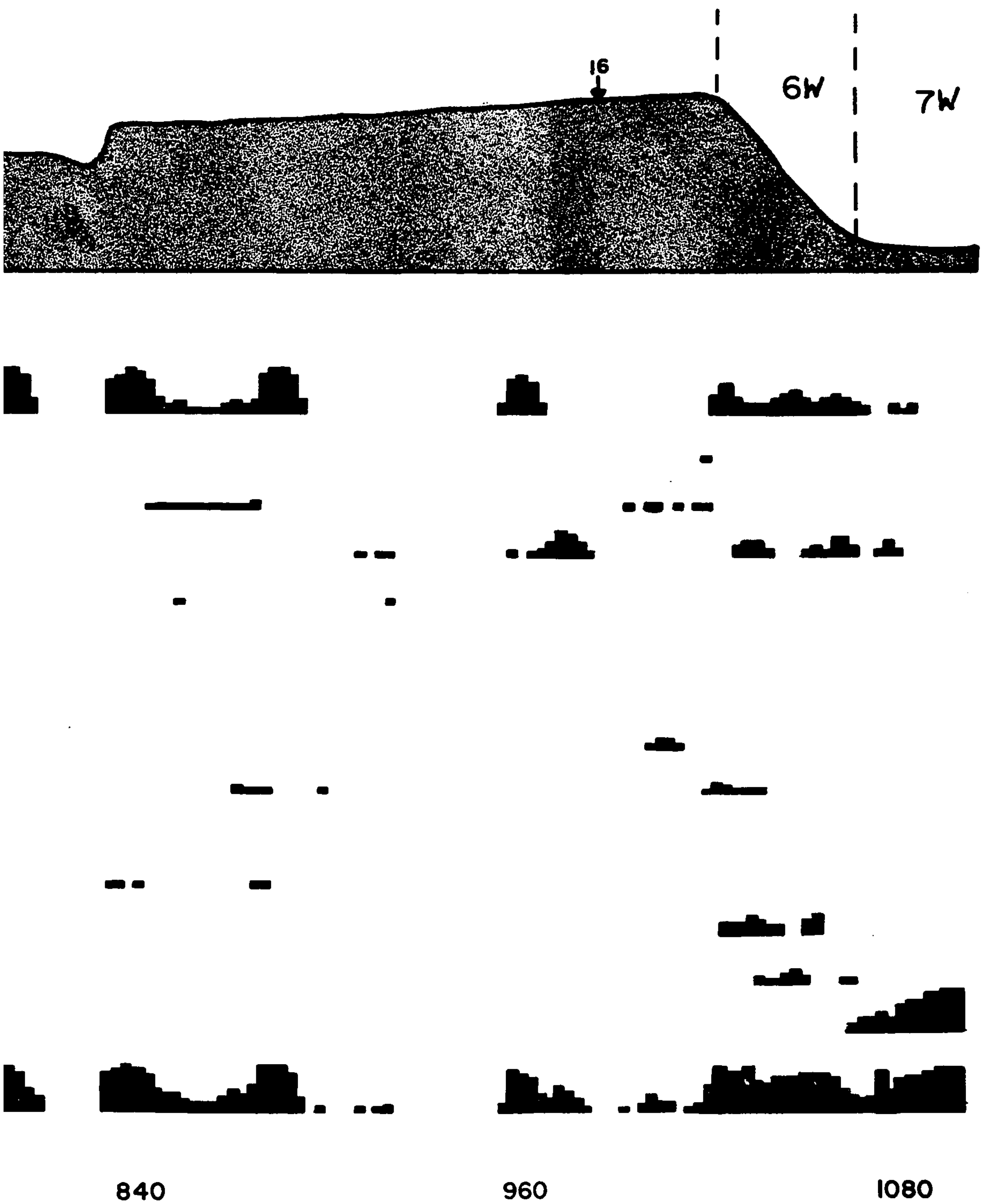


'om sea in feet

Erratum: title should read 'LAKES BEA

- 1 1 2.

FIG. 7·3



Erratum: title should read 'LAKES BEACH, BELLEPLAINE'.

in occasional poor looking clumps, apparently at its limit of tolerance. After the storm swells of December 1967 the zone was no longer in existence but is likely to return in the Spring of 1968. The species frequency can be seen by the following brief table:-

TABLE 7.6 SPECIES FREQUENCY - ZONE 1 - LAKES BEACH, BELLEPLAINE

Species	Growth form	Frequency per 100 quadrats
no plants rooted	--	90
Sporobolus virginicus	H	10

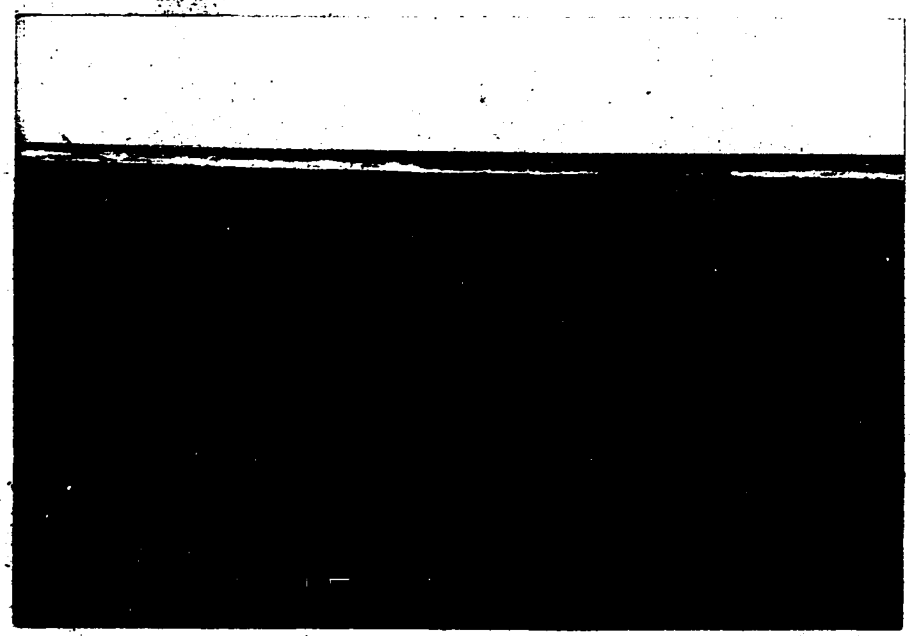


Fig. 7.23
Two of the embryonic dunes in front of the main crest at Lakes Beach, Belleplaine. These dunes form around the rootstocks and dead parts of Philoxerus vermicularis, and are aligned northeast-southwest with the dominant 'trade' winds. Each dune is usually composed of only one many-branched plant which has roots descending below sea-level.

Zone 2 is composed of a series of small embryonic dunes which occur irregularly at the foot of the main front-dune crest (Fig. 7.23). These dunes are barely four feet high and 15-20 feet in diameter. They are entirely in occasional poor looking clumps, apparently at its limit of tolerance. After the storm swells of December 1967 the zone was no longer in existence but is likely to return in the Spring of 1968. The species frequency can be seen by the following brief table:-

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Zone 2 is composed of a series of small embryonic dunes which occur irregularly at the foot of the main front-dune crest (Fig. 7.23). These dunes are barely four feet high and 15-20 feet in diameter. They are entirely built up around the root mat and dead parts of their dominant vegetation Philoxerus vermicularis. This species is similar in appearance and habitat to seaside samphire but attains its greatest cover in the siliceous sands of the island. These dunes are composed of blown sand and are similar to barchans, with their 'horns' pointing northeast-southwest. In the lee of the dunes fat pork, or seaside grape sometimes grow. Like zone 1, these embryonic dunes may be completely eroded during times of severe storm-swells. After the December 1967 swell the most seaward of the dunes had disappeared completely leaving just a few Philoxerus vermicularis rootstocks protruding from the level beach. However, these rootstocks would soon produce new plant material for the sand to collect around. With successive coverings of sand the stems of the plant would root at the nodes and become rhizomes, and the plant would grow upwards to the surface of the dune. Each dune so formed is usually the result of only one many-branched plant with roots extending more than eight feet down from the surface. Between the dunes there is bare sand. Vegetative cover on each dune increased from 5% around the outer edge to over 80% at the top and within the 'horns'. Species frequencies recorded are:-

TABLE 7.7 SPECIES FREQUENCIES - ZONE 2 - LAKES BEACH, BELLEPLAINE

Species	Growth form	Frequency per 100 quadrats
no plant rooted	--	55
Philoxerus vermicularis	Ch	45
Chrysobalanus icaco	P	10
Coccoloba uvifera	P	<5
Sporobolus virginicus	H	<5

The embryonic dunes of zone 2 are replaced by the open association of the 'white' dunes (Hardy 1934) in zone 3. Hardy suggested that the dune series could be subdivided: mobile, open association 'white' dunes; and stable, closed association 'grey' dunes. At the present, however, this definition would place all the region seaward of the rear dune crest in the 'white' category and only the lee of the rear dune in the 'grey', since blowouts and overgrazing have made most of the area mobile with an open vegetation cover.

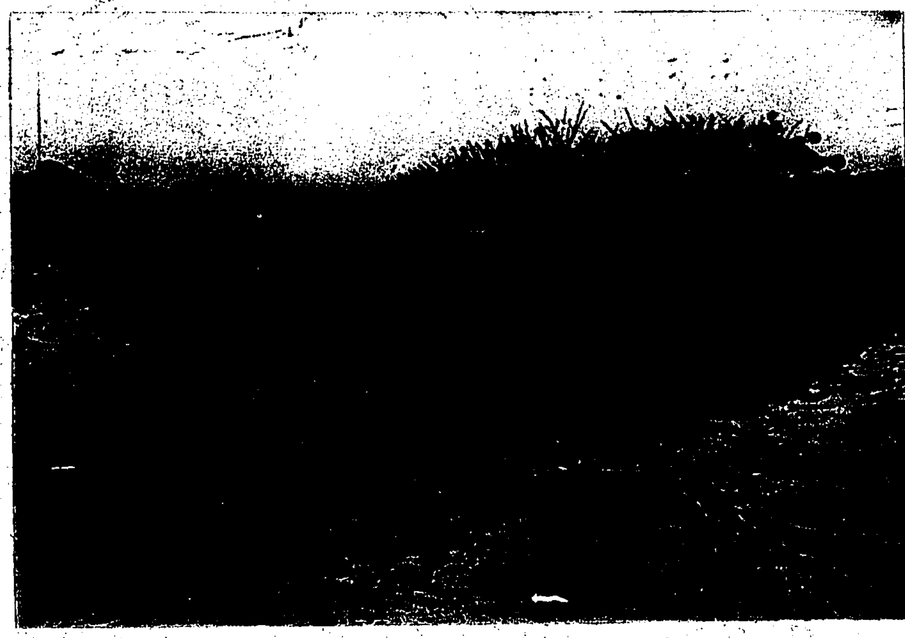

Fig. 7.24
Sea grape at the top of the main dune ridge at Lakes Beach, Belleplaine. The angle of growth on the windward side of the bush is similar to the angle of slope of the dune face, suggesting that salt-spray in wind deflected by the latter influences the former. Leafy development is mainly to the lee. Around the bush are clumps of crab grass and trailing stems of seaside yam.

Zone 3 is the first part of what Gooding (1947) describes as 'the Ipomoea pes-caprae association', so called because of the presence of seaside yam. This zone extends across the foredune and is colonized mainly by three low-growth plants, seaside spurge (Euphorbia mesembrianthemifolia), seaside yam, and crab grass, and two shrubs, seaside grape and fat pork.

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This zone is very open at the front of the dune, averaging about 20% cover but at the top a dense growth of the two shrubs results in almost 100% cover. The presence of seaside grape at the highest point of foredunes around the island is so regular that this has been designated a sub-zone, 3a. The sea grape is easily damaged by salt spray despite its large leathery leaves and preference for exposed habitats. Fig. 7.24 shows a typical sea grape bush on the east coast with no leaves present on the windward branches and strong development to the lee. The line of growth approximately follows the angle of slope of a dune. This suggests that the shrub is shaped by salt spray in the wind that is forced up the face of the dune. Experiments by Gooding (1947) using green wood smoke are evidence that sea grape can exist on the top of the high dunes because the outer slopes of the dunes deflect the wind and the full effects of the salt-laden air is not felt. However, the figures from salinity gauge 7 located in front of this zone (Table 5.6) were very high. Most likely sea grape is able to thrive in its adverse habitat because it has extremely long roots that reach down below the dune sand. Hardy (1934) dug down 21 feet through a dune at Belleplaine to the water-table in the alluvium below and still had not reached the bottom of the tap root.

The low-growth species in this zone are also very well adapted to life in such an environment. Like Philoxerus vermicularis in zone 2, crab grass exists so well in a mobile habitat because it can root at the nodes and send out long rhizomes to form new plants (Fig. 7.25). As each successive piece of stem is covered by accreting sand, small roots develop that do not go deep but run just below the surface where they can collect the smallest amount of moisture before it evaporates. When accretion temporarily ceases, aerial parts are sent up and rhizomes thrown out on which young plants grow, (as on the right of the photo). Seaside spurge also uses the shallow rooting method to exist in this mobile zone. This plant does not have a tap root but has a series of major roots, each about the same length as the stem, which run in several directions parallel to ground level about one to two inches below the surface of the sand. Many fine root-hairs grow from these roots and collect soil moisture, including surface dew which forms regularly in the high humidity environment as soon as the sun goes down. At times of sand movement this species is frequently eroded from its location and transported elsewhere in the zone but appears to re-root without suffering undue harm. Other than this the seaside spurge appears to have no adaptation to its environment for it has a frail stem, flimsy leaves and no capacity for water-retention.

Fig. 7.25
A specimen of crab grass illustrating how it roots at each node when covered with sand. It then sends out runners with a series of small plants when the habitat becomes more stable.

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Fig. 7.25
A specimen of crab grass illustrating how it roots at each node when covered with sand. It then sends out runners with a series of small plants when the habitat becomes more stable.

In zone 3, cover and species numbers vary both parallel with, and perpendicular to the line of the dune crest, since both increase inland, but cover also increases with height, parallel to the crest. Vegetation is either sporadic or absent in the lows between the dunes suggesting that these are blow-outs that have become permanent wind-funnels. The frequency distributions in this zone are:-

TABLE 7.8 SPECIES FREQUENCIES - ZONE 3 - LAKES BEACH, BELLEPLAINE

Species	Growth form	Frequency per 100 quadrats
Sporobolus virginicus	H	65
Ipomoea pes-caprae	Ch	60
Euphorbia mesembrianthemifolia	Ch	35
Chrysobalanus icaco	P	30
Coccoloba uvifera	P	10
no plant rooted	--	10
Calotropis procera	P	<5
Eleusine indica	H	<5

There is a fourth zone beginning about 450 feet inland, in which seaside yam is present in almost every quadrat, and a similar prostrate, creeping species, sea bean occurs also; conversely crab grass becomes much less important. This zone includes the back slope and lee of the front dune ridge.

Seaside yam and sea bean are very interesting members of the zone since their long, trailing stems are extremely useful for checking sand erosion and accumulating fresh wind-blown sand. Their leaves also spread out over the sand surface and act as a protective layer. Even when extremely large quantities of salt spray have killed specimens of seaside yam, in times of storm-swells, the woody trailing stems remain and help hold the sand (Fig. 7.26). The great quality of seaside yam is the frequency with

Fig. 7.26
Trailing stems of seaside yam criss-crossing the surface of a dune, aiding in stabilization of the sand. Most of the other vegetation present is duckweed.

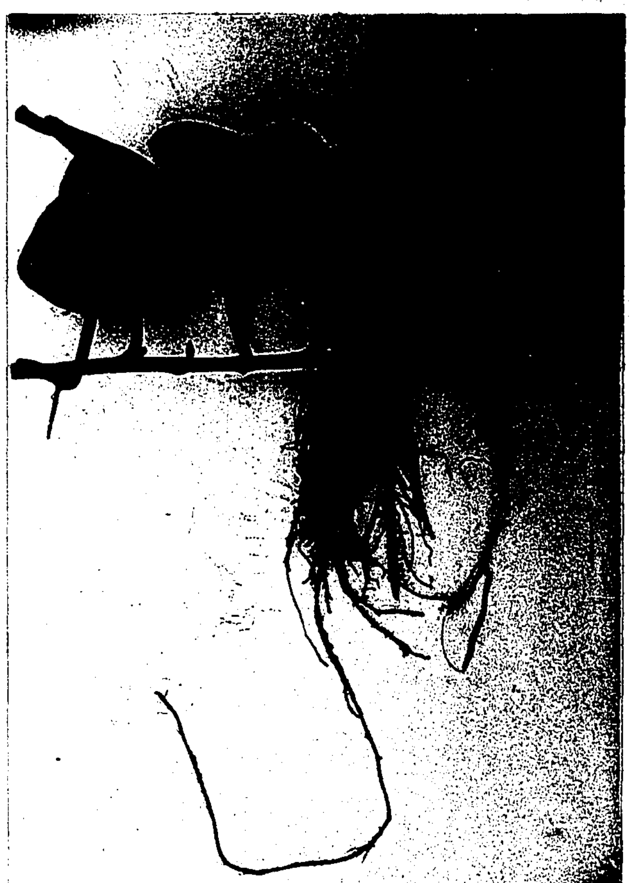
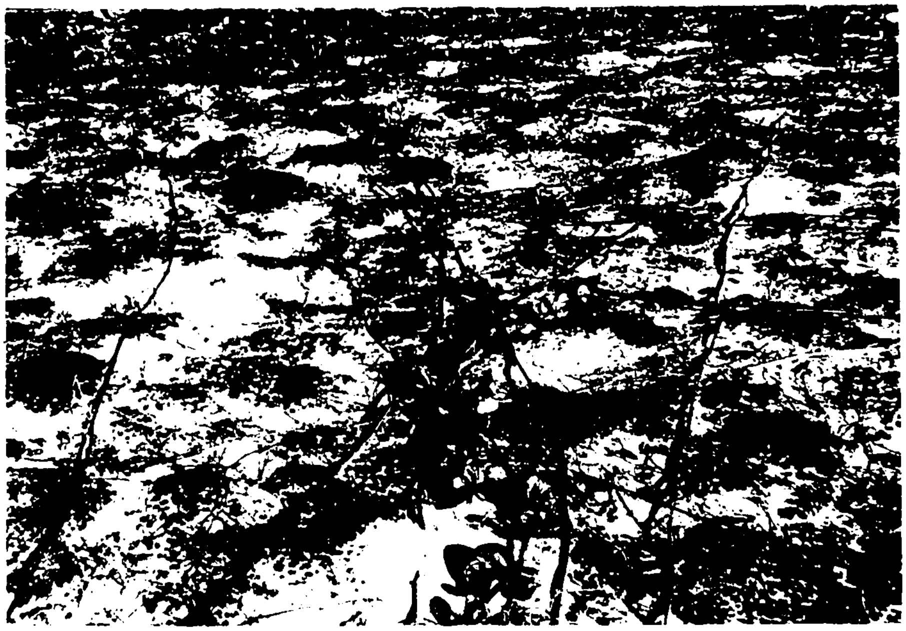


Fig. 7.27
Part of a stem of seaside yam. Note how roots are growing from nodes very close to one another. This is useful for holding sand even on slopes. However, seaside yam has leaves that grow upwards and do not cover much of the sand.



