A STUDY OF GROWTH AND PRIMARY PRODUCTION OF THE SEAGRASS, *POSIDONIA AUSTRALIS* HOOK *F*

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ABSTRACT

Biomass and productivity of the seagrass *Posidonia australis* have been investigated (1977-78), at sites in Botany Bay (N.S.W.), Jervis Bay (N.S.W.), Port Hacking (N.S.W.) and Spencers Gulf (S.A.). Leaf biomass, which represented 20-25% of total biomass, ranged from 100 to 600 g dry weight per m^2, and varied seasonally depending on water turbulence and growth rate. Leaf productivity was found to range from 0.6 to 5.2 g dry weight per m^2 per day, depending on site and season. Rhizome and shoot production in Botany Bay was estimated to be 0.12 to 0.20 g dry weight per m^2 per day. The turnover time (time to replace mean biomass) was found to be 93-117 days for leaves, and 11-19 years for the rhizome and shoot portions.

The area covered by *Posidonia australis* in Botany Bay (October, 1979) was estimated to be 500 ha. Total standing crop during a storm-free period (930-1460 tonnes) was used to estimate annual production of leaf material from *Posidonia australis* in Botany Bay (2790-5840 tonnes).

Laboratory experiments were performed to determine the effect of low light flux, salinity fluctuations and high temperatures on *Posidonia australis*. Changes in salinity had little immediate effect on leaf growth. Prolonged exposure to $30^{\circ}C$ was found to cause death of the shoots of *Posidonia australis*. A light flux of 250 $\mu E/m^2/sec$ was considered necessary to support *Posidonia australis* in laboratory culture, based on measurements of both oxygen metabolism and leaf growth.

Diurnal changes in the oxygen concentration, light flux and temperature of the waters surrounding a *Posidonia australis* community in Botany Bay have been investigated. Depending on light conditions and community metabolism, oxygen concentration can vary from 50-180% air saturation. The effect of storms on leaf biomass and oxygen metabolism of this community of *Posidonia australis* was also noted. Photosynthesis is much reduced after storm damage, due to leaf losses, and it is suggested that stored photosynthetic products allow regrowth.

Observations have been made on the dynamics of growth in mature plants of *Posidonia australis* and in seedlings grown under field and laboratory conditions. The difference between actively-growing (horizontal) rhizomes and erect shoots is discussed in relation to vegetative spreading of this seagrass.

The decomposition of leaf material of *Posidonia australis* during August-October (1978) at a Botany Bay site resulted in the loss of 38% of the initial dry weight over a fifty-day period. Leaf material is considered an important source of detritus in Botany Bay.

The loss in distribution of *Posidonia australis* in Botany Bay is discussed in relation to the changing nature of the predominant food web of the bay waters.

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Finally, I wish to thank my wife Jane for her continued support, help and love.

The work described in this thesis is to the best of my knowledge original, except where acknowledged in the customary form.

R.J. WEST.

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Chapter One

INTRODUCTION

Seagrasses are monocotyledonous plants adapted to living in a marine environment. Apart from the algae, they are the only group of plants to lead a completely submerged existance. Like all angiosperms they possess highly differentiated tissues, including leaves, stems, roots, flowers, seeds and a vascular system. There are approximately fifty-two presently described species of seagrasses, of which twenty-five species occur in Australian waters (Den Hartog, 1970; Cambridge and Kuo, 1979; Greenway, 1979). A brief table of classification has been included (Table 1, page 2).

With the exception of two species of *Halophila*, seagrasses have a creeping rhizome, with erect shoots bearing leaves and flowers. Leaves are linear, except in the case of *Halophila*, where they are elliptic or ovate. Flowers may be simple or actinomorphous, monoecious or dioecious. Fertilization is completed underwater, and involves a complex adaptation of the flower parts to function in the marine environment (Ducker and Knox, 1976). Little is known concerning the seedling growth of seagrasses, and in most cases, seagrasses exist in mature, monospecific communities, of indeterminant ages.

TABLE 1 : A Brief Table of Classifiction of Seagrasses.
(Adapted from Den Hartog, 1977; with reference to Cambridge and Kuo, 1979; and Greenway, 1979)

Family Subfamily	Genera	Nos. of Species	Australian Representatives
Potamogetonaceae			
Zosteroideae	*Zostera*	11	*Z. capricorni* *Z. muelleri* *Z. mucronata*
	Phyllospadix	5	None
	Heterozostera	1	*H. tasmanica*
Posidonioideae	*Posidonia*	5	*P. australis* *P. ostenfeldii* *P. sinuosa* *P. augustifolia*
Cymodoceoideae	*Halodule*	8	*H. uninervis* *H. pinifolia*
	Cymodocea	4	*C. rotundata* *C. serrulata* *C. augustata*
	Syringodium	2	*S. isoetifolium*
	Amphibolis	2	*A. antartica* *A. griffithii*
	Thalassodendron	2	*T. pachyrhizum* *T. ciliatum*
Hydrocharitaceae			
Hydrocharitoideae	*Enhalus*	1	*E. acoroides*
Thalassioideae	*Thalassia*	2	*T. hemprichii*
Halophiloideae	*Halophila*	9	*H. ovalis* *H. decipiens* *H. ovata* *H. spinulosa* *H. tricosta*
	Totals :	52	25

After reference to Arber (1920), and Den Hartog (1977), the following list can be compiled representing characteristics possessed by seagrasses enabling them to successfully colonise the sea :-

(i) Ability to live in a saline environment.
(ii) Ability to function normally whilst submerged.
(iii) A well developed anchoring system.
(iv) Ability to compete with other organisms in the marine environment.
(v) Ability to complete life cycle whilst completely submerged.

Seagrasses usually occupy the seafloor in areas of sandy substratum, from low-tide mark to depths of more than thirty metres (Den Hartog, 1977). Under optimum conditions, many species form productive meadows, offering shelter to a large and diverse range of fauna (Thayer, Wolfe and Williams, 1975).

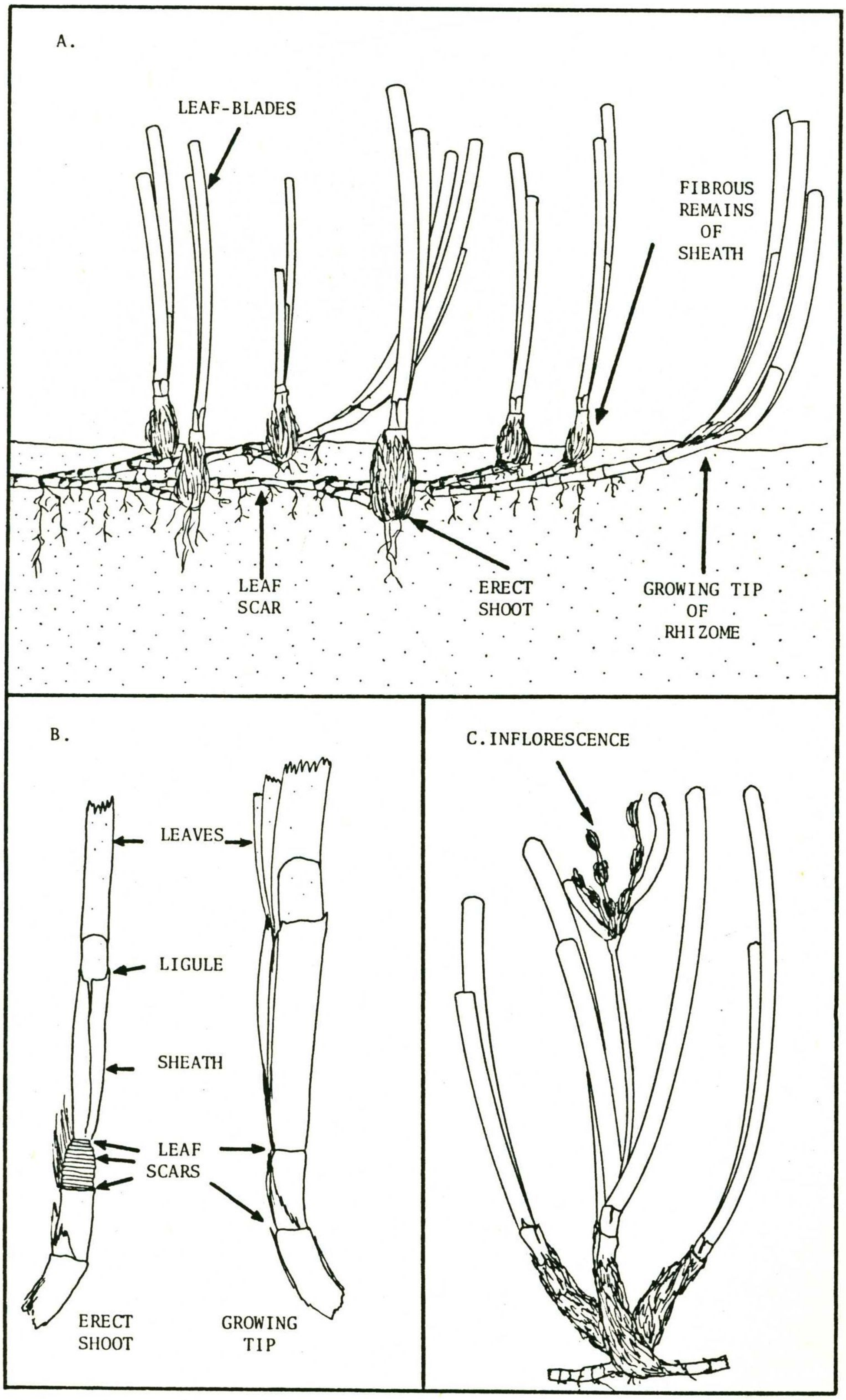
There are five species of seagrasses in the Sydney Region, these being : *Posidonia australis* Hook. *f.*, *Halophila ovalis* (R.Br.) Hook. *f.* *Halophila decipiens* Ostenfeld, *Zostera capricorni* Aschers and *Ruppia spiralis* Dumort. This thesis concerns the growth and metabolism of *Posidonia australis* (Figure 1, page 4), which is the climax species of seagrass in New South Wales (N.S.W.) marine waters, south of Port Stephens. It is absent from many brackish lagoons within this range (for example, Tuggerah Lakes) where the euryhaline species *Zostera capricorni* dominates. *Posidonia australis* occurs in dense meadows on sandy shores, under the sheltered conditions of bays and estuaries, to depths of eight metres (Den Hartog, 1970: Larkum, 1976).

FIGURE 1 : Illustration of *Posidonia australis*.

A. The rhizome, erect shoots and leaves.

B. The sheathing leaf base.

C. The inflorescence.


A.
LEAF-BLADES
FIBROUS REMAINS OF SHEATH
LEAF SCAR
ERECT SHOOT
GROWING TIP OF RHIZOME
B.
LEAVES
LIGULE
SHEATH
LEAF SCARS
ERECT SHOOT
GROWING TIP
C. INFLORESCENCE

Introductory Aspects of Seagrass Ecology

Although seagrasses have a widespread occurence, extending from low-tide mark to depths of more than thirty metres on almost all coastlines of the world (Phillips, 1978), their classification, structure, function and biology has received only recent attention, and is poorly understood (McRoy and Helfferich, 1977). Even so, studies in the last ten years have highlighted many facets of the seagrass ecosystem, showing that seagrasses are important in nutrient cycling, bottom stabilization and accretion, and in offering a nursery habitat for many species of juvenile animals (Thayer, Wolfe and Williams, 1975).

Seagrasses produce large amounts of organic matter. They often have high biomass, and fast growth rates, this being especially true of the leaf material (McRoy and McMillan, 1977). Although this plant material may be grazed quite heavily in tropical areas by fish (Odgen, 1976), turtles (Hirth, Klikoff and Harper, 1973) and dugongs (Heinson, Wake, Marsh and Spain, 1977), there are few direct grazers in temperate regions (Kikuchi and Peres, 1977). Secondary production in a seagrass bed occurs primarily through the detrital food chain (Fenchel, 1977). This process consists of the following steps (after Fenchel, 1977) :-

(i) Leaching of dissolved organic and inorganic molecules from the plant material, into the water column (these products may enter another food chain, for example, by incorporation into the plankton).

(ii) The mechanical breakdown of leaves into a particulate detritus. This can occur through wave action, or by repeated ingestion by fauna.

(iii) The bacterial and fungal decomposition of the cellulosic compounds.

(iv) The attack by bacteriovorous microfauna, and other detrital feeders.

(vi) The smaller invertebrates are prey for larger carnivorous invertebrates, fish, and other animals.

The difficulties in piecing together information concerning this diverse and complex food chain has resulted in slow progress in the understanding of the relationship between primary and secondary production in seagrass ecosystems. A more direct approach, using the stable isotope ratio (carbon-13 to carbon-12), has recently been applied (Thayer, Parker, La Croix and Fry, 1978). Each plant species is thought to have a unique range of isotope ratios, due to the characteristics of its photosynthetic process. Analysis of fauna should then indicate a ratio dependant on food source. By the analysis of many wetland and submerged plants, including phytoplankton, Thayer *et al* (1978) have arranged secondary producers in terms of detrital, planktonic, carnivorous, or mixed feeders, according to their isotope ratio.

As well as being a food source for some animals, seagrasses act as a nursery habitat for some commercial species. For example, in N.S.W., juvenile species of luderick (*Girella tricuspidata*), blue groper (*Achoerodus gouldii*), yellowfin bream (*Acanthopagrus australis*), tarwhine (*Rhabdosargus sarba*), leatherjackets (*Meuschenia spp.*), blue swimmer crabs (*Portuuna pelagicus*) and king prawns (*Penaeus plebejus*) have been monitored in the *Zostera capricorni* beds (Pease, Bell, Burchmore, and Conacher, 1979). These authors also suggest that the dusky flathead (*Platycephalus fuscus*) spawn in the seagrass bed habitats of Botany Bay. A shaded, sheltered environment is created by the leaf canopy of the larger species of seagrasses, which also acts as a protection from predators (Kikuchi and Peres, 1977). Kikuchi and Peres (1977) consider that the differentiation of the plant body into leaves, stems and rhizomes, and the existence of epiphytic algae, increases the ecological niches for associated biota. Hence the numerical abundance of invertebrates and fish faunas within seagrass areas usually exceeds adjacent unvegetated portions of sediment (Thayer, Wolfe and Williams, 1975).

Seagrasses also play an important role in nutrient cycling. The supply of nutrients to phytoplankton and most macroalgae is from oceanic waters, resulting in a seasonal bloom of particular species when conditions are favourable (Russell-Hunter, 1970). By comparison, quite high productivity rates can be maintained throughout the year in many species of seagrasses although they are growing in relatively nutrient poor waters (McRoy and McMillan, 1977). This is probably because nutrients can be obtained from the sediment (McRoy and Barsdate, 1970) and through association with nitrogen-fixing bacteria (Patriquin and Knowles, 1972). There is however some evidence that seagrass productivity may be limited by nitrogen supply (McRoy and McMillan, 1977; Patriquin, 1972; Orth, 1977). Cycling of these nutrients can occur by several means. For example, seagrasses may act to pump phosphates and ammonia from the sediment, through the leaves, and into the ambient water (McRoy, Barsdate and Nebert, 1972; McRoy and Barsdate, 1970). Also, direct transfer of carbon and phosphate from the leaves of *Zostera marina* to algal epiphytes has been demonstrated (Harlin, 1975). A third way that seagrasses may cycle nutrients is by the leaching of decomposing leaf litter, mentioned previously.

Another important aspect of seagrass ecology is derived from the effect that leaves and upright stems have in acting as a 'baffle' towards water currents (Wood, Odum and Zieman, 1969). In this way, the current is slowed, and smaller suspended particles may fall to the seafloor over seagrass beds, leading to stabilization and accretion of the sediment (Ginsberg and Lowenstam, 1958). In Shark Bay, Western Australia (W.A.), a a large seabank (129 km long, 8 km wide) has been formed by this process, in the last six thousand years (Davies, 1970).

To summarise, then, the many ways that seagrasses control and modify the environment (adapted from Wood, Odum and Zieman, 1969) :-

(i) They act as a food source for a limited number of organisms.
(ii) They serve as hosts for a range of epiphytes, which may be heavily grazed.
(iii) They provide material for the detrital food chain.
(iv) They act in nutrient cycling.
(v) They bind the sediment and encourage accretion
(vi) They are very productive.

Man has had an impact on the seagrass ecosystem through coastal development, and operations such as reclamation of foreshores and the dumping of wastes (Thayer, Wolfe and Williams, 1975). From the outline above, it is clear that seagrasses often play an important role in our coastal ecosystems, and that careful management is required to ensure that these areas are not in direct conflict with coastal development in future.

Posidonia australis Hook. *f.* : A Literature Survey

The first recorded specimen of *Posidonia australis* was collected at an unknown Australian location by R. Brown (*Type Specimen 5812, Herbarium of the Royal Botanic Gardens,* Kew, Richmond, England). There are many early collection lists that include *Posidonia australis* (Den Hartog, 1970), among which are the lists of Bentham (1877), containing seven genera of Australian seagrasses, none of which were collected from N.S.W. waters.

A description of the ecology of *Posidonia australis* is given by Ostenfeld (1916), after his visit to Western Australia in 1914. This author worked with material cast ashore at Carnavon and Geraldton, and described in some detail leaf morphology, the fruiting spikelets, and dispersal of fruit.

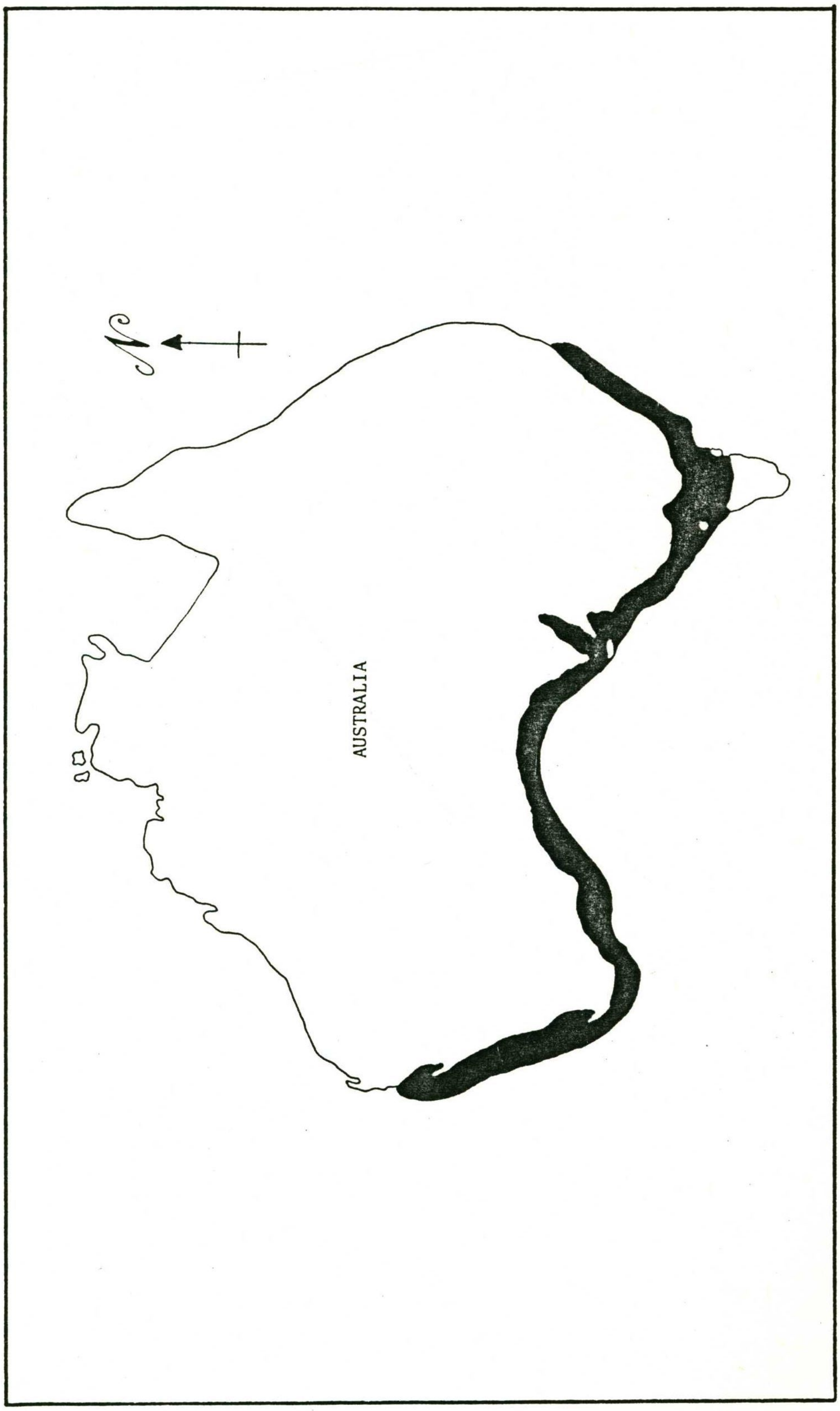
Ferguson Wood (1959) presented information concerning the ecology of *Posidonia australis*, as well as many other N.S.W. species of seagrasses. This author states " *Posidonia* has its greatest development in the South Australian gulfs " and that " on the east coast of Australia, however, *Posidonia* is of interest merely in forming a community in the seagrass association ". Ferguson Wood (1959) considered the *Zostera* communities to be more important in N.S.W., and restricted his treatment of *Posidonia australis* to a description of some growing locations (several locations within Botany Bay are mentioned), and some components of the community, for example, the epiphytes.

Den Hartog (1970) summarised a great deal of information concerning all seagrasses in his excellent monograph. This includes a description of taxonomy, distribution, gross morphology, flowering and fruit dispersal of *Posidonia australis*. Seedling establishment and physiology were treated rather poorly, due to lack of information. A map depicting the distribution of *Posidonia australis*, adapted from information contained in Den Hartog (1970) has been included (Figure 2, page 11).

Larkum (1973) describes the seagrass communities of Jervis Bay, N.S.W., and treats briefly, by means of comparison, the communities of Botany Bay. The *Posidonia australis* meadows of Jervis Bay are described as very extensive, and supporting a wide variety of marine life. Turbidity is mentioned by this author as a possible cause for the decline of the seagrass meadows in Botany Bay waters. This is described in more detail by Larkum (1976, see below).

A description of the seagrass communities of south-western Australia has been included by Cambridge (1975). This author has made

FIGURE 2 : Generalised Map of the Distribution of *Posidonia australis* on the Australian Continent.
(Adapted with reference to the localities listed in Den Hartog, 1970.)


N
AUSTRALIA

special reference to the ecology of *Posidonia australis* in a polluted environment. The deterioration of the *Posidonia australis* meadows in Cockburn Sound, Western Australia, is outlined, and mention is made of some biomass and growth studies.

Larkum (1976) details distribution, biomass (fresh weight) and density of the *Posidonia australis* meadows of Botany Bay, and several other N.S.W. estuaries. Distribution changes during past times are discussed, by this author, and results of clearing and transplant experiments presented. Larkum (1976) infers that degradation of the *Posidonia australis* beds in Botany Bay was due to pollution, perhaps increasing turbidity.

Kuo (1978) and Kuo and Cambridge (1978) have analysed the morphology anatomy, and histochemistry of *Posidonia australis*. Kuo (1978) presents in detail leaf-blade and leaf-sheath structure. The epidermal cells of *Posidonia australis* have been found to have a porous cuticle, and plasmodesmata linking them to the mesophyll cells. Rhizome and root morphology of *Posidonia australis* has been described by Kuo and Cambridge (1978).

Two new species, *Posidonia augustifolia* and *Posidonia sinuosa*, have been described recently by Cambridge and Kuo (1979). These species are distinguished by leaf morphology and anatomy. The range of these species is thought to be restricted to south-western Australia, and does not include N.S.W. waters.

General Morphology of *Posidonia australis*

The structure of *Posidonia australis* is illustrated in Figure 1, page 4. A single plant of *Posidonia australis* consists of a creeping rhizome, with lateral branches (or erect shoots) produced at regular intervals, by the dichotomous branching of the parent shoot, in the apical meristem. The lateral branches elongate minimally, and would appear to have the primary function of producing leaves. A lateral branch may, however, elongate in response to sediment influx, or when growing into a bare area (that is, in response to space).

The leaves of *Posidonia australis* are linear, strap-like, and range in mature length from thirty to one hundred centimetres, and in width from about eighty to one hundred and twenty millimetres. The outer leaf on an erect shoot is the oldest, and new leaves are produced within the sheathing base of older leaves. Each erect shoot has two to four leaves. For each leaf produced there is a corresponding leaf-scar in the meristem region which persists, forming the rhizome nodes. On erect shoots these leaf-scars are close together, indicating the slow elongation of the rhizome. However, on the parent shoot, the leaf-scars may be as much as seven centimetres apart.

Paired roots are often produced on the rhizome, at the node, usually along the parent shoot, and at the base of established erect shoots. They may be longer than twenty centimetres, and are approximately two to three millimetres in diameter.

The inflorescence is borne on a compressed peduncle, three to six millimetres wide, and eighteen to forty-five centimetres long. It consists of three to six hermaphroditic flowers. The fruit is ellipsoidal, three centimetres long, and one centimetre in diameter. It has a fleshy, green pericarp, which splits to release the seed (see also Den Hartog, 1970).

STATEMENT OF AIMS

The work undertaken in this thesis was initiated to provide information concerning *Posidonia australis* Hook *f.* in N.S.W. waters. The specific aims were :-

To investigate the growth and determine primary production of this seagrass.

To determine the effects of environmental variations on growth.

To make some general observations on the ecology and biology of *Posidonia australis* in N.S.W. waters.

This type of basic information is lacking for many species of Australian seagrasses. It is becoming increasingly important to have such information as these natural resources of our coastal areas are constantly threatened by urban and industrial development (Cambridge, 1975; Larkum, 1976; Larkum, 1977).

Chapter Two

BIOMASS AND PRIMARY PRODUCTION OF *POSIDONIA AUSTRALIS* IN THE WATERS OF BOTANY BAY

Production, when applied to biological systems, refers to the amount of organic matter formed in a given time. That amount of the sun's radiant energy which is captured by plants and stored in a chemical form is termed the 'primary production'. The measurement of primary production is important as it can give an indication of the capability of an area or ecosystem to support a food-web of secondary producers.

Production measurements have the units of dry matter per unit area per unit time, and are usually expressed as *grams dry weight per square metre per day* or *tonnes dry weight per hectare per year*. If the relationship between carbon content and dry weight of the organic matter is known, then another useful unit is *grams carbon assimilated per square metre per hour.*

Primary production may be measured by short or long term methods and the result gained will depend on the choice of method. Short term methods are based on the calculation of net photosynthetic rates, the period of experimentation being from a matter of minutes to perhaps as long as twenty-four hours. Two methods are usually employed, either the measurement of radioactive carbon fixation, or of net oxygen production. Long term methods of measuring primary production are based on the increase in dry matter of the plants, over a period of weeks, months or years, found by harvesting the plants before and after a known growing season.

