

## Litterfall in *Casuarina glauca* Coastal Wetland Forests

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### Abstract

Litterfall was measured over 3 years at two sites in coastal wetland forests dominated by *Casuarina glauca* Sieb. ex Spreng. in New South Wales. One site was in an incised river valley adjacent to the Hawkesbury River estuary, and the other site was in an open embayment adjacent to Botany Bay. Branchlets were the major litter component, followed by stems and infructescences. Significant year to year variation in branchlet fall correlated with storm events in one year. Overall, no significant differences in annual total litterfall were detected among sites and, averaged over all sites and years, the mean annual litterfall was 848 g m<sup>-2</sup>. This suggests that coastal wetland forests dominated by *C. glauca* have some of the highest recorded annual litterfall rates for Australian temperate and subtropical forests. A flood event in the river valley site removed about 75% of the standing litter accumulated on the forest floor prior to flooding (1244 g m<sup>-2</sup>). This suggests that accumulated organic matter and nutrients can be directly transported to estuarine ecosystems. Under non-flood conditions, however, these forests appear to act as organic matter and nutrient sinks.

### Introduction

The genus *Casuarina* includes species that generally grow on better soils than those of its sister genus *Allocasuarina* (Wilson and Johnson 1989). *Casuarina glauca* Sieb. ex Spreng. is a dioecous tree that commonly grows in saline areas marginally above normal tidal limits. It often fringes saltmarshes or tidal reaches of rivers, and on estuarine floodplains it can form extensive wetland (swamp) forests. *Casuarina glauca* has been successfully introduced to many countries and is regarded as a noxious plant in Florida and Hawaii (Midgley *et al.* 1983).

Wetland forests dominated by *C. glauca* occur along the coastal lowlands of eastern Australia from Bega in New South Wales to Rockhampton in Queensland (Beadle 1981). Much of these coastal wetland forests along with other lowland vegetation has been cleared for agriculture, and the remaining stands are under pressure to be cleared for residential development and small rural holdings. Unfortunately, there is a lack of understanding of not only the biodiversity attributes of these stands but also their functional significance in terms of biogeochemical and hydrological processes (Greenway 1994).

This paper presents data on litterfall and litter accumulation at two sites with different geomorphologies in wetland forests dominated by *C. glauca*. The aim of this research was to assess seasonal and annual variation in litterfall components and compare this variation between the two sites. In addition, comparisons of litterfall are made with other studies of coastal wetland forests.

### Materials and Methods

#### Study Area

Two sites at which *C. glauca* grows were selected for comparison. One site (site A) is located in the Towra Point Nature Reserve on the shores of Botany Bay at Woollooware Bay, on Holocene estuarine and aeolian sediments (see Clarke and Hannon 1969 for physiographic description). At this site, stands of *C. glauca* form a distinctive forest zone between sclerophyll woodland on sand-dunes and a

saltmarsh–mangrove complex. The soils on which these stands occur are sandy with an enriched organic A horizon and are periodically inundated with tidal waters (Clarke 1986). Within the *C. glauca* stand, the ground stratum is continuous and is dominated by *Juncus kraussii*, *Baumea juncea*, *Sporobolus virginicus* and the introduced grass *Stenotaphrum secundatum*. The shrub stratum is sparse and consists of occasional mesomorphic tree elements of *Syzygium paniculatum*, *Ficus coronata*, *Glochidion ferdinandi*, *Omalanthus populneum* and *Lantana camara*. Nomenclature of plant species follows Harden (1990–1993).

The second study site (site B) is located in Dharug National Park in the Hawkesbury River estuary at Mill Creek (see Dodson and Thom 1992 for a physiographic description). This site differs from the former in that the *C. glauca* stand is located in an incised valley that has been infilled with Quaternary alluvium with a high clay content; it is periodically inundated with tidal waters and floodwaters from the Hawkesbury River. At this site, stands of *C. glauca* form a forest that grades upstream into sclerophyll wetland forest of *Eucalyptus botryoides* and *Melaleuca* spp. (Clarke and Benson 1986). Incised into the alluvial deposits are creeks and drainage channels with steep banks that are lined with the mangroves *Avicennia marina* and *Aegiceras corniculatum*. Within the *C. glauca* stand, the ground stratum is sparse and consists of *Apium prostratum*, *Carex appressa*, *Goodenia ovata*, *Juncus kraussii* and *Phragmites australis*. The climber *Parsonsia straminea* was also commonly found on the trunks of *C. glauca*.