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Part of a stem of seaside yam. Note how roots are growing from nodes very close to one another. This is useful for holding sand even on slopes. However, seaside yam has leaves that grow upwards and do not cover much of the sand.

which it anchors itself with roots (Fig. 7.27). Internodal distance is very small and roots develop at every node so that when a stem is broken by sand movement, or by man, or when part of a plant is killed, very little of the ground surface is left at the mercy of the weather. The sea bean is not such an efficient sand protector because it has just one main root and extremely long, non-rooting, trailing stems. On the other hand it has a higher number of leaves per unit of stem length and thus has a greater density of ground cover. This species has expanded its habitat greatly in Barbados during the last 20 years. According to Gooding (1967), the species was not present on the south coast or common anywhere other than Belleplaine in 1947, but now it is locally very abundant at River Bay, Bathsheba, and Foul Bay. Species frequency figures for this zone are:-

TABLE 7.9 SPECIES FREQUENCIES - ZONE 4 - LAKES BEACH, BELLEPLAINE

Species	Growth form	Frequency per 100 quadrats
Ipomoea pes-caprae	Ch	70
Sporobolus virginicus	H	35
Canavalia maritima	Ch	20
Euphorbia mesembrianthemifolia	Ch	10
Calotropis procera	P	10
Coccoloba uvifera	P	10
Chrysobalanus icaco	P	10
Pectis humifusa	Ch	10
Egragrostis ciliaris	H	10
no plant rooted	--	10
Chloris barbata	H	<5
Eleusine indica	H	<5
Echinochloa colonum	H	<5
Fimbristylis cymosa	H	<5
Wedelia trilobata	Ch	<5
Stenotaphrum secundatum	H	<5

As in zone 3 there is both a perpendicular and a parallel pattern in the vegetation since, within this zone, the continuations of the wind-funnels are eroded down to the base level of the sand. Several additional species occur that, at Belleplaine, are limited to these areas. On the extremely steep slopes of the valley-sides, French cotton (_Calotropis procera_) and sea grape grow. Seaside yam is still the dominant species on the valley floors, but cover density is low. Other species recorded were mainly grasses and sedges and included crab grass, dog's grass, _Chloris barbata_, Dutch grass, _Echinochloa colonum_ and _Fimbristylis cymosa_, in that order of frequency.

Fig. 7.28
View over central Belleplaine dunes. Only the tops of the individual dunes are vegetated: with fat pork. In between the dunes there is little vegetation except for occasional runners of seaside yam as in foreground.

A fifth zone extends 150 feet inland over a series of small dunes to the crest of the main rear dune series. This zone is completely dominated by a dense cover of fat pork on the dunes but is virtually devoid of vegetation in the slacks (Fig. 7.28). A few goats graze within this zone, funnels are eroded down to the base level of the sand. Several additional species occur that, at Belleplaine, are limited to these areas. On the extremely steep slopes of the valley-sides, French cotton (Calotropis procera) and sea grape grow. Seaside yam is still the dominant species on the valley floors, but cover density is low. Other species recorded were mainly grasses and sedges and included crab grass, dog's grass, Chloris barbata, Dutch grass, Echinochloa colonum and Fimbristylis cymosa, in that order of frequency.

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TABLE 7.10 SPECIES FREQUENCIES - ZONE 5 - LAKES BEACH, BELLEPLAINE

Species	Growth form	Frequency per 100 quadrats
Chrysobalanus icaco	P	50
no plant rooted	--	45
Ipomoea pes-caprae	Ch	10
Coccoloba uvifera	P	10
Stenotaphrum secundatum	H	5
Pectis humifusa	Ch	<5
Wedelia trilobata	Ch	<5
Euphorbia mesembrianthemifolia	Ch	<5
Lippia strigulosa	Ch	<5
Calotropis procera	P	<5

The leeward slope of the rear dunes possesses a shrub community, zone 6, similar to that described by Gooding (1947). Cover is quite dense from top to bottom of the slope, averaging 80%. The dominant species are still the two main shrubs of the dunes, fat pork and sea grape but in addition two other shrubs occur, seaside sage and horse nicker. Stenotaphrum secundatum, a stoloniferous grass, is present on those parts of the slope where cover is most open.

On the flat, 'sandy field' area behind the dunes, this shrub zone grades into the final zone of the coastal vegetation pattern at Belleplaine. This is a manchineel forest (Fig. 7.29) which extends a few hundred feet inland as far as the pasture lands of Belleplaine village. Fat pork and sea grape are still present on the fringe of this zone, but under the manchineel trees there is no vegetation except occasional specimens of *Fimbrystilis cymosa*. The main reason undergrowth is absent in manchineel forest is not reduction in light since the canopy is usually quite open. Rather it is becuase the manchineel bark, leaves and fruits all exude an extremely caustic alkaline latex which burns organic matter upon which it falls. One of the reasons manchineel is still so prevalant, especially on the leeward coast of the island, may be because neither animals nor man wish to touch it.

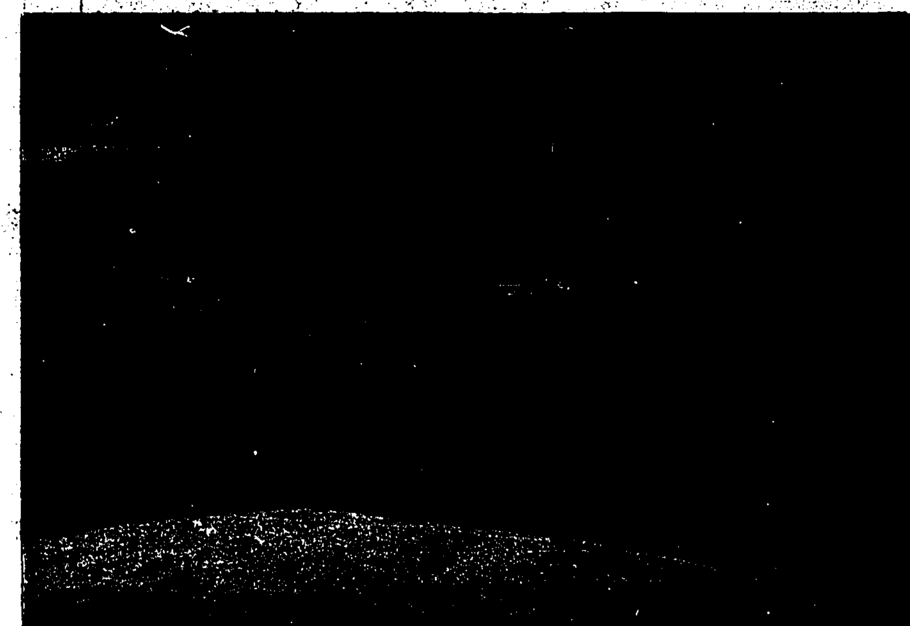

Fig. 7.29
From the top of the rear dune crest at Belleplaine there is a view over manchineel forest on the flat sand-covered alluvium behind. In front of the manchineel, there are tall, tree-like specimens of sea grape growing in the protection of the dune (most of the salt has been removed from the air by this distance inland). On the lee slope are shrubs of seaside sage and horse nicker.

As with the coastal cliff vegetation, this zonal pattern is repeated at other similar areas on the Windward coast, sometimes with other species present and often with one or more of the zones missing. At Bathsheba chineel trees there is no vegetation except occasional specimens of Fimbrystilis cymosa. The main reason undergrowth is absent in manchineel forest is not reduction in light since the canopy is usually quite open. Rather it is becuase the manchineel bark, leaves and fruits all exude an extremely caustic alkaline latex which burns organic matter upon which it falls. One of the reasons manchineel is still so prevalant, especially on the leeward coast of the island, may be because neither animals nor man wish to touch it.

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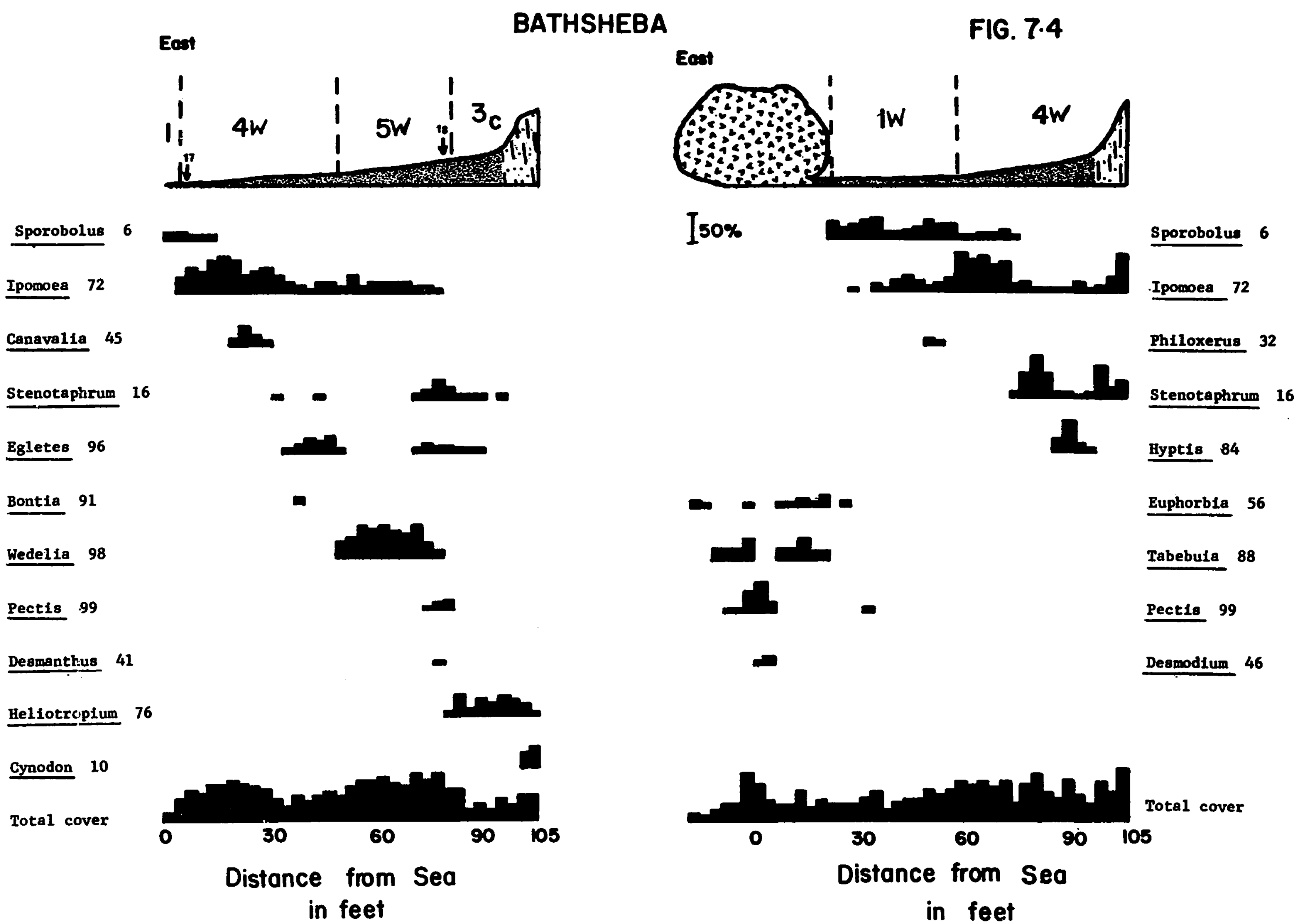
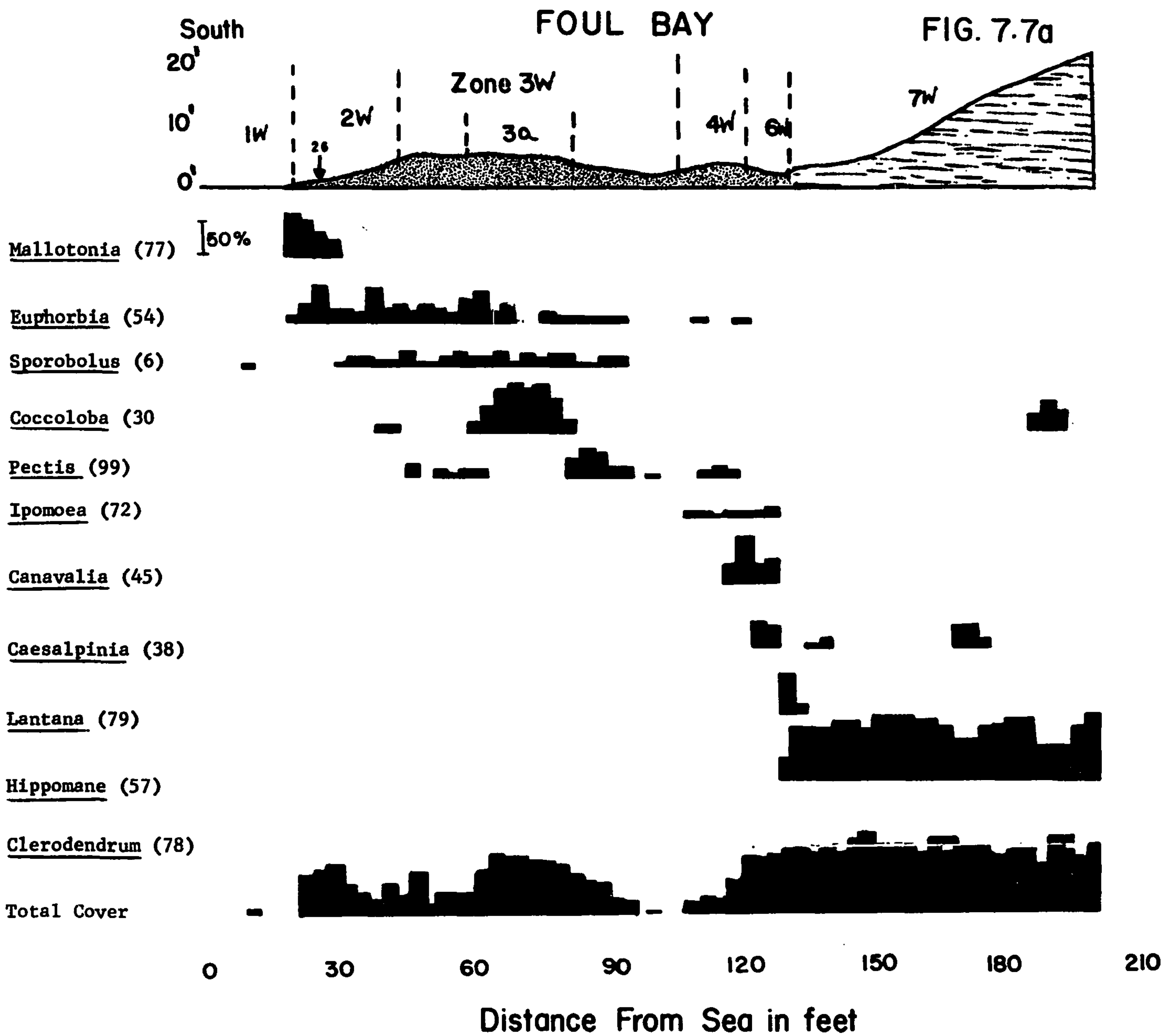

BATHSHEBA
FIG. 7·4
East
4W
5W
3c
17
18
East
1W
4W
50%
Sporobolus 6
Ipomoea 72
Canavalia 45
Stenotaphrum 16
Egletes 96
Bontia 91
Wedelia 98
Pectis 99
Desmanthus 41
Heliotropium 76
Cynodon 10
Total cover
0
30
60
90
105
Distance from Sea in feet
Sporobolus 6
Ipomoea 72
Philoxerus 32
Stenotaphrum 16
Hyptis 84
Euphorbia 56
Tabebuia 88
Pectis 99
Desmodium 46
Total cover
0
30
60
90
105
Distance from Sea in feet

(Fig. 7.4) which is still within the siliceous sand district, crab grass occurs in the first zone close to the sea, with Philoxerus vermicularis and seaside yam at the rear. This is followed immediately by a zone equivalent to zone 4 at Belleplaine, primarily because there is no dune section with the topographic change that results in zones 2 and 3.

Only the first five zonal equivalents of the pattern at Belleplaine occur on the dune at Bottom Bay (Fig. 7.6) before the cliff is reached and the coastal cliff pattern takes over. At Bottom Bay the more typical vegetation pattern of the near-sea zones on the calcareous sands is found. Crab grass still occurs alone in zone 1 but immediately landwards in zone 2 crab grass, seaside spurge and seaside yam occur with equal cover.

Because Bottom Bay is semi-circular in shape and faces due east, the zones of the vegetation pattern are not expressed by bands orthogonal to the shore but by concentric circles around the bay. Thus, from north to south across the bay at 30 feet from high water mark, a consecutive series of species occur. First, there is sea-grape, protected from the influence of the sea by the cliff-wall. As this dies out duckweed and seaside yam occur, still within the shelter of the cliff. Throughout the centre part of the bay crab grass and seaside spurge are present, with only crab grass in the very centre where conditions are most extreme. Seaside spurge recurs with seaside lavender near the southern cliff wall. The latter species is found in zone 2 both at Foul Bay and Chancery Lane.

Only occasional specimens of crab grass grow in zone 1 at Foul Bay (Fig. 7.7), but zone 2 has the same species as at Bottom Bay, and Chancery Lane. Zone 3 occurs at the dune top as at Belleplaine with the sub-zone of sea grape at the highest point, and in zone 4 seaside yam dominates.


