Aquatic Angiosperms in Coastal Saline Lagoons of New South Wales. III. Quantitative Assessment of *Zostera capricorni*

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Data on *Zostera capricorni* (total biomass, below-ground, detrital leaf, flowering stems and living shoot) and shoot measurements (percentage cover, density, leaflength and width) and biomass of *Halophila ovalis* and *Ruppia megacarpa* for summer and winter 1978-79 are presented for 7 sites in Lake Macquarie and 5 sites in Tuggerah Lakes. Regression equations are established relating *Zostera capricorni* total biomass and living shoot biomass to percentage cover for these sites in winter and summer and these equations applied to field survey data. The total biomass of *Zostera* in Lake Macquarie in summer 1985 was estimated as 1454 tonnes over an area of 11.57km^2; living shoot biomass was 330 tonnes. Comparable figures for Tuggerah Lakes are 1255 tonnes total biomass and 453 tonnes living leaf biomass over an area of 12.26km^2.

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INTRODUCTION

The distribution of aquatic angiosperms in the estuaries and coastal lagoons on the central and southern coast of New South Wales has been the subject of a number of papers but these have been quantitative only in the sense that the broad areas occupied by seagrasses have been mapped and in some cases surface area covered has been estimated (Wood, 1959, for Lake Macquarie; Higginson, 1965, for Tuggerah Lakes; Harris *et al.*, 1980, for Lake Illawarra; Evans and Gibbs, 1980, for 5 lagoons including Lake Macquarie and Lake Illawarra). West *et al.* (1985) provided an estuarine inventory for New South Wales but in this the only information on seagrasses was a value for the total area of seagrass and a list of those seagrasses occurring in each estuarine system. Detailed information on the distribution, relative abundance and the area occupied by seagrasses is available for Lake Macquarie (King, 1986b) and Tuggerah Lakes (King and Holland, 1986).

Despite the information in these publications and in the plethora of unpublished reports by State Government authorities until now there have been no biomass data available for these estuarine ecosystems except for two isolated values for the maximum total biomass of all species in Tuggerah Lakes in 1964 and 1967 (Higginson, 1971). Indeed it is only in the last few years that any data have been published for Botany Bay (Larkum *et al.*, 1984).

In both Lake Macquarie and Tuggerah Lakes the most abundant and widespread macrophyte is the seagrass *Zostera capricorni* Ascherson. It covers 11.57km^2 of Lake Macquarie (total seagrass area 14.17km^2) (King, 1986b), and 11.66km^2 (total seagrass area 20.44km^2) of the Tuggerah Lakes (King and Holland, 1986). *Zostera* commonly occurs with *Halophila ovalis* (R. Brown) Hooker f. but while *Halophila* is widespread (5.59km^2 and 9.82km^2 of Lake Macquarie and Tuggerah Lakes respectively) it is not such a significant contributor to biomass. The fibre-weed *Posidonia australis* Hooker f. does not occur in Tuggerah Lakes and is of restricted distribution in Lake Macquarie. *Ruppia megacarpa* R. Mason occurs in both systems but at the commencement of this study was relatively unimportant. Changes in the vegetation of Tuggerah Lakes since that time indicate that more attention should be paid to this species.

In this report we present basic data on biomass of *Zostera capricorni* of selected sites in both Lake Macquarie and the Tuggerah Lakes system. This information is then used to establish the relationship between various biomass attributes (total biomass, root, living leaf, detrital leaf and flowering stem) and shoot measures (percentage cover, shoot density, leaf height and leaf width). Relationships between percentage cover, and both total biomass and biomass of standing leaf stock are applied to data collected in the general surveys (King, 1986a,b; King and Holland, 1986).