#### Litterfall Sampling and Accumulated Litter

Litterfall from the trees was collected under the canopies of stands by catching falling material in 1 m<sup>2</sup> collectors. Litter traps were constructed of fine mesh shade cloth attached to frames of polythene tubing and were suspended between trunks of *C. glauca* at 2 m above the ground. At Woollooware Bay, 12 litter traps were randomly placed under the canopy, whilst at Mill Creek, 13 litter traps were randomly placed under the canopy. Litterfall was removed from each trap at monthly intervals for 42 months at Woollooware Bay (starting May 1984) and 39 months at Mill Creek (starting August 1984). Litterfall was sorted into three classes: branchlets ('leaves'); infructescences ('cones' that contain the true fruit); and stems (twigs, branches and bark). These were dried in an oven at 80°C. Additional litterfall from other species was minor and mainly consisted of fall from *Parsonsia straminea*. Observations of flower-bud formation, flowering and seed fall from trees were also made when litterfall was collected. Annual data for each component, and summed components, were analysed to test for differences between sites across 3 years using a two-factor ANOVA. Both sites and years were considered to be fixed factors. Litter traps were randomised at site A after 12 months to test for independence effects. It was found that a repeated measures model was not required. Data were tested for normality and heterogeneity of variances before analyses.

Accumulated litter on the forest floor was collected from the Mill Creek site where there was a sparse live ground stratum. Litter samples were collected from an area of 1 m<sup>2</sup> randomly chosen within the area in which litter traps were suspended. Single samples were taken at irregular intervals from September 1984 to July 1985; in all, five samples were collected and dried at 80°C. A further five 1 m<sup>2</sup> samples were removed from random points on the forest floor in February 1986 after a flood event inundated the forest in October 1985.

## Results

### Litterfall and Litter Accumulation

The major component of litterfall was branchlets, followed by stems and fruits (Fig. 1). Both site and annual variation were detected in all litterfall components and summed components (Table 1; Fig. 1), that is, patterns in space were not consistent in time. In 1985, there were no significant differences in litterfall components between the two sites over the year (Fig. 1). In 1986, however, both branchlet fall and stem fall were higher than those in 1985, at Woollooware Bay. Litterfall was also higher at Woollooware Bay than at Mill Creek for stem and branchlet components in 1986. By contrast, fruit fall decreased at both Woollooware Bay and Mill Creek in 1986. In the following year, the sites had similar component and total litterfall levels (Fig. 1). Rates of litterfall averaged over all months were the same for the sites, and total annual litterfall was estimated to be 848 g m<sup>-2</sup> or 8.5 tonnes ha<sup>-1</sup>.

