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Myrtaceous shrub species respond to long-term decreasing groundwater levels on the Gnangara Groundwater Mound, northern Swan Coastal Plain

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Abstract

Analysis of four vegetation transects that were established on the Bassendean Dune System, northern Swan Coastal Plain classified 42 native plant species into four 'habitat' groups based on their preferred soil moisture regimes (Havel 1968). Using adult abundance and distribution data from three of these transects and an additional transect established in 1976, we investigated the various ecological responses of myrtaceous shrub species representing the four habitat groups to long-term (20-30 yr) decreasing groundwater and soil moisture levels. Myrtaceous shrubs were chosen for analysis because of their widespread occurrence and diversity on the Swan Coastal Plain, and because Myrtaceae is the only plant family to be represented in all four of Havel's habitat categories. Myrtaceous species 'tolerant of excessive wetness' (*Astartea fascicularis*, *Hypocalymma angustifolium*, *Pericalymma ellipticum*, *Regelia ciliata*) are all shallow rooted (rooting depth < 1m), occur in winter-wet depressions, and displayed the greatest reduction in population size in response to decreasing groundwater levels. Species cateogorised as displaying 'maximum development on dry sites' (*Eremaea pauciflora, Melaleuca scabra, Scholtzia involucrata*) commonly occurred on the upper and mid-slopes of the transects, are deeper-rooted and varied in their population response to long-term declines in water availability. All three species probably rely to some extent on accessing soil moisture at depth (2-6 m) during summer drought. The scenario was similar for species 'optimum on moist sites' (*M. seriata*) and for species 'without clear-cut site preferences' (*Calytrix flavescens*). In the context of Havel's four habitat categories, whether a particular habitat preference is 'wet' or 'dry' refers to availability of soil moisture, although to what soil depth and moisture levels are uncertain. Habitat preferences, based on soil moisture availability, may have no relevance to a species preferred groundwater regime and hence response to decreasing groundwater levels. A species' groundwater requirements during periods of drought are dependent on their position in the landscape, summer groundwater depth and the species rooting depth.

Introduction

In the mid 1960s, an investigation into site (habitat) preferences of a range of native species from Bassendean Dune System of the northern Swan Coastal Plain (Havel 1968) related seasonal variations in soil moisture, and depth to confining layers (*e.g.* coffee rock) to species distribution along several transects positioned to cover a range of topographical scenarios. Using these data, species were classified as either being

1) tolerant of excessive wetness;

2) optimum on moist sites;

3) maximum development on dry sites; and

4) without clear-cut site preferences.

Overall, 10 overstorey (mainly *Banksia* and *Eucalyptus*) and 32 understorey species were included in the analysis.

The Bassendean and other dune systems form part of the northern Swan Coastal Plain, under which lies a large, shallow unconfined aquifer, the Gnangara Groundwater Mound. Groundwater and soil moisture levels have been gradually decreasing in most areas of the Mound since the 1970s as a combined result of several years of below average rainfall and increased groundwater abstraction (Davidson 1995). Species that, according to Havel (1968), are found in low lying, seasonally waterlogged areas (*e.g. Astartea fascicularis, Pericalymma ellipticum*) may not be able to tolerate decreasing groundwater levels due to their typically shallow root systems (Dodd *et al.* 1984). In contrast, deeper-rooted shrub species usually rely on groundwater sources for most, if not all, of the year, depending on their position in the landscape (depth to groundwater) and a species maximum rooting depth. In response to decreasing groundwater levels, these species may be forced to compete for soil moisture sources at depth. Both soil moisture and groundwater levels are dependent on recent rainfall events and evapotranspiration rates (Farrington & Bartle 1989), with the rise and fall of the water table depending on the movement of the wetting front and decreasing soil water storage respectively in the soils unsaturated zone.

The family Myrtaceae is well represented on the Gnangara Groundwater Mound, mainly consisting of small shrubs (24 species from 12 genera), but also *Eucalyptus* (4 species) and *Melaleuca* (2 species) trees. The many damplands are often surrounded by a shrub stratum of *Astartea fascicularis* and *Pericalymma ellipticum* in areas prone to waterlogging; species such as *Hypocalymma angustifolium* and *Regelia ciliata* are dominant along the upper edges of these depressions where the soil is rarely waterlogged (Farrington *et al.* 1990; Muir 1983). In elevated postions (upslope) deeper-rooted species (*e.g. Eremaea pauciflora, Calytrix flavescens*) are common. Their great diversity and widespread occurrence on the Mound makes the myrtaceous shrubs an ideal group of species to study changes in species distribution and abundance, in relation to long-term variations in groundwater levels and known site preferences. The Myrtaceae is also the only family to be represented in all four of Havel's habitat categories. To determine the ecological significance of these groups in response to long-term groundwater fluctuations and soil moisture levels, we examined data for selected myrtaceous shrub species (those mentioned by Havel 1968) collected over a 20-30 year period along topographical, and hence depth to groundwater, gradients.