South
FOUL BAY
FIG. 7.7a
20'
10'
0'
Zone 3W
1W
2W
3a
4W
6W
7W
26
50%
Mallotonia (77)
Euphorbia (54)
Sporobolus (6)
Coccoloba (30
Pectis (99)
Ipomoea (72)
Canavalia (45)
Caesalpinia (38)
Lantana (79)
Hippomane (57)
Clerodendrum (78)
Total Cover
0
30
60
90
120
150
180
210
Distance From Sea in feet

The equivalent of the fat pork/sea grape zone is missing because of the much shorter distance between the sea and the rear of the dunes but the same seaside sage and horse-nicker zone occurs on the lee slope of the sand. The dune area is backed with manchineel forest as at Belleplaine.

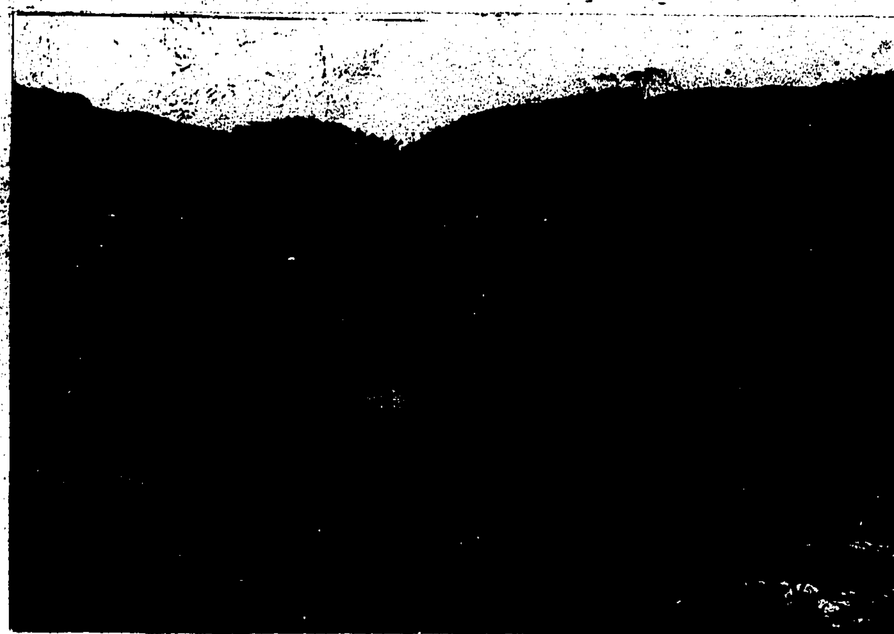


Fig. 7.30
The gully through the manchineel forest at the back of Foul Bay. Note the change in vegetation down the slopes of the gully as illustrated in Table 7.11. In the saline conditions of the floor of the gully only seaside samphire grows.

A gully has eroded a path down to the sea within the manchineel forest at Foul Bay (Fig. 7.30). This reaches high-tide level about 300 feet from high water mark and drops to minus six feet about 100 feet from the sea where it disappears into an area of mobile sand. A transect was made across this gully at a distance of 200 feet from the sea (Fig. 7.7b) to show how the vegetation varies with topography and salinity. Starting on the western slope it can be seen that the manchineel forest grades first into sea grape scrub then <u>Chloris petraea</u> 'grassland', then a seaside yam/

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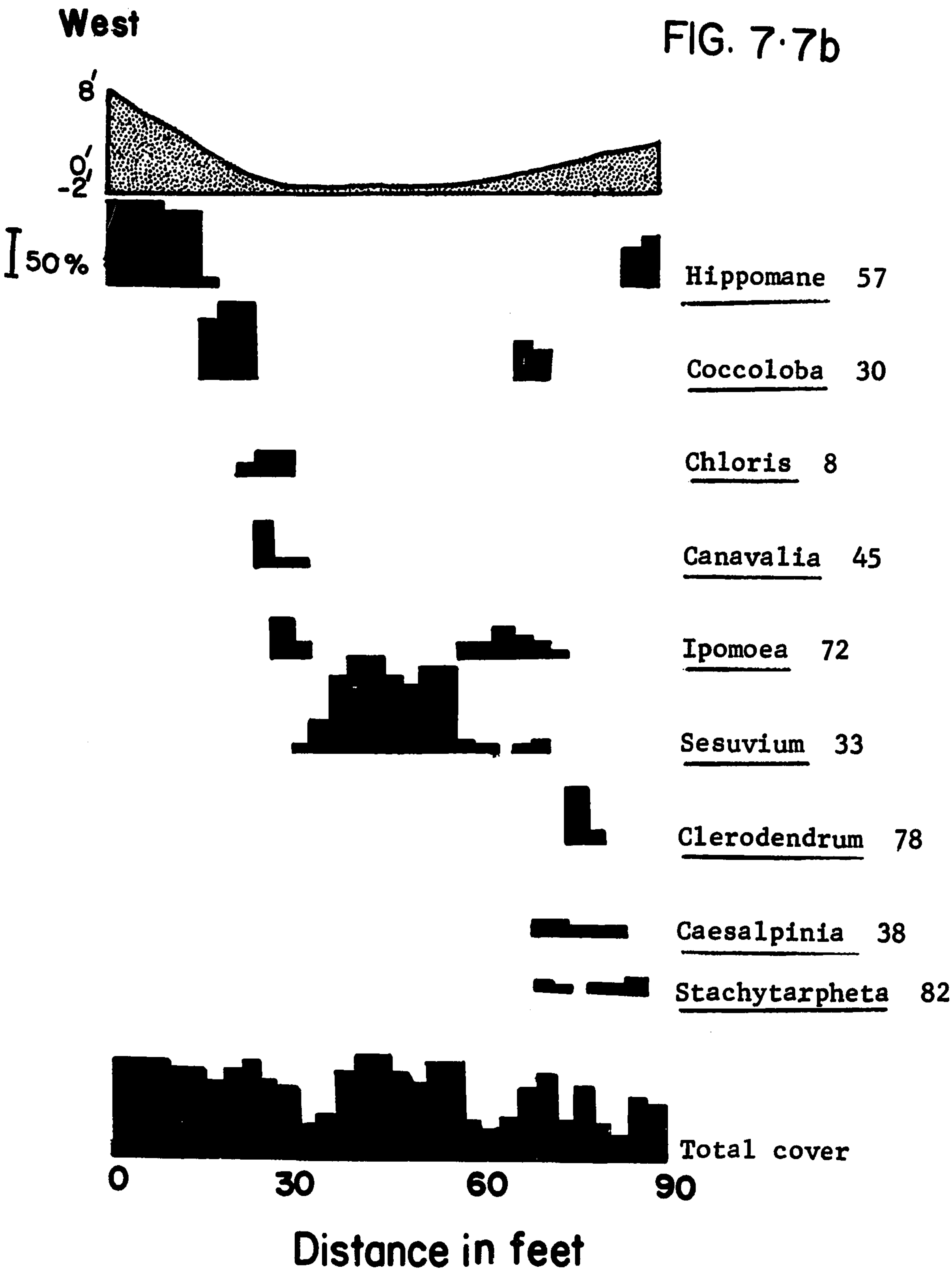
FOUL BAY (GULLY)

FIG. 7·7b



sea bean zone and finally on the floor of the gully to an area of seaside samphire. All this occurs within 15 feet and is equivalent to passing through zones 7-4 of the east coast sand pattern and into zone 1 of the coastal cliff pattern. Since this transect is parallel with the shore, and factors of soil grain-size and climate are approximately similar, the species change must be explained above all by the soil-salt gradient which alters with height at this location (Table 7.11).

TABLE 7.11 SOIL-SALT GRADIENT ACROSS FOUL BAY GULLY

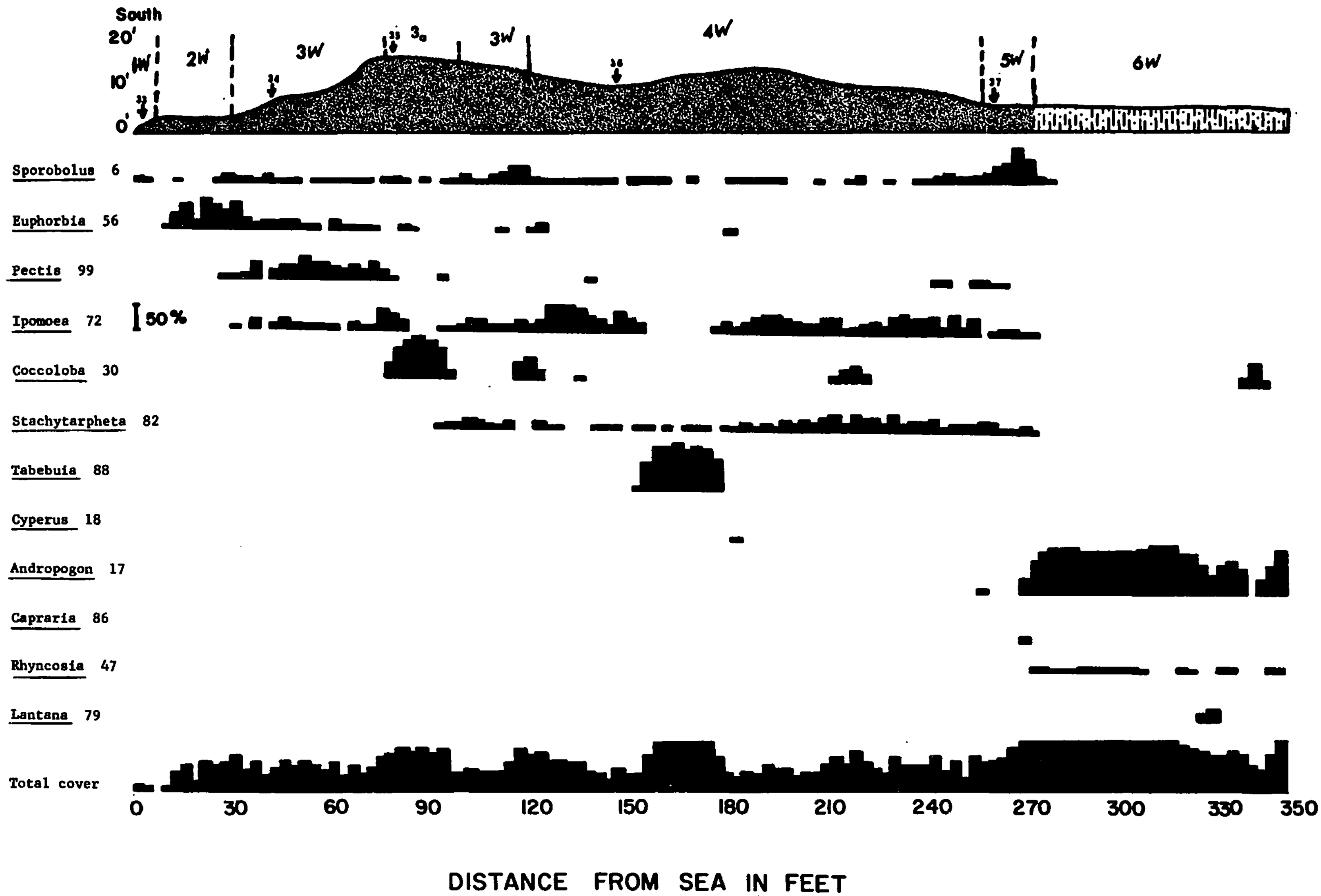
Species	Salt, mhos/cm	Species	Salt, mhos/cm
1. Manchineel	163	6. Seaside samphire	7802
2. Sea grape	385	7. Seaside yam	4008
3. <u>Chloris petraea</u>	477	8. Prickly wild coffee	705
4. Sea bean	2437	9. Horse nicker	760
5. Seaside samphire	7643	10. Manchineel	284

Soil-salt readings taken from 6 gms. soil in 50ccs. H_2O

The dunes at Long Bay, Chancery Lane (Fig. 7.9) have almost all the zones that occur at Belleplaine except the manchineel forest. The latter is missing because the dunes back onto Chancery Lane swamp which has been drained and put down to sour grass pasture. Chancery Lane is a much less harsh environment than northeast-facing Belleplaine, except when winds veer to the south, and this results in certain changes in zonal species. Zone 1 is present with crab grass and occasional specimens of samphire and seaside yam. In zone 2 crab grass is much less important and seaside spurge dominates, with up to 80% cover in some quadrats. Irregularly within this zone clumps of seaside lavender shrubs are found (Fig. 2.14). There seems to be no environmental reason for their exact location and it is thought to be an accident of their migrational history. Zone 3 occurs

LONG BAY, CHANCERY LANE

FIG. 7·9



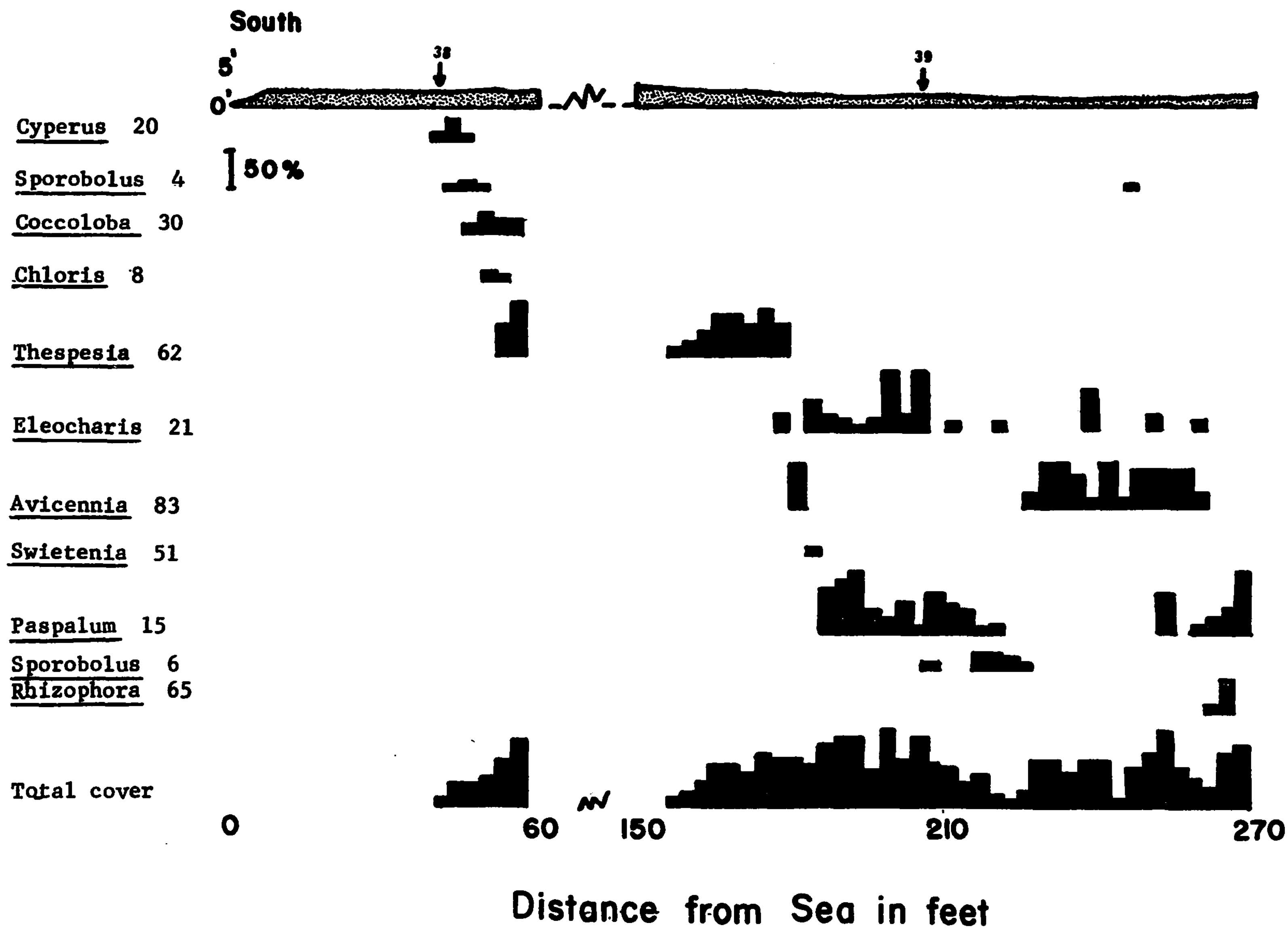
once more at the crest of the front dune, dominated by prostrate species but with seaside grape at the very highest point. In zone 4 seaside yam is the dominant species in terms of density and frequency as at Belleplaine but vervain, (Stachytarpheta jamaicensis) also occurs in 75% of quadrats. This species is much more common on the littoral of the west coast of the island. Also in zone 4 a few large clumps of shrubby whitewood grow. Of all woody species on the Barbados coast, whitewood seems to have the greatest range both in terms of habitat tolerance and physiology. A fifth zone occurs in the lee of the dunes and is represented by an upsurge of crab grass which seems second only to whitewood and its range of tolerance. Certainly it is the pioneer in mobile, saline habitats but it also seems able to compete very successfully in all zones of the littoral as far inland as sand soils are present. Although the dominant species in zone 6 is sour grass, it can be seen from the clumps of seaside grape, seaside sage, horse-nicker and prickly pear within the pasture, that if sour grass had not been planted this would be similar to the lee slopes of Belleplaine dunes.

Leeward Coast Beaches

The Leeward coast of Barbados has the least adverse environment of the littoral. Because of this, the coastal vegetation pattern is composed of a much narrower and smaller set of zones than on the Windward coast. Once inland from the pioneer fringe, the primary determinant of the zonal patterning seems to be soil rather than salt-spray. Leeward coast vegetation of the usual sandy beach type was examined at Rockley Beach (Fig. 7.11). Brighton (Fig. 7.12), Holetown (Fig. 7.13), Heywood's Beach (Fig. 7.14) and Maycock's Bay (Fig. 7.15). Mangrove swamp, which was

GRAEME HALL SWAMP

FIG.7·10



seen at Graeme Hall Swamp (Fig. 7.10), is included within the Leeward coast vegetation. Because of its limited importance at the present day in Barbados, the latter was only subjected to a transect analysis. It was found that the mangrove trees were limited to a narrow band along the banks of the main drainage channels of the swamp. The white mangrove was the commonest species but red mangrove increased in importance with distance from the sea. Away from the drainage channels there was a dense grass/sedge cover dominated by bulrush and Paspalum vaginatum, with some crab grass in the most saline soils near the mangrove trees. Seaside mahoe and mahogony (Swietenia mahagoni) are present on higher ground away from the water of the channels and at the head of the beach. Mangrove swamp now occurs only at a few riverine estuaries in Barbados, and the vegetation pattern is one that varies both with distance from the sea and with distance from a drainage channel.

