

**An examination of seagrass monitoring protocols
as applied to two New South Wales
estuarine settings**

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STATEMENT OF ORIGINALITY

This thesis contains no material published elsewhere or extracted in whole or in part from a thesis by which I have qualified for or been awarded another degree or diploma. No other person's work has been used without due acknowledgement in the main text of the thesis. This thesis has not been submitted for the award of any degree or diploma in any other tertiary institution. All research procedures reported in the thesis received the approval of the relevant Ethics/Safety Committees (where required).

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ABSTRACT

Many recent studies have sought to monitor health characteristics of seagrasses, including changes in aerial extent, biomass and fish community structure. While these studies have provided important information on the ecology of seagrass communities on southeast Australia, little attempt has been made to subject these sampling procedures to rigorous experimental testing and review. This study employed commonly-used standard methods for sampling seagrass community characteristics in two sites in New South Wales. Where possible, sampling protocols were tested for accuracy and efficiency at a range of temporal and spatial scales.

The ARCVIEW Geographic Information System was used to construct vegetation polygons of seagrass distribution on the Tweed River, and in the Ukerebagh Channel annually over a 5-year period. For one year (2000), distributions from identical photographs were mapped twice to identify procedural errors. In general, errors relating to incorrect boundary identification were low compared to inter-annual variability. Inter-annual variability in seagrass beds was higher than for adjacent mangrove and saltmarsh.

Estimates of biomass were derived from standard replicate 0.25m x 0.25m quadrats. The experiment contrasted two sites of similar geomorphic setting. Ukerebagh Channel on the Tweed River, and Woolooware Bay with Botany Bay are both shallow, sandy marine deltaic settings supporting stands of *Zostera capricorni*. Significant differences were found in the degree of replication required to identify significant changes in seagrass biomass at the two sites. Ukerebagh Channel supported relatively dense stands of *Z. capricorni* with low intra-site variability. Here 8 replicates were sufficient to detect 10 percent change. Towra Point presented a contrast, in which 15 replicates were required to detect a similar level of change. Woolooware Bay at Towra Point has suffered from increased sedimentation relating to alterations in current velocities at Towra Point, and the result highlights the greater degree of replication required to determine significance changes in disturbed systems.

The fish populations in the seagrass at Towra Point were sampled using buoyant pop nets. Fish communities differed significantly from those sampled in adjacent mangrove and saltmarsh. Differences in fish assemblages between spring high tides, neap high tides and low tides are attributed to movements of fish between seagrass and adjacent mangrove and saltmarsh. This mosaic of habitats is utilized by a number of species over a tidal cycle, with seagrass providing an important low-tide refuge for many species utilizing mangrove and saltmarsh at high tide. Limitations in the efficiency of buoyant pop nets were exposed in a novel experiment which demonstrated differences in escape rates between species. Flat-tailed mullet (*Liza argenta*) are likely to be under-represented in experiments using this technique.

Recommendations are made regarding optimal sampling protocols for monitoring seagrass in the region. All techniques tested are suitable, though some require modification. Some texts have under-estimated the degree of replication required to appropriately monitor changes in seagrass biomass in disturbed systems, where density is lower and intra-site variability higher. The buoyant pop-nets may require modification in open-water seagrass situations where escape by *Liza argenta* and *Acanthopagrus australis* were at unacceptable levels.

CONTENTS

Abstract.....	iii
List of Figures.....	vii
List of Tables.....	ix
Chapter One: Introduction and literature review.....	1
1.1 Introduction.....	1
1.2 Seagrass species in Australia.....	3
1.3 Seagrasses in southeast Australia.....	4
1.4 Threat / losses of seagrass.....	6
1.5 Monitoring of seagrass.....	7
1.6 Examination of fish utilizing seagrass habitat.....	8
1.7 Aims and structure of the thesis.....	9
Chapter Two: Seagrass mapping.....	12
2.1 Introduction.....	12
2.2 Site selection.....	13
2.3 Method.....	13
2.4 Results.....	16
2.5 Discussion.....	25
Chapter Three: Sampling biomass.....	27
3.1 Introduction.....	27
3.2 Study sites.....	29
3.3 Sampling methods.....	29
3.4 Results.....	31
3.5 Discussion.....	36

Chapter Four: Sampling nekton in seagrass.....	38
4.1 Introduction.....	38
4.2 Study site and methods.....	40
4.2.1 Study location.....	40
4.2.2 Fish collection.....	41
4.2.3 Statistical methods.....	41
4.3 Results.....	42
4.3.1 Seasonal variability in fish and crustaceans abundance.....	42
4.3.2 Fish abundance and species richness.....	45
4.3.3 Results from efficiency experiment.....	48
4.3.4 Fish assemblages among the habitats.....	48
4.4 Discussion.....	49
Chapter Five: Discussion and Recommendations.....	52
5.1 Important results.....	52
5.2 Recommendations regarding sampling.....	55
5.3 Recommendations for future research.....	56
REFERENCES.....	57

LIST OF FIGURES

Figure 1.1 Seagrasses in Australia: indicative distribution and sites of disturbance in continental Australia	4
Figure 1.2 Location of Towra Point and Tweed River within New South Wales	10
Figure 2.1 Distribution of seagrass and other intertidal wetlands in the lower Tweed River in 2000	17
Figure 2.2 Distribution of seagrass and other intertidal wetlands in the lower Tweed River in 2002	17
Figure 2.3 Seagrass extent in Ukerebagh Channel 1997	19
Figure 2.4 Seagrass extent in Ukerebagh Channel 1998	20
Figure 2.5 Seagrass extent in Ukerebagh Channel 1999	21
Figure 2.6 Seagrass extent in Ukerebagh Channel 2000(a)	22
Figure 2.7 Seagrass extent in Ukerebagh Channel 2000(b)	23
Figure 2.8 Seagrass extent in Ukerebagh Channel 2001	24
Figure 3.1 Systematic representation of biomass sampling strategy at Woolooware Bay and Ukerebagh Channel	30
Figure 3.2 Mean dry weight (+SE) of seagrass in Woowooware Bay at Towra Point in different seasons, 2002-2003	32

Figure 3.3 Mean dry weight (+SE) of seagrass in Tweed Head in different seasons, 2002-2003	33
Figure 3.4 Power analysis showing the change detectable with increasing plot replication at Woollooware Bay	35
Figure 3.5 Power analysis showing the change detectable with increasing plot replication at Ukerebagh Channel	35
Figure 4.1 Configuration and operation of the buoyant pop net	39
Figure 4.2 Location of pop nets within Woollooware Bay, Towra Point	40
Figure 4.3 Mean abundance (+SE) of fish in seagrass bed at Woollooware Bay in different seasons using pop nets	46
Figure 4.4 nMDS ordinations showing assemblages of fish in high and neap tide at Woollooware Bay using pop nets	47
Figure 4.5 nMDS ordinations showing assemblages of fish in seagrass, saltmarsh and mangrove at Woollooware Bay using pop nets	49

LIST OF TABLES

Table 1.1 Distribution of seagrass species in south-eastern Australia (Tweed River to Corner Inlet)	5
Table 2.1 Observable characteristics of seagrass species in estuaries of NSW	14
Table 2.2 Aerial photographs used to map the distribution of seagrass species in Ukerebagh Channel, Tweed River	15
Table 2.3 Area of seagrass vegetation in Ukerebagh Channel, Tweed River	18
Table 2.4 Seagrass cover in percentage (increase or decrease) in Ukerebagh Channel	18
Table 3.1 Size of the quadrat used by a number of authors for collecting sample	28
Table 3.2 ANOVA results for above ground biomass among the seasons in Woollooware Bay,NSW	32
Table 3.3 ANOVA results for above ground biomass between the seasons in Ukerebagh Channel, Tweed River, NSW	33
Table 3.4 Two way ANOVA results for biomass between season and sites (Woollooware Bay & Ukerebagh Channel, Tweed Head) NSW	34

Table 4.1 Species caught from seagrass meadow with pop nets at Woolaware Bay, Towra Point	44
Table 4.2 ANOVA results for fish abundance in spring high tide between seasons in seagrass using pop nets at Woolooware Bay, NSW	45
Table 4.3 ANOVA results for fish abundance in neap tide between seasons in seagrass using pop nets at Woolooware Bay, NSW	45
Table 4.4 Two way analysis results for fish abundance between season and tides at Woolooware Bay, NSW	46
Table 4.5 Contribution of species of dissimilarity between spring and neap high tide fish assemblages in the seagrass meadow of Woolooware Bay	47
Table 4.6 Released and retrived fish population from two buoyant pop nets as a test of net efficiency	48

Chapter One: introduction and literature review

1.1 Introduction

Seagrass communities are a key component of coastal ecosystems through the world (Kikuchi, 1980; Larkum, 1976; West, 1983; Robblee and Zieman, 1984; Walker, 1989; Hutomo and Peristiwady, 1996). Aside from their intrinsic value, they provide food, habitat and shelter for many commercially important species of fish and crustaceans (Poiner *et al.* 1989; Gray *et al.* 1996). For example, in Botany Bay the juvenile fish take shelter in *Zostera capricorni* beds but soon migrate to *Posidonia australis* beds, where the longer leaved meadows and associated epiphytes are considered to provide more food (Middleton *et al.* 1984). Rotherham (1999) found a similar situation occurred in *Z. capricorni* and *P. australis* beds in Port Hacking and St. Georges Basin. Two fish species, luderick (*Girella tricuspidata*) and tarwhine (*Rhabdosargus sarba*), appeared to move to *P. australis* after spending initial stages in *Z. capricorni* meadows.

Seagrasses contribute to detrital food chains by their high rates of primary production (King, 1981). For example, annual primary production of *P. australis* leaf material in Botany Bay was 0.3–2 tonnes/ha/year (West and Larkum, 1979) and in Port Hacking was 2.4 tons/ha/year (Kirkman and Reid, 1979). Seagrasses stabilise sediment, and contribute to the quality of marine and estuarine waters (Gambi *et al.* 1990). The plants filter nutrients and contaminants from the water, act as dampeners to wave action (Short and Coles, 2001).

Seagrasses are aquatic flowering plants and are generally found in soft sediments. In NSW it has been noted that *P. australis* generally occurs on sandy substratum, whereas *Zostera* species grows on a range of substrates (Harris *et al.* 1979; West and Larkum 1983). Seagrasses grow below the high tide level in the sheltered shallow waters of estuaries. They need light to grow and are usually restricted to the upper two meters of water where there is sufficient light (NSW Fisheries, 2004). Minimum light requirements for seagrasses appear to be higher than terrestrial plants (Abal *et al.* 1994). The same

species of seagrass can often be found distributed at different depths in different estuaries, in response to variations in turbidity of the waters. For example, Larkum (1976) observed that the lower limit for *P. australis* at Towra Point, Botany Bay was 3m below mean low water, whereas at Greenpatch, Jervis Bay, the lower limit was 9m. *Zostera* spp. are able to survive at much greater depths in clear waters than they are in highly turbid waters, with depth limits ranging from 2m to 30m (Kennish, 1986).

Seagrasses are composed of a set of vegetative modules: a piece of rhizome, which can be either horizontal or vertical; a bundle of leaves attached to the rhizome; and a root system. The leaves are either strap-like or paired ovals. The leaves of *Zostera* spp. are linear like and 1-5 mm wide and up to 500 mm long. *Posidonia* spp. have strap-like leaves 6-14 mm wide and 300-600 mm long. The leaves of *Halophila* spp. are paired and oval shaped, 5-20 mm wide and 10-50 mm long. The rhizome diameter of *Zostera* species varies from 1.6 – 3.5 mm, *Posidonia* species 5.5 – 9.7 mm and the *Halophila* species are 0.8 – 1.3 mm (Marba and Duarte, 1998). Seagrasses can reproduce both sexually and asexually, and thus possess two mechanisms by which they can recover from damage (Grey and Moffler, 1978).

In *Zostera* alternate male and female flowers are held in a spathe sheath on up-right reproductive stems produced between spring and late summer. *Zostera* is found growing under a variety of conditions, and exhibits a plasticity in leaf shape to suit. For example, in inter-tidal situations leaves may be as little as 20 mm long and 1 mm wide, whereas when growing in channels with strong currents the leaves attain lengths of more than 500 mm and width of 5 mm. *Zostera* is found in marine tidal waters and brackish non-tidal waters on sandy, muddy and more rarely gravelly sediments. In oceanic waters, on sand or sand-mud, it is often found at the inter-tidal and sub-tidal extremities of the *Posidonia australis* meadows (West, 1983). *Zostera capricorni* is common in New South Wales water, *Zostera muelleri* is thought to occur in infrequently opened lagoons and at some marine locations, south of Sussex inlet.

1.2 Seagrass species in Australia

Australia has a unique and rich seagrass flora with more than half of the world's species (Hartog, 1970). Seagrasses are a prominent feature of tropical and temperate coastlines of Australia. Australia's 32,000 km coastline contains the largest and most diverse seagrass assemblages in the world (Walker *et al.* 1999). There are 22 species in temperate waters and 15 in tropical waters in Australia. The highest species diversity occurs in Western Australia (CSIRO, 1997).

Globally, there are 58 recognised species of seagrasses (Kuo and McComb, 1989). Most countries have between two to six species. More than half of the world species of seagrasses grow in Australian tropical and temperate waters. Australia is therefore unique in having the largest and most diverse mix of seagrass species in the world (Larkum *et al.* 1989). There are eight species of seagrasses in NSW including *Posidonia australis*, three species of *Zostera* and three species of *Halophila* which are difficult to differentiate (Robertson, 1984). There are a number of species of *Ruppia* in NSW although *Ruppia megacarpa* is considered to be dominant (Robertson, 1984).

Distribution of seagrasses is influenced by a number of environmental factors, many of which are a function of the location within the estuary and the type of estuarine system. Each species of seagrass is distributed according to the interaction of light and temperature, sediment and nutrients, salinity, wave and current action (Day *et al.* 1989). The distribution of seagrasses in Australia is shown in Figure 1.1.

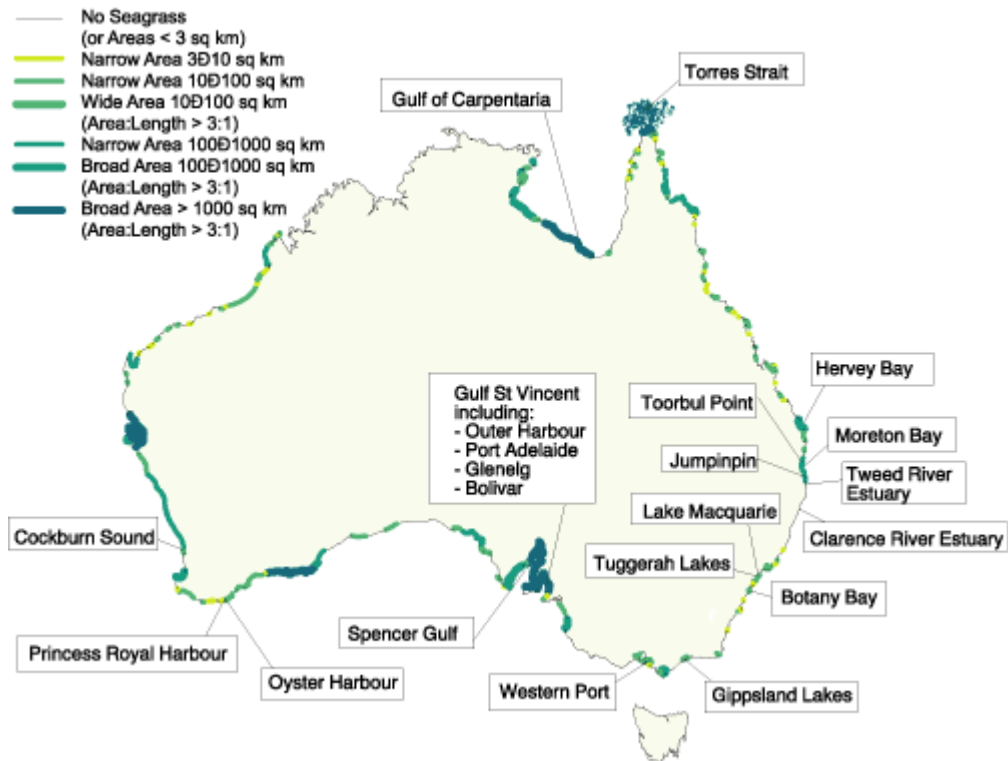


Figure 1.1: Seagrasses in Australia: indicative distribution and sites of disturbance in continental Australia. Source: Environment Australia , 2000 and Kirkman, 1997.