TABLE 1

Scale used to rate seagrass distribution, with estimations of percentage leaf cover

Abundance	Sociability		
	a Individual strands or clumps	b Patches up to 10 m diameter	c Beds of relatively even distribution
1 Sparse growth (<15%)	5%	10%	15%
2 Moderate growth (15-50%)	15%	25%	35%
3 Abundant growth (>50%)	inappropriate measure	60%	65%

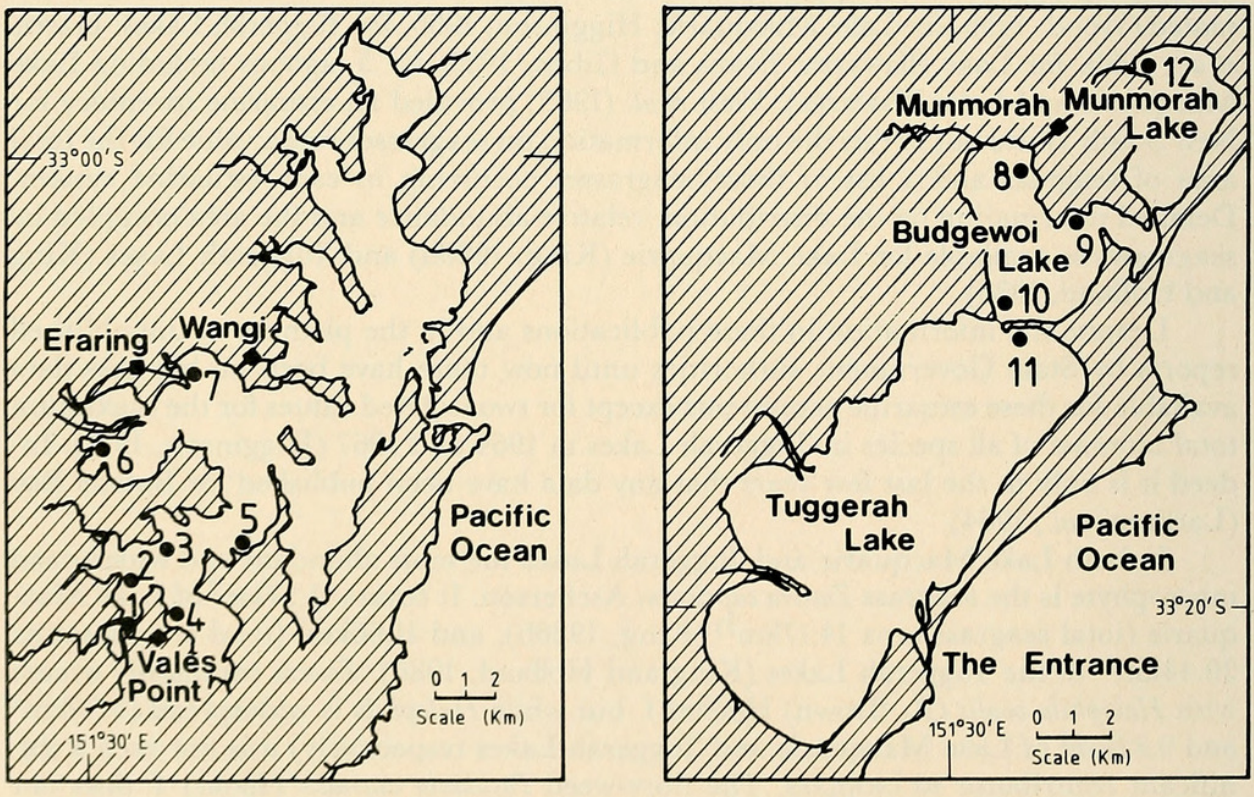

Fig. 1. **a** (left), sampling sites in Lake Macquarie: **b** (right), sampling sites in Tuggerah Lakes. See also Tables 2 and 3.

Methods

Sampling for the quantitative analysis

Twelve sampling locations were selected to cover a range of seagrass density: sites 1-7 in Lake Macquarie and sites 8-12 in Tuggerah Lakes (Fig. **1a,b**). These included sites in power station cooling water discharge plumes and sites near the edge of the plumes. Sites 1 to 5 are in the Vales Point power station cooling water plume, and sites 8 to 10 are in the Munmorah power station plume. Seagrasses at each locality were sampled in winter of 1978 and summer 1978/79 except for site 6 (Lake Macquarie) and sites 10 and 11 (Tuggerah Lakes) which were sampled in winter only.

