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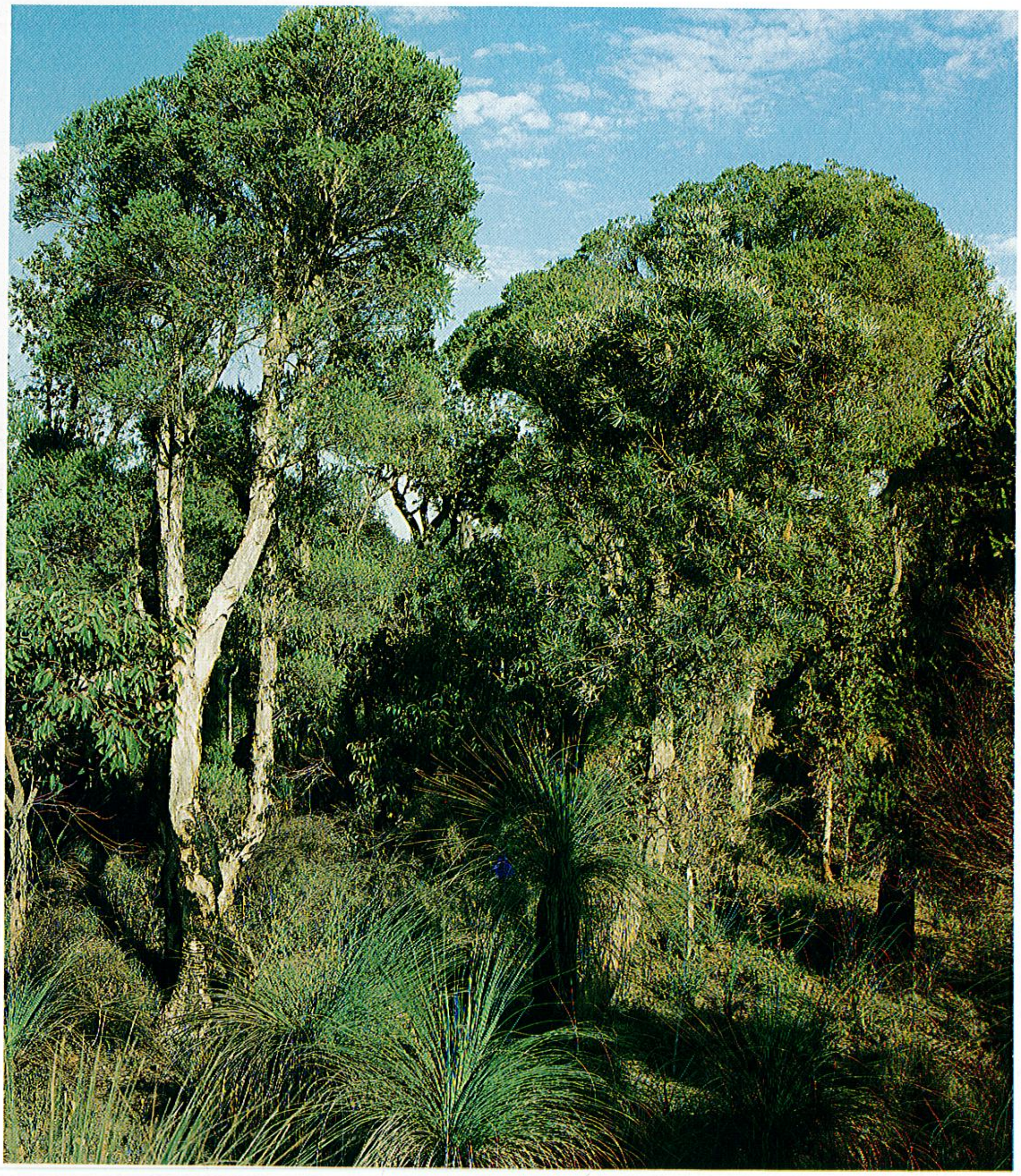
E. M. HEDDLE



FORESTS DEPARTMENT OF WESTERN AUSTRALIA

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Effects of Changes in Soil Moisture on the Native Vegetation of the Northern Swan Coastal Plain, Western Australia

by

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Perth, 1980

FRONT COVER

Coastal plain vegetation

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Summary

This ecological study is part of a long-term monitoring programme investigating the dynamic changes over ten years of the plant communities at four sites covering a broad range of topographical features on the northern Swan Coastal Plain, Western Australia.

Changes in soil moisture at the four sites between 1966 and 1976 are documented, and the response of the native vegetation is discussed. Several perennial species are selected as possible indicators of changes in the water table level; they can be used as the basis for predicting both the nature and the extent of the environmental changes occurring as a result of the withdrawal of underground water in the area.

Introduction

In its report on wildlife conservation (Commonwealth of Australia, 1972), the House of Representatives Select Committee emphasised the inadequacy of the reservation of wetlands and swamps in Australia. Despite the proximity of the Perth metropolitan area, attention has been directed only recently towards the reservation of the wetlands and swamps on the northern Swan Coastal Plain in Western Australia. On this area there are a large number of demands made by conflicting forms of land use such as housing development, recreation, agriculture, timber production, mining, water supply operations and conservation of the flora and fauna. Riggert (1966) stressed that an increase in these demands on the areas close to the lakes and water resources would reduce the area of wetlands near Perth. Furthermore, it would threaten the existing and proposed reserves for the conservation of flora and fauna.

The investigations reported in this bulletin focus on the native plant communities of the northern Swan Coastal Plain that are likely to be influenced by the proposed withdrawal of underground water by the Metropolitan Water Supply, Sewerage and Drainage Board (M.W.B.). They supplement other ecological studies currently being carried out in the area.

The occurrence of some of these plant communities in relation to environmental variants is at present understood adequately. However, there is no knowledge of their reaction over a period of time to fluctuations in the variants. Four transects originally installed in 1966 were therefore re-established as the basis for a ten-year comparison of a range of plant populations. The study areas cover a wide range of the ecological types likely to be affected by underground water withdrawal.

Description of the Area

LOCATION

The Swan Coastal Plain is bounded in the west by the Indian Ocean, in the south by the Blackwood Plateau and in the east by the Darling and Gingin Scarps. The study areas are located on the northern Swan Coastal Plain (the area north of the Swan River), in or on the fringes of State Forest No. 65 (Fig. 1).

CLIMATE

The northern Swan Coastal Plain has a typically Mediterranean climate with hot, dry summers and mild, wet winters (Gentilli, 1947, 1951, 1972; Commonwealth Bureau of Meteorology, 1966, 1969). The winter rain accounts for most of the annual rainfall.

Full climatic data are available only for Perth. The chief deficiency of climatic records for other centres is the lack of evaporation data.

The study areas are located within the 640-770 mm mean annual rainfall belt. Basing calculations on the Prescott formula

$$P = 0{\cdot}54E^{0{\cdot}7}$$

where P = precipitation and E = evaporation

the growing season is 6·3 months at Perth, diminishing to 5·7 months at Yanchep. Long-term rainfall records kept by the Forests Department of Western Australia for the northern Swan Coastal Plain include Gnangara (37 years), Wanneroo (20 Years) and Tick Flat (21 years). Full rainfall data from these three stations are given in Appendix I. Rainfall decreases from south to north, recordings generally being slightly lower at Wanneroo than at Gnangara and lower at Tick Flat than at Wanneroo.

The data for Wanneroo and Gnangara indicate a series of wet years prior to 1966, the year when the soil moisture levels were first recorded at the four transects. In contrast, the annual rainfall during 1975 and 1976 was below average at all three stations (Table 1).

Seasonal fluctuations in rainfall are reflected in changes in both the soil moisture levels (unsaturated zone) and the water table level (saturated zone) (Figs. 2 and 3). The soil moisture levels in March approximate the wilting point. Super-imposed on this seasonal fluctuation is the annual fluctuation in soil moisture content. The annual fluctuations in rainfall at Gnangara, Wanneroo and Tick Flat have been similar to those for Perth since records were first kept at these centres, so that the rainfall data for Perth can be used as a guideline to earlier rainfall in the study areas. Although Gentilli (1947) notes an increase in rainfall, ten-year averages calculated from rainfall data for the last fifty years show that there has been an overall decrease since 1920 (Fig. 4).

Table 1

ANNUAL RAINFALL (mm) FOR GNANGARA, WANNEROO AND TICK FLAT, 1962-76

	Gnangara	*Wanneroo*	*Tick Flat*
1962	802·4	824·8	718·8
1963	1113·5	1056·6	992·1
1964	1136·1	965·7	920·2
1965	1014·0	941·7	930·7
1966	617·1	574·5	616·5
1967	942·2	928·7	877·8
1968	909·1	922·2	869·5
1969	484·8	591·0	469·3
1970	866·8	747·2	758·4
1971	726·7	728·3	597·5
1972	568·8	561·1	596·7
1973	900·7	847·0	763·9
1974	1061·8	914·4	913·0
1975	794·6	739·0	703·7
1976	703·1	682·3	664·7

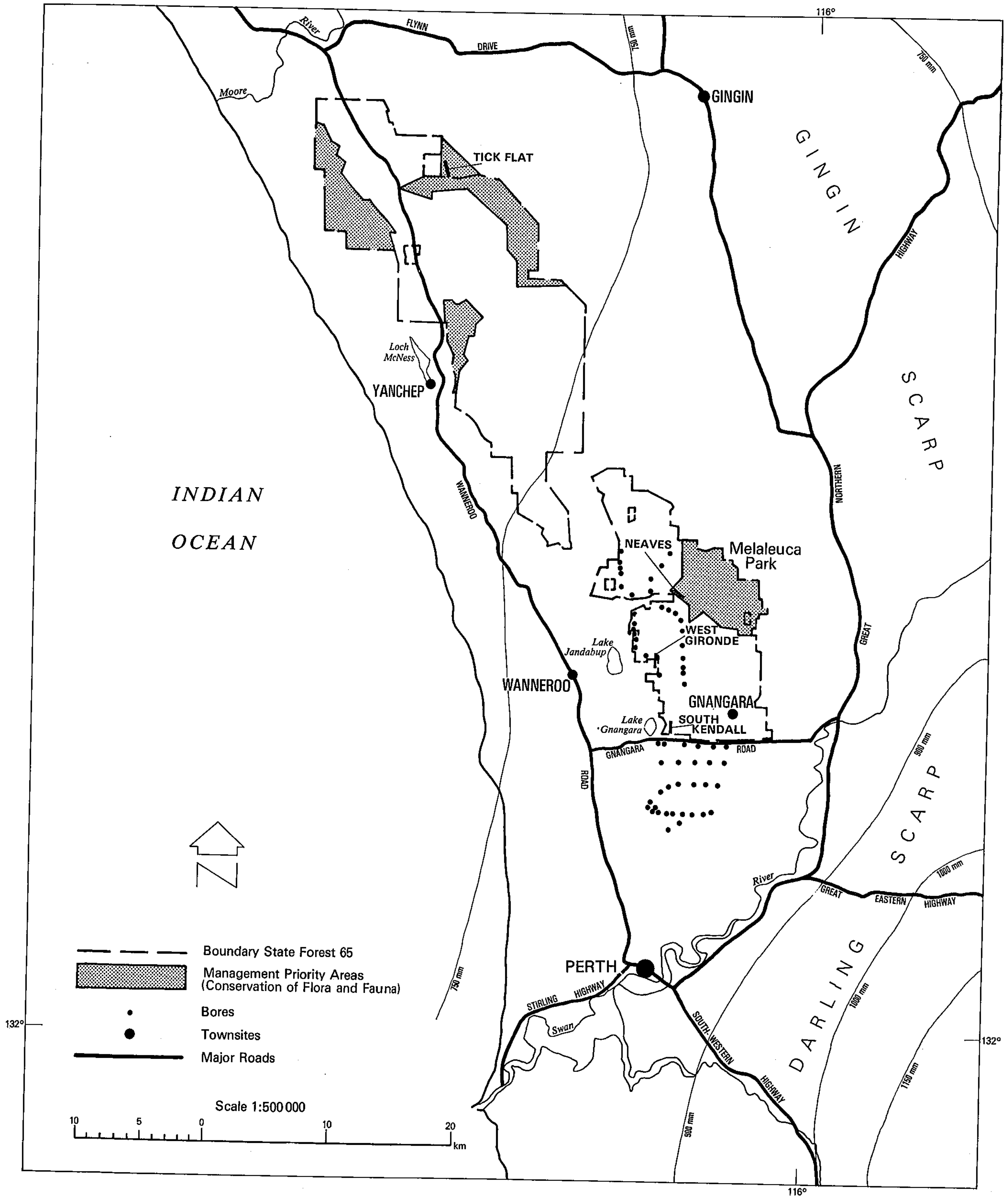
LANDFORM AND SOILS

The landform and soils of the northern Swan Coastal Plain were first described by Woolnough (1920). Smith (1952) produced a soil association map which was later modified by McArthur and Bettenay (1960) and Bettenay, McArthur and Hingston (1960). Further work in this field has recently been carried out by Churchward and McArthur (1980).

The Plain consists of a series of geomorphic entities parallel to the coastline. The northern part of the Plain, which is formed almost entirely of depositional material of either fluviatile or aeolian origin, consists of the Pinjarra Plain and three dune systems of different ages whose soils are at different stages of leaching and soil formation.

The Pinjarra Plain is a piedmont deposit formed where the rivers enter the Coastal Plain at its eastern edge. It is characterised by medium-textured, fairly well drained soils and gentle slopes.

Figure 1
Map of northern Swan Coastal Plain, showing location of study areas.

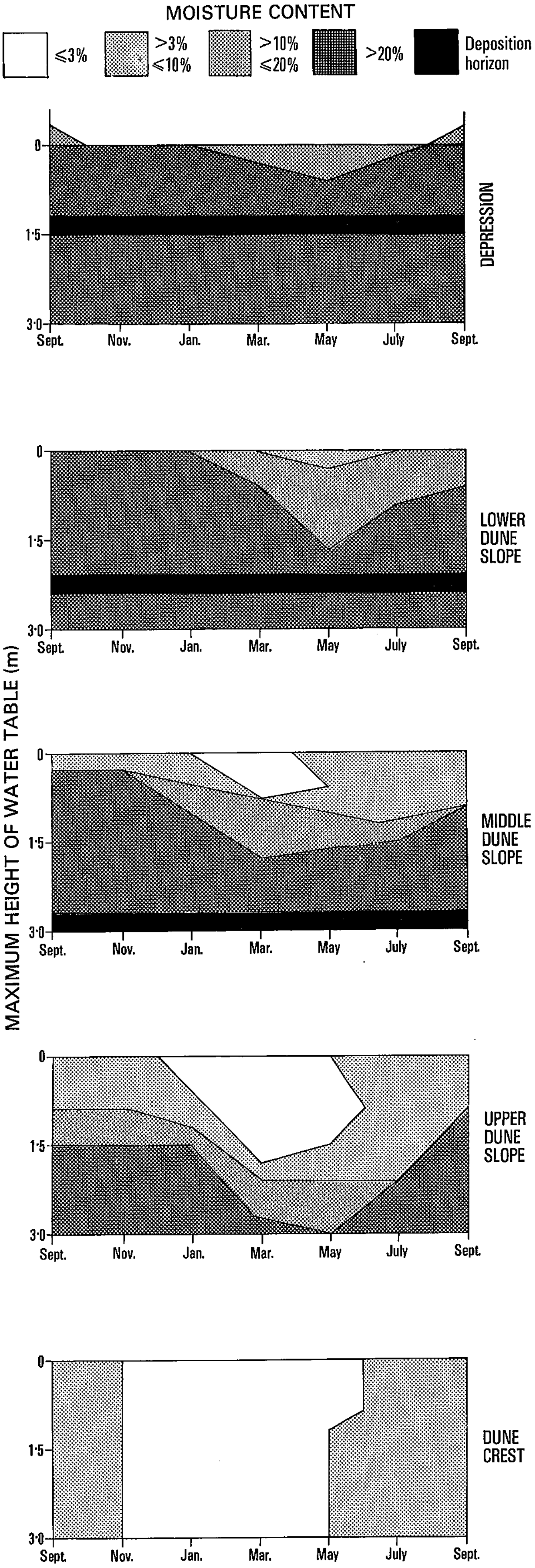


Immediately to its west is the Bassendean Dune System, which consists of highly leached grey sands devoid of virtually all nutrients. Although the dunes reach an altitude of 60 m in the north, they are generally gently undulating. Between them are extensive seasonal swamps with peaty soils and moist flats underlain by organic hardpan.

A series of lakes and swamps, including Yeal Swamp and Lakes Pinjar, Coogee, Mariginiup, Jandabup and Gnangara, occurs from north to south in a transition area between the Bassendean Dune System and the Spearwood Dune System to its west. The dunes here are generally higher and steeper, and consist of a core of calcium-rich aeolinite capped by a

Figure 2

Seasonal fluctuations in water table, northern Swan Coastal Plain, September 1965 to September 1966. (Based on Havel, 1968)

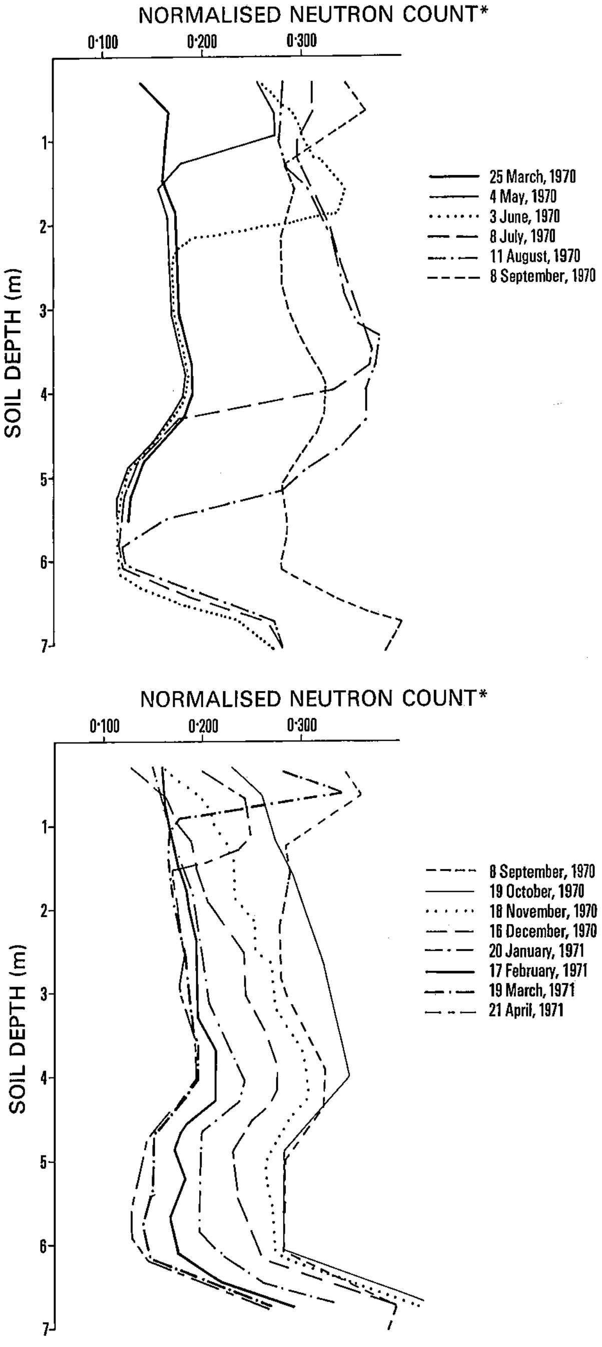


layer of hard limestone that is usually, though not always, covered by moderately leached sands.

The Spearwood Dune System was subdivided into two soil associations by Bettenay, McArthur and Hingston (1960). The first of these, the Karrakatta Association, which occurs at the easternmost fringes of the System, consists of deep, leached yellow and brown sands overlying limestone at depth. The second association, the Cottesloe Association, lies to the west of this and consists of shallow yellow and

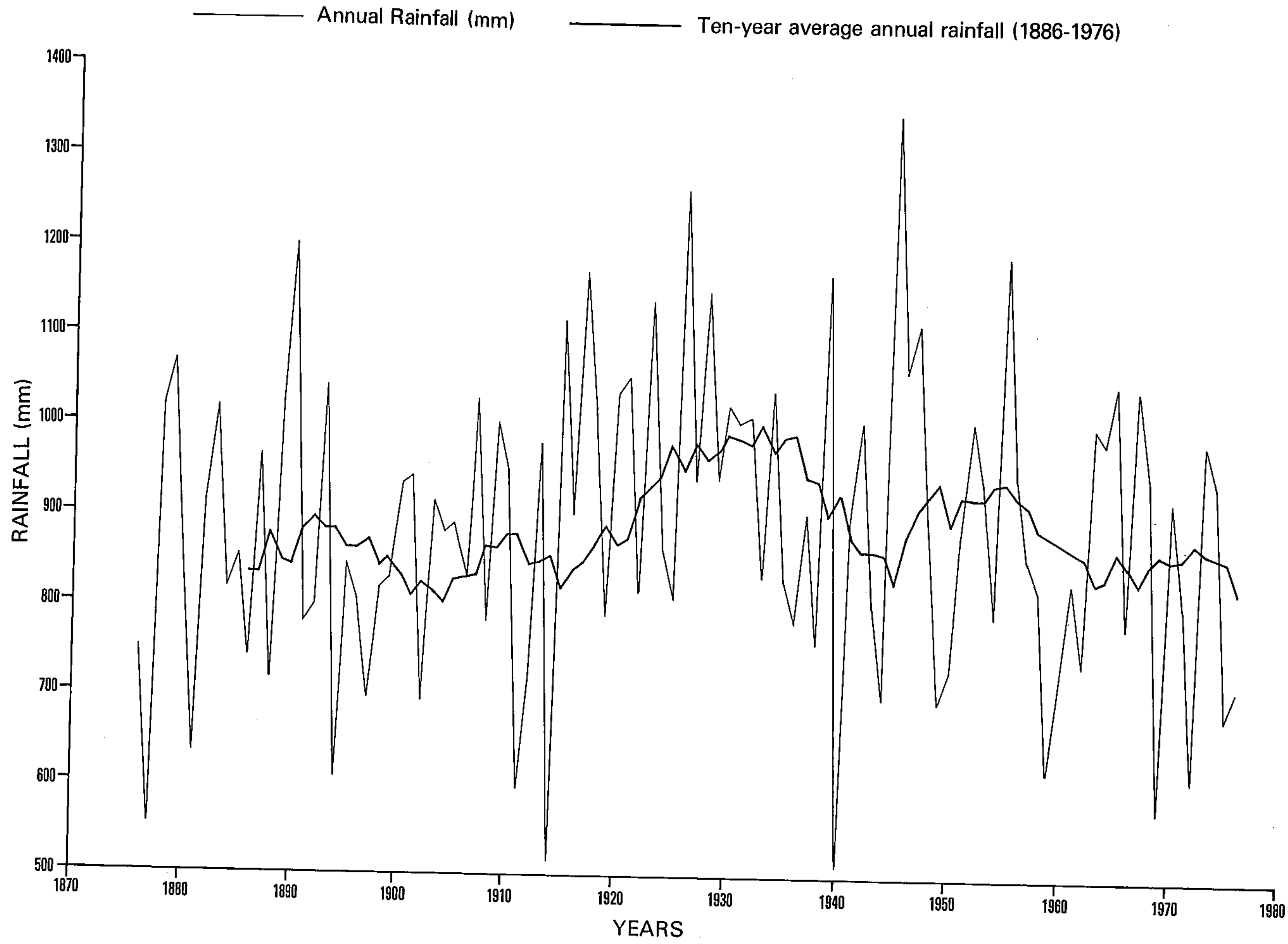
Figure 3

Moisture relationships of soil under native woodland at Yanchep, Western Australia. (Extracted from Butcher and Havel, 1976).



* Normalised neutron count reflects the amount of water held in the soil. Moisture levels in March approximate the wilting point.

Figure 4
Annual rainfall recordings and ten-yearly average annual rainfall, Perth, 1876-1976. (Data from records of Bureau of Meteorology, Perth.)



brown neutral soils over limestone, which is exposed in many places at the soil surface in the form of pinnacles. Between the two associations is another series of lakes, including Lake Joondalup.

West of the Spearwood System is the Quindalup Dune System, a narrow belt of unconsolidated calcareous sand.

WATER RESOURCES

Studies show that demands made on the limited water resources in the vicinity of Perth are increasing. The water requirements of the metropolitan area have recently been assessed by Sadler and Field (1975).

Sadler (1975) sees alternative water sources outside the south-western province as economically impractical. Water for use in the Perth metropolitan area is at present taken from reservoirs on the Darling Plateau and from shallow surface unconfined and deeper artesian aquifers on the Coastal Plain.