1.3 Seagrasses in Southeast Australia

West *et al.* (1985) mapped the distribution of seagrasses, mangroves and saltmarshes in NSW estuaries from aerial photos taken between 1977 to 1984, and reported 155 km² of seagrass in 111 estuaries. The largest single area of seagrass in NSW was found in Wallis lake, which at that time contained 21% of the state's total seagrass. While no more recent estimates on a state-wide basis exist, there have since been some significant changes (decrease or increase) in the estuaries of NSW (Poiner & Peterken, 1995; NSW Fisheries, 1999; Meehan, 1997 and Williams and Meehan 2001). The distribution of seagrasses in southeast Australian seagrasses is given in Table 1.1.

Table 1.1. Distribution of seagrass species in southeastern Australia (Tweed River to Corner Inlet) after West *et al.* (1989).

Genus	Species	Distribution in S. E. Australia
<i>Zostera</i>	<i>capricorni</i> Aschers	Whole coast
<i>Zostera</i>	<i>mulleri</i> Irmisch & Aschers	Jervis Bay and southward
<i>Heterozostera</i>	<i>tasmanica</i>	Port Stephens and southwards
<i>Halophila</i>	<i>decipiens</i> Ostenfeld	Whole coast
<i>Halophila</i>	<i>ovalis</i> (R.Br.) Hook.f.	Whole coast
<i>Halophila</i>	<i>australis</i> Doty & Stone	Central coast and southwards
<i>Posidonia</i>	<i>australis</i> Hook.f.	Wallis Lake and southwards
<i>Ruppia</i>	<i>megacarpa</i>	Whole coast

Source: Watford and Williams, 1998

Along the New South Wales coast seagrasses are confined to estuaries such as Botany Bay, except for the large sheltered embayment of Jervis Bay (CSIRO, 1997). The majority of the coastal features where seagrass grows in New South Wales are estuarine. *Zostera* spp. occur in 93% of estuaries, *Halophila* spp. in 66% and *P. australias* in 43% (West, 1983). There are also several open bays in New South Wales containing seagrasses. Bays which experience high wave energy are unlikely to support *P. australis*, eg. Batemans Bay (West *et al.* 1989).

Botany Bay is a shallow, marine dominated open embayment, located 12 km south of Sydney, NSW. It was reported (West *et al.* 1985) as having 340 ha of seagrass, the eighth largest seagrass area in New South Wales. Principal seagrass species are *P. australis* and *Z. capricorni* with smaller beds of *H. ovalis* and *H. decipiens* (Larkum, 1976).

1.4 Threat / losses of seagrass

Seagrasses can be easily destroyed. Once seagrass meadows are damaged, their recolonisation can be very slow. The leaves of the seagrass grow quickly, the rhizome grows relatively slowly. The ability to recover after disturbance varies between seagrass species. In NSW, observations over many years have indicated that *Halophila* spp. are relatively quick to respond to change and may recover from damage within months, while *Zostera* spp. take several years to recolonise denuded areas (West and Larkum, 1983; Larkum and West, 1990 and West, 1990). Larkum (1976) cleared seagrass from small plots (4m²) in Botany Bay and assessed regrowth, three years no regrowth was observed and movement of rhizomes into the denuded areas was negligible. Meehan (2002) estimated the rate of recolonisation of *P. australis* within blast holes in Jervis Bay, the lateral rate of recovery was estimated at 250 mm per year, and complete recovery may take nearly a century.

There has been a noticeable decline in the extent of some inshore habitats, particularly seagrasses in NSW. It was that at least 50% of NSW's seagrasses has been lost between the 1980s and 1990s (Poiner and Peterken, 1995). The condition of seagrasses in NSW is highly variable, but in general seagrass beds near urban or industrial area are often degraded, while more isolated seagrass areas are in good health (NSW Fisheries, 1999b). Overall, NSW has lost an estimated 50% of the *Zostera* sp. seagrass in its estuaries since European settlement (Zann, 1995). This loss has occurred through both natural events (eg. cyclones, floods) and anthropogenic events (eg. nutrient enrichment, coastal development etc).

Activities that threaten seagrass habitat include change to drainage, land management practices which lead to sedimentation, direct removal of seagrasses by dredging, boating, fishing or sand mining, nutrient run off from agricultural land and aquaculture, point source discharge from industry and storm water drains, introduced pests and diseases (Butler and Jernakoff, 1999). Contamination by herbicides, petrochemicals and heavy metals from catchment run-off has been linked with massive die-back of seagrasses in many areas. Changes to hydrology for harbour and coast line development have also

contributed to a decline in seagrass beds around the major population centres (SoEAC 1996). Sand deposition and cropping were thought to be the cause of the loss of *Z. capricorni* meadows in Moreton Bay, Australia (Kirkman, 1978).

Seagrasses are also susceptible to the effects of natural climatic events such as cyclones, flood and storms. Preen *et al.* (1995) reported that flood and cyclone related loss of more than 1000 km² of seagrass from Hervey Bay, Queensland. They found that seagrass loss in shallow water (<10m) could be attributed to uprooting during heavy seas; however seagrass loss in deeper water was probably due to a persistent plume of turbid water resulting from flooding or developed catchments. In Botany Bay mapping from aerial photographs taken between 1942 and 1986 showed that more than half (about 57%) of the seagrass was lost (Larkum and West 1990). Seagrasses in the Gulf of Carpentaria sustained considerable damage due to the passage of Cyclone Sandy in 1985. The cyclone removed, undermined or smothered 70% (128 km²) of seagrasses in the area and scouring and smothering eventually destroyed the remainder of the bed. Overall this represented a 20% loss of the seagrasses in the Gulf (Poiner *et al.* 1989). In another example, Seddon *et al.* (2000) reported a loss of 12,717 ha of intertidal and shallow subtidal *Amphibolis antarctica* and *Zostera* spp. in northern Spencer Gulf, South Australia. Increased turbidity brought by foreshore and catchment development appeared to reduce the depth limit of *P. australis* in Botany Bay (Larkum, 1976; Larkum and West 1990). Construction of airport runways and port facilities also caused the decline of seagrasses in this area.

1.5 Monitoring of seagrass

Seagrasses play an important role in estuarine ecosystems by stabilizing sediments and providing food and shelter to a wide variety of aquatic organisms. It is therefore important to monitor the changes of distribution and health of seagrasses so appropriate management strategies can be adopted. Monitoring is also important to ensure that any deterioration in seagrass health is quickly detected and to prevent large scale losses occurring. Monitoring can be carried out using remote sensing and on *in situ* techniques. Satellite imagery has until recently been provided at a scale which precluded the

detection of small scale changes in seagrass health. Aerial photographs cannot readily detect changes in density or biomass of seagrass. Aerial photograph also may be compromised by sun light, shading, cloud cover or wave action. Further, the process of on-screen digitizing can introduce a number of inconsistencies and errors which might contribute to variation in measures of seagrass area and distribution.

Monitoring the health of seagrass *in situ* usually requires describing changes in a specific seagrass community using one or more variables. The selection of a variable to monitor can be subjective (Wood and Lavery, 2000). The variables that have widely used to detect small scale changes include biomass, density and productivity (Kirkman, 1996). There is no standard set of protocols to monitor seagrass health using any of these variables, although there have been some attempts to evaluate various monitoring techniques (Mellors, 1991; Inglis and Smith, 1995). Many of the studies that have monitored seagrass health in southeast Australian estuaries have varied in terms of the type of variables measured, the number of samples, replication and the sampling interval (Larkum, 1976; West and Larkum, 1979; West, 1990; Wolterding, 2000).

1.6 Examination of fish utilizing seagrass habitat

Seagrass meadows have characteristics that make them a suitable habitat for many species of animals. The three-dimensional structure of the vegetation, with its network of roots and rhizomes and often dense leaf canopy, offers hiding places that protect against predation and also provides substrate for attachment (Hemminga and Duarte, 2000). The fish community of seagrass meadows is not fixed or constant for any particular species or combination of species. Juvenile species often dominate the fish communities of seagrass beds. In a study of the fish communities of estuarine seagrass beds in northern Queensland, 134 species were recorded (Coles *et al.* 1993). The average length of the individual species caught was only 32 mm because most of the fishes were juveniles, although some large adult fishes with length over 60 cm were also present (Coles *et al.* 1993). In the case of the seagrass meadows in Cairns Harbour, Queensland it was calculated that the potential annual yield of the three major commercial prawn species

from these meadows amounted to between 0.6 and 2.2 million Australian dollars per year (Watson *et al.* 1993).

Connolly (1994) compared fish catches from pop and seine nets in shallow eelgrass meadows to determine the relative catching efficiencies of the two methods. Buoyant pop nets usually consist of four mesh walls, quickly released and can be lifted clear of the water to collect ensnared fish. A total of 15 species were collected by Connolly (1994) and the number of fish caught in pop nets was greater than that of seine nets.

Measures of seagrass health or condition should consider not only the structural attributes of the seagrass (density, biomass, distribution) but also the habitat values of the seagrass. Buoyant pop-nets have been used by Connolly (1994) and Mazumder *et al.* (2004) to determine fish assemblages in shallow vegetated estuarine habitats. While these nets have provided insights into fish assemblages in these environments, the catch efficiency of the technique remains largely untested.

1.7 Aims and structure of the thesis

The thesis seeks to contribute to the development of accurate methods for determining and monitoring seagrass condition by testing the most commonly used methods of seagrass condition assessment.

Chapter 2 uses the ARCVIEW Geographic Information System to investigate the utility of on-screen digitizing of georectified air photographs as a means of accurately determining seagrass distributions. For this exercise, the Tweed estuary was used because of the clarity of the water and the extensive air photographic record. Maps were produced for the Ukerebagh Channel, one of the most important seagrass habitats on the Tweed. A variety of scales of temporal replication were considered to determine optimal mapping periods for change detection. Errors associated with on-screen digitizing were assessed by repeat mapping for the year 2000.

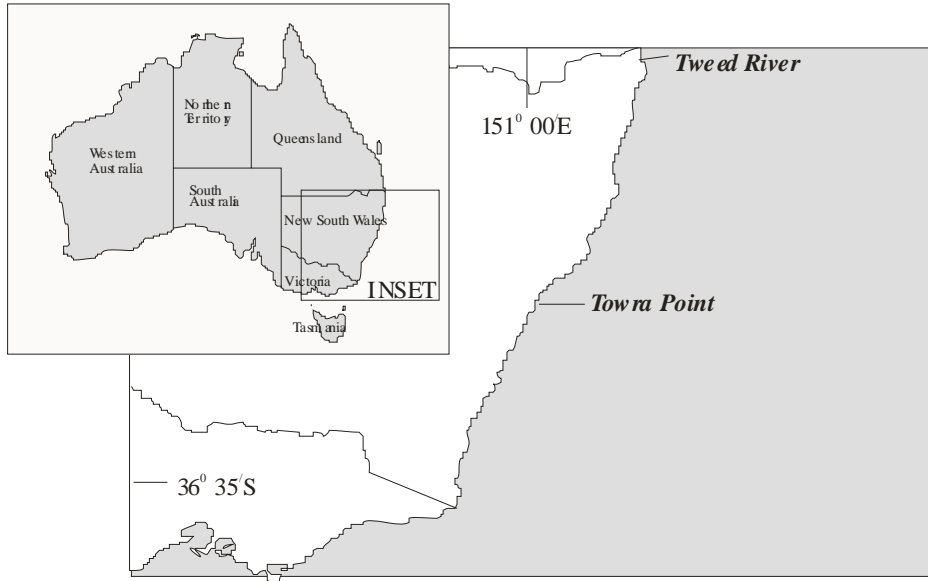


Figure 1.2: Location of Towra Point (Woolooware Bay) and Tweed River within New South Wales

Seagrass biomass is commonly estimated on the assumption that a design a 0.0625m^2 quadrats with 8 replicates in a $15\text{m} \times 20\text{m}$ plot will provide an accurate indication of biomass and that such a measure represents a useful as a benchmark against which change can be detected. This assumption was tested by applying this protocol seasonally over a period of 12 months in two estuarine setting. The two settings were geomorphologically similar. Both the Ukerebagh Channel on the Tweed River and the Woolooware Bay of Botany Bay being marine sand in a shallow estuarine deltaic settings (Fig. 1.2). However, the two settings differed in the degree of sediment stability and seagrass biomass, with the Woolooware Bay seagrass receiving sediment influx which created a patchy distribution. This afforded the opportunity to assess the sampling protocols in stable and disturbed settings. A power analysis was used to determine the degree of replication which would be required to detect appropriate levels of change in each context. The power analysis formed the content of Chapter 3.

Finally, it is important to assess the efficiency of methods used to sample fish assemblages in seagrass, because seagrass condition can also be assessed on the basis of functionality (e.g. fish habitat) rather than structure alone. Fish were sampled at Woollooware Bay using pop nets, monthly for a period of 12 months. The sampling strategy took into consideration linkages between seagrass and adjacent mangrove and saltmarsh habitat, by sampling at high and low tide, and in conjunction with a separate project assessing fish utilization of the adjacent mangrove and saltmarsh. In keeping with the theme of the thesis, an effort was made to determine the efficiency of the buoyant pop net by releasing fish into the sprung net and measuring recapture rates for a range of species. This forms the content of Chapter 4.

The concluding chapter (Chapter 5) provides recommendations about optimal strategies for measuring seagrass community characteristics, both floral and faunal, and detecting change. The aim of the work is therefore to provide guidelines for the more appropriate and reliable monitoring of this important coastal habitat.

Chapter Two: seagrass mapping

2.1 Introduction

Remote sensing is a technique that measures the reflectance characteristics (for example, colour, electromagnetic radiation) of the earth's surface and relates these measurements to vegetation and land use. Remote sensing of seagrass communities using aerial photographs has been used to document the status (West *et al.* 1985) and changes (Larkum and West 1990, Meehan 1997) in seagrass cover in a number of estuaries in southern New South Wales. Aerial photographs have been used to document the status and examine long term changes in seagrass cover in a number of estuaries in southern NSW (Larkum and West, 1990; Williams and Meehan 2001, Meehan 2002). These studies have been able to determine whether seagrass communities have decreased or increased over a period of time.

Seagrass meadows form characteristic landscapes that are visible from remotely sensed imagery (Steffenson and McGregor, 1976; Kendrick *et al.*, 1999 and 2000; Mumby and Green 2000b). Different species of seagrass, such as *Z. capricorni* and *P. australia* can exhibit noticeable differences in colour, tone and texture that can be detected on present and past remotely sensed imagery (Larkum and West, 1990; Meehan, 1997; Watford and Williams 1999).

Case study

The Tweed River Entrance Sand by Passing Project is a joint project under taken by the State Governments of Queensland and New South Wales in conjunction with the Gold Coast City Council and Tweed Shire Council. The main aims are to establish and maintain a navigable entrance to the Tweed River and to enhance and maintain the amenity of the Southern Gold Coast beaches.

The Tweed River is located in NSW near the NSW/Queensland border just south of the Gold Coast. The project uses a pier mounted jet pump system to bypass sand around a trained river entrance. The Tweed River entrance is in an area with high wave energy and longshore sediment transport averaging 500,000 cubic metres per annum (Hyder *et al.* 1997). During the period 1 to 25 March 2001, modeled daily sand transport rates varied from 442m³/day to 24,696m³/day (McQuade and Jackson, 2001). There have been two stages in the project : from 1995 to 2001 a temporary sand by-pass system and from 2001 a permanent system was installed. During the temporary phase 3.6 million cubic metres of sand were dredged from the entrance and used to nourish the beaches to the north (Dyson *et al.* 2001).