In winter at least 10 quadrats were sampled at each site. These were located randomly within a grid 20m × 5m parallel to the shore, and at approximately 1m depth. In shallower water in these lakes seagrasses are sometimes physically damaged due to wave action created by both wind and motor boat activity, and this may upset any general relationships involving the leaf component. Samples were collected complete with sediment using a diver-held corer with an internal diameter of 15cm.

Percentage cover of *Zostera capricorni* was visually estimated in quadrats 25cm × 25cm using a scheme similar to that of Kirkman (1978) but with 7 cover grades:

Grade	% Cover Range	Midpoint	Description
6	>80	90	occupying almost the entire quadrat
5	61-80	70	approx. three quarters quadrat
4	41-60	50	approx. half quadrat
3	25-40	33	approx. third quadrat
2	12-24	18	approx. fifth quadrat
1	2-11	7	1/10-1/20 quadrat
+	<2	1	very sparse, occasional leaves

The random location of quadrats in winter proved somewhat unsatisfactory since in areas of mosaic weed growth some quadrats contained no seagrass at all (see sample numbers in Tables 2 and 3 which summarize the data for all quadrats containing seagrasses). In summer the samples were taken in areas subjectively assessed (Kirkman, 1978) as having intermediate weed cover for that particular locality: the size of the core samples was increased to 18.5cm diameter, and the number of samples was standardized at 5 at each locality. Localities 10 and 11 in Tuggerah Lakes were sampled in winter only.

At the field site all plant material was washed free of sediment in a 1.5mm mesh sieve, bagged and then either preserved in formalin or frozen. In the laboratory the samples were treated following the recommendations of Wetzel (1965) and Vollenweider (1974). The macrophytes were separated into the different species, washed to remove salt and physically cleaned of macrophytes. The *Zostera* was sorted into four components: root and rhizome, detrital leaf, living leaf, and flowering stems. Fresh weights were obtained after a standard spinning of each component in a simple kitchen 'salad dryer'. Dry weights were obtained by drying to constant weight at 105°C. Percentage ash-free weights of subsamples were obtained after oxidation to constant weight in a muffle furnace at 550°C.

The following measurements were made for each core sample: number of upright living shoots per unit area ('density'); average length of the two longest living leaves per shoot ('leaf height'); average width of leaves, 10cm from the base of 10 mature living leaves ('leaf width'). A high level of correlation was found between biomass levels and leaf

TABLE 2

Seagrass biomass (g. dry wt. m^{-2}), and Zostera *shoot measurements, as mean ± standard error from sites in Lake Macquarie, 1978-1979*

SITE (Fig. 1a)		TIME	NO. SAMPLES	*Halophila* BIOMASS	*Zostera* biomass: TOTAL INC. DETRITUS	BELOW GROUND	DETRITAL LEAF	FLOWERING STEM	LIVING LEAF	*Zostera* shoot measurements: % COVER	DENSITY (shoots.m^{-2})	LENGTH (cm)	WIDTH (mm)
Vales Point Power Station outlet	1	Winter	7	142 ± 19	0	0	0	0	0	0	0	0	0
		Summer	5	179 ± 8	0	0	0	0	0	0	0	0	0
Wyee Bay	2	Winter	9	10 ± 5	127 ± 40	77 ± 16	31 ± 9	0	19 ± 4	20 ± 5	1032	10 ± 2	3.0 ± 0.2
(north west)		Summer	5	12 ± 3	163 ± 47	81 ± 22	24 ± 7	0	59 ± 19	50 ± 12	1888 ± 288	11 ± 2	3.0 ± 0.1
Bluff Point	3	Winter	10	5 ± 1	258 ± 19	209 ± 17	23 ± 2	0	25 ± 2	–	–	–	–
		Summer	5	4 ± 1	372 ± 31	221 ± 11	37 ± 5	14 ± 4	100 ± 13	71 ± 2	1280 ± 128	26 ± 2	3.5 ± 0.1
Chain Valley Bay Station inlet	4	Winter	10	1 ± 1	245 ± 19	164 ± 14	69 ± 6	0	[13 ± 4][1]	[13 ± 3	1184 ± 160	9 ± 2	2.3 ± 0.1][1]
		Summer	5	17 ± 4	182 ± 48	115 ± 30	27 ± 6	1 ± 1	39 ± 11	30 ± 6	544 ± 112	20 ± 3	3.1 ± 0.7
Summerland Point	5	Winter	8	0	320 ± 20	197 ± 12	109 ± 12	0	14 ± 2	22 ± 2	336 ± 64	16 ± 2	2.7 ± 0.1
		Summer	5	0	639 ± 36	332 ± 17	120 ± 8	15 ± 11	172 ± 14	83 ± 4	1360 ± 192	43 ± 3	3.3 ± 0.1
Bonnells Bay	6	Winter	10	24 ± 8	186 ± 56	(135 ± 23	74 ± 33)[2]	0	19 ± 4	–	1520 ± 352	–	–
Myuna Bay Eraring Station outlet	7	Winter	11	0	379 ± 18	(217 ± 17	120 ± 12)[3]	0	28 ± 4	30 ± 3	1120 ± 224	19 ± 2	2.8 ± 0.1
		Summer	5	0	303 ± 29	169 ± 14	52 ± 6	13 ± 5	68 ± 10	60 ± 4	832 ± 64	27 ± 2	3.2 ± 0.1

