

Mangrove, saltmarsh and peripheral vegetation of Jervis Bay

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Abstract

Clarke, P.J.* CSIRO Division of Fisheries, P. O. Box 94, Vincentia, NSW, Australia 2540) 1993. *Mangrove, saltmarsh and peripheral vegetation of Jervis Bay*. *Cunninghamia* 3(1): 231–254. Studies of the mangrove and saltmarsh vegetation of Jervis Bay were undertaken for inventory and baseline purposes. Vascular plant species composition, distribution and abundance were quantitatively measured. The vascular flora consists of about 140 species, of which 15 are introductions. Nine species are found at or near their distributional limits around Jervis Bay. The major ordination axes are interpreted as elevation and variability in moisture content. Classification of sites produced 12 complexes after fusion of 30 smaller groups. These complexes have the provisional rank of an association in phytosociology and can be recognised on aerial photographs. The area contains a number of species and vegetation types that are rare or absent from other locations in NSW. Jervis Bay is now a reference system against which changes in the distribution and abundance of intertidal vascular plants can be measured. Such information is fundamental to the management of Jervis Bay and other areas of estuarine vegetation in NSW.

Introduction

Mangroves and saltmarshes are plant assemblages that are periodically inundated with seawater and usually grow in waterlogged saline soils. In Jervis Bay, mangrove and saltmarsh plants are mainly found in six estuaries, although smaller pockets occur in minor creeks, lagoons and on rock platforms. General descriptions of the extent and composition of the vegetation are given in Adam and Hutchings (1987), and West (1987). Major mangrove, saltmarsh and seagrass stands have also been mapped by West *et al.* (1985) at a scale of 1:25 000 based on limited ground truthing.

A baseline study of the mangrove and saltmarsh vegetation was initiated in 1987 as a part of a major study of the marine environment in Jervis Bay. Detailed quantitative information on the distribution, abundance and performance of mangrove and saltmarsh vegetation was required as reference or baseline data, so that any change could be detected after developments in the bay. Such detailed data prior to major developments have been generally lacking for many Australian ecosystems.

Measures were made at the assemblage, population and individual levels of biological organisation over a wide range of spatial and temporal scales. This paper describes: 1) the species composition of the vegetation, 2) the distribution of species across environmental gradients, 3) the population structure of the major species, and 4) the assemblage or community patterns.

Study site

Jervis Bay is a circular marine embayment (35° 07'S, 150° 42'E) with a maximum depth of 30 m and a surface area of 102 km². In comparison with other embayments, the c. 400 km² catchment of Jervis Bay is small relative to the surface area of the bay (West

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1987). The mangrove, saltmarsh and fringe forests are found in the tidal creeks that enter the bay and in a few instances on rock platforms. The climate is mild with a mean daily temperatures range of 13.6°C to 19.9°C. The mean annual rainfall for Point Perpendicular is 1230 mm, although the mean rainfall was higher from 1986 to 1991 (c. 1500 mm). Rainfall along the Illawarra section of the south coast is several hundred mm higher than that recorded for the far south coast. The tides in Jervis Bay are semidiurnal with a maximum range of about 2.2 m; the range is attenuated in the tidal creeks and inlets. Anthropogenic influences on the mangroves, saltmarsh and fringe forests have been moderate with some historic clearing and draining, currently these influences are limited to occasional incursions by trail bike or four wheel drive vehicles.

Methods

Survey design

Sampling was designed to measure variables over hierarchies of space and time so that estimates of spatial and temporal variance could be made (see Underwood 1991). In the case of long-lived mangrove and saltmarsh plant species, the survey was designed to assess spatial variation in the distribution and abundance of mangrove and saltmarsh species. Six tidal inlets were sampled in Jervis Bay: Cararma Creek; Wowly Gully; Callala Creek; Currumbene Creek; Moona Moona Creek; and Flat Rock Creek (Figure 1). Each inlet was divided into 500 m sections and transects were randomly placed in these sections at right angles to zonation of vegetation. Adjacent to each transect, 50 X 20 m plots were established. These plots were subjectively located at low, mid and high tidal elevations in structurally similar vegetation. Four replicate quadrats of 5 X 5 m were placed within these plots in a random manner (Figure 1).

Species composition and distribution

Floristic lists were compiled from quadrat, transect samples and field reconnaissance. Voucher specimens have been collected for most species and are held by the John Ray Herbarium at The University of Sydney. Identifications were determined by the Royal Botanic Gardens, Sydney. Nomenclature follows that used by Jacobs and Pickard (1981) and Harden (1990, 1991).

Estimates of cover for each species present in quadrats were made in the following classes: 1 (less than 5%), 2 (5–20%), 3 (21–50%), 4 (51–80%), 5 (81–100%). In order to obtain information on the structure of mangrove communities, *Avicennia marina sensu lato* was divided into five classes based on information about tree height and shape. These classes (attributes) were: seedlings; shrubs <2 m; shrubs 2–5 m; single-stemmed trees >5 m; and multi-stemmed trees >5 m. Measures of cover were initially made from December 1988 to February 1989. A random subset of plots in four creeks was resampled from April to July in 1991 so that temporal comparison of species richness could be made. These data were analysed in a mixed ANOVA where time, creeks, and plots nested in creeks were treated as random factors, but elevation was treated as a fixed factor.

The presence/absence of plant species along each transect was also recorded at contiguous one metre intervals. These data were summed for ten metre lengths of each transect to provide frequency data for interpretation of aerial photography. Data for each creek were summed to provide an overall view of the most common species in

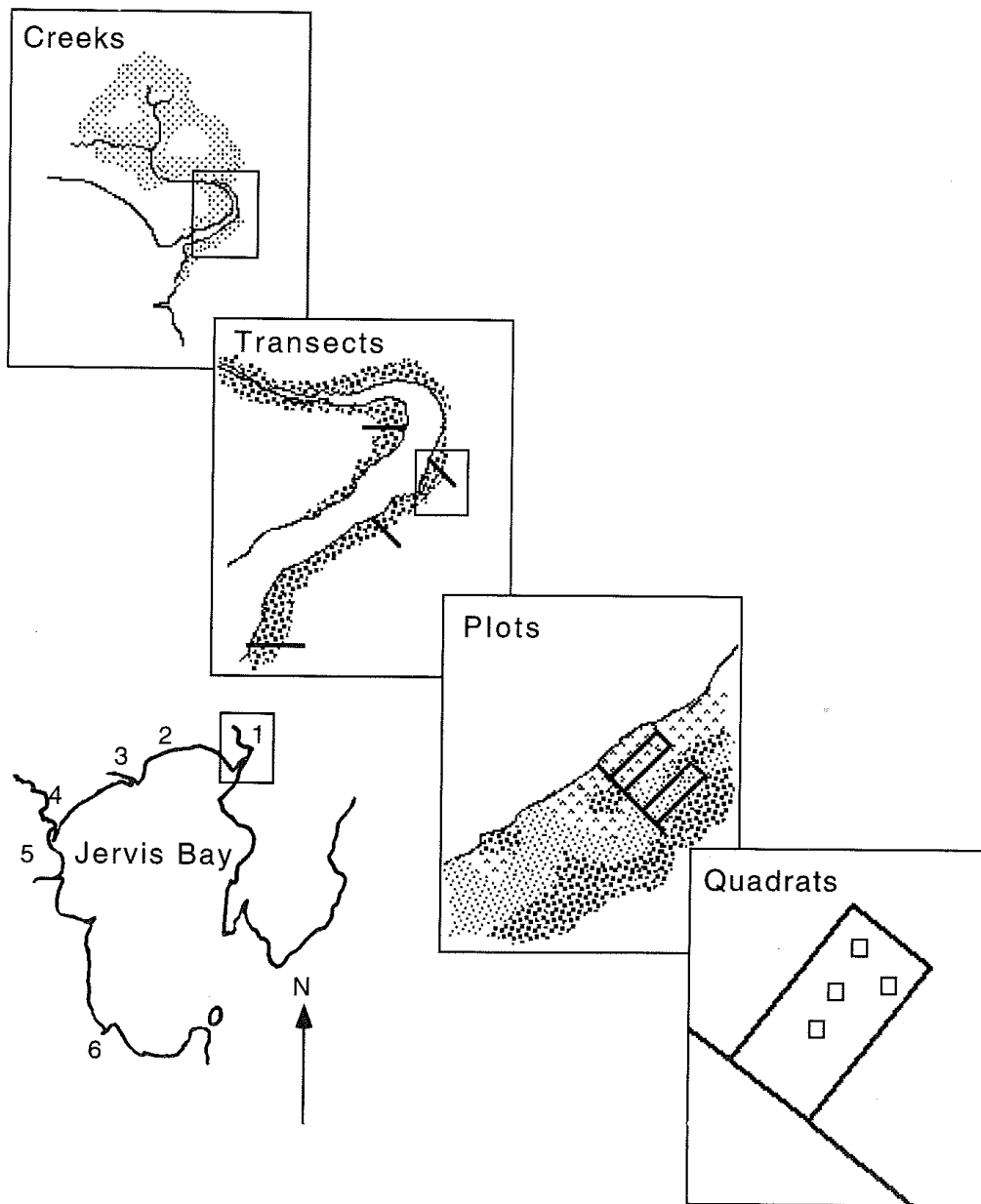


Figure 1. Diagrammatic representation of spatial hierarchies of sampling.