The aims of this study is

- 1) to determine whether seagrass extent in Ukerebagh Channel had undergone change following the opening of the Tweed sand bypassing project
- 2) to conduct annual mapping of seagrass community distribution in the Ukerebagh Channel to determine inter-annual variability in seagrass extent and the optimal frequency of mapping for change detection
- 3) to determine the extent of digitizer error.

2.2 Study site selection

As an exercise in developing monitoring skills a small portion of a NSW estuary was examined for temporal change in seagrass distribution. The Tweed River was chosen for the study as the sand bypassing project, provided an opportunity to examine seagrass variability in relation to a pulse event. Good air photo coverage exists prior to and following this event. Clarity of water is excellent for all photograph year.

2.3 Method

Aerial photographs are the most commonly used form of remotely sensed data for high resolution seagrass mapping studies. Aerial photographs of Tweed River, and successive years for the Ukerebagh Channel, were obtained from the Department of Infrastructure Planning and Natural Resource (DIPNR). All obtained images are not in same quality.

Image quality depends on image resolution, air quality, weather conditions, clarity of the water and tide levels.

The photographs were visually interpreted and the seagrass beds identified on the basis of reflectance characteristics (colour, tone and texture). The observable characteristics of seagrass species are given in Table 2.1.

Table 2.1: Observable characteristics of seagrass species in estuaries of NSW

Community type	Observable characteristics
Seagrass Spp.	Colour range light to dark green or light to medium Black. Colour varies depending on depth. Beds are large, smaller and fragmented. Sparse beds may be lighter in appearance. Beds usually have soft edges and are smooth in appearance.

Ground truthing, previous maps and knowledge of seagrass ecology were also used to identify the seagrass beds and draw their boundaries. The full list of aerial photographs used is presented in Table 2.2.

Aerial photographs were scanned at 360 dpi (dots per inch) and saved in JPEG file format and imported into the ArcView Geographic Information System (ESRI Inc). They were georectified to correct distortions of scale caused by the varying distances of photographed objects from the camera lens. A minimum of 6 ground control points were used to rectify each image, all derived from recognizable fixed points on the CMA topographic maps of the region.

The on-screen digitizing functions of ArcView were used to create polygons of seagrass areas. The size and shape of the polygons within or between sets of photos vary according to a number of factors, including the scale of the photo and the complexity of the habitat (Green *et al.* 2000b). For example a fragmented seagrass habitat may need a large number of smaller polygons than a continuous seagrass bed. The entire seagrass

was mapped on two occasions, before and after the beginning of the Sand Bypassing project. The following criteria were used when mapping seagrass communities :

-Seagrass beds were differentiated on the basis of colour, tone, texture and geomorphic and geographical context, using the criteria for saltmarsh and mangrove set out by Saintilan and Wilton (2000).

-Interpretations were crossed-checked with the earlier surveys of West *et al.* (1985).

-Where aerial photographs were compromised by solar reflectance, insufficient light penetration or shading by other vegetation, mapping was not attempted.

Table 2.2: Aerial photographs used to map the distribution of seagrass species in Ukerebagh Channel, Tweed River.

Date	Photo series	Run	Print number
28/05/01	Beach Protection Authority Tweed heads to Currumbin	Run 3	100, 101
11/05/00	Beach Protection Authority Tweed heads - Currumbin	Run 3	178
19/10/99	Beach Protection Authority Tweed heads to Currumbin	Run 3S	104,105
7/5/98	Beach Protection Authority Tweed heads – Currumbin	Run 3 Run 1	105, 112
10/09/97	Beach Protection Authority Tweed heads - Currumbin	Run 3	137, 146

Ground-truthing of intertidal seagrass communities

Ground-truthing is the process of determining the accuracy of mapped vegetation units by comparison with field observation. Field surveys were carried out to identify the status (sparse or dense) and boundaries of seagrass beds and to assist in visual interpretation of the aerial photographs. Ground-truthing was conducted in 28 randomly selected locations in the Ukerebagh Channel. A bathscope was also used to look at the seagrass and its boundaries in deeper water. This is particularly important if different species of seagrass were present with similar textures and colours in the air photograph, and the geomorphic context did not allow easy differentiation.

Mapping Error

Some component of the estimated changes in the extent of seagrass will be due to variations in quality between the fine set of photos (Table 2.2), georectification error and digitizing error. Variations always occur in photograph quality and image clarity leading to errors in aerial photography analysis and interpretation. Digitising error is also a potentially significant source of error. To determine the contribution of digitizing error, seagrass boundaries were mapped twice for the photo (only one: Run 3, Print 178) in 2000.

2.4 Results

Seagrass extent increased in the period immediately following the introduction of the Tweed sand bypassing project. The area of seagrass increased from 61.2 hectares in 2000 to 66.77 hectares in 2000 (Figures 2.1 and 2.2).

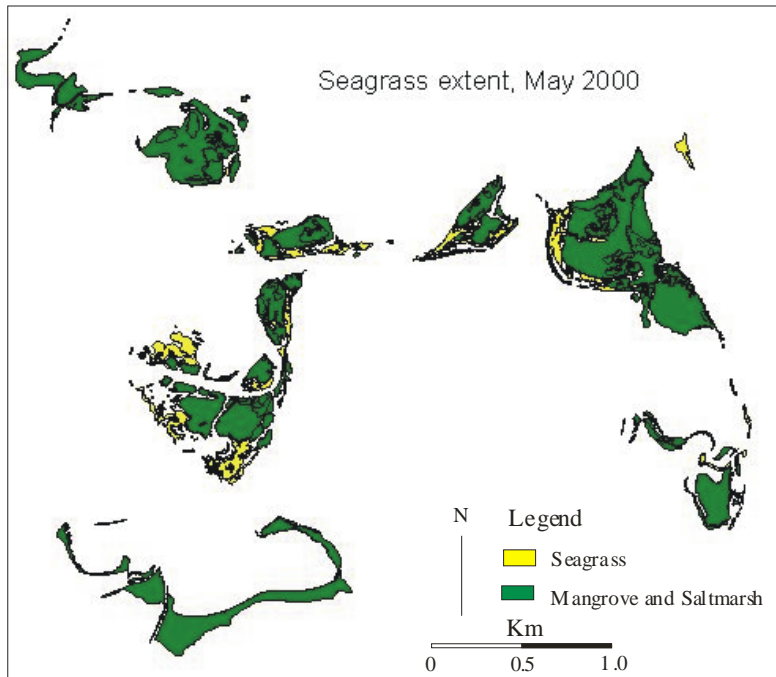


Figure: 2.1 Distribution of seagrass and other intertidal wetlands in the lower Tweed River in 2000.

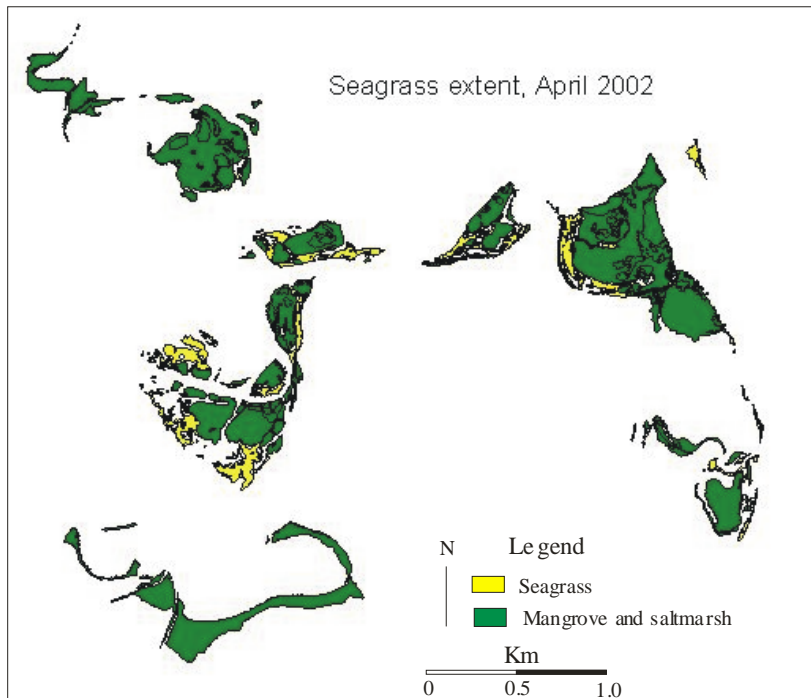


Figure: 2.2 Distribution of seagrass and other intertidal wetlands in the lower Tweed River in 2002.

Changes in seagrass extent within Ukerebagh Channel between 1997 and 2001 are shown in Figures 2.3 to 2.8. The seagrass cover reached its highest point in 2001 (8.95 ha). The aerial cover is in tables 2.3 and 2.4.

Table 2.3 : Area of Seagrass vegetation in Ukerebagh Channel, Tweed River

Year	Areas (ha)
1997	7.04
1998	7.47
1999	7.05
2000(a)	7.90
2000(b)	8.12
2000 (mean)	8.01
2001	8.95

Table 2.4: Seagrass cover in percentage (increase or decrease) in Ukerebagh Channel

Year	Percent (%) change
1997-1998	6.10 increase
1998-1999	5.62 decrease
1999-2000	12.05 increase
2000a-2000b	2.9 increase
2000-2001	13.29 increase