Where full data sets are not available these are indicated: [1]data for 6 quadrats only
[2]data for 4 quadrats only
[3]data for 8 quadrats only

TABLE 3

Seagrass biomass (g. dry wt. m^{-2}), and Zostera *shoot measurements, as mean ± standard error from sites in Tuggerah Lakes, 1978-1979*

SITE (Fig. 1b)		TIME	NO. SAMPLES	*Ruppia* BIOMASS	*Halophila* BIOMASS	*Zostera* biomass: TOTAL INC. DETRITUS	*Zostera* biomass: BELOW GROUND	*Zostera* biomass: DETRITAL LEAF	*Zostera* biomass: FLOWERING STEM	*Zostera* biomass: LIVING LEAF	*Zostera* shoot measurements: % COVER	*Zostera* shoot measurements: DENSITY (shoots.m^{-2})	*Zostera* shoot measurements: LENGTH (cm)	*Zostera* shoot measurements: WIDTH (mm)
Munmorah Power Station outlet	8	Winter	10	No Seagrasses										
		Summer	5	0	92 ± 2	0	0	0	0	0	0	0	0	0
Buff Point Budgewoi Lake	9	Winter	4	0	6 ± 3	37 ± 8	23 ± 8	4 ± 2	0	10 ± 1	10 ± 3	688 ± 304	8 ± 2	2.4 ± 0.5
		Summer	5	0	16 ± 5	114 ± 29	57 ± 11	23 ± 11	0	34 ± 8	30 ± 6	688 ± 144	18 ± 3	2.4 ± 0.1
Southern Budgewoi Lake	10	Winter	8	0.8 ± 0.8	0	64 ± 9	(58 ± 11	11 ± 4)[1]	0	11 ± 3	12 ± 2	848 ± 192	5 ± 1	1.8 ± 0.6
Northern Tuggerah Lake	11	Winter	10	11 ± 8	4 ± 1	161 ± 52	(133 ± 52	27 ± 14)[2]	0	39 ± 19	28 ± 9	976 ± 144	12 ± 3	2.2 ± 0.2
Munmorah Lake near station inlet	12	Winter	9	0	2 ± 1	81 ± 10	(47 ± 9	6 ± 3)[3]	0	24 ± 6	18 ± 3	800 ± 160	11 ± 1	2.7 ± 0.1
		Summer	5	0	2 ± 1	201 ± 58	79 ± 26	51 ± 19	0	68 ± 16	53 ± 10	880 ± 144	23 ± 3	3.2 ± 0.2

Where full data sets are not available these are indicated: [1]data for 6 quadrats only
[5]data for 5 quadrats only
[6]data for 6 quadrats only

measurements (Barclay, 1983). This suggests the potential of using regression analysis to estimate biomass with non-destructive sampling. The most relevant to broad scale surveys are those relating biomass to estimates of percentage cover.