The other five site locations on the Leeward coast of the island have a basically similar zonal pattern, which is best expressed at Maycock's Bay (Fig. 7.15). As on the east coast, the first zone of the west coast has only the one species present, crab grass, (see Fig. 2.2) which grows in irregular patches with open ground in between. The overall cover density averages under 5%. This pioneer fringe is maintained by the presence of aerial salt which is released in foam-spray by the breaking waves. Because the wave action is usually relatively slight and because the winds are offshore, this is the only zone that is strongly affected by the proximity of the sea. The species frequency in this zone is shown in Table 7.12.

MAYCOCK'S BAY FIG. 7·15

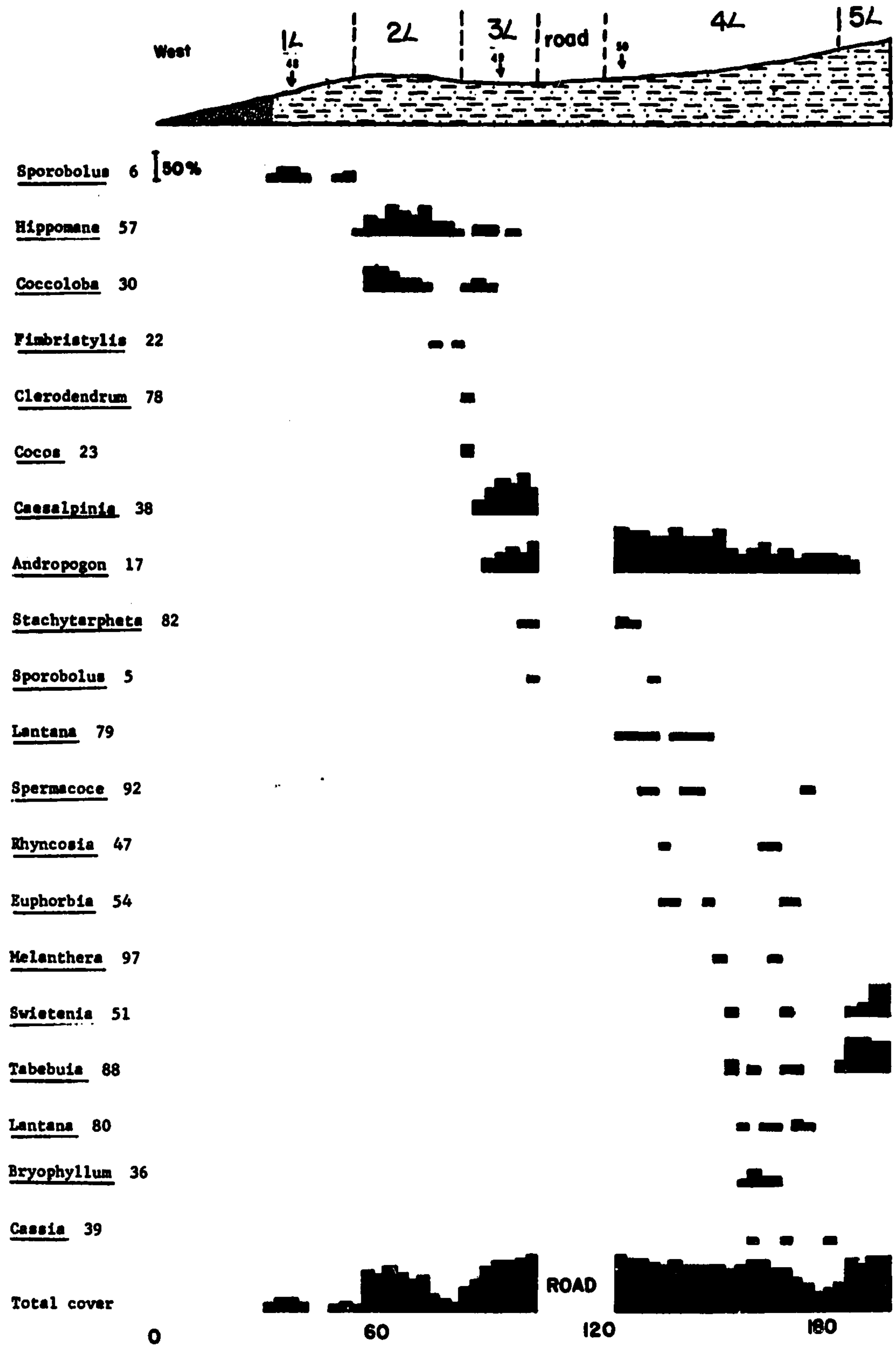


TABLE 7.12 SPECIES FREQUENCY - ZONE 1 - MAYCOCK'S BAY

Species	Growth form	Frequency per 100 quadrats
Sporobolus virginicus	H	55
no plant rooted	--	45

Inland from the pioneer zone but still on the beach sand is the second zone, dominated by the manchineel, an evergreen tree that grows to about 25 feet high (Fig. 2.2, 2.3). Along the Leeward coast the zone varies from only one tree wide to a small forest over 50 feet in width. It was the presence of this zone that resulted in the first description of the island (Anon 1629) stressing the great quantity of manchineels. The sea grape is also present in zone 2 at Maycock's Bay, but here instead of being a shrub five to ten feet high, it grows as a small tree about fifteen to twenty feet in height. The manchineel zone usually stops quite suddenly at the rear of the beach and few or no seedlings are found within the inland zones. On the other hand it is quite common in the rainy season to see a crop of tiny manchineel seedlings about two or three inches high littering the pioneer zone. These are not able to withstand the increased salinity that results with the higher waves of a storm swell and most have disappeared by the dry season. Within zone 2 the species frequencies recorded are:-

TABLE 7.13 SPECIES FREQUENCIES - ZONE 2 - MAYCOCK'S BAY

Species	Growth form	Frequency per 100 quadrats
Hippomane mancinella	P	70
Coccoloba uvifera	P	25
Fimbrystilis dichotoma	H	5
Clerodendrum aculeatum	P	<5
Sporobolus virginicus	H	<5
Caesalpinia bonduc	P	<5

A lower shrub zone occurs immediately behind the manchineel forest. The soils here are usually part of the local inland association but have a large admixture of sand. In this zone at Maycock's Bay horse-nicker, prickly wild coffee and the more usual shrubby form of sea grape occur. This zone has been removed along much of the Leeward coast because its species are both useless to man and prickly. Usually it has been replaced, either artificially or naturally by coconut trees and scarlet cordia (*Cordia sebestena*). The coconut is found at very many places around the coast and it is obvious from the location of many specimens that their occurrence is natural. Conversely there are frequent examples, as at Bottom Bay, Chancery Lane (Fig. 2.14) and at Maycock's Bay of groves of coconut palms that have been planted deliberately (Fig. 7.31). The species frequencies for zone 3 are as follows:-

TABLE 7.14 SPECIES FREQUENCIES - ZONE 3 - MAYCOCK'S BAY

Species	Growth form	Frequency per 100 quadrats
Caesalpinnia bonduc	P	60
Coccoloba uvifera	P	40
Clerodendrum aculeatum	P	30
Hippomane mancinella	P	15
Andropogon intermedius	H	15
Stachytarpheta jamaicensis	H	10
Cocos nucifera	P	10
Casuarina equistifolia	P	5
Sporobolus tenuissimus	H	5

Zone 4 is usually the widest zone of the Leeward littoral and is equivalent to the 'sandy field' described by Hardy (1934) and the 'inland littoral' of Sauer (1961). At Maycock's Bay this zone has been planted with sour grass, casuarina and coconut (Fig. 7.31) but many species of its natural vegetation are present. These include vervain, white sage, sage

(*Lantana trifolia*), *Melanthera nivea* and love leaf. Because this zone is affected so little by the proximity of the sea, it is inclined to have a very large number of plant species which differ from place to place, depending upon what garden escapes and hardy inland species are locally available. Thus of the 15 species present in the quadrats of this zone at Maycock's Bay, only five occurred at Brighton (Figs. 2.17, 7.12), while 12 of the species that were present at Brighton did not occur at Maycock's Bay. It is therefore almost impossible to show and analyze a representative sample from this zone. However, in order to complete the description the species frequenceis are given in Table 7.15.

TABLE 7.15 SPECIES FREQUENCIES - ZONE 4 - MAYCOCK'S BAY

Species	Growth form	Frequency per 100 quadrats
Andropogon intermedius	H	95
Euphorbia serpens	Ch	20
Lantana involucrata	P	15
Cocos nucifera	P	10
Casuarina equisitifolia	P	10
Spermacoce confusa	Ch	10
Desmanthus depressus	Ch	10
Stachytarpheta jamaicensis	Ch	10
Lantana trifolia	P	5
Bryophillum pennatum	Ch	5
Rhynchosia minima	Ch	5
Swietenia mahagoni	P	<5
Sporobolus tenuissimus	H	<5
Cassia glandulosa	Ch	<5
Melanthera nivea	P	<5

Several of the woody species present in zone 4 are in fact young mahogony trees from the coastal forest that occurs in zone 5. At Maycock's Bay this fifth zone extends up the cliff-face to the cane-fields above; elsewhere frequently it ceases at the highway and cultivation occurs on the other side of the road. The forest is mainly composed of whitewood and mahogony but may also contain casuariana, flamboyant, (*Delonix regia*), clammy cherry and inland trees such as lignum-vitae (*Guaiacum officinale L.*).[1]

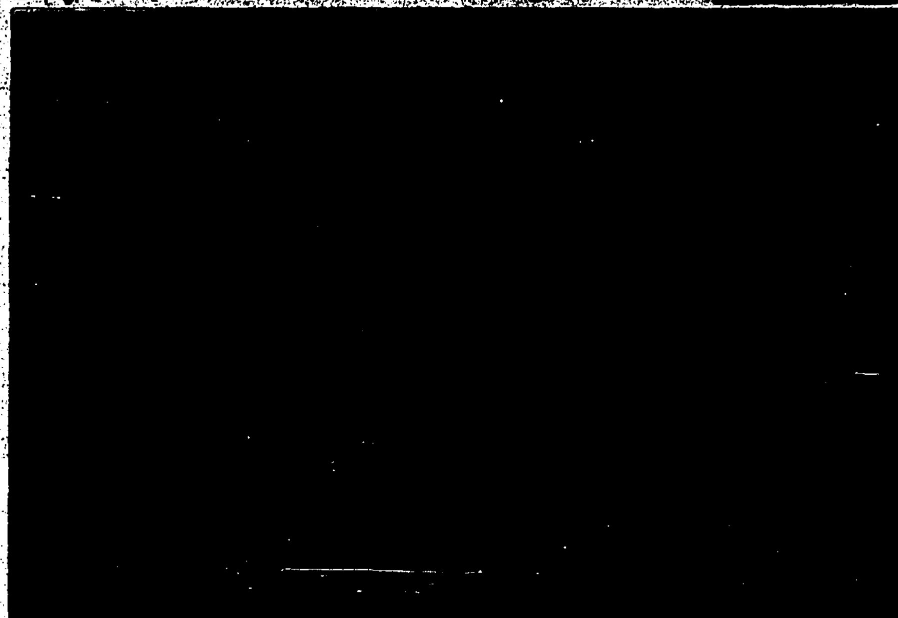


Fig. 7.31
View between the manchineel forest (back left) and whitewood-mahogony forest (right) at Maycock's Bay. In the centre of the photo is zone 4 which is mostly changed by man. Sour grass has been planted as the ground cover. This is cut for hay as well as grazed. Also coconut and casuarina have been planted in 'orchard fashion' between the two forests. Originally the vegetation here probably would have been woody sage bushes with a ground cover of vervain.

As happens elsewhere around the island, all the zones are not repeated at every location. At Rockley Beach (Fig. 7.11) on the Leeward south coast the manchineel forest does not exist, though occasional trees are common nearby. In fact Rockley Beach is a far from satisfactory location to describe the vegetation pattern since recently it has been disturbed so greatly by man. At Rockley (Fig. 2.15) and Brighton (Fig. 7.12) the seaside yam is present in most of the zones but it does not occur

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[1] Plants mentioned in text but not recorded at any of the 15 beach locations are cited with author in text and at the end of Appendix II.

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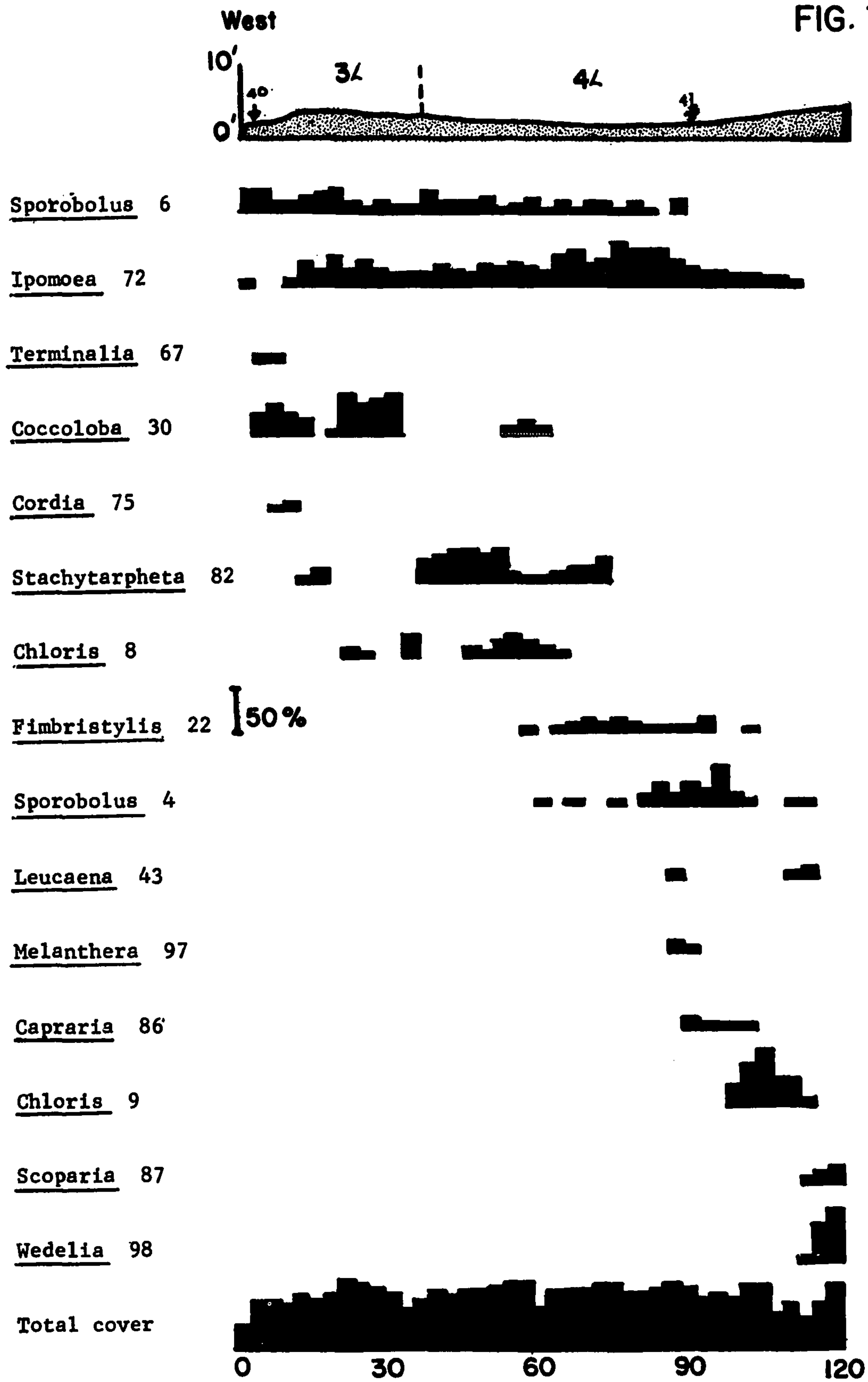
ROCKLEY BEACH

