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Above- and below-ground biomass of mangroves in a sub-tropical estuary

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Abstract. Above- and below-ground biomass of five species of mangroves was estimated for the Mary River, south-eastern Queensland. Below-ground : above-ground biomass ratios of species in the upstream reaches (*Avicennia marina, Aegiceras corniculatum* and *Excoecaria agallocha*) averaged <0.5, and those of species in the saline conditions of the mouth (*Avicennia marina, Rhizophora stylosa*) ranged between 0.9 and 1.5. Within the estuary mouth, above-ground biomass of *Avicennia marina* and *Ceriops tagal* decreased between frontal saline and upper-intertidal hypersaline environments, and this was reflected in the below-ground : above-ground biomass ratios, which increased to approximately 3.5 for both species.

Extra keywords: Salinity, intertidal, root mass, shoot mass.

Introduction

The growth characteristics of a plant are determined by the allocation of photosynthetic products to leaves, stems, roots and reproductive parts. Environmental conditions strongly influence this allocation, with root:shoot ratios increasing with aridity, infertility, light intensity, grazing and fire (Mooney 1972; Aung 1974; Russell 1977; Iwasa and Roughgarden 1984). Competitive interactions may also influence allocation of mass (Kozlowski *et al.* 1991).

Mangroves have higher relative root mass than other forest types (Saenger 1982), with root:shoot ratios closer to those of arctic, desert and grassland communities (Mooney 1972). High root:shoot ratios in mangroves have been attributed to unstable substratum conditions (Hutchings and Saenger 1987) but they could equally be due to low water potential in the substratum or nutrient deficiency, for root:shoot ratios of seedlings decline with decreasing salinity in laboratory conditions (Ball 1988) and with the addition of nutrients in brackish but not in saline soil cultures (Naidoo 1987).

Few data are available for mangrove root:shoot ratios under field conditions, partly because of difficulties of sampling. Clough (1992) and Snedaker (1995) provide useful summaries, although none of the studies cited compares root:shoot ratios of different species occupying the same environment or the same species over a range of environments on a single river. This information is important not only in understanding mangrove responses to environmental stress, but also in modelling the capacity of mangrove ecosystems to keep pace with a rise in the sea-level as carbon fixed in the leaves is transported to the roots (Snedaker 1995). Saintilan (1997) recorded above-ground and below-ground biomass of mangroves in the Hawkesbury River estuary, New South Wales, where *Avicennia marina* (Forssk.) Vierh. and *Aegiceras corniculatum* (L.) Blanco form a sympatric association. The present paper records above-ground and below-ground biomass for communities in a river of intermediate diversity of mangrove species, where five species form monospecific stands over widely ranging conditions of soil-water salinity.

Materials and methods

Study site

The Mary River, south-eastern Queensland (Fig. 1), has a mesotidal estuary showing the characteristics of tide dominance as described in the model of Dalrymple *et al.* (1992). The wide, funnel-shaped mouth is protected from wave attack by Fraser Island, and the intertidal flats fringing

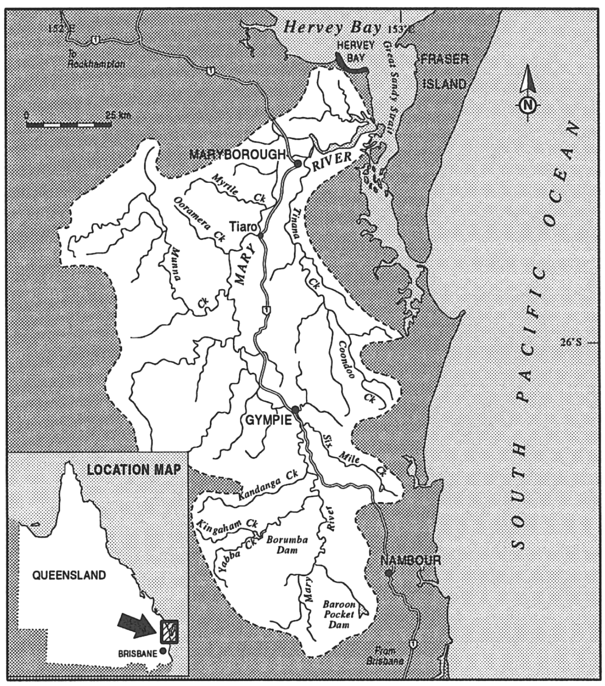

Fig. 1. Location of the Mary River, south-eastern Queensland.