Jervis Bay. In addition to the summed transect data, finer resolution data were collected along four transects in both Cararma Creek and Moona Moona Creek. For each of these transects, the presence of species and the ground elevation were measured at one metre intervals.

Population measures

The density, height and girth of species that were common and could be counted as genets were recorded in the same stratified manner as the multivariate data. Subsets of these data were selected for balanced univariate analyses. Nested analyses of variance (ANOVA) were performed for each variable measured on each species; all spatial factors (plots, transects and creeks) were treated as random factors. Data were tested for homogeneity and no transformations were required. The skewed distributions of some data were not normalised as in most cases they were unimodal.

Ordination and classification of plant communities

Ordination and classification was performed only on quadrat data collected from the 1988–1989 samples (412 quadrats). Both sites (objects) and species (attributes) were classified into groups using a polythetic hierarchical divisive classification (TWINSPAN, Gauch 1982), and agglomerative hierarchical classification using the Bray–Curtis association measure with flexible UPGMA sorting strategy (PATN, Belbin 1987). The gradational nature of these data was explored through ordination and direct gradient (transect) analysis. Indirect gradient analysis using hybrid non-metric multidimensional scaling was used to ordinate the site data (Faith *et al.* 1987).

Mapping

Maps of the major plant community types were prepared from enlarged black and white aerial photography. Colour infra-red photographs were taken in January 1989 from a height of 2286 m (scale 1:15 000) by the NSW Land Information Group. The photographic prints were examined and selected frames were enlarged and rectified to 1:4 000 scale by the Australian Land Information Group. Boundaries of the main vegetation types were drawn onto clear film overlays with a 0.35 mm drafting pen. Boundaries were determined using an iterative process of comparing: (1) structural differences on the enlarged images; (2) tonal differences on the enlarged images; (3) colour differences on contact prints; (4) ground transect data; and (5) general ground reconnaissance. Delineation of patchy mangroves proved difficult so canopy gaps were drawn only where they exceed four metres in circumference on the ground. The clear film overlays were subsequently scanned and the digital data reduced to vectors for data management in a GIS and for cartographic output. Copies of the maps are not reproduced here, but will be archived in the library at the Royal Botanic Gardens, Sydney, and the library of CSIRO Division of Fisheries, Hobart.

Results

Species composition and distribution

The seagrass, mangrove, saltmarsh and fringe flora of Jervis Bay contains at least 140 species of vascular plants (Appendix I). The mangrove and saltmarsh vascular flora consists of about 38 species, of which five are exotic. The fringe forest flora is more diverse, containing 80 species with 11 introductions. About 103 species of vascular plants were recorded in transects and 65 species were recorded in quadrat samples.

Nine vascular plant species have been found at or near their geographical limits of distribution in Jervis Bay. Their distribution and population status, based on general observations, are briefly outlined (Table 1) which shows the concentration of these species in the Carama Creek and Wowly Gully saltmarshes.

Differences in species richness in 5 X 5 m quadrats were detected among plots, elevations and creeks, but not among combinations of space and time (Table 2, Figure 2). Significant differences were detected across time, but the magnitude of the difference, (less than one species) was so small that it seemed to be of little biological importance.

Caution should be used in comparing summed frequencies for common species across different creeks because no statistical comparisons of frequencies within or between creeks have been performed. The relative abundance, however, indicates changes in species dominance among creeks (Figure 3a-f). Summed data for all creeks provided an overall view of the relative composition for all transects in Jervis Bay (Figure 3f), and indicates that the saltmarsh graminoids were predominant at sites sampled.

Table I Estimates of abundance of saltmarsh species of biogeographic interest in Jervis Bay. + = populations with < 100 plants or < 100m² cover, ++ = populations 100-1000 plants or 100-1000m², +++ = populations >1000 plants or > 1000m². A = Carama Creek, B = Wowly Gully, C = Callala Creek, D = Currumbene Creek, E = Moona Moona Creek, F = Other Locations

Species	A	B	C	D	E	F
<i>Atriplex cinerea</i>	+	-	-	-	-	+
<i>Cuscuta tasmanica</i>	-	++	-	-	-	-
<i>Disphyma clavellatum</i>	-	-	-	-	-	+
<i>Distichlis distichophylla</i>	-	++	-	-	-	-
<i>Gahnia filum</i>	+++	++	+++	+	++	+
<i>Limonium australe</i>	+	-	++	-	+	-
<i>Sclerostegia arbuscula</i>	+++	-	-	-	-	-
<i>Stipa stipoides</i>	+	-	+	+	+	++
<i>Wilsonia backhousei</i>	++	+++	+++	-	+	+

Table II ANOVA for species richness in Jervis Bay

Source	df	MS	F denom.	F	P
Year	1	6.828	Residual	6.26	**
Creek	3	32.58	Plot(C)	3.67	**
Y x C	3	6.70	Y x E	0.74	ns
Elevation	2	386.30	C x E	23.99	***
Y x E	2	2.99	Residual	2.74	ns
C x E	6	16.10	Plot(C)	1.81	ns
Plot(C)	36	8.87	Residual	8.13	***
Residual	330	1.09			

n.s. not significant, ** P < 0.01, *** P < 0.001

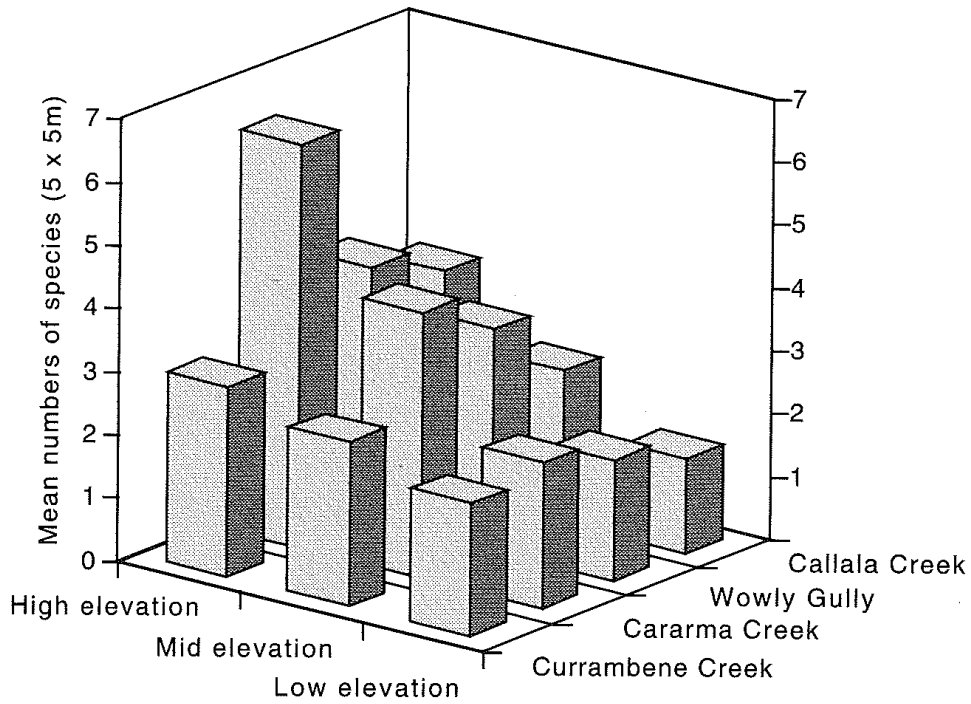


Figure 2. Mean species richness in 5 X 5 m quadrats across four creeks and three elevations in Jervis Bay.

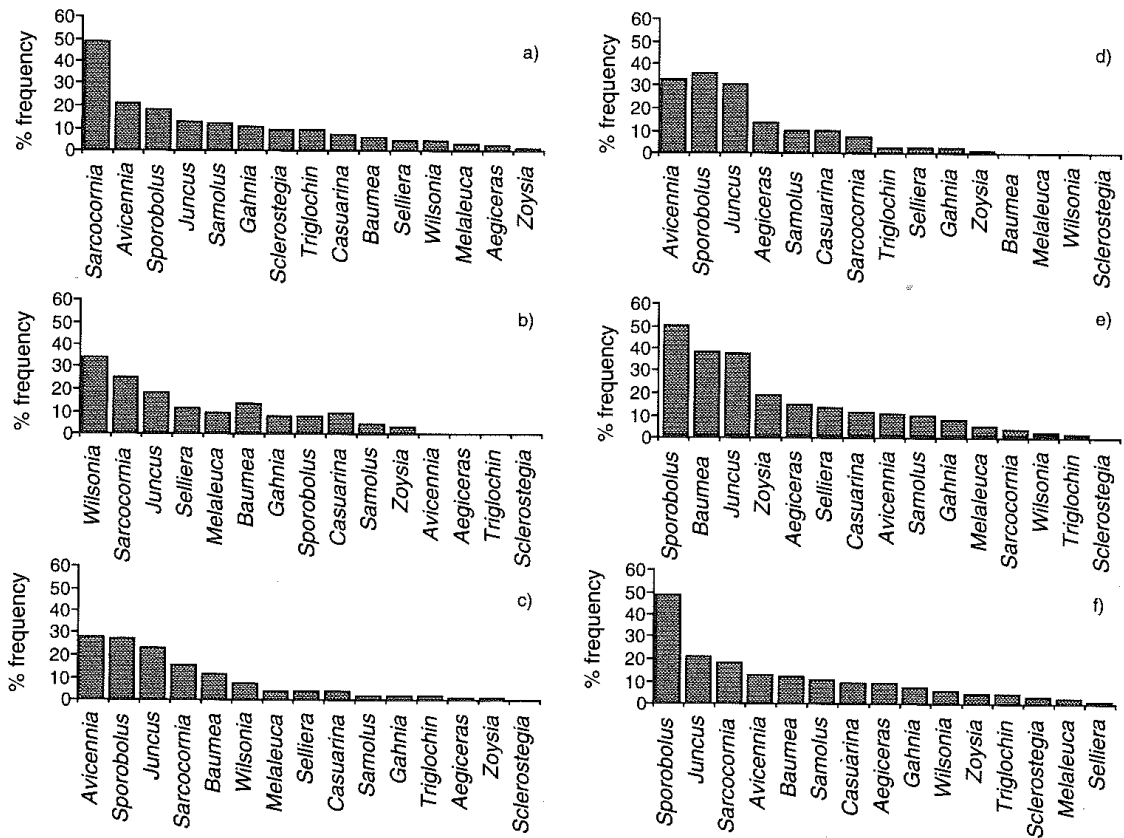


Figure 3. Percent frequency of the 15 most common species found in transects in a) Carama Creek, b) Wowly Gully, c) Callala Creek, d) Currambene Creek, e) Moona Moona Creek, and f) summed for all creeks sampled in Jervis Bay.

