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Long-term changes in vigour and distribution of *Banksia* and *Melaleuca* overstorey species on the Swan Coastal Plain

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Abstract

Long-term changes in vigour and distribution of the dominant *Banksia* (5 species) and *Melaleuca* (1 species) overstorey species were examined within four vegetation transects overlying the Gnangara Groundwater Mound, a superficial unconfined shallow aquifer on the northern Swan Coastal Plain, Western Australia. All transects were positioned along topographical gradients and monitored over a 20-30 year period. The two co-dominant overstorey species (*Banksia attenuata* and *B. menziesii*) inhabited a range of topographical positions within the landscape, from dune crest to low lying areas, with only *B. attenuata* increasing its distribution (moving further downslope) within the transects over time. Both species displayed a reduction in vigour, as indicated by foliage condition, during the monitored period. Species commonly inhabiting low-lying winter-wet areas (*e.g. Banksia littoralis*, *Melaleuca preissiana*) showed the greatest loss of tree vigour in response to declining groundwater levels, with *B. littoralis* replaced by the more drought tolerant *B. prionotes*. *M. preissiana* populations were overall more resilient to altered groundwater regimes, responding over a much greater time period (many decades) than *B. littoralis* (<10 years). Overall, changes in species distribution and vigour were primarily caused by long-term declines in groundwater levels resulting from the cumulative effects of abstraction and below average annual rainfall (low groundwater recharge). Long-term distribution trends and overall observed reductions in population vigour within the transects may be a function of the species' dependency on groundwater to fulfil its water requirements. This may explain declining vigour and tree numbers of *B. ilicifolia* on the Gnangara Groundwater Mound, as this species is considered an important indicator of significant long- and short-term reductions in groundwater levels.

Keywords: *Banksia* woodland, *Melaleuca*, groundwater, Gnangara Groundwater Mound, rainfall

Introduction

A large proportion of the total water usage (~70%) by metropolitan Perth is obtained from groundwater resources, which is used to supply domestic, industrial and agricultural water requirements (Davidson 1995). The Gnangara Groundwater Mound is the larger of the two superficial unconfined shallow aquifers from which water is abstracted. Groundwater abstraction lowers the water table, and may have a detrimental impact on ecosystems dependent on shallow groundwater (Kite & Webster 1989). To facilitate adaptive management of groundwater resources and conservation of native groundwater-dependent vegetation, we require greater knowledge of vegetation response to changes in groundwater levels than is currently available.

In the context of future long-term reductions in groundwater levels caused by abstraction and decreasing rainfall recharge, several authors have commented on potential changes in the overstorey composition of the *Banksia* woodlands overlying the Mound. In particular a shift in composition towards species capable of tolerating extended periods of drought has been predicted and/or observed (Havel 1975; Aplin 1976; Heddle 1980; Dodd & Heddle 1989), especially in low-lying areas where groundwater levels are typically at their shallowest. This could mean a decrease in abundance and distribution of drought sensitive tree species that fringe the many wetlands (*e.g. Banksia littoralis* R Br, *Melaleuca preissiana* Schauer) or inhabit low lying areas (*e.g. B. ilicifolia* R Br), and their replacement by the more drought tolerant *B. attenuata* R Br or *B. menziesii* R Br (Havel 1975; Muir 1983). Muir (1983) also suggested that *B. menziesii* could be expected to replace *B. attenuata* on the dune slopes, where local groundwater levels are at their deepest.

To examine changes in vegetation structure and composition, a triennial monitoring regime was established in 1976 by the Western Australian Forestry Department, and later the Water Authority of Western Australia, to coincide with the development of abstraction bore fields on the Mound. This monitoring program utilized existing and new transects that were positioned along topographical gradients (see Heddle 1980), starting at a localized depression and ending at a high point in the landscape, usually a dune crest. Existing transects were established in 1966 as part of an assessment of site suitability for pine plantations (Havel 1968).