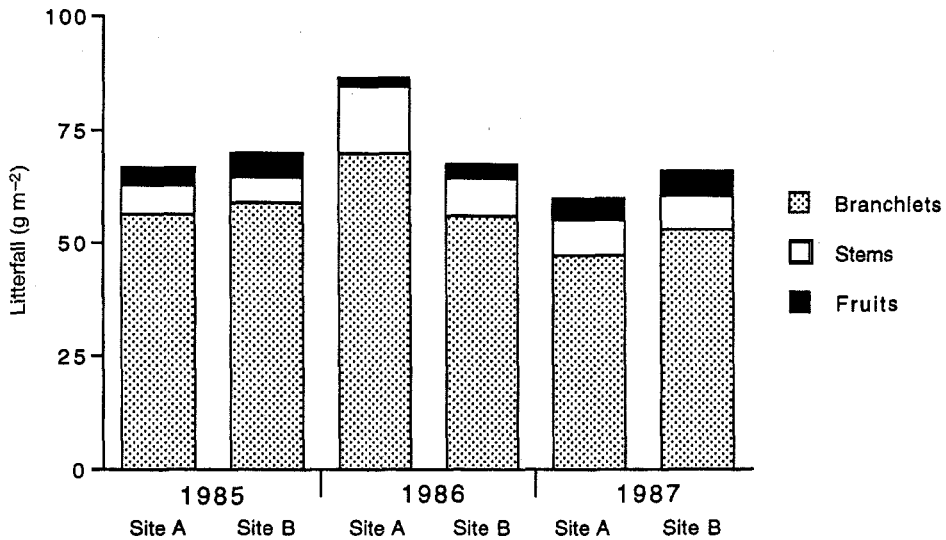


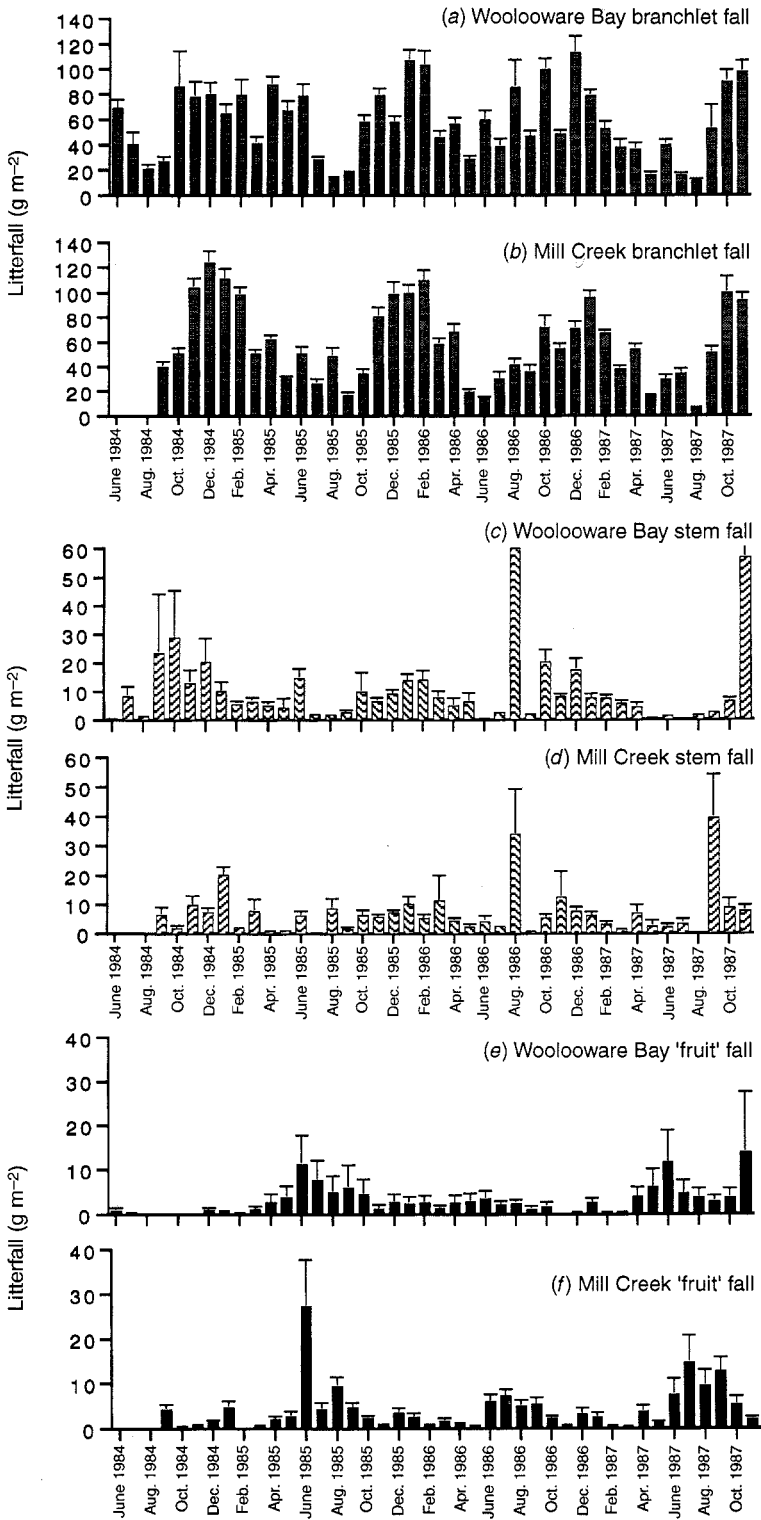
Fig. 1. Mean monthly litterfall averaged over a calendar year at each of two sites over 3 years. Site A, Woolooware Bay; site B, Mill Creek.