FIG. 7·11



Distance from Sea in feet

BRIGHTON

FIG. 7.12

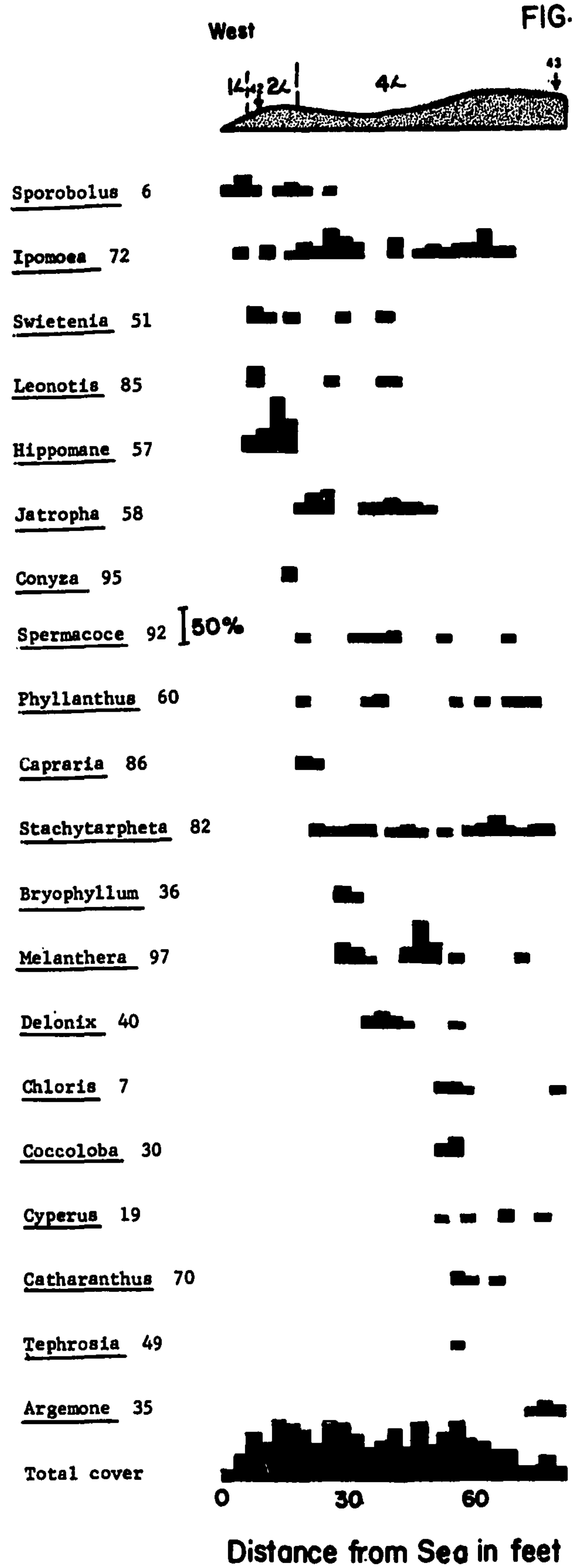
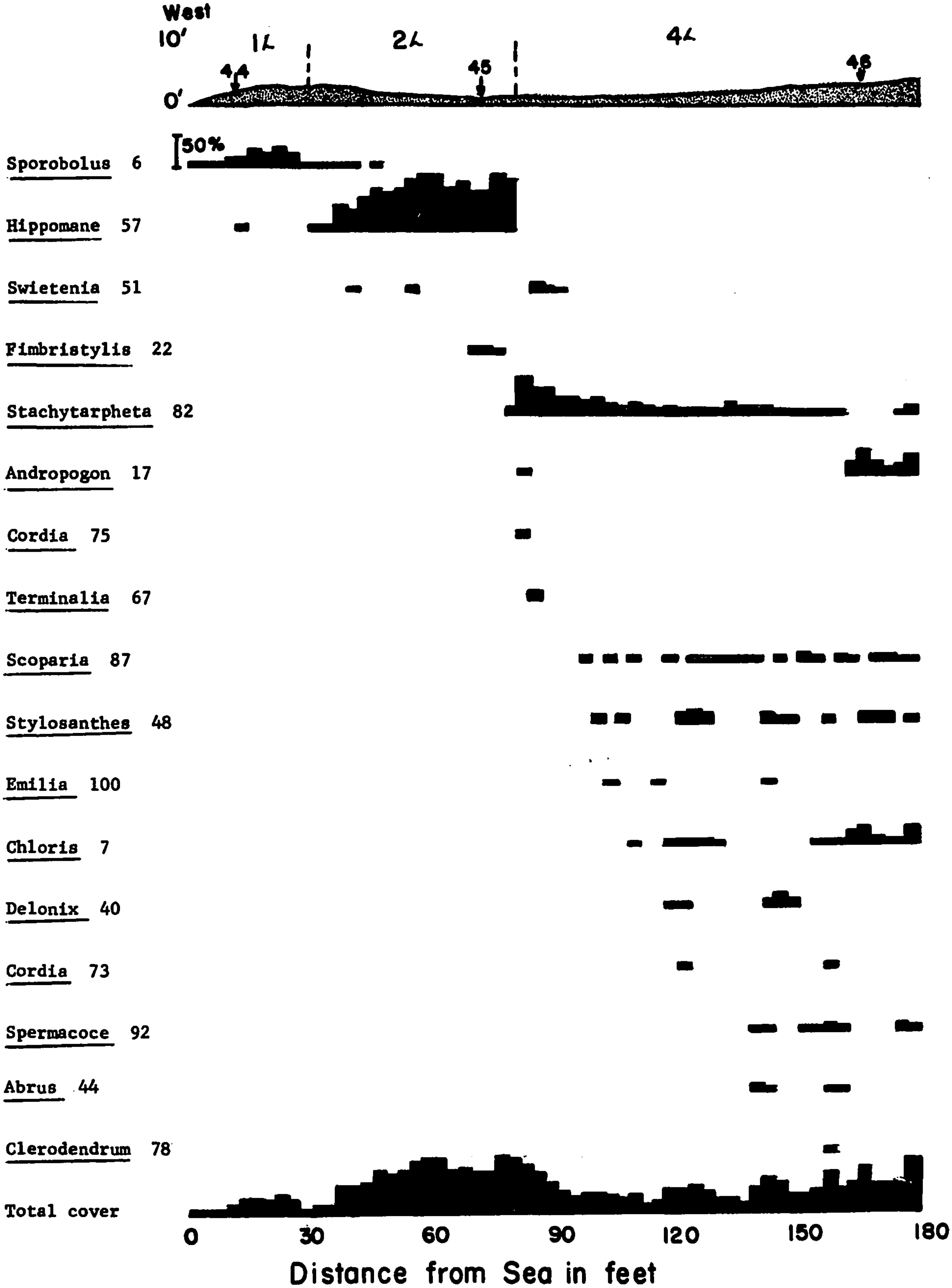
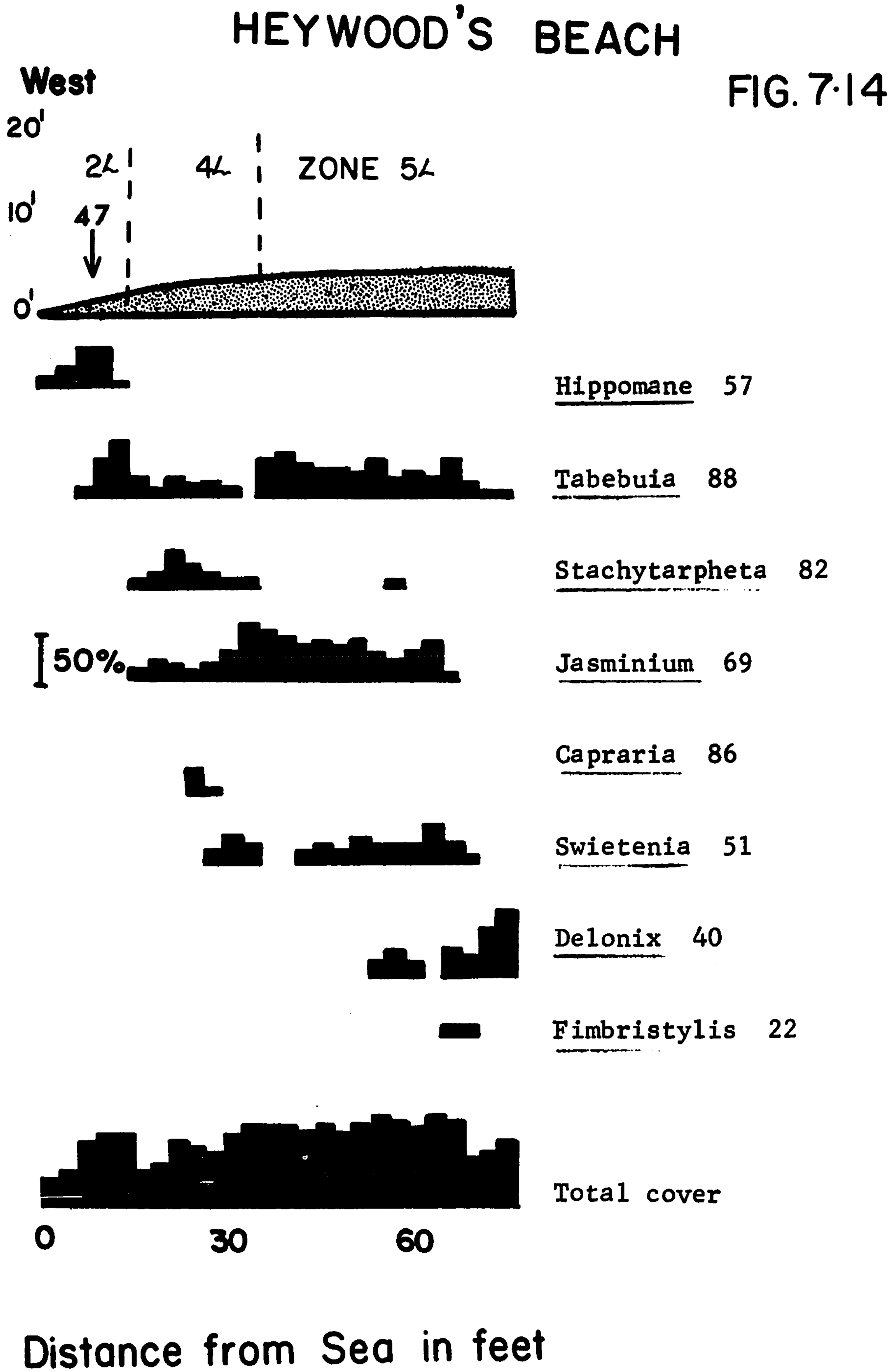


FIG. 7·13

HOLETOWN




HEYWOOD'S BEACH
FIG. 7·14
West
20'
10'
0'
2L
4L
ZONE 5L
47
50%
Hippomane 57
Tabebuia 88
Stachytarpheta 82
Jasminium 69
Capraria 86
Swietenia 51
Delonix 40
Fimbristylis 22
Total cover
0
30
60
Distance from Sea in feet

along the northern part of the west coast. Zone 5 is not present at any of the southern sites of the west coast but this is above all a result of human disturbance of the littoral and several of the zonal species occur in gardens along the coast.

At Brighton, the range of species found in zone 4 is very large (see Fig. 2.17). It is almost certain that this area of beach has been cultivated or at least used as a wild garden at some period. The location is shaded on all sides at present by huge casuarina trees which shed their needles over all the inland zones. This results in a decrease in cover with distance inland. The transect at Holetown (Fig. 7.13) shows the most natural change in cover density with distance from the sea. Cover increases slowly within the pioneer zone, then becomes almost complete in the manchineel forest. In the 'sandy field' of zone 4 it decreases again but slowly increases with distance towards the highway (or zone 5). The shallow sea and the coral reef at Heywood's Beach (Fig. 7.15) make waves break so far out that neither zone 1 nor crab grass exist. Instead manchineel grows at the very edge of the sea, with its roots awash at high tide and its branches over the water, (see Fig. 2.19). Despite this location manchineel cannot tolerate excessive salt in the air and during the storm swell of December 1967 most of the manchineel trees lost their seaward leaves from salt-scorch. Also at Heywood's Beach, whitewood occurs in zones 4 and 5 as a forest tree up to 35 feet tall.

It can be seen from the foregoing verbal descriptions and from Figs. 7.1 - 7.15, that regular patterns of zones exist within the Barbados coastal vegetation. Since changes orthogonal to the shore were also seen to exist among the soil factors and salt-spray of the coastal environment, it is suggested that these factors strongly influence the pattern of the vegetation.

CHAPTER 8

DISCUSSION AND CONCLUSION

Discussion

This research is concerned with the arrangement of zones that occurs in the vegetation along the littoral of Barbados. Since an examination of the complete littoral was impractical, 15 beaches were selected, from which it was hoped to obtain an idea of the total situation. In earlier chapters the major factors of the environment at these beaches were examined and the vegetation described. Here an attempt is made to relate the zones in the vegetation from one beach to another and to the environment.

TABLE 8.1 LOCATION AND NUMBER OF BEACH ZONES

Location	Number of zones
Animal Flower Bay	4
River Bay	4
Lakes Beach, Belleplaine	7
Bathsheba	4
Bottom Bay	7
Skeete's Bay	3
Foul Bay	6
Oliver's Cave	4
Long Bay, Chancery Lane	6
Rockley Beach	2
Brighton	3
Holetown	3
Heywood's Beach	3
Maycock's Bay	5

The fifteen beaches described in chapter 7 have different numbers of vegetation zones (Table 8.1). However, these beaches can be divided into three groups, coastal cliffs, Windward beaches and dunes, and Leeward beaches, within which groups the number of zones and the species from which they are composed are similar. In table 8.2, the 15 beaches are divided

TABLE 8.2 DIVISION OF BEACH ZONES INTO THREE GROUPS

Coastal Cliff Group		Windward Group		Leeward Group	
Location	Zone numbers	Location	Zone numbers	Location	Zone numbers
Animal Flower Bay	1C,2C,3C,4C (4)	Belleplaine	1W,2W,3W,4W,5W,6W,7W (7)	Maycock's Bay	1L,2L,3L,4L,5L (5)
River Bay	1C,2C,3C,4C (4)	Bathsheba	1W, 4W,5W (3)	Rockley Beach	3L,4L (2)
Bathsheba	3C (1)	Bottom Bay	1W,2W,3W,4W,5W (5)	Brighton	1L,2L, 4L (3)
Bottom Bay	3C,4C (2)	Skeete's Bay	4W (1)	Holetown	1L,2L, 4L (3)
Skeete's Bay	3C,4C (2)	Foul Bay	1W,2W,3W,4W, 6W,7W (6)	Heywood's Beach	2L, 4L,5L (3)
Oliver's Cave	1C,2C,3C,4C (4)	Chancery Lane	1W,2W,3W,4W,5W,6W (6)	Graeme Hall	not defined

N.B. No correlation is implied by the use of 1,2,3 ... in each group of zones.

into these groups and the actual zones present are shown. Since the occurrence of these zones is derived from their floristics it is possible to determine the sequence of zones for individual beaches as related to a type beach. In each of the three groups the longest beach was chosen as the type beach since it was that most likely to contain the maximum number of zones possible. Although there were few other locations that had the full complement of zones present at the type beach, all the zones were observable elsewhere within the environmental group. The overall system within the vegetation zones of the coastal cliff group is a series of four quite wide zones which are frequently recognizable as much by a change in density of species as by a change of species themselves. Windward coasts and dunes have a series of up to seven zones. These are usually narrower than those on cliffs and, within dunes, reflect the marked changes in topography. The presence or absence of certain species rather than a change in density allows the division into zones to be made. On Leeward coasts there is a series of five narrow zones, each with a very different complement of species.

The incomplete series that occurs at certain beaches can usually be explained by some external factor. If the cliffs occur behind a beach the more foreward zones are usually truncated. Thus at Bathsheba, Bottom Bay and Skeete's Bay the cliff zonation commences with zone 3C. Zone 4C is not present at Bathsheba because the roadway intervenes. At Windward locations where the beach is narrow and dunes are not present, some of the zones are absent. Thus at Bathsheba the pioneer zone, 1W, is immediately followed by zone 4W and at Foul Bay zone 5W is missing. At locations like Skeete's Bay, where considerable human activity occurs [1] much of the beach

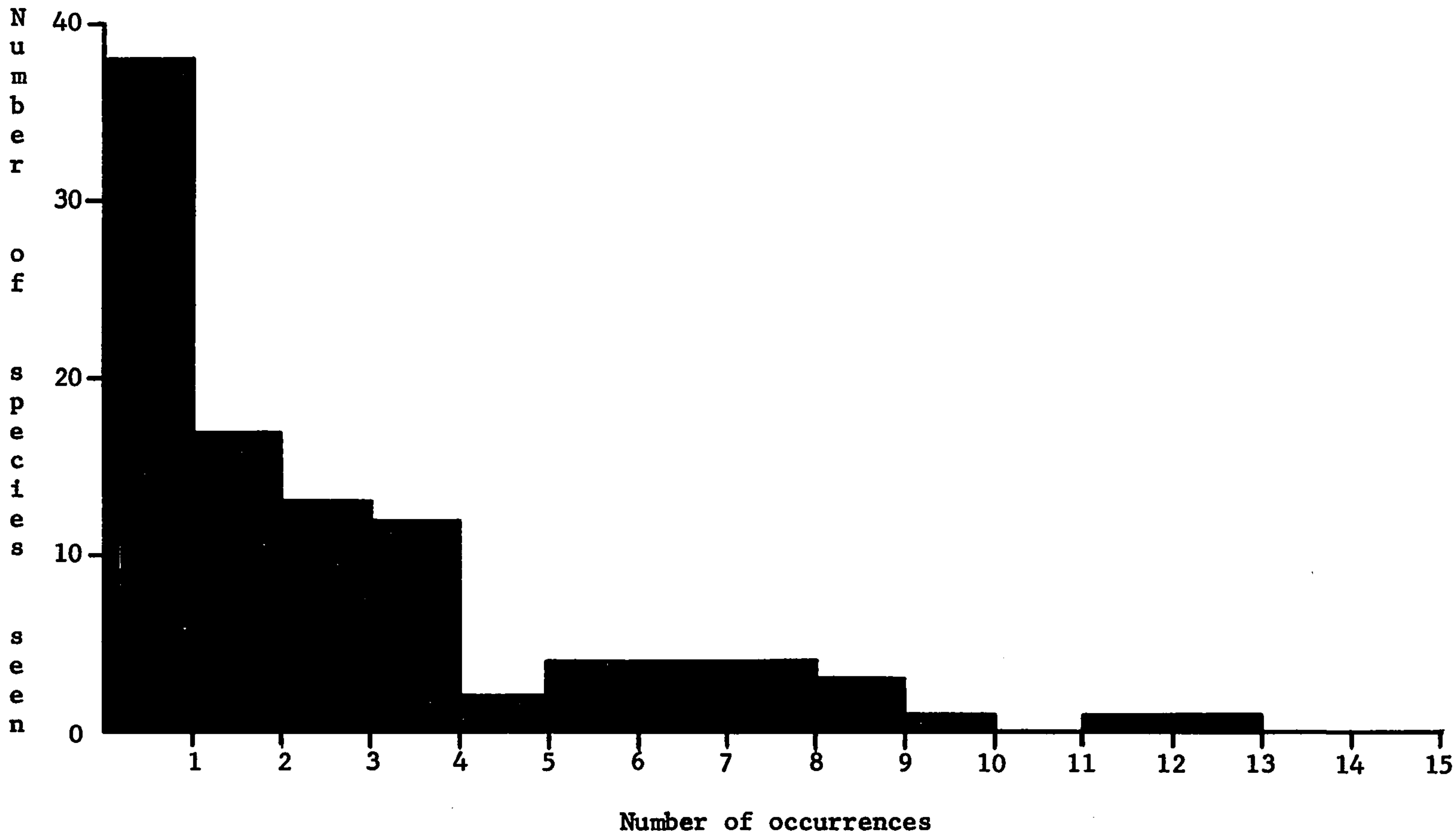
[1] Skeete's Bay is an important fishing centre.

is devoid of vegetation and here plants first occur in zone 4W. Skeete's Bay, Bottom Bay and Bathsheba are all backed by cliffs and their rear zones are truncated. At Chancery Lane the dunes are backed by swamp planted with sour grass pasture and thus zone 7W is missing. On Leeward coasts zone 3L is missing at Brighton, Holetown and Heywood's Beach. This zone is primarily composed of a thick, prickly growth of horse-nicker and has been removed to provide easier access to the water. Similarly zone 5L is absent at Rockley Beach, Brighton and Holetown because its vegetation has been removed to provide space for building houses and roads. Zone 1L does not occur at Heywood's Beach because this is apparently the calmest part of the littoral and species of zone 2L can grow at the water's edge.