This paper utilizes parts of the resulting datasets to investigate changes occurring between 1966 and 1996 in distribution and potential vigour of the dominant *Banksia* and *Melaleuca* overstorey species present within four transects, and complements a similar study involving myrtaceous shrub species (Groom *et al.* 2000a). In particular, this paper examines the changes in overstorey distribution and vigour as a function of the transect's hydrological and fire history and presence of plant disease, particularly the dieback fungus *Phytophthora cinnamomi*.

Methods

Study area

The Gnangara Groundwater Mound (Fig 1) underlies seasonal and permanent wetlands, pine plantations and extensive areas of native *Banksia* woodlands of the Swan Coastal Plain, north of Perth, Western Australia. The Mound is one of two large, shallow unconfined aquifers on the Plain that are recharged directly by rainfall. 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 vegetation of the three main dune systems (Bassendean, Spearwood and Quindalup) is dominated by an evergreen *Banksia* overstorey with occasional *Eucalyptus* and *Allocasuarina* stands, 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 northern Swan Coastal Plain experiences a dry mediterranean-type climate (Beard 1984), with hot dry summers (December-March) and cool wet winters (June-August) with a long-term average of 870 mm annual rainfall recorded at the Perth meteorological station.

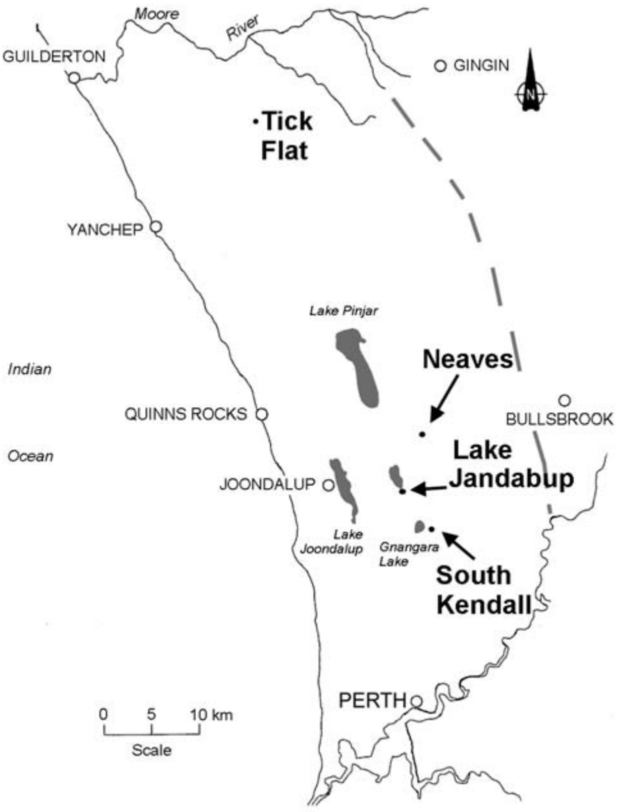

Figure 1. Location of four long-term vegetation monitoring transects (Lake Jandabup, Neaves, South Kendall, Tick Flat) on the northern Swan Coastal Plain, in relation to town sites and local lakes. Eastern boundary of coastal plain is represented by a dashed line. Underlying this section of the Plain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

Vegetation transects

Long-term vegetation monitoring of the *Banksia* woodlands overlying the Gnangara Groundwater Mound initially started in 1966 when four transects (named Neaves, South Kendall, Tick Flat and West Gironde) were established to provide an ecological assessment of suitable sites for establishing pine plantations (Havel 1968). These four transects were re-monitored in 1976 (Heddle 1980), when it was decided that these four transects would provide useful data on the floristic composition on the Mound prior to the commencement of public groundwater abstraction. In 1976, transects adjacent to Lake Jandabup were established, in response to concerns about the effects of decreasing lake levels on the fringing native vegetation. All transects occur within conservation reserves or on crown land and are positioned along a topographical gradient, commencing at a localized depression (dampland or wetland) and ending at a high point in the landscape, usually a dune crest.