Fine resolution transect data for two transects in each of Carama Creek and Moona Moona Creek are shown (Figure 4a-d) and indicate the gradational nature of the mangrove-saltmarsh-fringe forest zonation.

Table III Summary ANOVA results for population measures of: D = density, H = height, S = seedlings, St = stems, G = Girth. *Av* = *Avicennia marina*, *Ae* = *Aegiceras corniculatum*, *Ca* = *Casuarina glauca*, *Ga* = *Gahnia filum*, *Sc* = *Sclerostegia arbuscula*,

Factor	<i>Av</i>			<i>Ae</i>			<i>Ca</i>			<i>Sc</i>		<i>Ga</i>
	D	H	S	D	H	St	D	H	G	D	H	D
Creek	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	-	-	n.s.
Plot(C)	***	***	n.s.	***	***	*	*	***	*	**	**	***

n.s. not significant, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Population measures

Two species of mangrove *Avicennia marina* and *Aegiceras corniculatum*, the saltmarsh shrub *Sclerostegia arbuscula* and the tree *Casuarina glauca* could be readily counted and measured as genets. In addition, tussocks of the saltmarsh sedge *Gahnia filum* could be counted. Data from subsets of all plots sampled for *Avicennia*, *Aegiceras* and *Gahnia* were used in nested analyses of variance designed to compare a range of spatial scales. In most cases significant differences were detected at the smallest spatial scale, i.e. among plots (Table 3).

Avicennia marina

Seedling densities in quadrats range from one to more than 100 plants, with the distribution being skewed toward low densities (Figure 5a). Adult and juvenile densities for the same quadrats ranged from 1-56 plants and were also skewed toward low densities (Figure 5b). The height of adult plants ranged from 50 cm to 8 m, although few plants exceeded 5 m (Figure 5c).

Aegiceras corniculatum

The density of shrubs ranged from 1-60 plants in quadrats, and most had at least two basal stems (Figures 6a). Heights ranged from 20-300 cm, with a predominance of plants in the 60-80 cm size class (Figure 6b).

Casuarina glauca

The density of adult trees ranged from 1-20 plants in quadrats (Figure 7a). Heights ranged from 1-16 m and were approximately normally distributed (Figure 7b). In contrast, basal girth was skewed towards the smaller size classes, ranging from 10-120 cm (Figure 7c).

Sclerostegia arbuscula

The density of shrubs ranged from 1-40 plants in quadrats of (Figure 8a), with heights from 10-120 cm (Figure 8b).

Gahnia filum

The density of tussocks in quadrats ranged from 1-20 and was strongly skewed toward low densities (Figure 9).

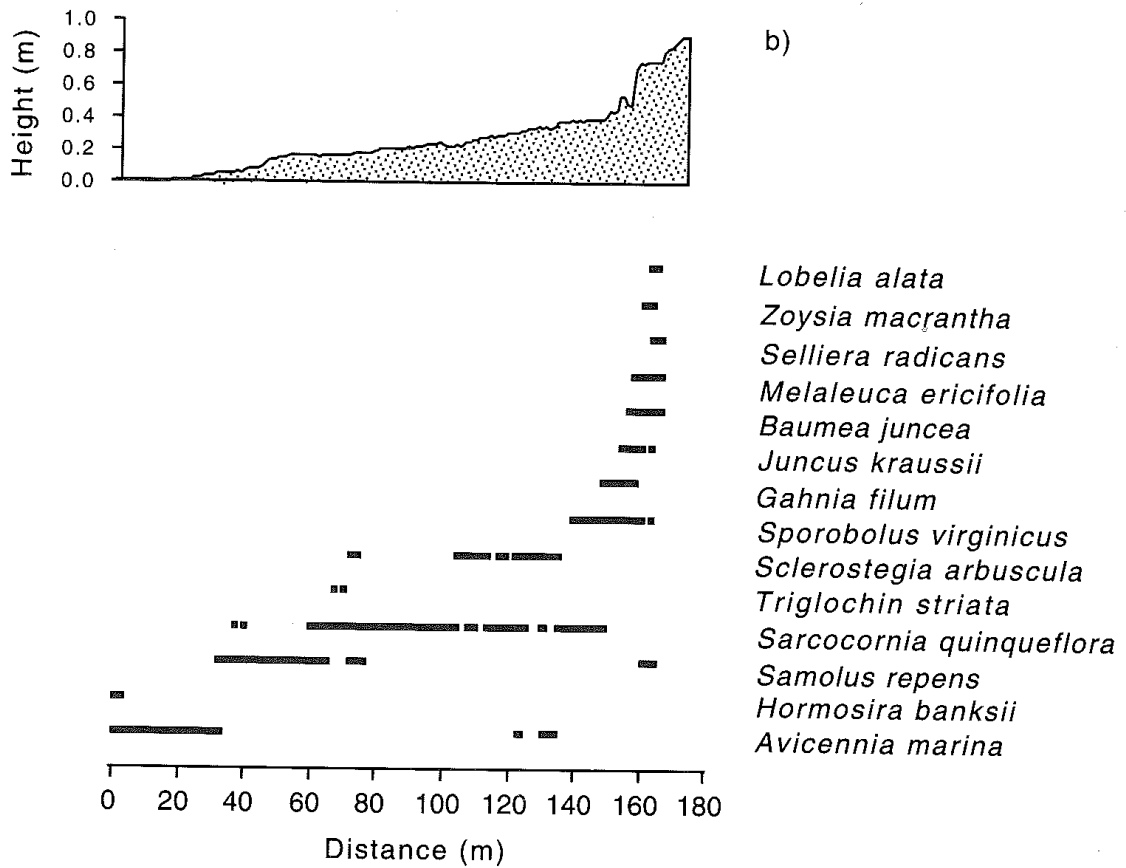
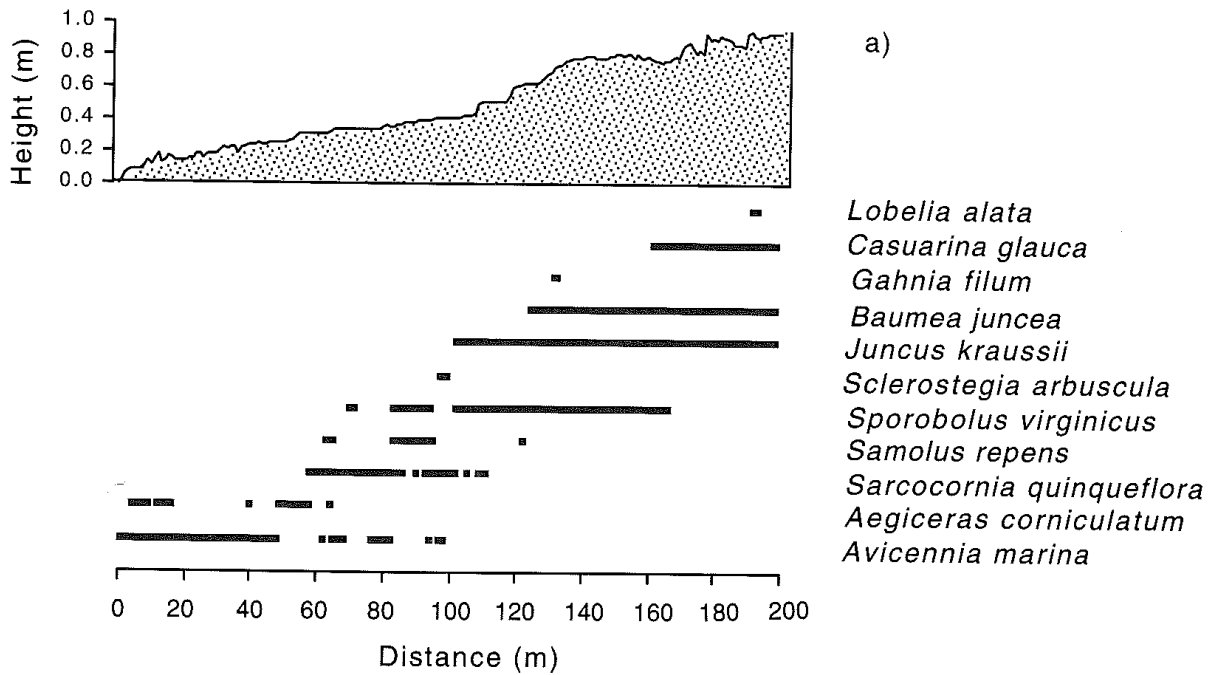
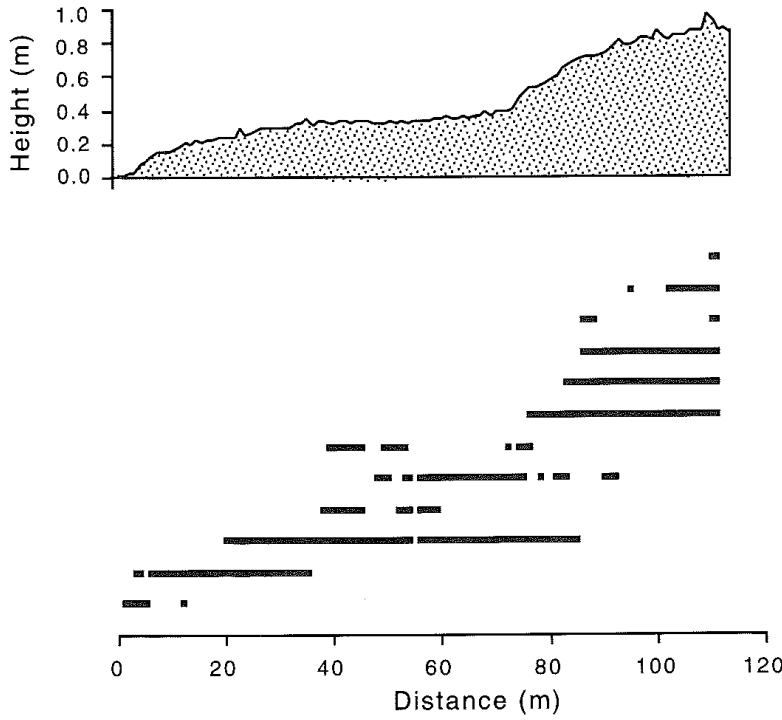
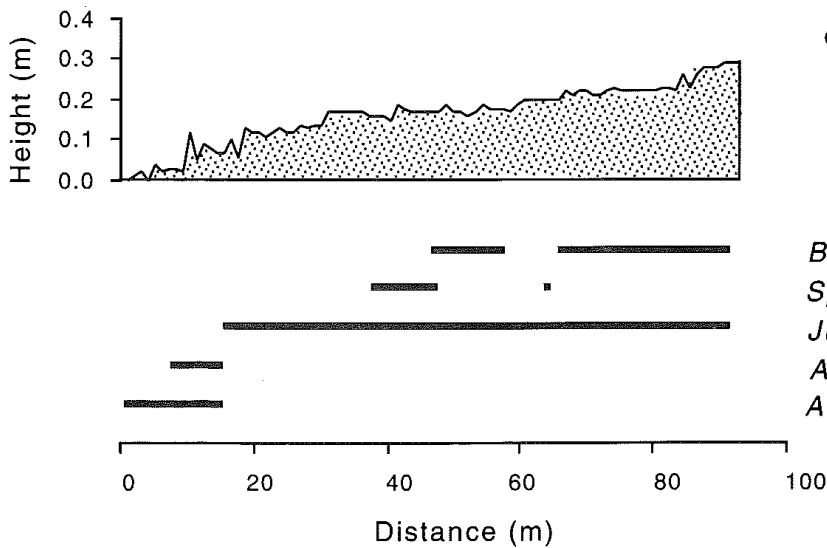