Thus the Barbadian coastal vegetation is composed of a series of recurring zones. Since these zones are floristically delimited it is useful to discuss the variation of the flora around the island before relating the three zonal series to each other.

During the period of research 100 species were recorded growing on the Barbados littoral. Some of these occurred at many of the beaches while others were present at only one. The frequency of occurrence of these species is shown as a histogram, Fig. 8.1. There are three recognizable classes on the histogram: those species (38) occurring at only one beach, those present at two to four beaches (42) and those found at more than four beaches (20). Many of the species that only occur once are of little use in identifying the vegetation zones though they are indications in combination with other species. The bulk of this group are either inland species which compete successfully in the inner littoral zones of the Leeward coast or species confined to Graeme Hall Swamp, the only mangrove

FIG. 8.1 FREQUENCY OF OCCURRENCE OF THE 100 SPECIES ENCOUNTERED



swamp location studied. Similarly the most frequently observed species are of little use in zonal definition since these ranges of tolerance are so great that they tend to occur in several zones and in more than one environmental group.

If these 100 species are examined by grouping them within the three environmental types, coastal cliff, Windward beaches and dunes, and Leeward beaches, 58 species are found to be limited to one or other of the three environmental types, 34 occur within two of the types but not a third while eight are common to all three (table 8.3).

At the six cliff locations 12 species were recorded (table 8.3) that did not grow in zones of the other environmental types. First there are those species like Egyptian grass and *Desmanthus virgatus* which occur predominantly in pastures and are common inland. Around the coast, these species are limited to the cliffs because they prefer the better developed soils present. They are mainly found in zones 3C and 4C of the cliffs where soils are reasonably well developed. The other group are species such as columnar cactus, prickly pear and *Strumfia maritima*, which occur in dry, rocky habitats. These are present within the rear zones of cliffs, (3C and 4C), and may be limited to coastal rocks, as *Strumfia maritima*, or occur widely in dry, rocky environments.

Within the zones of the six Windward locations 16 species were found that did not occur elsewhere. These are also divisible into two groups: the psammophytes of the dune zones, and the plants of the siliceous sands in the Scotland District. Seaside lavender, and sea bean are examples of the former, and fat pork, pawpaw okro, and *Stenotaphrum secundatum* are examples of the latter.

TABLE 8.3 OCCURRENCE OF SPECIES BY GROSS ENVIRONMENTAL DIVISIONS

Cliffs (6 locations)		Windward beaches (6 locations)		Leeward beaches (6 locations)		Cliff and Windward		Cliff and Leeward		Windward and Leeward		All three types	
Pandanus	2	Echinochloa	14	Ruppia	1	Egragrostis	3	Sporobolus	5	Chloris	7	Sporobolus	6
Dactyloctenium	11	Stenotaphrum	16	Sporobolus	4	Cynodon	10	Cenchrus	13	Chloris	8	Andropogon	17
Agave	26	Cyperus	18	Chloris	9	Eleusine	12	Rhynchosia	47	Fimbristylis	22	Casuarina	28
Desmanthus	42	Hymenocallis	25	Paspalum	15	Agave	27	Stylosanthes	48	Cocos	23	Coccoloba	30
Croton	53	Ficus	29	Cyperus	19	Lithophila	31	Vigna	50	Bryophyllum	36	Euphorbia	56
Phyllanthus	59	Philoxerus	32	Cyperus	20	Sesuvium	33	Euphorbia	55	Caesalpinia	38	Ipomoea	72
Cephalocereus	63	Chrysobalanus	37	Eleocharis	21	Portulaca	34	Jatropha	58	Tephrosia	49	Capraria	86
Opuntia	64	Canavalia	45	Sansevieria	24	Desmanthus	41	Clerodendrum	78	Hippomane	57	Tabebuia	88
Jaquinia	68	Desmodium	46	Argemone	35	Croton	52	Lantana	79	Stachytarpheta	82		
Ipomoea	73	Corchorus	61	Cassia	39	Euphorbia	54	Lantana	80	Wedelia	98		
Ruellia	90	Calotropis	71	Delonix	40	Heliotropium	76	Spermacoce	93				
Strumfia	94	Mallotonia	77	Leucaena	43	Egletes	96						
		Lippia	81	Abrus	44	Pectis	99						
		Hyptis	84	Swietenia	51								
		Tecoma	89	Phyllanthus	60								
		Bontia	91	Thespesia	62								
				Rhizophora	65								
				Conocarpus	66								
				Terminalia	67								
				Jasminium	69								
				Catharanthus	70								
				Cordia	74								
				Cordia	75								
				Avicennia	83								
				Leonotis	85								
				Scoparia	87								
				Spermacoce	92								
				Conyza	95								
				Melanthera	97								
				Emilia	100								
Total 12		Total 16		Total 30		Total 13		Total 11		Total 10		Total 8	

The six Leeward beaches contain 30 species that do not occur within the vegetation zones of other coastal locations around the island. This number, which is large when compared to that of the cliffs and Windward beaches, is the result of the less exposed environments found within the inner littoral zones of the Leeward beaches. Nearly a quarter of these 30 species, including the mangroves and some of the sedges are limited to the mangrove swamp habitat examined at Graeme Hall, and are only found elsewhere on the island at similar localities. The remaining species can be divided into two groups. The first is composed of those species that are either garden escapes or have been deliberately planted within the 'sandy field' of the littoral, to enhance its appearance. Such species are the Mexican poppy, the flamboyant and mimosa. The second group are primarily inland weeds that have a considerable range of tolerance and are able to compete successfully within the inner littoral. Conyza canadensis, Spermacoce confusa and the red thistle are examples. Both groups are confined to zone 4L of the Leeward beaches. There are no species that are limited to the Leeward foreshore of the island.

Some 13 species occur both on cliffs and on Windward beaches but are not present to Leeward. This can be explained partly by location, since all coastal cliffs occur on the Windward side of the island. For instance, duckweed and Egletes prostrata are two species limited to Windward shores of both types though both tolerate an extremely wide range of salt density and soil type. The other group of species common to the two locations is composed of those plants that can tolerate an extremely harsh environment. These are the pioneer plants that occur in the front zones of the salt-swept sandy beaches and on the overhanging rocks of the cliffs. Seaside samphire, purslane, seaside sage and wild lavender are the best examples.

The species limited to cliffs and Leeward beaches are of a very different type. Whereas many of the 'cliff and Windward' group are pioneers these 11 are mainly inner littoral species. They are common to both cliffs and Leeward beaches because both locations have areas of reasonable soil cover that are not too saline. Many of the plants like Rhynchosia minima, Euphorbia prostrata and Sporobolus tennuissimus are weeds of sour grass pasture, (zone 4) but some are inner littoral bushes that do not grow in the mobile habitats of the Windward coast. Prickly wild coffee is one of these.

A group of 10 plants occurs in the zones of both Windward and Leeward coasts but not on cliffs. These are primarily psammophytes, ranging from trees like coconut and manchineel, through bushes like horse-nicker to sea-shore grass. All will tolerate a mobile habitat.

The final, smallest group are those plants that are found within all three coastal types. Without doubt they are all extremely tolerant species but are still very different in habitat. Crab grass, which is the most widespread of all the species recorded is mainly a pioneer species and inhabits the front zones of the beaches but it may occur wherever the rooting medium is mobile. Sour grass on the other hand is limited to the rear zones of the beaches on which it occurs. Casuarina, Euphorbia serpens and West Indian tea are plants that occur widely both in the rear zones around the coast and inland wherever open ground allows them to colonize. Sea grape and whitewood occur as different varieties in different habitats. Sea grape can develop into a small tree 20 feet high in the relatively protected location of zone 2 on the Leeward coast. Where soil is thin in zone 3 on cliffs, a stunted bush occurs with small leaves and short roots but in zones 3-7 on Windward mobile sand dunes sea grape can send roots 30 feet down to the water-table (Hardy 1934) and produce a bush six feet high. Similarly whitewood can grow into a tree over 50 feet high in the inner littoral forests of zone 5 on the Leeward coast yet may be a tiny shrub only a few inches in height in zone 3 on cliff faces.

The mode of occurrence of these 100 species can be examined within the zones that have been defined. When this is done it will be seen that certain zones within the three coastal habitat types have a similar complement of species and they have therefore been associated (Table 8.4). This association represents related environments within the different groups.

One of the most obvious and interesting facts about this table is that, on the whole, the number of species present in each zone increases with distance away from the sea. Thus the harshest environments (zones 1C, 2C 1W 1L, 2W) have under 10 species whereas the environments further away from the sea contain up to 36 (zones 4C 4L). This general trend breaks down within some of the zones however. Zones 7W and 2L have only five species, but these zones are dominated by manchineel, which exudes a toxic secretion which is fatal to all but a few hardy species. Zone 3L is dominated by horse nicker which grows so densely that few other species can compete. Finally zone 5L is a forested zone dominated by mahogany and whitewood which shade out almost all other species.

Another general trend that occurs within these zones is an increase both in cover and height of species with distance inland. The most-seaward of the zones have mat and trailing species, the intermediate zones have grasses and low shrubs and the zones abutting inland vegetation have tall shrubs and trees. The manchineel forest (zones 7W 2L) is an exception to this trend.

If species ranges within the zones are examined (Table 8.4) it will be noticed that few species are limited to only one zone. There is enough continuity of species from one zone to another to show that all the zones are part of a larger unit, the littoral. However, the change in density of species and in grouping of species from one zone to another make this larger unit divisible. Quite an abrupt break is noticeable between zone 5W and zones 3C 6W. Suddenly a marked increase both in number and type of species occurs. Few other zonal divisions across the beach show such a lack of continuity in species. The boundary between these two zones is equivalent to the abrupt break discussed by Sauer (1961) which occurs between the 'outpost' and 'inner littoral' species in Mauritius. Most of the species that cross this boundary do not extend their range far on one side (see Table 8.4). The major exceptions to this are seaside yam which ranges over four zones on either side, and duckweed which is present in all but the forested zones.

Throughout discussion of the location of vegetation zones on the littoral of Barbados, their situation has been related to distance from the sea and the consequent change in severity of the environment. This is because the proximity of the sea is the major influence upon parameters of the habitat, and many of the factors that determine the lives of the plants within the zones alter with distance away from high water mark. Table 8.5 shows a generalization of some environmental parameters within the vegetation zones of the three coastal types. Immediately it will be noticed that the grouping of zones that occurred in Table 8.4 is not possible with

TABLE 8.4

OCCURRENCE OF SELECTED SPECIES BY ZONAL DIVISIONS
with some examples of ranges of tolerance

1C	2C 1W 1L	2W	3W	4W	5W	3C 6W	7W 2L	3L	4C 4L	5L
Sporobolus 6	Sporobolus 6	Sporobolus 6	Sporobolus 6	Sporobolus 6	Sporobolus 6	Sporobolus 6	Fimbristylis 22	Andropogon 17	Pandanus 2	Andropogon 17
Sesuvium 33	Sesuvium 33	Philoxerus 32	Coccoloba 30	Chloris 8	Stenotaphrum 16	Cynodon 10	Coccoloba 30	Fimbristylis 22	Sporobolus 5	Fimbristylis 22
Portulaca 34	Portulaca 34	Chrysobalanus 37	Chrysobalanus 37	Stenotaphrum 16	Coccoloba 30	Dactyloctenium 14	Swietenia 51	Cocos 23	Chloris 7	Delonix 40
Euphorbia 54	Euphorbia 54	Euphorbia 54	Canavalia 45	Desmanthus 41	Chrysobalanus 37	Eleusine 12	Hippomane 57	Coccoloba 30	Andropogon 17	Swietenia 51
Pectis 99	Egletes 96	Ipomoea 72	Euphorbia 54	Canavalia 45	Euphorbia 56	Andropogon 17	Stachytarpheta 82	Caesalpinia 38	Cyperus 19	Jasminium 69
	Pectis 99	Mallotonia 77	Calotropis 71	Ipomoea 72	Calotropis 71	Agave 27		Hippomane 57	Agave 26	Stachytarpheta 82
		Pectis 99	Ipomoea 72	Heliotropium 76	Ipomoea 72	Coccoloba 30		Ipomoea 72	Agave 27	Tabebuia 88
			Stachytarpheta 82	Stachytarpheta 82	Lippia 81	Lithophila 31		Clerodendrum 78	Casuarina 28	
			Pectis 99	Tabebuia 88	Egletes 96	Desmanthus 41			Coccoloba 30	
				Bontia 91	Wedelia 98	Croton 52			Bryophyllum 36	
				Pectis 99	Pectis 99	Euphorbia 55			Cassia 39	
						Euphorbia 56			Delonix 40	
						Jatropha 58			Desmanthus 41	
						Opuntia 64			Rhynchosia 47	
						Ipomoea 72			Stylosanthes 48	
						Heliotropium 76			Swietenia 51	
						Clerodendrum 78			Croton 52	
						Tabebuia 88			Croton 53	
						Egletes 96			Euphorbia 55	
						Pectis 99			Euphorbia 56	
									Hippomane 57	
									Jatropha 58	
									Ipomoea 72	
									Lantana 79	
									Lantana 80	
									Stachytarpheta 82	
									Capparis 86	
									Scoparia 87	
									Tabebuia 88	
									Spermacoce 92	
									Spermacoce 93	
									Melanthera 97	
									Pectis 99	
									Emilia 100	

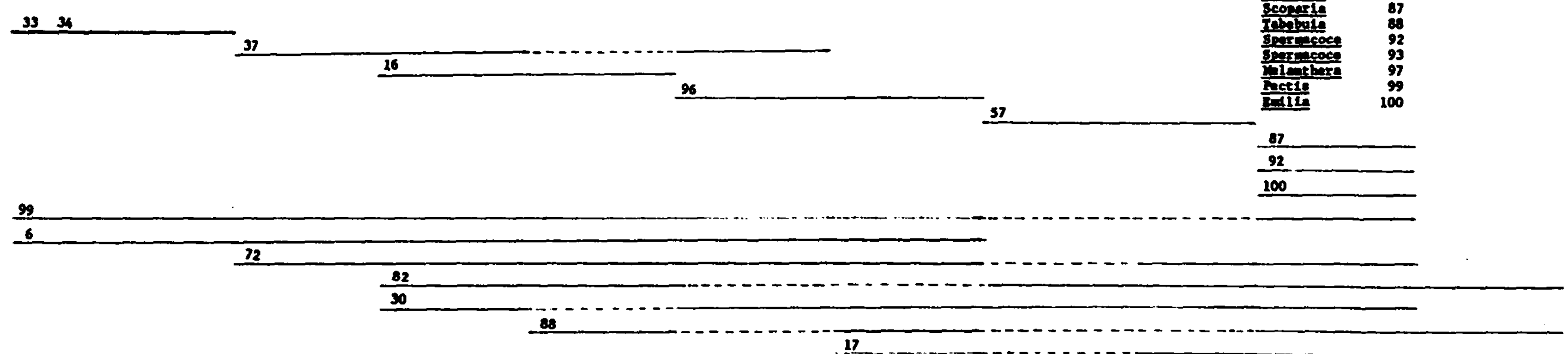


TABLE 8.5 GENERALIZED AVERAGES OF SOME ENVIRONMENTAL DATA WITHIN ZONES

Zone	1C	2C	3C	4C	1W	2W	3W	4W	5W	6W	7W	1L	2L	3L	4L	5L
Aerial salt (μmhos/cm/sq. ft./24hrs.	4,000	3,500	1,000	400	3,750	3,500	3,000	2,500	1,000	500	250	250	150	150	100	80
Ground surface salt (μmhos/cm)	1,500	1,100	300	250	550	500	600	1,000	500	800	250	150	100	80	75	50
Soil salt (μmhos/cm/6grm sample)	10,000	7,000	700	250	450	400	150	450	180	150	100	200	175	150	150	125
Clay %	20.0	25.0	30.0	30.0	0.1	0.1	0.1	5.0	0.5	0.5	5.0	0.1	5.0	15.0	20.0	25.0
Organic matter %	1.25	2.50	3.00	3.80	0.01	0.03	0.07	0.30	0.50	0.50	1.00	0.05	1.00	2.00	3.50	3.50
$CaCO_3$ %	35	6	5	5	x 10 y 98	10 98	10 98	12 98	12 98	15 85	15 35	90	80	45	16	10
pH	7.8	7.6	7.5	7.1	8.0	8.0	8.0	7.9	7.9	7.8	7.8	7.9	7.8	7.6	7.6	7.4

x = Scotland coast y = Coralline coast

the environmental parameters. This factor is most obvious when one observes the difference between quantities of salt present on Windward and Leeward coasts. Nevertheless a similar trend occurs through most sets of data at each location: aerial salt, ground surface salt, soil salt, $CaCO_3$ and pH values decrease with distance from the sea whereas clay and organic matter content of the soil increase. The only anomalies in this trend occur on the dunes of the Windward coast where ground and soil salt and clay content are higher than one would expect in certain zones. This is caused by eddying in the wind giving a deposition of small particles both in the lee of foredunes and with increasing height on main dunes. Also within the siliceous sand area the $CaCO_3$ trend is reversed for reasons discussed in chapter 4.

None of the major parameters of the environment have abrupt discontinuities in their data which can be related exactly to the zonal boundaries and neither can such breaks be expected with factors that are so obviously graded along a continuum. However, several factors vary regularly with distance either in logarithmic, square root or cube root scales (see chapters 4 and 5) resulting in considerable differences over short distances. These correspond to the zonation of the vegetation.

The reason that some vegetation zones can be grouped together despite differences in various parameters of the environment within those zones is that the major habitat factors vary in importance both relatively and absolutely within the three coastal types. On coastal cliffs there is little variation in soil grain-size, and clay is found in large quantities throughout. Salt particles are easily trapped within the clay colloids of coastal soils, so that quantities of soil salt are much higher here than elsewhere around the island. Thus, soil and aerial salt content are both so high at the front of coastal cliffs that both zones 1C and 2C are as saline or more saline than the pioneer zones elsewhere. A large gap occurs on Table 8.4 between these front zones and zones 3C and 4C because with increasing distance from the sea the adverse salt conditions ameliorate, resulting in a better developed soil. A contrasting situation occurs on Windward coasts and dunes. The foreward zones appear not to have such an adverse environment as coastal cliffs since the large soil particles, predominantly sand grains, cannot trap large quantities of soil salt. Thus species less tolerant of salt can occur nearer the sea. Nevertheless no marked increase in clay occurs with distance inland so that the factors of soil and aerial salt soon fade into insignificance in comparison with soil grain size. The overwhelming predominance of sand-sized soil particles results in an acute lack of moisture and organic matter within the soil throughout the littoral. Thus the Windward zones (1W-7W) on Table 8.4 are consecutive. On the Leeward coast soil grain-size varies abruptly, without marked change in relief, with distance inland. Soil salt content is low throughout and aerial salt unimportant except in the pioneer zone. Thus adverse qualities of soil and salt place zone 1L together with zone 1W but zone 2L occurs with the furthest inland of the Windward sandy zones (7W). Zones 3L, 4L and 5L have neither adverse salt conditions nor a great lack of clay within the soil. Thus in company with zone 4C they occur as the least harsh of all the littoral environments.