From 1976, the plant species occurring within these transects were surveyed every 2-3 years during September and October of the designated year, and the transects are continually monitored as part of the current groundwater management program. The only exception is the West Gironde transect which was partially cleared for urban development in 1987. 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 are located on the southern part of the Mound (Fig 1) within 10 km of each other and within close proximity (<2 km) to groundwater production bores. The Tick Flat transect (31° 24′ S, 115° 42′ E) is >25 km from the nearest production bore. Transects varied from 200 to 520 m in length, and were subdivided into two parallel bands (each 20 m wide) down the length of the transect. Each band was further subdivided into 20 x 20 m plots for overstorey assessment. For this paper, data from the two longitudinal parallel bands that formed each transect were pooled because of their topographical and groundwater depth similarity. Thus, instead of using data from two adjacent 20 x 20 m plots along the same topographic position as separate entities, overstorey data was combined to form one 20 x 40 m plot.

For each assessment, the number of stems at breast height (~1.5 m) and total number of adult plants per overstorey species within a plot were recorded. Adult plants were defined as those plants $\geq$ 1.5 m in height and showing signs of being reproductively active. For individual trees, a subjective assessment of potential vigour was recorded for each major branch at breast height based on foliage condition. Three categories of potential vigour were used; healthy (majority of foliage was green), stressed (majority of foliage was orange/brown), or dead (entire foliage was orange/brown or no leaves present). Because any one plant can have multiple branches at breast height, each individual tree was categorised as healthy, stressed or dead based on the condition of the majority of branches. Trees recorded as dead were still classified as dead in subsequent years unless they had fallen over.

To examine the relatively long-term changes in overstorey vigour and distribution occurring within the transects, only data collected at approximately 10 year intervals (1966, 1976, 1987 and 1996) were assessed. In contrast to the other transects, the initial monitoring of overstorey species at Lake Jandabup transect commenced in 1976. The transect was re-monitored in 1987, but unlike the other transects was not remonitored in 1996. In the absence of 1996 data, data obtained from monitoring in 1993 was used for comparing long-term changes in species distribution and vigour.

Hydrological data, fire history and dieback

Relating species distribution and changes in adult abundance to past groundwater levels experienced by the transects was difficult because past groundwater levels within the transects have not been monitored. Instead, species response to past groundwater regimes were analysed using hydrographical data (1975 onwards) from the closest groundwater monitoring bore to the transects (usually up to 1 km away from a transect) from data provided by the Water and Rivers Commission. Current groundwater levels within the transects were measured in June 1998 with a hand auger, every 30 m along the transects up to a depth of 10 m, the limit of the soil auger used.

Soil samples collected from each transect were analysed by the Western Australian Department of Conservation and Land Management for the presence of the dieback fungus *Phytophthora cinnamomi* (see Shearer & Dillon 1995 for details), a common cause of death in *Banksia* woodlands on the Swan Coastal Plain (Shearer & Hill 1989; Shearer & Dillon 1996). The fire history of each transect between 1966-1996 was obtained from maps and microfiche records of the Department of Conservation and Land Management, Western Australia. Annual rainfall data (1960 onwards) were obtained from the Western Australian Bureau of Meteorology, for the Perth meteorological station.

Results

Neaves transect

Between 1976 and 1996, there was an overall reduction in percentage healthy trees of the five *Banksia* and one *Melaleuca* species occurring within all transects (Fig 2). Within the Neaves transect, the lowest proportion of healthy trees for all species was recorded in 1987, coinciding with a decrease in the number of healthy trees for all species except *B. attenuata*. The proportion of healthy trees increased by 1996, although not to the same level as in 1976. Between 1976 and 1996, the greatest reduction in percentage healthy trees was for *B. menziesii* (40%), which was the only species to have a substantial reduction in number of healthy plants over this period.