Figure 4. Distribution of plants and height above Australian Height Datum along two transects in Cararma Creek (a, b) and Moona Moona Creek (c, d).



c)

- Lobelia alata*
- Hemarthria uncinata*
- Casuarina glauca*
- Zoysia macrantha*
- Selliera radicans*
- Baumea juncea*
- Gahnia filum*
- Juncus kraussii*
- Samolus repens*
- Sporobolus virginicus*
- Aegiceras corniculatum*
- Avicennia marina*



d)

- Baumea juncea*
- Sporobolus virginicus*
- Juncus kraussii*
- Aegiceras corniculatum*
- Avicennia marina*

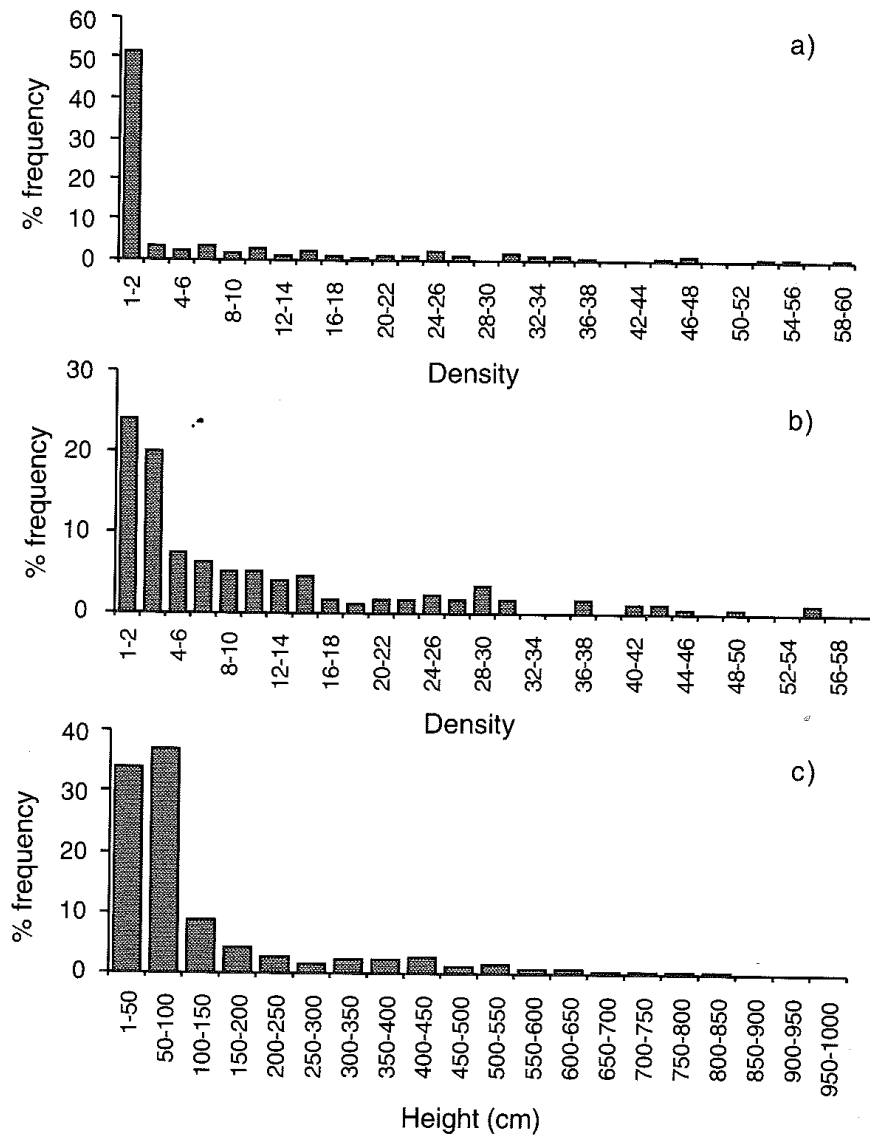


Figure 5. Percent frequency of population measures for *Avicennia marina* a) seedling density (n = 172 quadrats), b) juvenile and adult density (n = 172 quadrats), c) juvenile and adult height classes (n = 1863 stems).