Table 1. Analysis of variance of litterfall components  
n.s., not significant

Source of variation	d.f.	Branchlets		Cones		Stems		Total	
		<i>F</i>	<i>P</i>	<i>F</i>	<i>P</i>	<i>F</i>	<i>P</i>	<i>F</i>	<i>P</i>
		Years	2	8.3	<0.001	4.8	<0.01	5.4	<0.01
Sites	1	0.5	n.s.	2.2	n.s.	3.2	n.s.	1.1	n.s.
Interaction	2	5.9	<0.01	0.1	n.s.	1.8	n.s.	6.2	<0.01

Monthly variation in litterfall showed seasonal trends that were generally consistent across the Mill Creek and Woolooware Bay sites. Branchlet fall generally showed summer peaks and winter lows, although occasional high values were recorded during the cooler months (Fig. 2*a, b*). A particularly high value for the Woolooware Bay site was recorded in August 1986 together with a high stem fall. This high value corresponds with a series of severe storms that occurred from 6 to 8 August. Field records show that much of the litterfall consisted of 'green' branchlets and branches. A similar but less pronounced seasonal pattern in litterfall can also be seen in the stem fall data (Fig. 2*c, d*). Peaks in stem fall, however, corresponded with local storm events in the spring of 1984 at Woolooware Bay, the severe storm in August 1986, and localised hail-storms in the spring of 1987. By contrast to both branchlet and stem fall, fruit fall did not show summer increases nor did all large peaks in fall correspond with storm events (Fig. 2*e, f*). Instead, fruit fall generally peaked in the winter months, with larger peaks in 1985 and 1987 than in 1984 and 1986.

Observations of reproductive phenology showed consistent patterns among the 3 years of observations. The terminal male inflorescences were initiated in winter and became prominent as terminal structures on the branchlets during spring. Mass flowering of male flowers was observed, peaking during August and September each year. Female flowers were less



conspicuous but were present in smaller numbers throughout spring. Young fruits were observed on trees in summer and they were mature by the following autumn. Prolific seed fall occurred during winter and drew the attention of black cockatoos (*Calyptorhynchus banksii* and *C. lathami*), which frequently destroy cones to obtain seeds.

The standing stock of litter on the floor of the forest was measured on five occasions at Mill Creek during 1984, and the average dry weight was  $1244 \text{ g m}^{-2}$ . During October 1985, a heavy rainfall event caused flooding in Mill Creek, and rafts of ground litter were observed to be removed from the forest as the flood level rose to about 1 m above ground level. Subsequently, in February 1986, when the forest floor had dried out, five litter samples were removed from the forest floor. The average dry weight of these samples was significantly less than the samples taken prior to the flood ( $462 \text{ g m}^{-2}$ ;  $F_{1,8} = 28.6$ ,  $P < 0.01$ ).

## Discussion

Total annual litterfall in the wetland forests that were sampled did not differ significantly between the Woollooware Bay site (open embayment) and the Mill Creek site (riverine valley), which are typical of the range of environments in which these forests occur. In south-eastern Queensland, floodplain and riparian sites for *Melaleuca quinquenervia* wetland forests also have similar total annual litterfall (Greenway 1994). These results suggest that growth and productivity in coastal wetland forests may be similar over a wide range of physiographic locations, as they generally have a closed forest structure throughout southern Queensland and the northern and central coast of New South Wales. These patterns differ from those of mangrove forests of the region, where physiography and latitude correlate with productivity differences (see Table 2).

Seasonal patterns in litterfall were present each year and confirm a growth phenology that results in peak branchlet abscission during early summer, and peak infructescence abscission and seed fall during winter. Peak 'leaf' fall occurs in summer, which is the same time as that for *Melaleuca quinquenervia* in south-eastern Queensland (Greenway 1994) and in temperate and subtropical mangroves (Clarke 1994). Peak branchlet fall in *C. glauca* is generally preceded by the initiation of inflorescences and flowering in late spring; however, the precise timing of branchlet initiation in relation to flowering and fruit-set requires further observations. Nevertheless, it is clear that, as with temperate mangroves, there is a synchronous pattern of 'leaf' and floral phenologies. Such a mechanism for thinning of total photosynthetic surfaces may be advantageous in these closed forest systems for reducing canopy heat loads over summer.