The relationship between long and short term methods of measurement of primary production is demonstrated in Figure 3, page 16. It can be seen that these two options only yield comparative results when the following conditions apply :-

(i) There is no loss of photosynthetic products (for example, Dissolved Organic Carbon, D.O.C.).

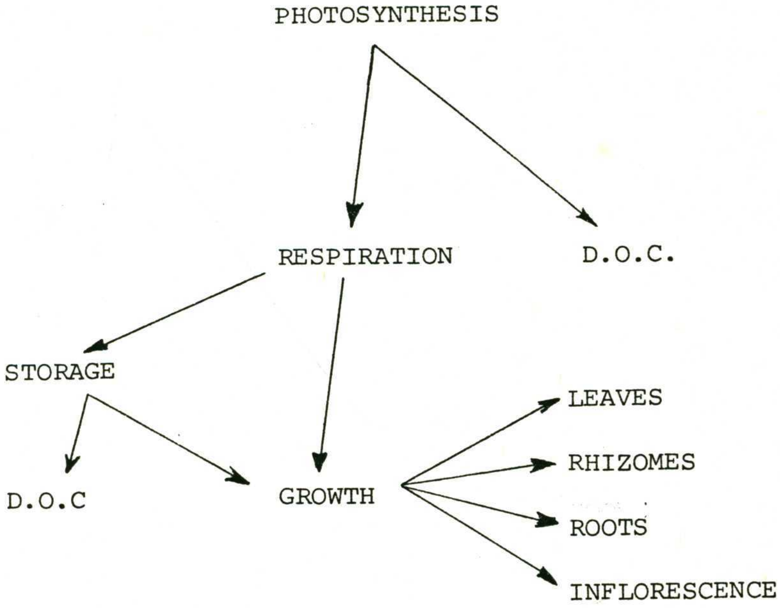
(ii) Storage of photosynthates is accounted for, with dry matter increases at a later time.

(iii) Dry matter and energy content of the plant are constant throughout the plant organs. (If this condition is not held, than it would mean that more energy is required to form the same dry weight in different parts of the plant.)

Since these conditions would be rarely met, and are certainly not met in seagrasses(for example, the loss of dissolved organic matter, Brylinsky, 1977), the two methods of measuring primary production will not yield the same result. Despite this, direct comparisons of the methods have been attempted (for example, Bittaker and Iverson, 1976).

For reasons of simplicity, accuracy and convenience, the long term method of the measurement of primary production has been chosen in this study. The biomass of the seagrass *Posidonia australis* has been found at several N.S.W. sites, each month for a one year period. Leaf

FIGURE 3 : A Schematic Carbon Cycle, showing the Relationship between Long and Short Term Methods of the Measurement of Primary Production.


PHOTOSYNTHESIS
RESPIRATION
D.O.C.
STORAGE
D.O.C
GROWTH
LEAVES
RHIZOMES
ROOTS
INFLORESCENCE

and rhizome primary production have been estimated for a one year period, employing a harvesting technique.

Biomass and Primary Production of Seagrasses : A Literature Survey

The short-term methods of estimation of primary production include measurement of oxygen production, or of radioactive carbon uptake (Vollenweider, 1971). Both of these methods may be affected by the recycling of gases in the extensive lacunal system possessed by most seagrasses (Hartman and Brown, 1967; Zieman, 1968; McRoy and McMillan, 1977). This aspect is also discussed in Chapter 3.

Methods employed to measure oxygen release from seagrass communities may involve the use of enclosing vessels, such as glass bottles or large acrylic chambers, or they may involve measurement in open waters (Vollenweider, 1971). The principal method of oxygen determination is the Winkler chemical method (Strickland and Parsons, 1972), although oxygen electrode techniques are also widely in use (Pijanowski, 1975).

Diurnal oxygen concentrations in a flowing water mass provided one of the earliest short term measures of productivity of aquatic plants (Odum, 1956; Odum, 1957). This method made no allowance for planktonic metabolism, and relied heavily on a crude estimate of water volume and speed. Loss of oxygen through bubbling, and changes in concentration due to reaeration were further problems. Several later studies also relied on this method (Odum, Burkholder and Rivero, 1959; Quasim and Bhattathiri, 1971). Improvements have been made, to this technique, by the measurement of the planktonic contribution (through the use of light and dark bottles), and of the oxygen reaeration (Nixon and Oviatt, 1972). A further improvement is the isolation of a known volume of water (Weiner, *personal communication*).

A variation of the above technique is the collection of single whole plants, or of leaf sections, which are subsequently incubated in glass jars, either *in-situ*, or under controlled laboratory conditions, and assayed for oxygen production (Jones, 1968; Buesa, 1974: Buesa, 1975; Drew, 1978).

The most sophisticated method employed in the measurement of oxygen release from seagrass communities is the simultaneous recording of oxygen, temperature, light and salinity, within a completely enclosed chamber, with circulating seawater, over a diurnal period (Weiner and Kirkman, 1980: Clough and Attiwill, 1979; *this study, Chapter Four*). Clough and Attiwill (1979) have used this method to predict the primary production of *Zostera muelleri* in Westernport Bay, Victoria. These authors have calculated a response curve from several diurnal incubations, for photosynthesis at different light levels. This treatment could be improved substantially, by increasing the number of diurnal incubations to exclude seasonal variations in photosynthesis, and by the continuous measurement of light, at the plant-canopy level. The problem created by the internal gas lacunae of seagrasses remains to be resolved, despite some theorectical discussions (Clough, 1967; Clough and Attiwill, 1979).

Wetzel (1964) and Drew and Larkum (1967) pioneered the use of radioactive isotopes to measure primary production, *in-situ*, of aquatic plants. These workers used bell-jars to incubate single plants which were later assayed for carbon-14 content. McRoy (1974) adopted a similar method with the seagrass *Zostera marina* in Alaskan waters, while Drew and Jupp (1976) measured uptake by *Posidonia oceanica* in Mediterranean waters. Penhale (1977) measured primary production of *Thalassia testudinum* and epiphytes, by a carbon-14 method, this time improved by reducing the unstirred layers about the plant, with circulation of the seawater. The use of radio-isotopes in the field is somewhat difficult, and does not overcome the problem caused by possible recycling of gases in the lacunae (McRoy and McMillan, 1977).

Long term methods of measurement of primary production were first used in relation to seagrasses in Denmark, in the early part of this century (Petersen, 1913). Petersen (1913) estimated the primary production of *Zostera marina*, by harvesting this seagrass at several stages of its growth cycle, and concluded that these plants made an important contribution to production in the estuarine system. This author did not, however, take into account the rapid turnover of leaf material that can occur in seagrasses, particularly in *Zostera* species (Sand-Jensen, 1975; Larkum, Collett and Williams Jnr, 1980). Petersen's estimates were therefore lower than the true production. Biomass is still often used as an estimate of productivity (Westlake, 1963), although turnover of biomass is the more important concept. Zieman (1968, 1974, 1975) developed a marking technique to measure leaf production in meadows of *Thalassia testudinum* in the waters of Florida. This method, described at the International Seagrass Workshop in the Netherlands (McMillan, *et al*, 1973) as the only reliable method to measure directly the primary productivity of seagrasses, has been used in many studies, involving *Thalassia testudinum* (Zieman, 1975; Patriquin, 1973; Greenway, 1977) and *Zostera marina* (Sand-Jensen, 1975).

The literature referring to biomass and productivity estimates for seagrasses is best summarised in a set of tables (Tables 2A and 2B, page 21). Table 2A, page 21, lists biomass, productivity and calculated turnover, found for seagrasses in overseas studies. In general, the estimates based on long term measurements are lower than those based on short term methods (refer to McRoy and McMillan, 1977). Table 2B, page 21, lists biomass of *Posidonia australis* at some locations in Australia. There are no published estimates of the primary production of this seagrass, except that arising from this study (West and Larkum, 1979).

The Study Sites

The principal site for this study is Botany Bay, N.S.W. For comparative reasons, another major sampling area was chosen in Jervis Bay, N.S.W. Other collection areas included Port Hacking, N.S.W., and Spencers Gulf, S.A., and although the results of the experiments at these latter two sites are not described until Chapter 5, some description of these areas is presented. The location of these sites on the Australian continent is shown in Figure 4, page 22.

Botany Bay, N.S.W. (34°00' S, 151°12' E)

Botany Bay is an area of water, about nine kilometres south of Sydney, formed in a minor tectonic depression (Phillips, 1973). There are two freshwater sources entering the bay, the Georges and Cooks River. The Cooks River includes flow from the Alexandria Canal. The Georges River has a high sediment and nutrient load, when compared to the bay-waters, especially during periods of heavy rain (State Pollution Control Commission, S.P.C.C., 1977, page 60). The Cooks River (and Alexandria Canal) contains some industrial effluent from the southern industrial suburbs of Sydney, and is severely polluted during wet weather, with high silt loads and adverse bacteriological quality (S.P.C.C., 1977, pages 145 - 147).

TABLE 2A : The Biomass, Productivity, and Turnover of Seagrasses : Literature Values. (Adapted from McRoy and McMillan, 1977. Values have been converted to dry weight according to McRoy and McMillan, 1977. Many new estimates have been included.)

TABLE 2B : The Biomass of *Posidonia australis* : a Literature Survey.

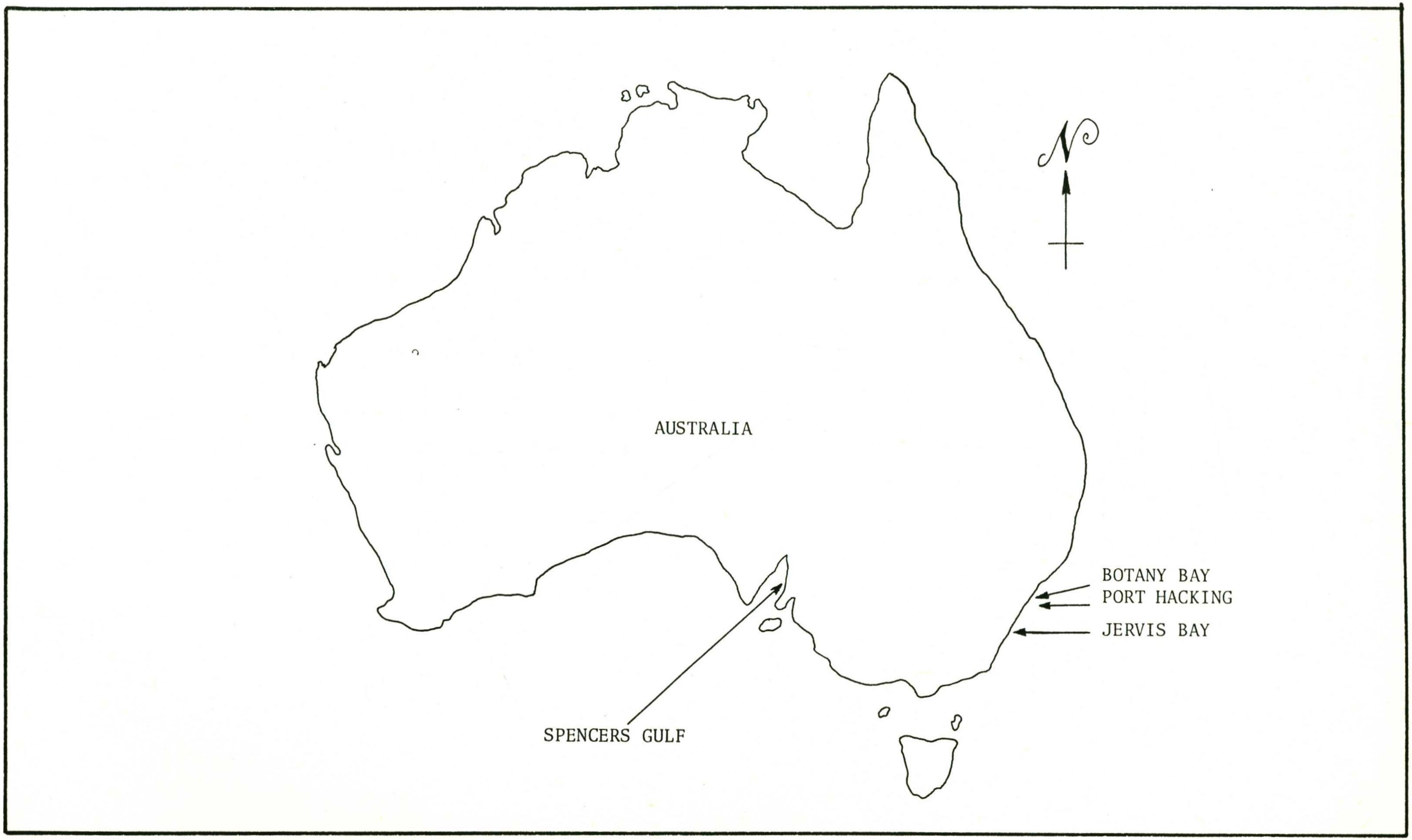
TABLE 2A

SEAGRASS	LOCALITY	STANDING CROP (g dw/m^2)	PRODUCTIVITY (g dw/m^2/day)	TURNOVER (crops/yr)	REFERENCE
Cymodocea nodosa	Mediterranean	13-342	14.2-49.2	53-397	(from McRoy and McMillan (1977) unless stated otherwise)
Halodule beaudettei	Nrth. Carolina	200	1.3- 5.3	2.4-9.1	
Posidonia oceanica	Malta	742	5.3-13.2	2.6-6.5	
Thalassia testudinum	Cuba	340	24.5-32.9	26- 35	
	Florida	81	0.9- 3.0	4.0- 14	
	Florida	835	2.4- 6.6	1.0-2.9	
	Florida	280	2.2-10.0	2.9- 13	Zieman (1975)
	Jamaica	249	6.0	8.7	Greenway (1976)
Zostera marina	Denmark	443	7.9	6.5	Sand-Jensen (1975)
	Alaska	1000	8.7- 10	3.1-3.6	
	Washington	94-539	1.6	1.1-6.2	
	Rhode Island	100	6.8	25	

TABLE 2B

LOCATION	LEAF BIOMASS (g dw/m^2)	TOTAL BIOMASS (g dw/m^2)	REFERENCE
Cockburn Sound, W.A.	0-800		Cambridge (1975)
Redcliffs, S.A.	61-2800		Shepherd (1974)
Botany Bay	300-500	about 1000	Larkum (1976)

FIGURE 4 : A Map of the Australian Continent, showing the Study Sites.


N
AUSTRALIA
BOTANY BAY
PORT HACKING
JERVIS BAY
SPENCERS GULF

The meadows of *Posidonia australis* in Botany Bay have been studied briefly by Ferguson Wood (1959), and in more detail by Larkum (1976). The latter author concludes that the *Posidonia australis* inhabiting Botany Bay was, in many cases, growing sub-optimally, possibly due to increased turbidity, after foreshore development. *Posidonia australis* is now restricted to the southern shoreline of the bay.

According to Larkum (1976), and on early inspection during this study, there are obvious differences in leaf characteristics of *Posidonia australis* at different sites in Botany Bay. There are also differences in environmental conditions (for example, exposure). For this reason two sites were chosen in Botany Bay for the study of biomass and production.

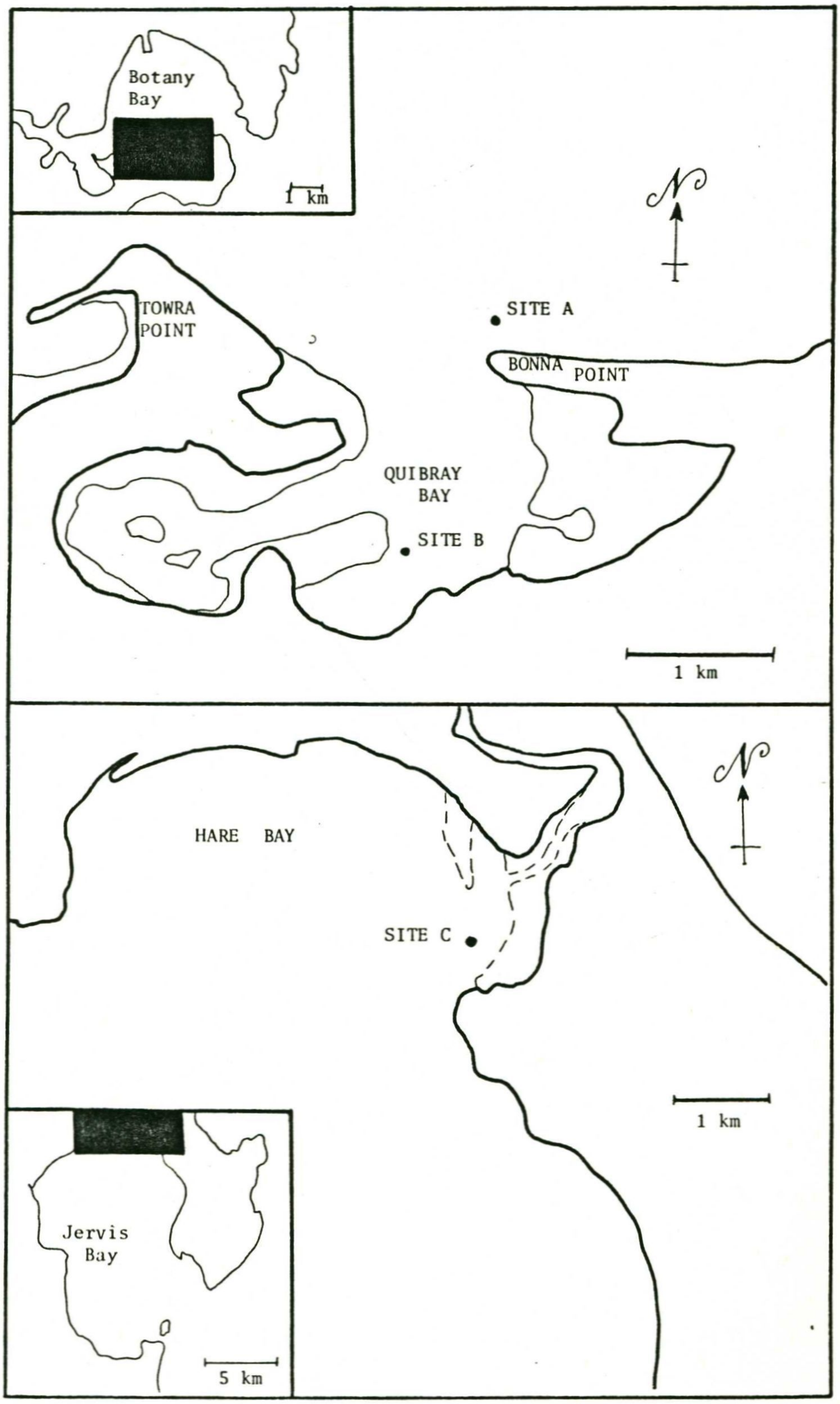
Site A (Figure 5A, page 24), the Bonna Point Site, is in approximately one metre of water, and exposed to moderate wave action, during heavy sea-swells. The sediment appears to be coarse sand, and the area is subject to the effects of the Georges River, such as salinity changes, during heavy rain periods.

Site B (Figure 5A, page 24), the Quibray Bay Site, is also in approximately one metre of water, but is exposed to less water movement. This is probably the reason for the sediment being a finer sand than that at Bonna Point.

As well as these two sites, a variety of other areas were sampled during the biomass studies, and these will be listed in the relevant section.

FIGURE 5A : The Botany Bay Sites. Site A is near Bonna Point.
Site B is in Quibray Bay.

FIGURE 5B : The Jervis Bay Site. Site C is in Hare Bay, Jervis Bay.


Botany Bay
1 km
N
TOWRA POINT
SITE A
BONNA POINT
QUIBRAY BAY
SITE B
1 km
N
HARE BAY
SITE C
1 km
Jervis Bay
5 km

Jervis Bay, N.S.W. (35°01' S, 150°46' E)

There are extensive meadows of *Posidonia australis* in the waters of Jervis Bay (Larkum, 1973). A site was chosen with the object of being as free from human interference as possible. For this reason Site C (Figure 5B, page 24), is situated in an isolated area on the northern side of Jervis Bay, known as Hare Bay. This site is in approximately one metre depth of water, and subject to a moderate degree of water movement, especially during southerly storms.

Port Hacking, N.S.W. (34°01' S, 151°08' E)

A sheltered area was chosen in Port Hacking, at approximately one metre depth of water. This site, sampled in summer and winter only, was situated on a sandbar, opposite the deep channel in Burraneer Bay.

Spencer Gulf, S.A. (32°33' S, 137°46' E)

An open water site in approximately one and one-half metres of water, and two hundred metres south of the entrance to Chinaman Creek, near Port Augusta, S.A., was sampled in summer and winter only. The Spencer Gulf area supports vast meadows of *Posidonia australis* (Shepherd, 1977).

Seasonal Changes in the Biomass of *Posidonia australis*

Early studies of the seagrass meadows of Botany Bay estimated the standing stock from a measure of fresh weight, not accounting for seasonal changes (Larkum, 1976). For the calculation of monthly primary productivity, and of turnover, the seasonal variation in biomass of *Posidonia australis* at each of the sites is required.

Materials and Methods

Biomass was estimated monthly, from February, 1977, to February, 1978, at the sites in Botany Bay and Jervis Bay. At each site, all plant material within six randomly placed 0.5 m x 0.5 m square quadrats was removed, and collected separately into polythene bags. This size quadrat was chosen as it offered a low variance to mean ratio, and was much less damaging than the use of a larger 1.0 m x 1.0 m quadrat (refer to Larkum, 1976). The material was analysed in the laboratory. After a brief rinse in tapwater to remove the sediment, the plants were separated into leaves and underground portions. The majority of epiphytes were removed by scraping. A record was kept of leaf and shoot numbers. The *Posidonia australis* material was then dried to constant weight at 80°C (generally for forty-eight hours).

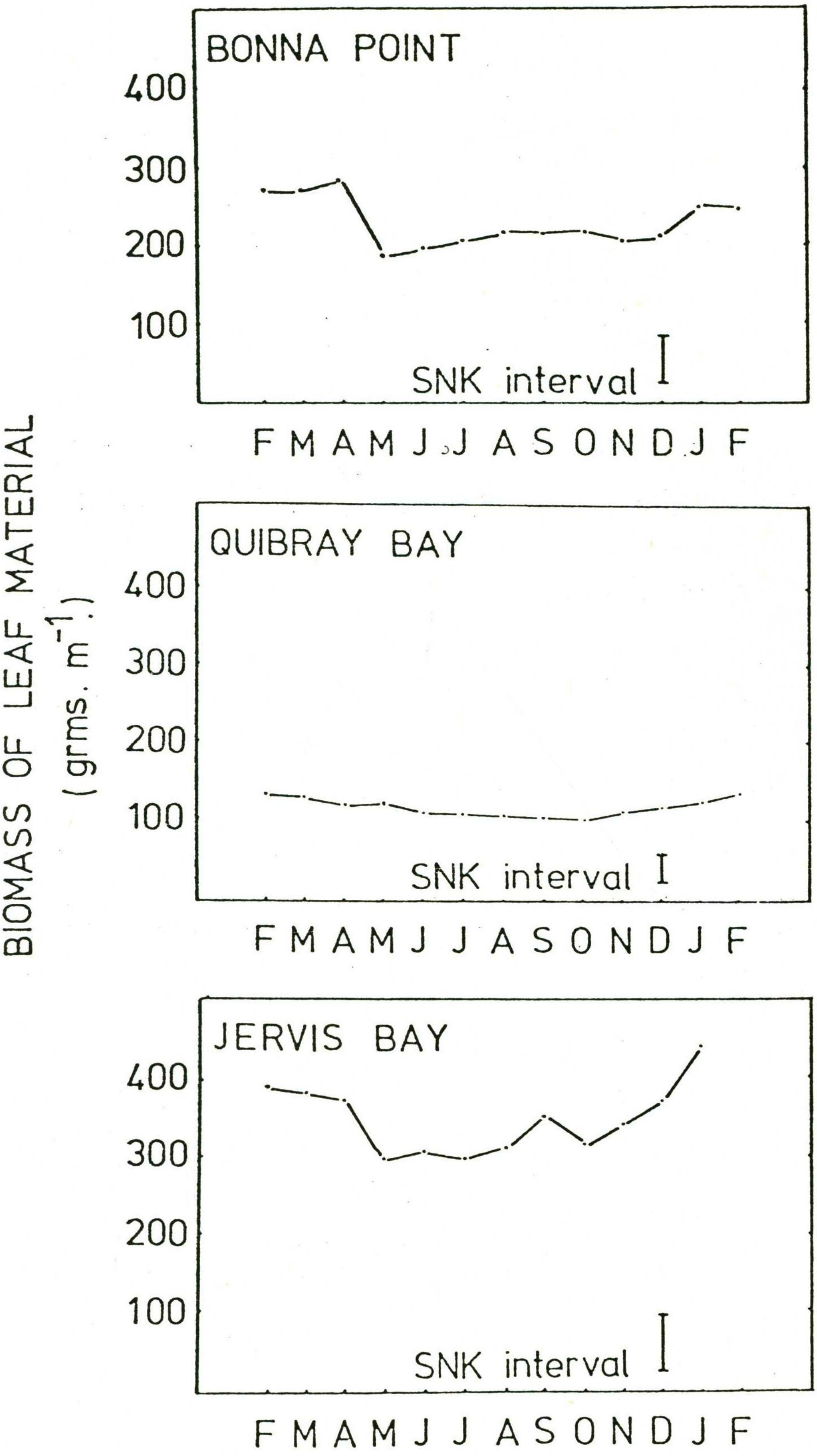
Statistical treatment of the results consisted of a test of variance homogeniety, and a one-way analysis of variance. The Student-Newman-Keuls (S.N.K.) interval has been calculated where applicable (Zar, 1974).

Results and Discussion

Data and calculations are shown in Appendix 1A.

At all three sites there are significant variations in leaf biomass (0.05 confidence level), throughout the one year period (Figure 6, page 27). The reasons for these variations are those of leaf growth and of leaf loss. Seasonal changes in leaf growth are discussed later in this chapter. Leaf loss occurs naturally after abscission but can be induced prematurely, during heavy seas. The most significant losses in leaf biomass occurred during April-May at the Jervis Bay and Bonna Point, Botany Bay sites. This leaf loss corresponds to the period of the year when southerly

FIGURE 6 : Leaf Biomass of *Posidonia australis* at the Bonna Point, Quibray Bay and Jervis Bay Sites, for the period February (1977) to February (1978).