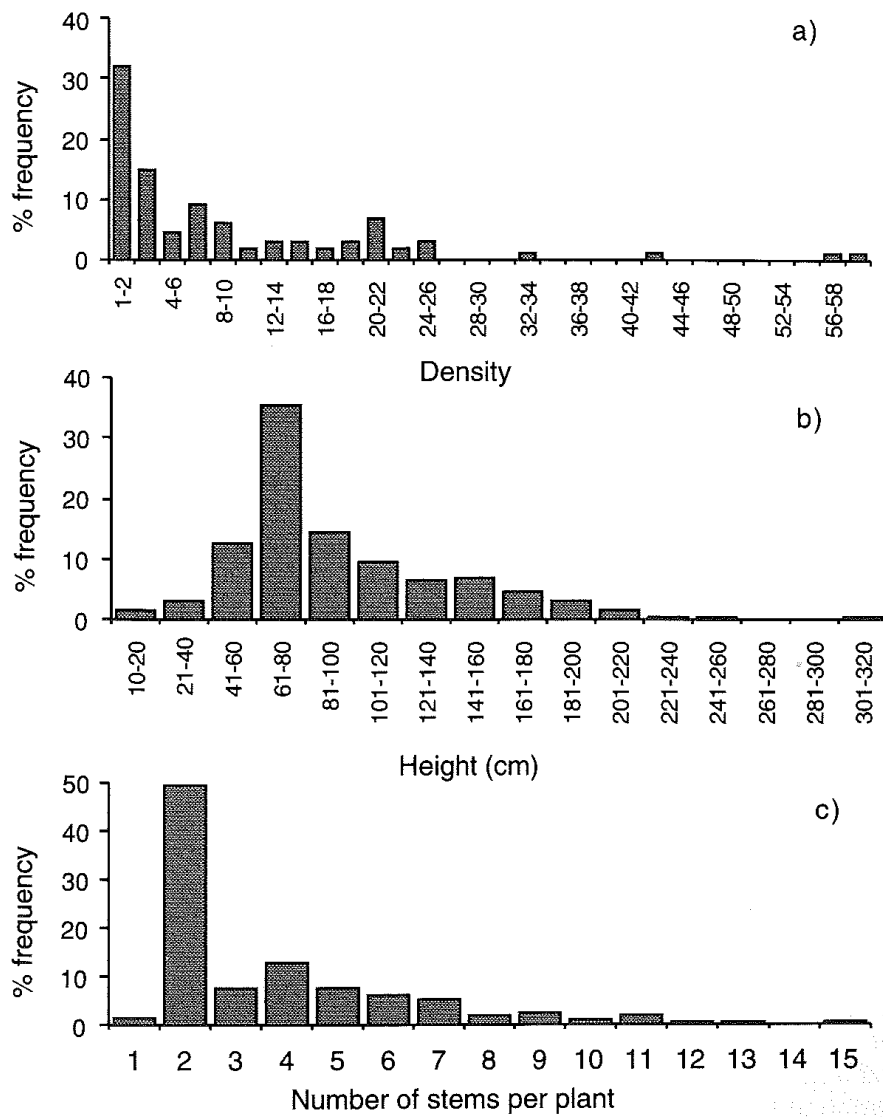


Figure 6. Percent frequency of population measures for *Aegiceras corniculatum* a) adult density (n = 88 quadrats), b) adult height classes (n = 1045 shrubs), c) adult stems per genet (n = 1045 shrubs).

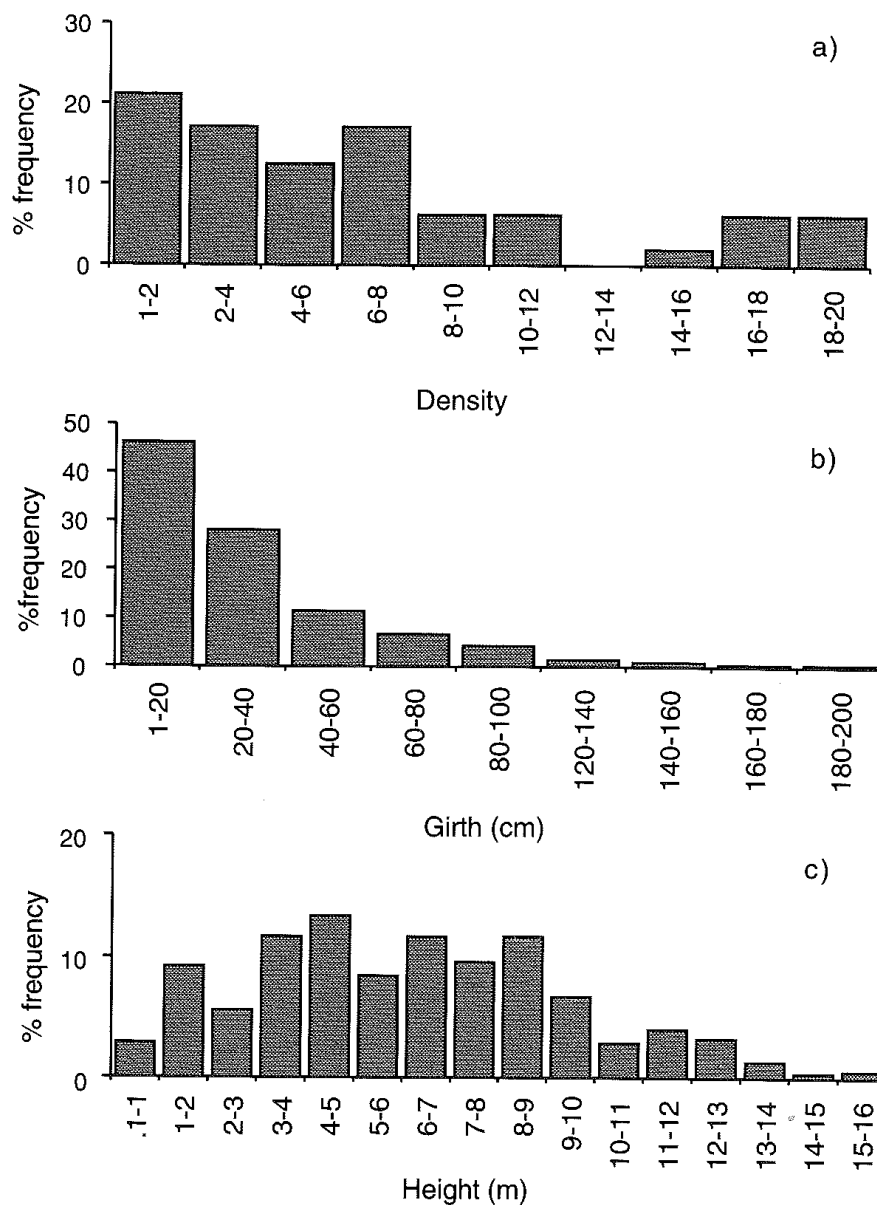


Figure 7. Percent frequency of population measures for *Casuarina glauca* a) adult density (n = 48 quadrats), b) basal girth classes (n = 340 trees), c) height classes (n = 346 trees).

Ordination and classification of plant communities

The ordination of site attributes showed a pattern across two major ordination axes that can be correlated with two broad environmental gradients (Figure 10). Both divisive and agglomerative classification methods produced the same overall pattern of classification although the level at which dendrograms defined similar groups was different. At the finer group level, the agglomerative method produced groups that were intuitively recognisable as patches that could be discerned in the field. Initial analysis erected some 30 groups and these were subsequently fused in 12 complexes (Figure 11), that have the equivalent rank of an association in phytosociology. Smaller sub-groups have the status of a sub-association. A constancy table of the relative

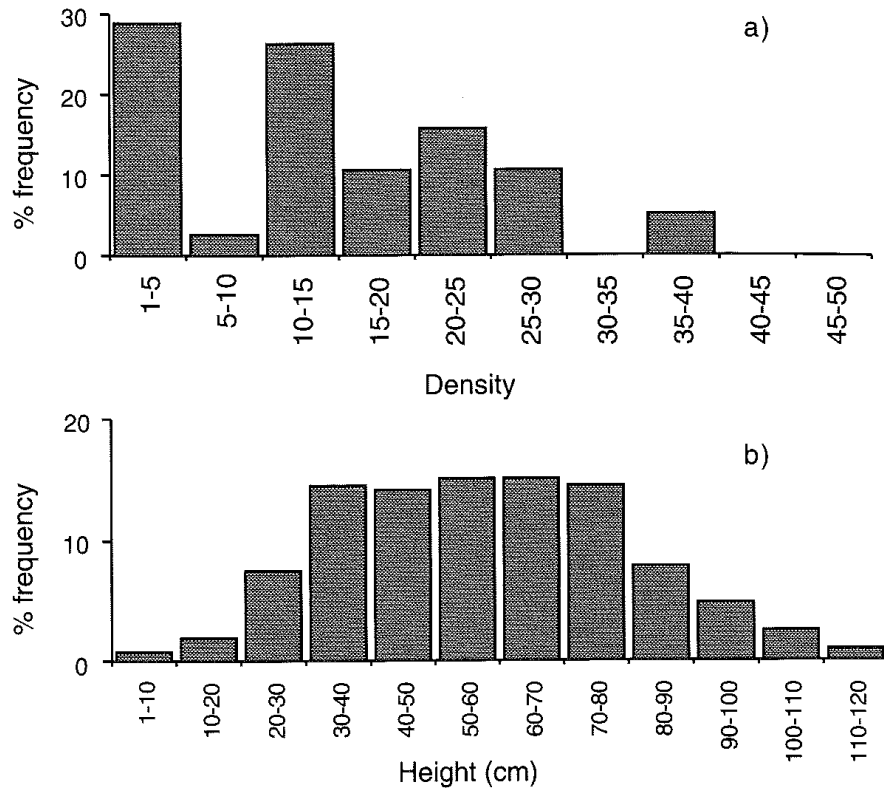


Figure 8. Percent frequency of population measures for *Sclerostegia arbuscula* a) adult density (n = 38 quadrats), b) height classes (n = 509 shrubs).

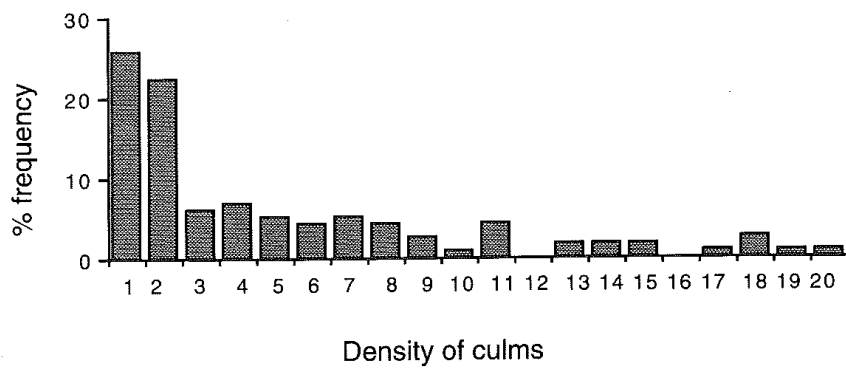


Figure 9. Percent frequency of the density of *Gahnia filum* (n = 116 tussocks).

occurrence of species in complexes and in the sub-groups is shown in Appendix II together with the number of quadrats sampled and species richness in quadrats.