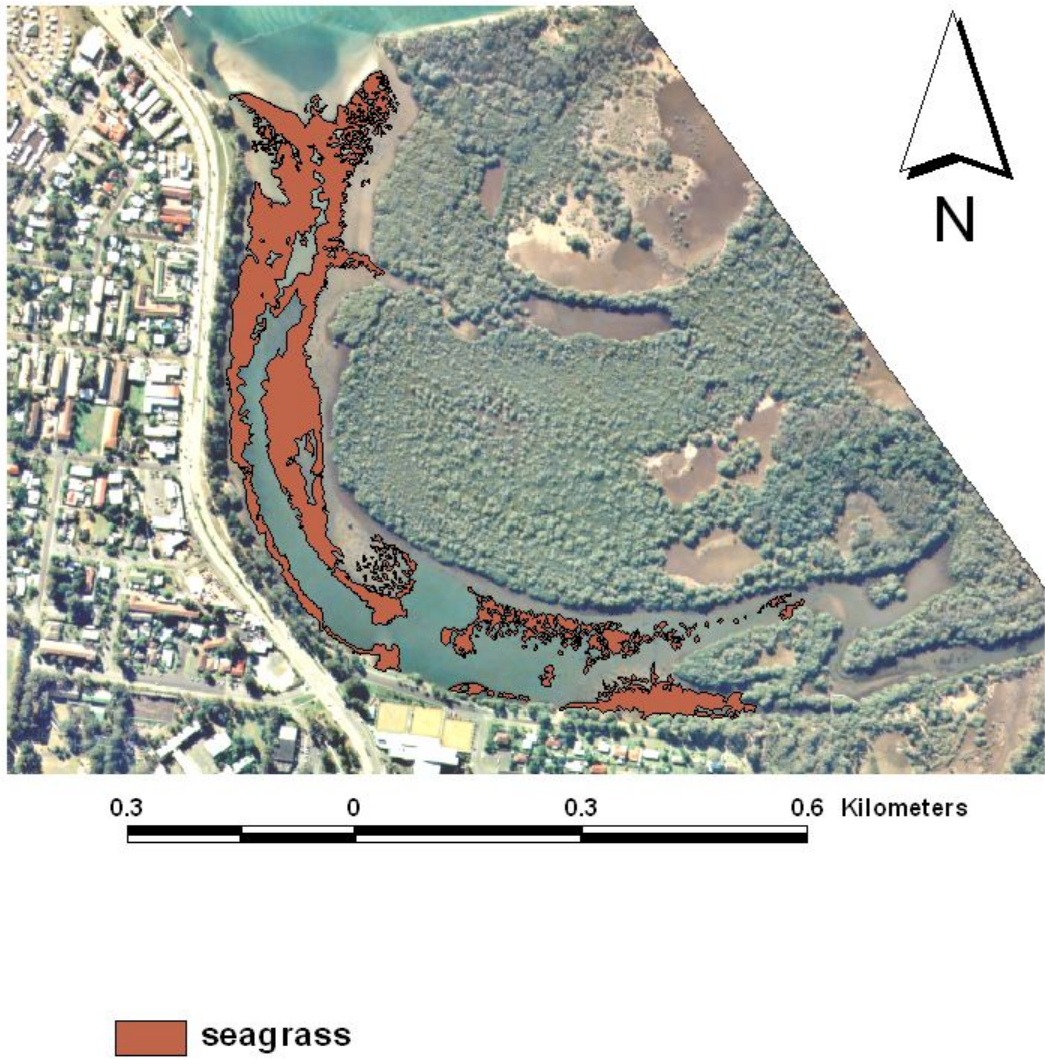


Figure 2.3: Seagrass Extent in Ukerebagh Channel 1997

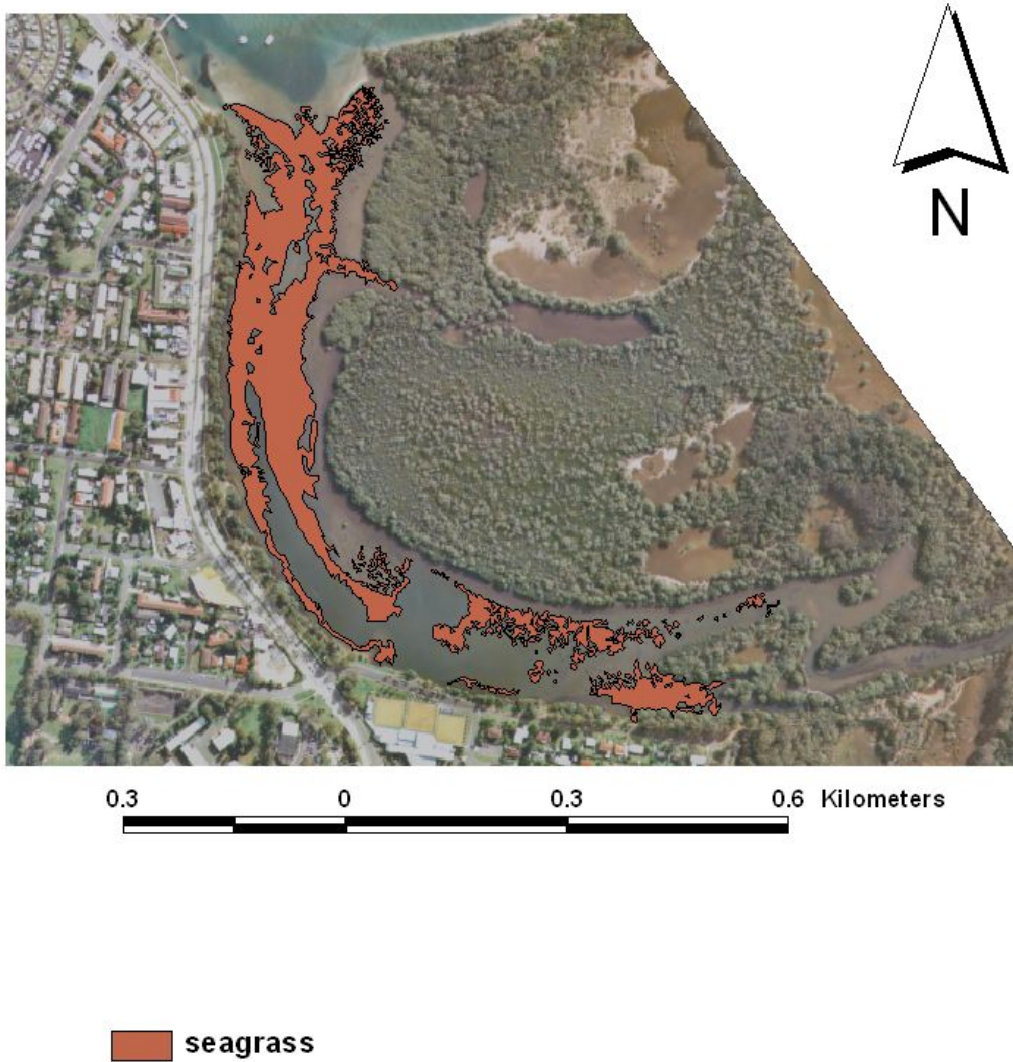


Figure 2.4: Seagrass Extent in Ukerebagh Channel 1998

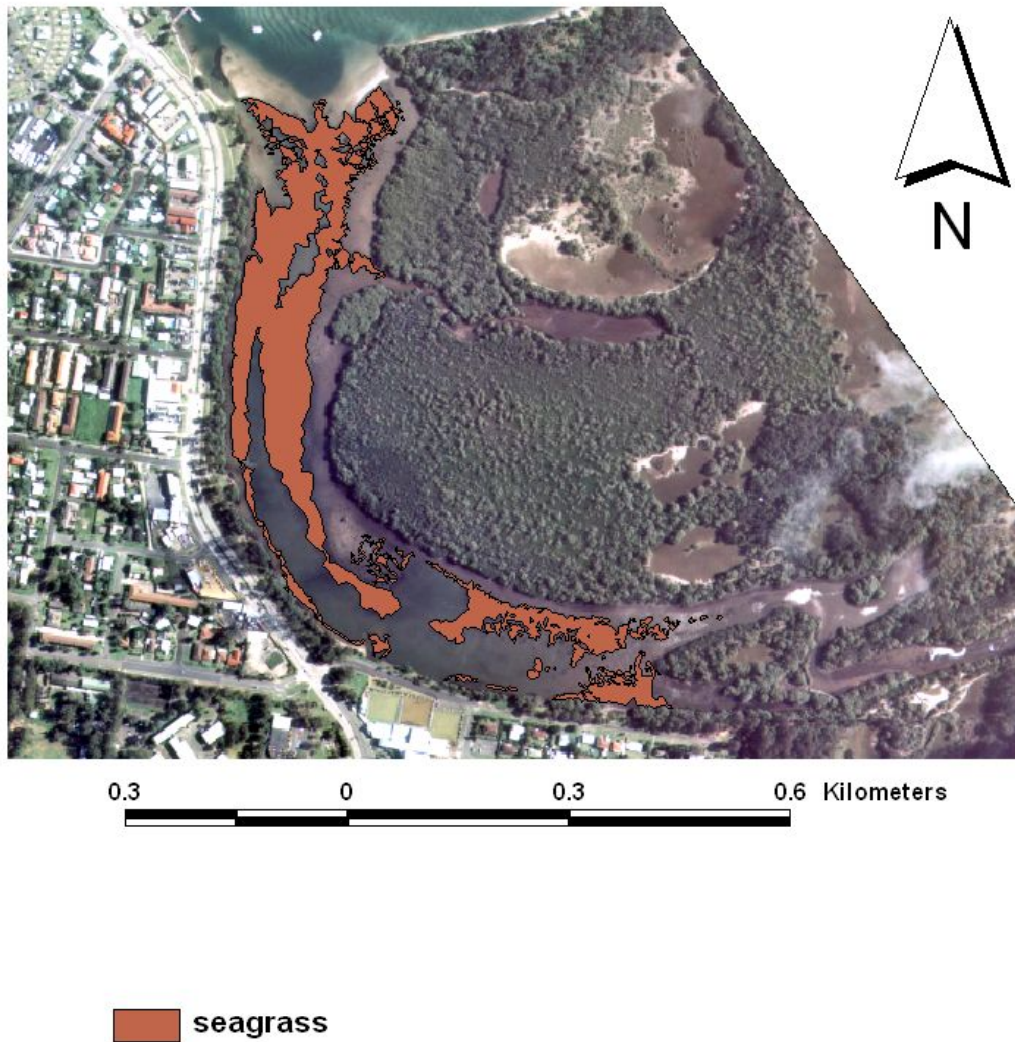


Figure 2.5: Seagrass Extent in Ukerebagh Channel 1999

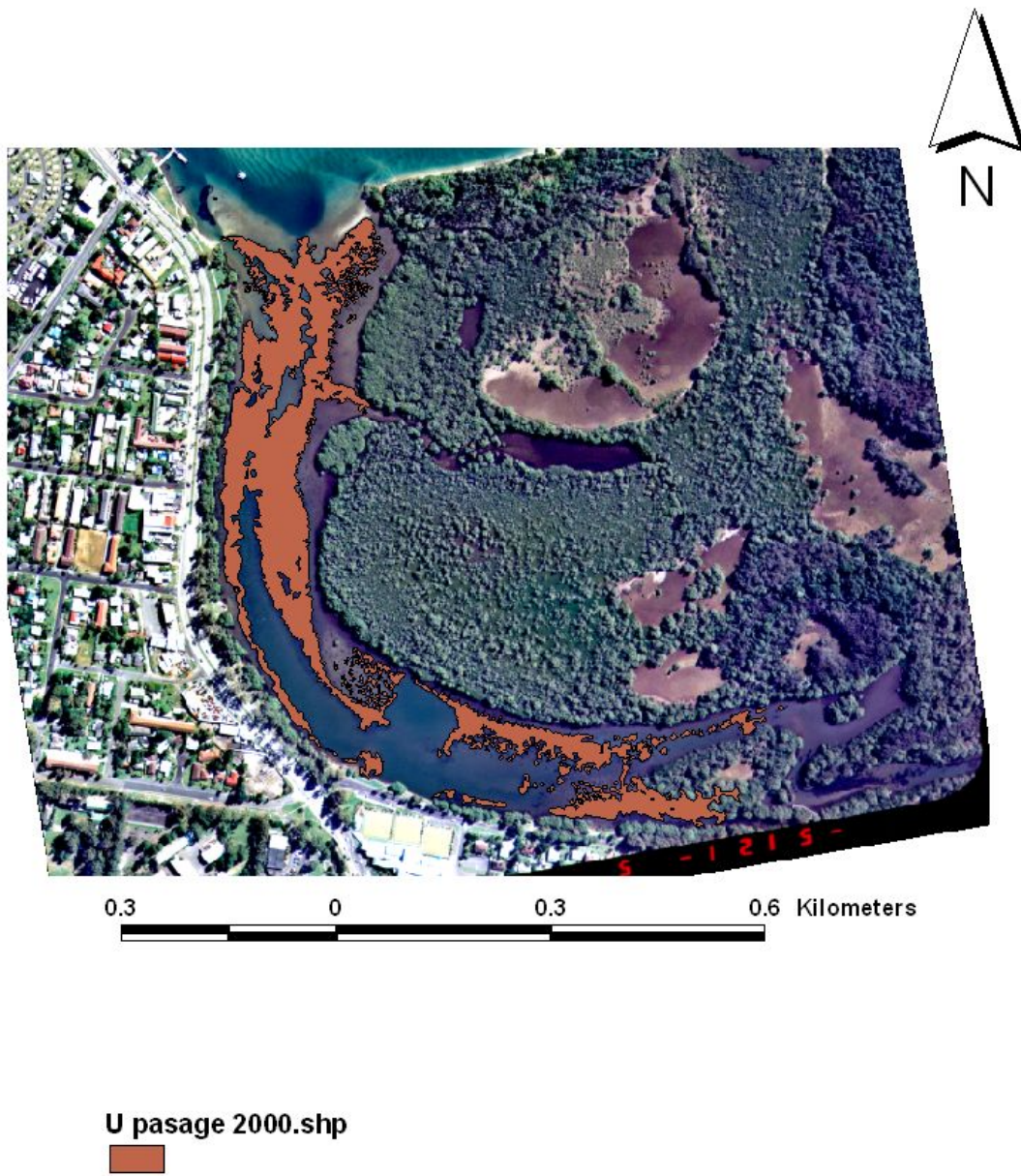


Figure 2.6: Seagrass Extent in Ukerebagh Channel 2000 (a)

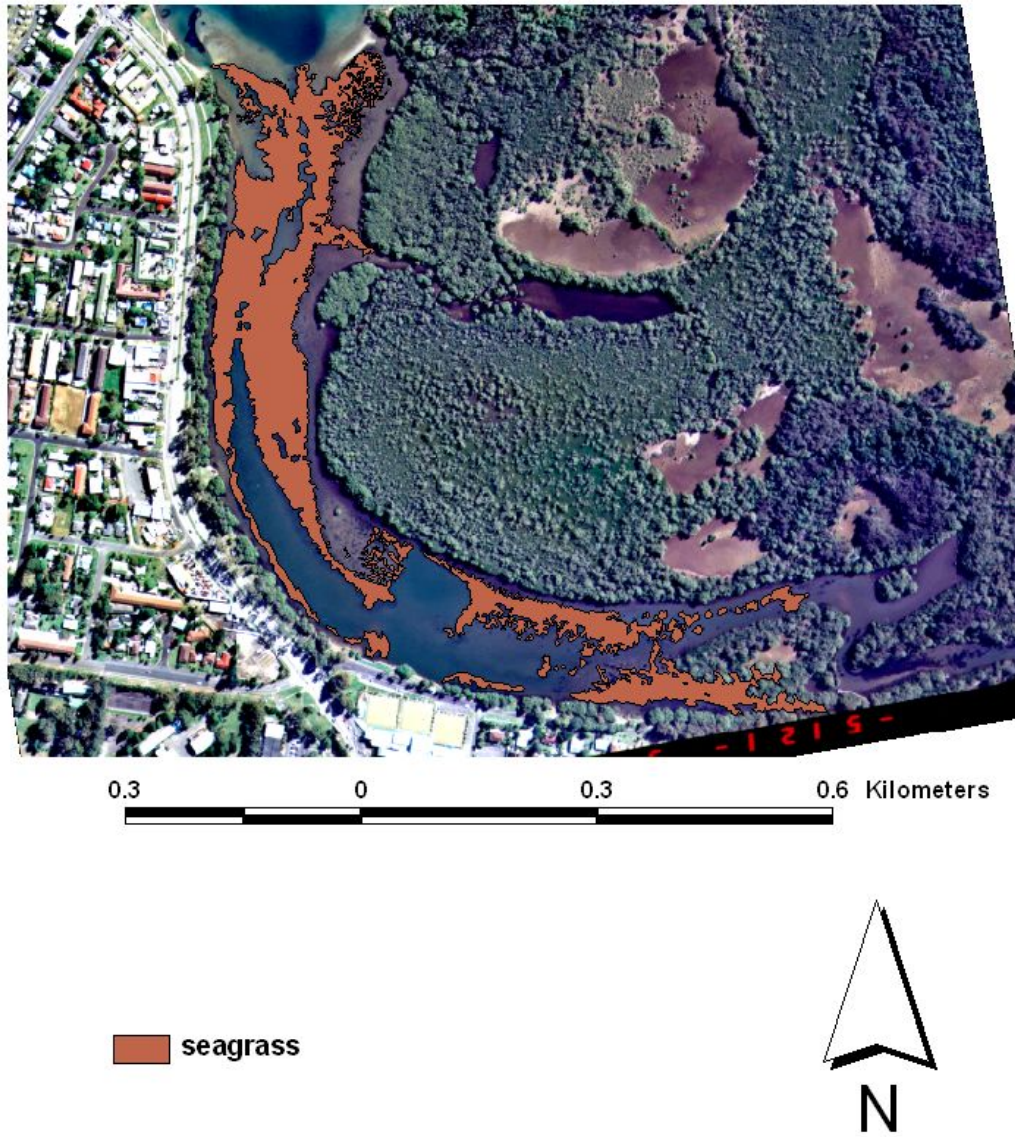


Figure 2.7: Seagrass Extent in Ukerebagh Channel 2000 (b)

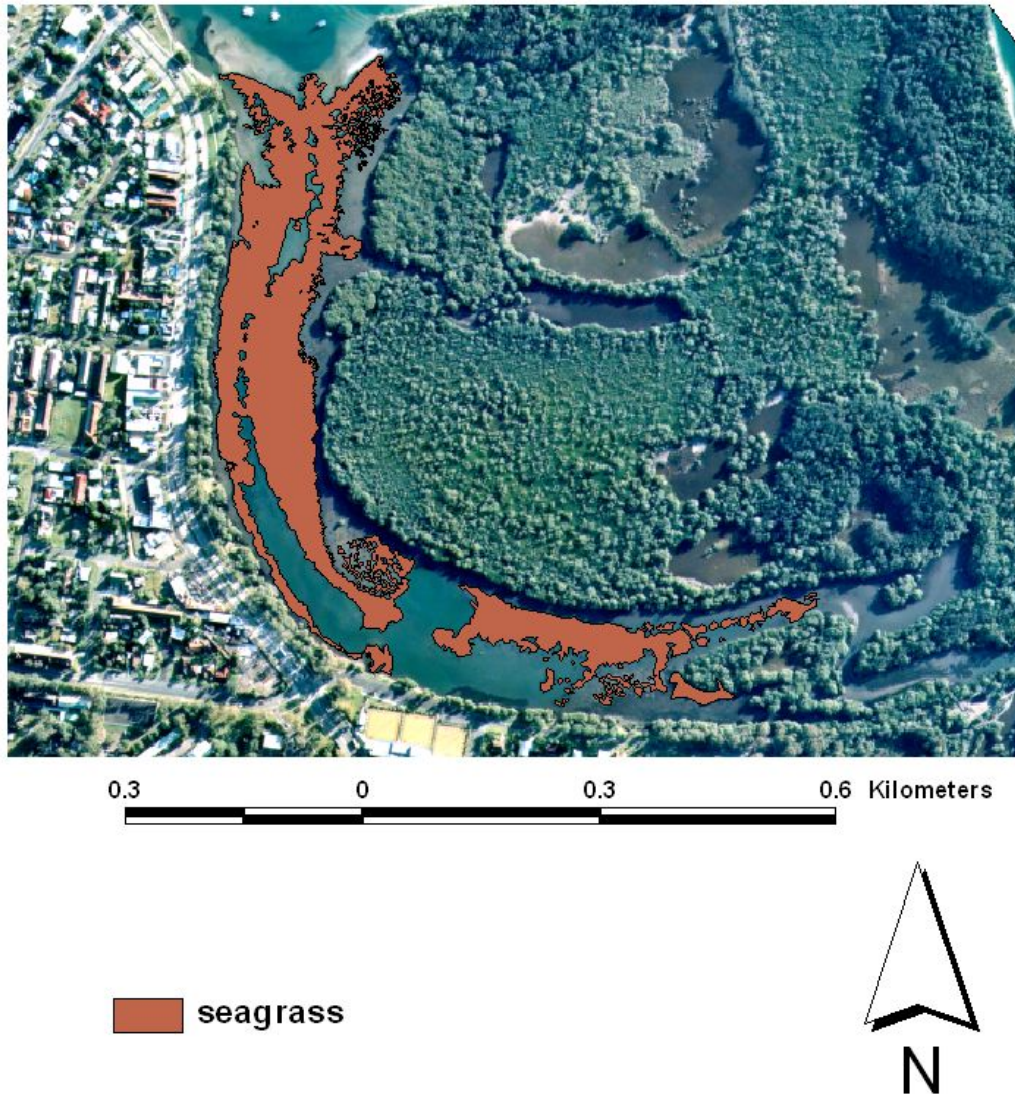


Figure 2.8: Seagrass Extent in Ukerebagh Channel 2001

2.5 Discussion

Seagrass in the Ukerebagh Channel showed a consistent increase in the period of 1999 to 2001. The overall rate of seagrass increase is 6.7% per annum. Factors which promote the increase of seagrass area include water clarity and salinity (which may be associated with drought conditions) and geomorphic stability. There is no indication that the small change in monitored tidal hydrological conditions that may be associated with the Tweed River Entrance Sand Bypass Project within the Tweed River estuary are having a detrimental impact on seagrass beds.