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the mouth support extensive mangrove forest and shrubland on Holocene fluvial sand deposits. The substratum increases in soil-water salinity from saline to hypersaline from the frontal to the upper intertidal sections of these flats (Saintilan 1996). The meandering upstream reaches of the estuary are fringed by highly dynamic fluvial mud and sand deposits where salinity of the intertidal substratum is freshened by fluvial discharge (Saintilan 1996).

The climate is subtropical, and ten species of mangrove fringe the estuary: *Rhizophora stylosa* Griff.; *Ceriops tagal* (Perr.) C.B. Rob, var. *australis* C.T. White; *Avicennia marina* (Forssk.) Vierh.; *Aegiceras corniculatum* (L.) Blanco; *Excoecaria agallocha* L.; *Bruguiera gymnorhiza* (L.) Lamk.; *Osbornia octodonta* F. Muell.; *Lumnitzera racemosa* Willd.; *Aegialitis annulata* R. Br.; and *Xylocarpus granatum* Koen. Of these species, five form pure stands and occur as dominants over significant areas: *R. stylosa, C. tagal, A. marina, A. corniculatum* and *E. agallocha. R. stylosa* and *C. tagal* are restricted to the funnel-mouth of the estuary, with *R. stylosa* occurring as a frontal stand. *C. tagal* tolerates hypersalinity in the landward high intertidal environments. *A. marina* is found throughout the estuary, whereas *A. corniculatum* and *E. agallocha* are found predominantly in the upstream reaches, being rare in the funnel mouth.

Sampling procedure

Quadrats were placed at equal distances along the range of the river occupied by each of the five species forming extensive monospecific stands; 150 quadrats were used in the estimation of above-ground biomass. At each site, two 4×4 m^2 quadrats were laid, and height and diameter at breast height (DBH) of all individuals were measured. Soil was sampled at 30–50 cm depth for the determination of soil-water conductivity.

Estimation of above-ground biomass

Two individuals of each of the five species were harvested for comparison with published allometric equations for mangrove biomass. Species within the Mary River departed significantly from the equations of Clough and Scott (1989) for DBH > 10 cm, reflecting differences between the growth habits of subtropical mangroves and those of the tropical forests harvested by Clough and Scott (1989). For these individuals, an extrapolation based on the general volumetric equation of Rochow (1974) was used to estimate above-ground biomass on the basis of diameter at breast height and tree height (Saintilan 1997), such that

$$\text{dry wt (kg)} = \frac{h(0.214(D\times\pi) - 0.113)^2}{10}, \qquad (1)$$

where h is tree height (m) and D represents DBH (cm).

Estimation of below-ground biomass

In a subsample of 56 quadrats, coring for below-ground biomass entailed four cores of 14 cm diameter in each quadrat, dug to the depth of root penetration. Samples were washed through a 599-µm sieve, and sandy material was separated from organic material by flotation. Because dead mangrove roots are well preserved in the anoxic soil medium, separation of live and dead roots following sampling is problematic. Previous studies have used microscopic inspection of root colour and branching (Lichacz *et al.* 1984) or buoyancy in a medium of colloidal silica (Robertson and Dixon 1993). In the present study a subsample of ten larger roots were dissected and analysed for turgidity and colour. The proportion of live roots identified on this basis was multiplied through the whole core sample for an estimation of live root mass, following drying to constant weight. These weights were converted to dry mass (Saintilan 1997).

Estimation of soil-water salinity

A sealed vial containing 5 g wet soil and 25 mL distilled water was shaken for 40 min. The electrical conductivity was then measured with a calibrated Metrohm 660 conductivity meter.

Statistical methods

Linear regression analysis was used to determine the nature and strength of relationships between biomass and soil-water conditions. Correlation coefficients were calculated and tested for significance by calculating the two-tailed *t*-statistic. Single-factor analysis of variance was used to assess the significance of differences between estuarine zones in the variables selected.

Results

Above- and below-ground biomass

Estimates of above- and below-ground biomass were highly variable in relation to both salinity and distance from the estuary mouth. Of all species sampled, only *R. stylosa* showed a consistent change in biomass with distance from the mouth of the estuary, decreasing with distance upstream. Above- and below-ground biomass of *A. marina* and *C. tagal* decreased significantly with distance upslope from the seaward edge of the wide intertidal flats at the estuary mouth as salinities increased from saline to hypersaline. There was little variation in biomass of *A. corniculatum* and *E. agallocha*.

Below-ground : above-ground biomass ratios

Below-gound : above-ground biomass ratios of *A. marina* and *C. tagal* were >3.0 in the landward portions of the wide intertidal flats of the channel mouth, where salinities were hypersaline (Fig. 2), but were significantly lower in less-saline environments at the seaward edge of these flats.