***Avicennia* complex (A)**

The *Avicennia* complex was found in the four major creeks entering the Bay and extended from about Mean Sea Level (MSL) to 50 cm above MSL. Physiognomically, the complex ranged from forests of single-stemmed trees with a closed canopy to low open shrublands. Floristic variation was limited to associated algal species, which were not included in the analysis, and the occasional saltmarsh plant found as a ground cover. Free living (unattached) *Hormosira banksii* commonly occurred as a ground cover in the lower intertidal. Four structural sub-groups have been defined: A1) single-stemmed stands of *Avicennia marina* that formed woodlands or dense thickets where recent accretion had occurred. *Aegiceras corniculatum* often formed a scattered understorey in more open situations; A2) multi-stemmed stands of *Avicennia marina* with occasional canopy gaps were common in most creeks and generally had an abundant seedling understorey; A3) multi-stemmed stands of *Avicennia marina* with open canopies allowed the growth of saltmarsh plants in canopy gaps. The main species were *Sarcocornia quinqueflora*, *Sporobolus virginicus* and *Samolus repens*; A4) low shrubland of *Avicennia marina*, was usually found behind taller stands on hypersaline flats adjacent to saltmarsh, but it also occurred on rock platforms in sheltered parts of the bay.

***Aegiceras* complex (B)**

Shrublands of *Aegiceras corniculatum* were found at higher elevation toward the back of the *Avicennia* complex in the seaward sections of creeks, although there were also dense thickets along the creek banks in Currambene Creek.

***Sclerostegia* complex (C)**

Open shrublands dominated by *Sclerostegia arbuscula* with an understorey of *Sarcocornia quinqueflora* were found only in Cararma Inlet. Two sub-groups were evident from classification analysis: C1) Bispecific stands of *Sclerostegia* and *Sarcocornia* with the alga *Chaetomorpha capillaris* as a ground cover; C2) *Sclerostegia* and *Sarcocornia* intermingled with *Avicennia* shrublands at lower elevations.

***Sarcocornia* complex (D)**

Extensive herbfields dominated by *Sarcocornia quinqueflora* occurred in most areas and were gradational with several complexes. They commonly occurred at about the 1.4–1.5 m tide level in the saltmarsh although an extensive sward was also found on the southern side of Bowen Island above high water. Two sub-groups could be distinguished in the analysis: D1) monospecific herbfields of *Sarcocornia quinqueflora*; D2) herbfields dominated by *Sarcocornia* associated with *Triglochin striata* which were found in depressions and at the edges of ponds.

***Sporobolus* complex (E)**

Grasslands forming the *Sporobolus* complex were generally found on well-drained soils in the saltmarsh. This vegetation was also found along the southern cliff tops of Bowen Island. Two sub-groups were distinguished: E1) monospecific grasslands of *Sporobolus virginicus* of variable cover; E2) mixed grasslands of *Sporobolus* and *Sarcocornia*.

***Samolus* complex (F)**

Herbfields dominated by *Samolus repens* were mainly found in the lower saltmarsh where they were often shaded by mangroves. Two sub-groups were described on the

basis of field observations: F1) monospecific patches of *Samolus* were found in shady areas adjacent to mangrove open woodland and were often extensive enough to be mapped; F2) mixed areas of *Samolus*, *Sarcocornia* and *Sporobolus* that intergraded with the *Sarcocornia* complex.

Wilsonia complex (G)

Saltmarsh with a constant presence of *Wilsonia backhousei* formed extensive areas in Wowly Gully and in Callala Creek at about the level of spring tides. *Wilsonia* was also occasionally found on sheltered rock platforms at Cabbage Tree Point. Four sub-groups in the complex could be distinguished: G1) monospecific herbfields of *Wilsonia backhousei*; G2) bispecific areas with *Wilsonia* and *Sarcocornia*; G3) mixed herbfields with *Sarcocornia*, *Triglochin* and *Juncus*; G4) mixed tussocky herbfields with *Gahnia filum* in the upper marsh.

Juncus complex (H)

Rushlands dominated by *Juncus kraussii* were typical of the upper saltmarsh in most localities. Considerable floristic variation occurred within the complex, and three sub-groups were described: H1) dense monospecific stands that were typical of the saltmarsh adjacent to the mangroves in the upper ends of creeks with freshwater runoff; H2) mixed rushlands of *Juncus* and *Sporobolus* which were widespread and occasionally contained scattered shrubs of *Aegiceras*; H3) more diverse areas of mixed *Juncus*, *Sporobolus*, *Gahnia* and *Baumea* which were typically found in the upper ends of smaller creeks.

Baumea complex (I)

Sedgeland dominated by *Baumea juncea* occurred in the upper marsh under the influence of freshwater creeks and groundwater. This complex was transitional between the saltmarsh and fringing forests in some locations. Two sub-groups were described from field observations and classification: I1) monospecific patches of *Baumea juncea*; I2) sedgelands of mixed *Baumea juncea* and *Juncus kraussii*.

Gahnia complex (J)

Tussocky sedgelands dominated by *Gahnia filum* and a ground cover of *Sporobolus* commonly occurred in the transition zone between the saltmarshes and the fringe forests. Three sub-groups of sedgeland were defined: J1) mixed stands with *Sarcocornia* and *Samolus*; J2) mixed stands with *Sarcocornia* and *Juncus*; J3) mixed stands with the tussock grass *Stipa stipoides*, which had a restricted distribution to sandy banks.

Casuarina complex (K)

The swamp oak, *Casuarina glauca*, formed extensive fringe woodlands behind saltmarshes in most localities. Fringe forests were defined as areas that were influenced by saline, waterlogged soils but were dominated by trees other than mangroves. Classification analysis indicated that this complex has close affinities with the saltmarsh and the species, like mangroves, graded from one type to the next. Four woodland sub-groups could be distinguished: K1) *Casuarina* woodlands with an understorey dominated by *Selliera radicans* were mainly found in basin areas; K2) woodlands similar to those described above but with a shrubby understorey of *Myoporum acuminatum* were restricted to Cararma Creek; K3) *Casuarina* woodlands with an understorey of *Sporobolus virginicus* were more common along freshwater creeks; K4) *Casuarina* woodlands with an understorey of *Sporobolus virginicus*, *Zoysia macrantha* and the rush *Juncus kraussii* were also commonly found where there was ground water runoff.

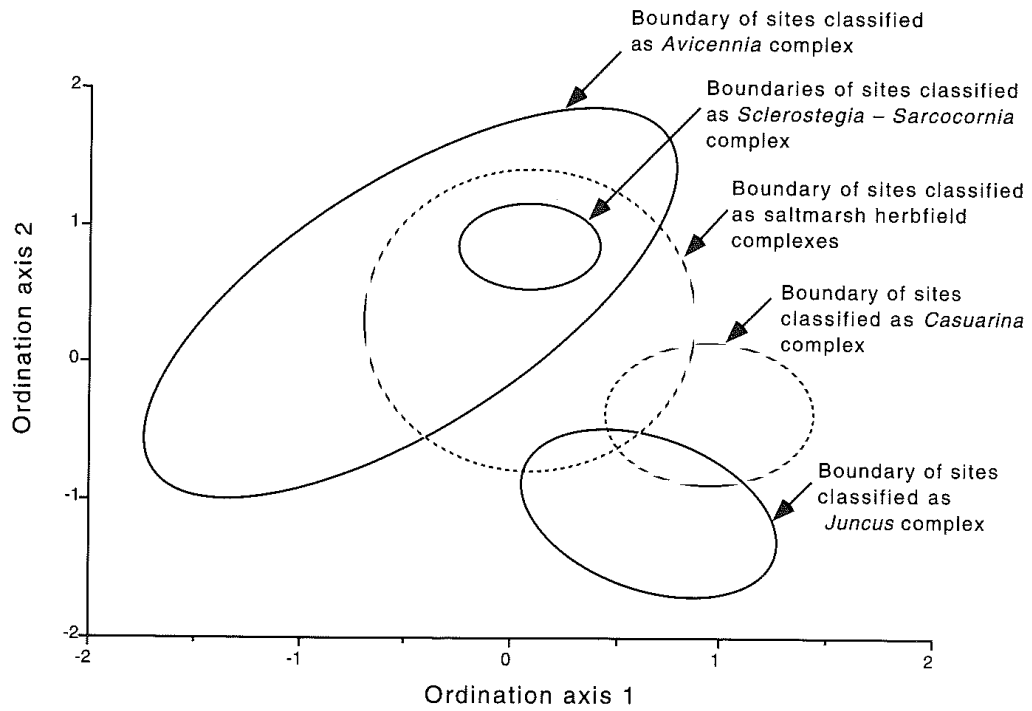


Figure 10 Ordination (hybrid multidimensional scaling) of quadrats simplified to two vectors. Boundaries of major classification groups shown.