The deeper artesian aquifers are currently being tapped at the 300 to 600 m level. Hillman (1971) has estimated that they could supply 10 per cent of the amount of water potentially available from the Plateau.

The shallow unconfined aquifers provide another ready source of water that has the advantage of being close to Perth. However, until recently they have not been used extensively for domestic supplies.

These aquifers consist of sand overlying clay. Their depth varies, but Bestow (1971) estimates that they extend to 40 or 50 m below the surface. On the Coastal Plain there is virtually no surface drainage outside of rivers originating on the Darling Plateau and running from the scarp to the coast; because the sand is very porous, the flow is underground from the highest points of the dune systems towards the coast and rivers (Balleau, 1973). The magnitude of this water resource has been estimated by Hillman (1971) at about 40 per cent of that available from the Plateau. The swamps and lakes occur where the water table approaches or rises above the surface of the ground. Consequently, most are shallow and subject to seasonal loss of water.

The M.W.B. has established a series of bores on a north-south line in State Forest No. 65 (Fig. 1). In the main, the bores are situated on the Spearwood and Bassendean Dune Systems, within a *Pinus pinaster* plantation maintained by the Forests Department.

The transect locations were selected within the predicted zone of influence of water withdrawal.

The future influence of the withdrawal scheme on the water table has been predicted by Burton (1976). Havel (1975) has summarised the probable effects of the withdrawal of underground water on other forms of land use in the vicinity of Perth. Land uses likely to be affected are those where the presence of the ground water table close to or above the ground is important, such as conservation of flora and fauna, softwood production, agriculture and water-based recreation.

VEGETATION

The first major attempts at defining the vegetation of Western Australia were those of Diels (1906) and Gardner (1942). Their division of the State into botanical provinces and districts formed the basis for later classifications of the vegetation. Speck (1952) classified the vegetation of the Swan Coastal Plain, which is part of the Darling Botanical District, according to its structural and floristic composition. Seddon (1972) summarised Speck's classification for the northern Swan Coastal Plain. Havel (1968) delineated site-vegetation types that were determined according to the degree of leaching and the soil moisture. His studies, which were restricted to the Spearwood and Bassendean Dune Systems, were based on the conception of the vegetation as a continuum. Heddle *et al.* (1980) achieved a compromise between the classification systems adopted by Speck (1952, 1958) and Havel (1968) by combining a broad approach based on the identification of structural formations and detailed analysis of the vegetation into site-vegetation types.

McComb and McComb (1967) and Congdon and McComb (1976) investigated the fringing and aquatic vegetation of Loch McNess in the Yanchep National Park and of Lake Joondalup, two of the lakes within the Spearwood Dune System.

On a regional basis, Australian plant communities react to drier conditions by changes in their structural and floristic composition. Within a localised area, these changes are further influenced by topographical and edaphic factors. The importance of soil moisture as a determinant of the distribution of plant communities has been recognised in most studies of the vegetation of the northern Swan Coastal Plain (Speck, 1952; Havel, 1968).

Given the same topographic position there are floristic and structural changes in the vegetation from south to north with decreasing rainfall and the associated decrease in water availability (Havel, 1968; Heddle *et al.*, 1980). For instance, on the dune crests of the Bassendean Dune System the vegetation ranges from a low open forest to an open woodland and low open woodland in the north near Moore River. A similar trend towards a reduction in height and percentage foliage cover of the tallest stratum is also evident from south to north on the Spearwood Dune System.

The floristic changes within the communities are clear. Species that depend on moister conditions in the south, such as *Eucalyptus marginata, E. calophylla, Banksia grandis* and *Casuarina fraserana,* are replaced in the north by *E. todtiana, B. attenuata, B. menziesii* and *B. ilicifolia,* which can tolerate the drier conditions.

There are more localised changes in the vegetation corresponding to the changes in soil moisture content on dune crests, dune slopes and depressions or swamps (Havel, 1968).

The high evapotranspiration and low rainfall during the summer place stress on the native vegetation (Speck, 1952; Grieve, 1957). The area's characteristic sclerophyll plants are adapted anatomically and physiologically to the seasonal and annual fluctuations in water availability, so that a large proportion do not suffer any detrimental effects. However, it is possible that many cannot adjust to extreme or sudden changes in the water regime. To determine which of the plants are able to adjust, it is first necessary to understand the anatomical and physiological characteristics of each species under a variety of environmental conditions.

Grieve (1955) reviewed the physiology of sclerophylls growing in areas of Mediterranean climate throughout the world. Grieve (1957) and Grieve and Hellmuth (1968, 1970) enumerated many specific examples of adaptations to this climate, using a range of Western Australian examples. Grieve (1957) noted a decrease in the rate of transpiration of a variety of sclerophylls in response to increasingly dry conditions. A noteworthy exception was *E. marginata.* Grieve and Hellmuth (1968) found that in many Swan Coastal Plain species such as *Banksia menziesii, Hibbertia hypericoides, Stirlingia latifolia* and *Bossiaea eriocarpa* there was a marked decrease in transpiration rates from spring to late summer. Further, plants such as *E. calophylla* and *S. latifolia* possess both a shallow and a deep rooting system and have medium water saturation deficits and medium osmotic values but do not go into dormancy during summer. They control water loss by stomatal closure or by the operation of some internal factor (Grieve, 1957). *Hibbertia hypericoides* and *B. eriocarpa* may close their stomata completely in summer, but only under conditions of extreme water stress in late summer are the stomata of *S. latifolia* known to be closed during most of the day.

However, in general there is only very little information available on the anatomical and physiological adaptations of particular Coastal Plain species to water stress.

The decrease in average annual rainfall on the Coastal Plain over the last fifty years, accentuated by the low rainfall during the last three years, has led to conditions of water stress. This is intensified during the seasonal dry period in late summer, and would be further increased by the withdrawal of underground water. The survival of the plants depends on their ability to adjust to changes in soil conditions and on their capacity to tolerate periods of water stress. Havel (1975) and Aplin (1976) both predicted a shift towards the xeric end of the vegetation continuum should the water table level fall. This would result in a reduction of those species found in or on the fringes of both the seasonal and the permanent swamps. Since many of these wetland areas are shallow, any lowering of the water table would be significant.

Some of the plants on the northern Swan Coastal Plain may have been unable to adapt to the current extreme water stress. If they are detected in the ten-year comparison they could serve as indicators of changes in soil moisture, so that the influence of the withdrawal of underground water on the native vegetation can be predicted.

Method

The vegetation was monitored along transects at South Kendall, West Gironde, Neaves and Tick Flat (Fig. 1).

The four transects, originally established by Havel (1968) in 1966 using the British Imperial system of measurement, were relocated and repegged where necessary. Their length varied from 201·0 to 522·6 m.

Each transect consisted of two lines of plots measuring 20·1 × 20·1 m located across a slope so as to sample the maximum topographical variation from a swamp or depression to a dune crest. The tree species were recorded on each plot, and the trunk diameter of all trees at breast height was recorded. In addition, the presence or absence of perennial plant species was determined on systematically located sub-plots (two per plot), each measuring 4 × 4 m.

These data were recorded to allow comparison with those collected in 1966 and to provide a basis for long-term monitoring in the future. For the detection of short-term changes, other data were also collected in 1976, including measurements of the density of perennial shrub species.

Soil moisture was measured in September and October 1966 and 1976 along all four transects. Using a Veihmeyer tube, soil samples were taken at intervals of 30 cm to a depth of 3 m from the centre of each group of four plots along the transect. Percentage soil moisture was then calculated from the weights of the wet and oven-dried samples (dried at 105°C for 24 hours).

The following categories were chosen on the basis of field observations:

Less than 3 per cent moisture (by weight)	Dry
3-10 per cent	Moist
10-20 per cent	Very moist
More than 20 per cent	Saturated standing water

On collection soil samples were not allowed to drain prior to weighing (i.e. moisture not limited to below field capacity), so a moisture content of over 20 per cent was considered to indicate that the soil sample was obtained from below the ground water table.

Percentage soil moisture =

$$\frac{\text{(wet weight—dry weight)}}{\text{dry weight}} \times 100$$

Results

GENERAL OBSERVATIONS

It is important to note the environmental factors other than soil-moisture level that were operative in the four areas during the study period.

The root fungus *Phytophthora cinnamomi,* which causes dieback disease and which is known to occur in pockets on the northern Swan Coastal Plain, was recorded only at South Kendall. Various native plant species are known to be susceptible to the disease, including *Banksia* spp., *Leucopogon* spp., *Xanthorrhoea* spp., and *Casuarina* spp. Stands of *Banksia littoralis* are particularly susceptible. *Eucalyptus rudis* and *E. calophylla,* however, are both known to show considerable tolerance to the disease (Shea, 1975; Batini, 1977). Because the fungal spores are transported in water, the greatest threat is to the plant communities on lowland areas (Shea, 1975).

Fire is another important factor affecting vegetation on the northern Swan Coastal Plain. Unlike the areas at South Kendall, West Gironde and Neaves, the area at Tick Flat had not been burnt since the transects were established in 1966. It is assumed in this study that because of the adaptation of most native perennial plant species to fire, through either vegetation regeneration or seeding establishment, the distribution of plant species along an environmental gradient would not be altered significantly by fire. It is acknowledged, however, that fire may affect the relative importance of the plant species within a community (shown by their numbers and biomass).

The water from the underground surface aquifers for the two schemes at Mirrabooka and Wanneroo is extracted by a series of pumping bores. These pumping bores are located more than a kilometre from all except the West Gironde transect. At this area they occur within 600 m of the transect, but pumping at the bores near West Gironde did not commence prior to the 1976 recordings.

None of the areas appears to have been previously cleared, logged or grazed by domestic animals despite their proximity to small agricultural properties, pine plantations and residential areas.

SOUTH KENDALL

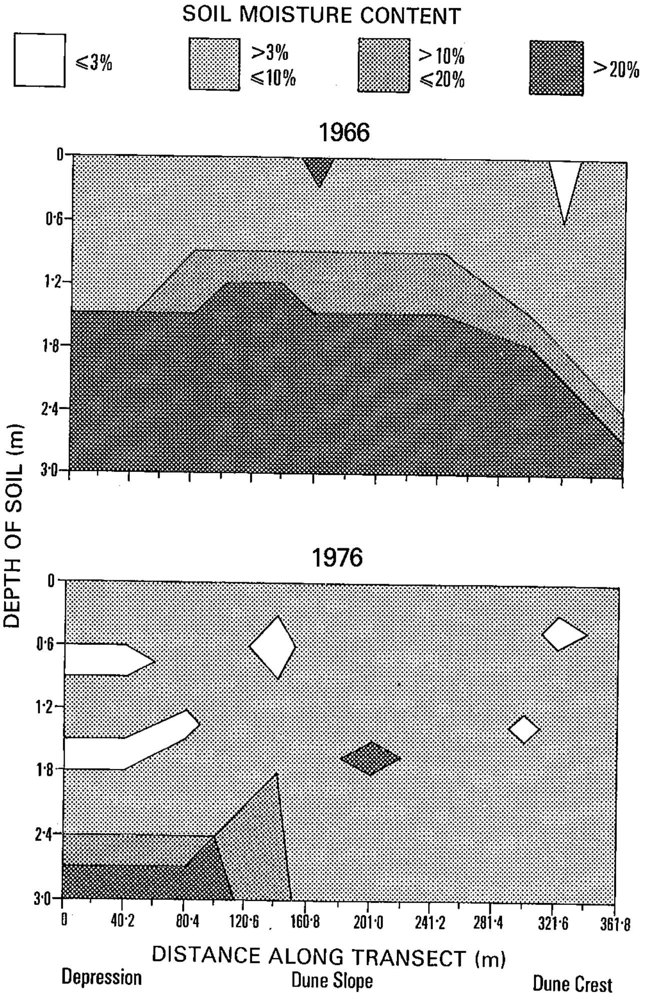
Phytophthora cinnamomi is known to be present at South Kendall. The area was burnt as part of the Forests Department's prescribed burning programme in the spring of 1969 and 1975. The transect is on both Bassendean and Spearwood sands one kilometre north of Gnangara Road. Northern pumping bores at the Mirrabooka Scheme (bores were operative prior to 1976) are located immediately south of Gnangara Road.

Soil moisture

Figure 5 illustrates soil moisture content at South Kendall in 1966 and 1976. Between 1966 and 1976 the water table fell by at least 1·2 m. An increase is evident in the dry soils (a moisture content below or equal to 3 per cent). These changes result in increased water stress in the plants, especially over the dry, hot summer months.

Figure 5

Soil moisture content at South Kendall (September 1966, October 1976)

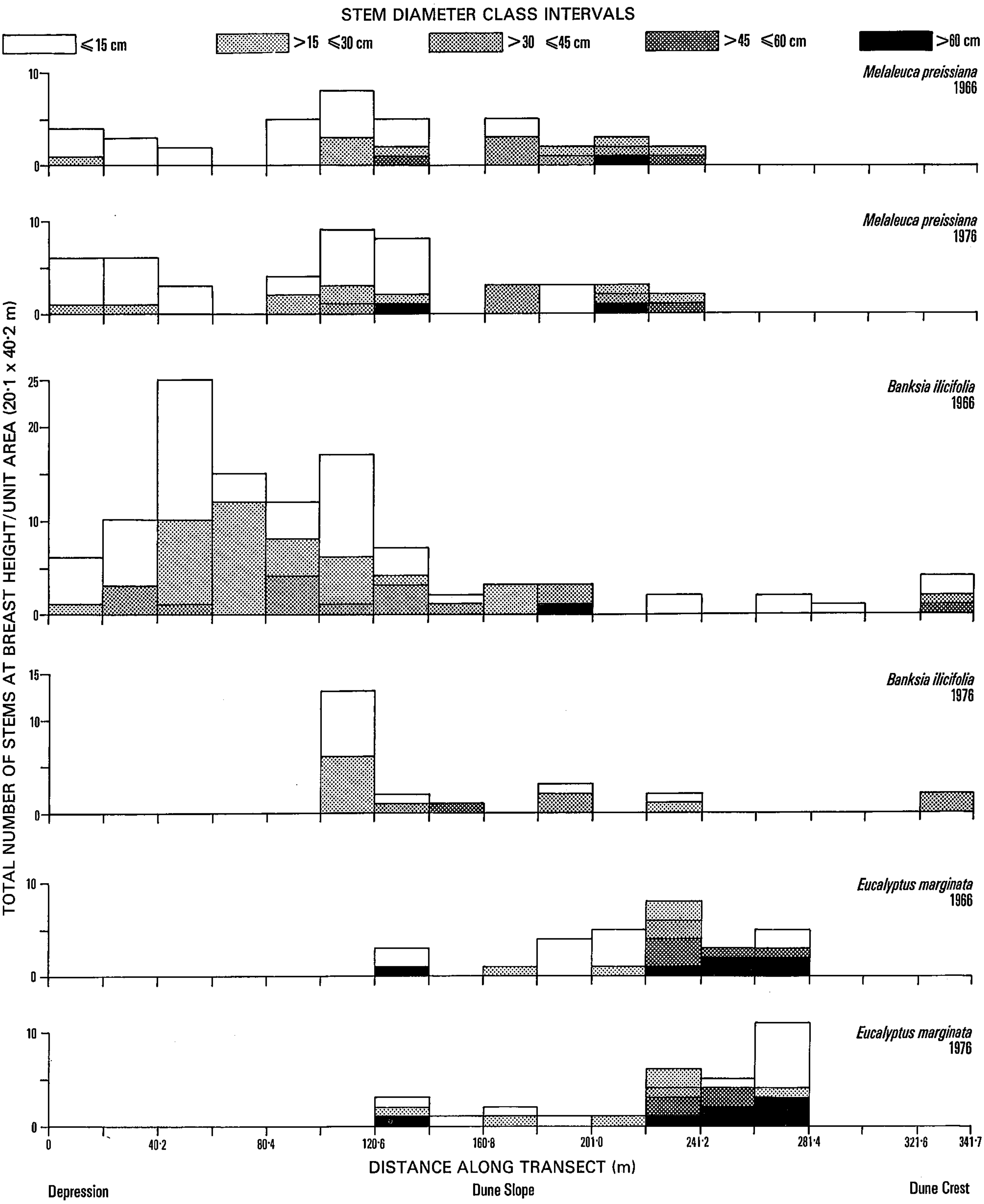


Vegetation

The distribution of the tree species classified by stem diameter is illustrated in Figure 6. The marked decrease in the numbers of *Banksia menziesii, B. attenuata* and *B. ilicifolia* may be accounted for by the presence of *Phytophthora cinnamomi.* However, on the upper slopes of the dune, *B. grandis* did not change significantly in numbers. Since this species is known to be particularly susceptible to dieback, the disease is apparently restricted to the low-lying areas. This suggests that the lower soil moisture levels may also have influenced the decrease in frequency of *B. menziesii, B. attenuata,* and *B. ilicifolia* on the dunes.

Figure 6

Distribution of tree species by stem diameter class intervals at South Kendall (September 1966 and 1976).



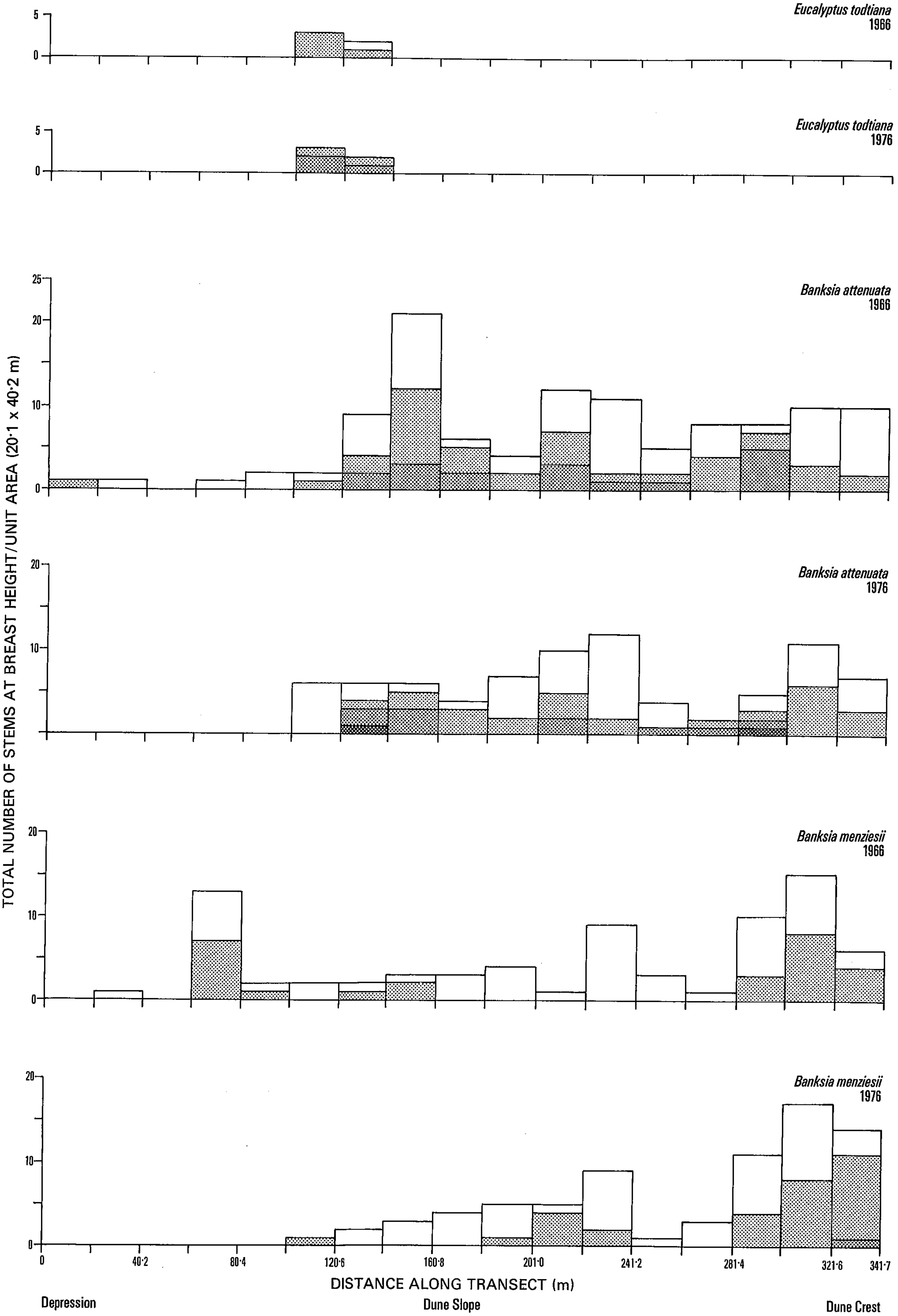
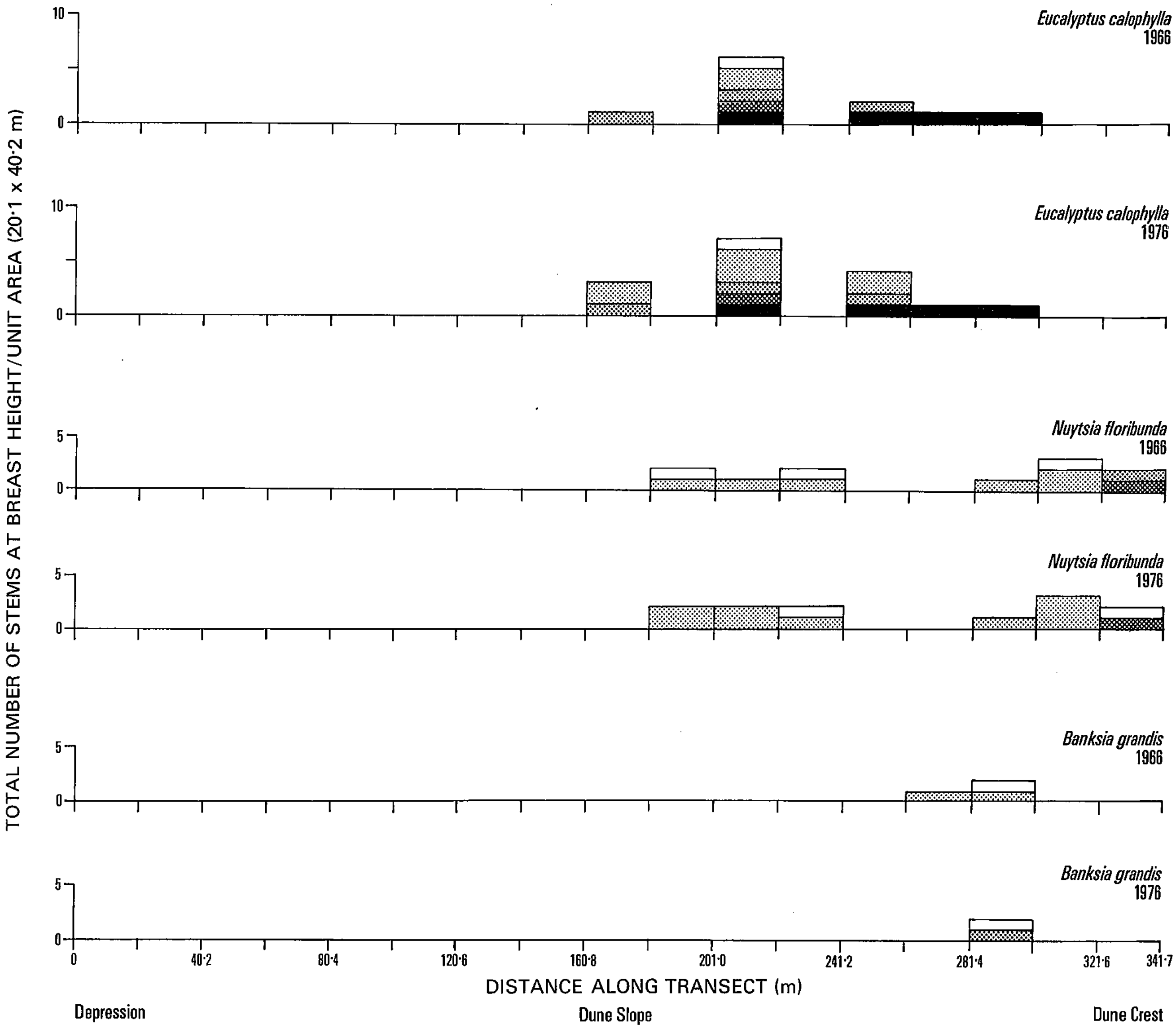

Eucalyptus todtiana 1966
Eucalyptus todtiana 1976
Banksia attenuata 1966
Banksia attenuata 1976
Banksia menziesii 1966
Banksia menziesii 1976
TOTAL NUMBER OF STEMS AT BREAST HEIGHT/UNIT AREA (20·1 x 40·2 m)
0
5
10
20
25
0
40·2
80·4
120·6
160·8
201·0
241·2
281·4
321·6
341·7
DISTANCE ALONG TRANSECT (m)
Depression
Dune Slope
Dune Crest

Figure 6 (*continued*)



The other tree species did not change markedly in either frequency or distribution, indicating their ability to tolerate dieback disease or their ability to adjust to fluctuations in soil moisture content or both. The diameter class intervals of the surviving trees show only minor changes between 1966 and 1976.