The Tweed River Entrance Sand Bypassing Project, Environmental Impact Statement/Impact Assessment Study (EIS/IAS) predicts very small tidal changes directly attributed to entrance improvements as a result of the operation of the Tweed River Entrance Sand Bypass Project (Hyder 1997). The EIS/IAS predicts that the operation of the Sand bypassing system will reduce the net infeed of marine sand into the river estuary. Operation of the system has the beneficial impact of reducing growth of the lower estuary shoals and lessening their adverse impact on tidal flushing and water quality. To date monitoring of the tidal data shows that there has been no significant change in tidal conditions that can be contributed to the operation of the sand bypassing system.

Meehan (2002) stated that in southern NSW, the area of *P. australia* has declined in five out of six estuaries over the last fifty years. In Port Hacking *P. australis* communities declined 18% in 1951-1999, in St. George Basin seagrass cover declined by 27% from 1961-1998. In Wagonga Inlet seagrass cover declined slightly (10%) from 1957- 1994. In Bermagui River seagrass cover declined by 33% from 1957 –1998. These declines occur due to a number of anthropogenic impacts, including engineering works, dredging and deterioration in water quality. Natural impact, such as storm damage, may have occurred at some sites.

By contrast, the Tweed River *Zostera* community distributions are fairly stable, at least over the time period of this study. There were no significant change in seagrass extent following the Tweed Sand Bypassing Project – a slight increase was noted. Within the Ukerebagh Channel, seagrass extent appears to have increased over a five-year period, in the order of 5-10 % per year. Given that the degree of error calculated by the remapping of 2000 was relatively small (2.9%), most of the increase is assumed to be real increases in seagrass cover. This would suggest that annual measures of seagrass extent can generate useful indications of change over that timescale, in contrast to mangrove and saltmarsh where five-year surveys are recommended (Saintilan and Wilton 2000).

Chapter Three: sampling biomass of seagrass

3.1 Introduction

Seagrasses are an important and often dominant component of ecosystems in estuaries and shallow coastal waters of Australia (Larkum, 1977, Long *et al.*, 1994). Their roles are so important that seagrass meadows are considered to be the most valuable ecosystems in terms of the value-added benefits of the services they provide (Costanza *et al.* 1997). Studies in other parts of the world have shown that many seagrasses have high primary production and that they may support rich communities, including many commercially important animals (Thayer *et al.*, 1975, Smith, 1981; Charpy-Roubaud and Sournia, 1990). They provide nursery grounds, adult habitat and food for commercially important prawns and fish (Young, 1978, Bell and Pollard, 1989, Blaber *et al.*, 1992), wading birds and dugongs (Preen *et al.*, 1992). They also produce large amounts of detritus and dissolved organic matter (Moriarty *et al.*, 1984). Seagrasses are areas of high food abundance (Hill and Wassenberg, 1993). They are present in only 0.15% of the ocean's surface (Charpy-Roubaud and Sournia, 1990) and contribute 1% of the net primary production of the global ocean (Duarte and Cebrian, 1996). In Botany Bay seagrasses are a major source of detritus (West and Larkum, 1979). Reliable and accurate estimates of the seagrass biomass are essential for estimating production and the links with the ecological system components that rely directly or indirectly on this resource.

Within Australia, only a few studies have considered in detail the biomass of *Z. capricorni*. In NSW biomass data were available for the Tuggerah Lakes (100 km north of Sydney) (Higginson, 1965), and in Queensland, Moreton Bay, (Kirkman, 1978). Harris *et al.* (1979) studied seasonal changes in biomass and phenology of communities in Illawarra Lake (110 km south of Sydney) and Kirkman *et al.* (1982) studied the biomass, leaf growth and productivity of *Zostera* communities in Port Hacking (30 km south of Sydney). Larkum *et al.* (1984) studied the standing stock, growth and shoot production of *Z. capricorni* in Botany Bay, New South Wales and Kerr *et al.* (1990) studied the

seasonal changes in standing crop of *Z. muelleri* in south-eastern Australia. No studies have been conducted of biomass and standing crop of *Zostera* sp. in the Tweed River, in spite of the potential of significant engineering works at the mouth of the Tweed to disrupt seagrass beds.

Aims of this study

△ The current experiment investigated the seasonal variation in the abundance of the above ground biomass of *Zostera* sp. in two locations within NSW : Woollooware Bay segment of Botany Bay and Ukerebagh Channel in the Tweed River.

△ Relationships between season, seagrass biomass and optimum number of quadrats for sampling were also examined.

△ The primary aim of this investigation was to determine the efficacy of commonly-proposed sampling regimes for seagrass biomass.

A number of authors (Larkum *et al.* 1984; Larkum and West, 1990; Kirkman and Cook 1982; Mellors 1991, and Lanyon and Marsh (1995)) suggest that the most appropriate level of sampling is 0.25m x 0.25m quadrats. The level of replication has commonly between 10 replicates plot (eg. Larkum *et al.* 1984). The opportunity exists to apply Power Analysis to assess the sufficiency of this level of replication in two estuarine settings.

Table 3.1: Size of the quadrat used by a number of authors for collecting seagrass sample in different parts of Australia.

Author	year	Location	Species	Quadrat Size (m ²)
Kirkman and Cook	1982	Port Hacking, NSW	<i>Z. capricorni</i>	0.0625
Larkum et al.	1984	Botany Bay, NSW	<i>Z. capicorni</i>	0.0625
Larkum and West	1990	Quibary Bay and Silver beach, NSW	<i>Posidonia</i> sp.	0.25

Mellors, J.E.	1991	Green Island, North Queensland	<i>H. uninervis</i>	0.25
Neverauskas, V. P.	1987	Gulf St. Vincent, South Australia	<i>Posidonia sp.</i> <i>Amphibolis sp.</i>	0.0625
Lanyon and Marsh	1995	North Queensland	Seagrass sp.	0.0625

3.2 Study sites

The biomass sampling was undertaken at Woollooware Bay (Towra Point) in Botany Bay (Figure 1.2) and the Ukerabagh Channel in Tweed River estuary (Figure 1.2). Botany Bay (34°00' S, 151°11' E) is a marine dominated open embayment, 12 km south of Sydney, New South Wales. Among the 130 estuaries of New South Wales, the bay was reported in a survey to contain 340 ha of seagrass, the eighth largest seagrass area in New South Wales (West *et al.* 1985). Tweed Heads is located 860 km north of Sydney. Both sites have some geomorphological similarities, being sandy marine deltas. The principal seagrass species in Botany Bay are *Posidonia australis* and *Zostera capricorni*. (Larkum and West, 1990). Sample sites Woollooware Bay segment of Botany Bay and Ukerabagh Channel in Tweed Heads were a monospecific stand of *Zostera sp.* Both sites are important as a commercial and recreational fishing area, as a site of historic significance and a popular recreation area in terms of boating, fishing, bush walking and bird watching.

3.3 Sampling Methods

The sampling method for estimating the biomass utilises random samples within plots. To improve precision, Downing and Anderson (1985) recommended the use of small quadrats with many replications in preference to a few large quadrats. For example Larkum *et al.* (1984) used ten (0.25m X 0.25m) 0.0625m² quadrats, for collecting *Zostera capricorni* sample from Botany Bay. Larkum and West (1990) collected *Posidonia* samples for biomass estimation from Quibray Bay and Silver Beach, Botany Bay, using six 0.25m² quadrats. Kirkman and Cook (1982) collected *Zostera capricorni* from Port

Hacking for estimating biomass through ten (0.25m X 0.25m) 0.0625m² quadrats. Mellors (1991) used 0.25m² quadrats for collecting sample. Neverauskas (1987) used nine (0.25m X 0.25m) 0.0625m² quadrats to collect seagrass sample from the study sites. Lanyon and Marsh (1995) also used sixteen (0.25m X 0.25m) 0.0625m² quadrats for collecting sample.

In each of Woollooware Bay and Ukerebagh Channel 32 of (0.25m X 0.25m) 0.0625m² quadrats (8 in each of four plots) were placed randomly within a plot of dimensions 15m X 20m (Figure 3.1). Seagrasses communities were sampled four occasions between winter/2002 until autumn/2003 (four occasions in one year). Sampling was carried out at low tide (< 0.4m) to avoid problems of water turbidity. All plant parts that originated from outside the quadrats were placed outside the frame and those that originated from inside are placed inside the frame. The quadrat was then pushed into the substrate and pegged down to prevent movement while the contents were removed. Above ground plant parts were cut at their bases. Care was taken to ensure that samples were always collected from a previously untouched area of seagrass.

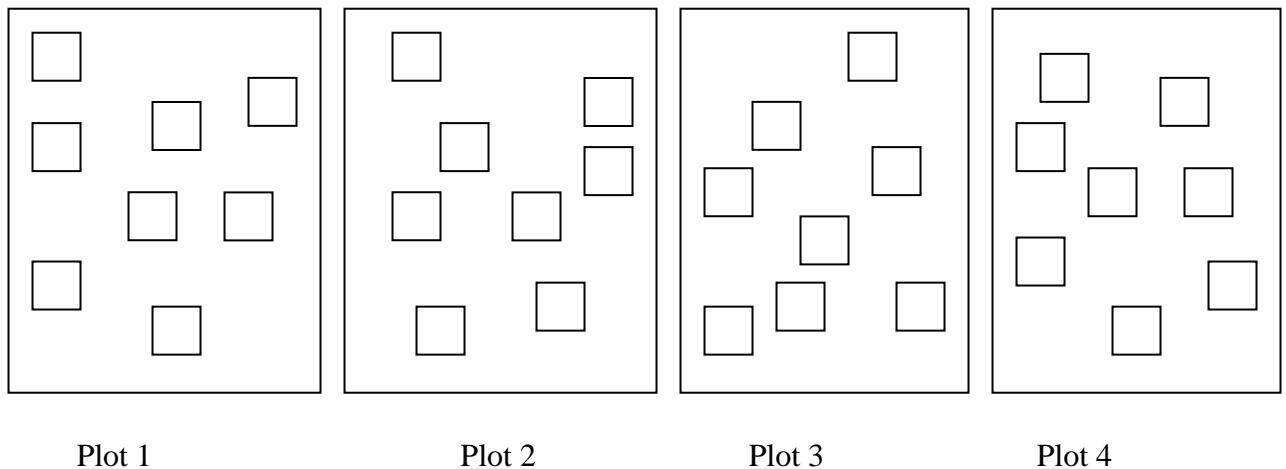


Figure 3.1 Schematic representation of biomass sampling strategy at Woollooware Bay and Ukerebagh Channel, showing plots and replicates within the plots.

Sampling problems in seagrass beds

Seagrasses often cover large expanses of mudflats which remain partially underwater even at low tide, making sampling difficult. The soft glutinous part often create major problems relating to access and disturbance. The mud is difficult to walk on, algae are abundant and clouds of silt arise to obscure the view during sampling. Some algae are epipelagic (on the mud itself), loose-lying or epiphytic (on seagrass leaves), or are on various non-living substrata protruding above the mud.

Sample Processing

Leaves and stems were brought back to the laboratory and rinsed with fresh water to remove the salts and sediments, and the plant parts were then separated from the associated epiphytes. The cleaned leaves and stems were oven dried to constant weight at 80°C (Larkum and West, 1990) for 24 hours and weighed immediately since they re-absorb moisture quickly.

Statistical methods

Univariate analysis (ANOVA) and post-hoc Student-Newmans-Kules (SNK) test were performed using GMAV5 (Underwood and Chapman 1989) to determine the significance of differences of above ground biomass among the seasons in two sites. Two way analyses of variance were used (Underwood, 1997) where season was considered as the first factor with three levels (1=Winter, 2= Spring, 3= Summer, 4= Autumn) that were orthogonal and fixed. Site was considered as second factor with two levels (1=Towra Point, 2=Tweed Head) that were also orthogonal and fixed.

3.4 Results

ANOVA results showed that the dry weight biomass of seagrass at Woollooware Bay in (Towra Point) vary within the season. The above ground biomass among the seasons differed significantly ($P < 0.0001$, Table 3.2).

Table 3.2: ANOVA results for above ground biomass among seasons at Woollooware Bay, NSW. Cochran's Test C= 0.3156

Source of variation	DF	MS	F	P
Season	3	9.8597	23.13	0.0001
Residual	124	0.4262		
Total	127			

The *post-hoc* SNK test for biomass in different seasons showed that the above ground seagrass biomass in winter is significantly different with the spring. Biomass is also significantly different between winter and summer & autumn and spring. There is no significant difference in biomass between the seasons of summer and autumn. The dry weight in spring is higher than all other seasons (Figure3.2).

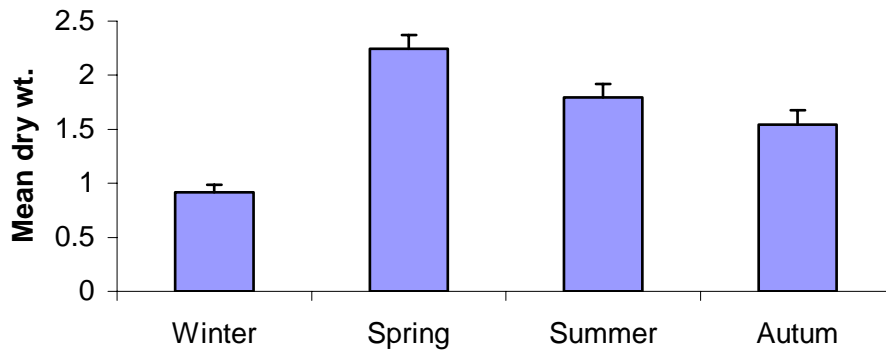


Figure 3.2: Mean dry weight (+ SE) of seagrass in Woollooware Bay at Towra point, in different seasons 2002-2003: n=128.

In the case of Tweed Head the ANOVA result showed that the biomass also varied within the seasons. Biomass among the seasons differed significantly ($P < 0.0003$ Table 3.3). Mean dry weight of above ground biomass at Ukerebagh Channel was higher than at Woollooware bay.

Table 3.3: ANOVA results for above ground biomass between the seasons in Tweed Head, NSW : Cochran's Test C=0.4955

Source of variation	DF	MS	F	P
Season	3	39.1152	6.62	0.0003
Residual	124	5.9110		
Total	127			

The post-hoc SNK test for biomass in different season showed that summer is significantly different with other seasons. Biomass between autumn and winter did not vary significantly. The mean dry weight of above ground biomass in summer is higher than in all other seasons (Figure 3.3).

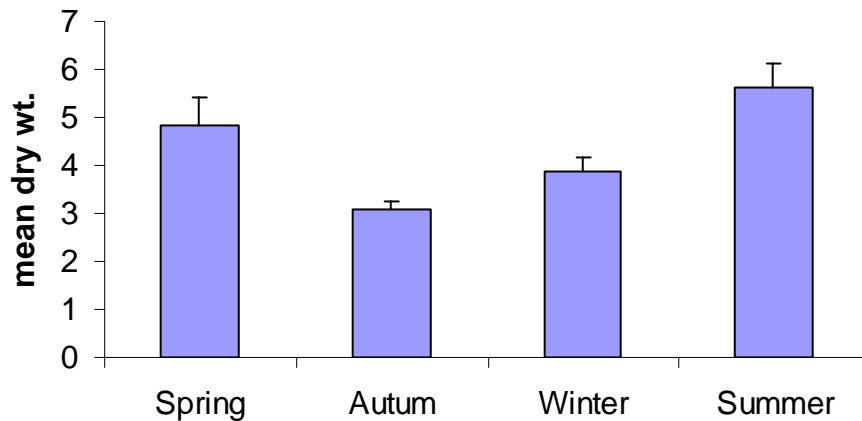


Figure 3.3: Mean dry wt. (+SE) of seagrass in Tweed Head in different seasons 2002-2003: n=128.