Methods

Study area

The Gnangara Groundwater Mound, bounded by the Swan River (south), Moore River and Gingin Brook (north), Darling Scarp (east) and the south-west Australian coast (Allen 1981), underlies seasonal and permanent wetlands, pine plantations and extensive areas of native *Banksia* woodlands of the northern Swan Coastal Plain. The Mound is one of two large, shallow unconfined aquifers on the plain, and is recharged directly by rainfall. The vegetation of the three main dune systems (Bassendean, Spearwood and Quindalup) is dominated by a *Banksia* overstorey with the occasional *Eucalyptus* and *Allocasuarina* stand, and an understorey consisting mainly of low shrubs from the Myrtaceae, Fabaceae and Proteaceae. The many seasonal damplands, swamps and permanent wetlands are often fringed by *Banksia littoralis* and *Melaleuca* tree species with a variable understorey consisting of species mainly from the Cyperaceae, Juncaceae and Myrtaceae (Semeniuk *et al.* 1990). The distribution of vegetation on the northern Swan Coastal Plain is predominately determined by the underlying landforms, soils, depth to water table and climatic conditions (Heddle *et al*. 1980; Cresswell & Bridgewater 1985). The Mound experiences a dry mediterranean-type climate (Beard 1984), with hot dry summers (December-March) and cool wet winters (June-August) with an average of 870 mm annual rainfall recorded at the Perth meteorological station.

Table 1

Myrtaceous shrub species occurring within the four study transects, listed according to their habitat preferences as determined by Havel (1968). Rooting depths were obtained from Dodd *et al.* (1984) where shallow roots are < 1 m, medium roots are 1- 2 m, and deep roots are > 2 m.

Species	Rooting depth
Tolerant of excessive wetness	
Astartea fascicularis (Labill) DC	shallow
Calothamnus lateralis Lindley	shallow
Hypocalymma angustifolium (Endl) Schauer	shallow
Pericalymma ellipticum (Endl) Schauer	shallow
Regelia ciliata Schauer	shallow
Maximum development on dry sites	
Eremaea pauciflora (Endl) Druce	deep
Melaleuca scabra RBr	deep
Scholtzia involucrata (Endl) Druce	medium
Optimum on moist sites	
Melaleuca seriata Lindley	deep
Without clear-cut site preferences	
Calytrix flavescens Cunn	deep

Vegetation transects

Four vegetation transects (including South Kendall, Neaves and Tick Flat; see Fig 1) were established in 1966 (Havel 1968) to assess the use of native species as indicators of suitable areas for growing pine plantations, and were positioned in areas where both existing pine plantation and relatively undisturbed native vegetation occurred side by side. These transects were resurveyed in 1976 (Heddle 1980), following the commencement of abstraction from public groundwater production bores. A transect were established near Lake Jandabup in 1976 in response to concerns about decreasing groundwater levels on the fringing native vegetation. Each transect contained at least one myrtaceous species (see Table 1) from 3 of the 4 habitat preferences listed by Havel (1968).

All transects were subsequently monitored on a tri-annual basis during September-October (spring) of the designated year. Transects were located along a topographical gradient, incorporating a dampland, wetland or local depression (low lying area) and terminating at a dune crest. They consisted of two parallel 20 m wide lines varying in length between 200 and 500 m. Each line was subdivided into 20 m x 20 m plots for assessment of overstorey composition, within which two 4 m x 4 m plots were used to assess the composition and abundance of understorey species. Fires have been relatively uncommon, with 2 or 3 fires occurring within each transect between 1966-1996.

Neaves (31°42’ S, 115°53’ E), Lake Jandabup (31°45' S, 115°51' E) and South Kendall (31°47' S, 115°52' E) transects were located on the southern part of the Mound (Fig 1), within 10 km of each other, with Neaves and South Kendall the only transects currently under the direct influence of groundwater drawdown resulting from the nearby Wanneroo and Mirabooka borefields respectively. The Tick Flat transect (31°24' S, 115°42' E) in the north (Fig 1), is not directly influenced