Although there was no decrease in the numbers of *Eucalyptus calophylla,* the crowns of several of the larger trees were dying off in patches in 1976, indicating that they were suffering water stress. The death of mature *E. calophylla* on the Bassendean Dune System east of Wanneroo (Havel, 1975) supports these observations.

The distribution of the majority of the forty-three perennial plant species identified at South Kendall (Fig. 7) did not change markedly over the ten-year period. This suggests that most are able to tolerate varying levels of water stress.

The perennial plant species whose frequency changed markedly (shown by a change of percentage frequency exceeding 5 per cent) are given in Table 2.

Table 2

PERENNIAL PLANT SPECIES AT SOUTH KENDALL SHOWING A MARKED CHANGE* IN FREQUENCY BETWEEN SEPTEMBER 1966 AND SEPTEMBER 1976

Increased frequency	*Decreased frequency*
Burtonia scabra	*Acacia huegelii*
Gompholobium tomentosum	*Calytrix flavescens*
Hibbertia subvaginata	*Hypocalymma angustifolium*
Hypocalymma robustum	*Petrophile linearis*
Lepidosperma angustatum	*Phlebocarya ciliata*
Leptocarpus scariosus	*Regelia ciliata*
Leucopogon conostephioides	
Lyginia barbata	
Scaevola sp.	
Schoenus curvifolius	
Xanthorrhoea preissii	

* Change in percentage frequency exceeding 5 per cent.

Hibbertia subvaginata appears to have no preference with regard to soil moisture; this observation supports Havel's (1968) observations. Furthermore, the species spread into the low-lying areas affected by *Phytophthora cinnamomi*. Similarly, *Gompholobium tomentosum* shows no clear pattern of response either to dieback or to soil moisture. Where these two species spread in distribution, they did so in considerable numbers (Fig. 8).

Several of the other species in Figure 7 show clear site preferences and their changes in frequency can therefore be attributed to the decrease in soil moisture content. *Leucopogon conostephioides, Burtonia scabra* and *Scaevola* spp. are restricted to the drier sands on the upper slopes of the dunes, while *Regelia ciliata* and *Hypocalymma angustifolium* are tolerant of excessive wetness (Havel, 1968) and *Acacia huegelii* prefers low-lying moist sites.

As *Hypocalymma robustum* is not known to be favoured by the presence of dieback disease, its increased frequency is perhaps attributable to the changes in soil moisture content.

In contrast, the increased frequency of the monocotyledons *Lepidosperma angustatum, Leptocarpus scariosus, Lyginia barbata* and *Schoenus curvifolius* may perhaps be accounted for by the presence of dieback disease. Such an increase in monocotyledons has been observed in the valley vegetation affected by dieback on the Darling Plateau. While *Xanthorrhoea preissii* increased in frequency, its density changed only slightly (Fig. 8).

WEST GIRONDE

After the death of some banksia plants in this area, soil and root samples were tested for *Phytophthora cinnamomi* but all results were negative.

The M.W.B. has three bores within 600 m of this transect but pumping of these bores did not commence until after the 1976 recordings. Consequently, any future response of the native vegetation to the withdrawal of underground water will be evident in this area sooner than in any of the other three, none of which is so close to bores.

The transect, on the Bassendean Dune System, crosses both State forest and private property. The lower slopes were burnt in the spring of 1970, while the upper slopes were burnt in the spring of 1972 as part of the Forests Department's prescribed burning programme.

Soil moisture

Figure 9 illustrates the changes in soil moisture content at West Gironde since 1966. As at South Kendall, the water table fell at least 1·2 m between 1966 and 1976, and in the swamp it dropped below the deposition horizon (coffee rock). Except for occasional pockets of slightly moister soil the upper slopes of the dune were particularly dry in 1976.

Vegetation

The distribution of tree species at West Gironde is shown in Figure 10.

The number of *Melaleuca preissiana* with a diameter of less than 15 cm increased in the low-lying areas; this species appears to have adapted to the drier years by producing a proliferation of stems. In contrast, *Banksia littoralis* died; this species, which also occurs on the depression and swamp fringes, was unable to adapt to the fall in the water table.

Nuytsia floribunda and *Eucalyptus todtiana* showed very little change in distribution. There was, however, a slight increase in the number of young stems of *E. todtiana.*

Although there was a substantial decrease in the numbers of *B. attenuata* and *B. menziesii* on the low-lying areas, both these species increased markedly in numbers on the lower to upper slopes of the dune.

Banksia ilicifolia showed a very marked response to the changes in environmental conditions. All trees on the depression died, while on the lower and middle slopes there were large decreases in numbers. As with the other banksia species, the older trees were the least capable of tolerating the changes.

There were, however, many young *B. ilicifolia* seedlings along the transect in 1976.

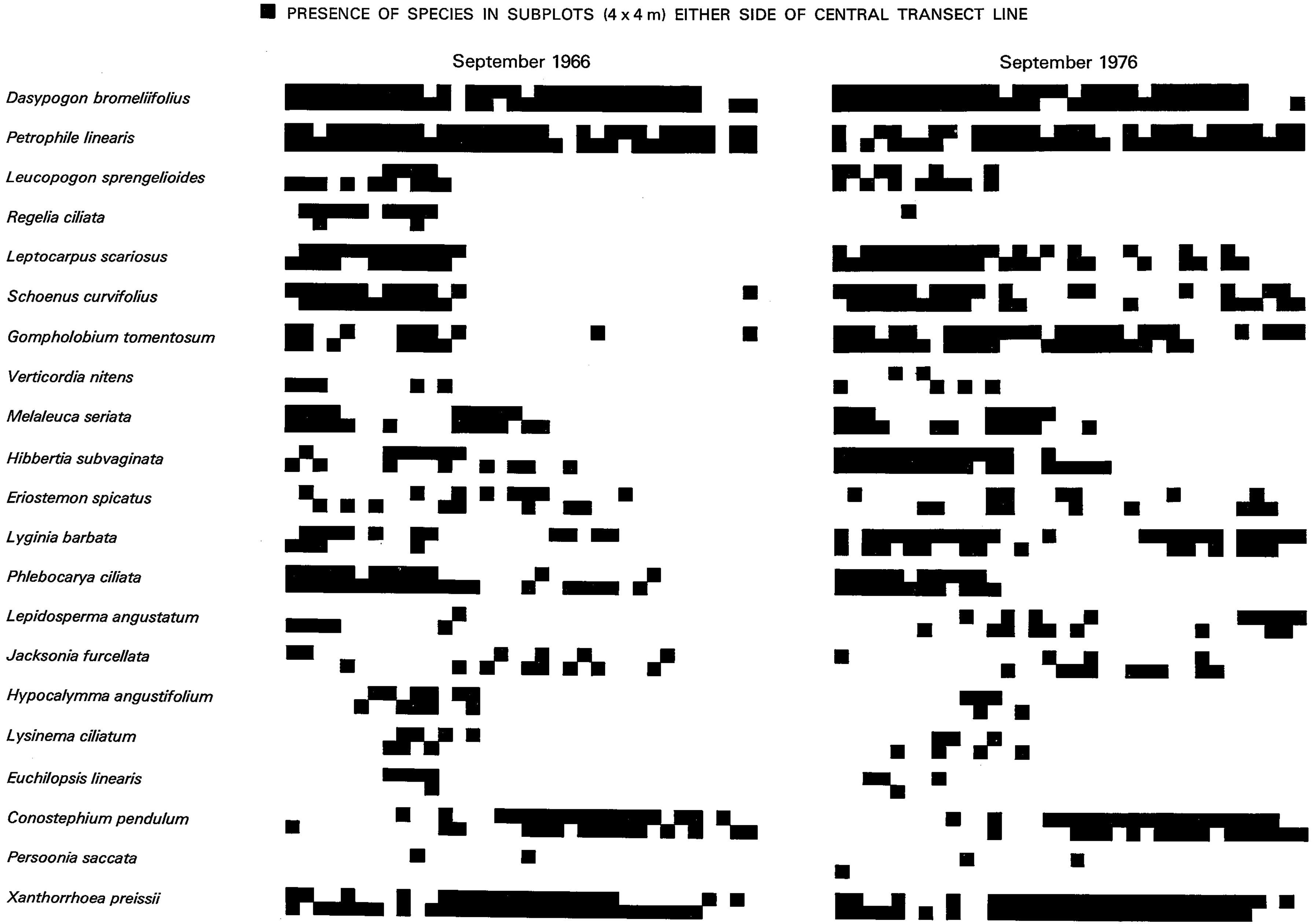
As no dieback was detected at West Gironde the death of the banksias must be due to their inability to adjust to the fall in the water table and general soil moisture levels.

The distribution of most of the forty-three perennial species other than trees identified at West Gironde did not change markedly (Fig. 11). Any changes appear to have occurred in response to the fall in the water table. The variation in response reflects the variation in the ability of the different species to adapt to the fluctuations in soil moisture.

The perennial species whose frequency changed markedly are given in Table 3.

Figure 7

Distribution of perennial plant species at South Kendall (September 1966 and 1976)



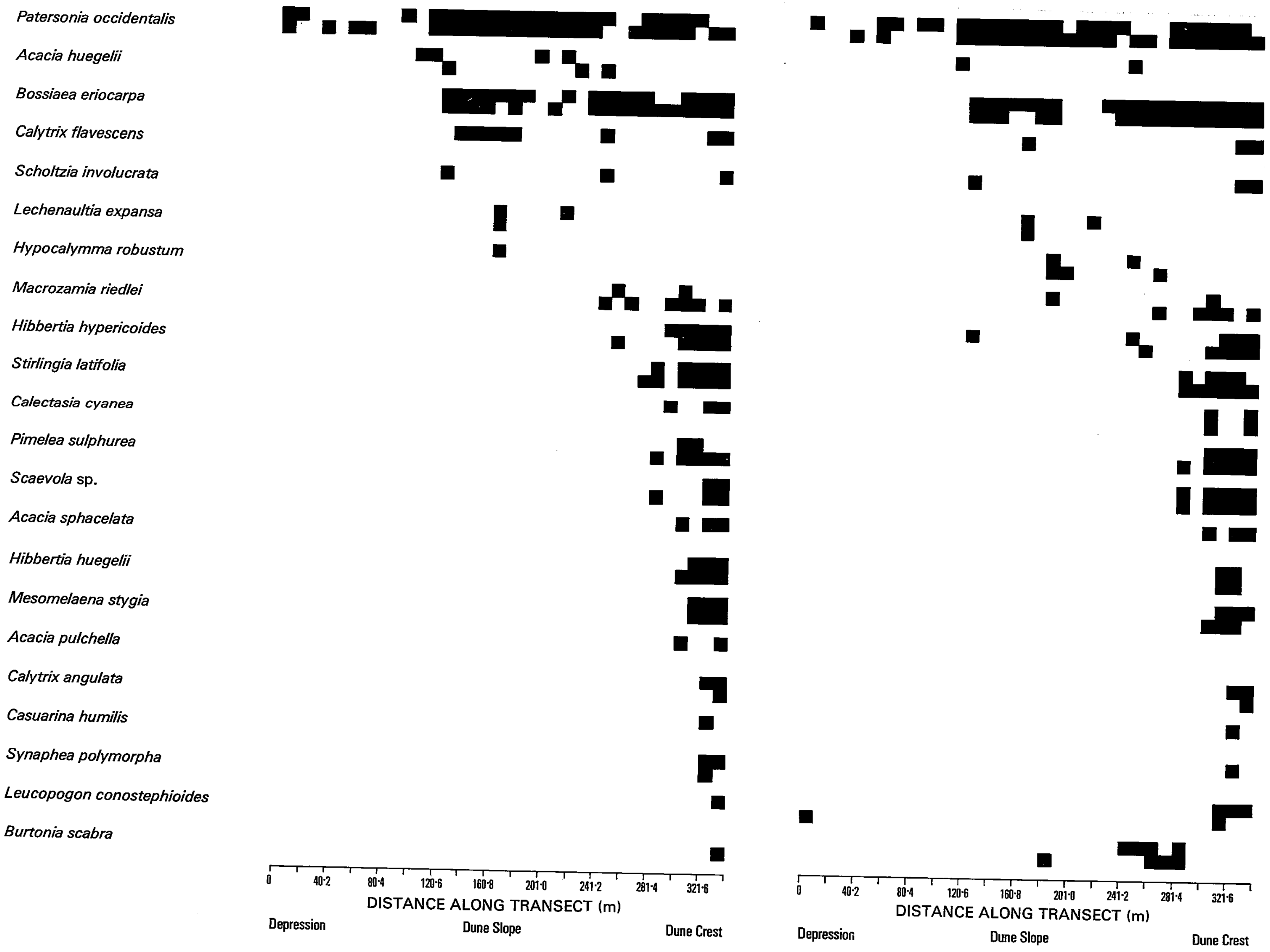
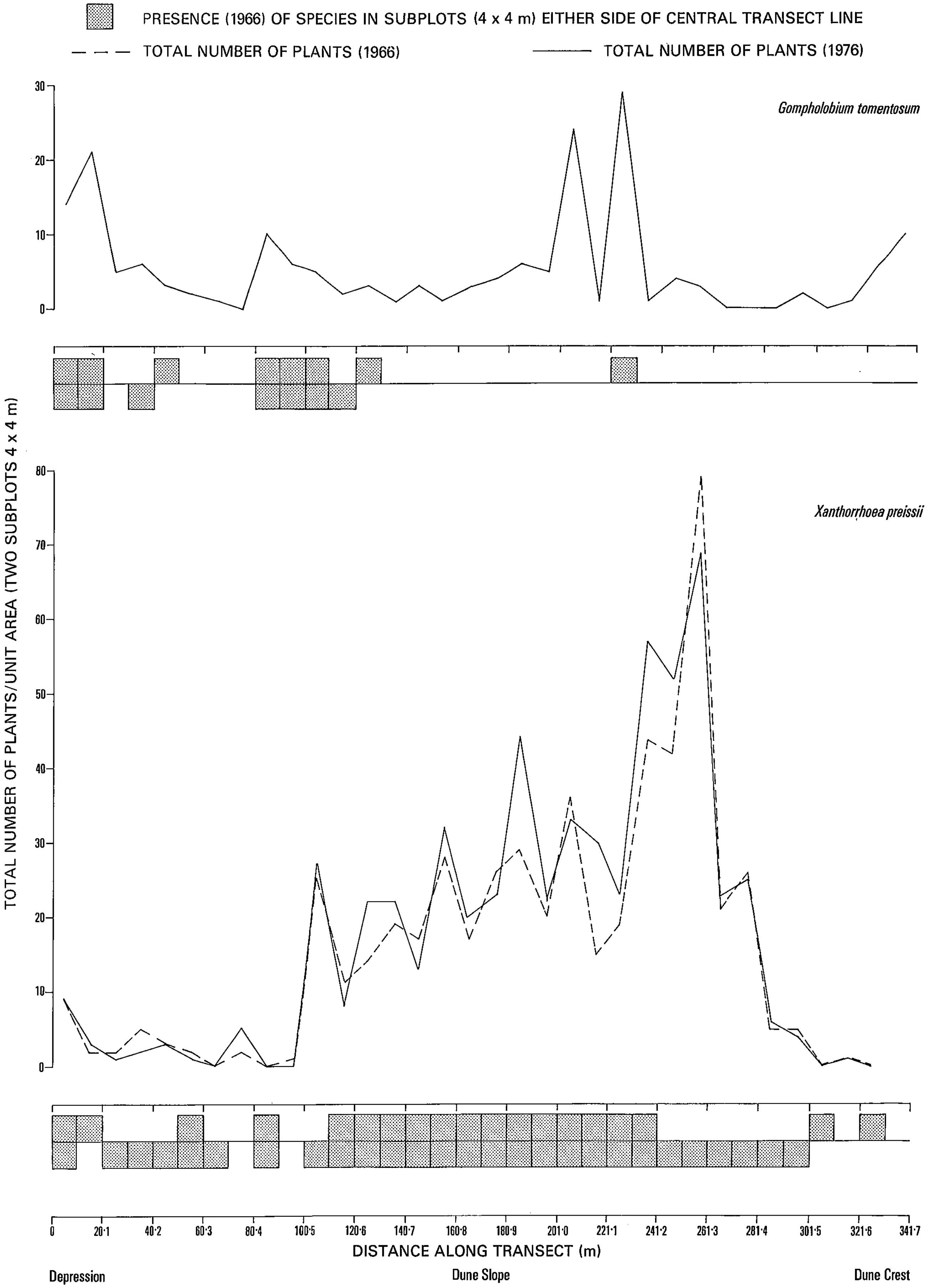

Patersonia occidentalis
Acacia huegelii
Bossiaea eriocarpa
Calytrix flavescens
Scholtzia involucrata
Lechenaultia expansa
Hypocalymma robustum
Macrozamia riedlei
Hibbertia hypericoides
Stirlingia latifolia
Calectasia cyanea
Pimelea sulphurea
Scaevola sp.
Acacia sphacelata
Hibbertia huegelii
Mesomelaena stygia
Acacia pulchella
Calytrix angulata
Casuarina humilis
Synaphea polymorpha
Leucopogon conostephioides
Burtonia scabra
0
40·2
80·4
120·6
160·8
201·0
241·2
281·4
321·6
DISTANCE ALONG TRANSECT (m)
Depression
Dune Slope
Dune Crest
0
40·2
80·4
120·6
160·8
201·0
241·2
281·4
321·6
DISTANCE ALONG TRANSECT (m)
Depression
Dune Slope
Dune Crest

Figure 8

Distribution and density of *Gompholobium tomentosum, Xanthorrhoea preissii* and *Hibbertia subvaginata* at South Kendall (September 1966 and 1976)



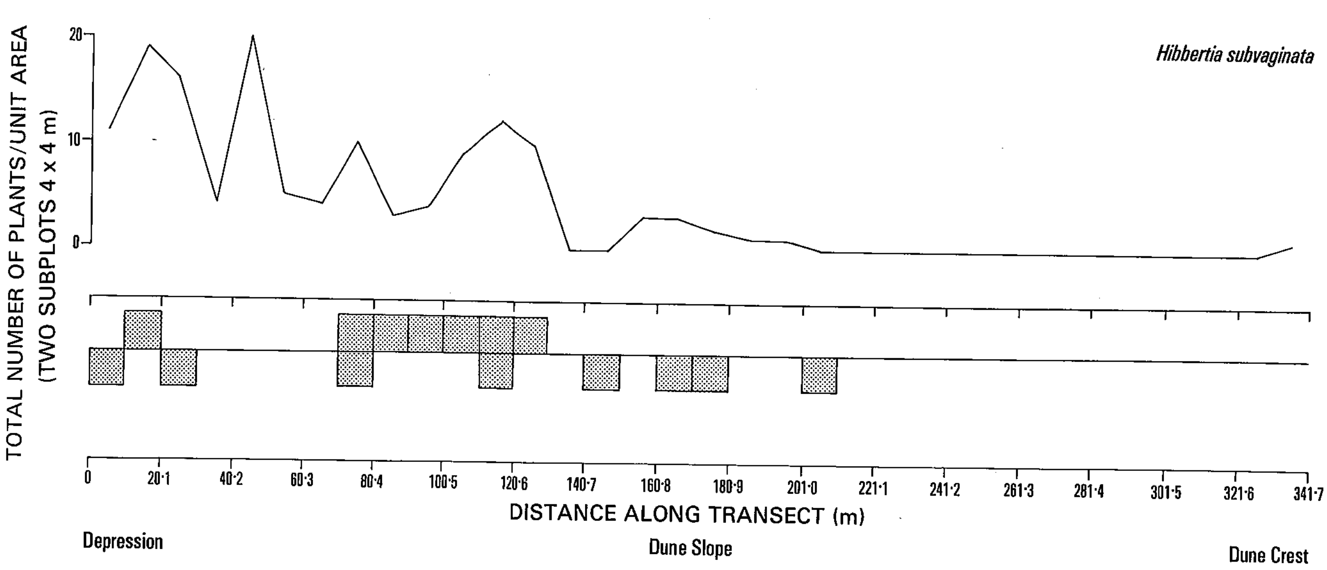


Figure 9

Soil moisture content at West Gironde (September 1966, October 1976)

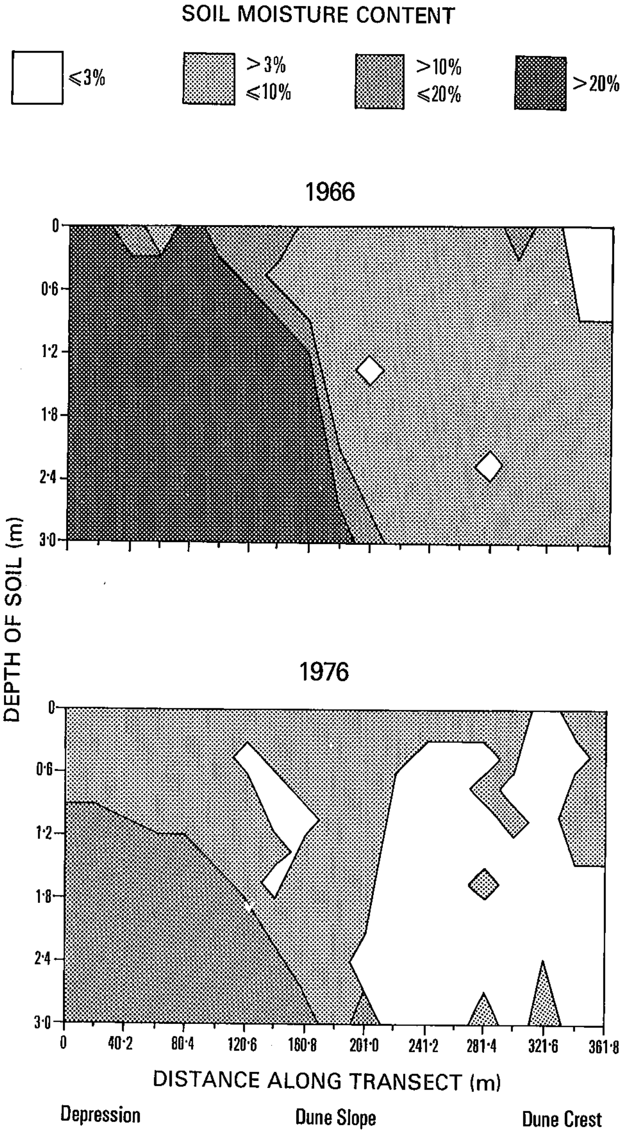


Table 3

PERENNIAL PLANT SPECIES AT WEST GIRONDE SHOWING A MARKED CHANGE* IN FREQUENCY BETWEEN SEPTEMBER 1966 AND SEPTEMBER 1976

Increased frequency	*Decreased frequency*
Bossiaea eriocarpa	*Adenanthos cygnorum*
Calytrix flavescens	*Astartea fascicularis*
Eriostemon spicatus	*Beaufortia elegans*
Gompholobium tomentosum	*Eremaea pauciflora*
Hibbertia helianthemoides	*Euchilopsis linearis*
Hibbertia subvaginata	*Hypocalymma angustifolium*
Hypocalymma robustum	*Leptospermum ellipticum*
Lepidosperma angustatum	*Lysinema ciliatum*
Lyginia barbata	*Melaleuca seriata*
Patersonia occidentalis	*Pultenaea reticulata*
Xanthorrhoea preissii	*Regelia ciliata*

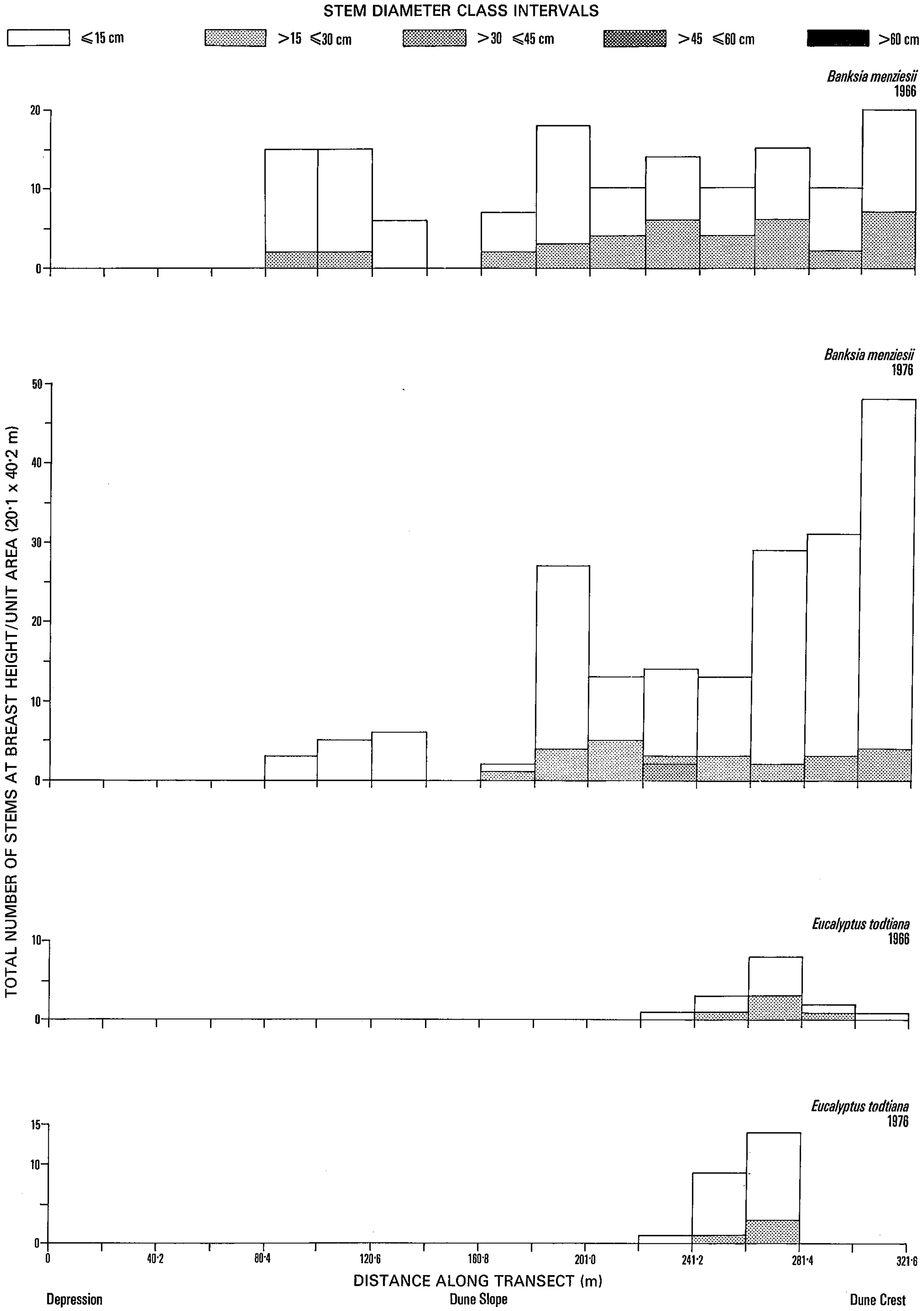
* Change in percentage frequency exceeding 5 per cent.