Data for total biomass of *Zostera* (excluding detrital material) and biomass of standing leaf stock were related to percentage cover through regression analysis. Using the data on area and abundance of *Zostera* (King, 1986a,b; King and Holland, 1986) these data have been used to give biomass figures for the entire lake systems. The categories of sociability and abundance used in the field surveys have been combined in a two-way table. For each category the cover was visually estimated, as above, and the percentage cover (to the nearest 5%) assigned to each (Table 1). The category 3a is unused since *Zostera* communities in which plants grow as individual strands or clumps cannot exhibit abundant growth.

RESULTS

The full data set on seagrass biomass and *Zostera* shoot measurements for Lake Macquarie and Tuggerah Lakes are given in Tables 2 and 3 respectively. The biomass figures are expressed in terms of per metre square but since the data refer only to quadrats in which plant material occurred they cannot be used in any comparative sense or to indicate biomass typical of an area. All data are expressed in terms of dry weight. The ratios of dry weight to fresh weight, and the organic contents as a percentage of dry weight for *Halophila* and *Zostera* are given in Table 4.

TABLE 4

Dry weight as a percentage of fresh weight of Zostera *and* Halophila *for sites in Lake Macquarie. Mean ± s.e; n = 82*
Organic weight as percentage of total dry weight of Zostera *and* Halophila *in both Lake Macquarie and Tuggerah Lakes. Mean ± s.e.; n=110*

		Zostera below ground	*Zostera* detrital leaf	*Zostera* live leaf	*Halophila*
Dry weight as percentage fresh weight	Lake Macquarie	9.6 ± 0.3	8.2 ± 0.5	10.5 ± 0.7	8.8 ± 0.5
Organic contents as percentage dry weight	Lake Macquarie	76.5 ± 1.5	78.5 ± 1.7	85.9 ± 1.0	69.7 ± 1.0
	Tuggerah Lakes	65.4 ± 2.0	67.3 ± 2.6	81.5 ± 2.7	

The relationship between percentage cover with both total biomass and leaf standing stock is described by the series of equations given in Table 5. Separate equations are provided for each season and for both Lake Macquarie and Tuggerah Lakes. Site 2 (Wyee Bay in Lake Macquarie) differs from other sites in a number of ways (Barclay, 1983) and is treated separately. In these equations biomass is expressed as a logarithmic scale since there appeared to be a logarithmic relationship between percentage cover and biomass (cf. Larkum *et al.*, 1984).

DISCUSSION

There are relatively few studies which deal with the estimation of seagrass standing stock or biomass in broad surveys, yet such data are important for management purposes and especially so if vegetation change is to be monitored. In regions where there is

TABLE 5

Linear regression equations relating $\log_{10}$ (total biomass) and $\log_{10}$ (living leaf biomass) to percentage cover for sites in southern Lake Macquarie and Tuggerah Lakes.
X_1 = percentage cover

SOUTHERN LAKE MACQUARIE				
All sites except those in Wyee Bay				
Summer				
$\log_{10}$ (total biomass)	=	$0.012X_1 + 0.525$	$r = 0.933$ ($n = 20$)	$p<0.001$
$\log_{10}$ (living leaf biomass)	=	$0.014X_1 - 0.200$	$r = 0.941$ ($n = 20$)	$p<0.001$
Winter				
$\log_{10}$ (total biomass)	=	$0.016X_1 + 0.697$	$r = 0.686$ ($n = 26$)	$p<0.001$
$\log_{10}$ (living leaf biomass)	=	$0.026X_1 - 0.586$	$r = 0.833$ ($n = 25$)	$p<0.001$
Wyee Bay (Site 2)				
Summer				
$\log_{10}$ (total biomass)	=	$0.010X_1 - 0.223$	$r = 0.806$ ($n = 5$)	$0.02<p<0.5$
$\log_{10}$ (living leaf biomass)	=	$0.017X_1 - 0.434$	$r = 0.986$ ($n = 5$)	$p<0.001$
Winter				
$\log_{10}$ (total biomass)	=	$0.035X_1 - 0.063$	$r = 0.894$ ($n = 9$)	$p<0.001$
$\log_{10}$ (living leaf biomass)	=	$0.030X_1 - 0.638$	$r = 0.917$ ($n = 9$)	$p<0.001$
TUGGERAH LAKES				
Summer				
$\log_{10}$ (total biomass)	=	$0.010X_1 + 0.417$	$r = 0.910$ ($n = 10$)	$p<0.001$
$\log_{10}$ (living leaf biomass)	=	$0.011X_1 - 0.037$	$r = 0.959$ ($n = 10$)	$p<0.001$
Winter				
$\log_{10}$ (total biomass)	=	$0.016X_1 + 0.240$	$r = .836$ ($n = 18$)	$p<0.001$
$\log_{10}$ (living leaf biomass)	=	$0.023X_1 - 0.501$	$r = .826$ ($n = 31$)	$p<0.001$