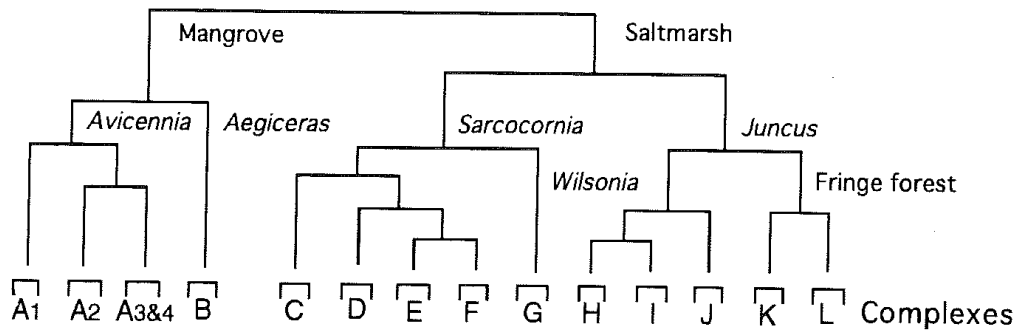


Figure 11 Classification (agglomerative) to the 12 group association level based on vascular plant species and mangrove pseudospecies. Letters correspond to associations described in the text.

Melaleuca complex (L)

Fringing thickets of the shrub *Melaleuca ericifolia* occurred on sandy sediments with some saline influence. Two floristic sub-groups could be distinguished from the analysis although they were mapped as a single complex: L1) thickets of *Melaleuca* occurred as an understorey of *Casuarina glauca* with a ground cover of *Baumea juncea*, *Lobelia alata* and *Hermarthria uncinata*; L2) thickets of *Melaleuca* also occurred as shrublands and graded into *Eucalyptus botryoides* woodland.

Other complexes

Several other complexes also occurred in areas that were infrequently inundated with saline water. However, they were not sampled so the structure and dominant species are only briefly described.

Reedswamps of *Phragmites australis* were common in Currambene Creek, while areas of swamp forest dominated by *Eucalyptus robusta* occurred adjacent to, and graded into, the *Casuarina glauca* forests. Sedgeland of *Cyperus laevigatus* were also found in the shallow, brackish creeks and lagoons at the backs of the beaches that fringe the Bay. The ephemeral and semi-permanent ponds of Cararma Creek supported an unusual submergent, macrophyte vegetation of *Ruppia* and the charophyte *Lamprothamnion*. *Mimulus repens* often colonised the edges of the ponds when they dried out.

Discussion

Species composition and distribution

About 140 species of vascular plants (native and exotic) were found in the mangroves, saltmarsh and fringe forests Jervis Bay. This is approximately half of the recorded flora for saltmarshes in New South Wales (Adam *et al.* 1988). Previous studies of saltmarshes at Lake Illawarra found 127 species (Yassini 1985), while Anderson *et al.* (1981) found 119 species in peripheral vegetation at eight estuaries adjacent to Jervis Bay.

Previous studies have indicated that Jervis Bay contains a number of species that are at their biogeographic limits and, therefore, are of conservation significance (Adam and Hutchings 1987). Several species are at their northern limits in Jervis Bay or have larger populations in Jervis Bay than elsewhere (Table 1). However, the status of saltmarsh plants in NSW is poorly understood and requires further study before conclusions can be made about rarity.

Species richness varied over several spatial scales, but more species were found in the upper saltmarsh than at lower elevations. Differences among creeks were also found; in particular Cararma Creek had consistently higher species numbers in quadrats than other creeks. This may be due the heterogenous physiography of the creek and the relatively undisturbed catchment. Differences in species richness were also detected in time; this was surprising given that all the species were long-lived. On close examination these difference were very small and simply reflect the ability of the sampling design to resolve small differences.

One of the pitfalls in using species richness as a general measure of assemblage trends is that species composition may change without affecting richness. Thus, exotic species could displace existing species, and the richness measure alone would not detect this. New methods using similarity measures to assess changes in diversity are currently being developed to address this problem.

Population measures

The density of *Avicennia marina* was highly variable in Jervis Bay at small spatial scales ranging from less than 100 plants ha⁻¹ to 20000 plants ha⁻¹. This range of density is not unusual, as similar variability has been found in Moreton Bay (Dowling 1986) and in other estuaries in south-eastern Australia (Clarke unpub.). Differences in mean density, height and basal girth between plots, (0.1 ha) reflect a high degree of spatial heterogeneity and highlight the difficulty in generalising for creek and bay spatial scales.

Densities of *Aegiceras corniculatum* showed a similar range to that of *Avicennia marina*, although a larger proportion of the population was found in denser patches. Higher densities and taller shrubs than those in Jervis Bay have been reported in Moreton Bay (Dowling 1986). The height of juvenile and adult *Aegiceras corniculatum* ranged from 10 to 350 cm in Jervis Bay, with most plants being between 60 and 80 cm tall. More than 95% of plants measured were multi-stemmed, and the range of variation appears to be the same at all locations. The low stature of *Aegiceras* in Jervis Bay make this species particularly susceptible to hydrocarbon pollutants because photosynthetic surfaces would be exposed. Recovery after such disturbances may be slow as few propagules appear to establish (as noted by Dowling (1986) in Moreton Bay).

Sclerostegia arbuscula has been found in only eight estuaries in southern New South Wales and the population at Cararma Inlet is the most northern and possibly the largest. Densities of *Sclerostegia* in Cararma Creek were highly variable and the average height of the shrubs (60 cm) appears to be less than that found at more temperate latitudes. No seedlings or juvenile plants were seen, although flowers were recorded each year in autumn. Scorching by fire appeared to have killed plants near the edge of the saltmarsh and plants were easily damaged by trampling. However, examination of aerial photographs suggested that the overall populations in Cararma Inlet have been stable since 1944.

Densities of *Casuarina glauca* ranged from 400 to 8000 plants ha⁻¹, and density distributions were less skewed toward low densities than the densities of either *Avicennia* or *Aegiceras*. The ranges of densities and heights of trees appeared to be similar in all locations. Very few seedlings and juvenile plants were found. Observations at Callala Creek and Moona Moona Creek suggested that fire will kill trees if their crowns are scorched, although partially scorched trees appeared to resprout from the base of the stem.

Vegetation ordination and classification

Both direct and indirect gradient analyses clearly showed that mangrove, saltmarsh and peripheral vegetation form continua when sampled and analysed in an unbiased way. The underlying environmental variables that correlated intuitively with these gradients appeared to be elevation and variability in moisture content, although the causal factors controlling the distribution of species are likely to be much more complex. When site classification was superimposed on the ordination, some broad clusters were discernible but smaller units of classification were poorly resolved. This indicated that the ecological variables influencing such patterns are more complex than a simple two dimensional model.

While site ordination showed the gradational nature of the vegetation, the classification of vegetation types was required for description and comparison among other areas of saltmarsh. A critical decision in the process was to select the level in hierarchical classifications at which vegetation units were described. In this study the 30 group level was initially selected and this was fused into 12 units based on subjective judgement and interpretation of ordination diagrams.

The mangrove complexes described in this study have the same floristic composition as the southern Australian associations described by Bridgewater (1989). However, sub-groups are not directly comparable with Bridgewater's because pseudospecies were used in the Jervis Bay study. Outhred and Buckney (1983) used a similar approach in the Hunter estuary but their pseudospecies were based on vigour rather than form. The distribution of *Avicennia* forms seemed to be correlated with sedimentation and salinity: taller, single-stemmed *Avicennia* stands grew on newly accreted substrates, while multi-stemmed trees were found on older sediments. In saltmarshes, *Avicennia* was shorter and stunted, which is interpreted as the influence of higher salinity (Davie 1984). Elsewhere on the south coast of NSW, grazing by cattle can reduce the stature of *Avicennia*. *Aegiceras* shrublands were found at the rear of *Avicennia* at the entrance to the bay in Cararma Inlet and Currambene Creek. In contrast *Aegiceras* fringed the creek banks in the more brackish sections of creeks. This pattern may be related to patterns of propagule dispersal rather than a growth response to salinity (Clarke and Myerscough 1991).

Of the 25 saltmarsh communities described by Adam *et al.* (1988), about 16 are analogous to complexes found in Jervis Bay during the present study. However, many of the sub-groups in this study, which have equivalent rank to the sub-association of Adam *et al.* (1988) and Bridgewater (1982), have not been described previously. This is not surprising given the lack of information concerning saltmarshes in NSW. The distribution of saltmarsh complexes is thought to be related to the influence of topography on salinity and drainage (Adam *et al.* 1988). This probably gave rise to the zonal patterns seen in Jervis Bay, although such patterns were rarely consistent within or between creeks. Mosaic patterns were also common in areas with cryptic topography and drainage, and these patterns may also have been influenced by interspecific interactions or the actions of fires and herbivores.

The fringing vegetation of saltmarsh in southern Australia has not been fully described or classified. The ground cover beneath the *Casuarina* woodlands and *Melaleuca* thickets in Jervis Bay often consisted of saltmarsh plants. This was particularly evident in the upper sections of Cararma Inlet where mangroves were intermingled with *Casuarina* and *Myoporum*. The boundaries between freshwater wetland and saltmarsh also became diffuse in the upper reaches of some tidal inlets and swamp woodlands the ground cover often contained saltmarsh species.