Hibbertia subvaginata and *Gompholobium tomentosum* have no site preference with respect to soil moisture. Their ability to tolerate the full range of environmental conditions along the transect resulted in a marked increase in their total numbers and distribution. *Xanthorrhoea preissii* changed only slightly in numbers (Fig. 12).

The other species that have increased in frequency occur on the dry middle and upper slopes of the dunes. They would all be expected to increase in frequency and distribution with any further lowering of the water table.

Figure 10

Distribution of tree species by stem diameter class intervals at West Gironde (September 1966 and 1976)



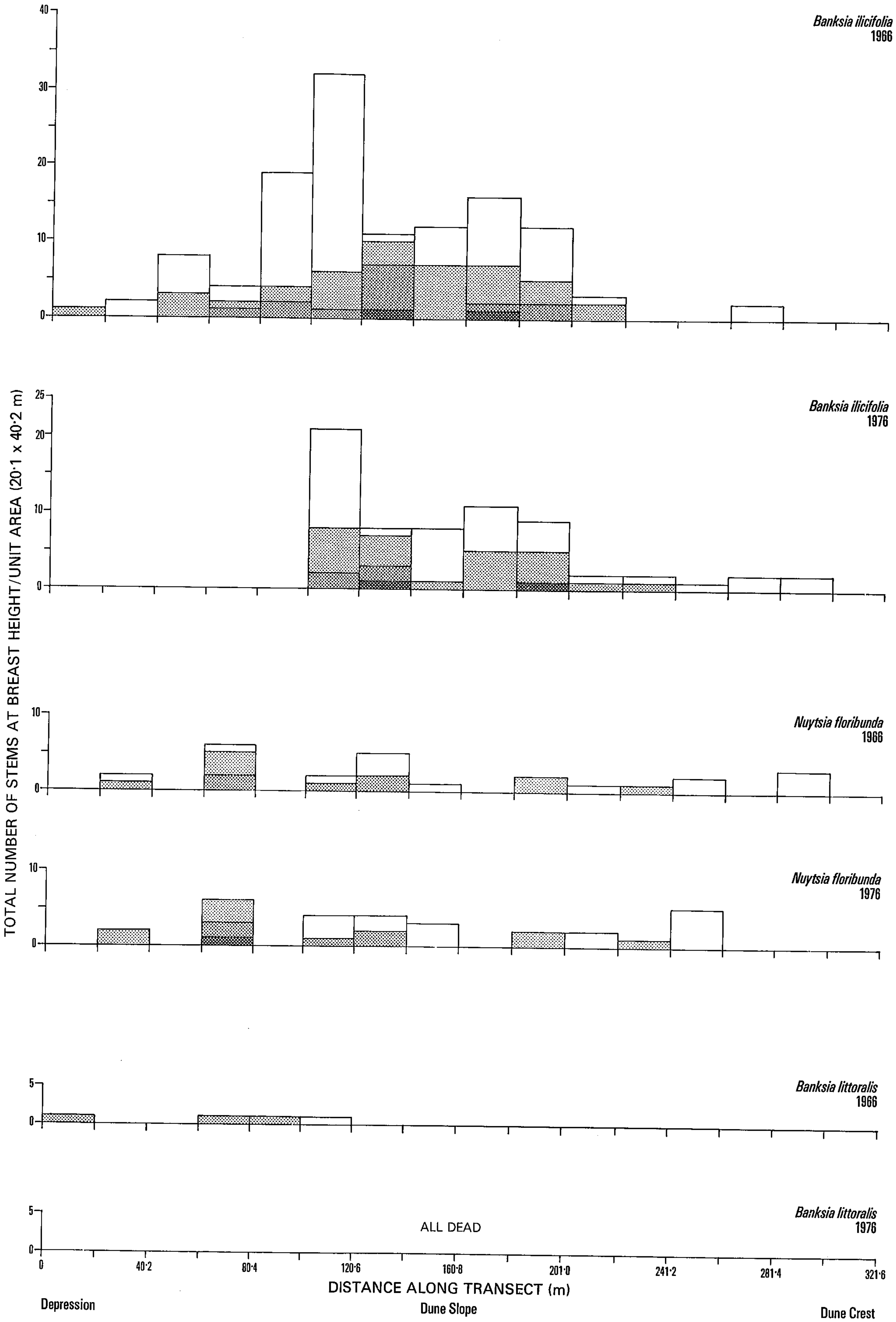
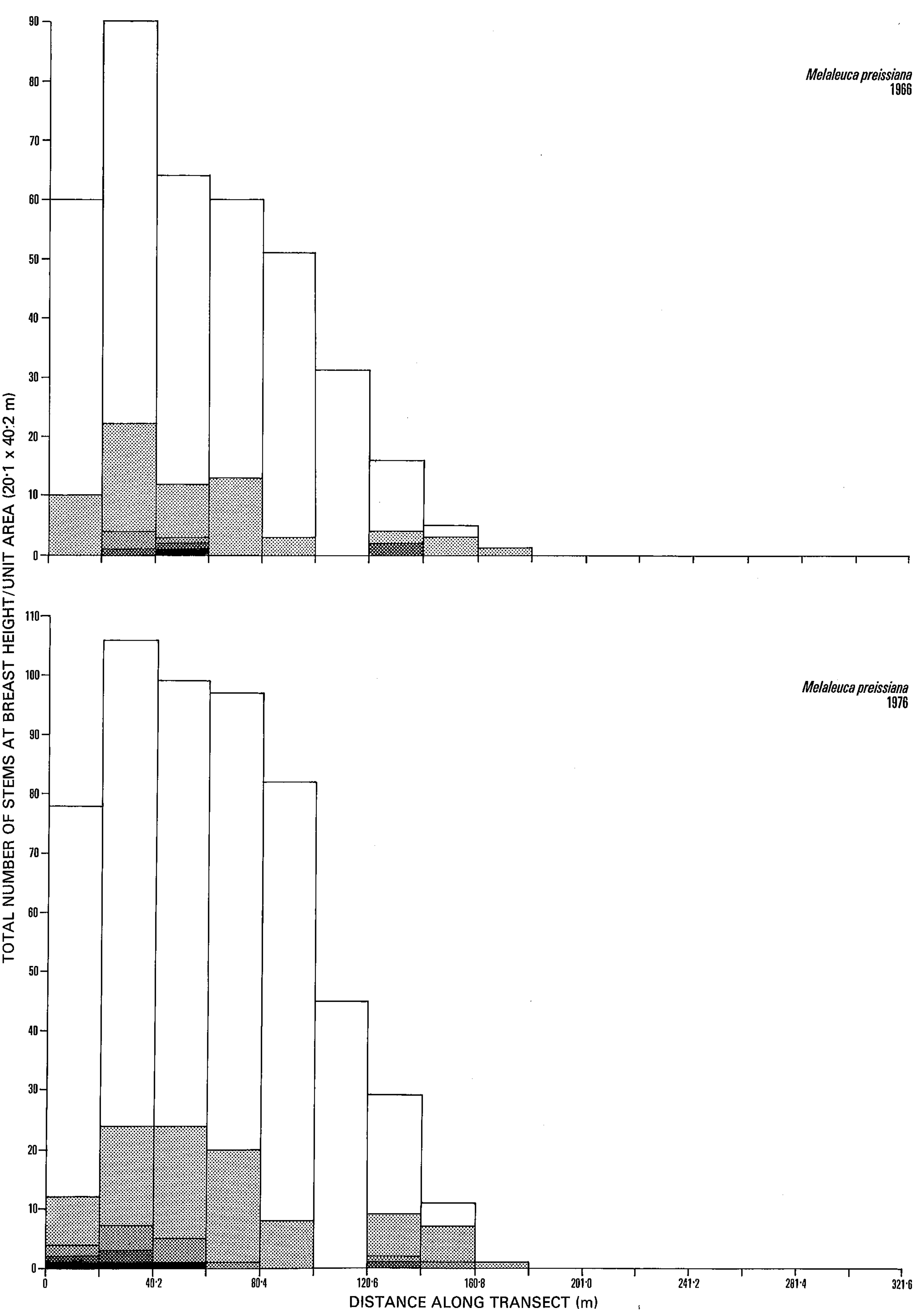
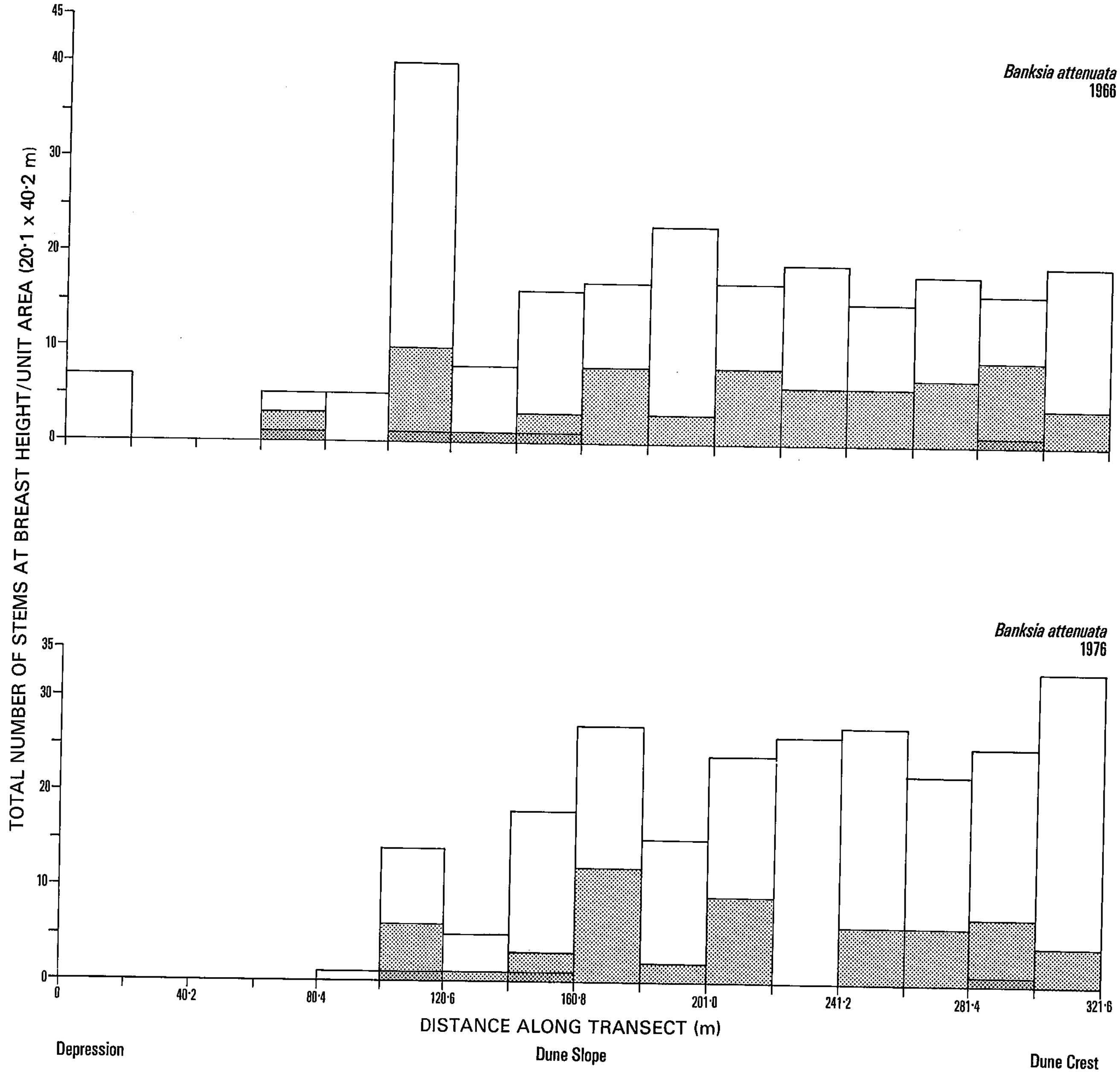

TOTAL NUMBER OF STEMS AT BREAST HEIGHT/UNIT AREA (20·1 x 40·2 m)
Banksia ilicifolia 1966
40
30
20
10
0
Banksia ilicifolia 1976
25
20
10
0
Nuytsia floribunda 1966
10
0
Nuytsia floribunda 1976
10
0
Banksia littoralis 1966
5
0
Banksia littoralis 1976
ALL DEAD
5
0
0
40·2
80·4
120·6
160·8
201·0
241·2
281·4
321·6
DISTANCE ALONG TRANSECT (m)
Depression
Dune Slope
Dune Crest

Figure 10 (*continued*)



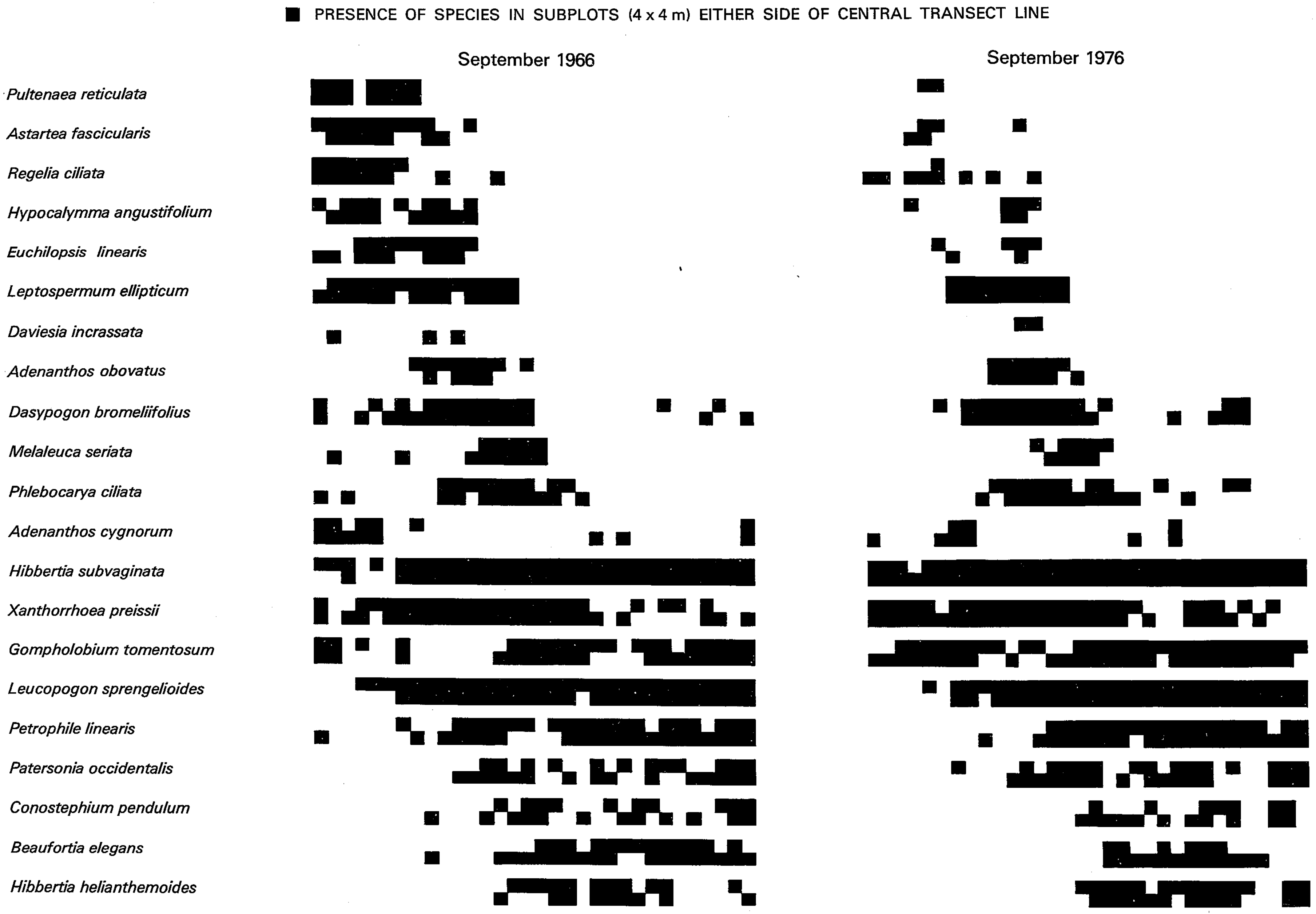


Of the species showing a decrease in frequency, *Hypocalymma angustifolium, Regelia ciliata, Leptospermum ellipticum, Astartea fascicularis, Pultenaea reticulata* and *Euchilopsis linearis* all grow on excessively wet sites (Havel, 1968). *Melaleuca seriata* occurs on the lower slopes of the dunes, although not on excessively wet sites. The decrease in frequency and distribution of these species can be accounted for by the fall in the water table.

Beaufortia elegans, Eremaea pauciflora and *Lysinema ciliatum* tolerate the drier conditions on the upper slopes of the dunes. Further examination of these species in the field would be required to resolve whether the decrease in frequencies is related to a fall in the soil moisture levels or the water table.

Since *Adenanthos cygnorum* is a coloniser, it is not a suitable species on which to base conclusions as to the relationship between soil moisture and plant distribution.

Figure 11
Distribution of perennial plant species at West Gironde (September 1966 and 1976).