Results of the 2-way ANOVA demonstrate significant differences between the biomass of seagrass at Ukerebagh Channel, Tweed River and Woollooware Bay, Towra Point ($P < 0.001$). The significant interaction term (Season * River: $P = 0.004$) suggests that the pattern of seasonal variability differs between the two sites (Table 3.4). Towra Point has a more pronounced Spring peak (Figure. 3.2).

Table 3.4: Two-way ANOVA results for factors River (Tweed and Woollooware Bay) and Season (Winter, Spring Summer and Autumn).

Tests of Between-Subjects Effects

Dependent Variable: Biomass

Source of variation	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	621.729(a)	7	88.818	28.031	0.000
Intercept	2284.960	1	2284.960	721.129	0.000
Season	103.558	3	34.519	10.894	0.000
River	474.804	1	474.804	149.847	0.000
Season * River	43.367	3	14.456	4.562	0.004
Error	785.809	248	3.169		
Total	3692.497	256			
Corrected Total	1407.538	255			

a R Squared = 0.442 (Adjusted R Squared = 0.426)

Statistical Power

Power analysis performed on data of mean biomass for seagrass at Woollooware Bay indicated that eight replicate quadrats per plot will only detect significant change of 70% or greater (Figure 3.4). Possibly as many as 15 quadrats per plot would be required to detect a 20% change. Alternatively, power analysis performed on seagrass mean biomass data in Ukerebagh Channel (Tweed Heads) indicated that with eight replicate quadrats is optimal, less than eight quadrats will not detect (as significant) change of less than 10% (Figure 3.5). More than eight quadrats is unnecessary, as statistical power is not increased.

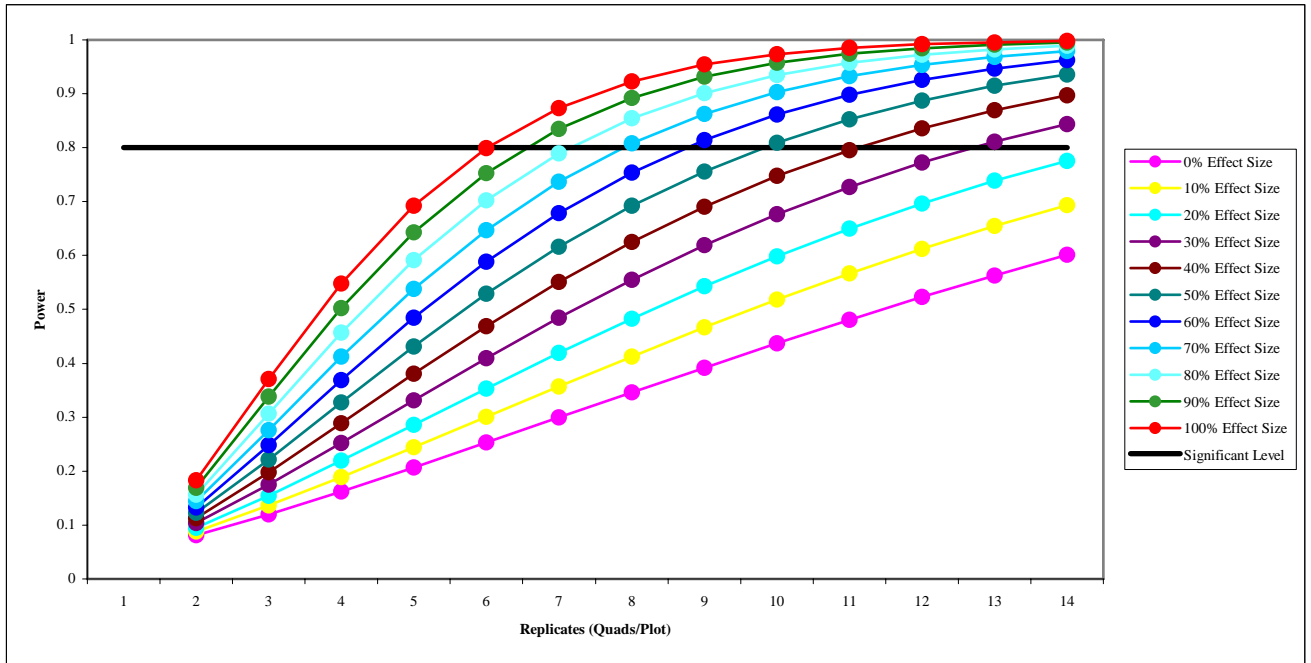


Figure 3.4. Power analysis showing the change detectable with increasing plot replication at Woolooware Bay (Towra Point).

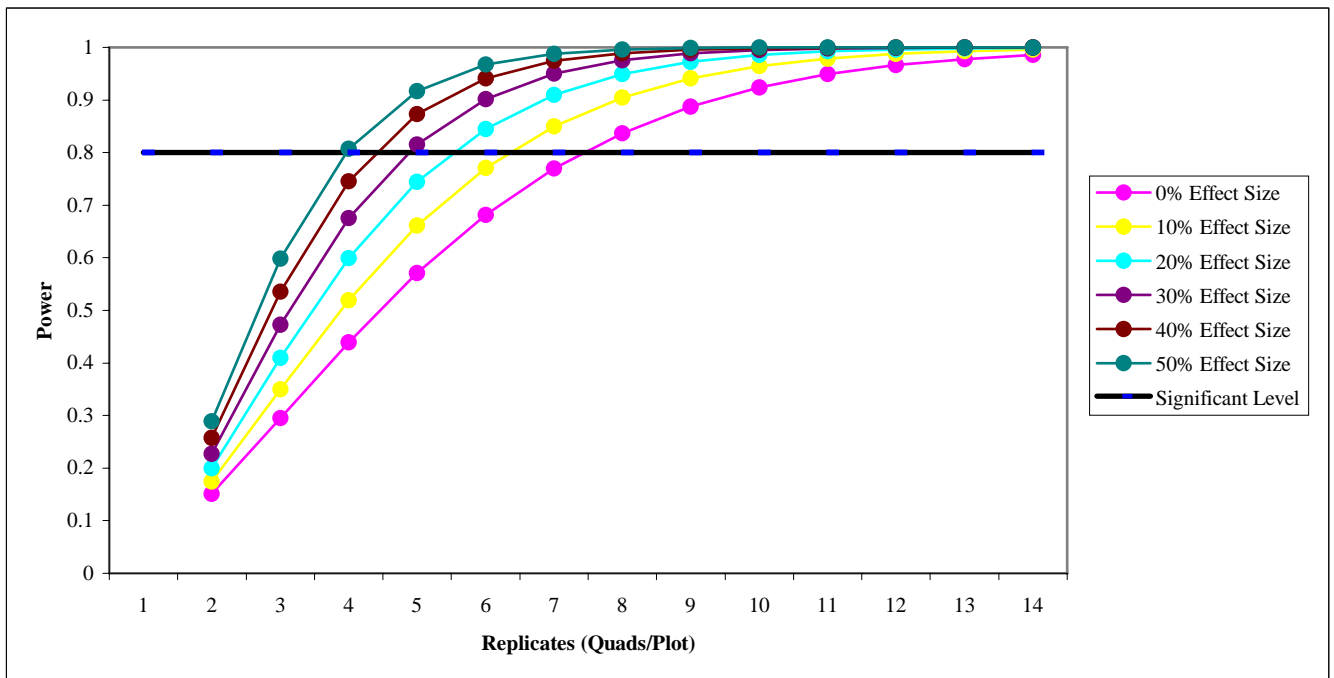


Figure 3.5. Power analysis showing the change detectable with increasing plot replication at Ukerebagh Channel (Tweed Heads).

3.5 Discussion

The current study has demonstrated that seagrass biomass varies significantly between the sites and periods of time (seasons). The differences in biomass may be due to different shoot densities or variability in leaf length and width (West and Larkum, 1983). The seasonal variation at Towra Point is similar to that found by Larkum *et al.* (1984) for *Zostera capricorni* measured over the same seasons in Botany Bay. Their result showed a 4-fold change in above ground biomass between summer and winter. The study found similar seasonal variability in Ukerabagh channel in Tweed Heads. Kirkman *et al.* (1982) also found biomass of *Z. capricorni* varying between summer and winter in Port Hacking, New South Wales. In south-eastern Australia Kerr and Strother (1990) found similar patterns for seasonal variability in *Z. muelleri*. The current experiment found the highest biomass of *Zostera capicorni* in Woollooware Bay (Towra Point) during spring followed by summer, autumn and the winter. The average mean biomass in Towra Point (Woollooware bay side) round the year is 78.0gm dry wt./m².

Results from Ukeberagh Channel at Tweed Heads were somewhat different. The highest biomass was found during spring followed by winter and autumn, though on the whole biomass varied less than at Towra Point. The average mean biomass in Ukeberagh Channel is 208.68gm dry wt./m², far higher than at Towra Point.

Both the sample sites were dominated by *Z. capicorni* but there was difference in shoot densities, length and width of the leaves, wave action, degree of pollution and other local conditions. The present study only examined the biomass difference between the 4 season of two locations. The biomass of *Zosteria capicorni* varies between sites depending on the morphological characteristics and local environmental conditions. West and Larkum (1979) compared five study sites and found large variations in biomass of *Posidonia australis*. According to West and Larkum (1983) biomass also vary depending on local conditions, such as depth, age of bed, degree of wave exposure and exposure to salinity changes. As seagrass meadows are known to contribute nutrients to estuarine food chains and to provide shelter for juvenile fish (Mann, 1972; Thayer *et al.*, 1975; Conacher *et al.*

1979; Middleton *et al.* 1984), the conservation of the beds of *Zostera capricorni* in both areas are of important.

Densities of biomass at Towra Point were consistently lower than in the Tweed Channel, a result which may be partly explicable by differing sediment regimes, in particular the movement of sediment into Woollooware Bay following erosion from Towra Point. Sedimentation in the seagrass beds was found to be in the order of 5cm in a 6-month period, nearly an order of magnitude higher than the adjacent mangrove. This high rate of sediment delivery is likely to create problems for the maintenance of biomass more than any latitudinal difference between the two seagrass sites.

Difference in biomass created important difference in the degree of replication required to provide an adequate sample. Within Ukerebagh Channel, biomass was consistently high, and the suggested level of replication (0.25mX 0.25m) was found to be sufficient to detect as significant a 10% variation. However, the situation at Towra Point was markedly different. Here, where biomass was low and variable, more than 15 quadrats would be required to detect as significant a change of 20%. The result highlights the need to determine the degree of replication for individual sites, rather than following suggestions as to the level of replication appropriate.

Chapter Four: sampling nekton in seagrass

4.1 Introduction

Seagrasses are a valuable component of Australia's coastal resources for fisheries through food webs and the habitat for important stages in the life cycle. Seagrasses form a three-dimensional canopy, which provides habitat for fish and crustaceans (Pollard, 1984). Seagrass meadows are the nursery grounds for many of Australia's commercial fish and crustacean species (Middleton *et al.* 1984; Bell and Pollard, 1989). In the Gulf of Carpentaria, along the east coast of Queensland and north-eastern Arnhem Land, juvenile tiger prawns and endeavor prawns use seagrass meadows as their nursery grounds (Staples *et al.* 1985; Poiner *et al.* 1987; Coles *et al.* 1993). The juveniles take shelter in seagrass bed for protection from predators. Minello and Zimmerman (1983) showed that the levels of predation on juvenile penaeids by fish were considerably lower in vegetated than in non-vegetated areas. An estuarine area that has been artificially modified and colonized by seagrass can provide a settlement habitat for large numbers of juvenile fish of economic value (McNeill *et al.* ,1992). Seagrass also support complex food webs by virtue of their physical structure and primary production and are well known for their role as breeding grounds and nurseries for important crustacean, finfish and shell fish populations (Short and Coles, 2001).

Numerous methods have been used to sample fish populations associated with natural habitat as well as artificial structures, including scuba, controlled angling, electrofishing, trap nets, drop nets, seine net and rotenone. None of these methods can consistently provide accurate estimates of the entire fish assemblage associated with artificial structures because of inherent biases and limitations (Larson *et al.*, 1986). The limitations of most methods have not been evaluated and would be difficult to determine.

The composition of fish assemblages at any one location depends on the method of collection. Assemblages collected from the same meadow using two different methods (poisoning and trawling) can be more different than assemblages collected from different

meadows with the same method (Gray and Bell, 1986). Even the catches from different types of beam trawl from within one seagrass meadow vary in number of species and number of individuals (McNeill and Bell 1992).

In present study buoyant pop nets (Figure 4.1) were used to collect fish sample from the seagrass meadow at Woollooware Bay. The buoyant pop net which was used for collecting fish sample from the vegetated fish habitats by Larson *et al.* (1986), Michael *et al.* (1989), Connolly (1994) and Mazumder *et al.* (2004) has the advantage of providing instantaneous assessment of fish density in shallow water vegetated habitats.

The aim of the study is to analyse the seasonal variability of fish between spring and neap high tides, and to compare fish use of seagrass with adjoining mangrove and salt marshes. Further, an attempt has been made to test the efficiency of the buoyant pop net.

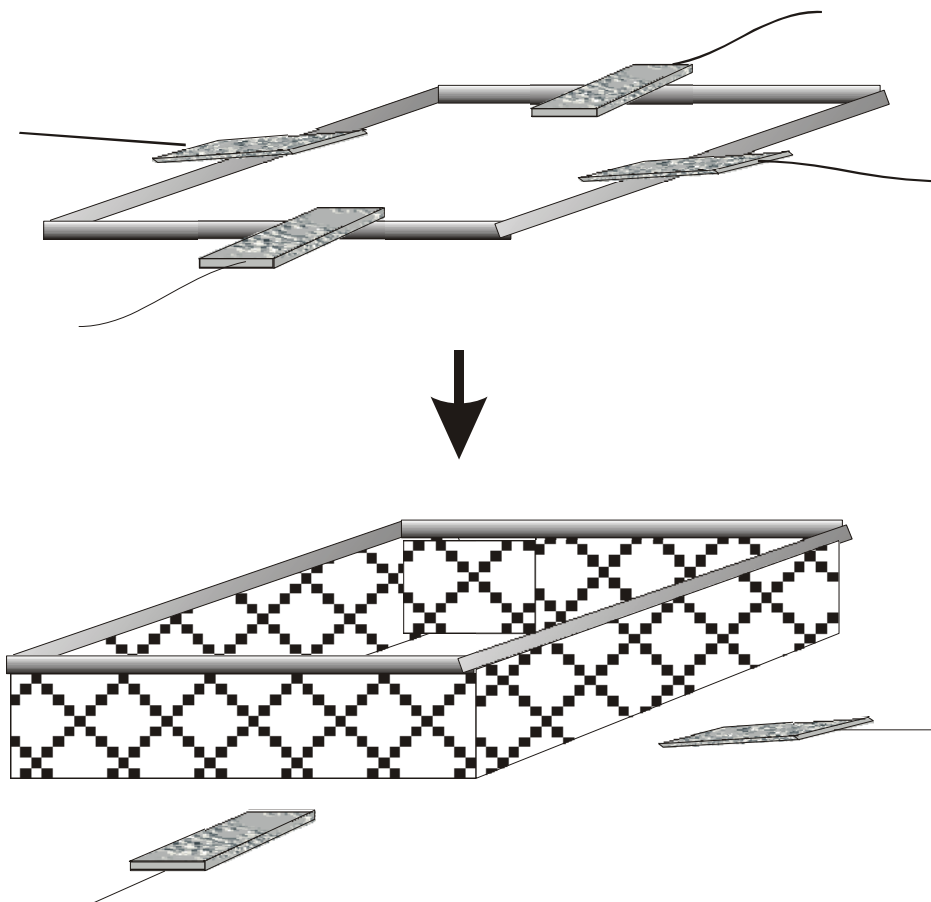


Figure 4.1 Configuration and operation of the buoyant pop net (after Mazumder 2004).

4.2. Study site and methods

4.2.1 Study Location

The study was conducted in seagrass meadow at Woollooware Bay which is one of the diverse tidal and estuarine wetlands in Sydney region of NSW (Figure 4.2). The seagrass meadow is comprised of *Zostera capricorni* (Larkum *et al.* 1984).