BIOMASS OF LEAF MATERIAL
(grms. m^{-1})
BONNA POINT
400
300
200
100
SNK interval
F M A M J J A S O N D J F
QUIBRAY BAY
400
300
200
100
SNK interval
F M A M J J A S O N D J F
JERVIS BAY
400
300
200
100
SNK interval
F M A M J J A S O N D J F

storms are most frequent in the Sydney region (Gentilli, 1969), and is thought to be a direct result of physical damage during heavy seas. Although the Jervis Bay site recovered in terms of biomass by December, 1977, the Bonna Point site did not recover during the recorded period. Indeed, a more severe storm, during April, 1978, resulted in a greater loss of leaf material at this site (refer to Chapter 4).

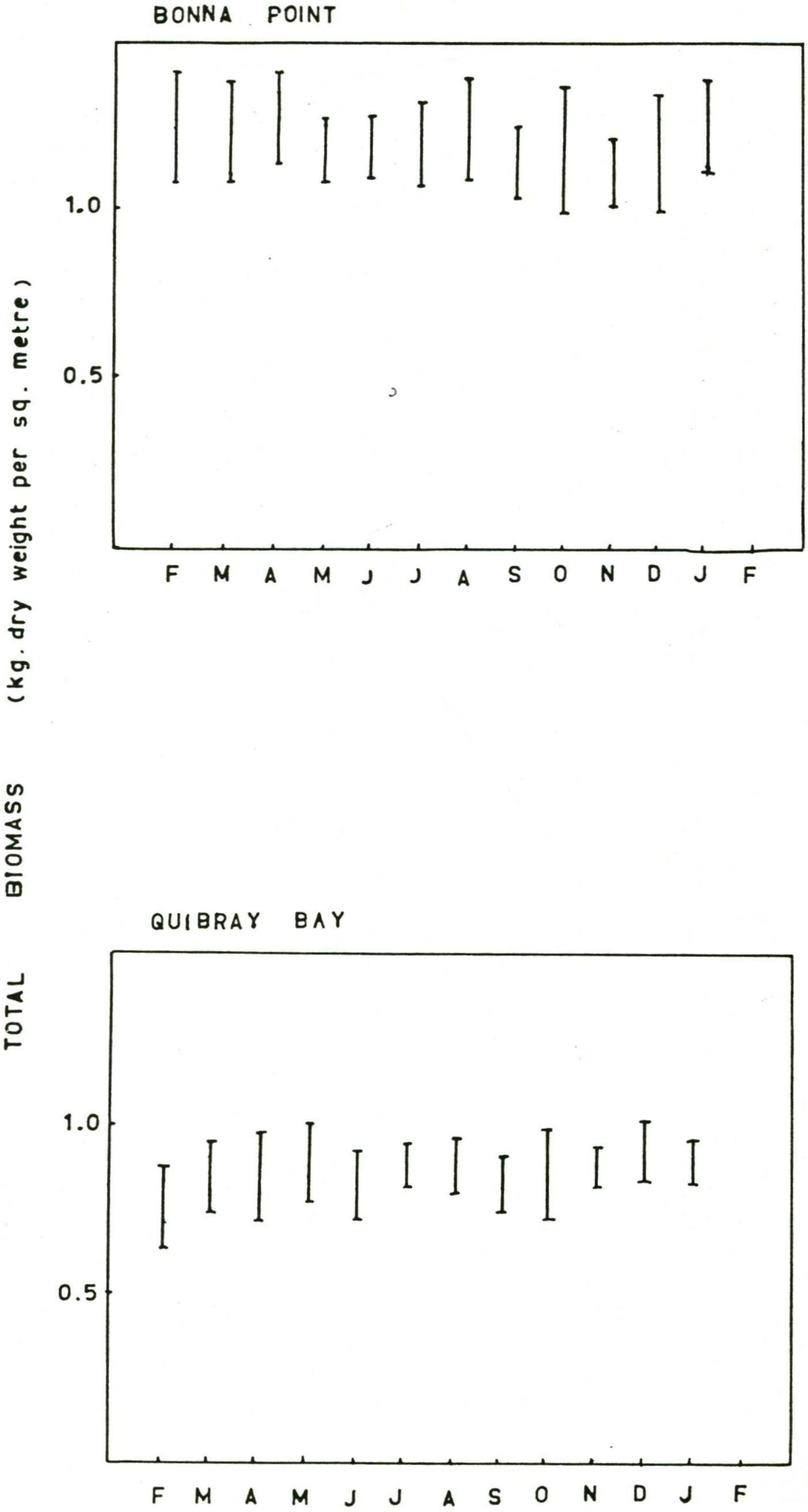
The monthly total biomass of *Posidonia australis* at the Bonna Point and Quibray Bay sites is shown in Figure 7 (page 29). An analysis of variance (Appendix 1A), indicates that there are no significant changes in total biomass at the Bonna Point site, and few at the Quibray Bay site. The total biomass of *Posidonia australis* at the Jervis Bay site was sampled in summer and winter only, and is listed in Appendix 1A. At this site the biomass was considerably higher, and did not appear to vary between the collection times. The underground portions of *Posidonia australis* contribute approximately seventy per cent of the total biomass, and the low variation on total biomass is explained by the slow growth of rhizomes, and the apparently long life of these portions (Chapter Five).

Total Standing Crop of *Posidonia australis* in Botany Bay

An attempt has been made to estimate the total standing crop of *Posidonia australis* in Botany Bay, in terms of area and biomass. Such information may prove useful in future work, providing a baseline from which the changes in distribution and density, due to further foreshore development, can be studied.

The total standing crop was estimated using aerial photographs taken in April 1979, and results of a biomass sampling program during October, 1979. Seasonal changes in biomass have been shown to be due mainly to water turbulence (previous section), and should not cause significant errors as biomass was sampled after a prolonged storm free period.

FIGURE 7 : Total Biomass of *Posidonia australis* at the Bonna Point and Quibray Bay Sites, during the period from February, 1977 to February, 1978.


BONNA POINT
QUIBRAY BAY
TOTAL BIOMASS (kg. dry weight per sq. metre)
1.0
0.5
F
M
A
M
J
J
A
S
O
N
D
J
F

Materials and Methods

Aerial photographs (Infra-red, Land Department Series, April, 1979) have been used to map the seagrass distribution. *Posidonia australis* meadows can be identified on these photos as a dark-green offshore band, and can be mapped with the assistance of ground 'truth' surveys (during October, 1979). A map was produced with scale 1 : 25,000. The map was photocopied onto a transparent sheet, and the seagrass areas cut from the map with care. The darkened areas on the map were estimated with a Leaf Area Instrument (Licor).

Ten sites within the known area of *Posidonia australis* were sampled for leaf biomass, during October, 1979, according to the previously described method. A total of sixty leaf biomass samples were taken, and the ninety-five per cent confidence limit, for leaf biomass, was calculated.

Results and Discussion

The map depicting the distribution of *Posidonia australis* meadows along the southern shoreline of Botany Bay is presented in a reduced format, as Figure 8, page 31. The meadows of *Posidonia australis* are shown in black on this map. The area covered by this seagrass, in Botany Bay, was found to be five hundred hectares.

Table 3, page 32, lists the median values of the ten sites sampled for leaf biomass, during October 1979. The full set of data, and statistical calculations are shown in Appendix 1B. At these sites, the standing crop of *Posidonia australis* shows significant variations, except at sites 2, 3 and 6 (refer to Table 3).

Cambridge (1975) states that in a continuous, healthy meadow

FIGURE 8 : Map Depicting the Distribution of *Posidonia australis* along the Southern Shoreline of Botany Bay, October, 1979.

Posidonia australis is shown thus : ■

Mangrove areas shown thus : ψψ

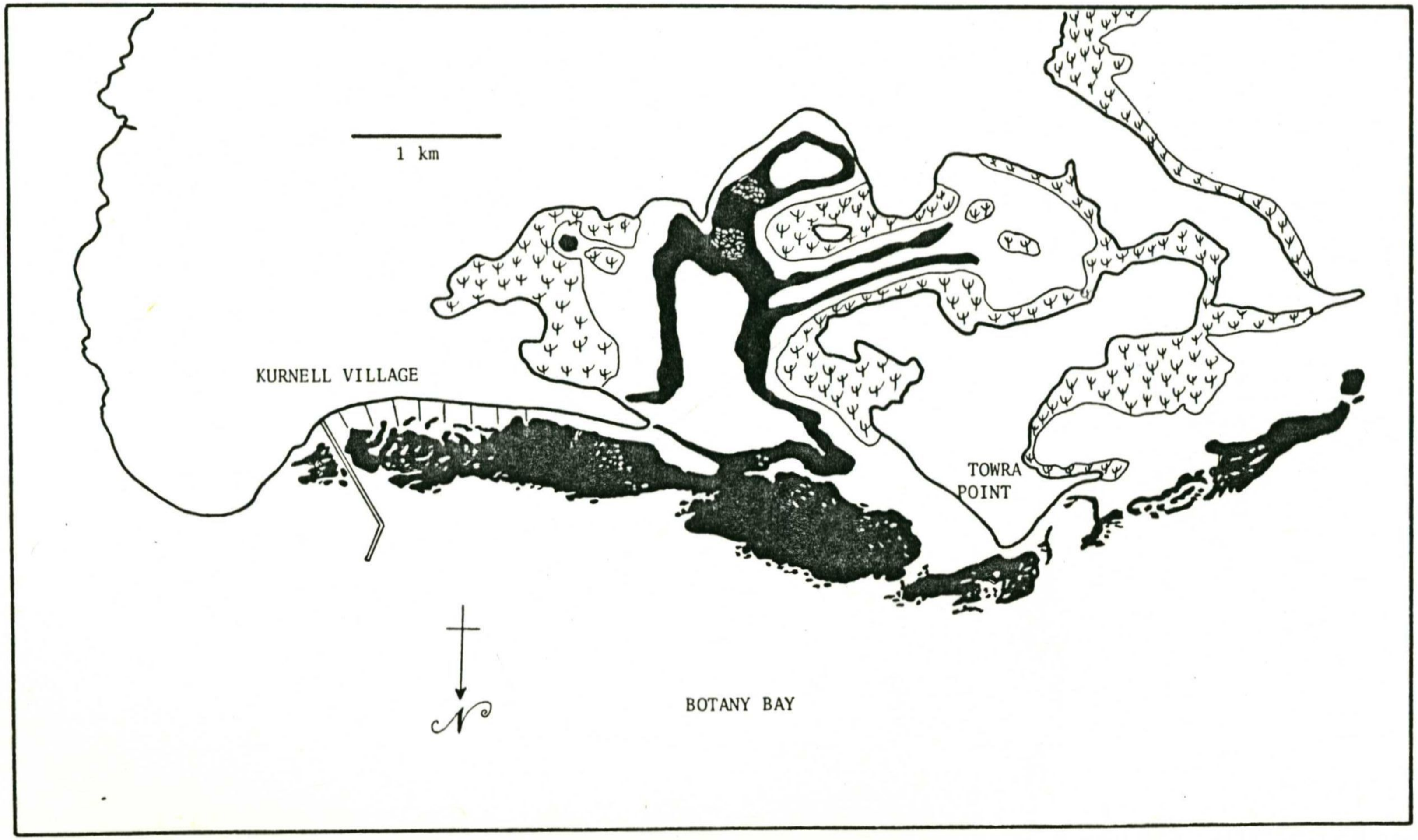

1 km
KURNELL VILLAGE
TOWRA POINT
N
BOTANY BAY

TABLE 3 : Median Leaf Biomass at the Ten Sites sampled in October, 1979.

AREA NUMBER	APPROXIMATE LOCATION	MEDIAN BIOMASS (grams/ m^2)
1	Between sand-bars, off Bonna Point	472 - 552
*2	Quibray Bay, north of Weeney Bay	260 - 272
*3	Quibray Bay, south of Weeney Bay	200 - 236
4	Quibray Bay, Site B, see text	129 - 132
5	Quibray Bay, south-east side	284 - 296
*6	Silver Beach, between groynes	232 - 256
7	Bonna Point, Site A, see text	476 - 508
8	Quibray Head, off Beach	336 - 352
9	Towra Point, off Beach	152 - 153
10	Pelican Point	62 - 71

* denotes no significant difference (0.05 level) between biomass at these sites

of *Posidonia australis*, situated in Cockburn Sound, Western Australia, standing crop values range from 300 - 800 g dry weight per square metre. In areas where the seagrass beds have declined due to industrial development, this author recorded values in the range 100 - 300 g dry weight per square metre. Twenty-one of the sixty leaf biomass samples collected in this study fall into the range above 300 g dry weight per square metre, and the remainder are in the lower range. The lower values for leaf biomass of *Posidonia australis* recorded here, were collected in areas close to the entrance of the Georges River (Pelican Point, Table 3, page 32), and at one site in Quibray Bay, where human activity (the digging of worms, for use as bait) has caused a patchy distribution. Overall, the leaf biomass appears to be at the lower end of the range, in N.S.W. waters, when compared to the *Posidonia australis* meadows of Western Australia (Cambridge, 1975) and of South Australia (refer to Chapter Five).

The values of leaf biomass for *Posidonia australis* presented in this study are in the same range as those listed for other seagrasses (Table 2, page 21).

Using the data collected for leaf biomass, it can be calculated that the standing crop of *Posidonia australis* in Botany Bay is between 186 and 292 g dry weight per square metre (this being the 95% confidence interval for the median standing crop; see Appendix 1B). Since the meadows of *Posidonia australis* cover an area of about 500 hectares, the total standing stock for this seagrass, based on the October, 1979, estimates, is approximately 930 - 1460 metric tonnes. This is about fifeteen times the standing stock of *Zostera capricorni* in Botany Bay, estimated by Larkum, Collett and Williams Jnr. (1980), which covers an area of

284 hectares. Clough and Attiwill (1979) have recorded that *Zostera muelleri* has a similar standing stock (940 metric tonnes) over a much wider area (3800 hectares) in Westernport Bay, Victoria. It would seem that *Posidonia australis* is capable of maintaining a higher concentration of leaf material than these two species of *Zostera*.

Leaf Production of *Posidonia australis*

Leaf production of *Posidonia australis* was estimated at the Botany Bay and Jervis Bay study sites, continuously for a one year period. An adaptation of the marking technique of Zieman (1974) was employed, to measure leaf turnover at each site.

Materials and Methods

All leaves inside a 0.5m x 0.5m square quadrat were marked at the level of the top of the ligule (refer to Figure 1B, page 4). Initially a modified stapler was used (Zieman, 1974), however, in most trials a small hole (diameter less than one millimetre) was punched through the leaves at the same level, according to the method of Kirkman (personal communication). The hole left by this method, with associated scar tissue, appeared to cause less damage and was easier to perform than the insertion of a staple. It was readily recognised for periods of up to a month. After 10 - 20 days, the marked leaves were collected, and newly grown tissue, above the ligule but below the mark, was separated from older plant tissue (above the mark). The weight of each fraction was obtained after drying (80^{0}C for forty-eight hours, or until constant). This mark and harvest technique was carried out for a one year period, at the three sites, in Botany Bay and Jervis Bay.

The turnover of leaf material was converted to leaf blade production by a multiplication with the respective month's biomass estimate.

Mean and variance were calculated for the set of data collected each month, at each site. Homogeneity of variance was tested using Cochran's Test Statistic (Till, 1974). An analysis of variance was performed on the data, and the Student-Newman-Keuls (S.N.K.) interval calculated to compare the means (Zar, 1974).

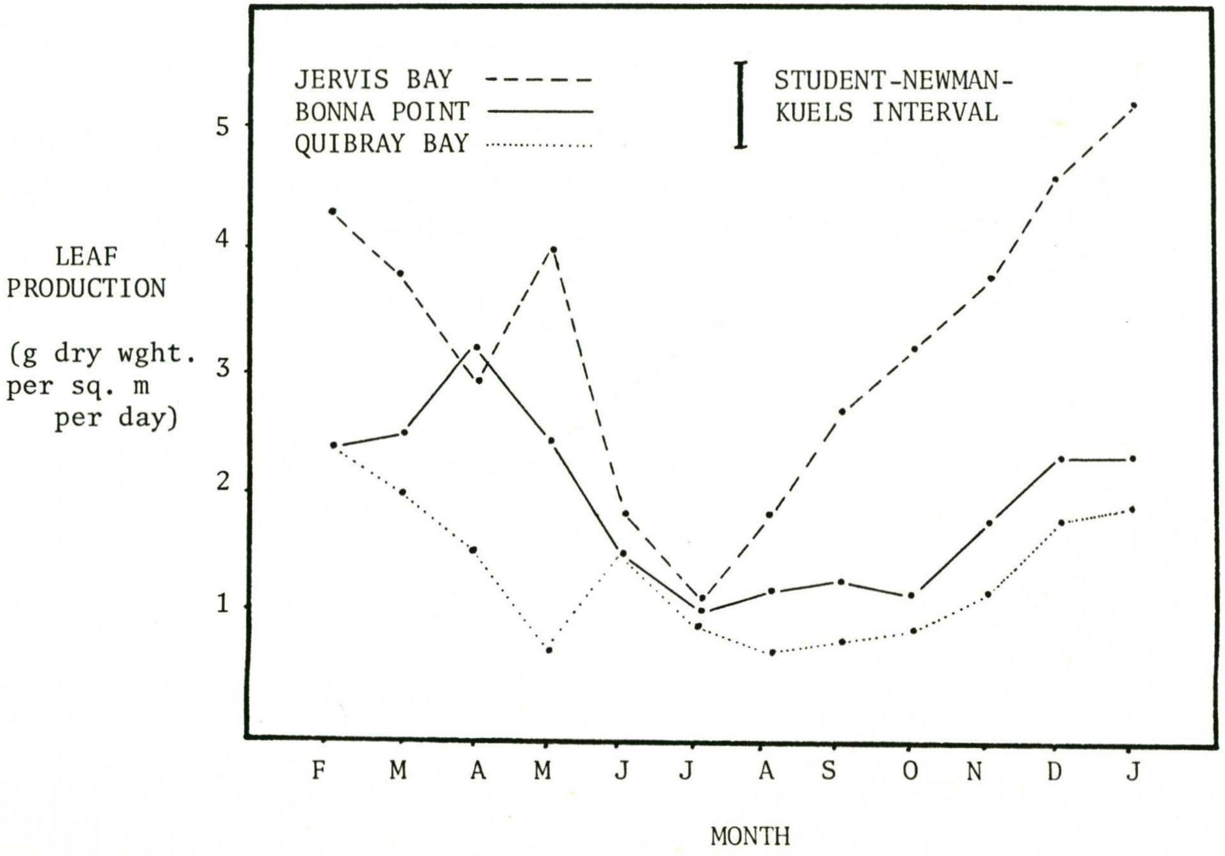
Results and Discussion

The data and statistical calculations are shown in Appendix 2.

Leaf blade production of *Posidonia australis* ranged from 0.6 to 5.2 g dry weight per square metre per day, depending on site and on season (Figure 9, page 36). The values found at the Jervis Bay site are significantly higher than those at the Botany Bay sites, for eight of the twelve months of trial. These leaf production values are comparable to the rates recorded for *Thalassia testudinum*, which forms large beds in shallow regions of the Caribbean and sub-tropical America (Den Hartog, 1970). Zieman (1975) has recorded a range of from 0.3 to 10.0 (means of between 2.3 to 5.0) g dry weight per square metre per day in South Florida; Greenway (1974) has found a yearly mean of 5.9 g dry weight per square metre per day in Jamaican waters; and Patriquin (1973) recorded rates of 1.2 to 14.8 g dry weight per square metre per day at different sites and in different seasons, in the Bermudas.

Leaf blade production appears to be markedly seasonal in *Posidonia australis*, with a maximum between November and February, and a minimum in July-August. The situation is complicated by the flowering process, which commences in about July. In Jervis Bay, where flowering occurs each year, leaf production is severely cut back during this flowering period. In Botany Bay, flowering is less common, nevertheless, leaf blade production declined during this period. A similar situation was recorded for *Thalassia testudinum* by Zieman (1975) :-

FIGURE 9 : Comparison of the Leaf Production of *Posidonia australis* at the Botany Bay and Jervis Bay Sites (1977-78). The S.N.K. Interval can be used to compare the significant difference (0.05 confidence level) between any two means.


JERVIS BAY
BONNA POINT
QUIBRAY BAY
STUDENT-NEWMAN-KUELS INTERVAL
LEAF PRODUCTION
(g dry wght. per sq. m per day)
5
4
3
2
1
F
M
A
M
J
J
A
S
O
N
D
J
MONTH

> 'during times of flower and fruit production ... the plants divert energies to sexual reproduction'.

It is interesting and useful to consider leaf blade production in terms of turnover of organic matter. The turnover rate is the fraction of the system that is produced per unit time (Zieman, 1975), and can be expressed as mg dry weight of new growth per gram dry weight per day, percentage change in biomass per day, or crops of leaves (or of roots, or of rhizomes) per year. If these expressions are labelled A, B and C respectively, they are related by the equation :-

$$A = 10 \times B = \frac{C}{0.365} \qquad \text{....equation 1.}$$

It can be calculated, from the mean values of standing crop and of leaf blade growth, that there are between three and four crops of leaves produced per year by the shoots of *Posidonia australis*, at all of the sites investigated (Appendix 2). For comparison, Kirkman (C.S.I.R.O., Cronulla, N.S.W., personal communication) has found a turnover of 2.6 crops of leaves per year, for *Posidonia australis* located in Port Hacking, N.S.W. A similar variable, the turnover time, can also be calculated. This is the time required to replace the standing crop, and is between 91 to 120 days (that is $^{365}/4$ and $^{365}/3$ days) for *Posidonia australis* in this study.

An estimation of the total production, in terms of leaf productivity, can be found by the multiplication of total standing stock (median values) and of the crops of leaves produced per year. Thus a minimum estimate would be 2790 and a maximum estimate 5840 metric tonnes of dry weight of leaf material produced per year (these figures being 950 x 3 and 1460 x 4 respectively). These values can be compared to the annual above-ground productivity of *Zostera capricorni* in Botany Bay, estimated by Larkum, Collett and Williams Jnr. (1980) to be 513 metric tonnes dry weight. The lower production figure for *Zostera capricorni* appears to be a result of a lower more variable standing crop, covering a smaller area than meristem region, containing immature leaf and rhizome material, was not included).

These separated sections of rhizomes, which varied considerably in length, depending on whether they were actively elongating (see Chapter Five), were considered together, for each sample, and weighed after drying at 80°C for 48 hours.

This method was employed at the two Botany Bay sites. The Mann-Whitney Procedure (Zar, 1974) was used to test for significant difference between the two sites.

Results and Discussion

The results and statistical calculations are to be found in Appendix 3.

On an annual basis, the rhizome and shoot production range from a minimum estimate of 46 to a maximum of 71 g dry weight per square metre. A significantly higher production rate was found at Quibray Bay, even though there is a lower density of shoots at this site (refer to Chapter Five).

The median value for rhizome and shoot production at the Bonna Point site was 0.14, and at the Quibray Bay site, 0.17 g dry weight per square metre per day. These values are lower than that of 1.5 g dry weight per square metre per day, found for *Zostera marina* growing in Danish waters (Sand-Jensen, 1975). However, species of *Zostera* do have fast growth rates and can often colonize areas quickly through rhizome proliferation (Sand-Jensen, 1975; Larkum, Collett and Williams Jnr., 1980; personal observation).

Patriquin (1973) has recorded an underground production rate of 4.4 g dry weight per square metre per day, for *Thalassia testudinum* in the Bermudas. This seems to be very high, and may be a result of overestimating the number of actively growing rhizome shoots.

From the data presented in Appendix 1, one can calculate the mean underground biomass (total biomass minus leaf biomass), using all monthly collections. For the Bonna Point site, this value is 962 g dry weight per square metre, and for the Quibray Bay site, the value is 727 g dry weight per square metre. Thus, the mean turnover time for these two sites is approximately 19 and 11 years respectively. The turnover of rhizome and shoot material at the Quibray Bay site is therefore about twice that at the Bonna Point site.

In this study, rhizome and shoot production has been estimated to be less than one tenth of leaf production, in terms of dry weight.

Biomass and Primary Production of *Posidonia australis* - Conclusions

This chapter has dealt with the biomass and productivity of *Posidonia australis*. Some important findings are summarised in Table 4, page 41. The primary production of *Posidonia australis* is not as high as estimates for other seagrasses (refer to Table 2, page 21). It is still comparable to many terrestial plant communities, and higher than phytoplankton production, when calculated on a similar 'area' basis (Westlake, 1963).

Primary production of leaf material contributes about ninety per cent of the total production of *Posidonia australis*, and hence, the leaf biomass is replaced approximately three times each year, while the underground portions remain for many years (refer also to Chapters Five and Six).

TABLE 4: Biomass and Primary Production of *Posidonia australis* - Summary of Data.

	Botany Bay		Jervis Bay
	Bonna Point	Quibray Bay	
Min - Max Leaf Biomass (g/m^2)	190-280	101-137	294-453
Min - Max Total Biomass (g/m^2)	1132-1254	741-913	2440-2658
Standing Crop Estimate (g/m^2)	186-292		
Min - Max Leaf Production (g/m^2/day)	1.0-3.2	0.7-2.4	0.9-4.6
Min - Max Underground Production (g/m^2/day)	0.12-0.16	0.16-0.20	
Turnover Time : Leaves (days)	117	93	110
Underground Portions (years)	19	11	
Area Covered (hectares)	500		
Total Standing Crop Estimate (metric tonnes)	930-1460		
Total Leaf Production Estimate (tonnes/year)	2790-5840		

Chapter Three

EFFECT OF ENVIRONMENT ON THE GROWTH OF *POSIDONIA AUSTRALIS* UNDER LABORATORY CONDITIONS

This chapter deals with the growth and metabolism of the *Posidonia australis* community, under laboratory conditions. In particular, the effects of changes in light intensity, salinity, and temperature are studied. Erect shoots of *Posidonia australis* were collected from Botany Bay, and maintained under controlled conditions, in large aquaria. After a period of acclimation, the environmental conditions were changed, and the effect on the leaf growth rate noted.

The results of this type of experiment can be used in an attempt to understand the growth rates, and distribution, of the *Posidonia australis* community in Botany Bay, and perhaps Australia.

Effect of the Environment on Growth of Seagrasses - A Literature Survey

The ecology of seagrasses will be briefly discussed, in relation to some major environmental factors.

Light

Light is the most critical ecological factor for plant growth, and both intensity and wavelength are important (Salisbury and Ross, 1978).