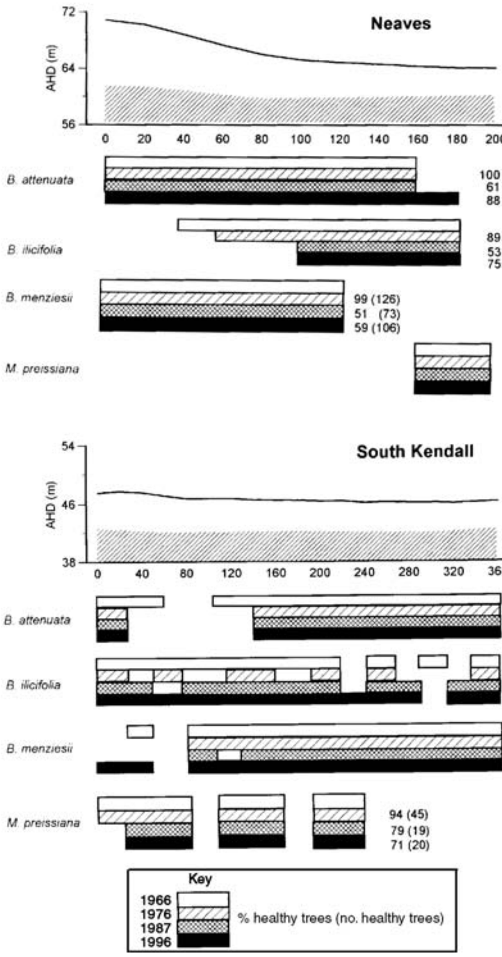

Figure 2. Distribution and vigour of overstorey species within the Neaves and South Kendall transects. Data shown for 1966 (open bar), 1976 (light hatching), 1987 (cross-hatching) and 1996 (solid bar) (see insert). Numbers represent the percentage of trees for a given species that were 'healthy' (majority of the foliage was green) when monitored with the total number of healthy trees in parenthesis. Transect topography (Australian Height Datum, AHD) and groundwater depth profiles (single hatching) are provided for comparative purposes. Groundwater data were collected in August 1998.

By 1996, *B. attenuata* increased in distribution within the Neaves transect, occurring further downslope. *B. ilicifolia* decreased in distribution, losing trees that had previously occurred in the upper and midslope regions of the transect. Despite the restricted distribution of *B. ilicifolia*, the number of healthy trees present did not significantly change, although there was considerable population re-structuring. The distribution of *B. menziesii* and *M. preissiana* did not change throughout the 30 year monitoring history. In 1998, depth to groundwater within the transect varied from 4 m (lower slope) to >10 m (dune crest).

South Kendall transect

The South Kendall transect is different from the other transects described in this paper, with most of the transect represented by a flat low lying sandplain, rising to a relatively small dune crest (Fig 2). In 1998, depth to groundwater within the transect varied from 3.7 m (lower slope) to 5.0 m (dune crest). The distribution of *B. ilicifolia* and *B. menziesii* varied from year to year, with their distribution in 1996 similar to that recorded in 1966. *M. preissiana* occurred on the South Kendall dune crest in 1966 and 1976, but was not recorded thereafter. In 1966 *B. attenuata* occurred on the dune crest and associated slopes, as well as most of the lower lying areas of the transect. By 1976, this had contracted to its current distribution.

The number of healthy *B. attenuata* trees doubled from 1976 to 1996, and the overall percentage of healthy trees remained relatively high (80-88%). In contrast, the number of healthy *M. preissiana* trees and percentage of healthy trees decreased over the same time period. Both *B. ilicifolia* and *B. menziesii* had a decrease in percentage healthy trees between 1979 and1996, although the number of healthy *B. ilicifolia* trees increased.