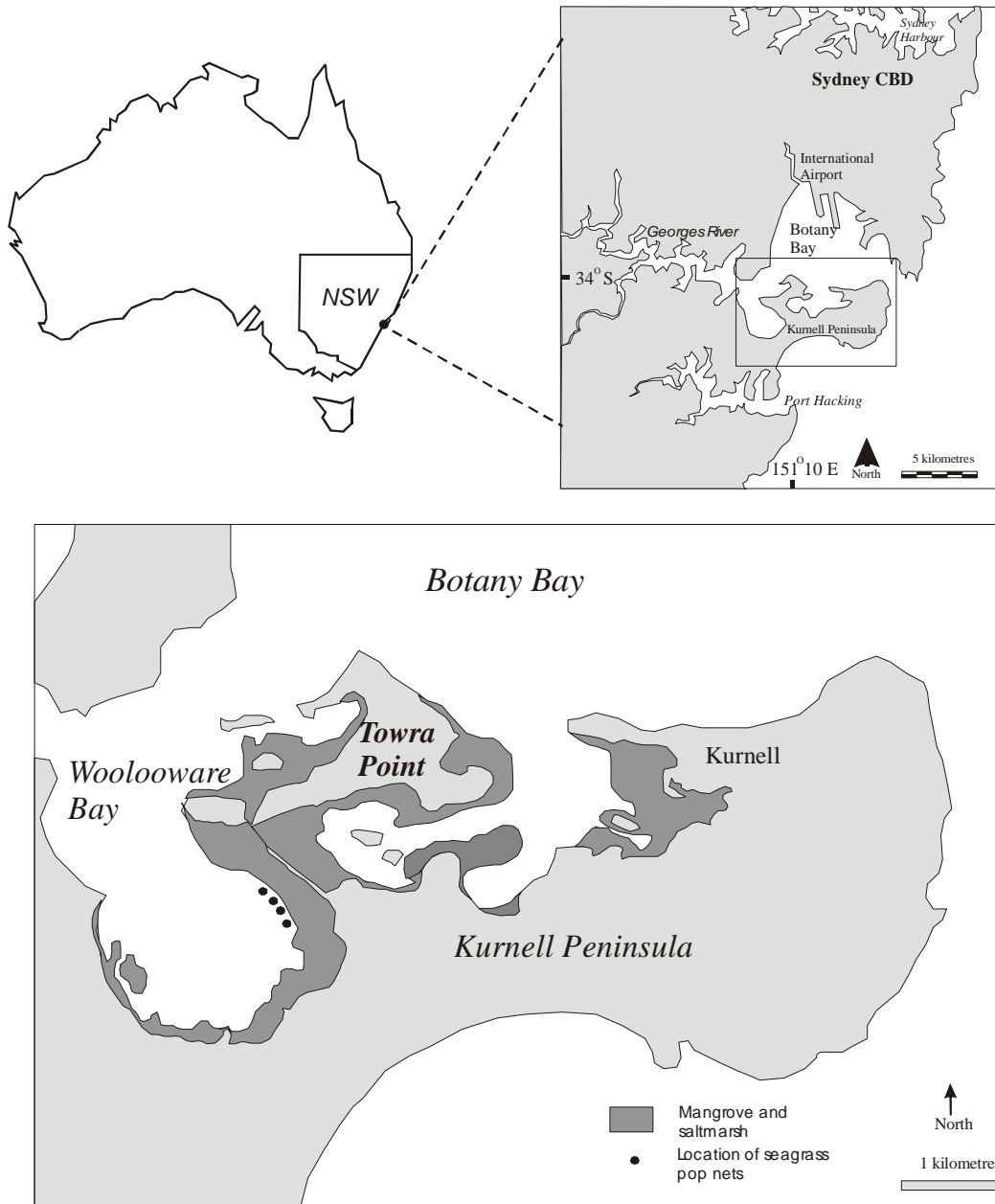


Figure 4.2 Location of pop nets within Woollooware Bay

4.2.2 Fish collection

Buoyant pop nets (Michel *et al.* 1989, Connolly, 1994) were used in seagrass to sample fish during spring and neap tide. The pop nets consist of 2.0 mm nylon mesh and are 5.5 m by 5.5 m square, elevating to a maximum height of 2.5 meters. The top of the mesh was attached to 15 mm diameter PVC pipe, sealed for flotation. The base of the net is secured tightly to the marsh surface using long tent pegs, with the nets hidden prior to release inside shallow trenches. Nets were weighed down with four concrete blocks attached with nylon rope to a remote point 150 meters from the nets. The nets were released from this remote point at the of spring and neap tide. Four replicate pop nets were used in seagrass bed, placed randomly. Fish were retrieved using a sweeping hand net. Fish sample were collected monthly during spring high tides (>1.8m) and neap tides (< 1.2 m) from January 2002 to December 2002.

Net efficiency

A component of this study was to test the efficiency of the pop nets in seagrass. A seine net was used to capture fish exiting the saltmarsh. Collected fish species were then placed into the floating pop nets that had been released at spring tide. Care was taken to remove fish from the vicinity of the pop nets prior to net release. A total of 286 fish representing four different species were captured in preparation for this experiment. These were divided between two buoyant pop nets, raised at the peak of a spring tide. Fish were collected during the receding tide.

4.2.3. Statistical methods

Differences in assemblages of fish between spring and neap high tide were examined using Bray-Curtis measures of dissimilarity (Bray and Curtis, 1957) with square root transformed data. Nonmetric multidimensional scaling (nMDS) plots were also used to demonstrate the patterns of fish assemblages in different seasons between high and neap tides (Clarke and Warrick 2001). Multivariate techniques such as ANOSIM (Clarke and Warrick 2001) was used to test the statistical significance of differences between the fish assemblages at spring and neap high tides. The contribution made by particular species to differences in species assemblages was determined using SIMPER (similarity

percentages-species contribution, Clarke and Warrick 2001) for spring and neap high tide.

Univariate analysis (ANOVA) and post-hoc Student-Newmans-Kuels (SNK) tests were performed using GMAV5 (Underwood and Chapman, 1989) to determine the significance of differences of fish abundance between spring and neap tides in different seasons. Two way analysis of variance was used (Underwood, 1997) where season was considered as the first factor with four levels (1=Winter, 2=Spring, 3=Summer and 4=Autumn) which were orthogonal and fixed. Tide was considered as second factor with two levels (1=spring tide and 2= neap tide), which were orthogonal and fixed.

4.3 Results

4.3.1 Seasonal variability in fish and crustaceans abundance

A total of 3972 fish and crustaceans of eleven species were caught in both spring and neap tides in Woollooware Bay, Towra Point, using pop nets (Table 4.1) where *Zostera capricorni* was the main seagrass species. Eleven species were found and most of them were juveniles. Among all the species *Metapenaeus macleayi* was most abundant contributing 20.80% of the total catch, followed by *Macrobrachium intermedium* (16.01%), *Alpheus edwardsi* (15.21%), and *Pelates quadrilineatus* (11.78%). *Liza argenta* and *Acanthopagrus australis* are the least abundant in seagrass bed contributing 3.40% and 2.90% of total catch.respectively.

P. quadrilineatus was most abundant in high tide during spring (13.83%) and summer (13.25%), almost equal abundant in winter (11.97%) and low in high tide during autumn (10.53%). *Arenigobius bifrenatus* was most abundant in high tide during winter (8.61%), spring (7.01%) and summer (9.88%) but less abundant in high tide during autumn (5.76%). *Pseudogobius olorum* was most abundant in neap tide during winter (7.38%), summer (7.58%), autumn (9.52%) and less abundant in neap tide during spring (8.67%). *Ambassis jacksoniensis* was most abundant in neap tide at all season (8.38% in winter, 11.90% in spring, 10.17% in summer and 7.00% in autumn).

The crustacean species *M. macleayi* was most abundant in spring, summer and autumn in neap tide contributing 22.18%, 21.99%, and 21.36% respectively of the catch by number. *M. intermedium* was most abundant in high tide in winter (18.91%), summer (19.04%) and autumn (16.04%). *A. edwardsi* was highly abundant in high tide during winter (19.12%) and autumn (17.29%) and less abundant during summer (13.73%) in high tide.

Three crustacean (*M. macleayi*, *M. intermedium*, *A. edwardsi*) and three species of fish (*P. quadrilineatus*, *P. olorum* and *A. bifrenatus*) are common in seagrass bed as they are found almost all time. Fish abundance vary during seasons. Among 11 species found in seagrass bed four were of commercial importance (Table 4.1).

Table 4.1. Species caught from seagrass meadow with pop nets at Woolaware Bay, Towra Point from January 2002 – December 2002. The asterisk (*) designates species of commercial and or recreational significance.

Family	Genus/species	Common name	% Contribution to catch									
			Winter (June-Aug.)		Spring (Sep.-Nov.)		Summer (Dec.-Feb.)		Autumn (Mar.-May)		All season	
			High	Neap	High	Neap	High	Neap	High	Neap	High	Neap
Gobiie	<i>Arenigobius bifreentus</i>	Bridled goby	8.61	6.39	7.01	6.05	9.88	8.87	5.76	7.18	7.79	7.16
Gobiidae	<i>Pseudogobius olorum</i>	Blue spot goby	6.72	7.38	9.81	8.67	5.54	7.58	8.77	9.52	7.84	8.31
Teraponidae	<i>Pelates quadrilineatus</i>	Trumpeter *	11.97	11.98	13.83	7.26	13.25	9.98	10.53	13.47	12.52	10.74
Tetraodontidae	<i>Tetractenos hamiltoni</i>	Common toad	2.73	2.20	4.90	2.42	4.82	3.33	4.51	3.59	4.25	2.91
Mugilidae	<i>Liza argenta</i>	Flat tail mullet *	0.64	4.79	2.63	4.64	3.86	2.40	3.52	4.85	2.58	4.15
Sparidae	<i>Acanthopagrus australis</i>	Yellow fin bream *	0.63	3.39	1.93	5.44	2.89	3.14	2.26	3.41	1.88	3.82
Ophichthidae	<i>Ophisurus serpens</i>	Eel fish	2.73	1.20	2.10	2.62	3.13	1.85	5.01	2.69	3.12	2.10
Chandidae	<i>Ambassis jacksoniensis</i>	Glass fish	5.67	8.38	9.81	11.90	6.99	10.17	5.51	7.00	7.20	9.31
Crustaceans												
Penaeidae	<i>Metapenaeus macleayi</i>	School prawn *	22.27	21.36	19.61	22.18	16.87	21.99	20.80	21.36	19.94	21.72
Atyidae	<i>Macrobrachium intermedium</i>	Grass shrimp	18.91	17.36	15.06	15.52	19.04	14.05	16.04	13.82	17.14	15.13
Alpheidae	<i>Alpheus edwardsi</i>	Common pistol shrimp	19.12	15.57	13.31	13.30	13.73	16.64	17.29	13.11	15.74	14.65

4.3.2 Fish abundance and species richness

Spring high tide

ANOVA results showed that fish abundance in seagrass varied significantly among the seasons in spring high tide ($P < 0.01$; Table 4.2).

Table 4.2: ANOVA results for fish abundance in spring high tide between seasons in seagrass using pop nets at Woollooware Bay, NSW: Cochran's Test $C = 0.3167$

Source of variation	DF	MS	F	P
Season	3	48.446	3.77	0.0107
Residual	524	12.855		
Total	527			

Neap high tide

ANOVA results showed that fish abundance in seagrass did not vary among the seasons in neap tide ($P > 0.6515$; Table 4.3).

Table 4.3: ANOVA results for fish abundance in neap tide between seasons in seagrass using pop nets at Woollooware Bay, NSW: Cochran's Test $C = 0.2767$

Source of variation	DF	MS	F	P
Season	3	7.8737	0.55	0.6515
Residual	524	14.4387		
Total	527			

Comparison of spring and neap high tide

ANOVA results showed that fish abundance in spring and neap tide vary between seasons ($P < 0.0039$) and no significant difference was found in fish abundance between the tides ($P > 0.4389$, Table 4.4).

Table 4.4: Two way analysis results for fish abundance between seasons and tides at Woollooware Bay, NSW: Cochran's Test C=0.1492

Source of variation	DF	MS	F	P
Season	3	61.1550	4.48	0.0039
Tide	1	8.5464	0.63	0.4289
Season X Tide	3	10.0464	0.74	0.5305
Residual	1048	13.64783		
Total	1055			

The post-hoc SNK test for fish abundance between high and neap tide in different seasons showed fish abundance in winter in neap tide to be significantly higher than spring tide. Fish abundance between spring and neap tide in spring, summer and autumn did not vary significantly (Figure 4.3).

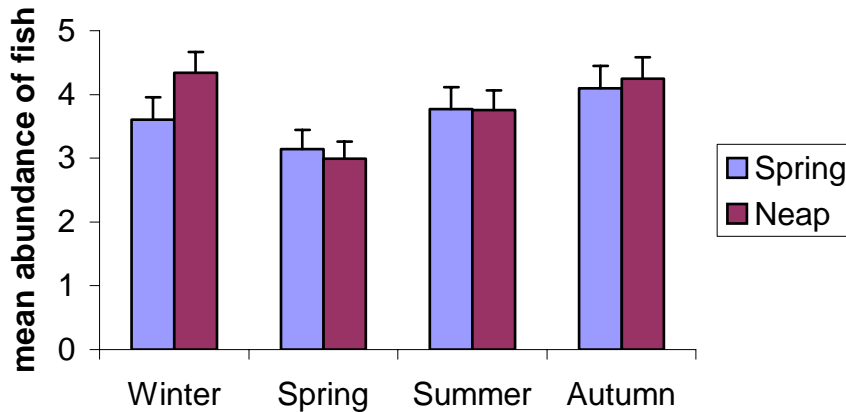


Figure 4.3: Mean abundance (+ SE) of fish in seagrass bed at Towra Point (Woollooware Bay) in different seasons using pop nets, n=132.

Fish assemblages in spring and neap high tides

Non-metric multidimensional scaling (nMDS) ordinations between the tides showed different assemblages of fish in seagrass meadow (Figure 4.4).

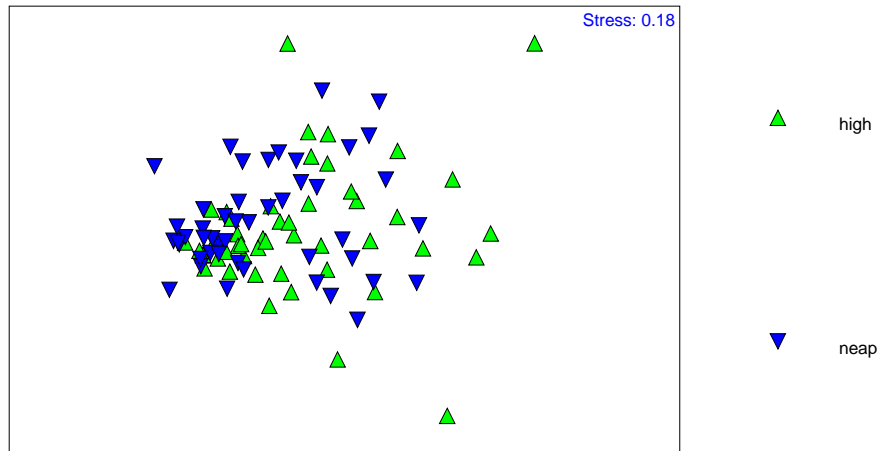


Figure 4.4. NMDS ordinations showing assemblages of fish in spring high and neap high tides at Woollooware Bay using pop nets.

Analysis of similarities (ANOSIM) results show that fish assemblages differed significantly between the spring and neap high tides (ANOSIM: $P < 0.04$). The dissimilarity between the tides appears primarily due to the higher abundance of *Ambassis jacksoniensis*, *Acanthopagrus australis*, *Metapenaeus macleayi*, and *Liza argenta* in the neap tide (Table 4.5).

Table 4.5: Contribution of species of dissimilarity between spring and neap high tides fish assemblages in the Woollooware Bay seagrass.