Around the Barbados littoral 16 zones are defined within the vegetation. Because of floristic similarity some of these can be grouped together, resulting in 11 recognizably different zones (Table 8.6).

TABLE 8.6 THE DIFFERENT ZONES OF THE BARBADOS LITTORAL

	A	B	C	D	E	F	G	H	I	J	K
Coastal cliffs	1	2					3			4	
Windward beaches		1	2	3	4	5	6	7			
Leeward beaches		1						2	3	4	5

This complete series does not occur at every beach on the island but is basically divisible into three groups occurring on coastal cliffs, Windward beaches, and Leeward beaches. Only division B (Table 8.6) is common to all three groups and even this is not present at two sites examined (Rockley Beach and Heywood's Beach). Nevertheless enough continuity is present within the floristic makeup of the zones to understand their sequence and enough change is visible in the environment to understand their existence.

Comparison

There are few published sources concerning other tropical coastal areas with which this project can be directly compared. Other information relating to coastal vegetation in Barbados is found in Gooding (1947) and Sauer (1959).

The work by Gooding is limited to a description of the sand dunes of Barbados and can only be compared with the Windward coast and dunes section of this project. The extensive building projects that have occurred during the 20 years between the time of Gooding's research and the present have changed several of his sites (Gooding 1947) beyond recognition. However, the sites at Belleplaine and Chancery Lane remain relatively similar. Differences concerning some species locations have already been mentioned, (chapter 7), but the major way in which Gooding's differs from the present examination is his division of the dune areas into three zones: pioneer, Ipomoea pes-caprae, and Coccoloba uvifera. Reference to Figs. 7.3 and 7.9 shows that, at the present time, these divisions do not adequately define the vegetation at either location. It is true that there is a pioneer zone forward of the dunes in which neither seaside yam nor sea grape are common, but on the dunes themselves both these species are present throughout most of the distance. It is apparent that such divisions cannot truly be made on the basis of one species but rather on groups of species - in which case very different divisions result.

Sauer included Barbados in his brief reconnaisance of 'Coastal Pioneer Plants of the Caribbean and Gulf of Mexico' (1959). In this work 11 beaches of Barbados were briefly described including six of the 15 examined here. Only diagrammatic representations of the actual beach profiles are shown with presence or absence of species. A much smaller complement of species is recorded at each beach yet they include several species not found during the present research. Zonation of vegetation is described as occurring in Barbados but neither the quantity of zones nor their composition is apparent. The bisection of the beach into low 'pioneer' and taller 'inner littoral' species is shown but this is obvious from a cursory observation. However, this paper was only intended to be reconnaisance.

The studies of the Mexican Gulf coast by Poggie (1963) and Sauer (1967) go into considerably more detail including soil analyses and percentage cover of different species but none of the environmental data is related to the location of the vegetation and no actual division of the vegetation data into groups or associations is attempted. However, it can be seen that a considerable number of the major species present in Barbados are also important on the Gulf coast of Mexico. Randia laetevirens Standl., Uniola paniculata L., Oenothera drummondii Hook, Scaevola plumieri (L.) Vahl., Rhacoma latifolia Gomez de la Maza, and Bidens pilosa L. (Poggie 1963) are the main species that colonize the Gulf coast that are not present in Barbados.

The most interesting work with which to compare this project is that by Sauer (1961), in which he attempts to examine Mauritius in a similar way using similar methods. He concludes that the coastal vegetation forms two obvious groups 'divided by unlike tolerances of the sea as a habitat factor'. He describes rainfall, substrate and prevailing sea conditions as the major environmental parameters. However, these are only graded by observation so that unfortunately little comparative idea of the parameters can be gained. The different migrational histories of the pioneer and inner littoral groups are examined. The foreshore species are a very similar group to the pioneers found around Barbados which is not surprising since many of them are pan-tropical. What is more surprising is that so many of the inner littoral species of Mauritius are plants endemic to the American and Asian tropics. Conversely there are only a few of Barbados' littoral species which are endemic to regions outside the Atlantic tropics except for those species deliberately introduced. The difference may be the result of the late 19th century tree plantations beyond the 'Pas Geometrique' of Mauritius. Indices of association are provided for the common species which show, like Table 8.4, that several species have similar ranges to each other, but this information is not taken further and associated with zones or the environment. Habitat diagrams of geographically divided sites and of the common species, attempt to portray similar data to Table 8.3 but since the divisions are by cardinal areas rather than natural units, the grouping of species is not obvious. Nevertheless it seems that where somewhat similar conditions to those of Barbados prevail, a similar situation results in the littoral vegetation. It is unfortunate that there is no data on salt conditions which can be compared to those obtained in Barbados.

Conclusion

The coast of Barbados has a series of well-defined habitats, differing in exposure, soil-type, climate and mobility, which make it a good laboratory for observing and analyzing the relationships between vegetation patterns and environment. Although Barbados has the disadvantage of a heavily used and greatly disturbed littoral, especially in the southwest, it has three advantages over other islands with equally well-differentiated coastal habitats. It is small and well endowed with roads and all coasts are easily accessible, and can be examined within one day if weather changes make it necessary. Secondly the post-1627 history of the vegetation is reasonably well documented so that the invasion of exotics and their relationships with the natural vegetation can be traced. Thirdly there are good facilities at Bellairs Institute, the Sugar Producers' Agronomy Research Unit and the Ministry of Agriculture for quantitative analyses of many of the ecological parameters.

The 100 species that compose the coastal vegetation can be ascribed to several easily recognized groups. First there is the minor division based upon sand type: Philoxerus vermicularis, fat pork, Stenotaphrum secundatum and Corchorus aestutans grow on the siliceous sands but only rarely do they occur on the coralline coasts. Secondly there are divisions caused by climate. Cactus and agave species like prickly pear, columnar cactus, maypole, and Spanish needle occur in the north and south of the island where there is lower rainfall and high evaporation. But higher rainfall and low evaporation on the west coast allow the development of a coastal forest dominated by mahogany and whitewood. Thirdly there are those plants which vary in their tolerance of the effects of the sea. This latter enables the coastal species to be divided into two groups, whether rainfall and evaporation are high or low, and sand siliceous or coralline. The larger 'inner littoral' group, comprising about $\frac{2}{3}$ of the species recorded, grows in the comparatively stable area behind the beach sands where there is some cohesion of the soil particles and where salt-spray is relatively light. The other $\frac{1}{3}$, the 'outpost' species, occupies areas of loose beach sand, and rocks, where salt-spray is heavy, or tidal areas on quiet shores, where roots are immersed in saline water. Usually the transition between the 'outpost' and 'inner littoral' species is a discontinuity far more abrupt than that between 'inner littoral' and inland vegetation. Divisions of a similar nature to these three have been recorded in most locations where tropical littorals have been observed (Poggie 1963, Sauer 1959, 1961, 1965a, 1965b, 1967) and are also found on coastal areas in other parts of the world (Oosting and Billings 1942).

Within the outpost and inner littoral vegetation of Barbados further divisions can be recognized. These are those series of zones parallel to the shore which comprise the coastal vegetation pattern examined in this research. Three series can be recognized, each of which is the result of its environment. There is one series that occurs on coastal cliffs (all of which are on the Windward side of the island) and has four zones, a second is found on beaches and dunes of the Windward coast and has seven zones and a third is present on the Leeward coast with five zones. The zones in each of these series vary in width and their size and species composition can be related to factors of the environment, especially salt and soil conditions.

Salt, which is blown inland from breaking waves is present in the air, on the surfaces of plants, and in the soil. Quantities of salt were found to be much higher on the Windward coast of the island than on the Leeward. Very little salt was present in the sandy soils either to Leeward or Windward since it was regularly leached by rain but very large quantities occurred in the clay soils of the Windward coast. Great amounts of salt were present in the air on the Windward coast and in the front zone of the Leeward coast, and during a period of storm swell, 15 grms. per square foot every 24 hours were recorded from an exposed location in the northeast. When the factors of distance, soil-salt, and clay content were correlated there was a significant relationship between the log of soil salt and the log of clay content. On sand soils a similar relationship was found between the cube root of distance and the log of soil-salt. Aerial salinity decreased logarithmically with distance, and exceeded ground surface salinity by a factor of 6 in exposed locations and $1\frac{1}{2}$ in sheltered locations. Thus aerial salt is an important control on sand soils while soil salt is not, whereas both are important on clay soils with soil-salt most probably dominating.

Soil analyses showed that a sharp decrease in coarse sand and a sharp increase in clay occur with increase in distance inland (with square root, log, and cube root transformations respectively). These variations in grain-size are critical since they express the differences in moisture, organic matter and pH which directly affect plant-life. Also there is the relationship with soil-salt already stated. Few stable profiles are able to develop in the coastal soils. Almost all the sands are mobile to some extend even if vegetated. On coastal cliff-slopes soils have been unable to develop because of the topography, and on cliff-tops the chemical action of salt and alternate flooding and desiccation cause continual reworking of the soils.

Obvious damage by sandblasting or wind desiccation was not seen on any of the vegetation examined and it is felt that this is of little or no importance in controlling the tropical coastal vegetation pattern.

Thus if one disregards those factors that do not vary greatly with distance from the sea at any one site, such as climate, topography and sand type, it is seen that coastal vegetation corresponds most closely in its zonal pattern with the grain-size of the rooting medium, the quantity of salt in the air and the quantity of salt in the soil. It is only within the limits of these controls that the other gross factors play their part in determining the species that make up the zones at any given location.

The vegetation that composes the pattern of zones contains a larger proportion of the original species of the island than any other plant community, except perhaps Turner's Hall Woods[1]. However, man and his livestock have had a great effect on the coastal ecology especially in the inner littoral. Man has decreased the distribution of many tree species which he has cut for timber or fuel and has eradicated several useless species (Watts 1966). He has also introduced many new species to the littoral including the casuarina, but some of these introductions have been

[1] Gooding (1944) and Watts (1966) are the most useful references for discussion of the history of inland vegetation in Barbados.

accidental and have resulted in the spread of small unpalatable species, like dog's grass and nut grass. Animals have browzed, grazed and trampled the vegetation, withdrawing from the litter cycle much of the humus, yet not replacing it with dung because they are taken away at nights. They have selectively eaten out the most palatable species but allowed the spread, by clearance of land or by carriage of seed of other species. They have cut and laid bare the topsoil with their hooves enabling the wind to blow it away. This situation is comparable to that of the littoral of many West Indian islands. Harris (1965) describes a similar history in the Outer Leeward Islands.

The result of four centuries of man and his animals has been to give a very different appearance to much of the island's coastline, even though he has used it so much less than inland areas. Many of the changes are irreversable, and many are now stable.

Thus the pattern of vegetation zones on the coast of Barbados seems to be the rational result of the environment; an environment in which man and the sea play the dominant roles. The plants are adapted to high light intensities, shortage of water and an excess of salt, all of which vary in a recognizable manner. It is the cumulative effects of these variations in envrionmental factors that cause the vegetation pattern to be based on series of zones parallel to the shore.

APPENDIX I

THE ESTIMATION OF SOLUBLE SALTS FROM ELECTRICAL CONDUCTIVITY

Electrical conductance, which is the reciprocal of resistance, is suitable for salinity measurements because it increases with salt content, thus simplifying the interpretation of readings. Also the expressing of results in terms of specific conductance make the determination independent of size or shape of sample. Electrical conductance is expressed in mhos, i.e., reciprocal ohms, having the dimension 'mhos per centimeter'. This standard unit, mho/cm. is large and most solutions have a conductivity of much less than one. Thus the milimho (Electrical Conductivity x 10^3) and the micromho (EC x 10^6) are normally used. An example of the latter in use (from Richards 1954) is the waters of the Rio Grande having 694 micromhos/cm.

The relation between electrical conductivity and salt content of sodium chloride solution is shown in Fig. AI.1. The line for NaCl approximates to that for sea water.

A worked example from the graph is as follows:-

Given: 1 square foot of towelling exposed for 48 hours and immersed in 300 cc's H_2O.

Result 6000 micromhos/cm.
- 6 millimhos/cm.
- 0.32 gms. salt in 300ccs. H_2O
- 0.96 gms. salt in 100ccs. H_2O
- 0.48 gms. salt/sq. ft./24 hours.

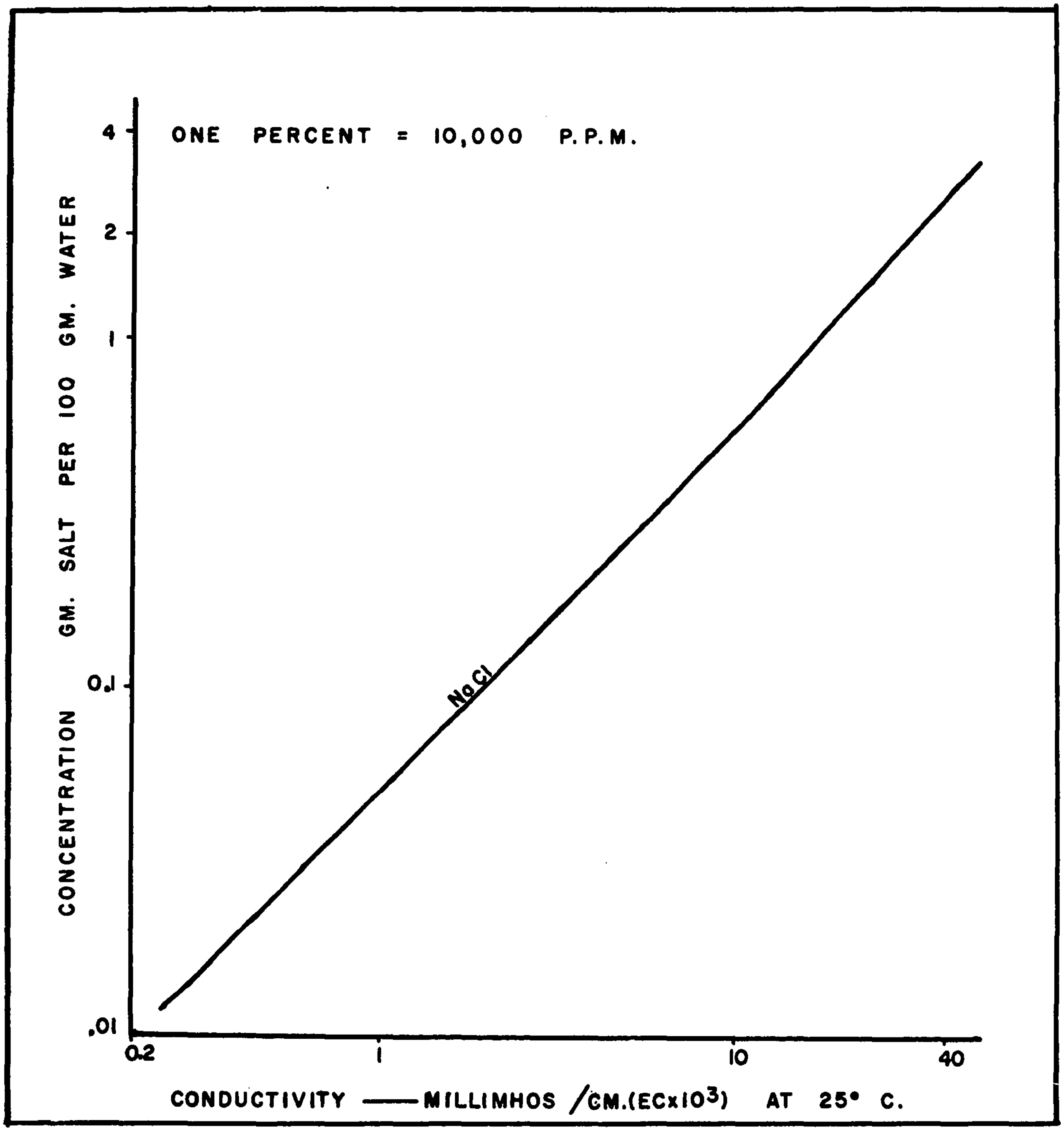


Fig. AI.1
Concentration of sodium chloride solution as related to electrical conductivity.

APPENDIX II

LIST OF FLORA AND LOCATIONS

Systematic list of plant species encountered,[1] with families arranged according to the system used by Gooding, Loveless and Proctor (1965). Species observed at a location during reconnaisance but not encountered within the quadrats are indicated by an asterisk. Numbers after a dash refer to location sites as follows:-

1.	Animal Flower Bay	2.	River Bay
3.	Lakes Beach, Belleplaine	4.	Bathsheba
5.	Skeete's Bay	6.	Bottom Bay
7.	Foul Bay	8.	Oliver's Cave
9.	Long Bay, Chancery Lane	10.	Graeme Hall Swamp
11.	Rockley Beach	12.	Brighton
13.	Holetown	14.	Heywood's Beach
15.	Maycock's Bay		

Upper case letters following the numbers refer to the pre-European distribution of the species, 'I' referring to species introduced from all areas (see text, chapter 6). Key as follows:-

A	- Americas	At	- Americas and Africa (Atlantic)
C	- Caribbean	C/CA	- Caribbean and Central America
C/CA/NA	- Caribbean, Central and North America		
C/CA/SA	- Caribbean, Central and South America		
C/SA	- Caribbean and South America		

[1] Species cited in the text that were not recorded at the 15 sites are given separately on page 175.