The lower depth limit to the establishment of seagrasses is generally considered to be due to the minimum light intensity required by a particular seagrass (Phillips, 1978), although very few conclusive experiments have been performed. Ostenfeld (1905) was one of the first workers to attempt to correlate distributional patterns of a seagrass (*Zostera marina*) to light transmittance. This author found that the lower margin of eelgrass in Danish waters coincided with the Secchi Disc depth (this corresponds to 18 - 24% of surface light, depending on how the extinction coefficient is calculated, refer to Backman and Barilotti, 1976).

The short term methods of measuring primary production described in the previous Chapter often yield information concerning the effect of light on photosynthetic rate. Table 5, page 44, summarises literature concerning the effect of light flux on metabolism of seagrasses. This table refers to the 'compensation light intensity', and the 'saturation light intensity'. The compensation light intensity is the light intensity required for the photosynthetic rate and respiration rate to cancel each other, and net production to equal zero. The saturation light intensity is the light intensity required for the rate of photosynthesis to be maximum. Particular attention needs to be placed on the method of determination of these values, especially of the compensation point. For example, Jones (1968) and Buesa (1972, 1974, 1975) have used leaf sections of *Thalassia testudinum* isolated in bottles, and Drew (1978) has employed a similar method for *Posidonia oceanica*. However, Clough and Attiwill (1979) have used an *in situ* benthic chamber to measure the photosynthetic rate of *Zostera marina*. Of course, the compensation light intensity will depend on whether root respiration is included (that is on whether leaf sections or whole plants are used).

TABLE 5 : The Effect of Light Flux on the Metabolism of Seagrasses - Summary of Literature.

SPECIES OF SEAGRASS	AUTHOR	SATURATION LIGHT INTENSITY	COMPENSATION LIGHT INTENSITY	COMMENT
Cymodocea nodosa	Drew (1978)	3 mW/cm^2	0.3-0.5 mW/cm^2	Leaf slices in in small jars (O_2)
Posidonia oceanica	Drew (1978)	2 mW/cm^2	"	
Zostera marina	McRoy (1974)	0.05 langleys/min	-	Whole plants in jars (C-14)
Zostera marina	Penhale (1977)	600 µE/m^2/sec	-	Whole plants in chambers (C-14)
Zostera muelleri	Clough and Attiwill (1979)	150 µE/m^2/sec	25 µE/m^2/sec	Whole plants *in situ* (O_2)
Thalassia testudinum	Jones (1968)	0.3' langleys/min	0.05 langleys/min	Leaf Slices in small jars (O_2)

McRoy and McMillan (1977) suggest that production can be expressed in terms of light quantity. They report three separate studies giving estimates between 5.3 - 17.0 microgram carbon per langley per gram biomass, for different species of seagrass, and propose that the similarity of the result may lead to a useful relationship, that could estimate seagrass production from light intensities.

Light (for example, daylength and seasonal changes in intensity) is also important in flowering and development in seagrasses (McMillan, 1976; McRoy and McMillan, 1977).

Backman and Barilotti (1976) have shown that turion density and flowering are reduced in *Zostera marina*, when irradiance is reduced. These authors suggest that development projects in coastal areas should be designed to maintain water quality, especially light transmission.

Salinity Tolerance

There are few literature references to the effect that changes in salinity have on seagrasses, and this is especially true for Australian seagrasses.

The effect of salinity on the photosynthesis of *Zostera marina* has been studied by Biebl and McRoy (1971). These authors report a reduction in photosynthesis when salinity is reduced from seawater, with distilled water. Ogata and Matsui (1965) found that a reduction in photosynthesis with increasing salinity, above that of seawater, was due principally to carbon limitation, for *Zostera nana*.

Other laboratory studies have involved the transplantation of seagrasses from their natural environment to aquaria, under controlled conditions of salinity (McMillan and Mosely, 1967; McMahan, 1968; McMillan, 1974). McRoy and McMillan (1977) summarise these results :

> '...*Halodule* shows the broadest salinity tolerance...*Halophila* the narrowest...and *Thalassia* and *Syringodium* show intermediate tolerance but are slightly different from each other. *Ruppia* was the only Texas seagrass which tolerated non-saline conditions'.

Zieman (1975) found an optimum salinity of thirty parts per thousand for *Thalassia testudinum* based on leaf growth data, measured in Florida waters. Leaf productivity decreased above and below this salinity.

Den Hartog (1970) comments that the salinity tolerance of *Posidonia australis* is probably wider than for *Posidonia oceanica*, as the former occurs in sea inlets in the Sydney region (N.S.W.), where 'after heavy rainfall marked decreases in salinity occur'. *Posidonia australis* also occurs in the hyper-haline waters of Shark Bay, W.A. (Den Hartog, 1970).

Temperature

Biebl and McRoy (1971) considered the effect of temperature on the photosynthetic rate of *Zostera marina* and found a difference in response between two morphologically different communities, one from a subtidal area and one from a tidepool. McRoy (1969) reports finding a healthy stand of *Zostera marina* in seawater of -1.8^{o}C.

The effect of high temperatures on the growth of *Thalassia testudinum* is well documented. Both Zieman (1975) and Thorhaug, Blake and Schroeder (1978) have studied the effect of heated effluents on this seagrass. These workers have shown that the optimum temperature for growth is approximately 30^{o}C, and that production is near zero at temperatures above 35°C or below 25°C.

Wignton *et al* (1979) has studied chilling response in various populations of *Thalassia testudinum*, *Syringodium filiforme*, and *Halodule wrightii*, and has concluded that the difference in response is based on inherited properties.

The Effect of Low Light Flux on *Posidonia australis* under Laboratory Conditions

Early studies concerning the distribution and biomass of *Posidonia australis* in Botany Bay indicated that this seagrass was sub-optimal, when compared to stands at similar sites in Jervis Bay and Pittwater, N.S.W. (Larkum, 1976). One possible cause for sub-optimal growth is low light intensity, due to high turbidity. The depth limitation of seagrasses has, in the past, often been attributed to lack of light (Phillips, 1978).

This section presents some information on the growth and metabolism of *Posidonia australis* under conditions of low light.

Materials and Methods

(i) Oxygen Metabolism

Shoots (10 - 15) of *Posidonia australis*, and substrate, were collected from Botany Bay in six, ten-litre buckets, and transported to aquaria (seventy-three litre capacity), kept under controlled conditions of light (cool white fluorescent and incandescent bulbs), temperature (17 - 20°C) and salinity (32 parts per thousand). The seawater was also collected from Botany Bay. Light was measured at the level of the uppermost leaves, as photosynthetically active radiation (P.A.R.), using an underwater quantum light sensor (Licor LI - 192S). Maximum light flux was

300 - 400 micro-Einsteins per square metre per second ($\mu E/m^2/sec$), and was controlled with the use of shadecloth of various thicknesses (or densities).

Oxygen was measured within the aquaria, over short periods of two to three hours, using a temperature-compensated oxygen electrode and recorder unit. Stirring was obtained with a motor-driven 'Dyna-Flo' aquarium filter (rated at 120 litres per hour).

The oxygen exchange rates were calculated at the point where the seawater was between 95 - 105 per cent oxygen saturation with respect to air, to minimise the problems associated with the estimation of the reaeration coefficients. This method incorporates a small error by the inclusion of the reaeration in the calculated oxygen exchange rate of *Posidonia australis* (refer to Appendix 4). After each experiment, the total dry weight of plant material was measured. Drying was at 80°C for 48 hours.

Percentage oxygen saturation of the seawater was converted to mg oxygen, using the tables of Carpenter (1966). Results were expressed as mg oxygen produced or consumed per gram dry weight per hour. The values were plotted, and the line of best fit calculated by a regression analysis.

(ii) Leaf Blade Growth

Shoots (10 - 15) of *Posidonia australis* were collected and maintained in a manner similar to that set out in (i), above.

Leaf growth in *Posidonia australis* is brought about by a basal meristem, and so leaf-blade growth can be measured by leaf length increases. Leaf length was assayed weekly. After five weeks, light was varied from 300 $\mu E/m^2/sec$ to 0, 100 and 200 $\mu E/m^2/sec$ in separate aquaria. A control was kept at 300 $\mu E/m^2/sec$ for ten weeks. Leaf length was monitored for both the pre-treatment period and post-treatment period, ten weeks in all.

The aquaria were filtered, aerated continuously and subject to a twelve hour light and dark regime. Analysis of variance was performed on the weekly measurements of leaf growth (summed for each shoot) to test the effect of the different light treatments.

Results and Discussion

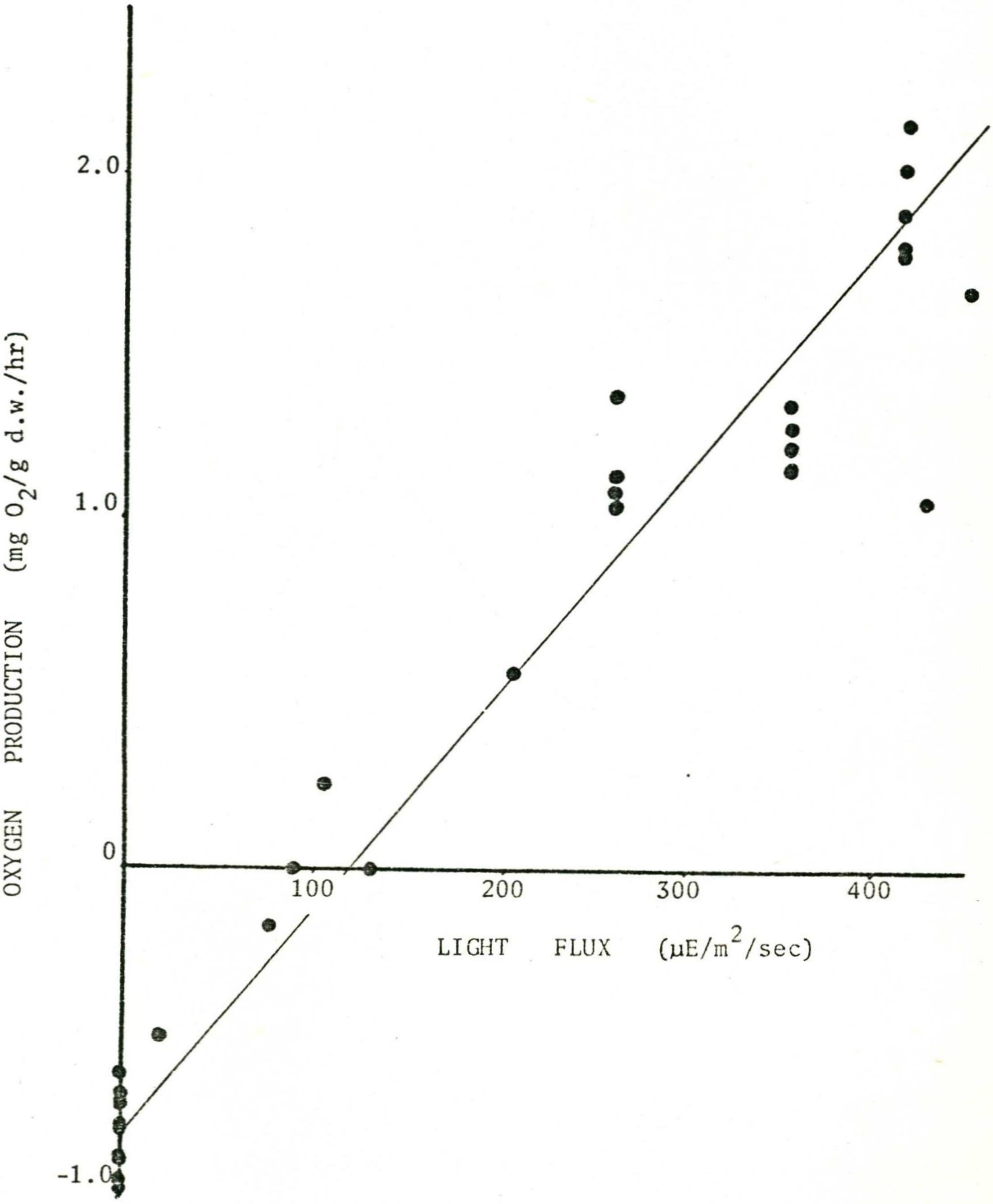
The relation between oxygen exchange rates and low light intensities for the *Posidonia australis* grown under the laboratory conditions is shown in Figure 10, page 50. The relationship is described by the line :

$$y = -0.766 + 0.006x \qquad \text{(refer to Appendix 5A)}$$

where y is the oxygen production rate (mg oxygen per gram dry weight per hour), and x is the light flux ($\mu E/m^2/sec$). Under these conditions, the shoots of *Posidonia australis* have a light compensation point at about 130 $\mu E/m^2/sec$ light flux. If one could equate oxygen production rates to the true metabolic rates, ignoring the problems of gas recycling (refer to the previous chapter), than this would mean that, at this light flux the photosynthetic to respiratory (P/R) ratio is unity. This result can be compared to the value of 25 $\mu E/m^2/sec$ obtained for *Zostera muelleri* growing in Westernport Bay, Vict. (Clough and Attiwill, 1979). The higher light flux required for compensation of *Posidonia australis* may be a consequence of the high underground biomass of this seagrass.

It can be calculated that a minimum light flux of approximately 250 $\mu E/m^2/sec$ would be required to balance oxygen production and consumption over a twenty-four hour period, composed of twelve hours alternate light and dark cycles (refer to Appendix 5B).

FIGURE 10 : Relation between Oxygen Production and Light Flux Under Laboratory Conditions (refer to text)


2.0
1.0
0
-1.0
100
200
300
400
OXYGEN PRODUCTION (mg O_2/g d.w./hr)
LIGHT FLUX (µE/m^2/sec)

It should be noted that variations in the ratio of leaf to total biomass will result in differences in the estimated compensation light flux.

The study of leaf growth of the shoots of *Posidonia australis*, under various light regimes was used to test the results of the oxygen metabolism experiment, outlined above. The results are listed in Appendix 5C, and summarised in Table 6, page 53. Plants kept in the dark, and not aerated, lost all green leaves within forty-eight hours, and appeared to exhibit a 'rotting' at the leaf bases. However, if constant aeration was provided, the plants grown with no light showed leaf length increases for several weeks, apparently relying on reserve material. These leaf length increases ceased after about three weeks, and the plants then appeared dead. Plants grown at light flux of 100 and of 200 μE/m^2/sec showed a significantly lowered leaf growth rate, after two to three weeks treatment, when compared to the pretreatment period. A control, kept at about 300 μE/m^2/sec showed no significant difference between leaf growth in the pre- and post-treatment periods.

There is much conflict over the use of oxygen measurements as a means of estimating metabolic rates of plants possessing gas lacunae (Hartman and Brown, 1967; Clough, 1967; McRoy and McMillan, 1977; Clough and Attiwill, 1979). Obviously more study should be directed toward gas exchange dynamics in such plants. Until this is done, some doubt must attach to studies of photosynthesis and respiration which involve ambient oxygen levels. However, in the experiments outlined above, oxygen production estimates, and leaf growth measurements substantiated one another, in that, *Posidonia australis* kept in laboratory culture required about 250 - 300 μE/m^2/sec for maintenance of growing conditions.

TABLE 6 : Leaf Growth of *Posidonia australis* Shoots, Under Various Light Regimes, in the Laboratory.

TREATMENT (TANK NOS.)	PERIOD	LIGHT FLUX ($\mu E/m^2/sec$)	WEEKS MEASURED	MIN - MAX LEAF GROWTH (cm per shoot/week)
1	not aerated	0	Dead within forty-eight hours, with 'rotting' at leaf base apparent.	
2	pretreatment	300	5	3.8 - 6.5
	posttreatment	300	5	3.1 - 7.1
3	pretreatment	300	5	1.9 - 8.5
	posttreatment	200	5	1.0 - 8.6 *
4	pretreatment	300	5	3.0 - 8.0
	posttreatment	100	5	1.2 - 6.9 *
5	pretreatment	300	5	3.9 - 7.6
	posttreatment	0	5	0 - 7.5 *

* denotes a significantly lowered leaf growth rate over the posttreatment range, when compared to the pretreatment range.

The Effect of Salinity Fluctuations on the Growth of *Posidonia australis* Under Laboratory Conditions

This section describes the effect of salinity change on the laboratory 'culture' of *Posidonia australis*, prepared in a manner similar to that described in the previous section. The results of these experiments are discussed in terms of the Botany Bay environment, where salinity often fluctuates after heavy rainfall.

Materials and Methods

Shoots (10 - 15) of *Posidonia australis* were collected and maintained under the laboratory conditions described previously, except that only leaf growth was assayed (not oxygen metabolism). The following treatments are designed to investigate the immediate effect of salinity fluctuations on leaf growth and survival :-

i. Control : kept in full seawater for 4 weeks (32.2 parts per thousand, $^{o}/oo$).
ii. Tank A : kept in half seawater (half distilled) for 4 weeks ($16.2^{o}/oo$).
iii. Tank B : kept in half seawater 1 week, full seawater 3 weeks.
iv. Tank C : kept in distilled water 1 hr, full seawater 4 weeks.
v. Tank D : kept in seawater 2 weeks, distilled water 3 hrs, seawater 2 weeks.

Leaf growth was measured weekly, and summed for each shoot. Significant differences due to the salinity treatment were assessed using a Kruskal-Wallis Rank test (Zar, 1974).

Results and Discussion

The data and statistical calculations are presented in Appendix 6. The results (Table 7, page 55) indicate that there is no immediate effect on leaf growth from these changes in salinity. However, freshwater treatment of *Posidonia australis*, in some cases, resulted in a high mortality of

TABLE 7 : Leaf Growth Rates of *Posidonia australis* Shoots, Under Various Salinity Regimes, in the Laboratory.

TREATMENT	CONDITIONS	MIN - MAX LEAF GROWTH (cm per shoot per week)	COMMENTS
CONTROL	FULL SEAWATER 4 WEEKS	1.2-10.0	
A	HALF SEAWATER 4 WEEKS	1.0- 6.0	
B	HALF SEAWATER 1 WEEK FULL SEAWATER 3 WEEKS	1.8- 9.1	
C	FRESHWATER 1 HOUR FULL SEAWATER 4 WEEKS	1.5- 9.8	A high mortality immediately after treatment
D	FULL SEAWATER 2 WEEKS FRESHWATER 3 HOURS FULL SEAWATER 2 WEEKS	2.9-10.7	"

shoots. It would be very rare for *Posidonia australis* to be exposed to freshwater except after extremely heavy rainfall, coinciding with a low tide. For the range of salinity fluctuations that has been recorded in Botany Bay (refer to page 97), it would seem that leaf growth of *Posidonia australis* would be unaffected.

Posidonia australis does not occur in many brackish lagoons on the N.S.W. coast (for example, Tuggerah and Illawarra Lakes), and would seem to be limited in this range by a low tolerance to salinity changes. However the results of this section support the finding of Tyerman (1979), that *Posidonia australis* is able to turgor regulate in response to a salinity change. Hatcher and Larkum (personal communication) have additional evidence concerning the effect of long-term salinity changes on growth and oxygen metabolism of this seagrass.

The Effect of High Temperatures on the Growth of *Posidonia australis* Under Laboratory Conditions

The last of the experiments performed under laboratory conditions were to determine the effect of a rise in water temperature on the leaf growth of *Posidonia australis*. Water temperature has been implicated in the seasonality of growth rate of some seagrasses (Zieman, 1975), and in causing limitations in the range of distribution of seagrasses (McRoy and McMillan, 1977).

Shoots of *Posidonia australis* have been grown for various periods under identical conditions, except for water temperature, which was maintained at 20°C, 25°C and 30°C in separate aquaria.

Materials and Methods

Shoots (10 - 15) of *Posidonia australis* were collected and maintained in a manner similar to that described in the previous sections, except that, in this case the temperatures of the aquaria were regulated at 20°C (two controls), 25°C and 30°C. Heating was obtained with glass insulated aquarium heaters, two required to heat to 25°C, and four required to heat to 30°C. The temperature of the water in the aquaria was checked regularly, and monitored for diurnal periods continuously, with the use of a thermistor temperature meter, and recorder unit. The minimum and maximum temperatures recorded for the three treatments were 20.0 - 20.7°C, 24.5 - 25.0°C and 34.5 - 35.1°C.

Leaf growth was measured weekly, and summed for each shoot. Significant differences due to temperature treatments were assessed using a Kruskal-Wallis Rank test (Zar, 1974).

Results and Discussion

The data, and statistical calculations are included as Appendix 6.

The increase in temperature to 30°C from the control of 20°C, and from the normal range of water temperatures experienced in Botany Bay (7.4 - 27.0°C, Wolfe and Collins, 1979) resulted in a significant inhibition of leaf growth after only two weeks (Table 8, page 58). After this period the plants exhibited no growth, and in many cases a 'rotting' in the leaf bases was apparent. This observation had been experienced in an earlier experiment, when no aeration was provided for dark-grown plants. (refer to Table 6, page 53). From available evidence, it would seem that this rotting of the leaf bases is in response to insufficient oxygen to maintain normal respiratory processes, resulting in some fermentation reactions, initiated in the rhizome. In this case, the insufficient oxygen may be a result of an increase in the requirement for oxygen (due to an increase in the respiration rate with temperature), coupled with a decrease in the oxygen availability (due to the lower solubility of gases in water as temperature is increased). An increase in respiration rate with increasing

TABLE 8 : Leaf Growth of *Posidonia australis* Shoots,
Under Various Temperature Regimes, in the Laboratory.

TREATMENT	CONDITIONS	TEMPERATURE	WEEKS MEASURED	MIN - MAX LEAF GROWTH (cm/shoot/week)
1	control	20°C	4	3.2 - 8.0
2	control	20°C	4	2.5 - 7.8
3	heated	25°C	4	2.5 - 7.2
4	heated	30°C	4	0 – 5.5 *

* denotes a significantly lowered leaf growth when compared to the controls.

temperature is a well documented response of many plants (Salisbury and Ross, 1978), and has been found to be true for some species of seagrasses (for examples, refer to Jones, 1968; and to Clough, 1967).

The oxygen level in the aquarium subjected to a temperature of 30°C was monitored over several diurnal periods, using the oxygen electrode described previously (refer to page 48). At no time did the seawater in this aquarium fall below 80% oxygen saturation with respect to air. This indicates that the overall oxygen level in this aquarium is not limiting growth, but that the shoots of *Posidonia australis* experience a problem in supplying oxygen to the underground rhizomes in the quantities required, at this temperature.

Effect of Environment on *Posidonia australis* under Laboratory Conditions - Conclusions

This chapter has dealt with the effect of changes in the environment on the *Posidonia australis* collected from Botany Bay, and kept under controlled laboratory conditions. The results can be summarised in a brief table (Table 9, page 60).

The results would indicate that changes in salinity and temperature have only a minor effect on leaf growth, except for the extreme case of a water temperature of 30°C maintained for several weeks. However, a light flux of greater than about 250 $\mu E/m^2/sec$ is required to support leaf growth, and the consequence of this result will be discussed in greater detail, in the general discussion (Chapter 6).

TABLE 9 : Effect of Environment on *Posidonia australis* - Summary of Results.

TREATMENT	CONDITIONS	EXPERIMENTAL PERIOD (weeks)	EFFECT ON LEAF GROWTH
Light	0 uE/m^{2}/sec	10	lowered when compared to pre-treatment
	100 "	10	"
	200 "	10	"
	300 "	10	not lowered Over the ten weeks
Salinity	32°/oo	4	not lowered over the four weeks
	16°/oo	4	"
	16°/oo then 32°/oo	4	"
	0°/00 then 32°/oo	4	high mortality of shoots
Temperature	20°C	4	control
	25°C	4	not lowered
	30°C	4	very high mortality (100%)

Chapter Four

FIELD STUDIES CONCERNING THE OXYGEN METABOLISM OF THE *POSIDONIA AUSTRALIS* COMMUNITY AND THE EFFECT OF STORMS

This chapter deals with the oxygen metabolism of the *Posidonia australis* community, *in situ*, principally at Bonna Point, Botany Bay, N.S.W. A small perspex chamber was used to isolate a section of the community. Light and oxygen production were measured continuously inside this chamber, for periods ranging from a few hours, to twenty-four hours. Salinity and temperature were also checked regularly during incubations.

This type of measurement offers a method to study the short term production of seagrasses (refer to Chapter 2, and to Clough and Attiwill, 1979). However, in this case, the interest lies in the diurnal changes of the natural environment, as problems are associated with the estimation of primary production from oxygen metabolism (refer to Chapter 2).

Also of interest is the effect that storms have on the biomass and oxygen metabolism of the *Posidonia australis* community, as some incubations described were performed preceding, and at intervals after a severe storm had damaged the seagrass beds at Bonna Point.

Oxygen Metabolism; the Effect of Storms - A Literature Survey

The use of measurements of the oxygen production of seagrasses, as a means of the estimation of primary production, has been discussed previously (refer to Chapter 2).

Kerneis (1960) reports on the oxygen content of water surrounding a meadow of *Posidonia oceanica*, near Banyuls, France. According to this author, the oxygen content of the water is minimum (5 mg/l) at dawn, and maximum (10 mg/l) in the afternoon. The difference between the maximum and minimum oxygen level decreases with increasing depth. The author suggests that this is due to a lower rate of photosynthesis with increasing depth, however, this supposition is complicated by not having a fixed volume of water.

Ott and Maurer (1977) discuss the strategies of energy transfer in a community based on *Posidonia oceanica*, and list 'community net production' estimates. The measurements are of surplus oxygen produced per day, and range from 0.95 to 6.24 grams oxygen per square metre. No details of daily ranges in oxygen content of the water are given, by these authors.

Although most seagrasses grow prolifically under conditions of moderate water movement (and, such conditions may be beneficial, as has been demonstrated for some freshwater plants; Westlake, 1967), extreme turbulence, such as can occur during storms, can cause physical damage to a seagrass bed (Thomas, Moore and Work, 1961). Patriquin (1975) has reported on the migration of 'blowouts', which can occur in the Caribbean region. These blowouts are crescent-shaped bare areas within a bed of *Thalassia testudinum*, caused from storm waves. The author considers that these blowouts play an important role in the seral and physiographic development of the seagrass beds, in regions of moderate to strong wave action.

Diurnal Changes in the Natural Environment

The changes in the diurnal environment of the *Posidonia australis* community are likely to affect the community structure. In this section changes in light, oxygen concentration, salinity and temperature are investigated. The incubations span a four-month period, from November to February.