Tick Flat transect

Tick Flat had the greatest change in population vigour over time, with only 8-35% of the main overstorey species trees in 1996 categorised as healthy, compared with 67-100% in 1976 (Fig 3). The exception was *B. prionotes,* with 72% of trees categorised as healthy. *B. prionotes* was the only species at Tick Flat to significantly increase in distribution within the transect since 1976. *M. preissiana* and *B. littoralis* had the greatest reduction in population size and vigour. Within the lower slope section of the Tick Flat transect, the number of healthy *B. littoralis* trees fell from 67 to 2 between 1976 and 1996. Further upslope (within the middle slope section of the transect) the number of healthy *M. preissiana* trees fell from 20 to 2 over the same 20-year period. In 1996, the two remaining healthy trees of *M. preissiana* and *B. littoralis* represented 8-10% respectively of the existing populations. *Banksia ilicifolia* and *B. menziesii* also had a significant reduction in number of healthy trees present within the transect. *B. menziesii* was the only species to show a relatively substantial increased in distribution within the transect since 1966; *B. littoralis* was the only species to have had a substantial reduction in distribution over the same time period. In 1998, depth to groundwater within the transect varied from 6.9 m (lower slope) to >10 m (dune crest).

Lake Jandabup transect

At Lake Jandabup, all overstorey species occurred on the mid- and upper slopes of the transect, where groundwater depth varied from 1.5 m (midslope) to 6 m (upper slope) as measured in June 1998 (Fig 3). All species, except *B. ilicifolia,* displayed a decrease in percentage and number of healthy trees within the transect between 1976-1993. For *B. ilicifolia,* the number of healthy trees increased 3-fold, accounting for 71% of the population by 1996. Distribution of the four most common species at Lake Jandabup did not change significantly over the monitoring period.

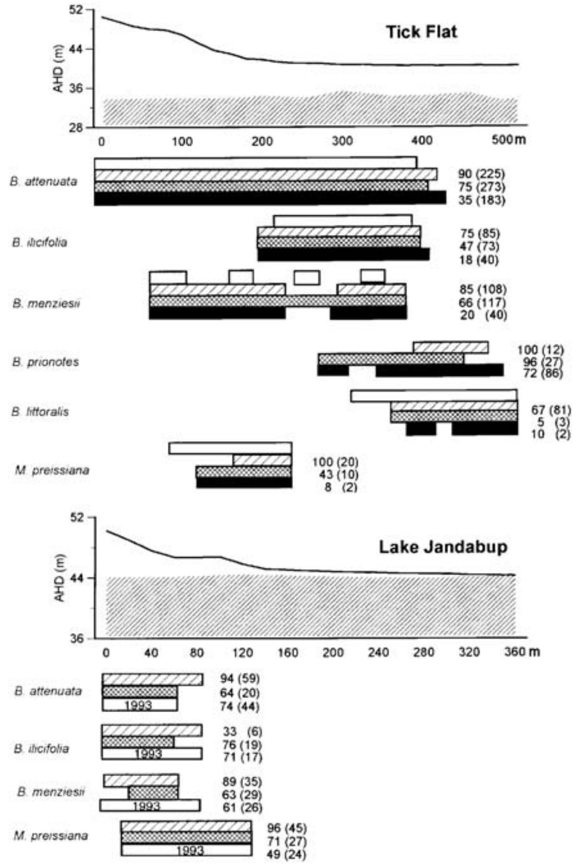

Figure 3. Distribution and vigour of overstorey species within the Tick Flat and Lake Jandabup transects. Data shown for 1966 (open bar), 1976 (light hatching), 1987 (cross-hatching) and 1996 (solid bar). For Lake Jandabup 1993 data was used in the absence of 1996 data. See Fig 2 for further details.

Hydrology

Similar annual hydrological cycles were observed at the closest monitoring bores to the four transects. Maximum groundwater depth occurred in March-April resulting from a 3-4 month period of summer drought (Fig 4). Annual groundwater recharge is dependent entirely on rainfall, occurring 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 4A), coinciding with periods of below average rainfall (Fig 4B). 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 4B) associated with an overall decrease in groundwater levels ranging from 0.2 m (Neaves) to 0.8 m (Tick Flat).