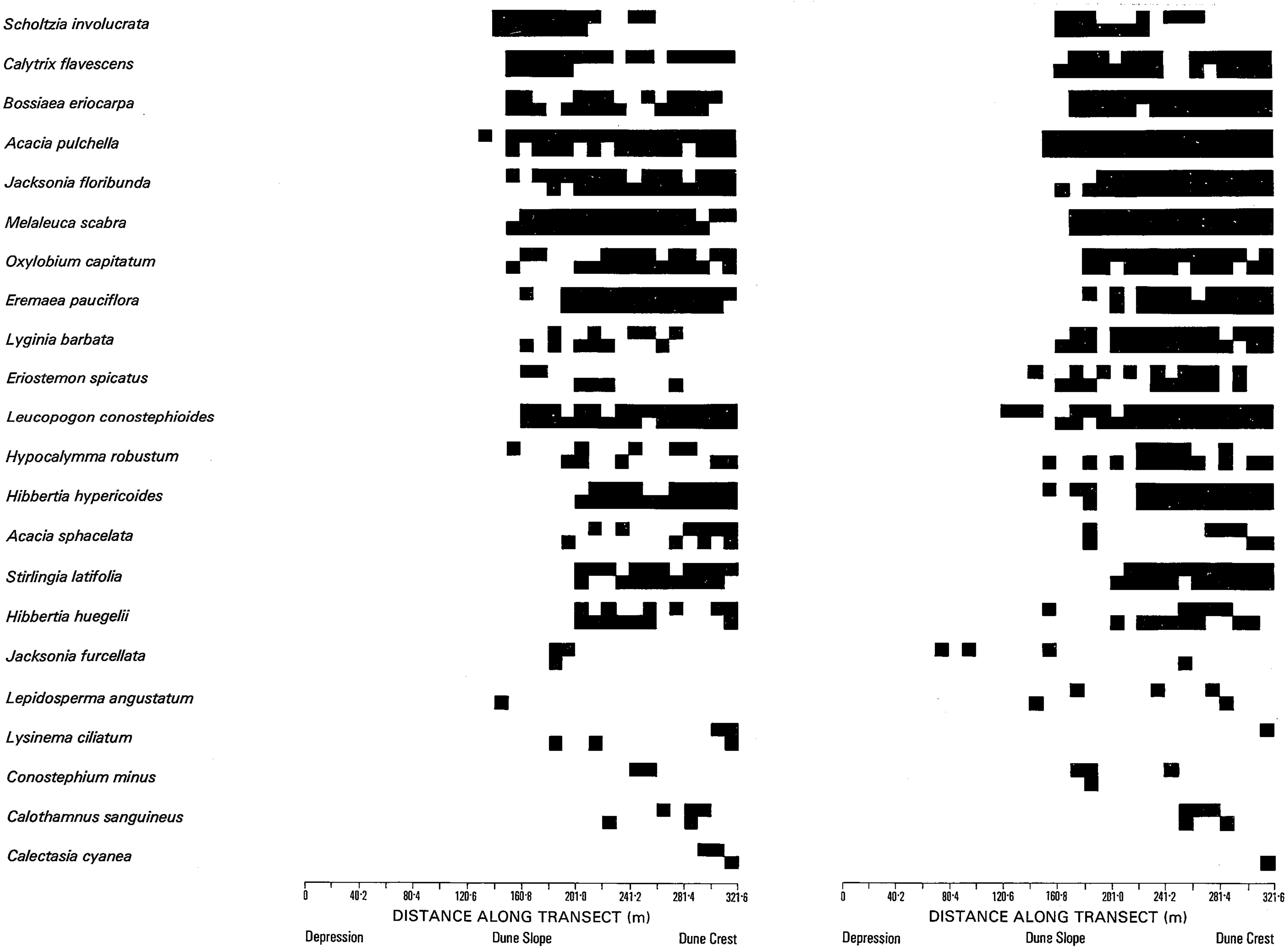
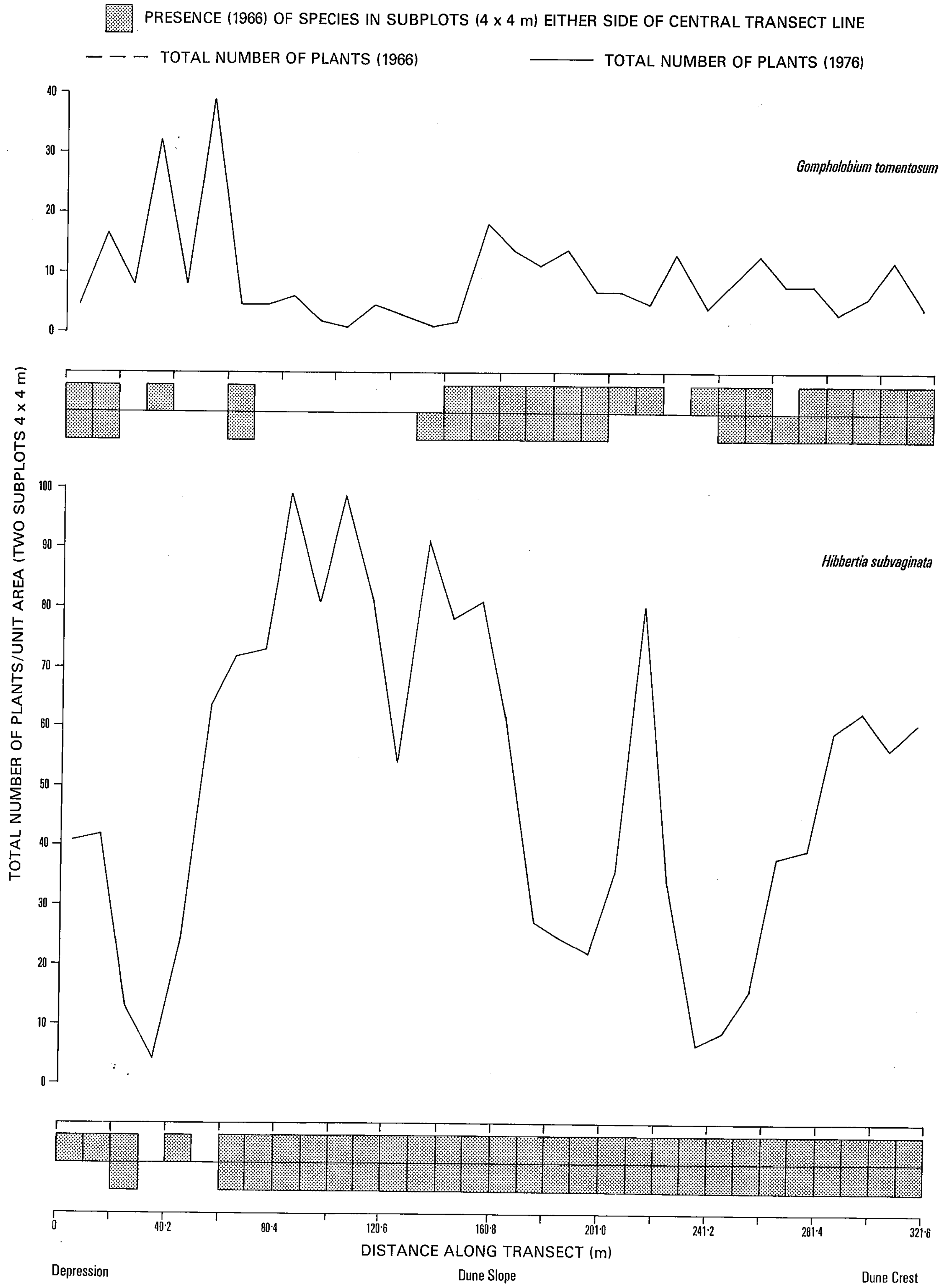
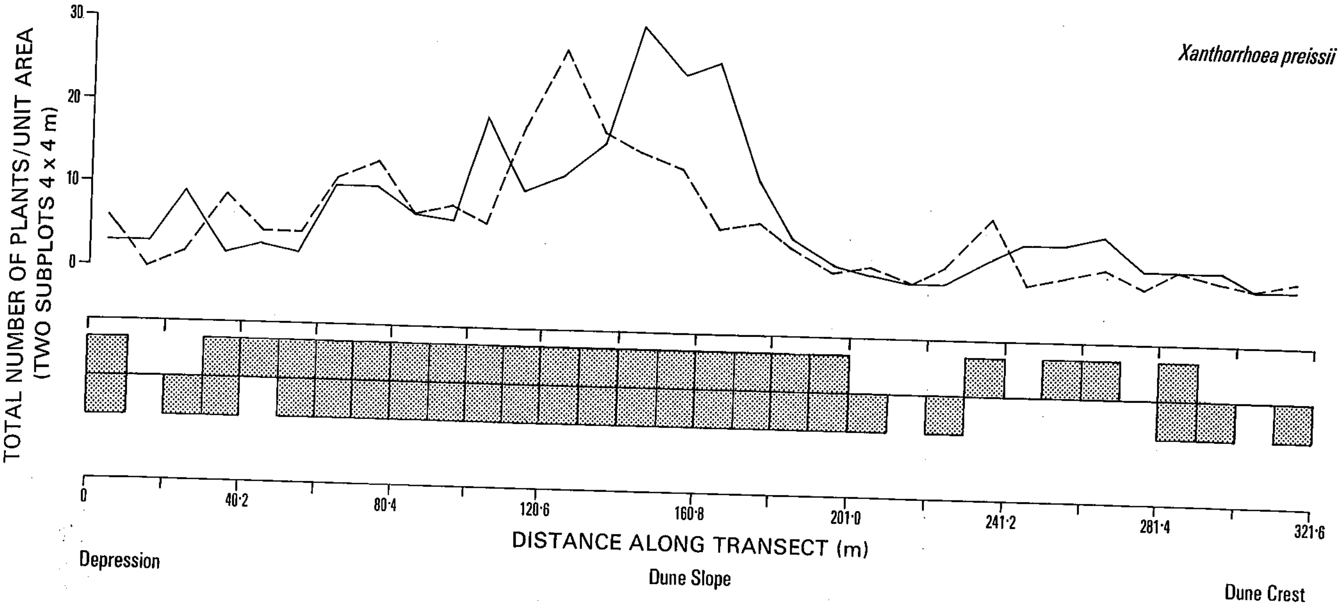

Scholtzia involucrata
Calytrix flavescens
Bossiaea eriocarpa
Acacia pulchella
Jacksonia floribunda
Melaleuca scabra
Oxylobium capitatum
Eremaea pauciflora
Lyginia barbata
Eriostemon spicatus
Leucopogon conostephioides
Hypocalymma robustum
Hibbertia hypericoides
Acacia sphacelata
Stirlingia latifolia
Hibbertia huegelii
Jacksonia furcellata
Lepidosperma angustatum
Lysinema ciliatum
Conostephium minus
Calothamnus sanguineus
Calectasia cyanea
0
40·2
80·4
120·6
160·8
201·0
241·2
281·4
321·6
DISTANCE ALONG TRANSECT (m)
Depression
Dune Slope
Dune Crest
0
40·2
80·4
120·6
160·8
201·0
241·2
281·4
321·6
DISTANCE ALONG TRANSECT (m)
Depression
Dune Slope
Dune Crest

Figure 12

Distribution and total numbers of *Gompholobium tomentosum, Hibbertia subvaginata* and *Xanthorrhoea preissii* at West Gironde (September 1966 and 1976)





NEAVES

The transect at Neaves is located on the Bassendean Dune System at the western edge of Melaleuca Park, a Management Priority Area for the conservation of flora and fauna (Forests Department of Western Australia, 1977). As the line of bores is close to this edge of the park (although still over 1·5 km away), any effects of the withdrawal of underground water will be detected first in the vegetation along the transect.

The area was burnt as part of the Forests Department's prescribed burning programme in the spring of 1968, 1972 and 1973. No *Phytophthora cinnamomi* was detected at Neaves.

Soil moisture

There was a fall in the water table of at least 1·2 m between 1966 and 1976 (Fig. 13). As at the other study areas, the proportion of soil with a moisture content of less than 3 per cent increased substantially.

Vegetation

The vegetation at Neaves contrasts to that at South Kendall and West Gironde in that it changed only slightly in most instances.

The tree species were able to tolerate the decrease in soil moisture content (Fig. 14). Furthermore, there were only minor changes in the diameters of all tree species over the ten years. These observations support the hypothesis that most tree species are adapted to a degree of fluctuation but that death will probably result if there is a further increase in water stress.

Figure 13

Soil moisture content at Neaves (September 1966, October 1976)

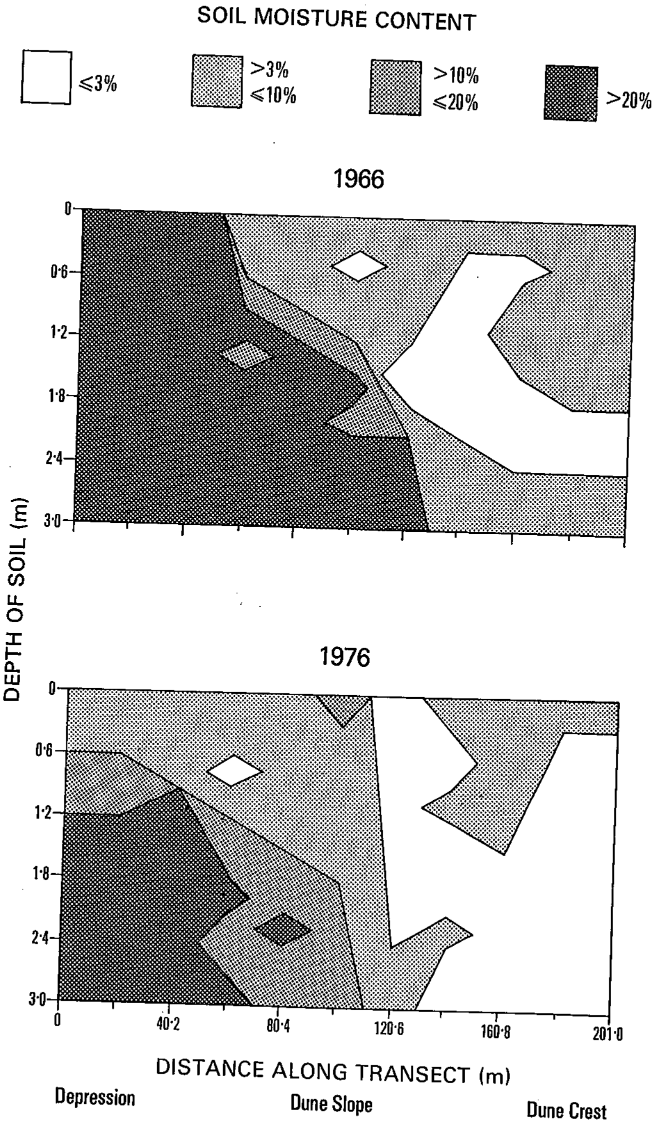
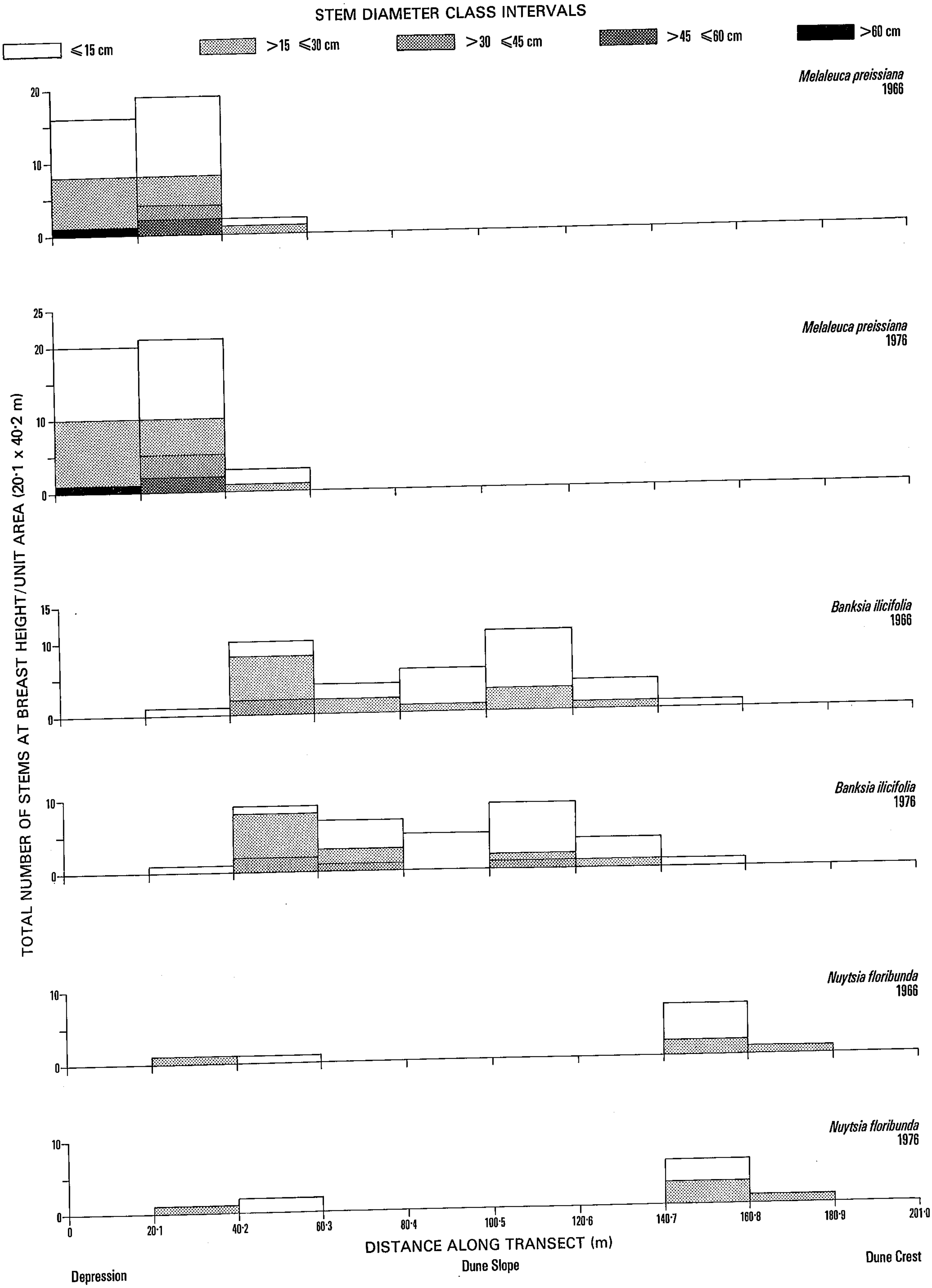


Figure 14

Distribution of tree species by stem diameter class intervals at Neaves (September 1966 and 1976)



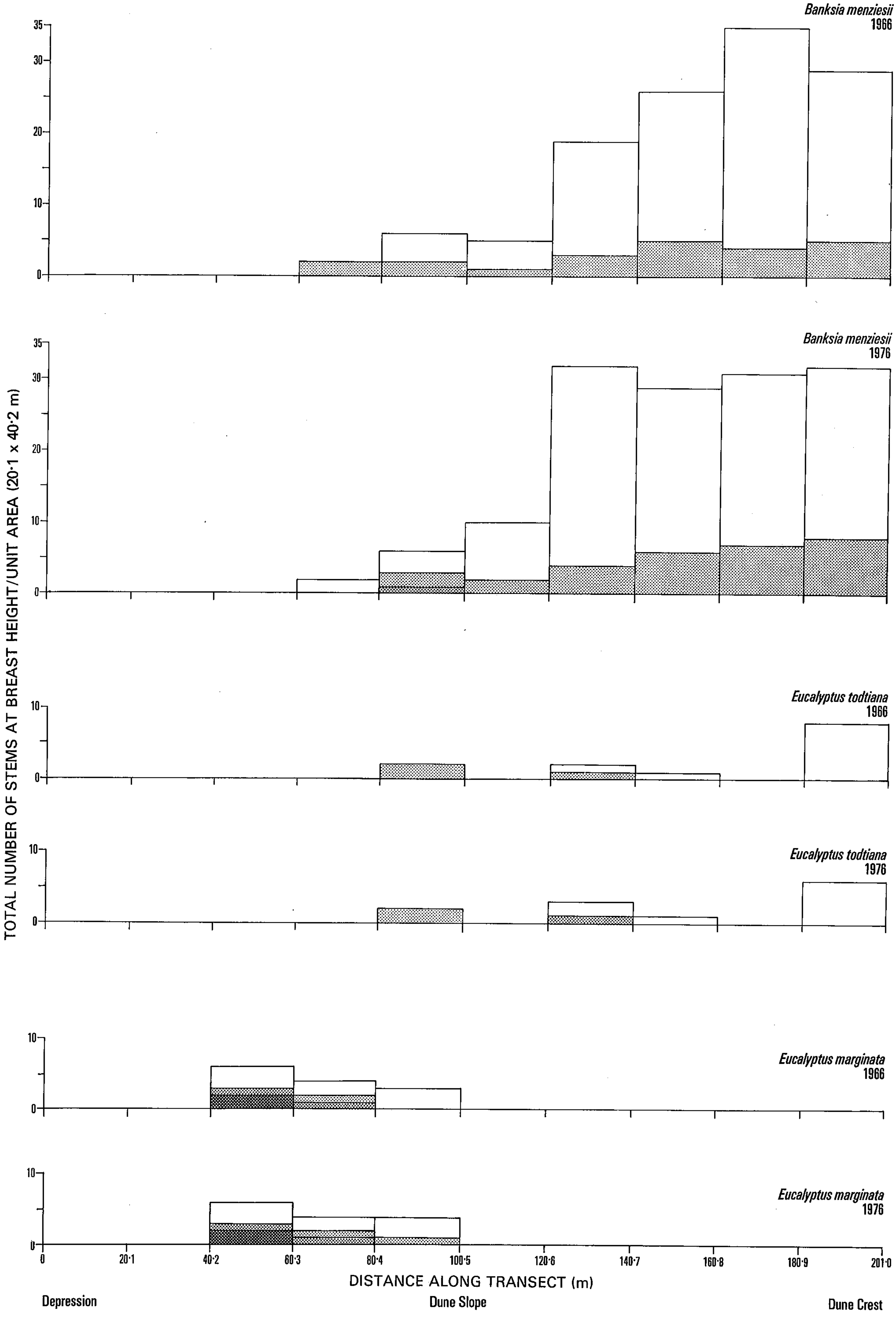
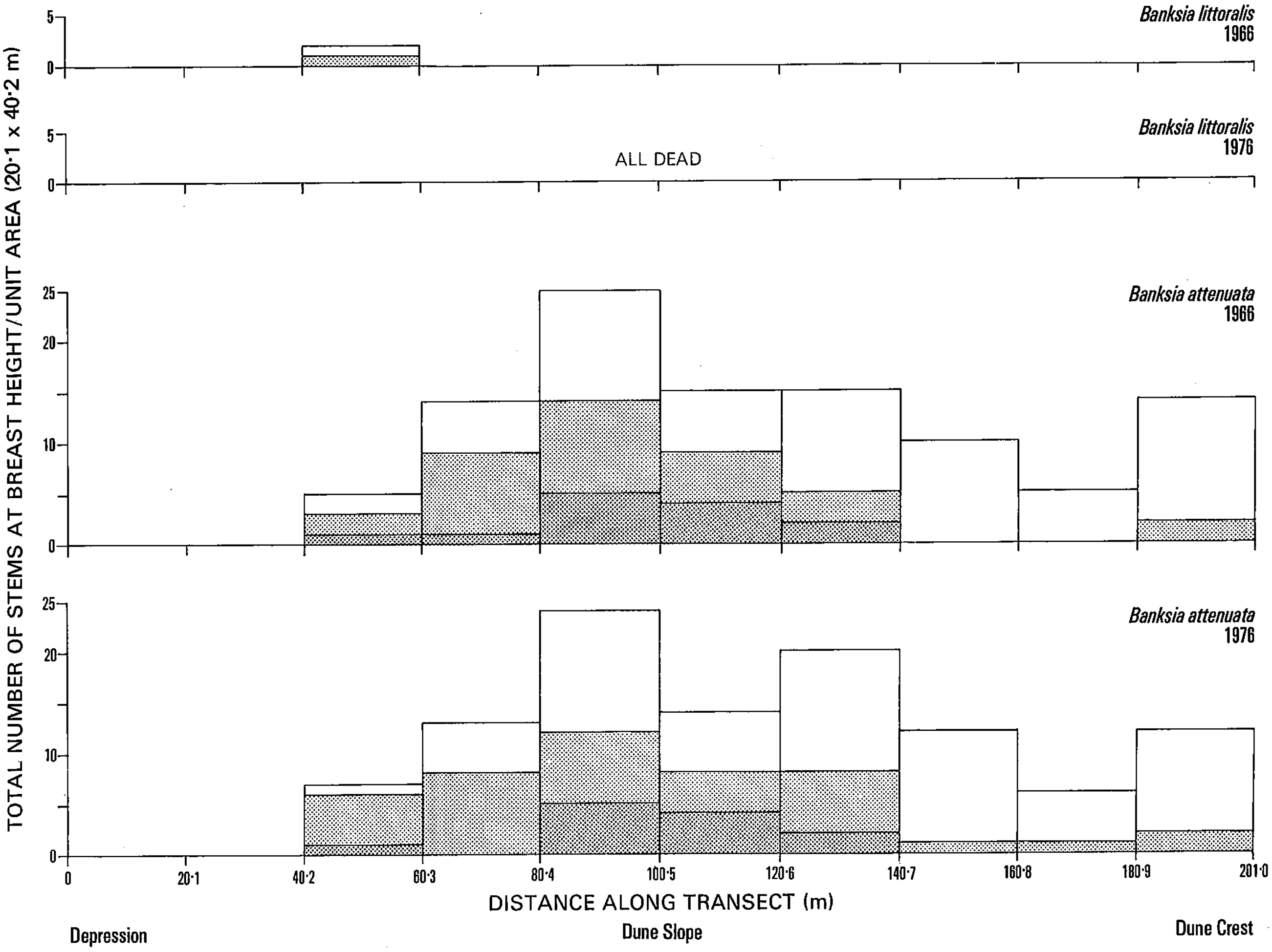

Banksia menziesii 1966
Banksia menziesii 1976
Eucalyptus todtiana 1966
Eucalyptus todtiana 1976
Eucalyptus marginata 1966
Eucalyptus marginata 1976
35
30
20
10
0
TOTAL NUMBER OF STEMS AT BREAST HEIGHT/UNIT AREA (20·1 x 40·2 m)
0
20·1
40·2
60·3
80·4
100·5
120·6
140·7
160·8
180·9
201·0
DISTANCE ALONG TRANSECT (m)
Depression
Dune Slope
Dune Crest

Figure 14 (*continued*)



The changes in distribution of the fifty-three perennial species other than trees identified at Neaves are slight (Fig. 15). Even those that tolerate excessively wet and moist sites changed only slightly, if at all, despite the fall in the water table. This suggests that the vegetation was not under severe water stress.

The species whose frequency changed markedly are given in Table 4.

As at South Kendall, *Calytrix flavescens* avoided excessively wet areas; however, it shifted towards the low-lying areas as a result of the decrease in the soil moisture content. In contrast, the other species that increased in frequency occur on the slopes of the dune.

Acacia huegelii is restricted at Neaves to moist sites, and this suggests that its distribution is determined by soil moisture conditions.

Scholtzia involucrata, Beaufortia elegans, Conostephium minus, Hibbertia hypericoides, Leucopogon conostephioides, Boronia purdieana, Oxylobium capitatum and *Hibbertia helianthemoides* all establish on the dry middle and upper slopes of the dunes. Unless these species have deep root systems that tap the water table their decreased frequency must be related to factors other than soil moisture.

Hibbertia subvaginata does not show any site preference with respect to soil moisture content.

The numbers of *Xanthorrhoea preissii* show little change over the ten-year period (Fig. 16).

Table 4

PERENNIAL PLANT SPECIES AT NEAVES SHOWING A MARKED CHANGE* IN FREQUENCY BETWEEN SEPTEMBER 1966 AND SEPTEMBER 1976

Increased frequency	*Decreased frequency*
Calytrix flavescens *Calytrix fraserii* *Hypocalymma robustum* *Patersonia occidentalis* *Petrophile linearis*	*Acacia huegelii* *Adenanthos cygnorum* *Beaufortia elegans* *Boronia purdieana* *Conostephium minus* *Gompholobium tomentosum* *Hibbertia helianthemoides* *Hibbertia hypericoides* *Leucopogon conostephioides* *Lysinema ciliatum* *Oxylobium capitatum* *Scholtzia involucrata*

* Change in percentage frequency exceeding 5 per cent.