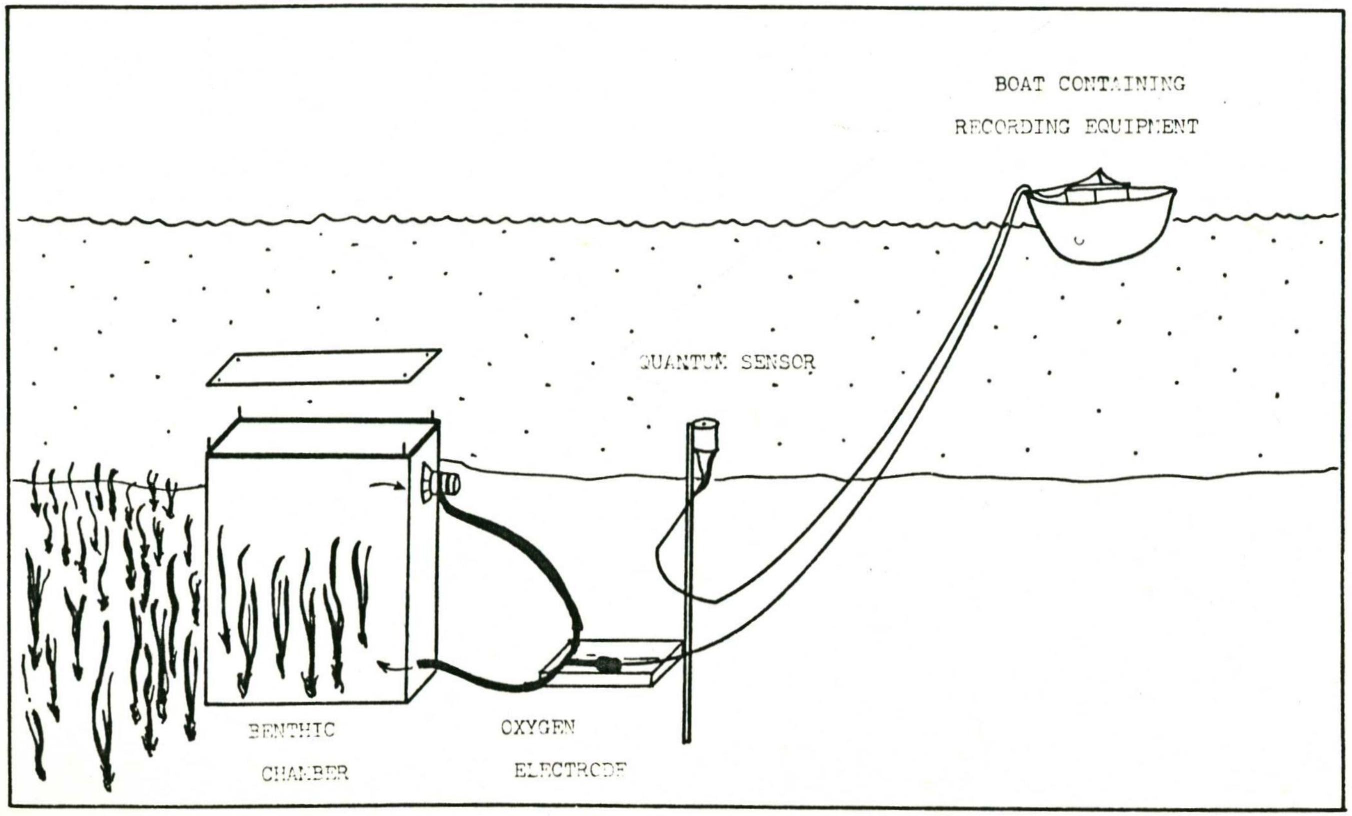
Materials and Methods

A small rectangular perspex chamber, with a detachable lid, and of volume ninety litres, was used to enclose an area 30 cm x 30 cm of sediment. A twelve-volt bilge pump (Hanimex), flow rate 18 litres per minute, provided excellent mixing of the seawater within the chamber. The equipment has been illustrated (Figure 11, page 64).

Incubations were carried out for twenty-four hour periods. During an incubation, oxygen production within the chamber was monitored with the use of an oxygen electrode (Titron, Townsend and Mercer) and field chart recorder (Goertz Minigor). Light flux was measured continuously with a Licor Light Sensor (LI - 192S) connected to another field chart recorder. Temperature was checked regularly in the chamber, using the thermistor of the oxygen electrode, previously calibrated to a mercury centigrade thermometer.

The oxygen electrode was calibrated *in situ* with the use of zero oxygen solutions (Radiometer Type 10 - S4150), and seawater of known oxygen saturation. Oxygen was measured by the Winkler chemical method (Major, Dal Pont, Klye and Newell, 1972). Water samples were returned to the laboratory for conductivity measurements. Conductivity was converted

FIGURE 11 : The *In Situ* Incubation Chamber, and Associated Equipment.


BOAT CONTAINING
RECORDING EQUIPMENT
QUANTUM SENSOR
BENTHIC
CHAMBER
OXYGEN
ELECTRODE

to salinity, using the formula of Bennett (1976).

Results and Discussion

The results of the incubations are summarised in Figure 12, page 66.

Diurnal variations in temperature were minimal during this study, and depended on tidal exchange and weather conditions. For example, at a depth of one metre (low water), on a sunny, warm day, with slight seas, the water temperature rose a maximum of 3°C, to 25°C, during an afternoon low tide, but fell back to the original temperature of 22°C, on the incoming tide (refer to Figure 12B, page 66). The range of temperatures experienced, 20°C - 25°C, were 'normal' for the November to February period (Wolfe and Collins, 1979).

Salinity did not vary from seawater, even during, and after a period of light rain, probably as the freshwater formed a surface layer under these calm conditions (refer to Figure 12C and 12D, page 66). The overall mean salinity of Botany Bay waters has been found to be 32.5 parts per thousand (°/oo), but dilution can occur during periods of heavy rainfall, and flooding of the Georges River (N.S.W. S.P.C.C. Annual Report, 1977; Wolfe and Collins, 1979).

The diurnal variations in light, at the level of the *Posidonia australis*, are also shown in Figure 12, page 66, for both clear days (12A, 12B and part of 12D) and for overcast days (12C, and part of 12D). These values of light flux (photosynthetically active radiation), are the average readings over two-hour periods. This step is necessary as the variation in light due to waves, and due to rippling of the water surface, is great. For example, fifty per cent and larger variations of light occurred at a frequency of two to five per second, during the December sampling (Figure 12B, page 66). The maximum light on each sampling occasion ranged from

FIGURE 12 : Diurnal Changes in the Natural Environment.

12A. 11/11/77. Clear, bright conditions. Very calm. 33.1^{o}/oo salinity.

12B. 12/12/77. Cloudless. Sea calm, with slight rippling. 32.9^{o}/oo.

12C. 2/ 1/78. Cloudy with overnight rain. 33.0^{o}/oo.

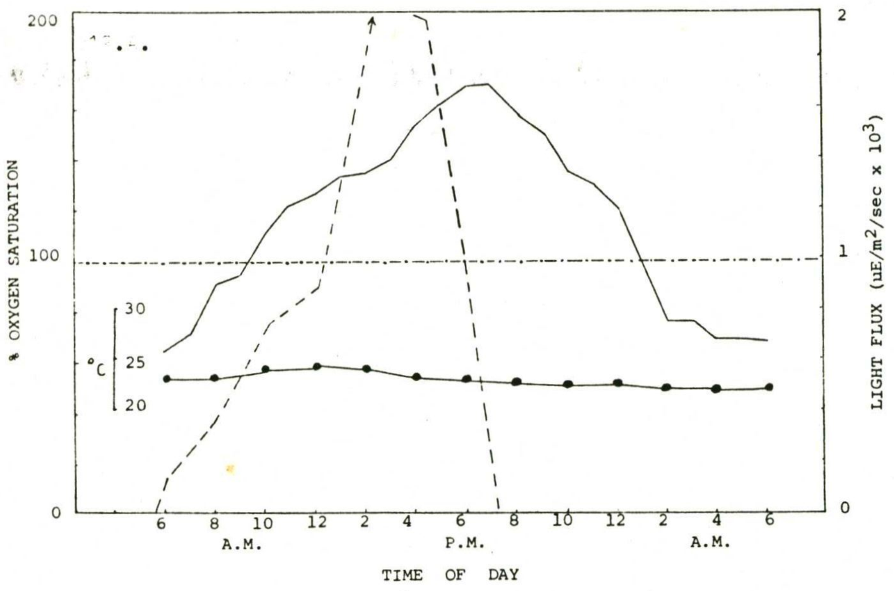
12D. 21/ 2/78. Survey started on a sunny afternoon, light rain overnight and next day. Sea calm. 32.5^{o}/oo.

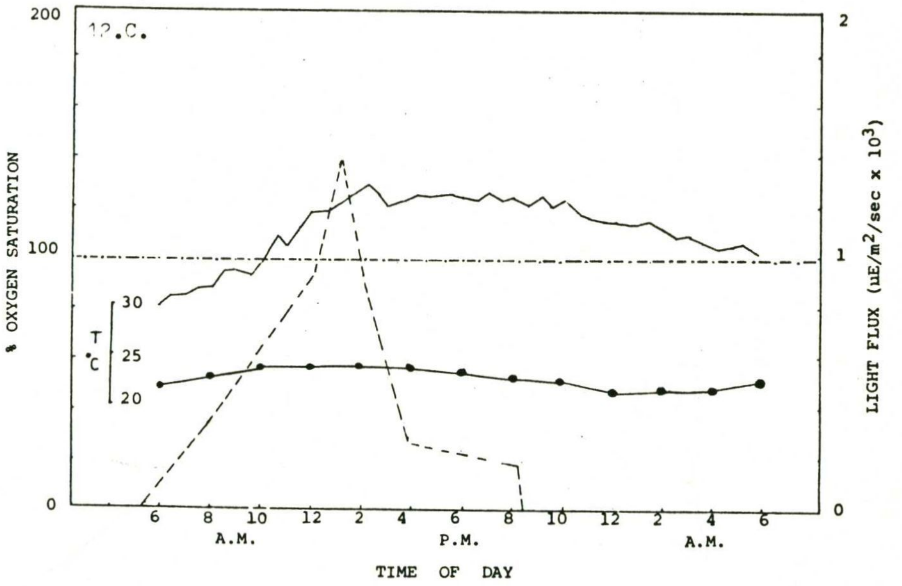
LEGEND

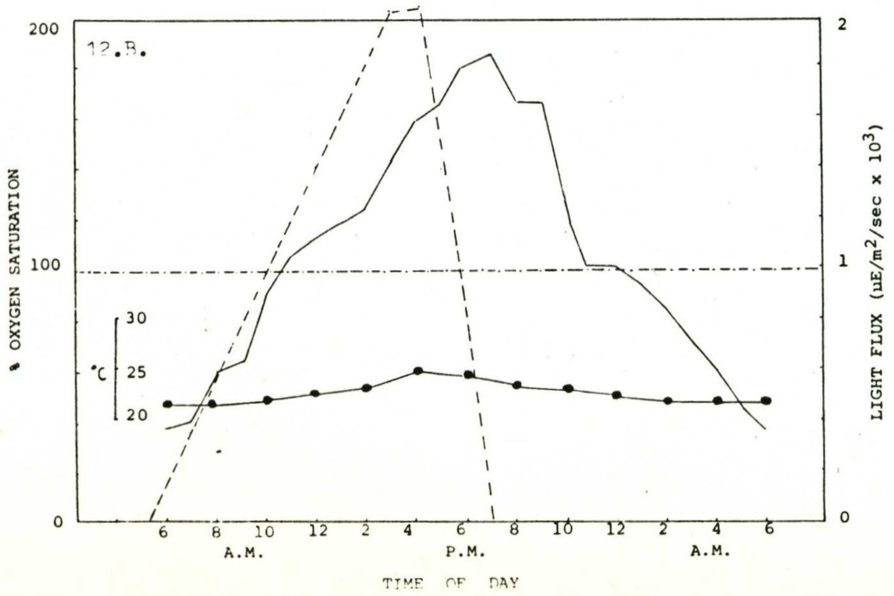
——— % oxygen saturation.

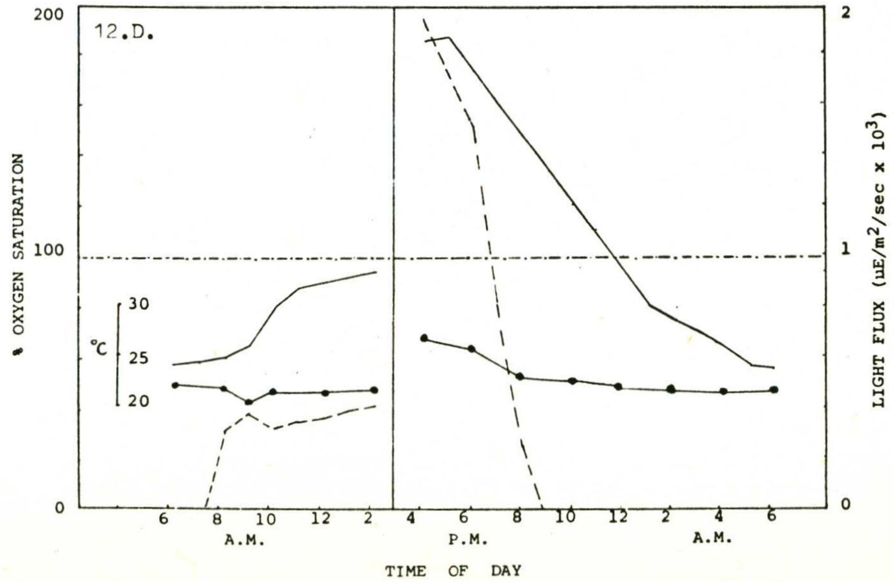
- - - - - - light flux (uE/m^{2}/sec).

●—●—● temperature (^{o}C).


12.A.
200
100
0
% OXYGEN SATURATION
°C
30
25
20
6
8
10
12
2
4
6
8
10
12
2
4
6
A.M.
P.M.
A.M.
TIME OF DAY
2
1
0
LIGHT FLUX (uE/m²/sec x 10³)


12.C.
200
100
0
% OXYGEN SATURATION
T
°C
30
25
20
6
8
10
12
2
4
6
8
10
12
2
4
6
A.M.
P.M.
A.M.
TIME OF DAY
2
1
0
LIGHT FLUX (uE/m²/sec x 10³)


12.B.
200
100
0
% OXYGEN SATURATION
°C
30
25
20
6
8
10
12
2
4
6
8
10
12
2
4
6
A.M.
P.M.
A.M.
TIME OF DAY
2
1
0
LIGHT FLUX (uE/m²/sec x 10³)


12.D.
200
100
0
% OXYGEN SATURATION
°C
30
25
20
6
8
10
12
2
4
6
8
10
12
2
4
6
A.M.
P.M.
A.M.
TIME OF DAY
2
1
0
LIGHT FLUX (uE/m²/sec x 10³)

500 $\mu E/m^2/sec$ on a cloudy day, to 2200 $\mu E/m^2/sec$ during fine conditions.

Oxygen concentration generally reached a maximum at sunset, of about 180% air saturation (approximately 13 mg/l), and a minimum of about 50% air saturation (approximately 2.5 mg/l), preceding dawn. On a cloudy day however, less variation would be observed. For example, refer to Figure 12C, where variation is from 80% to 120% air saturation. These values compare with those found for a *Posidonia oceanica* community of between 5 to 10 mg O_2/l , over a diurnal period (Kerneis, 1960).

Seasonal variations in environment experienced by the *Posidonia australis* community will be discussed in Chapter 6.

The Effect of Storms on the Oxygen Metabolism and Biomass of *Posidonia australis*

Since water turbulence, hence storms, are often an important determinant in the distribution of seagrasses (Patriquin, 1975), it is useful to consider the effect that a storm during April, 1978 had on the biomass and metabolism of *Posidonia australis*, at Bonna Point, Botany Bay.

Materials and Method

Oxygen metabolism was measured according to the method described in the previous section. Biomass was sampled by a method similar to that described in Chapter 2.

Results and Discussion

Data and calculations are included as Appendix 7.

The effect of the heavy seas during May (1977) and April (1978), on the leaf biomass of *Posidonia australis* at the Bonna Point site is shown in Table 10, page 68. For comparison the leaf biomass at the Quibray

TABLE 10 : The Effect of Storms on the Leaf Biomass of *Posidonia australis* at the Bonna Point and Quibray Bay Sites.

MONTHLY BIOMASS (LEAVES) g/m^2	BONNA POINT	QUIBRAY BAY
APRIL (1977)	286	124
MAY (1977)	189	127
% reduction	34	0
MARCH (1978)	217	130
APRIL (1978)	64	126
% reduction	71	3

Bay site is included, and was relatively constant throughout the same period. Leaf loss during storms has been treated briefly in Chapter 2.

After the April 1978 storm, there was a decrease in the leaf to total biomass ratio of *Posidonia australis* from approximately 22% to 6%, at the Bonna Point site. The effect that this decrease had on the photosynthetic capacity of *Posidonia australis* is shown by the change in the P/R ratio (that is, the photosynthetic/respiration rate ratio). The P/R ratio of the *Posidonia australis* community prior to the storm, ranged from values of 1.0 - 1.5 during overcast periods, up to values as high as 4.1 during clear, sunny conditions (refer to Table 11, page 70). Immediately after the heavy seas, the P/R ratio had decreased to less than unity. This shows that the net photosynthesis was negative, and that *Posidonia australis* could have only regrown, if stored material was available (refer to Figure 3, page 16). Regrowth did occur, and some recovery of the meadows was noted on the next survey, fourteen days later (refer to Table 11, page 70). On this second occasion after the storm, the P/R ratio had improved, and was approximately 1.0. This indicates that the community was now able to support itself, in terms of production, but only during optimum light conditions, and for the daylight hours alone. Clearly the *Posidonia australis* community was relying on reserves (stored material) during these weeks, enabling regrowth of the leaf material.

The areas in Botany Bay prone to damage from heavy seas are inshore, along Silver Beach, Bonna Point and to a lesser extent along Towra Point. These areas have received the brunt of redirected wave energy, that has resulted from the deepening of the entrance to Botany Bay, to cater for large oil-tankers.

TABLE 11 : The *In Situ* Oxygen Metabolism (shown as P/R ratio) of *Posidonia australis*, and the Effect of Storm Damage.

(Light Flux is the maximum recorded during the experimental period.)

Heavy seas also cause noticeable changes in sand distribution. For example, many areas where rhizomes were exposed could be seen after the heavy seas of April, 1978, as well as other areas where sand had been deposited, covering all but the tops of plants. Another example is shown by the situation that occurs along Silver Beach, between the groynes. These groynes have been constructed to lessen the effect of waves (refer to Figure 8, page 31). At this site there are portions of the *Posidonia australis* meadows several feet above the surrounding sand areas, indicating both the effect of heavy seas in removing sand, and the resistance to that movement offered by the rhizome mat of this seagrass.

The moderately exposed conditions at Bonna Point, which often experiences heavy seas, are probably responsible for the apparently 'stunted' community at this site, which has a high shoot density, but short, narrow leaves (refer to Chapter 5).

Oxygen Metabolism; the Effect of Storms - Conclusions

Diurnal variations in oxygen content of seawater surrounding the *Posidonia australis* community range from 50% to 180% air saturation, and this is a consequence of the metabolism of the community. The P/R ratio of the community may be as high as 4.0. Such diurnal changes in oxygen have been suggested to effect community structure, and cause vertical migration of epifauna in *Zostera marina* meadows (Ledoyer, 1964b from Kikuchi and Peres, 1977).

The damage that occurs to the *Posidonia australis* community during heavy sea swells is obviously an important factor in the survival of this seagrass at exposed sites. Severe reductions in leaf biomass were recorded at the Bonna Point site during 1977 and 1978, due to storm damage, however no such damage occurred in 1979. The reduction in leaf biomass results in a period during which *Posidonia australis* relies on reserved storage material.

CHAPTER FIVE

OBSERVATIONS ON THE ECOLOGY OF *POSIDONIA AUSTRALIS*

As indicated in the introductory chapter there is a lack of information concerning Australian seagrasses, and their environment. For this reason, this chapter will deal with some general observations of the ecology and functioning of the *Posidonia australis* community.

The topics covered are diverse, and include, the dynamics of leaf and rhizome growth, the aging of shoots, seedling growth, decomposition rates and finally, a comparison of community characteristics at all of the sites at which data was collected.

Growth Dynamics in *Posidonia australis*, and the Aging of Shoots.

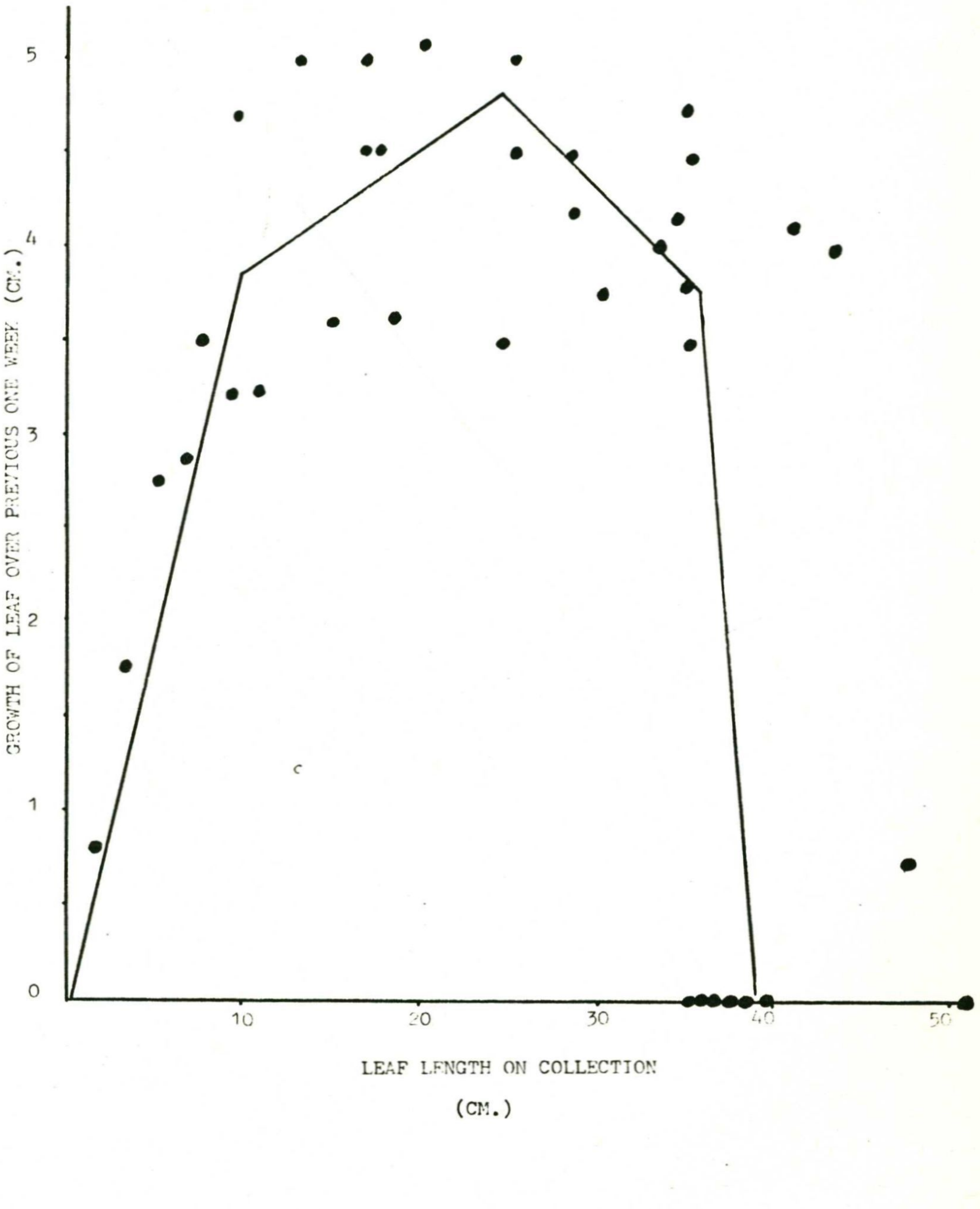
Chapter 1 included a brief description of the morphology of *Posidonia australis*, and Chapter 2 dealt with rates of primary production. This section relates morphology to production, and growth dynamics of *Posidonia australis*.

The striking feature of a healthy, mature community of *Posidonia australis* is the erect shoots, and dense foliage, and not the creeping underground rhizome. Each shoot has two to four leaves of varying age, produced at a basal meristem. New leaves arise on alternate sides of the meristem, which is enclosed and protected by the sheaths of older leaves (refer to Figure 1B, page 4). During the leaf marking study (Chapter 2), the relationship between the length and growth rate of individual leaves was investigated, and is now presented (Figure 13, page 74). The data refers to a collection at Bonna Point, during 1978. Leaf growth rate apparently increases as the leaf elongates, until a length of about 20 cm is reached. A steady growth rate is then maintained. When the leaves reach a mature length of between 30 and 50 cm, growth ceases.

Field data discussed in Chapter 2, indicated a turnover of about three to four crops of leaves produced per year. The turnover time at Bonna Point is approximately 117 days (Table 4, page 41). This must therefore be the average life span of individual leaves of *Posidonia australis* at this site. Using the data presented in Figure 13, page 74, it would appear that this life span is composed of about 90 to 100 days of active growth, after which the leaf may remain on the shoot, fully grown, for several weeks, depending on water turbulence (refer to Chapters 2 and 4).

The primary production of rhizome and shoot material was discussed in Chapter 2. The method used to estimate primary production was based on the average time between production of new leaves (and hence leaf scars), of twenty-seven days (refer to Appendix 3). There are marked differences between actively-growing rhizomes, and rhizomes that have become erect shoots, producing the dense foliage. Actively-growing rhizomes may have an internode length (that is, distance between leaf scars) of between 1.0 to 3.0 cm, indicating a fast growth rate of 1.0 to 3.0 cm per twenty-seven days. However, the same length of rhizome on an erect shoot may contain about thirty leaf scars, or about two years growth.

FIGURE 13 : Relationship between Length of Leaf, and Growth Rate, for *Posidonia australis* at Bonna Point.


5
4
3
2
1
0
GROWTH OF LEAF OVER PREVIOUS ONE WEEK (CM.)
10
20
30
40
50
LEAF LENGTH ON COLLECTION
(CM.)

There is also a difference in the appearance of rhizomes found at sites within Botany Bay, probably related to the average age of the erect shoots. For example, at the Bonna Point site, one can easily distinguish between actively growing rhizomes, and erect shoots many years in age. There are only six to nine growing rhizome tips per square metre, at this site, and several hundred erect shoots. The shoots are 'bunched' into groups of two to six. From the appearance of the erect shoot rhizome, it would seem that these shoots have been growing steadily upward, producing leaves continuously, at a rate of about one centimetre per year, for at least the past fifteen years (shoots with about 200 leaf scars are common). Occasionally, these erect shoots divide dichotomously, producing another erect shoot, and resulting in the 'bunching' mentioned. Rarely, and probably in response to the prevailing conditions, this division may result in the formation of a new actively growing rhizome.