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

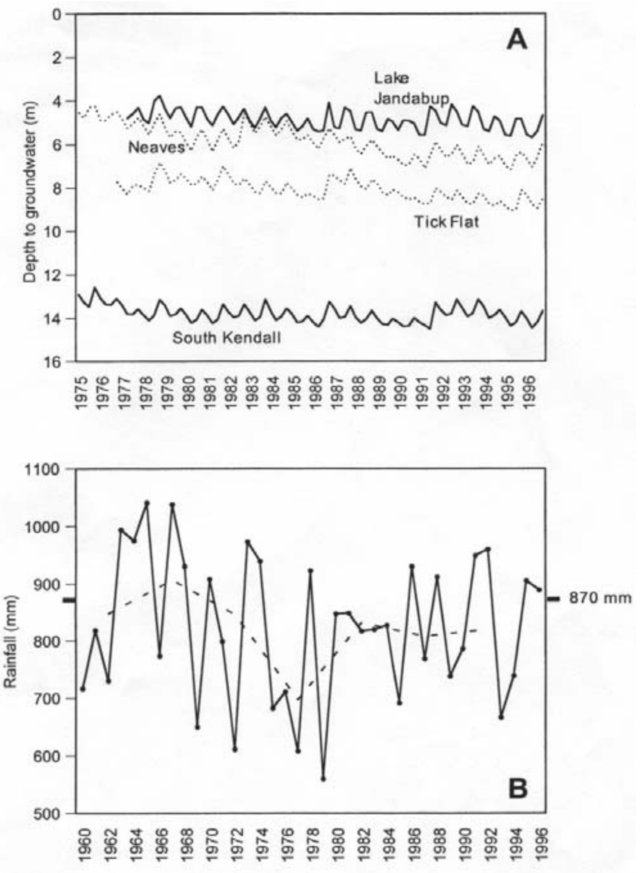

Figure 4. **A:** Hydrographs from the closest groundwater monitoring bores to the four vegetation transects. **B:** Total (solid line) and 5 yearly mean (dashed line) rainfall for Perth for 1960-1996. Perth's long term average annual rainfall is 870 mm.

comparison, groundwater depths decreased by 0.2 and 0.4 m at South Kendall and Lake Jandabup respectively. Below average rainfall in 1989 and 1990 (750 and 790 mm respectively), may have caused a decrease in water levels in 1991 at all four monitoring bores as a direct result of poor groundwater recharge.

Fire history and dieback

Fires have been relatively uncommon, with only two or three fires occurring within each transect between 1966-1996. The most recent fire event within the four transects occurred during 1980-83 (Neaves, South Kendall, Lake Jandabup) and 1985-86 (Tick Flat). The Lake Jandabup transect experienced two fires within 5 years of establishment and has not been burnt since. South Kendall was the only transect to record the presence of *Phytophthora cinnamomi* throughout its monitoring history, with the fungus occurring predominantly within the low-lying areas (Heddle 1980).

Discussion

Long-term monitoring of the native vegetation overlying the Gnangara Groundwater Mound have shown that the floristic composition has been changing continuously as a result of periods of below average annual rainfall, spread of pathogens, impacts of fire, prolonged summer drought and groundwater abstraction (Heddle 1980; Dodd & Heddle 1989; Groom *et al.* 2000b). Of these, neither fire nor *P. cinnamomi* infection can be viewed as having had any significant influence on the distribution and overall vigour/health of *Banksia* and *Melaleuca* overstorey populations within the four study transects, with *P. cinnamomi* detected only within South Kendall. Fire has had a relatively limited impact on vigour, as it has been relatively infrequent (2 or 3 fires during the 30 years) within the transects, although the ability of a particular species to survive a fire depends on the fire's intensity and frequency, and season of burn (Hopkins & Griffin 1989; Bell *et al.* 1992). All overstorey species investigated in this paper recover post-fire via epicormic shoots, except *B. prionotes* which is killed by fire.