a marked seasonal growth pattern peak biomass may also be used as an indicator of productivity (Nienhuis and de Bree, 1977). In broad-scale survey work normal destructive methods of vegetative sampling are rarely appropriate, not only because they are time-consuming, but also, because the removal of vegetation may itself affect the result, particularly if the survey area is ecologically sensitive or has only a sparse vegetation cover.

Percentage cover has been used successfully to estimate 'above-ground' biomass of aquatic angiosperms by a number of workers: Rorslett *et al.* (1978) in studies of freshwater macrophytes; Kirkman (1978) in monitoring the decline of *Zostera capricorni* in Moreton Bay, Queensland; and locally by Larkum *et al.* (1984) in assessing total above ground stock of *Zostera capricorni* in Botany Bay. A more sophisticated population density index was used by Sheldon and Boylen (1978) to estimate cover and subsequently biomass in a large freshwater lake in N.Y. State. In a broad-scale survey Mukai *et al.* (1980) used a similar approach to that here to estimate the biomass of *Zostera marina* in Odawa Bay, central Japan. They used somewhat fewer data, 9 samples only in an area of 68 hectares.

In the study of Larkum *et al.* (1984) percentage cover was related logarithmically to both underground biomass and shoot biomass. A similar association was found in this project in Lake Macquarie and Tuggerah Lakes. In other studies, (Nienhuis and de Bree, 1977), in the Netherlands; McRoy, 1970, in Alaska) linear relationships were established between the standing stock of *Z. marina* and percentage cover. Larkum *et al.* (1984) suggested that the logarithmic relationship may indicate a 'synergistic effect of the presence of one plant on the growth of another', but whether this is caused by a more favourable redox potential and/or enhanced nutrient availability in dense stands (Orth, 1977) was not determined.

Non-destructive methods of estimating abundance were generally restricted to above-ground material and in seagrass studies root biomass has often been ignored; as indeed it is in most ecosystem studies (Caldwell, 1979). If the root to shoot ratio is any indication of the energy investment in root systems then it is clear that the importance of the root component has been underestimated. There are, however, several reports on below-ground productivity in seagrasses which indicate that it is much less than would be predicted by this ratio (see West and Larkum, 1983). The root/living shoot ratio of *Z. capricorni* was in the range of 1.16-2.94 in summer (data from Tables 2 and 3). Such ratios are compatible with observations made on a wide variety of communities where below-ground productivity has been shown to account for 50-80% of total net production (Caldwell, 1979). In winter when the living shoots die back the ratio of root/shoot is much greater and more variable, but the picture is complicated by the impossibility of distinguishing between living and non-living components and the root biomass.

The regressions established in this survey indicate that total biomass and standing stock of living leaves can be estimated from percentage cover. Separate regressions are required for the seasons (winter and summer). In this study separate regressions were required for data from site 2 (Wyee Bay, 1.5km from the Vales Point power station outlet). These regressions differed significantly from those at all other sites in Lake Macquarie.