On the other hand, at certain sites in Quibray Bay (for example, the study site, page 23) one finds a proliferation of rhizome growth. The higher undergound production that occurs in Quibray Bay has already been noted (Table 4, page 41), as well as the faster turnover time. At these sites it is rare for the internode length to be less than 5 mm. Also the shoots are not as old as those found at Bonna Point. There is probably a need to replace rhizome material at a faster rate at the Quibray Bay sites, either due to higher rates of sedimentation in the more sheltered waters (smothering older shoots), or faster rhizome decomposition in the more anaerobic conditions (refer to section on decomposition, later in this chapter).

The colonization of *Posidonia australis* into a cleared area of sediment, within a mature meadow, is known to be slow (Larkum, 1976), and the low number of actively growing rhizomes per square metre, that has been found in this study may partly explain this observation. However, colonization of a new area, or regrowth after being covered with sediment, may happen at a much faster rate. For example, there are several bare areas of sediment in Quibray Bay, that are being slowly colonised by *Posidonia australis*. Under these conditions a large number of actively growing rhizome tips can be found along the 'invasion line', all directed toward the area that is being colonised. Further into the meadow, it is obvious that secondary shoots are formed, and that the non-directional rhizome mat takes shape.

Meinesz and Laurent (1978) have found similar differences between the shoots at the boundary and those in the mature meadow of deep beds of *Posidonia oceanica* in the Mediterranean.

Seedling Establishment in *Posidonia australis*.

Vegetative spreading of *Posidonia australis* appears to be much more important than sexual reproduction, especially in sub-optimal communities where flowering is rare. There have been no reports of naturally occurring seedlings in N.S.W. waters, and only one report of seedling establishment in south-east Australian waters (Gilham, 1965). Seedlings may however be much more frequent in South Australian and Western Australian waters (Cambridge, University of W.A., personal communication).

During a field trip to Jervis Bay, on the 17th December, 1978, a number of fruit of *Posidonia australis* were found at high tide level on Greenpatch Beach. These fruit were placed in a bucket of seawater, and the seeds were released within one to two days. The fruit floats freely and splits open to free the seed, which sinks quickly in seawater.

The germinating seedlings were used in a number of experiments.

Fifteen to twenty seeds were planted under a centimetre of sediment in a previously cleared, sandy area within the *Posidonia australis* meadows one hundred metres off Greenpatch Beach, Jervis Bay. These seedlings were lost within four weeks, apparently through excessive water movement.

The remainder of the seeds were returned to Sydney, and allowed to germinate in a shallow tray of aerated seawater. Five days after germination had started, the seeds had developed a small leaf, about ten centimetres long, and after eight days there were three leaves, up to twelve centimetres in length. At this stage two small roots had also emerged.

Seedlings at this state of development were planted in four locations. Firstly, two groups of fifteen seedlings were planted in buckets of sediment, and kept under controlled environmental conditions, in 73 l aquaria (refer to Chapter 3). One bucket contained mud collected from Botany Bay, the other contained washed river sand. Two further groups of seedlings were planted at two sites in Botany Bay. This procedure involved the following steps :-

(i) An area of 0.5m x 0.5m was cleared of seagrass.
(ii) Shadecloth was pegged-down over the cleared areas.
(iii) Seedlings were planted such that seed was held under the cloth but the leaves were above it.

The areas chosen were situated in Quibray Bay, and on the northern side of Botany Bay, near the Kingsford-Smith Airport runway extension. Both sites had approximately 0.5m depth of water, at low tide.

The development of the seedlings of *Posidonia australis* is shown in Plate 1, page 79. After almost one year of growth, there are only five seedlings remaining of the group planted under laboratory conditions, and four remaining in the field.

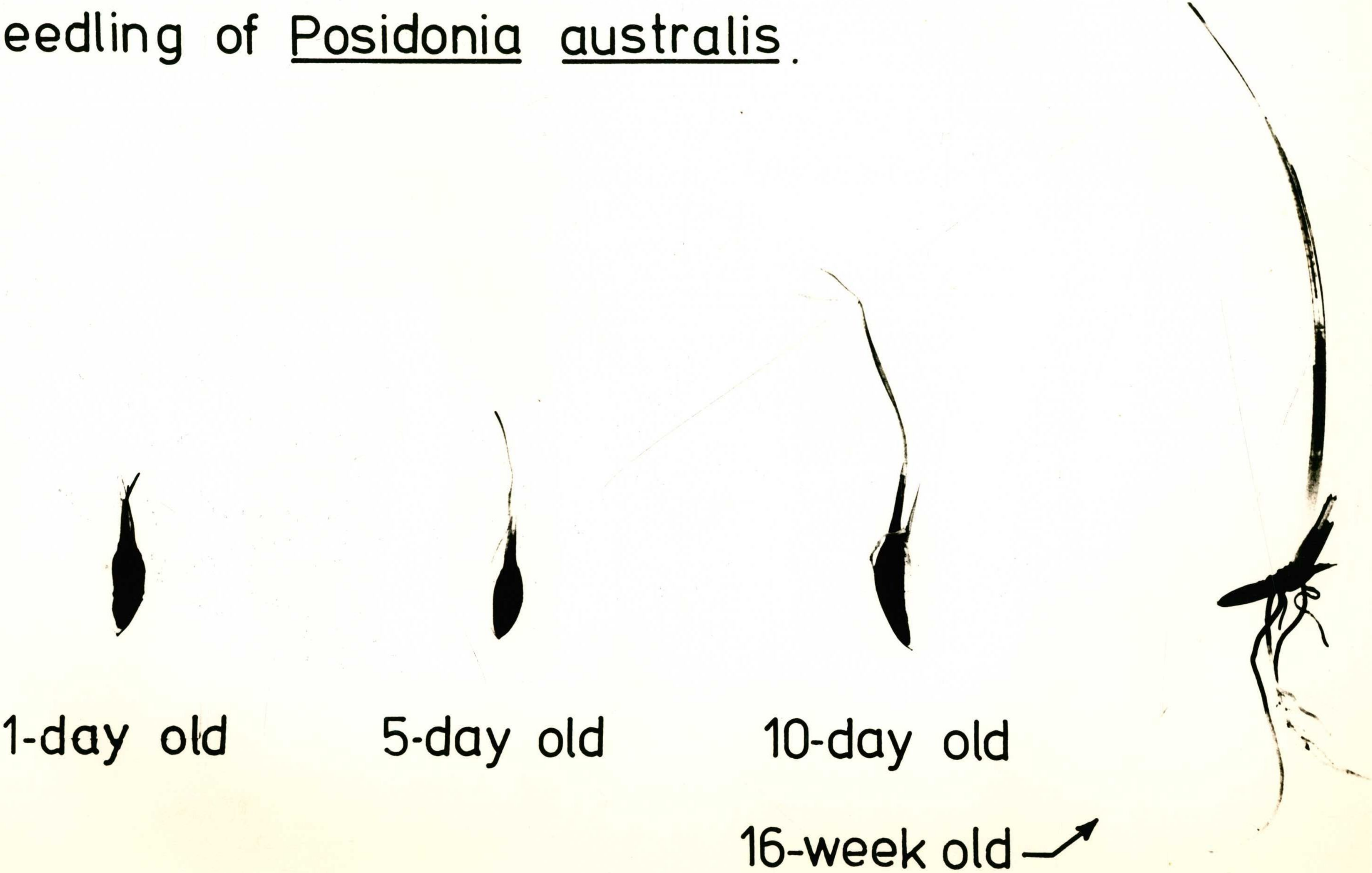
The seedlings planted in mud from Botany Bay survived, and grew until Semptember, 1978, when a bloom of a species of amphipod consumed all green leaf material in this aquaria. One amphipod, isolated and placed in a dish of filtered seawater with a small section of *Posidonia australis* leaf, was observed to consume large portions of this leaf. The digested leaf material formed a fine detritus, on which the animal survived for for several days, not attempting to break off further sections of whole leaf. Kirkman (1978) describes the consumption of *Zostera capricorni* by an amphipod population, under aquarium conditions.

Of the seedlings planted in clean sand, under laboratory conditions, five remain. After one year of growth, these seedlings have leaves 30 - 37 cm long and 0.7 cm in width. Growth rate of newly emerging leaves is about 3 cm per week. One harvested seedling had seven roots arising from the rhizome, all at least 10 cm in length. The rhizome was no longer connected to the seed, which had apparently disinegrated. This seedling had leaf scars (and old sheaths) corresponding to the development of ten leaves, and had two green leaves. The leaves had varied in width (from the evidence of the sheaths), from 2 mm (four leaves), 3 mm (two leaves), 4 mm (one leaf), 5mm (three leaves), and had two green leaves of 7 mm width.

At least four seedlings of those planted in the field remain. The seedlings planted on the north side of Botany Bay have not been located since a prolific growth of *Zostera capricorni* during 1979. Four seedlings remain at Quibray Bay, the tallest of which was 27 cm on the 10th October, 1979.

PLATE 1 : Development of *Posidonia australis* Seedlings

Seedling of *Posidonia australis*.



At this stage none of the seedlings have developed an extended rhizome. Leaves have been produced along a short rhizome (12 leaves on 5 mm of rhizome).

Spreading of the range of *Posidonia australis* in N.S.W. waters must have been (or still be) an extremely slow process, as wastage of seed is high, and flowering irregular. An observation made during January, 1977, would indicate that conditions for seedling establishment are more favourable in South Australian waters. Mounds, composed of large quantities of fruit were found on many beaches in the Victor Harbour region of this state. With this high production of seeds one would expect successful seedling establishment to be more common.

Decomposition of the Leaves of *Posidonia australis*

Posidonia australis has been found to be highly productive in Botany Bay waters (Chapter 2), but it would appear that few animals are adapted to utilise this food resource directly. Conacher, Lanzing and Larkum (1979) have found that less than 1% of daily leaf production was utilised by the fanbellied leatherjacket (*Monocanthus chinensis*), probably the main grazing herbivore found in the meadows of *Posidonia australis* in the Sydney Region. As indicated in Chapter 2, it is the leaf material and not the underground rhizomes, that is the principle component of production of this seagrass. It is thought that the leaves enter the detrital food chain, which is of great importance in many estuarine waters (Odum, Zieman and Heald, 1972).

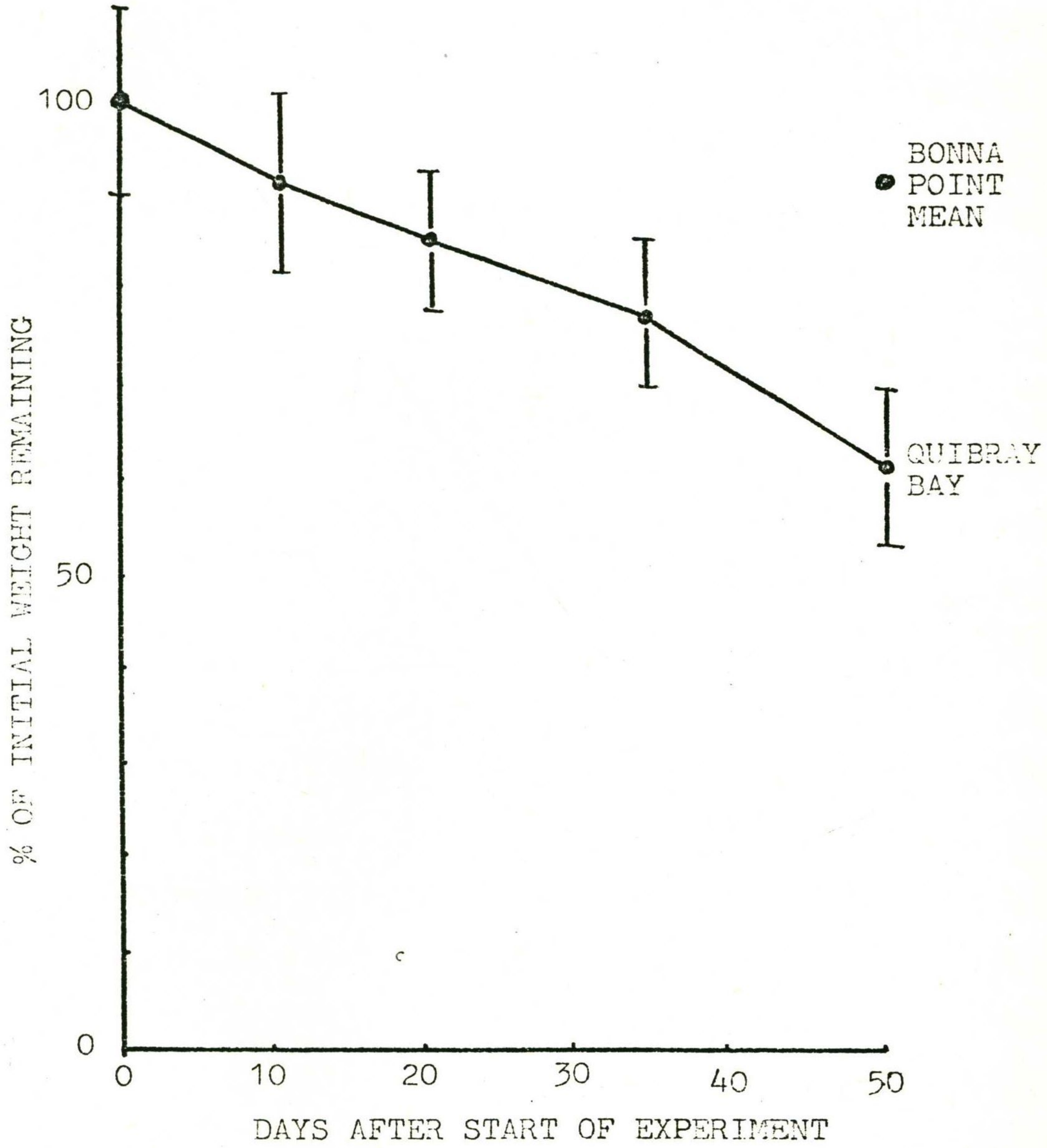
For this reason the decomposition of leaf material of *Posidonia australis* was considered briefly, with three objectives. Firstly, to gauge the resistance of leaves to decomposition; secondly, to investigate differences in decomposition rates at the two Botany Bay sites (refer to page 20); and thirdly, to identify the the types of animals found on decomposing leaf litter.

A single experiment was performed from 30th August, 1978, to the 19th October, 1978. In most studies of decomposition, recently fallen material is used (for example, Goulter and Allaway, 1979), however, this is not possible with seagrasses, since decomposition often occurs on the intact plant, and as well, older leaves are heavily epiphytised, and not indicative of seagrass alone. For these reasons, it is necessary to use fresh material in a manner similar to Zieman (1975).

For this study 180 sections of *Posidonia australis* with no visible epiphytes, were cut from plants collected from Quibray Bay. These leaf sections were of the same width (1.2 cm, not cut) and were 9.5 cm in length (cut at both ends). Thirty sections were returned to the laboratory, dried (24 hours at 80^{o}C) and weighed individually. Ten sections of fresh leaf material were placed in each of fifteen nylon mesh bags, and the bags were placed below tide level, twelve at the Quibray Bay site, and three at the Bonna Point site. The mesh size was 7 mm. Three bags were collected from Quibray Bay after each of 10, 15 and 34 days (that is nine bags in all). The remaining bags from both sites were collected after 50 days. It was found that even after this period of time the sections within each bag could be separated, and weighed individually. This gave ten dry-weight estimates for each bag collected.

The results for this experiment have been included as Appendix 8, and are summarised in Figure 14, page 82.

FIGURE 14 : Decomposition of the Leaves of *Posidonia australis* in Botany Bay waters. Mean and Standard Deviation of 30 samples shown (see Appendix 8).


100
50
0
% OF INITIAL WEIGHT REMAINING
0
10
20
30
40
50
DAYS AFTER START OF EXPERIMENT
● BONNA POINT MEAN
QUIBRAY BAY

The sections of leaf placed in litter bags, and left in Quibray Bay, showed a loss in dry weight, and were obviously decomposing. After ten days, the sections showed a 'browning' at the cut edges, indicative of bacterial decomposition. This infection of the leaf spread, and after fifty days had elapsed, the sections had lost approximately 38% of their initial dry weight, and were completely brown. This appears to be a slower rate than that found for the mangrove *Avicennia marina* using the same mesh size (Goulter and Allaway, 1979), although the use of fresh material in this study makes comparisons to the decomposition of mangrove litter somewhat difficult. Zieman (1975) has measured the decomposition of *Thalassia testudinum*, and found that approximately 65% of the initial weight (measured as dry weight) is lost in six weeks. A similar pattern of decay, as that mentioned above, is described by Zieman (1975, page 557).

A range of animals were found on these litter bags. In greatest numbers were several members of the order Amphipoda, among which could be identified a species of *Caprella*. Amphipods have been shown to be important in the decomposition of *Thalassia testudinum*, by decreasing the particle size of the detritus and thus increasing the biologically active surface (Fenchel, 1970). There is little doubt that the same process operates in the decomposition of the leaves of *Posidonia australis*, and the effect that a bloom in the amphipod population had on the growth of seedlings in laboratory culture (page 78), is further evidence to this effect. On the last collection of litter bags (50 days), many larger animals were present, including crabs (possibly juveniles) and shrimp.

A problem arose when trying to assess the difference in decomposition rates at the two Botany Bay sites. The sections of leaf, placed in litter bags and left at Bonna Point, did not lose weight in the same manner as those left at Quibray Bay. At Bonna Point the leaf sections remained green for several weeks, in fact some sections showed no signs of bacterial infection after the full fifty day period. These sections, in some cases, increased in weight, apparently after colonization by epiphytes. Thus, there is a significant difference in the decomposition of *Posidonia australis* at the two Botany Bay sites (refer to Appendix 8).

These introductory experiments concerning decomposition indicate that leaf litter from *Posidonia australis* is incorporated into the detrital food chain, and that the characteristics of particular sites are important in determining the rate of decomposition. Much of the leaf litter produced in Botany Bay appears to be washed onto the beaches (personal observation) and the consecutive wetting and drying that occurs due to the tide is likely to cause an increased rate of degradation of this litter (compare with Zieman, 1975). It is clear that the artificial nature of litter bag experiments, and the special problems associated with attempting these experiments in the natural conditions of a seagrass bed, require careful consideration in future investigations.

A Comparison of the *Posidonia australis* Communities at all Collection Sites

It is interesting to compare the *Posidonia australis* communities found at all sites sampled during this study. Table 12, page 85, summarises information previously presented in Chapters 2 and 5. Values for Port Hacking N.S.W., and Spencers Gulf, S.A. are also shown, and this data has been compiled and treated statistically in Appendix 9.

There are quite large differences in shoot density, leaf biomass, total biomass, and growth rates between the sites investigated. The two Botany Bay sites showed similar leaf production rates (per m^2), even though leaf biomass is higher at Bonna Point. The leaves at this latter site are short, and shoot density high, when compared to the Quibray

TABLE 12 : Selected Characteristics of the *Posidonia australis* Communities at the Various Study Sites

	BONNA POINT	QUIBRAY BAY	JERVIS BAY	PORT HACKING	SPENCER GULF
Max. Leaf Biomass (g/m^2)	280	137	453	198	616
Min. Leaf Biomass (g/m^2)	190	101	294	190	444
Mean Total Biomass (g/m^2)	1193	847	2550	929	2457
Summer Leaf Production (g/m^2/day)	2.3	1.9	5.2	3.6	5.5
Winter Leaf Production (g/m^2/day)	1.0	1.0	0.9	1.2	2.7
Rhizome and Shoot Production (g/m^2/day)	0.14	0.17	-	-	-
Mean Shoot Density (nos./m^2)	215	80	199	121	240
Mean Leaf Length (longest 50 leaves, cm)	35	62	65	53	97
Max. L.A.I. (m^2/m^2 sediment)	3.2	1.7	5.1	1.8	5.7
Occurence of Flowers	Rare	Infrequent	Abundant	Frequent	Prolific
Turnover Time - Leaves (days)	117	93	110	81	130
- Rhizomes (years)	19	11	-	-	-
Decomposition Rate	Slow	Fast	-	-	-

Bay site. Turnover time is faster at the Quibray Bay site (that is, the individual plants produce leaves at a faster rate). The rhizome and shoot production is also higher at the Quibray Bay site, and the difference in rhizome morphology has already been discussed for the two sites (pg. 75).

Biomass and leaf production at the Port Hacking site were comparable to those at the Bonna Point, Botany Bay site, although shoot density was lower, and leaf length longer. This site was chosen as it is close to Botany Bay, but less obviously influenced by urban and industrial development. The Spencer Gulf, S.A., site had the highest leaf biomass and production values, although summer leaf production was only marginally greater than that at Jervis Bay, N.S.W. This site is near the middle of the geographical range of *Posidonia australis*, and growth is very vigorous, to judge from the exceptionally long leaves (refer to Table 12, page 85), and thick deposits of fibre (Shepherd, 1977).

The values for Leaf Area Index (L.A.I.) presented in Table 10, page 85, are lower than many literature values for seagrasses. For example, a L.A.I. of seven has been recorded for *Posidonia oceanica* (Drew, 1978), and values as high as twenty are listed by McRoy and McMillan (1977) for species such as *Zostera marina* and *Thalassia testudinum*. By comparison, McRoy and McMillan (1977) state that a maximum L.A.I. for a cereal crop is in the order of nine, and for a rain forest, in the order of twenty.

Chapter Six

GENERAL DISCUSSION

Overseas research has demonstated that the dense meadows formed by many species of seagrasses are very productive, and contribute large amounts of organic matter, in the form of detritus, to coastal ecosystems (summarised by McRoy and McMillan, 1977). For example, *Thalassia testudinum* forms an important and productive community in many areas of tropical and sub-tropical America (Patriquin, 1973; Zieman, 1975; Greenway, 1977), and *Zostera marina* plays a similar role in temperate regions on both sides of the Atlantic Ocean (McRoy, 1966; Penhale, 1977; Sand-Jensen, 1975). Primary production estimates for many seagrass communities have been summarised in Table 2A, page 21. Comparative information for Australian species of seagrasses is sparse, even though twenty-five of the fifty-two presently described species of seagrasses are found in Australian waters (refer to pages 1 and 2).

In this study leaf production of *Posidonia australis* has been found to range between 0.6 and 5.5 g dry weight per square metre per day, depending on site and season. This represented approximately 90% of the total production of this seagrass (refer to Table 4, page 41). Rhizome and shoot production contribute little in terms of primary production, and this is further demonstated by the slow turnover rate of these portions (11 - 19 years, refer to Table 4, page 41). Kuo and Cambridge (1978) have also commented on the age of rhizome material in meadows of *Posidonia australis* in Western Australian waters. These authors have found rhizomes that may be 'at least 20 - 30 years old, on the basis of the number of nodes and average life of leaves'. Thus, although rhizomes may be important in nutrition (Patriquin, 1972; Patriquin and Knowles, 1972) and in providing anchorage (Den Hartog, 1977, pg. 90), it is the leaves of seagrasses that provide a possible food source for higher trophic levels. The important consideration to make, therefore, in the determination of the role of *Posidonia australis* in supporting a food web of secondary producers, is the total production of the standing crop (or leaves).

The estimate of the total leaf production of *Posidonia australis* in Botany Bay of 2790 - 5840 tonnes dry weight per year, would seem to indicate a significant contribution toward the total primary production from 'wetland' communities in this bay. These 'wetland' communities are : seagrasses, mangroves, salt marshes, benthic algae and phytoplankton. It is useful to make a comparison between production arising from these communities, even though some estimates must be included in such an analysis. The primary production estimates for plant communities of Botany Bay are shown in Table 13, page 89.

The primary production of the two major species of seagrasses has been measured (this study; Larkum, Collett and Williams Jnr, 1980). Goulter and Allaway (1979) have studied litter production of a mangrove stand in Middle Harbour, Sydney, N.S.W. and this work has been used to estimate production from the same species of mangrove, *Avicennia marina*, in Botany Bay. The benthic algal production of the mangrove zone of Botany Bay has been measured by King (personal communication). Phytoplankton productivity can be gauged from recent studies in Sydney Harbour (Revelante and Gilmartin, 1978) and Port Hacking, N.S.W. (Scott, 1978). Primary

TABLE 13 : Primary Production Estimates for Plant Communities in Botany Bay, N.S.W. (see text for source of estimates)

COMMUNITY	ANNUAL PRODUCTIVITY (tonnes/ha/yr)	AREA (ha)	TOTAL PRODUCTION (tonnes/yr)	% OF TOTAL
Seagrasses				
*Posidonia australis**	8.6	500	4300	25.6
Zostera capricorni	1.8	284	513	3.1
Epiphytic algae	2.6	500	1290	7.7
Total for Seagrass Community			6103	36.4
Mangroves	5.8	400	2320	13.8
Salt Marshes	6	150	900	5.3
Benthic Algae	3	200	600	3.6
Phytoplankton	1.5	4600	6900	40.9
TOTAL			16823	100.0

* denotes median estimate.

production arising from seagrass epiphytes, and from salt marshes must be estimated from overseas studies, as no data is available for Australian situations. Epiphyte production has been taken as 20% of the *Posidonia australis* production for two reasons. Firstly, this seagrass is colonised to a much greater extent than is *Zostera capricorni* (May, Collins and Collett, 1978), and secondly, this figure is suggested by the work of Jones (1968; refer also to McRoy and McMillan, 1977) with *Thalassia testudinum* epiphytes. Epiphyte production should be the subject of future work. Salt marsh production is estimated from Jefferies (1972). Even a large error here is unlikely to affect the accuracy of the overall treatment, as this community does not occupy a large area.

In this assessment, the production arising from seagrasses and epiphytes contribute approximately 36% of the total productivity. These communities are the largest source of detritus. The phytoplankton component of primary production is possibly the largest contribution from any of the aquatic communities of Botany Bay.

A generalised theory concerning estuarine food webs has been postulated by Odum and Heald (1975). These authors consider two types of food chain, one based on detritus, and the other on phytoplankton. The detrital food chain is thought to dominate in shallow muddy estuaries, that have extensive macro-plant communities. These authors state :-

> 'the key organisms in this food web are a group of detritus consumers - herbivores and omnivorous crustaceans, mollusks, insect larvae, nematodes, polychaetes and a few fishes'.

The phytoplantonic food web is thought to be characteristic of deeper estuaries of larger water volume. This is a grazing food web of zooplankton and zooplankton grazers (Odum and Heald, 1975). Odum and Heald (1975) also accept that there may be estuaries in which specific sites show the reverse situation of that of the estuary as a whole.