Current distribution trends of overstorey species on the Mound may be a function of their groundwater dependency and water-use requirements. The distribution of a species within the landscape is closely associated with groundwater depth, and hence topography, whereby species which rely almost exclusively on groundwater throughout the year (e.g. *Banksia littoralis*, S Zencich, Edith Cowan University, personal communication) typically occur in areas where groundwater is relatively shallow and easily accessible. Current work (S Zencich & R Froend, Edith Cowan University, personal communication) shows that during periods of summer drought, species restricted in distribution by groundwater depth (*e.g. B. ilicifolia*, 2-10 m) are more reliant on groundwater sources than species inhabiting a wider range of groundwater depths (*e.g. B. attenuata*, 2->30 m). If reductions in groundwater levels observed over the past 20 years continue, as a result of below average rainfall and increased groundwater abstraction, groundwater requirements may ultimately determine the topographical distribution of the Mound's overstorey species.

Of all the transects examined in this paper, Tick Flat showed the greatest overall reduction in tree vigour (based on foliage/canopy coloration) over the 30 year monitoring period. Prior to the 1960s, the lower section of Tick Flat was a swamp, which has only recently been filled in naturally with sand from the surrounding dunes (Heddle 1980). Filling in of swamps and damplands is a common scenario impacting other areas of the Swan Coastal Plain, and is primarily a result of decreasing groundwater levels (Muir 1983). It is within such low-lying areas that the greatest loss of tree vigour occurred at Tick Flat, particularly of *B. littoralis* and *M. preissiana*, two species favouring winter-wet locations (Havel 1968).

The combination of reduced recharge and regional drawdown are the most likely cause for the observed decline in health and population numbers of *B. littoralis* at Tick Flat. This population has been gradually replaced by the more drought-tolerant *B. prionotes* (Heddle 1980). The ability of *B. prionotes* to tolerate falling groundwater levels may be due to its fast-growing nature and a deep, dimorphic root system (Pate *et al.* 1998). *B. prionotes* has been shown to access groundwater during the dry summer period via its main tap root, switching to rainfall and soil moisture acquired from lateral and other shallow roots during the wet seasons (Dawson & Pate 1996). This doesn't occur in *B. littorialis*, as both lateral and tap roots access groundwater throughout the year (S Zencich & R Froend, Edith Cowan University, personal communication).

Groundwater levels measured at the closest long-term monitoring bore to Tick Flat have decreased steadily since the 1970s, which is most likely a direct result of poor recharge caused by extended periods of below average rainfall (Davidson 1995). However, despite Tick Flat not being directly influenced by nearby/local groundwater abstraction, we cannot discount the regional effect of abstraction on Tick Flat's groundwater levels. All transects displayed an overall reduction in overstorey vigour regardless of their proximity to abstraction borefields, with the greatest changes in vigour occurring in transects that on average have a current groundwater depth greater than 6 m (*i.e.* Neaves and Tick Flat). Within these two transects groundwater levels have decreased by up to 2 m over a 30-year period, resulting in reduced groundwater availability to overstorey and understorey species.

Summer groundwater dependency may also explain the decline in proportion of healthy *B. ilicifolia* trees at Tick Flat and the loss of individuals on the midslope of Neaves, as both transects have been subjected to relatively high levels of groundwater drawdown. Within the short-term (<10 years) declining *B. ilicifolia* populations can be attributed to poor groundwater recharge, caused by excessive localised groundwater abstraction and/or below average annual rainfall (Groom *et al.* 2000b). In particular up to 80% reduction in *B. ilicifolia* tree numbers has been observed when groundwater levels fell by 2 m between two consecutive summers, in conjunction with extremes in summer temperature (Groom *et al.* 2000b). Reductions in the vigour and population structure of *B. ilicifolia* is considered (*e.g.* Havel 1968; Heddle 1980; Muir 1983) an important indicator of significant long- and short-term reductions in groundwater levels on the Mound and other shallow aquifers on Western Australia's Swan Coastal Plain, although further studies are required to explain the significance and potential impacts of declining groundwater levels on this drought sensitive species.