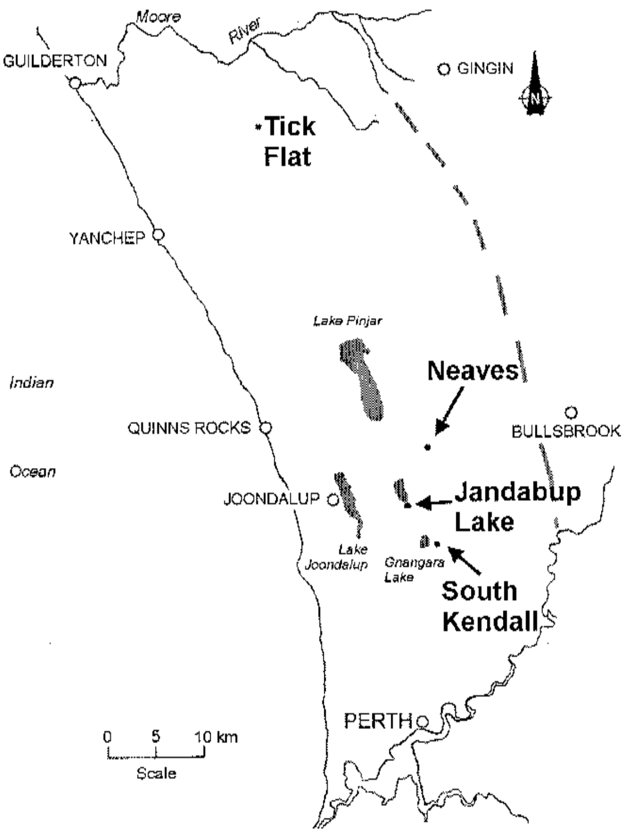

Figure 1. Location of four long-term vegetation monitoring transects (Lake Jandabup, Neaves, South Kendall, Tick Flat) on the northern Swan Coastal Plain, in relation to town sites and local lakes. Eastern boundary of coastal plain is represented by a dashed line.

by abstraction due to its great distance from any existing borefields.

Species distribution, groundwater and soil moisture

Abundance (number of adult plants) and distribution data along the transects for each species under investigation (Table 1) were compiled over approximately 10 year intervals from floristic data collected by J Havel, and Mattiske Consulting Pty Ltd, (unpublished data) between 1966-1996. Only distribution data were available for those transect monitored in 1966 (Neaves, South Kendall, Tick Flat).

Relating species distribution and changes in adult abundance to past groundwater levels experienced by the transects could not be achieved, because the transect's groundwater levels were not monitored. Instead species response to past groundwater regimes were analysed from hydrographical data obtained from the closest groundwater monitoring bore to the transects (usually about 1 km away from a transect) from a database maintained by the Water and Rivers Commission. Groundwater depths within the transect were measured in June 1998 using a hand auger every 30 m along the transects up to a depth of 10 m.

Soil samples were collected with a hand auger at 20 cm intervals to 3 m soil depth, every 20 m along the transects during each vegetation survey, and the moisture content measured gravimetrically. Perth's annual rainfall data since 1960 was obtained from the Western Australian Bureau of Meteorology.

Results

Groundwater levels

The annual hydrological cycle observed at monitoring bores within the vicinity of the four transects are typical of the hydrology of the Western Australia's Swan Coastal Plain. Maximum groundwater depth occurred in March-April resulting from a 3-4 month period of hot summer drought (Fig 2). The main recharge, and minimum groundwater depths, occurs during the winter and spring months (April-October).

Since 1976, groundwater monitoring bores near the four vegetation transects have shown a gradual decrease in groundwater levels (Fig 2A), resulting from several years of below average rainfall (Fig 2B). This decrease was greatest near Neaves and Tick Flat, where the maximum groundwater drawdown during the 20 year period was approximately 2 m, compared with less than 1 m for South Kendall and Lake Jandabup. Between 1979-1985, Perth experienced several years of below average (<870 mm) rainfall (Fig 2B) resulting in a 0.4-0.8 m drop in groundwater levels at monitoring bores near Tick Flat,

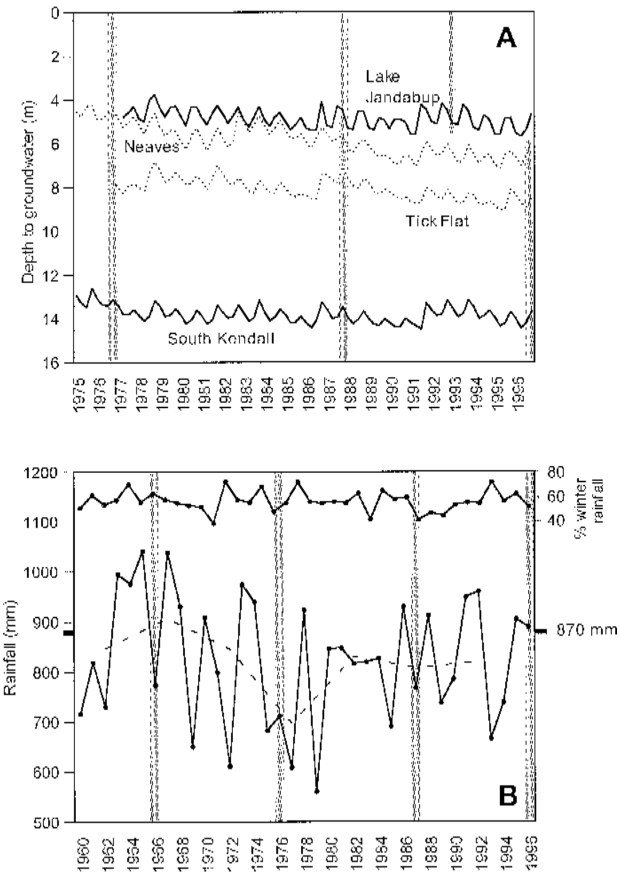

Figure 2. A: Hydrographs from the closest groundwater monitoring bores to the four vegetation transects. **B**: total (solid line), 5 yearly mean (dashed line) and winter contribution to Perth's rainfall from 1960-1996. Perth's long term average annual rainfall is 870 mm. Bars represent years when transects were monitored.