Long-term studies of litterfall in south-eastern Australia also show large variations between months, and these can be correlated with localised climatic events such as storms. Similarly, annual differences in litterfall can also occur, and these may be linked to more widespread climatic events, as suggested for temperate mangroves (Clarke 1994). Thus, when comparing annual rates of litterfall among species and locations, as in Table 2, caution is required when studies have a duration of less than 2 years and where spatial replication is limited.

The total annual litterfall for *C. glauca* wetland forests in this study was greater than that recorded for subtropical *Melaleuca* wetland forests (Table 2) and exceeds that of some tropical wetland forests (Finlayson *et al.* 1993). Similarly, the litterfall rates presented here exceeded those of adjacent dry sclerophyll forests (c.  $200\text{--}700 \text{ g m}^{-2} \text{ year}^{-1}$ ) (Lamb 1985) and mangrove forests in south-eastern Australia (c.  $200\text{--}650 \text{ g m}^{-2} \text{ year}^{-1}$ ) (Table 2). Thus, along with subtropical *Melaleuca* wetland forests, *C. glauca* wetland forests appear to have some of the highest recorded annual litterfall rates for Australian temperate and subtropical forests.

**Fig. 2.** Mean ( $\pm$  s.e.) monthly litterfall—(a and b) branchlet fall, (c and d) stem fall and (e and f) fruit fall—at two sites: site A, Woollooware Bay (a, c and e); and site B, Mill Creek (b, d and f).

**Table 2. Litter production by coastal wetland forests and mangrove forests at various sites in southern Australia**  
NSW, New South Wales; Qld, Queensland; WA, Western Australia; Vic., Victoria

Forest dominant	Site	Latitude	Vegetation structure	Length of study (months)	No. of samples	Litterfall $\pm$ s.e. (g dry weight m <sup>-2</sup> year <sup>-1</sup> )	Leaf (%)	Reference
<i>Casuarina glauca</i>	Hawkesbury River, NSW	34°S	Forest	39	13	832.8 $\pm$ 59	78	This study
	Botany Bay, NSW	34°S	Forest	42	12	862.7 $\pm$ 42	81	This study
	Logan River, Qld	28°S	Forest	24	16	743 $\pm$ 162	60	Greenway (1994)
<i>Melaleuca quinquenervia</i> (Cav.) S.T. Blake	Blackwood River, WA	35°S	Closed scrub	12	24	430	36	Congdon (1979)
<i>Avicennia marina</i> (Forsk.) Vierh.	Mud Island, Qld	27°S	Low closed forest	17	14	642 $\pm$ 94	67	Davie (1984)
	Mud Island, Qld	27°S	Closed scrub	12	12	342 $\pm$ 47	89	Davie (1984)
	Mud Island, Qld	27°S	Low open shrubland	12	18	194 $\pm$ 29	78	Davie (1984)
	Kooragang Island, NSW	33°S	Low closed forest	30	10	562 $\pm$ 28	70	Murray (1985)
	Fullerton Cove, NSW	33°S	Low closed forest	19	10	514 $\pm$ 67	50	Murray (1985)
	Roseville, NSW	34°S	Low closed forest	13	24	580	79	Goulter and Allaway (1979)
	Jervis Bay, NSW	35°S	Low closed forest	35	16	367	73	Clarke (1994)
<i>Aegiceras corniculatum</i> (L.) Blanco	Westernport Bay, Vic.	38°S	Low closed shrubland	<sup>A</sup>	<sup>A</sup>	162	<sup>A</sup>	Clough and Attiwill (1982)
	Jervis Bay, NSW	35°S	Low closed shrubland	35	16	208	53	Clarke (1994)

<sup>A</sup>Not given.