When considering the calculated biomass data the following qualifications should be borne in mind:

(i) it is assumed that the relationship between biomass measures and percentage cover at various sites and in various seasons has remained constant during the period of the surveys,

(ii) there is a compromise between breadth and intensity of survey such that only 8 categories of percentage cover of *Zostera* are mapped. Hence there is a built-in error in the estimation of biomass for any category of abundance/sociability even assuming a particular area is accurately identified. This error could be especially critical when small areas of the lake are considered separately,

(iii) the equations do not take into account any possible variation in the relationship between percentage cover and biomass with depth (cf. Larkum *et al.*, 1984).

There are few relevant data with which to compare the biomass figures calculated using these relationships (Table 6). Larkum *et al.* (1984) recorded a total above-ground biomass of 81 ±4.2 tonnes for the 309ha of *Zostera capricorni* beds in Botany Bay. They pointed out that this figure was considerably less (by a factor of 6-10) than would have been estimated by taking the product of the area of the beds and biomass from a typically healthy bed. Their estimate took into account the patchy distribution of the beds. The average biomass figure in tonnes per square kilometre of 26 for Botany Bay is comparable to the average values of 28 tonnes.km^{-2} for Lake M, cquarie and 37 tonnes.km^{2} in Tuggerah.

The only published estimates of the dry weight standing biomass for either Lake Macquarie or Tuggerah Lakes are those of Higginson (1971) for Tuggerah Lakes. A single maximum value for 1964 and a single minimum value (1967) were given: 21000 tons (21333 tonnes) and 2300 tons (2337 tonnes) respectively. These figures include all species and related to the much larger area of the lake which was then colonized by plants. The figures were said to represent the equivalent of 2.5 tons.$acre^{-1}$ (627 tonnes.km^{-2}) and 0.4 tons $acre^{-1}$ (100 tonnes.km^{-2}). These values seem inordinately high

TABLE 6

Total biomass (tonnes) and shoot biomass of Zostera capricorni *in summer 1985 calculated using the linear regressions in Table 5 in conjunction with the area and relative abundance of* Zostera *shown on maps for Lake Macquarie (King, 1986b) and Tuggerah Lakes (King and Holland, 1986). Note that the total of Lake Macquarie includes seagrass from several small areas not listed separately*

	Total biomass (T)	*Zostera capricorni* Shoot biomass (T)	Area (km^2)
LAKE MACQUARIE			
Myuna Bay	26	6	0.29
Goonda — Fishing Station Pt	52	11	0.26
Northern Lake (Fishing Station Pt — Cardiff Pt)	161	35	1.30
Central eastern Lake	364	78	3.69
Crangan Bay	227	55	1.05
Chain Valley Bay	171	39	1.21
Wyee Bay inc. Mannering Bay	4	4	0.16
Wyee Pt — Bluff Pt	72	16	0.62
Bonnells Bay	289	67	2.00
Total — Lake Macquarie	1454	330	11.57
TUGGERAH LAKES			
Tuggerah Lake	1052	376	9.58
Budgewoi Lake	89	34	1.19
Munmorah Lake	114	43	0.59
Total — Tuggerah Lakes	1255	453	12.26

when compared with the range (10-55g.m^{-2} or 10-55 tonnes.km^{-2}) for *Zostera* species in Australia (see review of McComb *et al.*, 1981) and values in the range 70-156g.m^{-2} for mature stands of *Zostera capricorni* in summer in Botany Bay (Larkum *et al.*, 1984). The highest values for any site in this survey were 172 ± 14g.m^{-2} (n=5) for site 5 (Summerland Point) in summer. Higginson (1971) included all plants in his biomass but again published data for 'apparently healthy growing stands of plants' are 49.9g.m^{-2} for *Halophila* (see McComb *et al.*, 1981) and 403g.m^{-2} for *Ruppia*; considerably less than the values anticipated throughout the lakes. Unfortunately Higginson (1971) did not indicate the way in which he derived his values. The method of estimating biomass described here is appropriate to broad-scale surveys but it could be readily adapted to more detailed surveys. It is especially useful when there is a need to embrace wide variability in both time and space but resources are limited. Although correlations are high the field data are still prone to subjective assessment of the percentage cover. A multiple regression based on several measured leaf characters (Barclay, 1983) is potentially more accurate but the general applicability of such equations would need to be investigated.

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