In the upstream reaches of the estuary, the below-ground: above-ground biomass ratios of *A. marina* and *A. corniculatum* were lower than in the channel mouth and were comparable with that of *E. agallocha*. The ratio in *E. agallocha* and *R. stylosa* did not differ significantly over their range.

When mangrove communities were grouped together (Fig. 3) the ratios decreased significantly with distance from the mouth $R = 0.443$, $n = 56$, $P < 0.005$) and increased with increasing soil-water salinity ($R = 0.338$, $n = 56$, $P < 0.005$).

Discussion

The below-ground : above-ground biomass ratios of species were found to vary in relation to distance from the mouth of the estuary and distance from the seaward edge of the wide intertidal flats of the channel mouth. The lowest ratios were found in communities of *A. marina*, *E. agallocha* and *A. corniculatum* in the upstream, meandering segment of the estuary. Downstream, the ratios in *A. marina* and *R. stylosa* attain unity in the frequently inundated seaward edges of the wide intertidal flats of the channel mouth, a value camparable to those found in saline field conditions for *Kandella candel*, *Bruguiera sexangula*, *Rhizophora stylosa* (Lin *et al.* 1990), *Rhizophora mangle* (Golley *et al.*

1962; Golley *et al.* 1974), and *Avicennia marina* (Briggs 1977; Clough and Attiwill 1982; Lichaz *et al.* 1984; Saintilan 1997), although Gong and Ong (1990) reported lower relative root mass for *Rhizophora apiculata* in Malaysia. The increase in the below-ground : above-ground biomass ratio of *A. marina* toward the estuary mouth is effected primarily by a decrease in shoot mass, which declines to a value compable to estimates for the same species in marine environments in temperate regions (Briggs 1977; Saintilan 1997).

The shoot biomass of *A. marina* and *C. tagal* decreases landwards on these flats to <1 kg m^{-2}, a value lower than