Standing stocks of litter on the forest floor ( $1244 \text{ g m}^{-2}$ ) were about 1.5 times greater than annual litterfall, indicating a higher rate of decomposition than that in *Melaleuca* wetland forests (Greenway 1994). These results must be treated cautiously, as litter accumulation is also affected by water flow and transport during flood events. Such a flood event occurred once in the 3 year study, when rafts of litter were observed to be transported from the forest and into the nearby major estuary (Hawkesbury River). Measurement of ground litter after the flood confirmed that up to 75% of the ground litter ( $780 \text{ g m}^{-2}$ ) had been removed by the flood. Flood events are likely to provide important pulses of nutrients and organic matter to large estuaries, where the material is incorporated into estuarine food chains. Throughout most of the year, however, these forests appear to act as nutrient sinks, as evidenced by high litter accumulation (Greenway 1994) and high levels of nutrients (Clarke 1986; Clarke and Jacoby 1994) relative to adjacent tidally inundated saltmarsh and mangrove zones. Whilst an understanding of the nutrient cycles and the trophic links between coastal wetland (swamp) forests and estuarine food chains requires further intensive and multi-disciplinary studies, this study shows that these threatened forest systems are highly productive.

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### References

- Beadle, N. C. W. (1981). 'The Vegetation of Australia.' (Cambridge University Press: Cambridge.)
- Clarke, P. J. (1986). Nitrogen pools and soil characteristics of a temperate estuarine wetland in eastern Australia. *Aquatic Botany* **23**, 275–290.
- Clarke, P. J. (1994). Baseline studies of temperate mangrove growth and reproduction; demographic and litterfall measures of leafing and flowering. *Australian Journal of Botany* **42**, 37–48.
- Clarke, P. J., and Benson, D. (1986). 'Vegetation Survey of Dharug National Park.' (National Herbarium of NSW, Royal Botanic Gardens: Sydney.)
- Clarke, P. J., and Jacoby, C. A. (1994). Baseline studies of saltmarsh plants in south-eastern Australia; biomass and productivity. *Australian Journal of Marine and Freshwater Research* **45**, 1521–1528.
- Clarke, L. D., and Hannon, N. J. (1969). The mangrove swamp and salt marsh communities of the Sydney District. II. The holocoenotic complex with particular reference to physiography. *Journal of Ecology* **57**, 231–234.
- Clough, B. F., and Attiwill, P. M. (1982). Primary productivity of mangroves. In 'Mangrove Ecosystems in Australia—Structure, Function, and Management'. (Ed. B. F. Clough.) pp. 213–222. (Australian Institute of Marine Science: Townsville.)
- Congdon, R. A. (1979). Litterfall of the paperbark tree (*Melaleuca cuticularis*) in the marshes of the Blackwood River Estuary, Western Australia. *Australian Journal of Ecology* **4**, 411–417.
- 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. (Boolarong Press: Brisbane.)
- Dodson, J. R., and Thom, B. G. (1992). Holocene vegetation history from the Hawkesbury Valley, New South Wales. *Proceedings of the Linnean Society of New South Wales* **113**, 121–134.
- Finlayson, C. M., Cowie, I. D., and Bailey, B. J. (1993). Biomass and litterfall dynamics in a *Melaleuca* forest on a seasonally inundated floodplain in tropical, northern Australia. *Wetland Ecology and Management* **2**, 177–188.
- Goulter, P. F. E., and Allaway, W. G. (1979). Litter fall and decomposition in a mangrove stand, *Avicennia marina* (Forsk.) Vierh., in Middle Harbour, Sydney. *Australian Journal of Marine and Freshwater Research* **30**, 541–546.

- Greenway, M. (1994). Litter accession and accumulation in a *Melaleuca quinquenervia* (Cav.) S.T. Blake wetland in south-eastern Queensland. *Australian Journal of Marine and Freshwater Research* **45**, 1509–1519.
- Harden, G. J. (Ed.) (1990–1993) 'Flora of New South Wales. Vols 1–4.' (University of New South Wales Press: Sydney.)
- Lamb, R. J. (1985). Litter fall and nutrient turnover in two eucalypt woodlands. *Australian Journal of Botany* **33**, 1–14.
- Midgley, S. J., Turnbull, J. W., and Johnston, R. D. (1983). 'Casuarina Ecology, Management and Utilization.' (CSIRO: Melbourne.)
- Murray, F. (1985). Cycling of fluoride in a mangrove community near a fluoride emission source. *Journal of Applied Ecology* **22**, 277–285.
- Wilson, K. L., and Johnson, L. A. S. (1989). Casuarinaceae. In 'Flora of Australia. Vol. 3'. (Ed. A. S. George.) pp. 100–182. (Australian Government Publishing Service: Canberra.)

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