Many recent studies to determine the role of seagrasses, epiphytes and phytoplankton in the food web of estuaries have utilized the stable carbon isotope ratio of these components. This method is based on the observation that many species of plants exhibit a carbon-13 to carbon-12 ratio value ($\delta^{13}C$ value) that is characteristic of their photosynthetic reactions (Benedict, 1978). Seagrasses range in $\delta^{13}C$ values from -3.0 to -13.0 ^{o}/oo, whereas phytoplankton generally have an isotope ratio of between -18.0 to -25.0 ^{o}/oo (Fry and Parker, 1979). Several studies have been concerned with the measurement of the $\delta^{13}C$ values of consumer organisms in the estuarine community, to enable the identification of the major sources of primary production (Thayer, *et al*, 1978; Haines and Montague, 1979; Fry and Parker, 1979).

Thayer, *et al* (1978) with results based on the $\delta^{13}C$ method suggested that, with the exception of a few animals and epibiota, 'the majority of other organisms analysed appeared to be linked more directly to a plankton-carbon food chain', whereas Fry and Parker (1979) conclude that their 'data support the notion that in Texas bays, seagrasses and other benthic plants are significant sources of nutrition'.

The major problem associated with the $\delta^{13}C$ method is that specificity for carbon isotopes may occur in metabolic reactions at all levels of the food chain. Evidence also exists that, in at least some instances, changes in the $\delta^{13}C$ values may accompany biological degradation of organic matter (Tan and Strain, 1979). Yet another problem is that detritus from terrestial communities has a high $\delta^{13}C$ value (for example, values of -12 to -26^{o}/oo are reported by Haines and Montague, 1979), which is thus indistinguishable from that of phytoplankton. However it seems that if care is taken to resolve the associated problems, stable isotope ratio analysis will be a powerful tool for the determination of the carbon food chains in any type of ecosystem, including estuaries.

Without the use of carbon isotope analysis, the methods available to evaluate the possible contribution of detritus to the food web are those involving studies of decomposition. Such studies have led to the emphasis, by a number of authors, of the importance of plant detritus to estuarine consumers (for summary refer to Odum, Zieman and Heald, 1972). In Chapter 5 (pages 80 ff) it was demonstrated that at certain sites, decompostion of the leaves of *Posidonia australis* resulted in a loss of approximately 38% of the initial dry weight, in fifty days. Although, as stated (pages 83 and 84), the many problems experienced in the determination of seagrass decomposition rates make the result difficult to interpret. Several species of animals were attracted to the litter bags, in particular members of the order Amphipoda. Mangrove litter has been shown to decompose rapidly under conditions similar to those in Botany Bay, by Goulter and Allaway (1979). Fenchel (1977) has reviewed in detail decomposition of seagrasses. In this author's opinion, the detrital system with its high degree of 'stability' (due to the time delay in utilisation of detritus), is an example of a ' "mature" stage of ecosystem succession' (refer to Odum, 1969). The steps in the process of decomposition of detritus have already been outlined (pages 5 and 6).

In N.S.W. waters it seems logical to suggest that the deep estuaries, often formed in drowned river valleys (for example, Sydney Harbour, Jervis Bay, Port Stephens and Lake Macquarie) are all examples of waters dominated by a phytoplankton based food web, and that shallow lagoon systems (such as, Illawarra Lake, Tuggerah Lakes and Wallis Lakes) have macro-plant communities as the dominant primary producers. Local variations occur in these waterbodies, such as the extensive seagrass and mangrove communities of Jervis Bay (refer to Larkum, 1973; Chapter 2, page 25). However, Botany Bay, with a moderate depth of water, and many areas of extensive plant communities is not dominated by either food chain (refer to Table 13, page 89). This must partly be due to the changing conditions of this bay under human interference.

Evidence exists, from sediment cores and observations of adjacent estuaries (Larkum, 1976; Larkum, personal communication), that before European settlement of the area, approximately 200 years ago, a large proportion of the bay-floor was covered with meadows of *Posidonia australis*. This was as much as ten-fold the present area. If this is true, then at that time, the primary production of the bay would have been completely dominated by *Posidonia australis*. Aerial photographic evidence confirms the loss of 20% in terms of area covered by seagrasses, in the last fifteen to twenty years (Larkum, personal communication). This would represent a loss of 5% in the contribution of seagrasses to the total primary production from aquatic communities in Botany Bay. This continued reduction in the role of *Posidonia australis* in Botany Bay must have consequences on the structure of the food web in these waters, and therefore be a matter of concern.

A similar situation is reported for the meadows of *Posidonia oceanica*, in the Mediterranean, particularly off the French coast (Peres and Picard, 1975). Considerable effort has been made to map the lower limit of these meadows, now at an average depth of twenty-five metres, but known to have once extended to at least thirty metres depth (Meinesz and Laurent, 1978). Meinesz and Laurent (1978) have summarised a number of studies in listing the causes of the demise of *Posidonia oceanica* as mechanical erosion from fishing practices, damage from anchors of large boats, coastal development, domestic pollution, chemical pollution and increased turbidity.

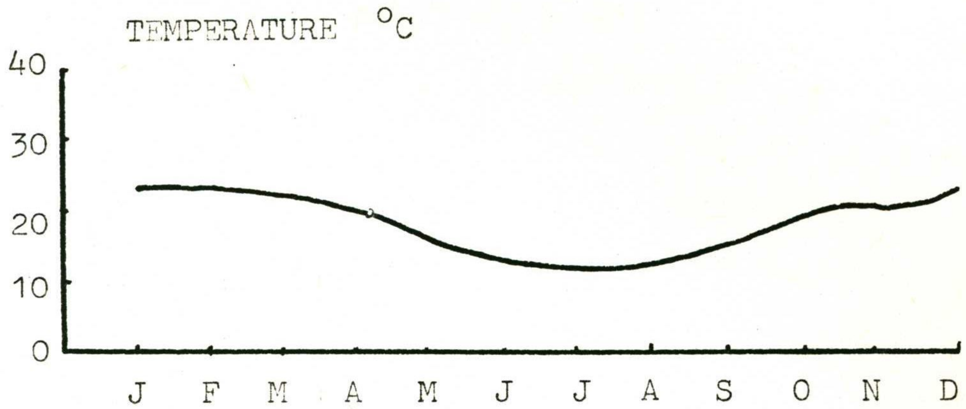
Even when significant losses of seagrasses have occurred in an area, there is conflicting evidence concerning the effect that the loss has had on associated biota. An example is the studies related to the 'wasting' disease of *Zostera marina* (eelgrass), in Atlantic waters. This disease, which has recently been linked to temperature change, caused the disappearance of eelgrass from almost all North Atlantic coastlines, during the 1930's (Rasmussen, 1977). This loss was expected to have a devastating effect on the fisheries industry. Milne and Milne (1951) stated that undoubtedly it was the reason for a major decline in 'bottom' fishes in the North Atlantic. There is also evidence that in some instances all the *Zostera*-associated fauna disappeared from many areas (Stauffer, 1937). However, Rasmussen (1977) considers that such cases are isolated. This author cites the appearance of algal benthic vegetation, in denuded Danish waters, which assisted in making the effect of eelgrass losses minimal. It is also probable that the slow degradation of detrital material (refer to page 92) resulted in the formation of a 'bank' of energy available to heterotrophs, that assured constant supply, irrespective of the quantity of living material (compare with Fenchel, 1977). Thus although the loss of vast areas of *Zostera marina* had a relatively small effect on fauna, this is not indicative of the importance of these communities in supplying detritus to coastal waters (Odum, Zieman and Heald, 1972; Mann 1972).

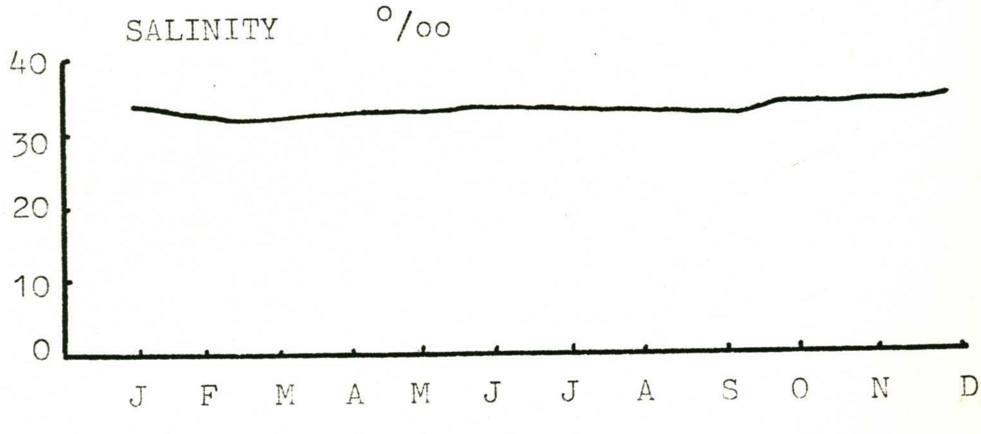
The losses in the area covered by meadows of *Posidonia australis* in Botany Bay waters (refer to page 93), make it important to consider the effect on the growth of this seagrass imposed by the controlling factors of the environment. These factors are many, and are probably complex in interaction. Light, salinity, temperature and water turbulence have been considered in this study (Chapters 3 and 4). Nutrients, toxic contamination and other sources of human interference are factors not yet investigated, on which experience must be drawn from overseas studies (McRoy and McMillan, 1977; Thayer, Wolfe and Williams, 1975).

Past records exist for salinity and temperature of Botany Bay waters, and the waters of many other N.S.W. estuaries (Wolfe and Collins, 1979). Graphs to summarise the mean monthly salinities and water temperatures for Botany Bay (1966 - 1973) have been included (Figure 15, page 96).

Water temperatures vary from 11.4°C to 22.8°C (Figure 15, page 96), although extremes of 7.4°C and 27°C have been recorded (Wolfe and Collins, 1979). The experiments described in Chapter 3 (Table 8, page 58), indicate that *Posidonia australis* would not be adversely affected by such temperature conditions. However, a rise of 3 - 5°C in water temperature, during the summer maxima, could be detrimental. It is probable that such conditions existed in the vicinity of Bunnerong Power Station, after it commenced operation in the 1930's. This may be one contributing factor to the decline of *Posidonia australis* on the northern shoreline of Botany Bay, as noted by Larkum (personal communication). The slightly warmer waters in estuaries north of Port Stephens, N.S.W. (Wolfe and Collins, 1979) is a possible reason for the northern limit of *Posidonia australis* in these latitudes (refer to page 3, and Den Hartog, 1970). The effect that high temperatures have on *Posidonia australis* may be related to an increase in respiration, and the inability to supply oxygen to the rhizome at a sufficient rate (refer to page 57 and 58). If this proves to be true, than a comparative study of the effect of temperature on temperate and tropical species of seagrasses would be interesting (for example, a comparison of *Posidonia australis* with *Enhalus acoroides*). Thorhaug, Blake and Schroeder (1978) have reviewed the

FIGURE 15 : Mean Monthly Salinity and Temperature Recordings
for a Site in Botany Bay, 1966-1973.
(Adapted from Wolfe and Collins, 1979)


TEMPERATURE °C
40
30
20
10
0
J F M A M J J A S O N D


SALINITY °/oo
40
30
20
10
0
J F M A M J J A S O N D

effect of temperature on *Thalassia testudinum* in tropical and temperate waters, and concluded that in both regions elevated temperatures of a few degrees above summer maxima is 'devastating to populations of plants and animals in *Thalassia* communities'.

The experiments of Chapter 3 also indicate that salinity fluctuations in Botany Bay (refer to Figure 15, page 96) would have little effect on leaf growth rate of *Posidonia australis*. The absolute maximum and minimum recorded for 1966 - 1973 are 40.3 and 7.1 parts per thousand, respectively, but these limits would only last for short periods (Wolfe and Collins, 1979). Some attention should be directed towards determination of the long-term effects of salinity changes on the growth and colonisation of *Posidonia australis* so that distribution may be explained (refer to pages 54 and 56). Short-term variations in salinity may not be experienced in the meristem region of this seagrass due to the protection of the sheath (Tyerman, 1979). This possibility may explain the finding that leaf growth is unaffected when salinity is lowered (Table 7, page 55).

The damage that occurs to the *Posidonia australis* meadows during heavy seas (refer to pages 67 to 71) is obviously an important factor in the survival of this seagrass, especially in exposed situations, such as at Bonna and Towra Points. These exposed areas have recieved the brunt of redirected wave energy associated with the deepening of the entrance of Botany Bay to cater for large oil-tankers, and made the construction of rocky groynes to deter sand movements necessary. As stated in Chapter 4 severe reductions in leaf biomass were recorded after storm damage, and this resulted in a period during which photosynthetic rates were lowered, and *Posidonia australis* must have survived by drawing on stored reserve materials for regrowth. Storm damage occurred at Bonna Point during 1977 and 1978, but not in 1979. The fact that 1979 was the only year of these three during which a high incidence of flowering was recorded at Bonna Point (personal observation) may be related to the absence of storms, and the photosynthetic storage products available for the flowering process.

By far the most important environmental parameter for any plant is light flux, yet there is little available information concerning the light conditions experienced in any N.S.W. estuary, including Botany Bay. Kirk (1976, 1977) has investigated the light conditions of inland and oceanic waters, and discussed vertical attenuation. However, inland waters are likely to be more turbid, and oceanic waters less turbid, than estuarine waters. Therefore the values found by Kirk (1977) are not applicable to this study. The N.S.W. State Pollution Control Commission (S.P.C.C.; personal communication) has made an investigation of turbidity in Botany Bay. This work has led to the finding that turbidity and penetration of light are logarithmically related. The S.P.C.C. has treated penetration of light in terms of the euphotic zone, or depth at which 10% surface radiation (photosynthetically active radiation, P.A.R.) is available.

Accepting that the light flux required for maintenance of leaf growth in *Posidonia australis* is 250 $\mu E/m^2/sec$, then we can assume that this light requirement is approximately 10% of the maximum surface radiation on a clear summer's day. This assumption is based on data presented in Chapter 4 (Table 11, page 70), where values of light flux on clear summer days varied between 2190 and 2475 $\mu E/m^2/sec$. An attempt can now be made to relate the laboratory study to field conditions in Botany Bay.

Using the data collected by the S.P.C.C. (refer to Appendix 10) and the equations relating turbidity and euphotic zone, it is possible to calculate the depth to which *Posidonia australis* can be expected to grow (calculations are shown in Appendix 10). For the mean turbidities this depth is -3.1 m at Towra Point and -6.4 m at Silver Beach. These values are obviously deeper than would be expected if the annual mean light flux could be used, instead of the summer maxima. Adaptation to low light levels may also affect the validity of this treatment. Nevertheless, this result is at least circumstantial evidence that light may be limiting *Posidonia australis* to the depth of approximately -3m, as found by Larkum (1976).

Thus light, salinity, temperature, and water turbulence have been investigated as possible factors causing the slow decline of *Posidonia australis* in Botany Bay. Other factors that need investigation are, for example, the effects of oil spills, dispersants and treated effluents. Any of these factors could lead to a situation where beds of seagrass become degraded, and bare patches may be formed.

The recovery of the *Posidonia australis* community into these degraded areas may be extremely slow. Clearing experiments by Larkum (1976) showed little regrowth over many years. Some insight into the reason for this slow recolonization was revealed in Chapter 5 (pages 75 and 76), when a low number of actively-growing rhizome tips was found in a mature bed of *Posidonia australis* at Bonna Point. Thus once an area is cleared, the slow vertical growth of most rhizomes (erect shoots) does not facilitate recolonization, which occurs through active horizontal rhizome growth, and meristem proliferation. Regrowth of bared areas may be faster in Quibray Bay, where the *Posidonia australis* has a faster rhizome and shoot growth rate (Table 4, page 41).

Tomlinson (1974) has stressed the need to study meristem proliferation in seagrasses as the source of biomass and productivity. *Posidonia* and *Enhalus* have been described as monomorphic, in that they possess shoots bearing only foliage leaves, whereas plants such as *Halophila* and

Thalassia are dimorphic, having shoots with either scale or foliage leaves. However, the situation is more complicated than this author has suggested. During this study, the difference between actively-growing rhizomes and erect shoots has been stressed (refer to pages 73 to 76). This difference in growth habit probably depends on environment, such that, under some conditions (such as high density of shoots), there is very little active (horizontal) rhizome growth.

Not only is vegetative spreading within a mature meadow of *Posidonia australis* slow, but recolonization from seedlings is very rare in N.S.W. waters (refer to page 76). The conditions in Botany Bay make re-establishment from seed even less probable, due to a low incidence of flowering (refer to Table 10, page 85). The autocatalytic nature of degeneration of seagrass beds was treated by Larkum (1976), and the low incidence of flowering under sub-optimal conditions is another factor that can be added to this effect.

When one considers the slow regrowth and recolonization of *Posidonia australis*, it seems that the need for artificial restoration of damaged seagrass beds may be necessary. In this regard some relevant information can be drawn from this study where both rhizome growth of mature plants, and seedling growth, have been briefly surveyed. Two possible methods of restoration are the transplantation of vegetative shoots (Fuss and Kelly, 1969) and the planting of seeds (Thorhaug, 1974). Fuss and Kelly (1969), Kelly *et al* (1971) and van Breedveld (1975) have all had some success in transplanting vegetative shoots of *Thalassia testudinum* into bared areas, while Ranwell *et al* (1974) have also succeeded in transplanting 'turfs' of *Zostera noltii* and *Zostera marina*. The most successful restoration of a seagrass bed has been performed by Thorhaug (1974) after planting seeds of *Thalassia testudinum* into an area in which the previously existing beds had failed, due to human interference. Further studies of this restored area have included an economic analysis (Thorhaug and Austin, 1976), and the observation of natural flowering and seed-setting, some four years after the restoration (Thorhaug, 1979). However, it is apparent that many problems will exist in attempting restoration of *Posidonia australis* meadows, as rhizome growth is unpredictable in this seagrass, and seedling growth is slow and often met with a low success rate (refer to page 76).

The existence of *Posidonia australis* in Botany Bay is not threatened while the Quibray Bay and Weeney Bay foreshore areas remain relatively undeveloped. However, losses in overall distribution are likely to continue especially along Silver Beach, Bonna Point and Towra Point, as conditions such as frequency of oil spills, storm damage and increased turbidity, become more detrimental to growth. The dramatic effect that planning decisions will have on these communities is shown by the recent 'reclamation' of the northern shoreline of Botany Bay to establish a low-cost roadway. This resulted in the loss of about 50% of the area covered by *Zostera capricorni* in Botany Bay (N.S.W. State Pollution Control Commission, 1978; Larkum, personal communication).

This thesis has provided information concerning the productivity of *Posidonia australis*, the effect of some environmental variants on growth, and observations on the ecology of this community. Clearly, much more study is needed on Australian seagrass ecosystems. Nevertheless, from the evidence of this, and other work, it may be concluded that the nature of the food web of Botany Bay waters is in a state of change (from detrital dominance to phytoplanktonic dominance, refer to page 93). It seems clear that careful management, and in some cases restoration, will be necessary in the future, to create a buffer zone between development of our foreshores, and the often fragile natural communities of the Australian coastline.

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Appendix 1A : Leaf and Total Biomass of *Posidonia australis* at Bonna Point, Quibray Bay and Jervis Bay (1977-78).

Measurements are in grams dry weight per square metre. Means ($\overline{X}$) and standard error are shown (n = 5 or 6). Null hypothesis for Bartlett's Test is that the population variances are not significantly different at the 0.05 confidence level. The null hypothesis for the analysis of variance is that monthly means are not significantly different at the 0.05 confidence level. The following abbreviations are used : SS, sum of squares; Df, degrees of freedom; MS, mean square; H_o, null hypothesis; SNK interval, Student-Newman-Kuels interval. For the procedures used, test-statistics and other terms referred to, please consult Zar (1974).

	BONNA POINT		QUIBRAY BAY		JERVIS BAY	
	Leaf ($\overline{X}$±se)	Total ($\overline{X}$±se)	Leaf ($\overline{X}$±se)	Total ($\overline{X}$±se)	Leaf ($\overline{X}$±se)	Total ($\overline{X}$±se)
Feb.	273±43	1226±165	137±23	741±123	405±91	-
March	273±40	1222±148	135±27	838±107	384±35	-
April	286±34	1254±120	124±26	846±131	375±53	-
May	189± 9	1153± 77	127±25	879±114	294±46	-
June	198±25	1176± 86	125±13	801±106	320±39	2440±283
July	207±33	1185±116	112±13	872± 58	351±36	-
Aug.	218±21	1220±150	111±14	867± 76	311±55	-
Sept.	214±26	1132± 98	107±11	822± 68	353±36	-
Oct.	216±26	1168±183	101±15	847±132	330±35	-
Nov.	203±13	1192± 89	115±12	858± 46	345±40	-
Dec.	213±21	1160±163	121±12	913± 85	374±64	-
Jan.	249±39	1226±144	134±12	884± 58	453±60	2658±300
Feb.	250±26	-	140±13	-	-	-
March	218±42	-	-	-	-	-
April	64±15	-	-	-	-	-
Bartlett Test Statistic	21.7	9.8	15.1	12.8	7.0	-
$X^2_{(0,05)}$	23.7	19.7	21.0	19.7	19.7	-
H_o	Accept	Accept	Accept	Accept	Accept	-
Total SS	293200	696353	30988	528699	172785	-
DF	89	71	77	71	59	
Group SS	228639	33116	11075	158992	98282	-
DF	14	11	12	11	11	-
MS	16331	3011	923	14454	8935	-
Error SS	64561	6632383	19913	369707	74504	-
DF	75	60	65	60	48	-
MS	861	11054	306	6162	1552	-
F ratio	19	0.3	3	2.4	5.8	-
F (0.05)	1.8	2.0	1.9	2.0	2.0	-
H_0	Reject	Accept	Reject	Reject	Reject	-
SNK interval	60	n.a.	34	154	71	-

Appendix 1B : Standing Crop of *Posidonia australis* at Ten Sites within Botany Bay (refer to Table 3, page 32), October, 1979.

Measurements are in grams dry weight per square metre. Sites are labelled as in Table 3, page 32. Ranks are shown in brackets. The null hypothesis that there is no significant difference (0.05 confidence level) between standing crop at any site is tested using the Kruskal-Wallis Procedure (Zar, 1974). A nonparametric multiple comparison has been performed. (Zar, 1974).

SITE	STANDING CROP
1	400 (49), 552 (57), 576 (58), 600 (59), 424 (51), 472 (52).
2	376 (47), 164 (20), 304 (41), 164 (20), 272 (35), 260(32.5).
3	316 (43), 160 (18), 236 (30), 200 (23), 148 (14), 260(32.5).
4	132 (10), 108 (7), 118 (18), 129 (9), 157 (17), 136(11.5).
5	264 (34), 296 (39),284(36.5), 344 (45),284(36.5), 312 (42).
6	205 (24), 256 (31), 232 (29), 216 (25), 228 (27), 301 (40).
7	508 (54), 520 (55), 476 (53), 416 (50), 632 (60), 228 (27).
8	544 (56), 228 (27), 388 (48), 336 (44), 292 (38), 352 (46).
9	152 (15), 186 (22), 164 (20),136(11.5), 142 (13), 153 (16).
10	56 (2), 62 (3), 81 (5), 54 (1), 92 (6), 71 (4).

H_0 : All sites have identical standing crop (0.05 confidence level).

H_a : At least one site has larger values than the others.

$$\text{Test statistic} = \frac{12}{N(N+1)} \sum_{i=1}^{k} \frac{R_i^2}{n_i} - \frac{3(N+1)}{1}$$

$$= 49.70.$$

(Correction factor for tied ranks is unity, and can be ignored)

Degrees of freedom = 10 – 1 = 9

$\chi^2 = 17$ (Chi squared at 0.05 conf. level)

∴ Reject H_0

∴ At least one site has higher standing crop than the others.

A nonparametric comparison reveals that sites 2, 3 and 6 are not significantly different at 0.05 confidence level:-

∴ The sites can be arranged in increasing order, with median values for each site shown in brackets,

10 (62-71), 4 (129-132), 9 (152-153),
2 (260-272)= 3 (200-236)= 6(232-256),
5 (284-296), 8 (336-352), 7 (476-508), and 1 (472-552).

If we make the assumption that the above values represent a random sample of the standing crop of the bay as a whole, the 95% confidence limits can be found using the procedure described by Conover (1971, pg. 111) :

$$r^* = np^* + w\sqrt{np^*(1-p^*)} = 22.41$$

$$s^* = np^* + w\sqrt{np^*(1-p^*)} = 37.60$$

∴ The approximate (95%) confidence limits of standing crop are

186 - 292 g dry wght/ m^2.

Appendix 2 : Leaf Production of *Posidonia australis* at Bonna Point, Quibray Bay and Jervis Bay (1977-78).

Measurements shown are in grams dry weight per square metre per day. Means ($\overline{X}$) and population variance shown (n=6). Homogeneity of variance is tested using the Cochran's Test Statistic (Till, 1974). Analysis of variance has been performed, and SNK interval calculated (refer to Appendix 1A and Zar, 1974) Turnover has been calculated from the following formula :

$$\text{The mean turnover (T.O.)} = \frac{\text{daily leaf production} \times 365}{\text{mean leaf biomass}}$$

	BONNA POINT		QUIBRAY BAY		JERVIS BAY	
	$\overline{X}$	σ	$\overline{X}$	σ	$\overline{X}$	σ
Feb.	2.40	0.14	2.39	0.17	4.30	0.14
March	2.50	0.13	2.00	0.16	3.70	0.09
April	3.24	0.14	1.52	0.10	2.90	0.13
May	2.38	0.01	0.65	0.02	4.00	0.23
June	1.50	0.04	0.83	0.01	1.81	0.05
July	1.00	0.03	0.95	0.01	0.90	0.01
Aug.	1.20	0.01	0.70	0.01	1.80	0.10
Sept.	1.32	0.02	0.78	0.01	2.70	0.06
Oct.	1.24	0.02	0.85	0.02	3.20	0.12
Nov.	1.80	0.01	1.20	0.01	3.80	0.16
Dec.	2.25	0.05	1.80	0.03	4.59	0.12
Jan.	2.32	0.13	1.91	0.03	5.20	0.24
Mean	1.93		1.31		3.25	
Mean leaf biomass	228		121		358	
T.O.	3.0		3.9		3.3	

Cochran's Test Statistic = 0.0870 (C statistic is 0.0908, Till, 1974)
∴ The variances are not significantly different (0.05 level)

Analysis of variance is now performed :

H_o : The mean monthly production does not vary with site or month (0.05 confidence level)

	SS	DF	MS
TOTAL	320	215	-
GROUP	306	35	8.73
ERROR	14	180	0.08

F ratio = 112.70
F (0.05) = 1.53

∴ Reject H_o, and so the mean values are significantly different

The SNK Interval (Zar, 1974) is calculated to compare all means.