Figure 15

Distribution of perennial plant species at Neaves (September 1966 and 1976)

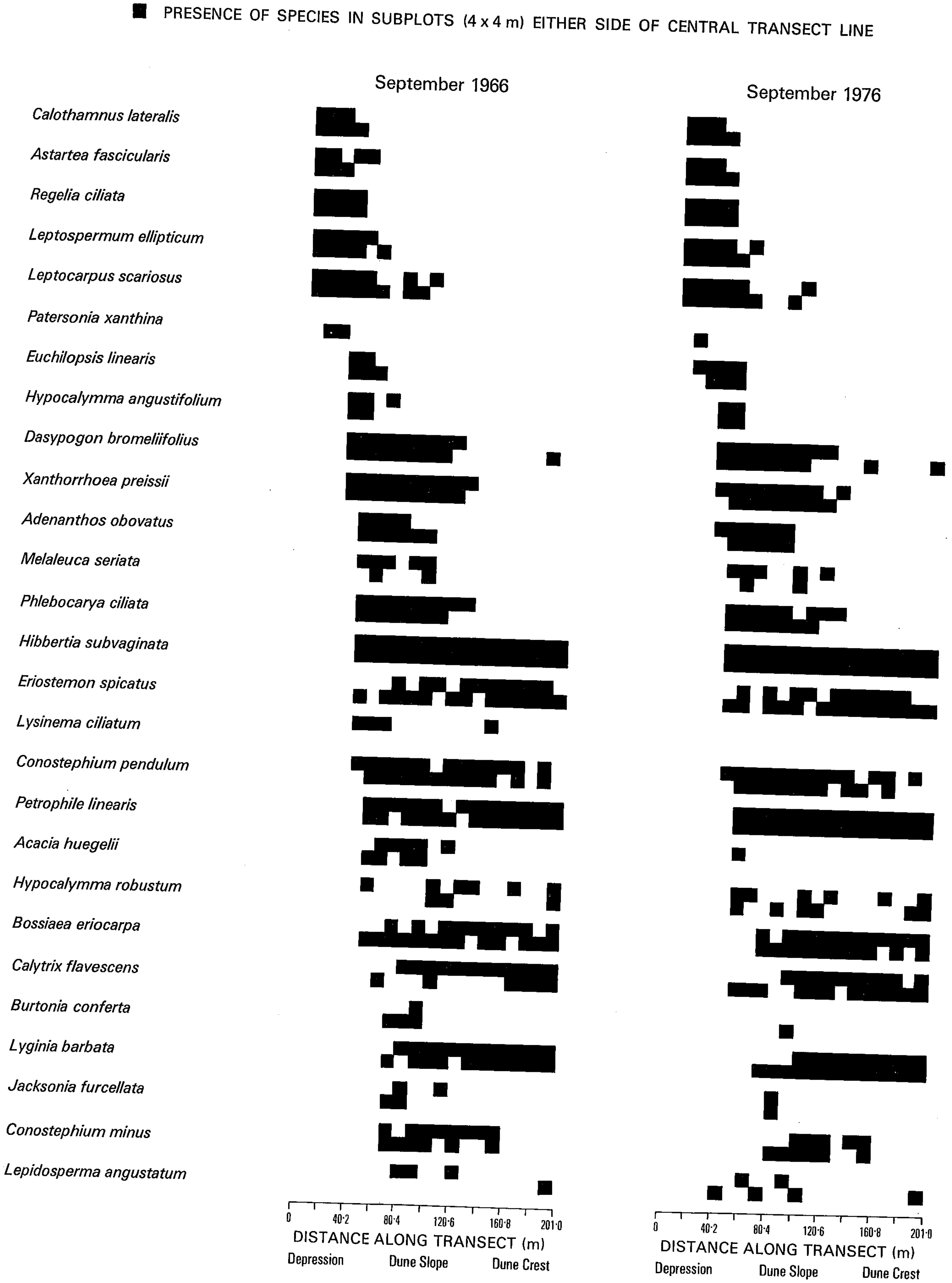


Figure 15 (*continued*)

Figure 16

Distribution and total numbers of *Gompholobium tomentosum, Hibbertia subvaginata* and *Xanthorrhoea preissii* at Neaves (September 1966 and 1976)

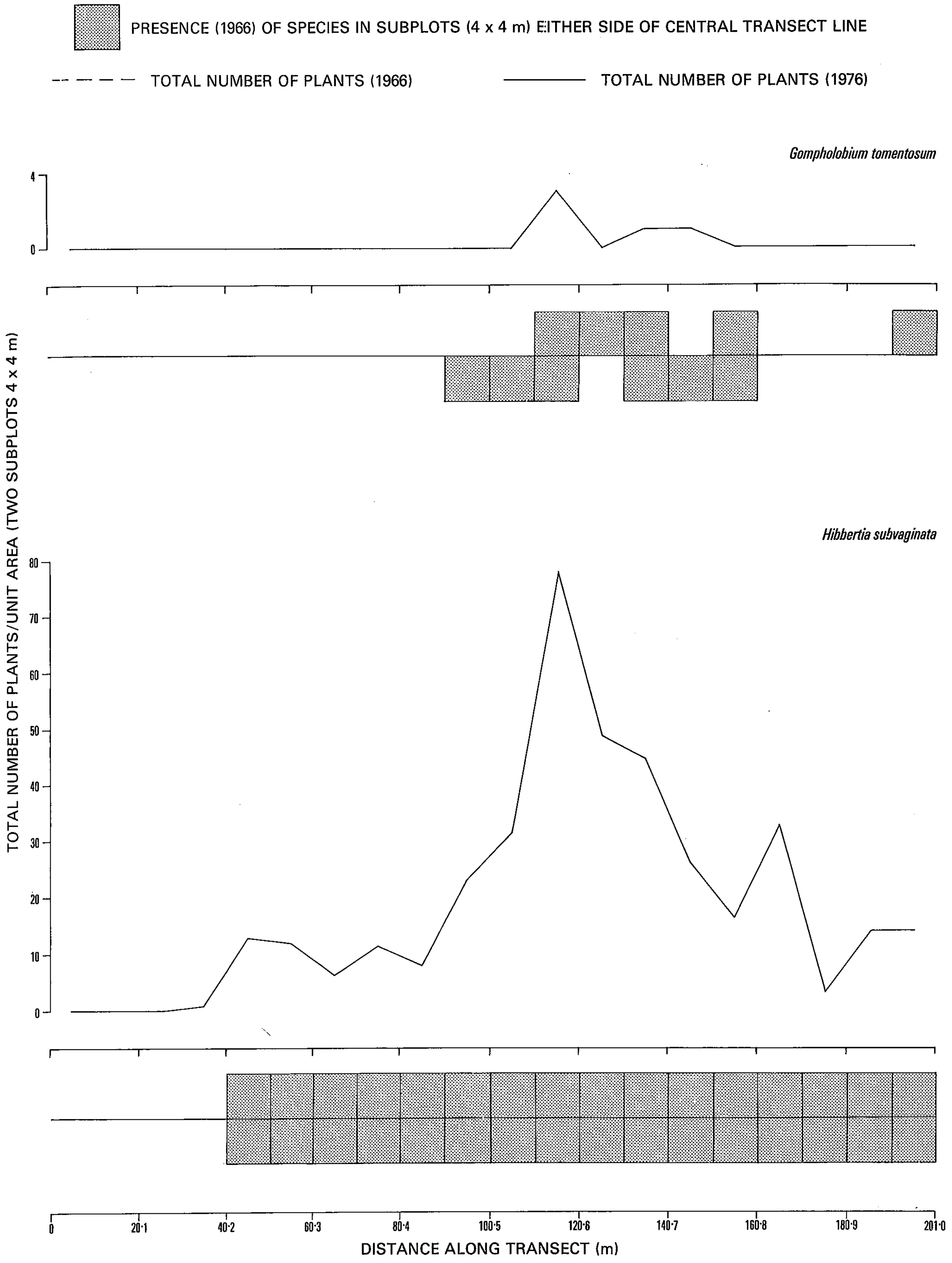
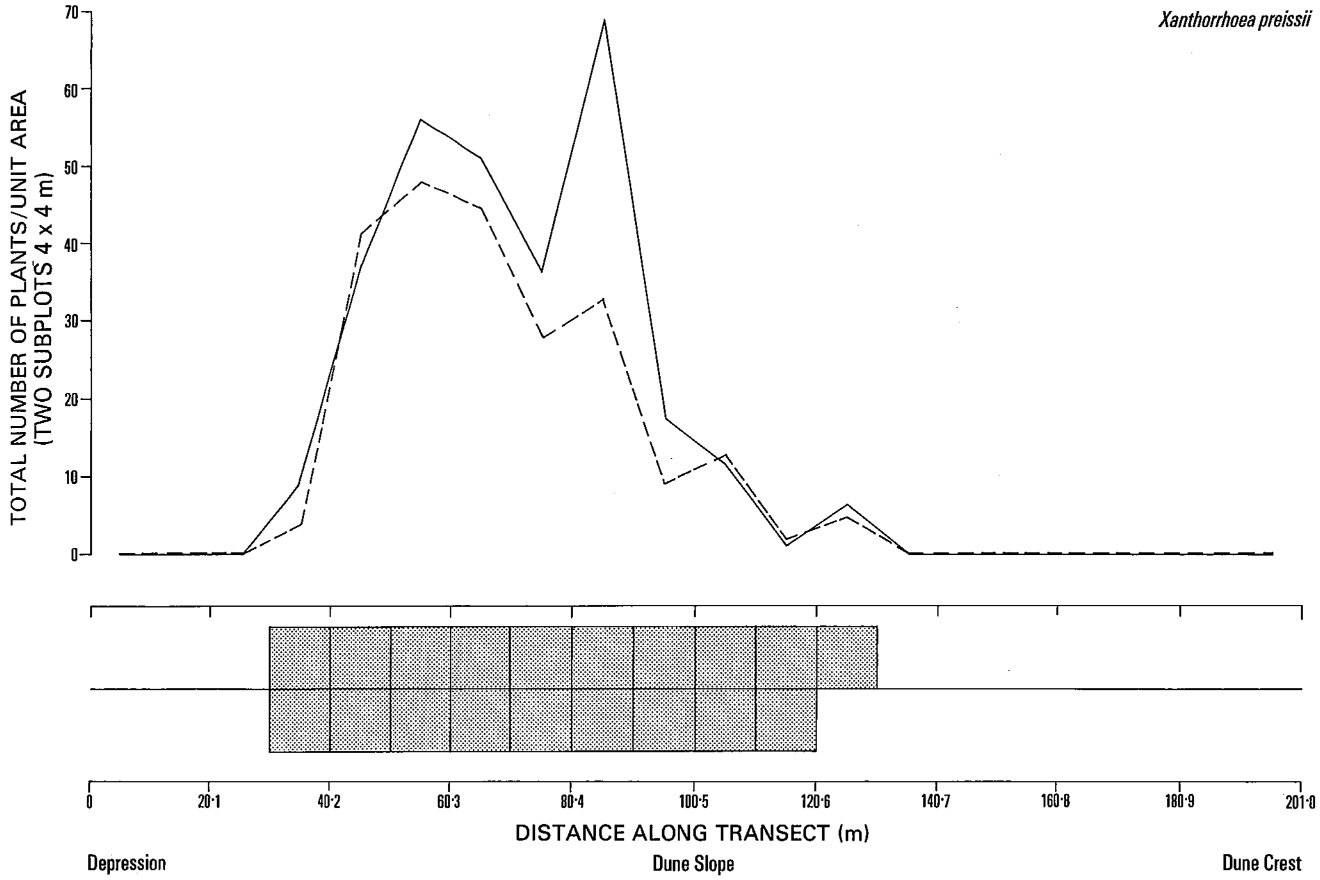


Figure 16 (*continued*)



TICK FLAT

The transect at Tick Flat overlaps both State Forest and the Protection of Flora Reserve A24436 vested in the National Parks Authority. The area has not been burnt since the transect was first established, and does not occur near any pumping bores.

Tick Flat provides an interesting contrast to the other study areas in that it is thought to be a former swamp that has been filled with sand from the adjacent Spearwood dunes and is therefore unstable. This is suggested by the location of the stands of older *Melaleuca preissiana* and *Eucalyptus rudis* on the fringes of the original swamp, and by the unusual distribution of the other plant species.

No dieback has been recorded in the study area.

Soil moisture

Figure 17 clearly shows that the water fell at least 1·2 m between 1966 and 1976. A distinctive feature at Tick Flat is the maintenance of soil moisture levels in the upper slopes and the dune crests.

Vegetation

While Tick Flat differs from the other study areas in its flora and in the relative distribution of the species, the results nevertheless show that, as at the other areas, most of the plant species are adapted to a degree of fluctuation in soil moisture content.

The distribution of the tree species on the basis of stem diameter is illustrated in Figure 18. Despite the drop in the water table most tree species survived.

Figure 17

Soil moisture content at Tick Flat
(September 1966, October 1976)

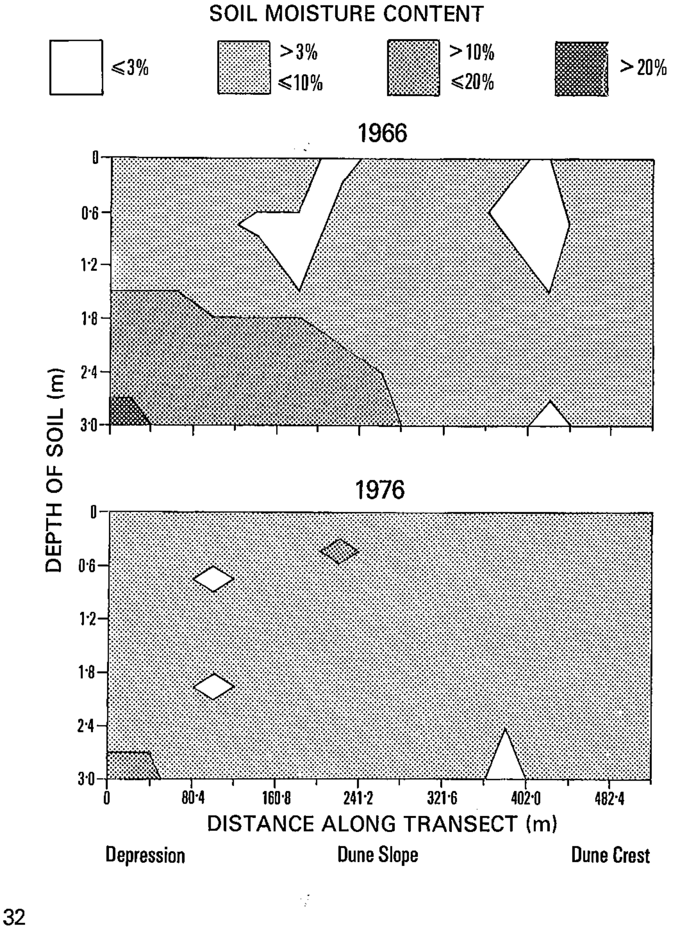


Figure 18

Distribution of tree species by stem diameter class intervals at Tick Flat (September 1966 and 1976)

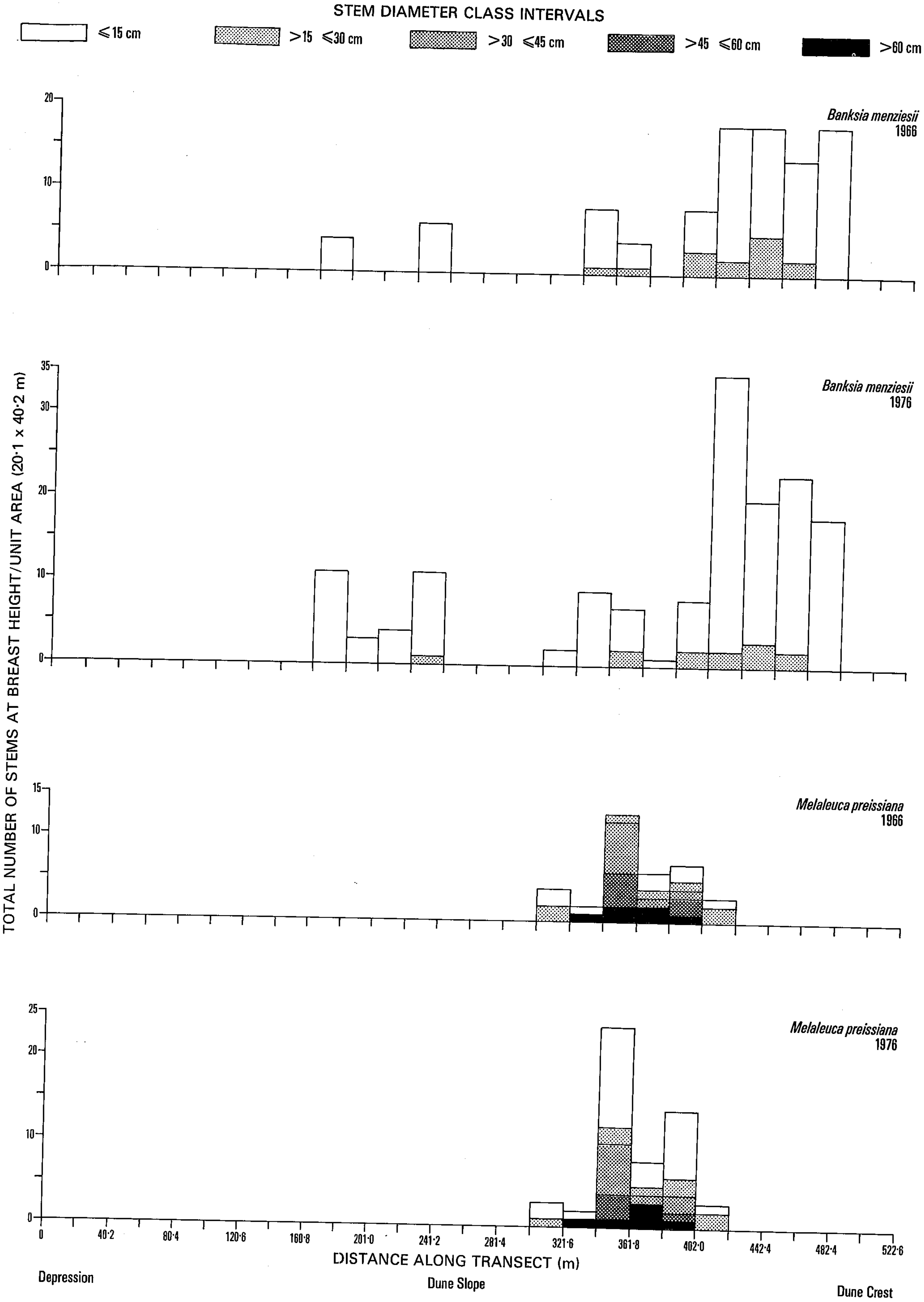
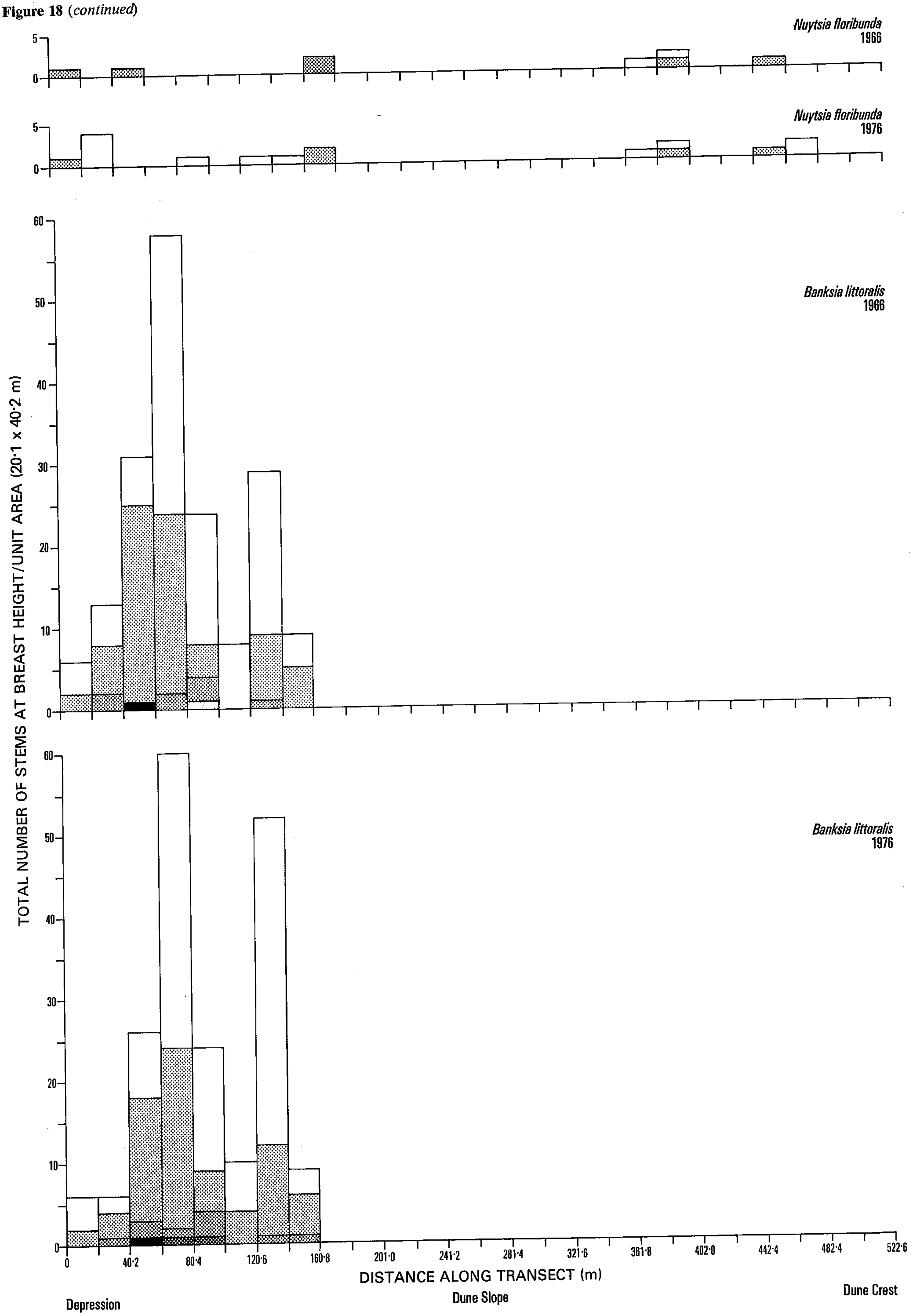


Figure 18 (*continued*)