Species	Group		Av.Diss	Diss/SD	Contrib%	Cum.%
	spring	neap				
Pistol shrimp	6.10	6.48	6.25	1.36	15.11	15.11
School prawn	7.73	9.48	6.02	1.39	14.56	29.66
Grass shrimp	6.65	6.60	5.64	1.35	13.64	43.30
Glassfish	2.79	4.06	4.32	1.30	10.45	53.76
Trumpeter	4.85	4.69	4.29	1.37	10.38	64.13
Blue spot goby	3.08	3.62	3.86	1.37	9.32	73.46
Bridal goby	3.02	3.12	3.45	1.27	8.35	81.80
Flat tail mullet	1.00	1.81	2.19	1.13	5.31	87.11
Yellow fin bream	0.73	1.67	2.10	1.03	5.09	92.20

4.3.3 Results from efficiency experiment

A total of 286 fish were released in to two pop nets but only 78 (27.3%) were retrieved from the two nets (Table 4.6). In net 1, there were 3 *Liza argenta*, 4 *Tetractenos hamiltoni*, 8 *Acanthopagrus australis* and 117 *Ambassis jacksoniensis* were released but retrieved 3 *Acanthopagrus australis*, 23 *Ambassis jacksoniensis*, all *Tetractenos hamiltoni* were retrieved but none of *Liza argenta* were retrieved. The retrieval rate in net 1 was 22.7%.

In net 2, there were 4 *Liza argenta*, 4 *Tetractenos hamiltoni*, 8 *Acanthopagrus australis*, and 138 *Ambassis jacksoniensis* released but retrieved 3 *Tetractenos hamiltoni*, 2 *Acanthopagrus australis*, and 43 *Ambassis jacksoniensis*. None of *Liza argenta* were retrieved. The retrieval rate in pop net 2 was 31.2%.

Table 4.6: Released and retrieved fish population from two buoyant pop nets as a test of net efficiency

Species	Common name	Net 1		Net 2	
		Released	Retrieved	Released	Retrieved
<i>Liza argenta</i>	Flat tail mullet	3	0	4	0
<i>Tetractenos hamiltoni</i>	Common toad	4	4	4	3
<i>Acanthopagrus australis</i>	Yellow fin bream	8	3	8	2
<i>Ambassis jacksoniensis</i>	Glass fish	117	23	138	43

4.3.4 Fish assemblages among the habitats (seagrass, mangrove and saltmarsh)

The experiments were conducted in tandem with an identical experiment performed by Debashish Mazumder in adjacent mangrove and saltmarsh (Mazumder, 2004). His data have been included with permission in an nMDS plot (Figure 4.5), which compares similarity of assemblages between adjacent seagrass, mangrove and saltmarsh habitat for five months between October, 2001 and February, 2002.

Non-metric multidimensional scaling (nMDS) ordinations showed different assemblages of fish in seagrass, saltmarsh and mangrove (Fig. 4.5). Analysis of similarities (ANOSIM) results show that fish assemblages differed significantly between the habitats (ANOSIM: $P < 0.0001$).

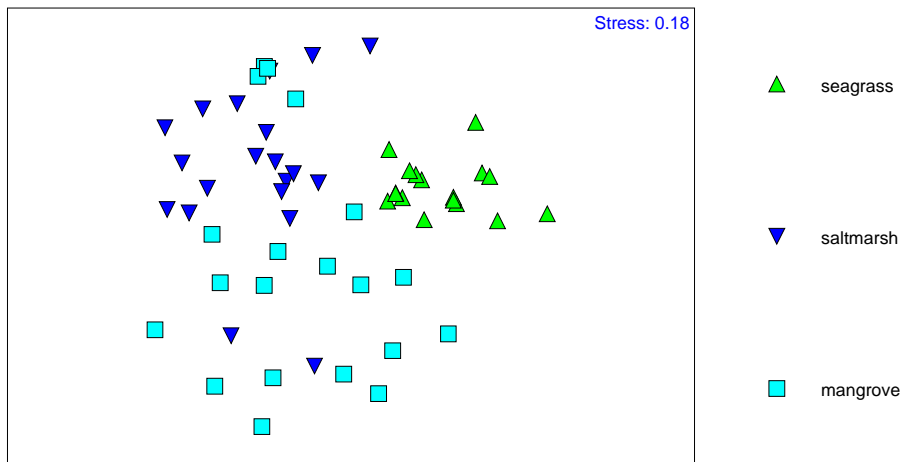


Figure 4.5. nMDS ordinations showing assemblages of fish in seagrass, mangrove and saltmarsh at Woollooware Bay using pop nets (including data from Mazumder, 2004).

4.4 Discussion

The results of the capture efficiency of pop nets demonstrated inter-specific difference in recapture rate. Low recapture of *Liza argenta* (zero recapture), high recapture rate for *Tetractenos hamiltoni* and moderate recapture rate for *Acanthopagrus australis* and *Ambassis jacksoniensis* were demonstrated for two released buoyant pop nets. Such results would under-represent some species particularly those able to jump out of the net (eg. *Liza argenta*). However the two nets were relatively consistent in their efficiency and comparison between nets and the environment remain valid. Mazumder (2004) found the average size of fish retrieved from the pop nets was consistently larger than from fyke nets and smaller fish caught in the pop net were not retrieved. He also suggested pop net catches were biased toward the larger size classes of fish. Further studies utilizing buoyant pop nets may wish to extend this efficiency test.

Although there were no significant differences in fish species abundance between the tides there were differences found between seasons. Almost all the species are present in both spring and neap high tides. Most of the fish species captured from *Zostera capricorni* bed in Woollooware Bay were juveniles. Settlement and recruitment of juvenile fish was estimated by Upston and Booth (2003), in natural and artificial seagrass in Botany Bay, NSW but there was no significant difference in abundance of recruits among the habitats. Middleton *et al.* (1984) found smaller fish species dominate *Zostera* meadow and larger fish species dominate the *Posidonia* site in Botany Bay, a finding reflected in this study. The study suggests that the *Zostera capricorni* meadow of Woollooware Bay is dominated by juvenile fish.

Fish abundances in Woollooware Bay were generally highest in autumn (Figure 4.3). State Pollution Control Commission (1981) reported the highest abundance of fish in autumn in Botany Bay. This seasonal peak in abundance was probably due to a peak in the seasonal recruitment of juveniles, as summer (February) is the peak in the abundance of fish eggs in the plankton and autumn is the peak in abundance of post larvae and small juveniles of commercial species (SPCC 1981).

Fish found in lower abundance in seagrass during the spring tide were those which Mazumder *et al.* (2004) found to be common in mangrove and saltmarsh during the same spring tides (*Alpheus edwardsi*, *Metapanaeus macleayi*, *Ambassis jacksoniensis*, *Pseudogobius olorum*, *Liza argeta*, *Acanthapagrus australis*). *Pelates quadrilineatus* was found not to differ between spring and neap tides in seagrass, and this species appears to be a seagrass specialist, rarely venturing into the mangrove or saltmarsh (Mazumder *et al.* 2004).

A different assemblage of fish is found in spring high tide compare to neap tide. The monthly spring tide had the lower diversity and abundance of fish species than the neap tide. These are species which were found to moving into the adjacent mangrove and salt marsh by Mazumder *et al.* (2004). Indeed the nMDS plot (Figure 4.5) shows clear

difference in the fish communities in the three adjacent habitats at the peak of the spring tide, with seagrass exhibiting lower concentration of fish species.

The results strongly suggest nekton move out of the seagrasses during the spring tides and into the adjacent inter tidal habitats, and less so during the neap tide when only seagrass and mangrove are covered. Nekton using estuarine habitats are highly mobile and move readily between multiple habitat types regularly over a tidal cycle or during the course of their life cycle (Skilleter and Loneragan, 2003). Many species move into intertidal areas during the flood tide and retreat to the shallow subtidal during the ebb flow (Rozas and Odum 1987; Hettler 1989; Kneib and Wagner 1994; Thomas and Connolly 2001). This illustrates the importance of viewing estuarine wetlands as a mosaic of inter-connected habitats.

Chapter Five: Discussion and Recommendations

5.1 Important results

Commonly used protocols for biological monitoring are seldom subject to rigorous assessment. More often, techniques used are justified by simple reference to authority which can become an expedient means to propagate unreliable methods or unreplicable results (Peters 2001). This thesis sought to examine and apply seagrass monitoring protocols with a view to analyzing their efficiency and reliability. Primarily, it was hoped that the outcomes of the thesis might lead to recommendations concerning optimal sampling strategies for *Zostera capricorni*. In the process, some new insights were gained into the functioning of *Zostera* as a fish habitat.

The ARCVIEW Geographic Information System was used to construct vegetation polygons of seagrass distribution on the Tweed River, and in the Ukerebagh Channel annually over a 5-year period. There were a number of reasons for choosing the Tweed River. Firstly, the quality of the aerial photograph coverage was excellent. The clarity of the water over the study period allowed for relatively easy identification of the seagrass boundaries. This eliminated identification errors from the analysis, allowing this work to concentrate on errors relating to boundary definition. The Tweed River was also subject to major entrance modification works over the period of study. The opportunity existed to study a system in flux, as increased tidal velocities modified tidal shoals, potentially redistributing seagrass.

The mapping showed relatively low inherent error in boundary definition. A 2.9% discrepancy was found when the Ukerebagh Channel was mapped twice from the year 2000 photographs. On this basis, the inter-annual variability was deduced to be real, being a consistent increase in extent in the range of 5-12% per annum. There was no evidence that this increase was the result of the Tweed sand bypassing, which commenced in 2001, as increases in extent were occurring before this time. More likely, the increases in seagrass extent within the Ukerebagh Channel related to the *El Nino* drought, with natural extension unimpeded by flood scouring or sedimentation.

Importantly, the study suggests inter-annual variability relevant to any monitoring study. This can be contrasted to the mapping of mangrove and saltmarsh, in which inter-annual variability is insignificant in most cases (Saintilan and Wilton 2000). One clear recommendation is that seagrass extent could usefully be mapped more frequently than the 5-yearly period recommended by Saintilan and Wilton (2000) for mangrove and saltmarsh.

Estimates of biomass were derived from standard replicate 0.25m x 0.25m quadrats following Larkum et al. (1984), Larkum and West (1990), Kirkman and Cook (1982), Mellors (1991) and Lanyon and Marsh (1995). The experiment contrasted two sites of similar geomorphic setting. Ukerebagh Channel on the Tweed River, and Woolooware Bay with Botany Bay are both shallow, sandy marine deltaic settings supporting stands of *Zostera capricorni*. Significant differences were found in the degree of replication required to identify significant changes in seagrass biomass at the two sites. Ukerebagh Channel supported relatively dense stands of *Z. capricorni* with low intra-site variability. Here 8 replicates were sufficient to detect 10 percent change at $P = 0.05$. Towra Point presented a contrast, in which 15 replicates were required to detect a similar level of change. Towra Point has suffered from increased sedimentation relating to alterations in current velocities at Towra Point, and the result highlights the greater degree of replication required to determine significance changes in disturbed systems.

Previous research on estuarine habitats has led to significant advances in our understanding of the importance of specific features of habitats, such as the complexity of mangrove root systems on finfish and crustacean abundance. However, this approach has treated different types of habitat as isolated and separate patches rather than as a 'mosaic' of interlinked habitats. Recent studies have shown that fish species utilise habitat mosaics and move between multiple habitat types regularly over a tidal cycle or during the course of their life cycle (Skilleter and Loneragan, 2003). Fluxes in the density of fish and the availability of food between the interlinked habitats of seagrass and mangrove, and the contribution of this mosaic to the fishery is worthy of quantification.

The fish populations in the seagrass at Towra Point were sampled using buoyant pop nets, concurrently with surveys using the same technique in the mangrove and saltmarsh performed by Mazumder (2004). Fish communities differed significantly from those sampled in adjacent mangrove and saltmarsh. Differences in fish assemblages between spring high tides, neap high tides and low tides are attributed to movements of fish between seagrass and adjacent mangrove and saltmarsh. This mosaic of habitats is utilized by a number of species over a tidal cycle, with seagrass providing an important low-tide refuge for many species utilizing mangrove and saltmarsh at high tide.

The result is of significance for a number of reasons. Firstly, it underscores the importance of managing estuaries with consideration of linkages between habitats. The value of seagrass, mangrove and saltmarsh might differ depending on their placement with respect to adjacent habitats. It may be that the finding of Mazumder et al (2004) that the Towra Point mangrove and saltmarsh fish assemblage is more diverse than Homebush Bay and Allens Creek can be attributed to the absence of seagrass adjacent to these locations, rather than the marine effects cited by the authors. Future studies would do well to consider the influence of seagrass on the diversity and abundance of fish assemblages in mangrove and saltmarsh in a more controlled experimental design.

Limitations in the efficiency of buoyant pop nets were exposed in a novel experiment which demonstrated differences in escape rates between species. Flat-tailed mullet (*Liza argenta*) are likely to be under-represented in experiments using this technique, as are bream (*Acanthopagrus australis*). This is an important consideration when sampling in these environments. The buoyant pop net has considerable advantages over fyke nets and seine nets in a seagrass setting, because catch can be translated directly into density. However, this is the first study that has considered catch efficiency in anything but a comparative study. Clearly, the pop net will require some design modifications if they are to be employed in inter-site comparisons of fish assemblages.

5.2 Recommendations regarding sampling

A number of recommendations can be made regarding optimal sampling protocols for monitoring seagrass in the region. These can be summarized as follows:

1. Seagrass should be mapped more frequently than mangrove and saltmarsh if changes in distribution are to be detected in time series. The 5-year period nominated for mangrove and saltmarsh is inadequate as applied to seagrass.
2. The degree of replication required for biomass assessment varies depending on the characteristics of the seagrass community. Patchy disturbed seagrass communities require 15-20 replicate 0.25m by 0.25m quadrats to detect 20% change at $P < 0.05$. Stable, dense seagrass communities require a lesser degree of replication, and eight replicates may be sufficient to identify even 10% change at $P < 0.05$. In all cases power analysis should be performed to determine whether an adequate sample has been attained.
3. The buoyant pop net should be modified to more adequately retain fish caught within the net at the time of release. This might best be done by securing an additional barrier to escape after release, such as a heightened wall. The net could, for instance, be propped up to an extended height above the water level with the use of vertical stakes. This would prevent the escape of fish over the top of the buoyant rim, which was clearly happening in the case of *Liza argenta* (which can jump), and most probably *Acanthopagrus australis*.

5.3 Recommendations for future research

The study has suggested a number of lines of enquiry which might further clarify the ecological function of seagrass and the means of studying these interactions. While this study has identified one source of mapping error (boundary definition in identical images), other sources of mapping error could be studied experimentally. One example would be the comparison of results where seagrass boundaries were not so clearly delineated. This might occur where image quality is poor, (either due to poor photograph quality or poor water quality), or where seagrass grades into fluvial muds, rather than the quartz sand found on the Tweed.River It would be useful to gain an appreciation of circumstances in which seagrass mapping using on-screen digitizing from colour images is inappropriate, and whether the infra-red spectra might provide better results.

The study has suggested important linkages between seagrass and adjacent wetland habitats over the course of the diurnal and neap-spring tidal cycles. The importance of habitat mosaics and linkages cannot be overstated, and this new area of research deserves more thorough treatment. As previously suggested, a controlled study might be envisaged which compares mangrove and saltmarsh utilization by fish in the presence and absence of seagrass. Such an experiment could either use natural habitat mosaics or incorporate a BACI design (Underwood 1991, 1992) through the removal or planting of seagrass.

The study has showed the abundance of commercial and ecological important fish species in the seagrass during high and neap tidal cycles. To what extent seagrass, seagrass epiphytes and epibenthic microalgae provide food for these species were beyond the scope of the current research. However, a detailed assessment of nutritional contribution of seagrass, epiphyte and epibenthic microalgae to the commercial and ecological fish species is therefore desirable.

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