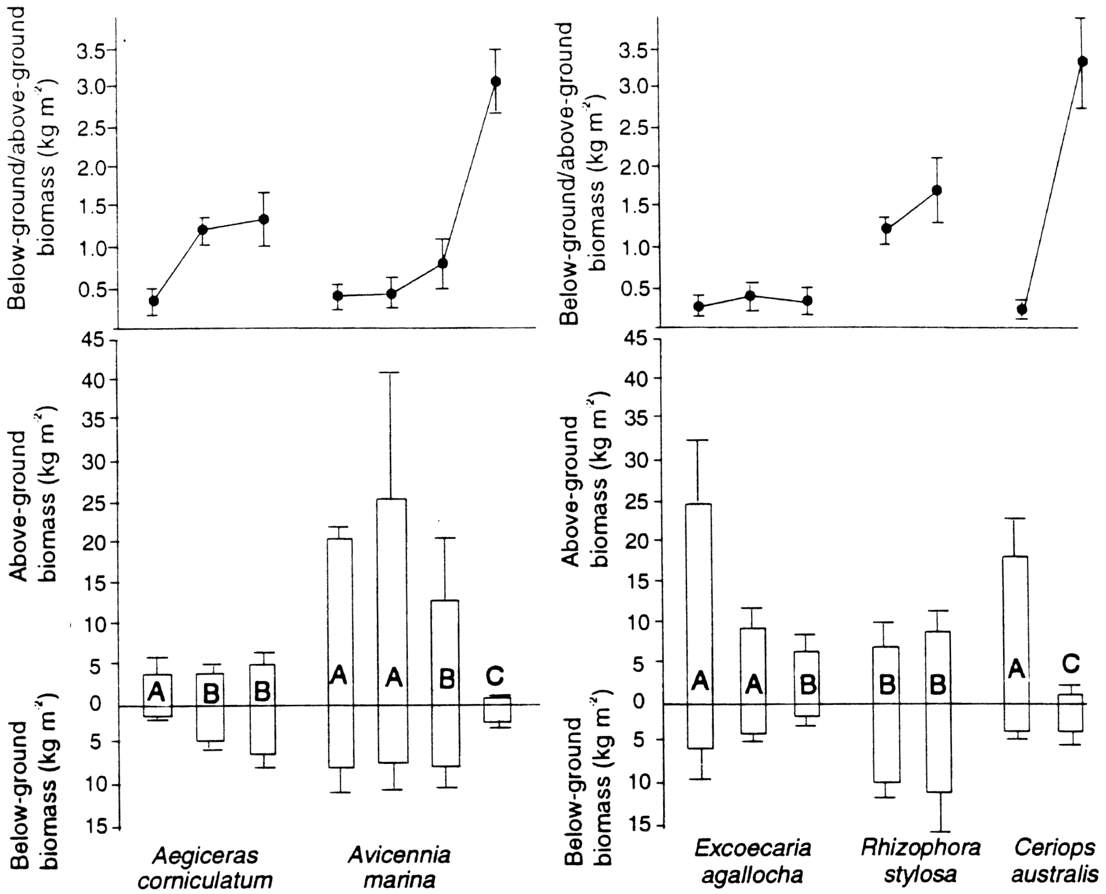

Fig. 2. Above- and below-ground biomass of five mangrove species on the Mary River (mean ± s.e.). A, upstream meandering reaches; B, seaward edge of wide intertidal flats in the channel mouth; C, landward segment of wide intertidal flats of the channel mouth.

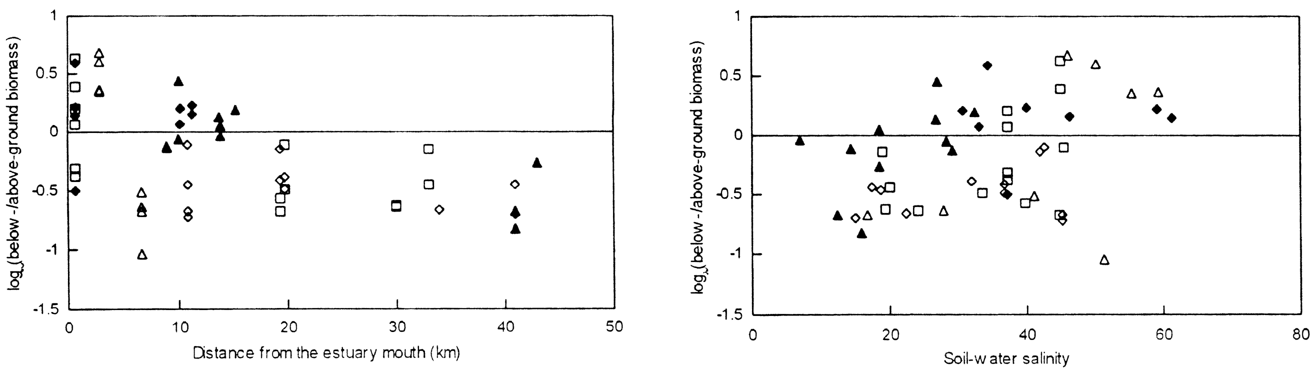

Fig 3. Above-ground : below-ground biomass ratios ($\log_{10}$) of five species with *(a)* distance from the mouth of the Mary River and *(b)* variation in soil-water salinity. (▲) *Aegiceras corniculatum,* (◇) *Excoecaria agallocha,* (□) *Avicennia marina,* (△) *Ceriops tagal,* (◆) *Rhizophora stylosa.*

that found in comparable environments in temperate localities (Woodroffe 1985; Saintilan 1997); this possibly reflects the seasonally lower rainfall of the region which contributes to hypersaline conditions in less-frequently inundated sites. In these environments, below-ground : above-ground biomass ratios of *A. marina* and *C. tagal* increase to ~3.5, a figure similar to that attained by *A. marina* in a comparable bay-head deltaic environment on the Hawkesbury River (Saintilan 1997). Again, the increase in the ratio is effected primarily by a decrease in shoot mass.

Increases in the ratio with increasing salinity have been observed in laboratory studies of seedlings of *A. marina* (Burchett *et al*. 1984; Naidoo 1987; Ball 1988) and *A. corniculatum* (Ball 1988). Ball (1988) and Ball and Passioura (1995) have argued that an increase in root:shoot ratio with salinity is a response to water stress, and is linked to a conservative water-use strategy, particularly in *A. marina*.

Estimates from this study suggest that below-ground : above-ground biomass ratio increases logarithmically with a linear increase in substratum salinity. Perhaps in the arid upslope environments of the river mouth a point is reached where the respiratory demand of an extensive root system exceeds the carbon fixing ability of a smaller shoot system. This may be one factor delimiting the upslope distribution of mangroves.

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References

Aung, L. H. (1974). Root–shoot relationships. In ‘The Plant Root and Its Environment’. (Ed. E. W. Carson.) pp. 29–61. (University Press of Virginia: Charlottesville.)

Ball, M. C. (1988). Salinity tolerance in mangroves *Aegiceras corniculatum* and *Avicennia marina* I. Water use in relation to growth, carbon partitioning, and salt balance. *Australian Journal of Plant Physiology* **15**, 447–64.