SNK Interval = $\pm$ (S.E.).Q = 0.65 (for Q, refer to Zar,1974)

Appendix 3 : Calculation of the Number of Leaves Produced Per Year, and Rhizome and Shoot Production.

Three estimates are required to find the approximate number of leaves produced per year. These are :-

(i) Unit Frond Weight : (epiphyte free sections, freshly cut and dried at 80°C until constant weight)

Mean = 7.04mg/cm^2
standard deviation = 0.64
" error 0.12

(ii) The maximum length of the leaves, based on the 50 longest (mature) intact leaf blades, at each site, January (1978) collection.

	$\overline{X}$	st. dev.
Bonna Point	35	4
Quibray Bay	62	10
Jervis Bay	65	8

(iii) The number of shoots per square metre, based on collections at each site in July (1977), Feb (1977) and Jan (1978). Total number of collections at each site is eighteen.

	$\overline{X}$	st. dev.
Bonna Point	215	31
Quibray Bay	80	14
Jervis Bay	199	34

*Calculation of the approximate number of leaves produced per shoot at each site :

	Bonna Point	Quibray Bay	Jervis Bay
Total leaf prod. (grams)	704.5	475.2	1186.3
(cm.)	100071	67500	168509
Nos. shoots	215	80	199
Growth (cm./shoot)	465	844	847
Mean leaf length	35	62	65
Nos. leaves per year	13.3	13.6	13.0

∴ Approximately 13 leaves are produced per year on each shoot. Rhizome and shoot production is based on the dry weight of the section of rhizome containing the last 13 leaf scars, five replications of 0.5 m x 0.5 m quadrats at Bonna Point and Quibray Bay. The Mann-Whitney Procedure (Zar, 1974) is used to find if one site has a majority of larger values. Units are dry weight (grams) per sq. metre per year. Ranks are shown in brackets.

Bonna Point	66.0 (9), 71 (10), 60.1 (7), 58.2 (5), 60.5 (8).
Quibray Bay	53.6 (4). 58.4(6), 42.8 (1), 50.9 (3), 46.2 (2).

H_0 : The values found at Quibray Bay are lower or equal to values found at Bonna Point.

Appendix 3 (cont.)

(MANN-WHITNEY TEST)

$$U \text{ calc.} = n1.n2 + \frac{n1(n_1+1)}{2} - R_1$$

(R_1 is the rank sums of the highest group = 39)

$\therefore$ U calc = 1
U (0.05) = 21

$\therefore$ Reject H_o.

Therefore the Quibray Bay site has higher values of rhizome mass in the top thirteen 'nodes' (ie) rhizome production.

The range of rhizome production at each site, calculated on a daily basis (g dw/m^2/day) :

Quibray Bay : 0.16-0.20
Bonna Point : 0.12-0.16.

Appendix 4 : The Effect of Reaeration on the Calculation of Oxygen Production of *Posidonia australis*.

The following calculation is included to demonstrate the magnitude of the error involved in the estimation of oxygen production from *Posidonia australis* (pages 47-56).

Liss (1974) has dealt with the reaeration of oxygen into natural waters and states that oxygen fluxes can be expressed by the following equation :-

$$F = k\Delta C,$$

where F is flux of oxygen, units $mgO_2/cm^2/hr$
k is the exchange constant, 4 cm/hr for oxygen
C is the difference in oxygen concentration between the seawater and air, causing reaeration to occur, units mgO_2/cm^3.

To obtain an overestimate of the error due to reaeration in the experiments described, consider the case where the aquaria (volume 73 l, surface area 900 cm^2) contain seawater that has reached 105 % oxygen saturation with respect to air (8.33 mgO_2/l at 17°C), over a period of one hour.

The flux of oxygen under these conditions is :

$$F = 4\ \Delta C$$

$$= \frac{4 \times 73(8.33-7.93)}{73 \times 1000} \qquad mgO_2/cm^2/hour$$

$\therefore$.The maximum oxygen influx due to reaeration over a surface area of 900 cm^2 and period of one hour (C = 5% over air saturation at 17°C)

$$= \frac{900\ (4 \times 73(8.33-7.93)}{73 \times 1000}$$

$$= 1.44\ mg\ O_2$$

At reaching 105% oxygen saturation with respect to air, the change in oxygen in the aquaria (volume 73 l) would be :

$$73\ (8.33-7.93) = 29\ mgO_2$$

$\therefore$.The percentage error due to reaeration would be 5%

Appendix 5A : Oxygen Production at Various Light Fluxes.

Oxygen production measurements are shown in the units of mg O_2 /g total dry weight/hr, and light flux in $\mu E/m^2/sec$. The results were obtained in four separate experiments between October (1977) and January (1978).

Light Flux	Net Oxy. Prod.
0	-0.960
0	-0.872
0	-0.952
0	-0.941
420	1.773
420	2.034
420	2.149
340	1.261
340	1.135
340	1.336
340	1.210
450	1.681
0	-0.630
0	-0.757
0	-0.757
0	-0.757
0	-0.757
135	0
135	0
20	-0.514
80	-0.178
265	1.071
265	1.032
265	1.377
265	1.128
0	-0.680
0	-0.680
0	-0.711
95	0
105	0.225
430	1.054
210	0.570
0	-0.934
0	-0.934
0	-0.750
0	-0.750
0	-0.938

Linear Regression :

$$y = -0.7559 + 0.006108x,$$

y is oxygen production.
x is light flux.

Correlation Coeff. 0.97
Standard Error 0.222

Appendix 5B : Calculation of the Light Required over a Diurnal Period

The relationship found in the previous section for the oxygen production at low light flux is used here to calculate the light requirement over twelve hours to satisfy respiration over a full twenty-four hours.

Respiration over twenty-four hours : -0.7559×24 mg O_2/g dry weight
$= -18.14$ mg O_2 /g dry weight.

Photosynthetic rate required over 12 hours to compensate for this respiration deficit : $\frac{18.14}{12}$ mg O_2/g dry weight/hr
$= 1.51$ "

Light flux req'd for this rate of photosynthesis : $\frac{1.51}{0.006108} = 247.5$ $\mu E/m^2$/sec.

∴ Approximately 250 $\mu E/m^2$/sec is required for these laboratory cultures of *Posidonia australis* to compensate over a diurnal period, in terms of oxygen .

Appendix 5C : Leaf Growth at Low Light Intensities.

Measurements are of leaf growth summed for each shoot (or plant). Units are centimetres growth per week. Analysis of variance is performed using Friedman's Test (Zar, 1974). The null hypothesis (H_o) is that there is no significant difference between leaf growth of any one week (or group), at the 0.05 confidence level. The following abbreviations are used : R_i, sum of ranks in the i th week; b, nos. of plants; a, nos. of weeks; T, correction factor for ties; X^2, chi-square. For treatments in each tank, please refer to Table 6, page 53.

		Week									
Tank	Plant	1	2	3	4	5	6	7	8	9	10
2	1	6.5	6.5	5.9	6.5	6.4	7.1	5.8	6.2	6.3	5.8
	2	5.6	5.3	5.7	6.0	5.2	5.8	6.1	4.6	5.0	5.2
	3	3.8	5.1	4.9	5.0	4.6	4.2	4.2	5.3	5.1	4.5
	4	5.1	5.0	5.1	4.8	4.2	5.9	6.1	6.0	5.8	6.1
	5	4.6	4.8	4.8	5.0	4.8	4.5	4.2	3.8	3.8	4.0
	6	4.0	5.1	3.9	4.0	3.8	6.1	3.1	5.0	5.4	5.1
	7	6.0	5.8	6.0	5.2	5.5	4.0	5.1	5.0	4.8	4.6
	R_i	34.5	50.5	40.0	47.0	32.5	43.5	28.5	36.5	36.0	31.0

$(\Sigma R_i)^2/10$ = 14,440

ΣR_i^2 = 14,900

$ba(a+1)/12$ = 64.16'

$\Sigma T/(a-1)$ = 0.5

X_{calc} = 7.22

X_{tab} = 12.20

.˙. Accept H_o, the leaf growth does not vary significantly between weeks at the 0.05 confidence level.

		Week									
Tank	Plant	1	2	3	4	5	6	7	8	9	10
3	1	6.7	6.3	5.2	5.5	5.8	5.2	5.4	4.2	4.1	4.2
	2	4.0	4.2	4.3	3.9	4.0	3.5	2.1	3.0	2.8	3.0
	3	5.5	5.5	6.3	5.7	5.6	4.5	6.5	1.0	1.5	1.5
	4	6.9	5.9	6.6	6.0	6.2	4.8	4.7	3.5	3.0	3.1
	5	4.5	4.0	4.5	4.9	4.2	5.1	3.0	3.0	3.5	3.0
	6	4.7	4.0	2.0	1.5	1.9	2.5	3.5	1.0	2.0	2.1
	7	4.2	4.8	7.5	3.5	4.1	7.3	4.3	3.0	2.5	3.0
	8	5.8	5.7	4.0	6.1	5.6	5.7	6.6	5.4	4.7	4.5
	9	6.1	7.9	7.3	5.7	6.2	5.0	5.5	7.5	5.0	6.0
	10	8.5	6.4	6.6	4.0	5.1	8.6	4.9	3.5	3.0	3.7
	R_i	79.5	75.0	71.5	60.0	62.5	62.5	56.0	31.5	21.5	29.5

$(\Sigma R_i)^2/10$ = 30,195

ΣR_i^2 = 33,931

$ba(a+1)/12$ = 91.7

$\Sigma T/(a-1)$ = 0.833

X_{calc} = 41.11

X_{tab} = 16.92

.˙. Reject H_o, the leaf growth rate is significantly different for at least one week at the 0.05 confidence level.

The standard error is $\sqrt{ba(a+1)/12}$ = 9.6

(continued on next page)

Appendix : 5C (cont).

		Week									
Tank	Plant	1	2	3	4	5	6	7	8	9	10
4	1	3.8	3.7	5.3	4.2	4.6	6.0	3.2	5.2	3.1	2.9
	2	5.5	5.3	3.2	3.0	3.5	6.9	2.1	5.2	1.5	1.6
	3	6.5	5.0	6.3	5.2	5.8	3.0	2.8	1.7	1.5	1.5
	4	7.8	5.7	6.0	6.5	6.3	2.2	2.5	1.5	2.5	1.3
	5	6.5	5.0	4.5	4.5	4.8	2.5	3.0	3.0	2.0	1.5
	6	6.0	8.0	6.8	5.2	5.5	4.0	1.8	1.2	1.5	1.5
	7	6.0	4.0	5.3	5.7	5.6	3.5	3.5	5.3	2.5	2.0
	8	5.2	5.0	5.5	5.7	5.9	4.5	4.0	3.2	2.8	2.0
	9	6.5	6.0	6.5	6.7	6.3	4.0	2.0	2.5	3.0	2.8
	R_i	77.5	60.0	68.5	66.5	69.0	49.5	31.5	37.0	21.5	14.0

$(\Sigma R_i)^2/10 = 24,502.5$

$\Sigma R_i^2 = 28,951.5$

$ba(a+1)/12 = 82.5$

$\Sigma T/(a-1) = 0.444$

$X_{calc} = 54.22$

$X_{tab} = 16.92$

.˙. Reject H_o, the leaf growth rate is significantly different for at least one week at the 0.05 confidence level.

The standard error is $\sqrt{ba(a+1)/12} = 9.1$

		Week									
Tank	Plant	1	2	3	4	5	6	7	8	9	10
5	1	7.0	6.3	6.5	5.9	6.4	6.5	4.5	0.6	0.2	0
	2	7.6	5.9	6.3	7.2	6.9	7.4	3.9	2.0	0.5	0.1
	3	5.8	5.8	6.0	3.9	5.7	4.3	1.2	0.5	0	0
	4	7.2	7.8	6.5	6.1	6.8	7.5	3.1	1.5	0.4	0.1
	5	7.1	6.9	7.8	6.1	6.8	7.5	3.1	1.5	0.4	0.1
	6	5.8	6.0	5.9	6.5	6.0	5.5	4.0	3.6	0.2	0
	7	5.8	6.2	6.5	5.2	5.5	5.0	2.0	2.0	0	0
	8	6.0	7.2	6.5	7.8	7.6	6.1	3.9	1.0	1.5	0
	R_i	63.5	62.0	64.5	54.0	58.5	57.5	31.5	23.5	16.0	9.0

$(\Sigma R_i)^2/10 = 19,360$

$\Sigma R_i^2 = 23,562.5$

$ba(a+1)/12 = 73.3'$

$\Sigma T/(a-1) = 0.3'$

$X_{calc} = 57.6$

$X_{tab} = 14.1$

.˙. Reject H_o, the leaf growth rate is significantly different for at least one week at the 0.05 confidence level.

The standard error is $\sqrt{ba(a+1)/12} = 8.6$

Appendix 6 : Leaf Growth Rate and the Effect of Salinity and Temperature.

Analysis of variance has been performed on weekly leaf growth data (summed for each shoot), in a similar manner as has been outlined in Appendix 5C. Growth was measured weekly over a four week period. For conditions in each treatment see page 54 of text. H_0 : that growth is not significantly different in any one week.

SALINITY EXPERIMENT

		Plant												
Control Tank	Week	1	2	3	4	5	6	7	8	9	10	11	12	13
	1	dead	3.5	6.1	3.5	2.1	2.7	3.5	1.8	3.5	4.5	5.7	4.1	5.2
	2	"	5.3	9.8	3.5	8.3	5.5	8.3	5.4	5.3	5.7	3.5	5.7	1.2
	3	"	4.8	8.1	3.2	6.0	5.5	7.6	4.6	3.5	3.8	4.0	2.0	1.5
	4	"	3.2	10	4.0	4.2	2.8	4.0	5.0	4.0	7.0	4.5	4.5	4.5

$(\Sigma R_i)^2/4$: 3721
ΣR_i^2 : 3822
$ba(a+1)/12$: 21.6'
$\Sigma T/(a-1)$: 0.5

X_{calc} = 5.00
X_{tab} = 21.0

∴ Accept H_0, the leaf growth does not significantly vary between weekly measurements at the 0.05 confidence level.

		Plant												
Tank	Week	1	2	3	4	5	6	7	8	9	10	11	12	13
A														
	1	3.5	2.3	3.5	4.7	2.3	3.5	4.1	5.3	1.2	2.9	3.5	2.3	2.3
	2	2.5	3.1	2.6	4.4	4.6	3.7	dead	6.0	3.5	3.1	3.5	4.0	2.2
	3	3.0	2.5	2.8	5.0	4.6	3.5	"	5.0	3.2	2.0	3.6	3.0	1.0
	4	4.0	4.0	1.0	2.0	3.0	2.0	"	6.5	1.5	1.0	4.0	2.0	1.5

$(\Sigma R_i)^2/4$ = 3660.25
ΣR_i^2 = 3679
$ba(a+1)/12$ = 20
$\Sigma T/(a-1)$ = 0.5

X_{calc} = 1.0
X_{tab} = 21.0

∴ Accept H_0, the leaf growth is not significantly different between weekly measurements (0.05 confidence level)

		Plant										
Tank	Week	1	2	3	4	5	6	7	8	9	10	11
B												
	1	3.5	dead		4.7	3.8	3.5	7.3	2.3	2.8	4.7	1.8
	2	5.0	"		9.1	6.6	4.8	6.7	7.0	4.6	3.9	6.1
	3	4.0	"		3.0	6.8	1.5	5.0	6.5	5.0	4.0	5.0
	4	3.0	"		4.0	5.0	6.0	5.5	5.0	4.0	4.0	4.5

$(\Sigma R_i)^2/4$ = 1980.25
ΣR_i^2 = 2089.5
$ba(a+1)/12$= 16.6'
$\Sigma T/(a-1)$ = 0.16'

X_{calc} = 6.61
X_{tab} =18.3

∴ Accept H_0, the leaf growth is not significantly different between weekly measurements (0.05 confidence level)

Appendix 6 (cont)

Tank	Week	Plant 1	2	3	4	5	6	7	8	9	10	11	12
C	1	2.3	4.3	4.7	2.3	10	3.8	2.9	3.5	5.9	all	dead	
	2	6.1	3.5	9.2	5.7	9.8	5.3	5.3	5.3	5.0		"	
	3	5.5	4.2	3.0	3.0	8.0	6.0	4.0	4.0	3.0		"	
	4	4.8	3.1	6.0	1.5	8.5	5.1	3.0	6.0	3.5		"	

$(\Sigma R_i)^2/4 = 2025$

$\Sigma R_i^2 = 2102$

$ab(a+1)/12 = 15$

$\Sigma T/(a-1) = 0$

$X_{calc} = 5.13$

$X_{tab} = 15.5$

.˙. Accept H_o, the leaf growth is not significantly different between weekly measurements (0.05 confidence level).

Tank	Week	Plant 1	2	3	4	5	6	7	8	9	10	11
D	1	2.9	3.3	7.0	2.3	dead	5.3	6.9	4.1	3.5	4.1	6.0
	2	3.0	4.0	6.5	3.0	"	10.7	3.9	5.3	3.8	6.6	5.5
	3	all	shoots	dead		"	5.0	4.0	5.0	3.4	5.0	6.0
	4			"		"	4.0	5.0	6.1	3.5	4.5	4.5

$(\Sigma R_i)^2/4 = 900$

$\Sigma R_i^2 = 913.5$

$ba(a+1)/12 = 10$

$\Sigma T/(a-1) = 0.3'$

$X_{calc} = 1.40$

$X_{tab} = 11.1$

.˙. Accept H_o, the leaf growth is not significantly different between weekly measurements (0.05 confidence level).

SUMMARY OF SALINITY EXPERIMENT :

i. Of the plants (shoots) that survived the full four week period there is no significant difference in leaf growth rates, at the 0.05 confidence level.

ii. There is quite a high mortality of shoots after the 3 hr treatment with freshwater, and after the 1 hr treatment with freshwater (Tanks D and C respectively).

(Appendix 6, continued
on next page)

Appendix 6 cont.

TEMPERATURE EXPERIMENT

The results for only one control are shown. The second control showed similar results and H_o was also accepted.

		Plant										
Tank	Week	1	2	3	4	5	6	7	8	9	10	11
Control (20°C)	1	4.8	5.7	4.5	3.8	4.0	2.5	5.0	7.8	6.2	6.0	6.1
	2	3.0	5.5	4.0	4.0	2.5	5.5	4.5	5.0	6.0	4.5	5.1
	3	3.2	5.5	4.1	4.5	3.0	1.5	3.0	4.8	6.3	5.0	5.5
	4	5.0	4.5	5.0	3.6	3.5	1.5	4.2	6.0	5.0	6.5	5.8

$(\Sigma R_i)^2/4 = 3025$

$\Sigma R_i^2 = 3184.5$

$ba(a+1)/12 = 18.3'$

$\Sigma T/(a-1) = 0.3'$

$X_{calc} = 8.8$

$X_{tab} = 18.3$

.˙. Accept H_o, the leaf growth is not significantly different between weekly measurements (0.05 confidence levels)

		Plant									
Tank	Week	1	2	3	4	5	6	7	8	9	10
25°C	1	6.5	7.7	6.5	7.5	7.5	8.0	6.0	6.5	3.5	7.2
	2	4.2	5.5	7.5	5.5	4.5	5.0	5.0	7.5	5.8	3.5
	3	4.9	5.0	6.5	7.6	6.1	5.0	5.2	8.0	2.5	6.5
	4	5.0	4.5	6.8	6.4	4.8	6.0	5.5	6.1	6.2	4.5

$(\Sigma R_i)^2/4 = 2500$

$\Sigma R_i^2 = 2588.5$

$ba(a+1)/12 = 16.6'$

$\Sigma T/(a-1) = 0.16'$

$X_{calc} = 5.36$

$X_{tab} = 16.90$

.˙. Accept H_o, the leaf growth is not significantly different between weekly measurements (0.05 confidence level)

		Plant												
Tank	Week	1	2	3	4	5	6	7	8	9	10	11	12	13
30°C	1	2.0	2.5	3.5	2.0	4.0	3.5	2.0	4.5	5.5	2.5	2.0	1.0	3.5
	2	0	0	0	0	0	0	0	0	0	0	0	0	0

Shoots all dead after two weeks at this temperature.

SUMMARY OF TEMPERATURE EXPERIMENT :

i. Plants grown at 20°C and 25°C showed no significant changes in the growth rate over four weeks.

ii. Plants grown at 30°C were all dead after two weeks.

Appendix 7 : The Effect of Storms on Biomass.

Measurements are of leaf biomass expressed as grams dry weight per square metre.

	BONNA POINT	QUIBRAY BAY
April (1977)	284	136
	240	145
	291	84
	303	151
	336	106
	260	120
MEANS	286	124
May (1977)	192	122
	186	159
	198	120
	181	158
	179	104
	199	101
MEANS	189	127
March (1978)	262	122
	270	128
	182	132
	167	170
	204	150
	221	80
MEANS	218	130
April (1978)	75	95
	82	121
	52	115
	66	122
	42	142
	65	158
MEANS	64	126

Appendix 8 : Decomposition of Leaves at Bonna Point and Quibray Bay

Measurements are expressed as grams dry weight of the decomposing leaf sections cut to a standard size (see method) with a template.

QUIBRAY BAY RESULTS

	START	10 DAYS	15 DAYS	34 DAYS	50 DAYS
	0.0750	0.0630	0.0762	0.0680	0.0468
	0.0825	0.0693	0.0761	0.0658	0.0472
	0.0708	0.0713	0.0752	0.0614	0.0484
	0.0859	0.0540	0.0640	0.0671	0.0597
	0.0770	0.0623	0.0800	0.0670	0.0553
	0.0875	0.0720	0.0652	0.0646	0.0526
	0.0890	0.0646	0.0703	0.0606	0.0552
	0.0761	0.0700	0.0724	0.0661	0.0546
	0.0783	0.0800	0.0684	0.0731	0.0512
	0.0949	0.0640	0.0650	0.0646	0.0568
	0.0828	0.0698	0.0734	0.0621	0.0382
	0.0875	0.0793	0.0664	0.0563	0.0561
	0.0710	0.0919	0.0674	0.0583	0.0498
	0.0750	0.0777	0.0636	0.0654	0.0572
	0.0761	0.0799	0.0775	0.0584	0.0591
	0.0718	0.0709	0.0746	0.0628	0.0476
	0.0829	0.0748	0.0685	0.0545	0.0462
	0.0723	0.0778	0.0731	0.0723	0.0363
	0.0844	0.0754	0.0664	0.0540	0.0591
	0.0842	0.0704	0.0775	0.0579	0.0582
	0.0718	0.0716	0.0698	0.0641	0.0476
	0.0911	0.0826	0.0636	0.0628	0.0468
	0.0911	0.0797	0.0685	0.0608	0.0389
	0.0788	0.0699	0.0721	0.0571	0.0521
	0.0889	0.0799	0.0771	0.0507	0.0512
	0.0773	0.0714	0.0593	0.0662	0.0362
	0.0750	0.0643	0.0680	0.0535	0.0439
	0.0666	0.0646	0.0640	0.0677	0.0512
	0.0814	0.0703	0.0787	0.0542	0.0502
	0.0870	0.0828	0.0687	0.0607	0.0475
MEAN:	0.0805	0.0725	0.0704	0.0619	0.0500
s.d.:	0.0073	0.0078	0.0054	0.0056	0.0067
%	100	90.1	87.5	76.9	62.1

BONNA POINT RESULTS

START : as above

50 DAYS :

0.0981	0.0658	0.0895	0.1005	0.0894
0.0723	0.1007	0.0734	0.0563	0.0653
0.0870	0.0798	0.1014	0.0746	0.1015
0.0523	0.0399	0.0653	0.0892	0.0893
0.0647	0.0754	0.0982	0.0634	0.0561
0.0745	0.0976	0.0467	0.0874	0.0398

MEAN : 0.0739

s.d. : 0.0225

Appendix 9 : Data Collected from Port Hacking and Spencers Gulf.

Units are : biomass grams per square metre.
production " " " " per day.

	PORT HACKING	SPENCERS GULF
leaf biomass (winter)	201	351
	215	443
	162	509
	164	396
	158	484
	242	478
MEAN (s.d.)	190 (35)	444 (60)
leaf biomass (summer)	210	610
	194	582
	252	495
	164	682
	172	636
	197	689
MEAN (s.d.)	198 (31)	616
total biomass (winter)	1008	2812
	1052	2410
	848	3050
	950	2216
	862	2098
	853	2156
MEAN (s.d.)	929 (88)	2457 (389)
leaf prodn (winter)	1.2	2.7
leaf prodn (summer)	3.6	5.5

Appendix 10 : Compilation of S.P.C.C. Data, and calculation of 'Compensation Depth'

The following abbreviations are used :

%T : percentage transmission at 0.5 metres depth
Z_{sd}: Sechii Disc Depth
Z_{ez}: Depth to which 10% of surface radiation (PAR) reaches

The following relationships are taken from the State Pollution Control Commission Report entitled 'Turbidity of Botany Bay', which was to be released in early 1980,

$$\%T = 37.8 + 22.8 \log_e Z_{sd}$$

$$Z_{sd} = \frac{Z_{ez} - 0.09}{1.29}$$

from which can be calculated :

$$\begin{aligned} \%T &= 37.8 + 22.8 \log_e(Z_{ez} - 0.09) - 22.8 \log_e 1.29 \\ &= 32 + 22.8 \log_e(Z_{ez} - 0.09) \end{aligned}$$

or,

$$\log_e(Z_{ez} - 0.09) = \frac{\%T - 32}{22.8}$$

The report also contains values for the mean turbidities of both Silver Beach and Towra Point waters, in Botany Bay. These values are expressed in %T, and are 74% and 57% respectively. We wish to know the Z_{ez} corresponding to these mean turbidity figures :

For Silver Beach, %T = 74

$$\therefore \log_e(Z_{ez} - 0.09) = \frac{74 - 32}{22.8} = 1.8421052$$

$$\therefore \quad Z_{ez} \doteqdot 6.4 \text{ metres.}$$

For Towra Point, %T = 57

$$\therefore \log_e(Z_{ez} - 0.09) = \frac{57 - 32}{22.8} = 0.9649123$$

$$\therefore \quad Z_{ez} \doteqdot 3.1 \text{ metres.}$$

Z_{ez} has been used in the General Discussion as an estimate of the 'compensation depth' of *Posidonia australis* but is likely to be an overestimate of the depth to which this seagrass can survive since the calculation is based on light flux available on a summer's day (see page 98-99).