E - Endemic I - Introduced

P - Pantropical

RUPPIACEAE

1. *Ruppia maritima* L. - 10*. P

PANDANACEAE (screw-pine family)

2. *Pandanus utilis* Bory (screw-pine) - 1,2*. P

GRAMINEAE, now POACEAE (grass family)

3. *Egragrostis ciliaris* (L.) R. Br. (dog's grass) - 1,3. I
4. *Sporobolus pyramidatus* (Lam.) Hitchc. (seashore grass) - 10,11. A
5. *Sporobolus tenuissimus* (Schrank) Kuntze - 1,6,9*,15. C/SA
6. *Sporobolus virginicus* (L.) Kunth (crab grass) - 1,2,3,4,6,7,8,9, 10,11,12,13,15. P
7. *Chloris barbata* Sw. - 3,6,12,13. C/CA/SA
8. *Chloris petraea* Sw. - 7,10,11. C/CA/NA
9. *Chloris radiata* (L.) Sw. (plush grass) - 11. I
10. *Cynodon dactylon* (L.) Pers. (Devil's grass) - 1,8,15. P
11. *Dactyloctenium aegyptium* (L.) Beauv. (Egyptian grass) - 1,8. P
12. *Eleusine indica* (L.) Gaertn. (Dutch grass) - 1,3. I
13. *Cenchrus echinatus* L. (burr grass) - 6*,12. A
14. *Echinochloa colonum* (L.) Link - 3. I
15. *Paspalum vaginatum* Sw. - 10. P
16. *Stenotaphrum secundatum* (Walt.) Kuntze - 3,4,5. P
17. *Andropogon intermedius* var. *acidulus* Stapf. (sour grass) - 1,2, 4,5,6,8,9,13,15. C

CYPERACEAE (sedge family)

18. *Cyperus ligularis* L. - 7*,9. At
19. *Cyperus rotundus* L. (nut grass) - 12. I
20. *Cyperus sphacelatus* Rottb. - 10. At
21. *Eleocharis mutata* (L.) Roem. & Schult. (bulrush) - 10. I
22. *Fimbristylis cymosa* R. Br. - 3,5,11,13*,14,15. P

PALMAE (palm family)

23. *Cocos nucifera* L. (coconut) - 2*,4*,5*,6*,7*,9*,13*,14*,15. I

LILIACEAE (lily family)

24. *Sansevieria metallica* G. & L. (bowstring hemp) - 14*. I

AMARYLLIDACEAE (amaryllis family)

25. *Hymenocallis caribaea* (L.) Herb. (spider lily) - 4*. C

AGAVACEAE (agave family)
26. Agave angustifolia Haw. (Spanish needle) - 8. I
27. Agave barbadensis Trel. (maypole) - 1,2*,5,8*. E

CASUARINACEAE (beefwood family)
28. Casuarina equisetifolia J.R. & G. Forst. (casuarina) - 2,4*,5*, 6*,9*,11*,12*,13*,14*,15*. I

MORACEAE (mulberry family)
29. Ficus citrifolia Mill. (bearded fig) - 7*. C

POLYGONACEAE (buckwheat family)
30. Coccoloba uvifera (L.) L. (sea grape) - 1*,2*,3,5,6,7,9,10,11, 12,14*,15. C/CA/SA

AMARANTHACEAE (amaranth family)
31. Lithophila muscoides Sw. - 1,2*,8. C
32. Philoxerus vermicularis (L.) Beauv. - 2,3,4. At

AIZOACEAE (carpet-weed family)
33. Sesuvium portulacastrum (L.) L. (seaside samphire) - 1,2,5,7,8, 9,10*. P

PORTULACACEAE (purslane family)
34. Portulaca oleracea L. (purslane) - 1,6,7,8. I

PAPAVERACEAE (poppy family)
35. Argemone mexicana L. (Mexican poppy) - 12. C/CA/SA

CRASSULACEAE (stonecrop family)
36. Bryophyllum pinnatum (Lam.) Oken (love leaf) - 6*,12,15. I

ROSACEAE (rose family)
37. Chrysobalanus icaco L. (fat pork) - 3. A

CAESALPINIACEAE (senna family of Leguminosae)
38. Caesalpinia bonduc (L.) Roxb. (horse nicker) - 3,5*,7,9*,15. P
39. Cassia glandulosa var. swartzii (Wilkstr.) J.F. Macbr. (wild tamarind) - 14*,15. C
40. Delonix regia (Boj. ex Hook.) Raf. (flamboyant) - 12,13,14. I

MIMOSACEAE (mimosa family of Leguminosae)
41. Desmanthus depressus H. & B. - 1,4,5,6,8,9*. A
42. Desmanthus virgatus (L.) Willd. - 1*,6*. A
43. Leucaena leucocephala (Lam.) De Wit (wild mimosa) - 11. A

FABACEAE (bean family of Leguminosae)
44. Abrus precatorius L. (crab's-eye vine) - 13. P
45. Canavalia maritima (Aubl.) Urb. (seaside bean) - 2,3,4,7. P
46. Desmodium canum (J.F. Gmel.) S. & T. (iron vine) - 4. At
47. Rhynchosia minima (L.) DC. (burn-mouth vine) - 1*,6,9,15. P

48. Stylosanthes hamata (L.) Taub. - 1,13. C/CA/NA
49. Tephrosia wallichii Grah. ex Fawc. & Rendle - 3*,12. I
50. Vigna vexillata (L.) A. Rich - 6*,15*. P

MELIACEAE (mahogany family)

51. Swietenia mahagoni (L.) Jacq. (Barbados mahogany) - 10,12,13,14, 15. I

EUPHORBIACEAE (spurge family)

52. Croton balsamifer Jacq. (seaside sage) - 1,2,3,5,6,8*. C
53. Croton lobatus L. - 6*. At
54. Euphorbia mesembrianthemifolia Jacq. (seaside spurge) - 2,3,4,5*, 6,7,8,9. A
55. Euphorbia prostrata Ait. (doveweed) - 1,6*,8*,15*. A
56. Euphorbia serpens Kunth - 1,4,6,15. C
57. Hippomane mancinella L. (manchineel) - 2*,3,6,7,12,13,14,15. C/CA/SA
58. Jatropha gossypifolia L. (belly-ache bush) - 1,6*,12. C/CA/SA
59. Phyllanthus epiphyllanthus L. (seaside laurel) - 6. C
60. Phyllanthus fraternus Webster (seed-under-leaf) - 12. I

TILIACEAE (linden family)

61. Corchorus aestutans L. (pawpaw okro) - 3. P

MALVACEAE (mallow family)

62. Thespesia populnea (L.) Soland. ex Correa (seaside mahoe) - 10. P

CACTACEAE (cactus family)

63. Cephalocereus barbadensis Britton & Rose (columnar cactus) - 2*. E
64. Opuntia dillenii (Ker-Gawl.) Haw. (prickly pear) - 1,8*,9*. A

RHIZOPHORACEAE (red mangrove family)

65. Rhizophora mangle L. (red mangrove) - 10. P

COMBRETACEAE (white mangrove family)

66. Conocarpus erectus L. (white mangrove) - 9*. At
67. Terminalia catappa L. (Barbados almond) - 11,13. I

THEOPHRASTACEAE (theophrasta family)

68. Jaquinia arborea Vahl. (pie-crust) - 6*. C

OLEACEAE (olive family)

69. Jasminium fluminense Vell. (wild jasmine) - 14. I

APOCYNACEAE (periwinkle family)

70. Catharanthus roseus (L.) G. Don. (periwinkle) - 12. I

ASCLEPIADACEAE (milkweed family)

71. Calotropis procera (Ait.) Ait.f. in Ait. (French cotton) - 3. I

CONVOLVULACEAE (morning-glory family)

72. Ipomoea pes-caprae subsp. brasiliensis (L.) Ooststr. (seaside yam) - 2,3,4,5,6,7,9,11,12. P
73. Ipomoea tuba (Schlecht) G. Don. - 5. P

BORAGINACEAE (heliotrope family)

74. Cordia obliqua Willd. (clammy cherry) - 13. I
75. Cordia sebestena L. (scarlet cordia) - 10*,11,13. C
76. Heliotropium curassavicum L. (wild lavender) - 1,2,4,5. A
77. Mallotonia gnaphlodes (L.) Britton (seaside lavender) - 6,7,9. C/CA

VERBENACEAE (verbena family)

78. Clerodendrum aculeatum (L.) Schlecht. (prickly wild coffee) - 1, 2,7,13,14*,15. C/CA
79. Lantana involucrata L. (white sage) - 2*,5,6,7,8*,9,15. C/CA
80. Lantana trifolia L. (sage) - 6*,15. C/CA/SA
81. Lippia strigulosa M. & G. - 2,3. C/CA/SA
82. Stachytarpheta jamaicensis (L.) Vahl (vervain) - 7,9,11,12,13,14, 15. A

AVICENNIACEAE

83. Avicennia schauerana Steph. & Leechman ex Moldenke (white mangrove) - 10. C/SA

LABIATAE, now LAMIACEAE (mint family)

84. Hyptis pectinata (L.) Poit. - 4. C/SA
85. Leonotis nepetifolia (L.) Ait. f. in Ait. (lion's tail) - 12. P

SCROPHULARIACEAE (snapdragon family)

86. Capraria biflora L. (West Indian tea) - 2,5,6,9,11,12,14. A
87. Scoparia dulcis L. - 11,13. P

BIGNONIACEAE (catalpa family)

88. Tabebuia pallida (Lindl.) Miers (whitewood) - 4,5,6,7*,8*,9,14, 15. C/CA
89. Tecoma stans (L.) Kunth (buttercup) - 9. A

ACANTHACEAE (acanthus family)

90. Ruellia tuberosa L. - 1,6*. C/SA

MYOPORACEAE (myoporum family)

91. Bontia daphnoides L. (wild olive) - 4. C/SA

RUBIACEAE (coffee family)

92. Spermacoce confusa Rendle - 12,13,15. A
93. Spermacoce tenuior L. (button weed) - 1*,15*. C/CA

94. Strumfia maritima Jacq. - 8. C/CA

COMPOSITAE, now ASTERACEAE (sunflower family)

95. Conyza canadensis (L.) Cronq. - 12. I
96. Egletes prostrata (Sw.) Kuntze - 1,2,3*,4,5,6*,8,9*. C
97. Melanthera nivea (L.) Small - 11,12,13,15. C/CA
98. Wedelia trilobata (L.) Hitchc. (carpet daisy) - 3,4,11,14*. C/CA
99. Pectis humifusa Sw. (duckweed) - 1,2,3,4,5,6,7,8,9. C
100. Emilia coccinea (Sims) G. Don. (red thistle) - 13. I

Species cited in text but not recorded at the 15 beach locations

Authorities are after Harris (1965), Poggie (1963) and Watts (1966).

GRAMINAE now POACEAE
Uniola paniculata L.

ZYGOPHYLLACEAE
Guaiacum officinale L. (lignum vitae)

CELASTRACEAE
Rhacoma latifolia (Sw.) Gomez de la Maza?

COMBRETACEAE
Laguncularia racemosa (L.) Gaertn. (broad-leaved mangrove)

ONAGRACEAE
Oenothera drummondii Hook

SAPOTACEAE
Manilkara bidentata (A.DC.) A. Chev. (bully tree)

AVICENNIACEAE
Avicennia germinans (L.) L. (dwarf mangrove)

RUBIACEAE
Randia laetevirens Standl.

GOODENIACEAE
Scaevola plumieri (L.) Vahl.

COMPOSITAE now ASTERACEAE
Bidens pilosa L.

APPENDIX III

INDEX TO COMMON NAMES OF PLANTS MENTIONED IN THE TEXT

Barbados almond	Terminalia catappa
Barbados mahogany	Swietenia mahagoni
Bearded fig	Ficus citrifolia
Belly-ache bush	Jatropha gossypifolia
Bulrush	Eleocharis mutata
Burn-mouth vine	Rhynchosia minima
Burr grass	Cenchrus echinatus
Buttercup	Tecoma stans
Button weed	Spermacoce tenuior
Carpet daisy	Wedelia trilobata
Casuarina	Casuarina equisetifolia
Clammy cherry	Cordia obliqua
Coconut	Cocos nucifera
Columnar cactus	Cephalocereus barbadensis
Crab grass	Sporobolus virginicus
Crab's eye vine	Abrus precatorius
Devil's grass	Cynodon dactylon
Dog's grass	Egragrostis ciliaris
Dove weed	Euphorbia prostrata
Duckweed	Pectis humifusa
Dutch grass	Eleusine indica
Egyptian grass	Dactyloctenium aegyptium
Fat pork	Chrysobalanus icaco
Flamboyant	Delonix regia
French cotton	Calotropis procera
Hemp (bowstring)	Sansevieria metallica
Iron vine	Desmodium canum
Manchineel	Hippomane mancinella
Maypole	Agave barbadensis
Mexican poppy	Argemone mexicana
Nicker, Horse nicker	Caesalpinia bonduc
Nut grass	Cyperus rotundus

Pawpaw okro	Corchorus aestutans
Periwinkle	Catharanthus roseus
Pie-crust	Jaquinia arborea
Plush grass	Chloris radiata
Prickly pear	Opuntia dillenii
Prickly wild coffee	Clerodendrum aculeatum
Purslane	Portulaca oleracea
Red mangrove	Rhizophora mangle
Red thistle	Emilia coccinea
Sage	Lantana trifolia
Scarlet cordia	Cordia sebestena
Screw pine	Pandanus ?utilis
Sea grape	Coccoloba uvifera
Seashore grass	Sporobolus pyramidatus
Seaside bean	Canavalia maritima
Seaside laurel	Phyllanthus epiphyllanthus
Seaside lavender	Mallotonia gnaphlodes
Seaside mahoe	Thespesia populnea
Seaside sage	Croton balsamifer
Seaside samphire	Sesuvium portulacastrum
Seaside spurge	Euphorbia mesembrianthemifolia
Seaside yam	Ipomoea pes-caprae
Seed-under-leaf	Phyllanthus fraternus
Sour grass	Andropogon intermedius
Spanish needle	Agave angustifolia
Spider lily	Hymenocallis caribaea
Vervain	Stachytarpheta jamaicensis
West Indian tea	Capraria biflora
White mangrove	Avicennia schauerana
White mangrove	Conocarpus erectus
White sage	Lantana involucrata
Whitewood	Tabebuia pallida
Wild jasmine	Jasminium fluminense
Wild lavender	Heliotropium curassavicum
Wild mimosa	Leucaena leucocephala
Wild olive	Bontia daphnoides
Wild tamarind	Cassia glandulosa

APPENDIX IV

DESCRIPTIONS OF COMPUTER PROGRAMMES

Normstand

The Normstand computer programme tests normality in large samples. One can test both kurtosis and skewness, two ways in which distributions may depart from normality. Kurtosis is measured by g2, a statistic based on the sum of the fourth powers of deviations from mean. If g2 is zero, there is no departure from normality so far as this measure is concerned. A positive value of g2 indicates an excess of items near the mean and far from it, with a corresponding depletion of the flanks of the distribution. This is the manner in which the student's t distribution departs from normal. Negative values of g2 result from flat-topped curves. Skewness is a condition in which frequencies above and below the mean occur in disproportionate quantities. It is measured with the statistic gl. If gl is zero symmetry in the sample obtains. A positive gl indicates an excess in the number of items smaller than the mean, (see Snedecor 1956).

The skewness and kurtosis of the soil parameters analyzed (Table 4.1) are shown in table AIV.1

COR-DP

The COR-DP computer programme will perform simple correlation and regression analysis on all pairs of variables in a given data matrix. The data presented for analysis is normalized if desired, the correlation coefficient computed, and the regression line according to the least-squares criterion determined. The coefficient of correlation is tested for significance (t-test) and the standard error of estimate as well as the residuals from regression and the coefficient of determination are calculated.

TABLE AIV.1 MEASURES OF SKEWNESS AND KURTOSIS

Variable[1]	Skewness[2]	Kurtosis[2]
1	1.81	0.25
2	1.40	-0.38
3	2.43	0.16
4	1.08	-0.12
5	0.39	-1.29
6	-0.34	0.32
7	0.55	2.00
8	1.24	-1.71
9	0.31	-2.00
10	0.75	-1.98
11	0.08	4.79
12	4.11	1.73
13	-0.47	-2.27
14	-1.57	-0.68
15	-1.70	-0.46

[1]As defined in text chapter 4, table 4.1.

[2]Using the measures of Snedecor (1956).

APPENDIX V

CROSS-TRAVERSE DATA

Some examples of data collected along cross-traverses at sample locations. Information is from 40 contiguous quadrats randomly located within zones defined by transect data (see chapter 1).

Leeward Coast - Maycock's Bay, Zone 1L

Species	Quadrats in which species were present with percentage cover shown in brackets
Sporobolus virginicus	2(10),3(5),4(5),5(5),6(15),7(45),8(15), 9(30),10(20),11(15),12(15),13(5),14(15), 15(30),16(30),17(25),18(30),19(15),20(15), 21(15),22(10),23(5),38(5),39(5).
Hippomane mancinella	33(5) seedling.
No species recorded	1,24,25,26,27,28,29,30,31,32,34,35,36,37, 40.

Coastal Cliff - Animal Flower Bay, Zone 2C

Sporobolus virginicus	1(70),2(65),3(65),4(40),5(55),6(75),7(100), 8(100),9(100),10(100),11(100),12(100), 13(95),14(90),15(60),16(70),17(90),18(55), 19(40),20(10),21(5),22(95),23(95),24(10), 25(15),26(5),27(10),28(65),29(100),30(65), 31(20),32(40),33(15),34(60),35(45),36(70), 37(85),38(100),39(15),40(10).
Sesuvium portulacastrum	1(5),2(5),4(5),5(5),6(5),14(5),15(10),16(5), 18(5),19(20),20(5),21(15),22(5),26(5),27(5), 30(5),31(5),33(5),34(5).
Pectis humifusa	18(10),19(10),20(5),21(5),26(5),27(5),32(5), 33(5),39(5),40(5).

Windward Coast Beaches and Dunes - Chancery Lane, Zone 2W

Euphorbia mesembrianthemifolia	1(35),2(10),3(60),5(10),6(60),7(15),8(5), 9(15),10(10),11(15),12(10),13(10),14(5), 18(5),20(5),21(5),22(5),23(10),24(15),25(30), 26(35),27(50),28(20),29(75),30(60),31(25),

Euphorbia mesembrianthemifolia	32(50),33(45),34(45),35(70),36(75),37(40), 38(60),39(5),40(75).
Sporobolus virginicus	1(10),2(5),3(5),4(5),7(5),18(5),24(5),35(5), 36(5),37(5),38(5),39(20).
Ipomoea pes-caprae	1(5),10(10),11(15),12(15),13(5),26(5),28(5), 30(5),31(5),33(5).
Mallotonia gnaphlodes	13(20),14(80),15(70),16(75),17(80),18(65), 19(50),20(15),21(40),22(60),23(50),24(5).

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