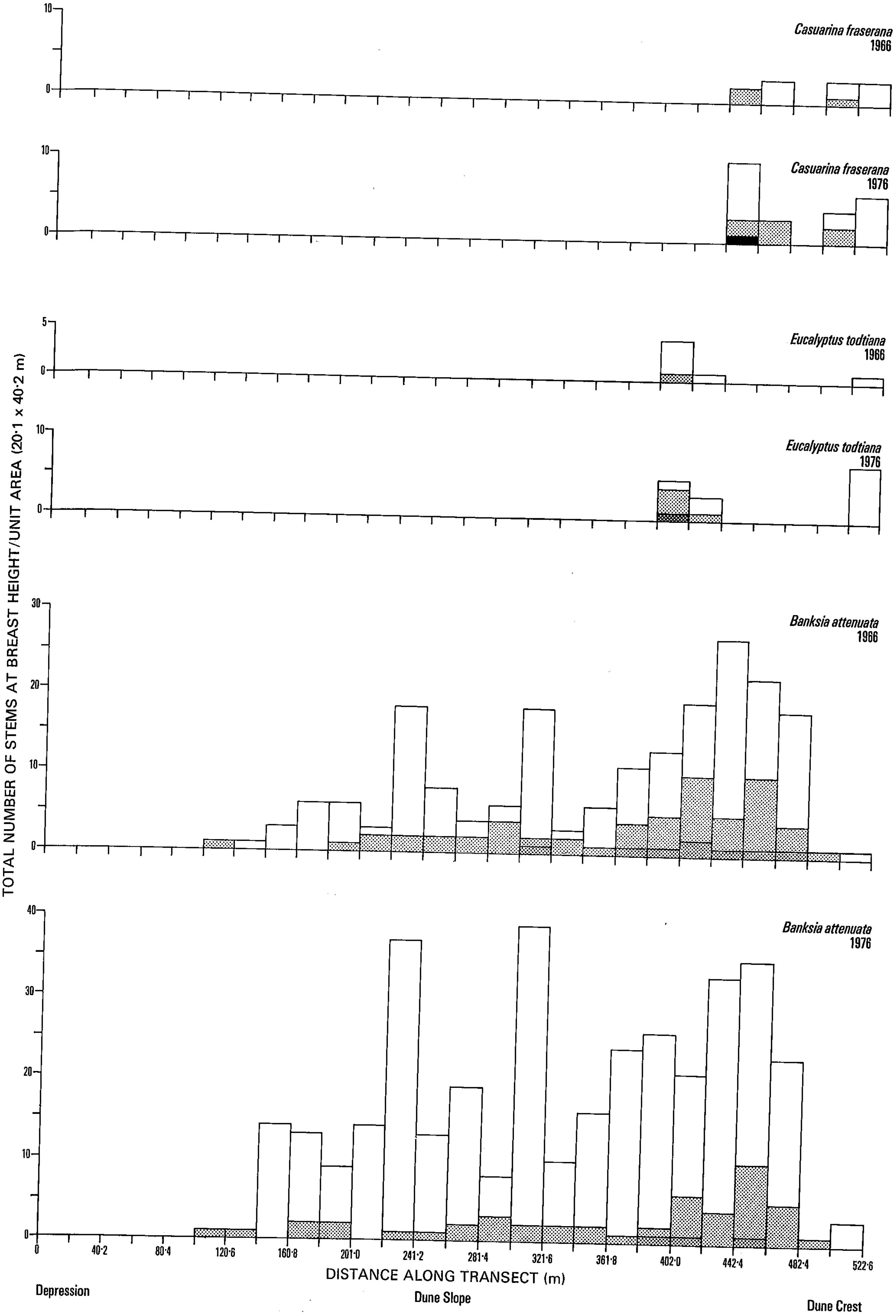
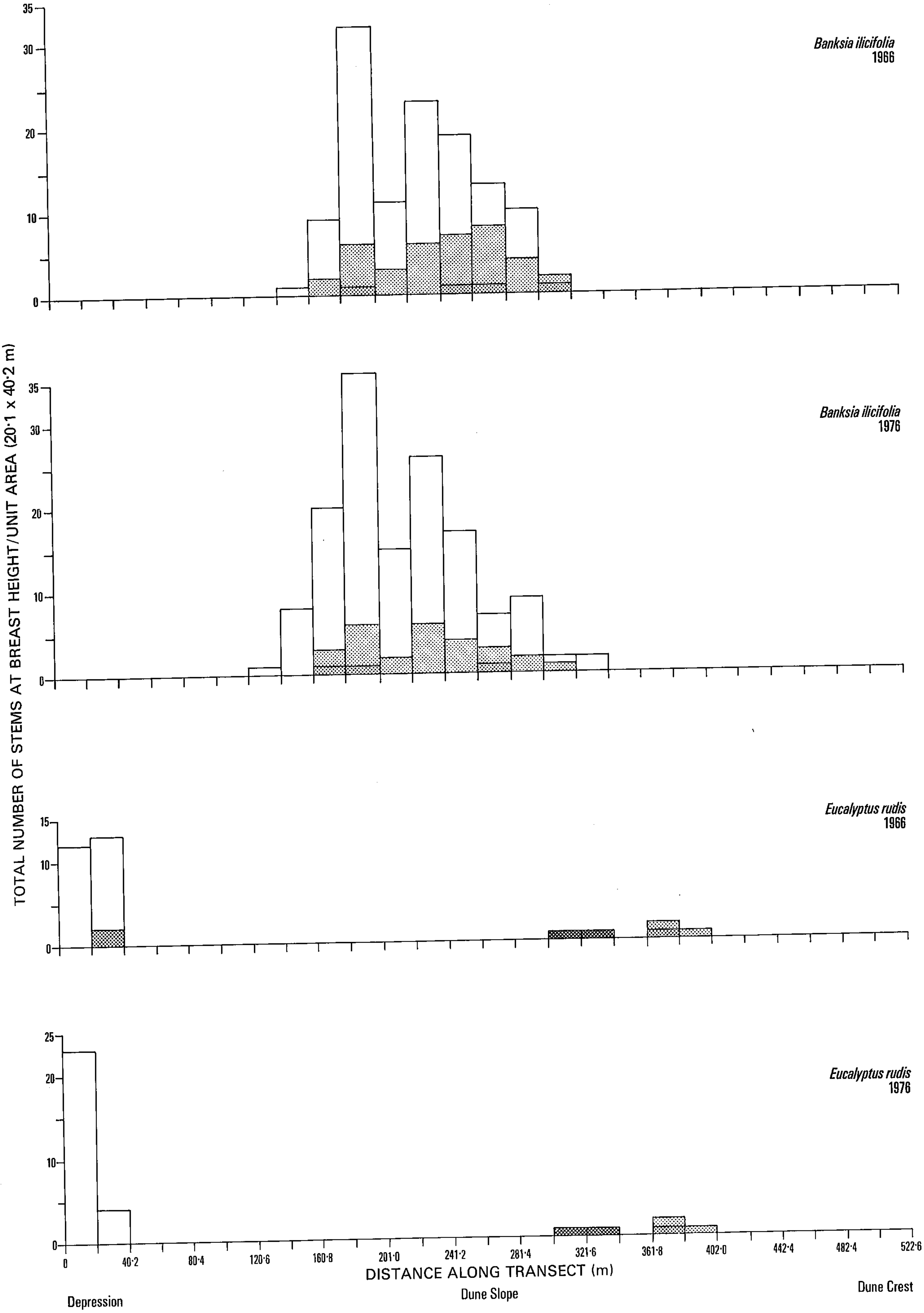
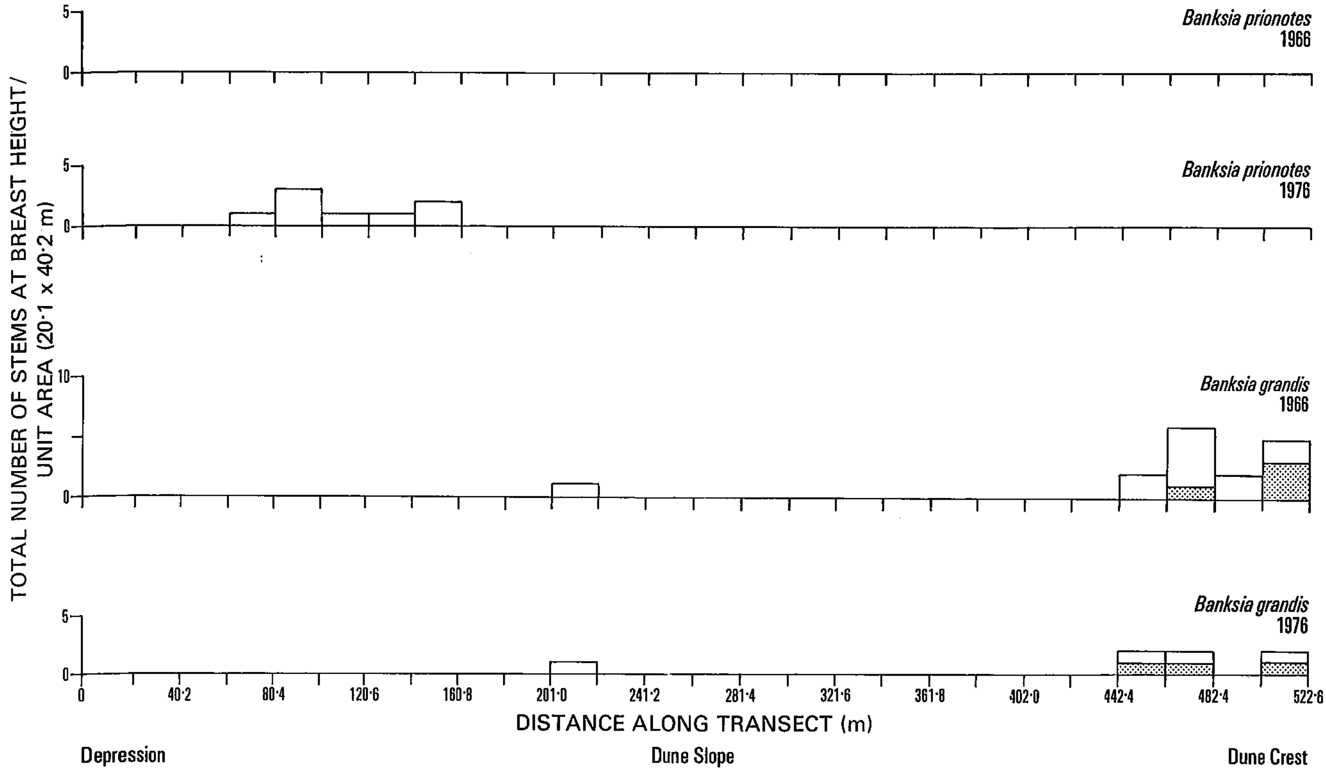

Casuarina fraserana 1966
Casuarina fraserana 1976
Eucalyptus todtiana 1966
Eucalyptus todtiana 1976
Banksia attenuata 1966
Banksia attenuata 1976
TOTAL NUMBER OF STEMS AT BREAST HEIGHT/UNIT AREA (20·1 x 40·2 m)
0
5
10
20
30
40
0
40·2
80·4
120·6
160·8
201·0
241·2
281·4
321·6
361·8
402·0
442·4
482·4
522·6
DISTANCE ALONG TRANSECT (m)
Depression
Dune Slope
Dune Crest

Figure 18 (*continued*)





The changes in the water table level affected mainly the species of banksia. Some of the mature *B. littoralis* on the low-lying sections of the transect died, but on some plots there was an increase in young seedlings. The mature trees, unlike the young seedlings, appear to have been unable to cope with the fluctuations in soil moisture content. Similarly, odd mature *B. ilicifolia* died, but in most instances the numbers of young seedlings increased. A similar trend was evident at West Gironde. These observations can also be compared with the death of mature *Eucalyptus calophylla* east of Wanneroo, in the vicinity of bores already tapping the underground water.

Banksia attenuata and *B. menziesii* are similar in their tolerance of soil moisture conditions. The view that the plant communities at Tick Flat are unstable as a result of a build-up in sand on the swamp is supported by the increase in numbers over the last ten years of these two species on the low-lying areas below the main occurrence of *Melaleuca preissiana* and *Eucalyptus rudis.* At other areas where this instability of the communities is not evident these two banksias are restricted to the mid and upper dune slopes.

Melaleuca preissiana and *E. rudis,* which occur on the fringes of the depression, are mainly mature trees with large diameters. Their distribution is similar to that of the same species on the fringing areas of the lakes on the northern Swan Coastal Plain.

The other tree species, *Nuytsia floribunda, E. todtiana, Casuarina fraserana* and *B. grandis,* show only minor changes in the number of stems.

One species of note is *B. prionotes,* which occurred outside the transect at Tick Flat in 1966. By 1976 it had spread on to the transect, and like *B. attenuata* and *B. menziesii,* it was increasing in numbers on the depression.

The majority of the sixty perennial species other than trees identified at Tick Flat did not change greatly in distribution over the ten-year period (Fig. 19). Those species whose frequency changed markedly are given in Table 5.

Table 5

PERENNIAL PLANT SPECIES AT TICK FLAT SHOWING A MARKED CHANGE* IN FREQUENCY BETWEEN SEPTEMBER 1966 AND SEPTEMBER 1976

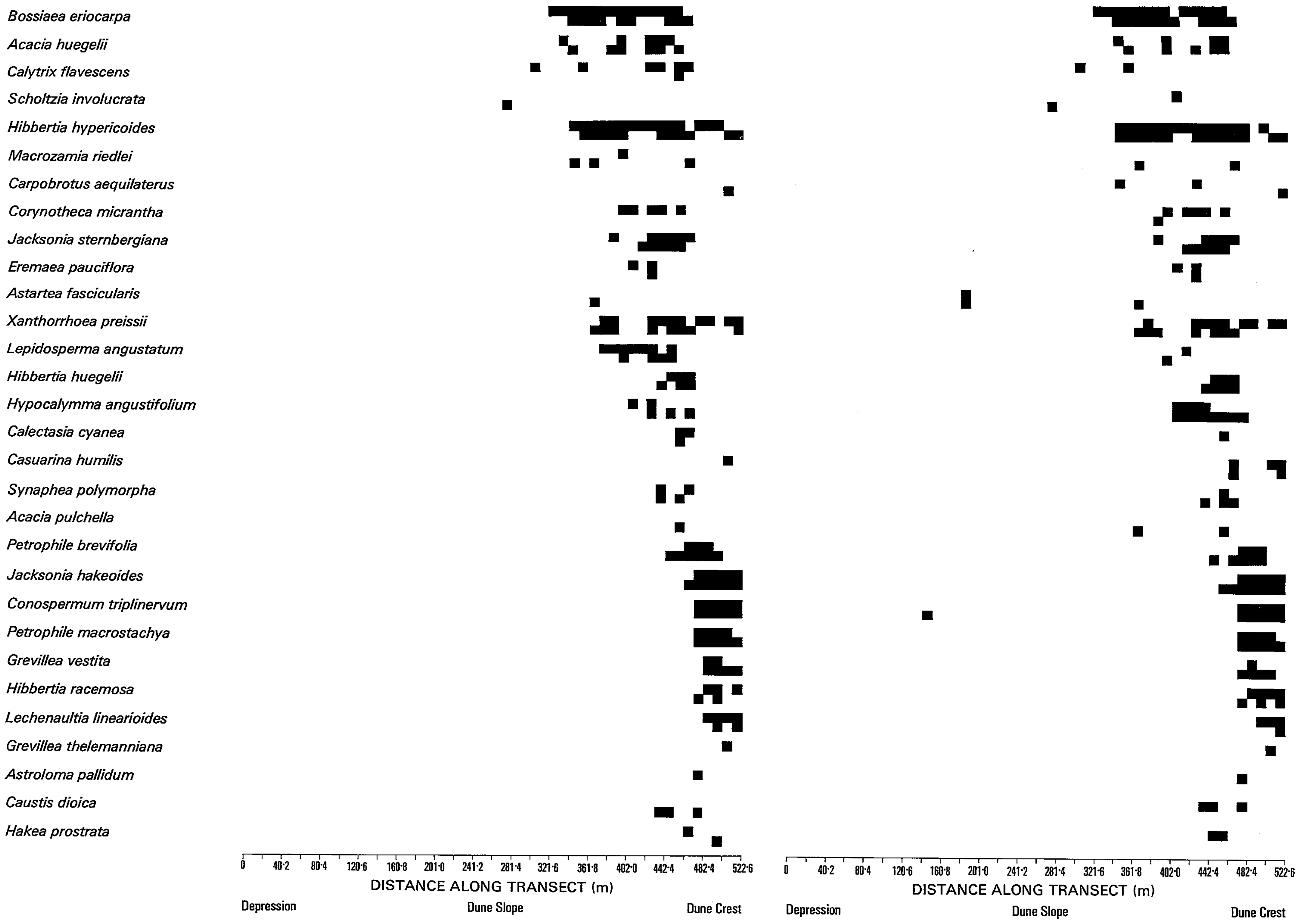
Increased frequency	*Decreased frequency*
Adenanthos cygnorum	*Aotus villosus*
Calytrix angulata	*Gompholobium tomentosum*
Hypocalymma angustifolium	*Lechenaultia floribunda*
Leptocarpus scariosus	*Lepidosperma angustatum*
Leptospermum ellipticum	*Lyginia barbata*
Petrophile linearis	
Petrophile serruriae	

* Change in percentage frequency exceeding 5 per cent.

In some instances these changes are the reverse of the trends seen in the other study areas. For example, *Hypocalymma angustifolium* and *Leptospermum ellipticum,* which tolerate wet soil conditions, increased in frequency despite the lowering of the water table.

Figure 19

Distribution of perennial plant species at Tick Flat (September 1966 and 1976)


Bossiaea eriocarpa
Acacia huegelii
Calytrix flavescens
Scholtzia involucrata
Hibbertia hypericoides
Macrozamia riedlei
Carpobrotus aequilaterus
Corynotheca micrantha
Jacksonia sternbergiana
Eremaea pauciflora
Astartea fascicularis
Xanthorrhoea preissii
Lepidosperma angustatum
Hibbertia huegelii
Hypocalymma angustifolium
Calectasia cyanea
Casuarina humilis
Synaphea polymorpha
Acacia pulchella
Petrophile brevifolia
Jacksonia hakeoides
Conospermum triplinervum
Petrophile macrostachya
Grevillea vestita
Hibbertia racemosa
Lechenaultia linearioides
Grevillea thelemanniana
Astroloma pallidum
Caustis dioica
Hakea prostrata
0
40·2
80·4
120·6
160·8
201·0
241·2
281·4
321·6
361·8
402·0
442·4
482·4
522·6
DISTANCE ALONG TRANSECT (m)
Depression
Dune Slope
Dune Crest
0
40·2
80·4
120·6
160·8
201·0
241·2
281·4
321·6
361·8
402·0
442·4
482·4
522·6
DISTANCE ALONG TRANSECT (m)
Depression
Dune Slope
Dune Crest

This increase could relate to the occupation of a relatively open site. *Adenanthos cygnorum,* which is a coloniser, decreased in frequency at West Gironde and Neaves but increased at Tick Flat. As it has no site preference its distribution is unlikely to be related to soil moisture levels.

Petrophile linearis, Calytrix angulata and *P. serruriae* all occur on the fringes of the depression, where the soil moisture levels did not change significantly over the ten years, and where there was consequently no severe water stress. In any case, *P. linearis* is known to develop a deep root system enabling it to reach the water table.

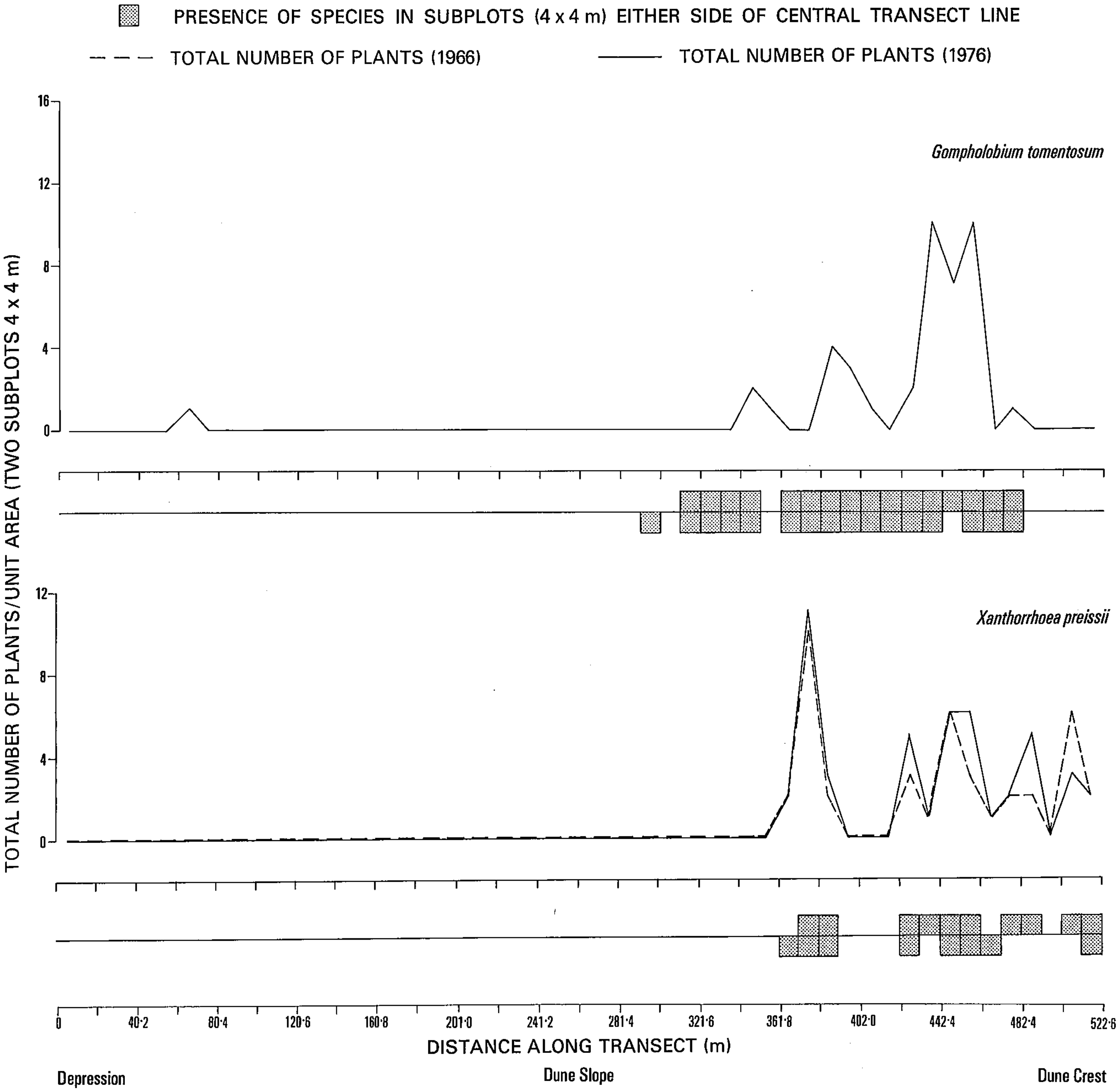
Unlike *Lechenaultia floribunda* and *Aotus villosus, Lepidosperma angustatum* is restricted to the upper slopes of the dunes, where patches of limestone occur at the surface. All three species are similar, however, in that they decreased markedly in frequency.

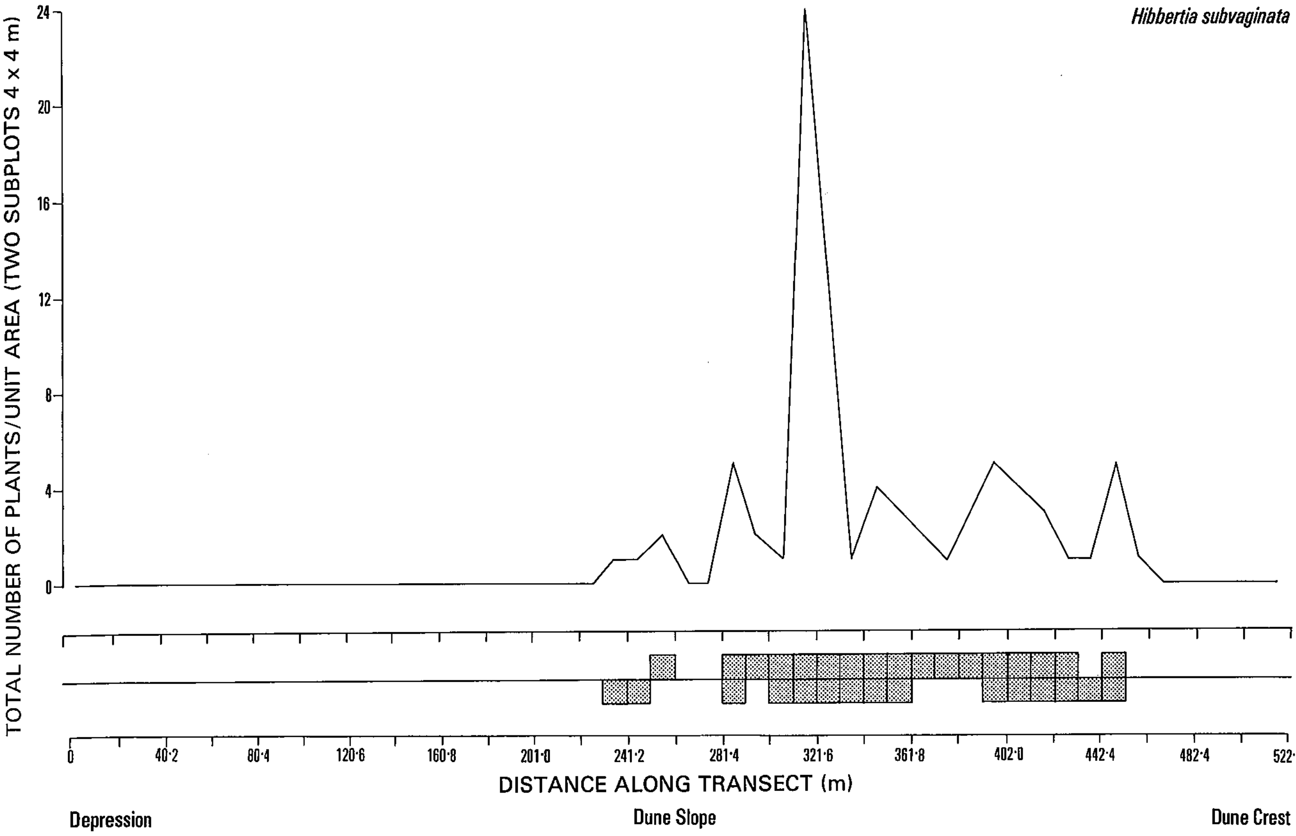
Lyginia barbata and *Gompholobium tomentosum* are capable of tolerating a wide range of soil conditions. Their decrease in frequency is therefore probably not related to the change in soil moisture.

The distribution of *Hibbertia subvaginata, G. tomentosum* and *Xanthorrhoea preissii,* all of which avoid the excessively wet areas, did not change greatly over the ten years (Fig. 20). In contrast to their frequency at the other study areas, *H. subvaginata* and *G. tomentosum* occur at Tick Flat in low numbers.