South Kendall and Lake Jandabup. For all transects groundwater recharge, calculated as spring (maximum) minus preceding autumn (minimum) groundwater depth, ranged from 0.5-0.8 m on average between 1979-1985.

Comparing 1976-1986 with 1987-1996 groundwater data, mean annual minimum groundwater depths decreased by 1.2 m for Neaves but only 0.1 m at Tick Flat. In comparison, groundwater depths decreased by 0.2 and 0.4 m at South Kendall and Lake Jandabup respectively. There was no significant difference in the mean annual groundwater recharge between or within sites over the two 10 year periods. Below average rainfall in 1989 and 1990 (750 and 790 mm respectively) caused a decrease in water levels in 1991 at all four monitoring bores as a direct result of poor groundwater recharge.

Soil moisture

Profiles of soil moisture content show that in spring (October) 1966, groundwater occurred within 3 m of ground level somewhere (usually the lower areas) on all four transects (Fig 3). Soil moisture content >20% indicated that the soil sample was obtained from or below the groundwater table (Havel 1968). By 1976, soils at both 1 and 3 m depth were drier at all sites, with the exception of Lake Jandabup where a significant proportion of the transect is influenced by the adjacent wetland water levels. Eleven years later, a soil moisture content > 20% was not detected at either Neaves or Tick Flat. Overall there was a decreasing trend in soil moisture content over the 30 year period. Soil samples used to calculated moisture content were collected in years where rainfall was more than 100 mm below (1966, 1976, 1987) or just above (1996) the average. The year 1976 had the lowest annual rainfall (711 mm) with winter rainfall accounting for 48% of the annual total. In comparison, winter rainfall accounted for 62% of the total in 1996. However, higher annual rainfall does not necessarily imply a greater contribution of winter rainfall (Fig 2B).

Species abundance and distribution

Half of the myrtaceous species studied were shallow-rooted and classified as tolerant of excessive wetness (Table 1). In 1966, these species were confined to the lower end (both in terms of topography and groundwater depth) of the transects (Fig 4), with *Astartea fascicularis* (only 1 individual) and *Hypocalymma angustifolium* at Tick Flat being the exceptions. In 1976, the distribution of these species had moved further upslope at South Kendall and Tick Flat (but not Neaves).