Conservation

The total area of 'saltmarsh' and 'mangrove' in NSW is estimated to be less than 57 km² and 108 km² respectively (West *et al.* 1985). Consequently, these vegetation formations are of high conservation significance in NSW because of their small area and distribution. Existing conservation reserves in New South Wales of mangrove, saltmarsh, and their associated fringe forests may not adequately protect all assemblage types because the range of variation within the broad terms 'mangrove', 'saltmarsh' or 'fringe forest' has not been adequately documented. Similarly, comprehensive information about species distribution and abundance is lacking and therefore their conservation status is difficult to assess. Detailed studies, such as the Jervis Bay study and those of Adam *et al.* (1988), begin to address these inadequacies.

Jervis Bay contains extensive areas of relatively undisturbed mangrove and saltmarsh vegetation in catchments that have not been severely degraded by urban development and agriculture. These wetlands also contain a number of species and vegetation types that are apparently rare or absent from other saltmarshes in southern NSW. Added to this biogeographic significance is their importance as a reference

system against which future changes can be measured and against which other areas can be compared. The latter, of course, will depend on the preservation of existing wetlands and their catchments. Current zoning as State Environmental Planning Policy 14 Wetlands has, in part, restricted the development of mangroves and saltmarsh wetlands. However, long-term conservation will not be assured until formal conservation reserves are declared and appropriately managed.

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References

- Adam, P. & Hutchings, P. (1987) The saltmarsh and mangroves of Jervis Bay. *Wetlands (Australia)* 6(2): 58-64.
- Adam, P., Wilson, N. & Huntley, B. (1988) The phytosociology of coastal saltmarsh vegetation in New South Wales. *Wetlands (Australia)* 7(1): 35-84.
- Anderson, J. R., Storey, K. J. & Carolane, R. (1981) Distribution of sixteen peripheral vegetation communities in eight estuaries on the south coast of New South Wales and a checklist of species. *CSIRO Division of Land Use Research Technical Memorandum* 81/21.
- Belbin, L. (1987) *PATN, Pattern Analysis Package*, CSIRO Division of Wildlife and Ecology.
- Bridgewater, P.B. (1982) Phytosociology of coastal salt-marshes in the Mediterranean climatic region of Australia. *Phytocoenologia* 10(3): 257-296.
- Bridgewater, P.B. (1989) Syntaxonomy of the Australian mangal refined through iterative ordinations. *Vegetatio* 81: 159-168.
- Clarke, P.J. & Myerscough, P.J. (1991) Buoyancy of *Avicennia marina* propagules in south-eastern Australia. *Australian Journal of Botany* 39: 77-83.
- Davie, J.D.S. (1984). Structural variation, litter production, and nutrient status of mangrove vegetation in Moreton Bay. In: *Focus on Stradbroke* (eds. R. J. Coleman, J. Covacevich, and P. Davie) pp. 208-223. Brisbane, Boolarong Press.
- Dowling, R.M. (1986) *The mangrove vegetation of Moreton Bay*. Queensland Botany Bulletin 6, Department of Primary Industries, Queensland.
- Faith, D. P., Minchin, P. R., and Belbin, L. (1987). Compositional dissimilarity as a robust measure of ecological distance. *Vegetatio* 69, 57-68.
- Gauch, H. (1982) *Multivariate analysis in community ecology*. (Cambridge University Press: Cambridge).
- Harden, G.J. (ed.) (1990) *Flora of New South Wales. Volume 1* (NSW University Press: Sydney).
- Harden, G.J. (ed.) (1991) *Flora of New South Wales. Volume 2* (NSW University Press: Sydney).
- Jacobs, S.W.L. and Pickard, J. (1981). *Plants of New South Wales*. (NSW Government Printer: Sydney).
- Outhred, R.K. & Buckney, R.T. (1983) The vegetation of Kooragang Island, New South Wales. *Wetlands (Australia)* 3: 57-70.
- Underwood, A.J. (1991) Beyond BACI: Experimental designs for detecting human environmental impacts on temporal variations in natural populations. *Australian Journal of Marine and Freshwater Research* 42: 569-78.
- West, R.J., Thorogood, C., Walford, T. & Williams, R. (1985) *An Estuarine Inventory for New South Wales, Australia*. Fisheries Bulletin 2, Department of Agriculture, NSW.
- West, R.J. (1987) Littoral and sub-littoral habitats of Jervis Bay. *Wetlands (Australia)* 6(2): 48-57.
- Yassini, I. (1985) Foreshore vegetation of Lake Illawarra. *Wetlands (Australia)* 5(2): 97-115.

APPENDIX 1 Vascular plant species list for the littoral habitats of Jervis Bay. * introduced species

DICOTYLEDONS

Aizoaceae

Carpobrotus glaucescens
Disphyma crassifolium
Tetragonia tetragonioides

Apiaceae

Apium prostratum
Centella asiatica
*Hydrocotyle bonariensis**
Hydrocotyle acutiloba

Apocyanaceae

Parsonsia straminea

Asteraceae

*Aster subulatus**
Brachyscome graminea
Centipeda minima
*Chrysanthemoides monilifera**
*Conyza albida**
Cotula coronopifolia
Leptinella longipes
Eclipta platyglossa
Epaltes australis
Ozothamnus diosmifolius
*Hypochaeris radicata**
Olearia viscidula
Pseudognaphalium luteoalbum
Senecio hispidulus
Senecio lautus
Senecio linearifolius
*Senecio madagascariensis**
Senecio minimus
*Sonchus asper**
*Sonchus oleraceus**
*Taraxacum officinale**

Avicenniaceae

Avicennia marina

Brassicaceae

*Cakile maritima**

Campanulaceae

Wahlenbergia gracilis

Caryophyllaceae

Spergularia sp.B
*Spergularia rubra**
Stelleria flaccida

Casuarinaceae

Casuarina glauca

Chenopodiaceae

Atriplex australasica
Atriplex cinerea
Chenopodium glaucum
Einadia hastata
Rhagodia candolleana

Chenopodiaceae (cont'd)

Sarcocornia quinqueflora
Sclerostegia arbuscula
Suaeda australis

Convolvulaceae

Calystegia soldanella
Cuscuta tasmanica
Dichondra repens
*Ipomea cairica**
Wilsonia backhousei
Wilsonia rotundifolia

Euphorbiaceae

Poranthera microphylla

Epacridaceae

Monotoca elliptica

Fabaceae

Viminaria juncea
Pultenaea dentata

Gentianaceae

Centaurium spicatum

Geraniaceae

Geranium sp.
Pelargonium australe

Goodeniaceae

Goodenia heterophylla
Goodenia ovata
Selliera radicans

Haloragiaceae

Gonocarpus micranthus

Lauraceae

Cassytha pubescens

Lobeliaceae

Lobelia alata

Loranthaceae

Amyema cambagei

Lyrthaceae

Lythrum hyssopifolia

Fabaceae

Acacia longifolia
Acacia Isophorae

Menyanthaceae

Villarsia exaltata

Myoporaceae

Myoporum acuminatum
Myoporum boninense ssp. australe

Myrsinaceae

Aegiceras corniculatum

Myrtaceae

Acmena smithii
Eucalyptus robusta
Eucalyptus sp. aff. *longifolia*
Eucalyptus tereticornis
Leptospermum juniperinum
Melaleuca ericifolia
Melaleuca squarrosa
Melaleuca styphelioides

Oxalidaceae

Oxalis corniculata

Pittosporaceae

Billardiera scandens
Pittosporum undulatum

Plantaginaceae

Plantago coronopus

Plumbaginaceae

Limonium australe

Primulaceae

Samolus repens

Proteaceae

Banksia ericifolia

Ranunculaceae

Ranunculus inundatus

Rubiaceae

Opercularia aspera

Polygonaceae

Rumex sp.

Scrophulariaceae

Mimulus repens

Solanaceae

Solanum pungetium

Stackhousiaceae

Stackhousia spathulata

Violaceae

Viola hederacea

MONOCOTYLEDONS

Amaryllidaceae

Crinum pedunculatum

Cyperaceae

Baumea juncea
Carex appressa
Carex pumila
Cyperus laevigatus
*Cyperus polystachyos**
Gahnia filum
Gahnia sieberiana
Isolepis cernua

Cyperaceae (cont'd)

Isolepis inundata
Isolepis nodosa
Schoenoplectus validus
Schoenoplectus litoralis

Hydrocharitaceae

Halophila decipiens?
Halophila ovalis

Iridaceae

*Gladiolus gueinzii**

Juncaceae

*Juncus articulatus**
Juncus kraussii

Lomandraceae

Lomandra longifolia

Juncaginaceae

Triglochin procera
Triglochin striata

Orchidaceae

Dendrobium linguiforme
Dendrobium teretifolium

Poaceae

Agrostis billardieri
*Ammophila arenaria**
Cynodon dactylon
Danthonia linkii var. *linkii*
Danthonia setacea
Distichlis distichophylla
Deyeuxia quadriseta
Festuca littoralis
Hemarthria uncinata
Imperata cylindrica
Paspalum vaginatum
Phragmites australis
*Parapholis incurva**
Poa labillardieri
*Polypogon monspeliensis**
*Spartina anglica**
Spinifex sericeus
Sporobolus virginicus
*Stenotaphrum secundatum**
Stipa stipoides
Themeda australis
Zoysia macrantha

Posidoniaceae

Posidonia australis

Restionaceae

Leptocarpus tenax

Ruppiaceae

Ruppia maritima

Zosteraceae

Heterozostera tasmanica
Zostera capricornii/muelleri?