Ball, M. C., and Passioura, J. B. (1995). Carbon gain in relation to water use: photosynthesis in mangroves. In ‘Ecophysiology of Photosynthesis’. (Eds E. D. Schulze and M. M. Caldwell.) pp. 247–59. (Springer: Berlin.)

Burchett, M. D., Meredith, S., Pulkownik, A., and Walsh, S. (1984). Short-term influences affecting growth and distribution of mangrove communities in the Sydney Region. *Wetlands (Australia)* **4**, 63–72.

Briggs, S. V. (1977). Estimates of biomass in a temperate mangrove community. *Australian Journal of Ecology* **2**, 369–73.

Clough, B. F. (1992). Primary productivity and growth of mangrove forests. In ‘Tropical Mangrove Ecosystems’. Coastal and Estuarine Studies 41. (Eds A. I. Robertson and D. M. Alongi.) pp. 225–92. (American Geophysical Union: Washington, DC.)

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. 213–23. (Australian National University Press: Canberra.)

Clough, B. F., and Scott, K. (1989). Allometric relationships for estimating above-ground biomass in six mangrove species. *Forest Ecology and Management* **27**, 117–27.

Dalrymple, R. W., Zaitlin, B. A., and Boyd, R. (1992). Estuarine facies models: conceptual basis and stratigraphic implications. *Journal of Sedimentary Petrology* **62**, 1130–46.

Golley, F., Odum, H. T., and Wilson, R. F. (1962). The structure and metabolism of a Puerto Rican red mangrove forest in May. *Ecology* **43**, 9–19.

Golley, F. B., McGinnis, J. T., Clements, R. G., Child, G. I., and Duever, M. J. (1974). ‘Mineral Cycling in a Tropical Moist Forest Ecosystem.’ (University of Georgia Press: Athens.) 248 pp.

Gong, W. K., and Ong, J. E. (1990). Plant biomass and nutrient flux in a managed mangrove forest in Malaysia. *Estuarine, Coastal and Shelf Science* **31**, 519–30.

Hutchings, P., and Saenger, P. (1987). ‘Ecology of Mangroves.’ p. 388. (University of Queensland Press: Brisbane.)

Iwasa, Y., and Roughgarden, J. (1984). Shoot/root balance of plants: optimal growth of a system with many vegetative organs. *Theoretical Population Biology* **25**, 78–105.

Kozlowski, T. T., Kramer, P. J., and Pallardy, S. G. (1991). ‘The Physiological Ecology of Woody Plants.’ (Academic Press: San Diego.) 657 pp.

Lichacz, W., Hardiman, S., and Buckney, R. T. (1984). Below-ground biomass in some intertidal wetlands in New South Wales. *Wetlands (Aust.)* **4**, 56–62.

Lin, P., Lu, C., Wang, G., and Chen, H. (1990). Biomass and productivity of a *Bruguiera sexangula* mangrove forest in Hainan Island, China. *Journal of Xiamen University of Natural Science* **29**, 209–213.

Mooney, H. A. (1972). The carbon balance of plants. *Annual Reviews of Ecology and Systematics* **3**, 315–43.

Naidoo, G. (1987). Effects of salinity and nitrogen on growth and water relations in the mangrove *Avicennia marina* (Forsk.) Vierh. *New Phytologist* **107**, 317–25.

Robertson A. I., and Dixon P. (1993). Separating live and dead fine roots using colloidal silica: an example from mangrove forests. *Plant–Soil* **157**, 151–4.

Rochow, J. J. (1974). Estimates of above-ground biomass and primary production in a Missouri forest. *Journal of Ecology* **62**, 567–77.

Russell, R. S. (1977). ‘Plant Root Systems: their Function and Interaction with the Soil.’ (McGraw–Hill: London/ New York.)

Saenger, P. (1982). Morphological, anatomical and reproductive adaptations of Australian mangroves, In ‘Mangrove Ecosystems in Australia’. (Ed. B. F. Clough.) pp. 153–91. (Australian National University Press: Canberra.)

Saintilan, N. (1996). Mangrove environments of the Mary River. *Wetlands(Australia)* **15**, 31–8.

Saintilan, N. (1997). Above- and below-ground biomass of two species of mangrove on the Hawkesbury River estuary, New South Wales. *Marine and Freshwater Research* **48**, 147–52.

Snedaker, S. C. (1995). Mangroves and climate change in the Florida and Caribbean region: scenarios and hypotheses. *Hydrobiologia* **295**, 43–9.

Woodroffe, C. D. (1985). Studies of a mangrove basin, Tuff Crater, New Zealand. I. Mangrove biomass and production of detritus. *Estuarine, Coastal and Shelf Science* **20**, 265–80.

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