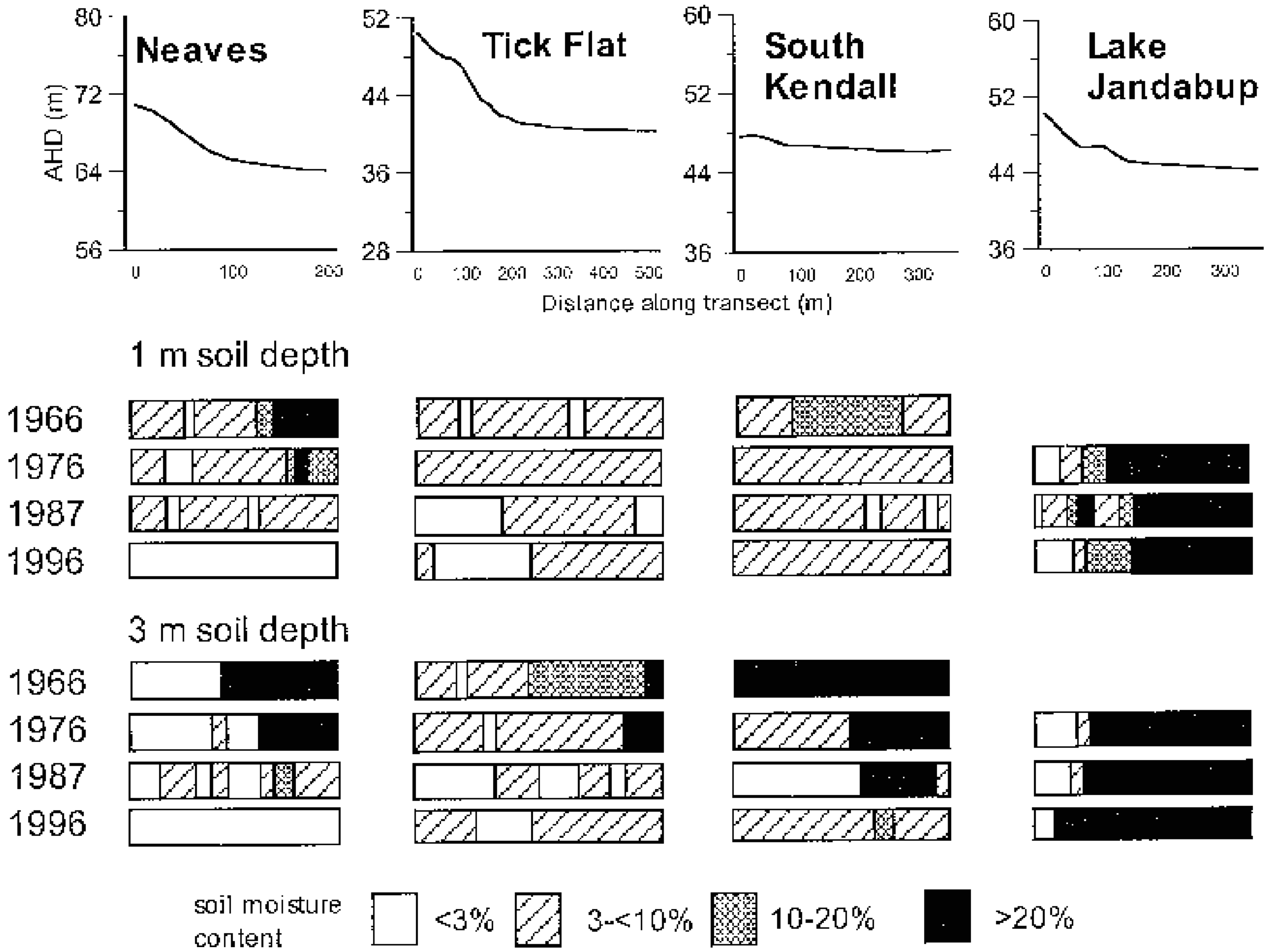

Figure 3. Spring (October) soil moisture profiles along the four transects at 1 and 3 m soil depth between 1966-1996. For the Lake Jandabup transect, the most recent soil moisture data was collected in 1993 (not 1996). Transect topography provided for comparative purposes. Soil moisture data collated from Heddle (1980) and unpublished sources.