Unlike the *Banksia* species, *Melaleuca preissiana* showed no change in distribution within the transects over the 30 year period and was typically confined to the low-lying areas. It has previously been concluded that the response of *M. preissiana* populations to altered water regimes occurs over a much greater period of time than for co-occurring species, and is measured in order of decades (Froend *et al.* 1993). Successful seedling recruitment and establishment is essentially episodic in nature, reliant on the combination of seed release, high soil moisture levels and/or flooding events (Froend *et al.* 1993). In contrast, adult plants are more tolerant of water regime extremes (from seasonal flooding to moderately deep groundwater levels), and are often are the only remaining signs of the location of former swamps/damplands. Because *M. preissiana* populations are relatively restricted in their topographical distribution on the Mound, it is assumed that they are groundwater-dependent although their groundwater requirements have yet to be quantified. As for *Banksia* species, the decreased vigour of *M. preissiana* populations over time is most likely a result of decreasing groundwater levels, particularly in areas that once had shallower groundwater levels (*i.e.* Tick Flat).

Muir (1983) suggested that as groundwater levels continue to decline on the Gnangara Groundwater Mound, "*B. menziesii* can be expected to replace *B. attenuata* on dune slopes, being better adapted to drier conditions. *Banksia attenuata* will probably persist in damper areas but *B. ilicifolia*, being very dependent on moisture availability, may succumb completely." However, Muir's concept of overstorey succession in response to groundwater drawdown has not been observed within the study transects, although the loss of *B. ilicifolia* and the potential 'replacement' by *B. attenuata/B. menziesii* has been observed elsewhere on the Mound (Groom *et al.* 2000b). Between 1966 and 1996, *B. attenuata* increased its distribution (at Neaves, Tick Flat and Lake Jandabup), moving further down-slope to lower groundwater depths. These areas may have previously experienced shallow groundwater depths. Soil moisture levels in these lower slope regions have become progressively drier as groundwater levels decreased over time (Heddle 1980) providing a more suitable environment for *B. attenuata* recruitment and long-term survival. As previously mentioned, decreasing groundwater levels may also account for the loss of *B. ilicifolia* from the midslope of Neaves transect, although it is unlikely that *B. ilicifolia* has been 'replaced' by *B. attenuata* or any other overstorey species. The 'replacement' of *B. attenuata* by *B. menziesii* on the dune slopes has not occurred within the study transects, although there is some evidence to suggest that *B. menziesii* is more drought tolerant than *B. attenuata* (Groom *et al.* 2000b), despite exhibiting similar seasonal water relations (Dodd & Bell 1993). Both species co-dominate the *Banksia* woodlands of the Swan Coastal Plain, inhabiting a range of topographical positions within the landscape, and are know to be groundwater-dependent at groundwater depths of 6-7 m (Dodd & Bell 1993), but do not have access to groundwater at deeper depths of >10 m (Farrington *et al.* 1989).

Sustainable management of Perth's shallow groundwater resource must be a major objective to ensure adequate supply to the urban and industrial environments as well as maintaining the intricate link with groundwater-dependent vegetation and wetlands. Management of water extraction is based on a water resources allocation process, which includes the determination of environmental water requirements (Anon 1992). These are determined by identification of values and/or beneficial uses of water-dependent components of the environment, and the establishment of water requirements for ecosystem protection. For the overstorey component of *Banksia* woodlands on the Gnangara Groundwater Mound, identifying environmental water requirements on a plant-community basis needs to take into account the underlying topography and watertable levels, the impact of local or regional groundwater drawdown caused by abstraction, and the impacts of reduced groundwater recharge resulting from below average rainfall. The decreasing trend in average rainfall currently being experienced may be a part of a longer cycle that should show an increasing trend in the future (Davidson 1995). However, it has been predicted that by

2030, Perth may experience up to 10% less winter rainfall, and 5% more, or less, summer rainfall. By 2070, winter rainfall may decrease by 20% with summer rainfall increasing/decreasing by 10% (Anon 1996). Future changes in the groundwater recharge rate may ultimately result in a decline in population vigour and restricted distributions of those overstorey species that are dependent on relatively shallow groundwater sources.

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