Figure 20

Distribution and total numbers of *Gompholobium tomentosum, Xanthorrhoea preissii* and *Hibbertia subvaginata* at Tick Flat (September 1966 and 1976)




Hibbertia subvaginata
TOTAL NUMBER OF PLANTS/UNIT AREA (TWO SUBPLOTS 4 x 4 m)
24
20
16
12
8
4
0
0
40·2
80·4
120·6
160·8
201·0
241·2
281·4
321·6
361·8
402·0
442·4
482·4
522·6
DISTANCE ALONG TRANSECT (m)
Depression
Dune Slope
Dune Crest

Discussion

SOIL MOISTURE

Although the M.W.B. began tapping the underground water on the northern Swan Coastal Plain in 1970, no water was withdrawn north of Gnangara Road until late 1976. The observations at the four study areas for 1966 and 1976 therefore reflect natural fluctuations in the water table rather than changes occurring as a result of the withdrawal scheme. Between 1966 and 1976 there was a fall in the level of the water table of at least 1·2 m at all four transects. The soil moisture levels of the upper slopes and dune crests fell in 1976 to well below 3 per cent. Soil moisture readings indicate that a relationship exists between the depth of the water table and both annual and seasonal fluctuations in rainfall. The withdrawal of underground water will of course modify this further.

VEGETATION

Structural and floristic changes in the vegetation in response to decreasing water availability were evident at all four transects. Similar patterns of species distribution occurred along the transects in relation to local soil-water regimes from depressions through dune slopes to dune crests.

In all four areas most of the native plant species tolerated the fluctuations in soil moisture content and the changes in the water table level. This supports the hypothesis that most of the native plants are adapted to natural fluctuations in environmental conditions and, more specifically, the soil-water regime. Those species whose frequency and distribution decreased in response to the series of years with below-average annual rainfall are possibly suitable as indicators of further changes in the soil-water regime. They would be expected to decrease further in frequency and distribution as a result of increased water stress, and to increase during above-average annual rainfall years, provided no outside influences are operative.

The indicator species can be used to distinguish between natural and man-made impacts and therefore to provide information on which to base management decisions aimed at minimising possible side-effects of the scheme to withdraw underground water.

Table 6 summarises the percentage frequency of the tree species at the four study areas and the total number of stems at breast height in September 1966 and September 1976. The data are organised according to Havel's (1968) four categories of site preference.

Among the species that tolerate excessive wetness, *Melaleuca preissiana* has been able to adjust to the fluctuations in soil moisture levels at all areas. Moreover, the total number of stems increased substantially. This is most obvious at West Gironde. The death of *Banksia littoralis* at both West Gironde and Neaves shows that at these areas this species has been unable to tolerate the recent below-average annual rainfall. However, this is not so evident at Tick Flat, where only odd mature trees died. Within this category, *B. littoralis* is therefore the most suitable as a possible indicator of water stress.

The results presented to date for the tree species that occur on moist sites but that are intolerant of extremes in moisture show that both *Eucalyptus marginata* and *E. calophylla* have been able to tolerate the recent fluctuations in soil moisture. At both South Kendall and West Gironde, *Banksia ilicifolia* showed a very marked decrease in frequency and total number of stems over the ten-year period, but at Neaves and Tick Flat its frequency and total numbers remained relatively stable. The recent occurrence of *B. prionotes* on the low-lying areas at Tick Flat reflects the area's instability. *Banksia grandis* is relatively restricted in distribution on the northern Swan Coastal Plain and does not appear to have changed significantly in response to the recent fluctuations in water level or to the known occurrence of dieback at South Kendall. Within this category, *B. ilicifolia* appears to be the best choice as an indicator of water stress.

For the tree species that have a wide tolerance of sites but that show maximum development on dry sites, the trend has in the main been towards an increase in both frequency and total numbers. This increase, although generally small, supports Havel (1975) and Aplin (1976) in their predictions of an increase in the distribution of species of the xeric end of the continuum in response to water stress. At Tick Flat, the greatest increases in both *B. menziesii* and *B. attenuata* were recorded on the almost treeless depression. If there is further lowering of the water table and if lower soil moisture levels are maintained in coming years, these two species can be expected to increase further in distribution and numbers.

The species with no clear-cut site preference show in the main only slight changes in frequency and total numbers, with an overall trend towards an increase.

The percentage frequencies of the perennial species other than trees are summarised in Table 7. Once again, the data are organised into the four categories delineated by Havel (1968).

Table 6

PERCENTAGE FREQUENCY AND TOTAL NUMBER OF STEMS AT BREAST HEIGHT OF TREE SPECIES AT THE FOUR STUDY AREAS IN 1966 AND 1976

	South Kendall				*West Gironde*				*Neaves*				*Tick Flat*			
	Percentage frequency		*Total number*		*Percentage frequency*		*Total number*		*Percentage frequency*		*Total number*		*Percentage frequency*		*Total number*	
	1966	*1976*	*1966*	*1976*	*1966*	*1976*	*1966*	*1976*	*1966*	*1976*	*1966*	*1976*	*1966*	*1976*	*1966*	*1976*
(*a*) Species tolerant of excessive wetness:																
Banksia littoralis	—	—	—	—	13	—	4	—	5	—	2	—	25	25	178	193
Eucalyptus rudis	—	—	—	—	—	—	—	—	—	—	—	—	15	15	30	32
Melaleuca preissiana	35	35	39	47	53	53	381	548	25	30	37	44	17	17	35	54
(*b*) Species of optimum moist sites, intolerant of extremes in moisture conditions:																
Banksia grandis	9	6	3	2	—	—	—	—	—	—	—	—	10	8	16	7
Banksia ilicifolia	73	24	109	23	63	50	122	66	60	60	37	36	31	37	120	142
Banksia prionotes	—	—	—	—	—	—	—	—	—	—	—	—	—	10	—	8
Eucalyptus calophylla	15	18	11	16	—	—	—	—	—	—	—	—	—	—	—	—
Eucalyptus marginata	26	32	29	30	—	—	—	—	25	30	13	14	—	—	—	—
(*c*) Species with wide tolerance, but with maximum development on dry sites:																
Banksia attenuata	79	68	111	80	78	72	226	237	80	80	103	108	65	73	195	361
Banksia menziesii	68	59	75	75	69	59	140	191	70	70	122	142	31	40	98	152
(*d*) Species without clear-cut site preference:																
Casuarina fraserana	—	—	—	—	—	—	—	—	—	—	—	—	8	10	11	23
Eucalyptus todtiana	6	6	5	5	19	13	15	24	20	20	13	12	8	10	7	15
Nuytsia floribunda	21	21	11	12	38	34	25	29	25	30	10	10	12	21	8	16

The species of the group tolerant of excessive wetness show very marked decreases in frequency at both South Kendall and West Gironde. This is not so at Neaves and Tick Flat, however, where the data for the perennial plants follow the same trends as those for the tree species. Of this group *Leptospermum ellipticum, Astartea fascicularis, Pultenaea reticulata, Regelia ciliata, Euchilopsis linearis* and *Hypocalymma angustifolium* are the most suitable possible indicators of water stress. The density data collected in 1976 may in the future help to justify this choice.

The species that occur on optimum moist sites have on the whole shown little change in relation to the fluctuations in the water table and soil moisture levels between 1966 and 1976. One exception is *Melaleuca seriata,* which has decreased slightly in numbers at West Gironde. *Acacia huegelii* has affinities with *M. seriata* in both its distribution and its reaction to water stress.

In the light of the results for the tree species, an increase in those species that have maximum development on dry sites could be predicted as a result of a further decrease in soil moisture content. While there have been varying responses to the below-average annual rainfall over the ten-year period, the majority of species in this group appear to have changed little in frequency. Some, however, have increased markedly, including *Leucopogon conostephioides* and *Boronia purdieana* (both at South Kendall only) and *Hibbertia helianthemoides* (at West Gironde only), and some have decreased markedly, including *Scholtzia involucrata, L. conostephioides, B. purdieana, Oxylobium capitatum* and *H. helianthemoides* (particularly at Neaves). These decreases in frequency were not expected and as yet cannot be explained. Further investigation of the anatomical and physiological characteristics of the individual species may be of help.

The species without clear-cut site preference show very slight changes in numbers. This is similar to the trend shown by the tree species in the same category. Any changes are generally towards an increase in frequency and total numbers, and this reflects the ability of species such as *Hibbertia subvaginata, Gompholobium tomentosum* and *Bossiaea eriocarpa* to take advantage of changes in environmental conditions.

Figure 21, which gives total numbers of perennial plants along the transects, illustrates that the plants have been able to adjust to the changes in soil moisture over the ten-year period. The results for West Gironde, Neaves and Tick Flat clearly indicate that the number of species on the depressions is lower than on the dune slopes, where the number is in turn lower than on the dune crests. These results do not hold for South Kendall, where the topographical range is much less than at the other three areas.

A minor point of interest is the decrease in the number of plants on the top of the dune crest at Tick Flat. This is due to the occurrence of limestone pinnacles and shallow soils which, during periods of water stress, may limit water availability to the perennial plant species.

The results from the four areas could be used to support earlier predictions of the response of the vegetation if the water table remains at a low level. These include a reduction in those species that occur on both the depressions and lower slopes and an increase in those species that occur on the upper slopes and drier soils. Although such a shift may be desirable for some land uses, it could be detrimental in the long term in the wetlands and low-lying areas.

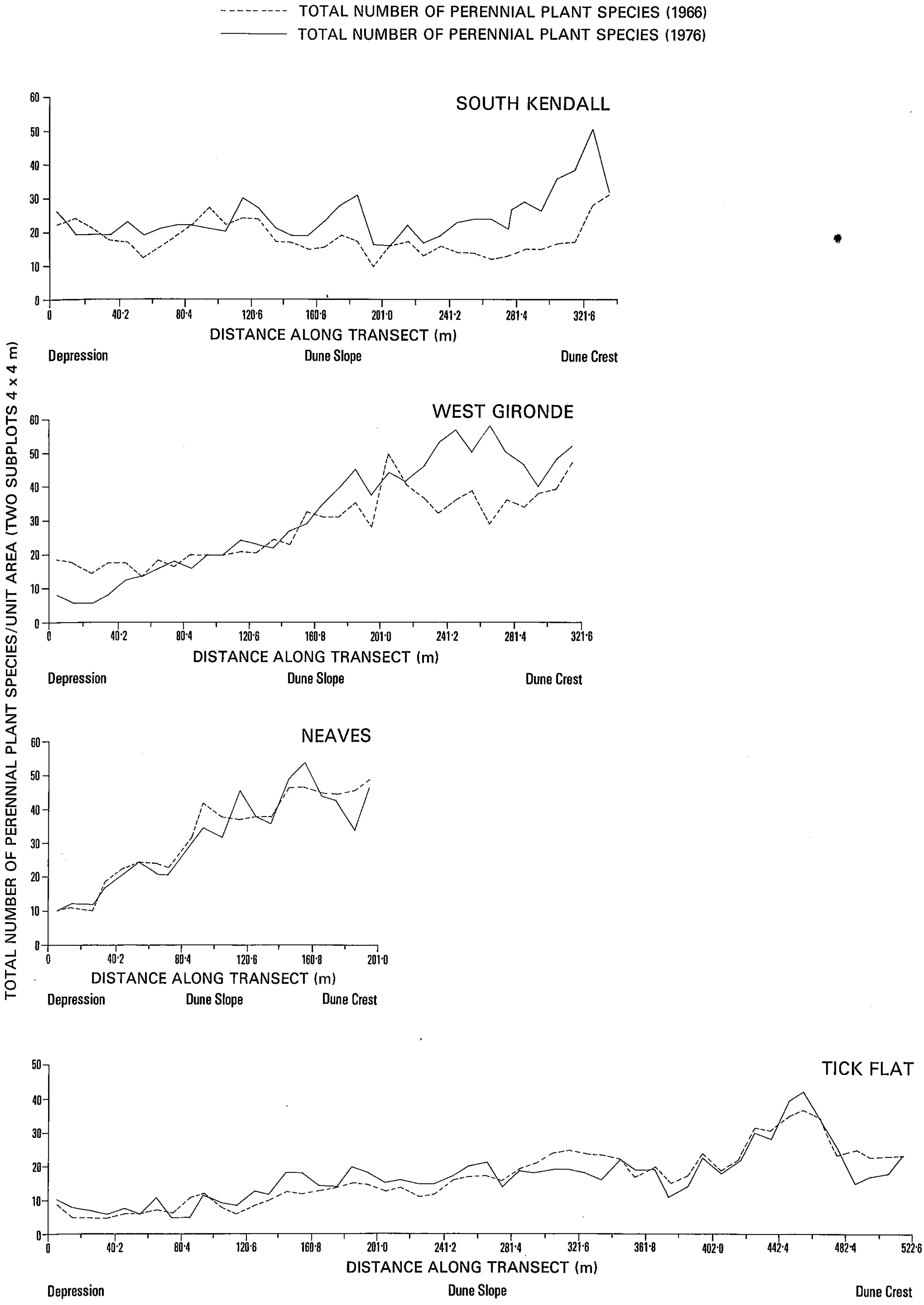
Table 7

PERCENTAGE FREQUENCY OF PERENNIAL SPECIES OTHER THAN TREES AT THE FOUR STUDY AREAS IN SEPTEMBER 1966 AND 1976

	South Kendall		*West Gironde*		*Neaves*		*Tick Flat*	
	1966	*1976*	*1966*	*1976*	*1966*	*1976*	*1966*	*1976*
(*a*) Species tolerant of excessive wetness:								
Astartea fascicularis	—	—	27	8	20	18	1	3
Calothamnus lateralis	—	—	—	—	18	18	—	—
Euchilopsis linearis	7	6	27	9	13	18	—	—
Hibbertia stellaris	—	—	2	—	8	8	—	—
Hypocalymma angustifolium	16	7	27	9	13	10	6	12
Leptospermum ellipticum	—	—	42	28	25	25	21	28
Patersonia xanthina	—	—	2	—	5	3	—	—
Pultenaea reticulata	—	—	22	3	—	—	—	—
Regelia ciliata	16	1	23	14	20	25	26	30
(*b*) Species of optimum moist sites:								
Adenanthos obovatus	—	—	19	19	25	28	—	—
Dasypogon bromeliifolius	84	82	44	42	45	45	—	1
Melaleuca seriata	31	28	20	14	18	20	—	—
Phlebocarya ciliata	47	38	31	36	40	38	35	36
Xanthorrhoea preissii	76	75	70	77	48	43	17	16
(*c*) Species with maximum development on dry sites:								
Astroloma xerophyllum	—	—	3	—	18	15	—	—
Beaufortia elegans	—	—	48	28	50	43	—	—
Boronia purdieana	—	9	—	2	33	20	—	—
Conostephium minus	—	—	3	6	35	28	—	1
Eremaea pauciflora	—	—	41	34	43	38	3	3
Hibbertia helianthemoides	—	—	31	41	30	18	—	—
Jacksonia floribunda	—	—	44	44	50	45	—	—
Leucopogon conostephioides	1	7	45	50	53	43	19	21
Leucopogon strictus	—	—	—	—	20	15	—	—
Melaleuca scabra	—	—	47	47	43	43	—	—
Oxylobium capitatum	—	—	34	38	35	18	—	1
Scholtzia involucrata	4	4	27	22	45	25	1	2
(*d*) Species without clear-cut site preference:								
Bossiaea eriocarpa	50	51	34	45	58	58	22	22
Calytrix flavescens	12	4	31	39	45	55	7	2
Conostephium pendulum	47	49	33	28	63	58	13	11
Hibbertia subvaginata	22	47	89	98	80	83	31	29
Lyginia barbata	22	54	17	42	58	58	49	39

Figure 21

Total number of perennial plant species at all four study areas (September 1966 and 1976)



Conclusions

The results presented define a series of plants indicative of water stress, including some that decrease and some that increase in frequency and distribution with increasing soil water deficits.

Species that have decreased are as follows:

(1) Species that occur on depressions and swamps and that can tolerate excessive wetness:
Banksia littoralis, Leptospermum ellipticum, Astartea fascicularis, Pultenaea reticulata, Regelia ciliata, Euchilopsis linearis and Hypocalymma angustifolium.

(2) Species that occur on moist sites:
Banksia ilicifolia, Melaleuca seriata and *Acacia huegelii.*

Species that have increased are as follows:

(1) Species with wide tolerance, but with maximum development on dry sites:
Banksia attenuata, B. menziesii, Leucopogon conostephioides and *Boronia purdieana.*

(2) Species without clear-cut site preference:
Lyginia barbata, Hibbertia subvaginata and *Bossiaea eriocarpa.*

Although these species did not react consistently at all areas, they appear to be the best possible indicators of water stress. Obviously, many more species would react similarly if the stress applied were sufficient.

The results support Havel's (1975) and Aplin's (1976) predictions of a shift towards the xeric end of the continuum in response to increased water stress. The data provide a basis for future monitoring of the native vegetation with respect to long-term changes in the soil-water regime over a range of areas on the northern Swan Coastal Plain. It is hoped that the species selected as indicators will provide a ready determinant of any adverse changes that may occur as a result of the future withdrawal of underground water and that management decisions in relation to the native vegetation and other land uses already established in the area can consequently be modified and improved.

Recommendations

The research completed to date has suggested many avenues of study aimed at broadening current understanding of the water relations of the individual plant species. The main areas where more information is needed include the following.

(1) The anatomical and physiological adaptations of individual plant species to varying environmental conditions.

(2) The reasons why particular native species are able or unable to tolerate extremes in fluctuations of environmental conditions.

(3) The limits of fluctuations in environmental conditions for individual plant species and for plants of different ages.

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Postscript

Results and observations gathered since 1976, as part of the long-term monitoring programme, further reflect the effect of water stress due to the below-average annual rainfall years. The marked differences in results seen in 1976 at West Gironde as compared with the other three areas is not as apparent in later years. In recent years the plant communities at Neaves, South Kendall and Tick Flat have also reacted to water stress, either by death, loss of leaves or general lack of vigour. This lag in response to water stress appears to be related to the inherent differences in the age and structural characteristics of the plant communities at the four transects.

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APPENDIX I

Monthly rainfall (mm) for Gnangara (1962-1976), Wanneroo (1962-1976) and Tick Flat (1967-1976) recorded by Forests Department of Western Australia

GNANGARA

	1962	*1963*	*1964*	*1965*	*1966*	*1967*	*1968*	*1969*	*1970*	*1971*	*1972*	*1973*	*1974*	*1975*	*1976*	*Total rainfall*	*Ave. monthly rainfall (15 years)*
Jan.	10·2	8·4	0·0	0·5	0·0	4·6	32·5	6·9	3·8	14·0	0·0	14·7	0·0	0·0	26·1	121·7	8·1
Feb.	3·3	7·4	5·6	0·5	2·5	5·8	20·1	0·0	66·5	10·4	0·0	0·0	42·0	0·0	65·0	229·1	15·3
Mar.	1·0	23·1	6·1	4·1	11·2	8·4	42·9	20·6	0·0	55·6	1·5	0·0	0·0	9·2	1·1	184·8	12·3
Apr.	15·2	56·9	93·2	16·0	42·9	68·1	72·1	35·1	71·9	11·4	22·9	34·8	80·5	32·2	108·1	761·3	50·8
May	175·3	265·4	15·0	126·2	49·5	292·4	57·7	61·7	130·3	118·9	26·2	87·4	217·0	103·4	97·9	1824·3	121·6
June	174·5	239·5	358·4	203·5	163·3	205·5	231·9	162·6	225·3	89·9	116·1	180·6	113·5	204·5	64·2	2734·3	182·3
July	179·3	194·3	293·1	175·3	144·3	143·3	150·1	86·1	128·8	107·2	180·1	221·7	332·5	226·9	81·3	2645·3	176·4
Aug.	92·7	191·8	154·9	197·1	52·1	104·1	94·2	72·4	88·1	95·3	158·2	168·9	149·5	98·6	145·4	1854·3	123·6
Sept.	52·1	76·2	112·0	76·7	89·2	33·5	150·4	9·7	86·6	141·0	33·8	147·6	17·2	54·6	36·0	116·6	74·4
Oct.	54·6	41·1	59·2	126·5	38·4	38·9	43·9	1·3	34·0	69·6	29·5	45·0	77·7	50·7	32·9	744·3	49·6
Nov.	24·4	9·4	8·6	59·4	9·7	11·7	6·9	25·4	13·5	12·4	0·5	0·0	30·7	10·7	40·9	264·2	17·6
Dec.	19·8	0·0	30·0	28·2	14·0	25·9	6·4	3·0	18·0	1·0	0·0	0·0	1·2	3·8	3·2	154·5	10·3
Total (yearly)	802·4	1113·5	1136·1	1014·0	617·1	942·2	909·1	484·8	866·8	726·7	568·8	900·7	1061·8	794·6	703·1	12634·7	842·3

WANNEROO

	1962	*1963*	*1964*	*1965*	*1966*	*1967*	*1968*	*1969*	*1970*	*1971*	*1972*	*1973*	*1974*	*1975*	*1976*	*Total rainfall*	*Ave. monthly rainfall (10 years)*
Jan.	10·4	8·9	0·0	7·4	0·5	4·1	16·5	4·3	3·1	6·1	0·8	24·7	0·0	0·0	23·2	110·0	7·3
Feb.	3·6	8·1	6·9	0·0	4·1	8·4	15·7	0·0	45·7	12·4	0·0	0·0	9·5	0·0	51·7	166·1	11·1
Mar.	3·8	11·2	6·4	6·6	8·9	6·9	31·8	13·0	0·0	53·1	2·5	0·0	0·0	10·7	2·1	157·0	10·5
Apr.	17·3	61·5	80·0	16·0	31·0	69·1	53·1	54·4	52·8	4·8	33·3	38·3	85·3	28·6	49·6	675·1	45·0
May	188·0	259·8	18·8	123·2	62·5	256·5	86·9	73·7	118·4	124·2	23·6	74·2	235·5	104·7	78·9	1828·9	121·9
June	178·3	245·1	296·4	204·5	158·8	227·8	208·8	200·2	185·4	98·0	127·8	183·7	91·6	188·9	68·1	2663·4	177·6
July	169·7	170·9	227·6	144·3	162·6	162·6	134·1	97·8	131·6	97·0	130·3	191·1	237·5	204·1	125·8	2387·0	159·1
Aug.	87·9	170·4	142·2	190·8	51·3	96·8	194·1	92·2	80·5	88·6	156·0	146·8	127·8	83·2	120·1	1828·7	121·9
Sept.	54·6	68·1	99·8	70·1	63·5	26·2	127·8	17·8	88·6	124·2	45·7	140·5	22·0	49·6	73·6	1072·1	71·5
Oct.	71·1	43·7	68·6	108·2	26·7	34·0	42·2	1·8	27·4	81·3	40·6	30·3	75·9	44·6	33·8	730·2	48·7
Nov.	19·8	8·9	0·5	47·2	3·6	8·9	8·4	28·7	10·4	36·1	0·5	17·4	27·6	14·1	44·3	276·4	18·4
Dec.	20·3	0·0	18·5	23·4	1·0	27·4	2·8	7·1	3·3	2·5	0·0	0·0	1·7	10·5	11·1	129·6	8·6
Total (yearly)	824·8	1056·6	965·7	941·7	574·5	928·7	922·2	591·0	747·2	728·3	561·1	847·0	914·4	739·0	682·3	12024·5	801·6

TICK FLAT

	1967	*1968*	*1969*	*1970*	*1971*	*1972*	*1973*	*1974*	*1975*	*1976*	*Total rainfall*	*Average monthly rainfall (10 years)*
Jan.	4·1	27·7	5·1	1·5	13·5	0·5	16·3	0·2	0·0	20·2	97·8	9·8
Feb.	4·3	20·6	0·0	67·1	14·5	3·0	0·3	21·5	0·0	51·8	187·4	18·7
Mar.	8·9	49·0	10·7	3·0	56·4	16·3	0·0	0·0	19·3	0·8	174·2	17·4
Apr.	80·5	74·2	33·5	61·2	4·1	37·1	39·4	137·2	30·4	62·2	559·8	60·0
May	199·9	64·5	75·7	127·5	64·0	63·0	85·3	209·2	106·4	81·2	1276·6	127·7
June	205·2	193·5	159·0	174·0	71·9	105·9	156·2	107·7	110·8	79·2	1568·6	156·9
July	189·0	165·4	86·9	127·5	105·4	131·3	192·8	235·4	201·5	70·9	1695·1	169·5
Aug.	101·3	120·4	46·2	58·4	65·5	134·1	108·5	92·8	85·0	143·9	1057·4	105·7
Sept.	27·9	105·2	6·9	93·5	92·7	65·3	130·3	28·5	68·6	72·3	719·1	71·9
Oct.	35·8	45·2	1·3	22·9	80·8	39·9	25·9	62·8	46·0	46·3	442·7	44·3
Nov.	10·2	2·0	30·5	9·1	27·9	0·3	8·9	16·1	28·7	33·7	117·6	11·8
Dec.	10·7	1·8	13·5	12·7	0·8	0·0	0·0	1·6	7·0	2·2	61·0	6·1
Total (yearly)	877·7	869·5	469·3	758·4	597·5	596·7	763·9	913·0	703·7	664·7	8055·1	809·6