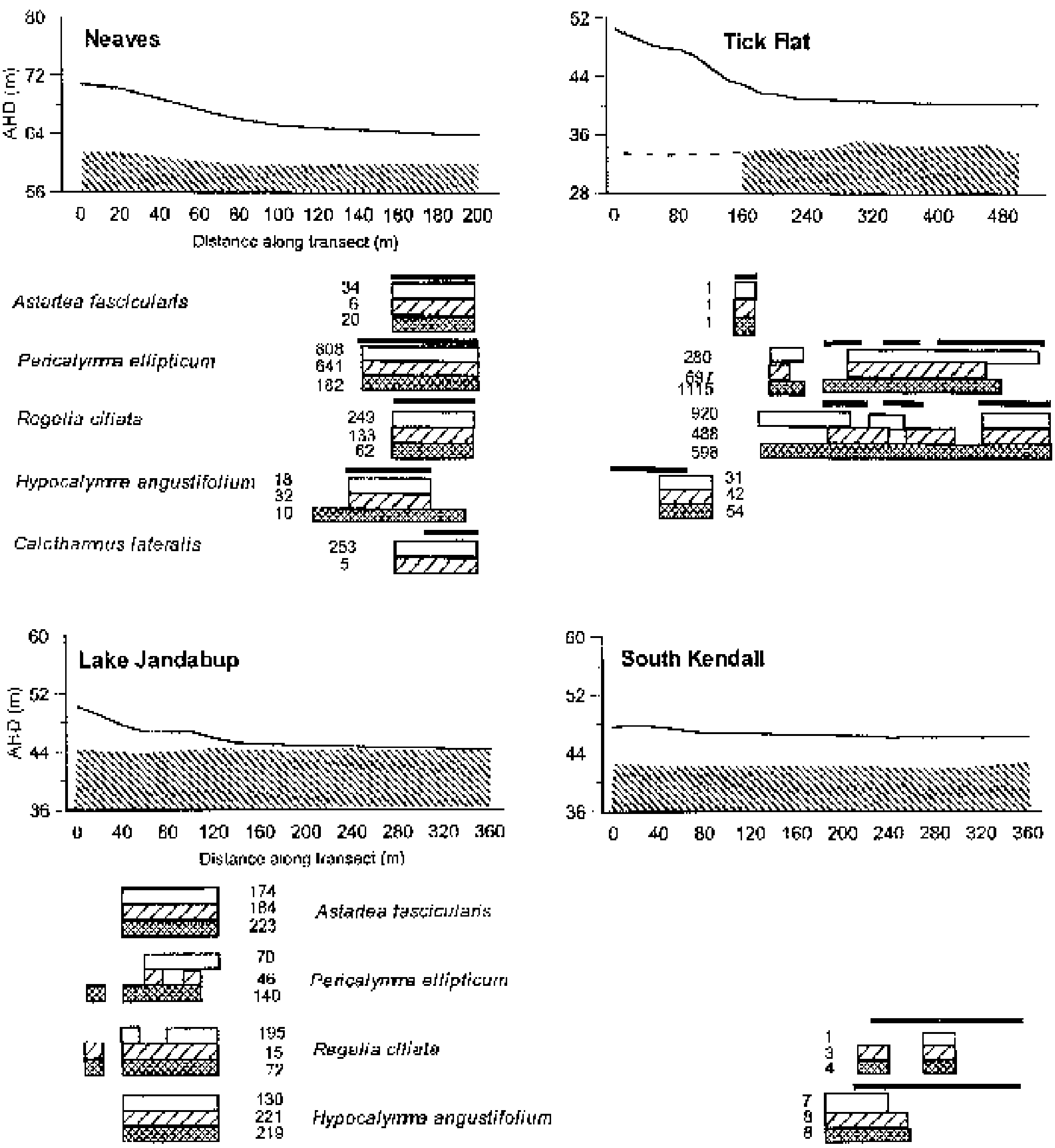

Figure 4. Distribution and abundance of myrtaceous shrub species 'tolerant of excessive wetness' within the four transects. Data shown for 1966 (thick solid line), 1976 (non-shaded bar), 1987 (light cross-hatching) and 1996 (dense cross-hatching). Transect topography and groundwater depth profiles are provided for comparative purposes. Groundwater data was collected in August 1998.

From 1976 onwards, only minor changes in the distribution of these 'excessive wetness' species were recorded within the four transects. At Neaves, the number of *Pericalymma ellipticum*, *Regelia ciliata* and *Calothamnus lateralis* plants decreased significantly between 1976 and 1996, with *C. lateralis* not found in the transect by 1996. The total number of adult plants increased for *P. ellipticum* and decreased for *R. ciliata* at Lake Jandabup and Tick Flat. *Hypocalymma angustifolium* also increased in their abundance at these two transects, with no change in their distribution. The number of *P. ellipticum* and *R. ciliata* plants at South Kendall were < 9 throughout the 20 year monitoring period.

Melaleuca seriata, the only myrtaceous shrub species classified by Havel (1968) as being 'optimum on moist sites' occurred at three of the four transects in various positions along the landscape (Fig 5), decreasing in numbers at Neaves and Tick Flat (shift in distribution or removed from transect) and South Kendall (no change in distribution) by 1996. The three species classified as 'wide tolerance, maximum development on dry sites' occurred on the mid- and upslopes of the transect (Fig 5). *Eremaea pauciflora* had decreasing numbers at all sites where it occurred with only a slight change in their distribution along the transect, although at Jandabup and Tick Flat the numbers were always < 11. *Scholtzia involucrata* had a disjunct distribution at South Kendall and Tick Flat, with the most significant changes in distribution patterns occurring between 1966 and 1976. *Calytrix flavescens,* the only myrtaceous shrub species to be classified as 'without clear-cut site preferences', occurred almost along the entire length of

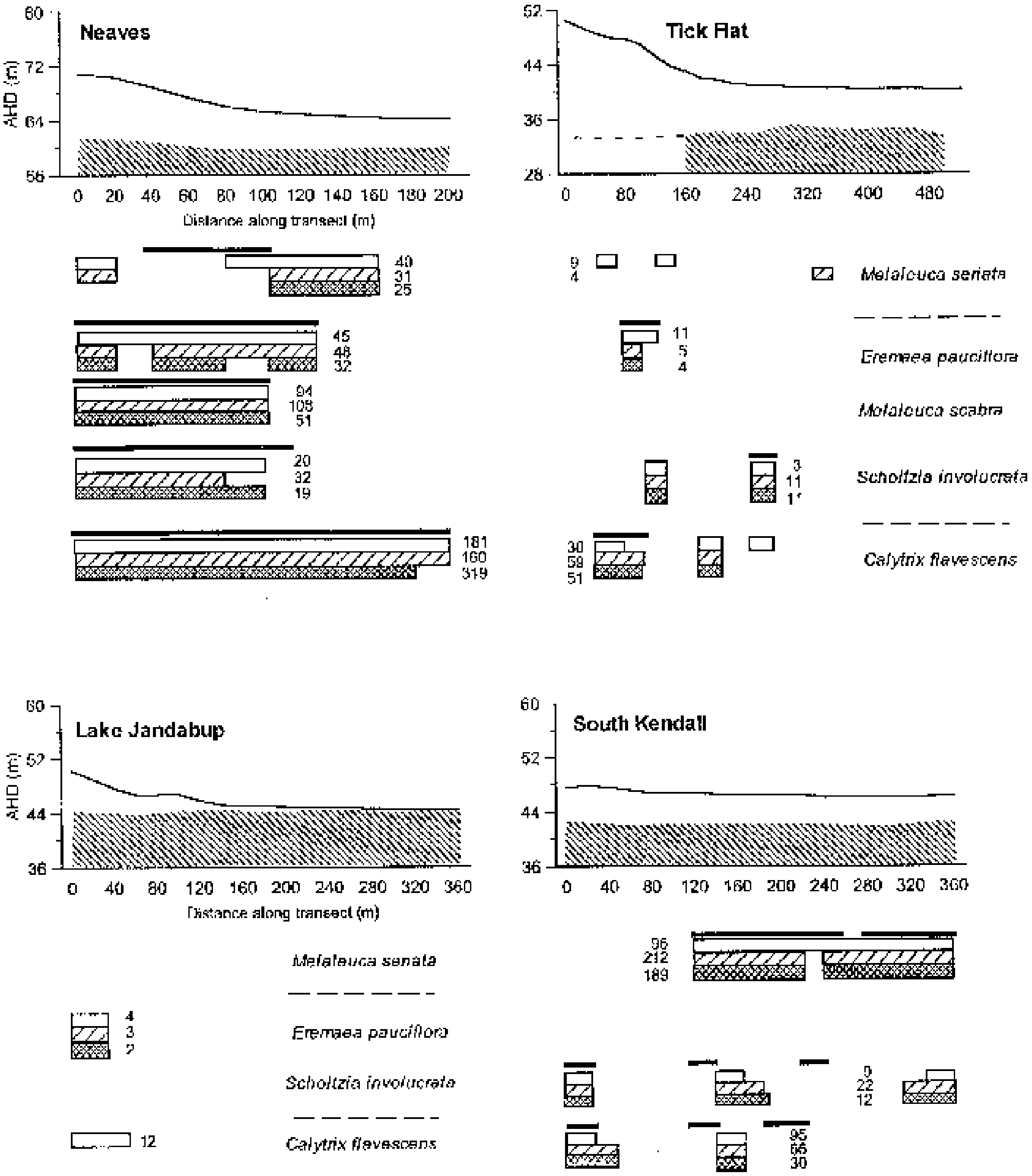

Figure 5. Distribution and abundance of myrtaceous shrub species that display ‘optimum on moist sites’ (*Melaleuca seriata*), ‘maximum development on dry sites’ (*Eremaea pauciflora, M. scabra, Scholtzia involucrata*), and with ‘no clear-cut site preferences’ (*Calytrix flavescens*) within the four transects. See Figure 4 for further details.

the Neaves transect, but was lost from Jandabup by 1987. Between 1966 and 1976, the distribution of *C. flavescens* decreased (South Kendall) or increased (Tick Flat). At Neaves the number of individuals of *C. flavescens* almost doubled between 1976 and 1996.

Discussion

Neaves was the only transect currently under the influence of borefield abstraction to show any significant change in myrtaceous shrub species abundance since abstraction began on the Gnangara Groundwater Mound. The influence of groundwater drawdown was not confined to any particular species group, but was more prominent for those species ‘tolerating excessive wetness’; however, the decrease in abundance was not caused by a change in their topographical distribution. Long-term reduction in groundwater levels at Neaves, resulting from the combined effects of poor groundwater recharge and increased groundwater abstraction, is the most likely cause of the decline of these shallow-rooted ‘excessive wetness’ species, resulting in the species succumbing to the continual water deficit pressures during the dry summer periods. These species may have been dependent on groundwater sources during the 1960's and early 1970's when groundwater depths were shallower. Groundwater levels in 1976 were estimated to be between 1-2 m (Heddle 1980), at the lower end of the transects compared with current levels (2-6 m). As groundwater levels receded only individuals capable of maintaining root growth, or surviving on limited soil moisture reserves, survived. Depth to groundwater fluctuations was not considered to be an important factor influencing the distribution of myrtaceous shrub along the South Kendall transect (also under the influence of abstraction), due to its relatively flat landscape (extending 220 m) rising to a small dune crest.

The dominant shrub species in winter-wet depressions on the Swan Coastal Plain are shallow-rooted, myrtaceous species (Muir 1983). Indeed all the species studied in this paper classified as 'tolerating excessive wetness' occur in low lying areas of relatively shallow groundwater depths, that during the winter months, may sustain high soil moisture levels within the unsaturated zone. However, *Astartea fascicularis* and *Hypocalymma angustifolium* were also located in areas upslope from these localised depressions, suggesting the presence of 'coffee rock', a ferruginous confining layer that can cause water tables to be **perched**. The five species mentioned in this paper may be able to tolerate 'excessive wetness', but also occur over a range of groundwater depths (1 to 9 m, in 1998) which may not be currently prone to excessively wet conditions. The ability of these species to tolerate 'wet' conditions, must be ultimately be viewed in the context of seasonal fluctuations in water availability, position within the landscape, underlying geology, and groundwater depths. Ecophysiological responses to soil-drying and a lowering water table during summer may be more important in explaining the distribution of these species on the Mound. However we can not discount the influence of fire on the adult populations of these shallow rooted species. Adults of *Pericalymma ellipticum* and *Regelia ciliata* are killed by fire, whereas adults of *A. fascicularis* and *H. angustifolium* recover from underground rootstocks (Dodd *et al.* 1984; B Lamont, Curtin University, *pers. comm.*). All other myrtaceous shrub species mentioned in this paper have the capacity to resprout after a fire (B Lamont, *pers. comm.*).

Species categorised as 'maximum development on dry sites' commonly occurred on the upper and mid-slopes of the transects. For the medium-rooted *Scholtzia involucrata*, Dodd *et al.* (1984) described its response to periods of summer drought to be similar to that of co-occurring shallow-rooted species (*i.e. Hibbertia subvaginata*), although the level of water stress incurred was less severe. This may be due to the ability of medium-rooted species to access soil moisture at depths unavailable to species with shallower root systems. Soil moisture seems to be the only source of water available to *S. involucrata*, as none of the transects had groundwater levels < 2 m where this species occurs, even accounting for past hydrological fluctuations. Despite an overall reduction in soil moisture since 1976 along the transects, the number of individuals increased or did not change.

The remaining species in the 'dry sites' category were deep-rooted, with root depths > 2 m. At a groundwater depth of 7 m, low xylem pressure potentials during summer indicated that the root system of *Melaleuca scabra* were not in contact with the water table (Dodd & Bell 1993). Based on this information, Dodd & Bell (1993) suggested that the maximum rooting depth of *M. scabra* was between 3-4 m and utilized soil moisture stored at these depths. A similar explanation was used for *M. seriata*, a species 'optimum on moist sites'. For both these species, water stress during drought is caused by gradual exhaustion of soil moisture storage at depth, which for *M. seriata* at Neaves and Tick Flat resulted in a shift towards shallower groundwater depths, or loss from the transect. A similar ecophysiological scenerio may also occur for *Calytrix flavescens* (Dodd *et al.* 1984), the only myrtaceous shrub species cited by Havel (1968) as having 'no clear-cut site preference'. *Eremaea pauciflora* (a 'dry site' species) is considered to function as a phreatophyte until the onset of summer drought (Dodd & Bell 1993). In their study, Dodd & Bell (1993) showed that for *E. pauciflora* the critical depth at which the water table apparently fell beyond the reach of the root systems, resulting in water stress, was 6.5 m (at an annual depth to groundwater ranging from 6-7 m). Groundwater levels falling below the reach of the root systems may have been responsible for the long term decline observed in *E. pauciflora* populations.

The concept of 'wet' or 'dry' habitat preferences mentioned in this paper relates to soil moisture levels up to 3 m depth, as described by Havel (1968). Whether a particular location on the landscape is 'wet' or 'dry' is presumably dependent on the presence of soil moisture throughout the year, although the critical soil depth and moisture levels are uncertain. On the deep sands of the Swan Coastal Plain, soil moisture levels are strongly in phase with the seasonal pattern of rainfall up to 10 m depth (Sharma & Craig 1989). Groundwater levels are closely tied to rainfall events, which in turn, are directly related to soil moisture levels. Typically water levels rise in response to a rainfall event soon after the wetting front has reached the groundwater. At relatively shallow soil depths (3-5 m) the soil profiles progressively dries out by evapotranspiration during summer, once significant rainfall ends in spring, reaching a minimum moisture level by autumn (Farrington & Bartle 1991). Beyond 10 m depth, evapotranspiration is non-existent due to a lack of plant root activity (Sharma & Craig 1989). Recharge within *Banksia* woodlands on the Gnangara Groundwater Mound has been calculated to be 10-43% of annual rainfall (Carbon *et al.* 1982; Farrington & Bartle 1989; Sharma & Craig 1989; Sharma *et al.* 1991), with the recharge rate varying with changes in land use, topography and soil type.

Whether a species prefers 'wet' or 'dry' habitats is not directly related to groundwater depth preferences, and depends on the plant species in question. Shallow rooted shrub species at relatively shallow depths to groundwater, may utilize both water sources depending on the degree to which water levels drop over summer. At deeper depths these species rely exclusively on soil moisture sources all year round. In contrast, deep rooted species may rely on groundwater sources during the dry summer months reverting to soil moisture when groundwater sources become unavailable. The habitat groups defined by Havel (1968) do provide valuable ecological information on a selection of Swan Coastal Plain species; however they may not be useful indicators of long term changes in groundwater levels or soil moisture at depth.

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