Physical effects of hauling on seagrass beds

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NON TECHNICAL SUMMARY

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OBJECTIVES:

1. Identify whether the effects of estuary hauling on seagrass meadows is identifiable at the estuary level,
2. Assess the 'within-estuary' impacts of hauling, if any, on seagrass shoot and leaf density, and leaf length,
3. Interpret the results in relation to known information on the utilisation of the seagrass habitat by fish,
4. Recommend what further studies need to be done if effects are detected.

The study used large scale field sampling and manipulative field experiments to examine the physical effects of hauling on seagrass beds. The research concentrated on the eelgrass, *Zostera capricorni* because of the likely greater net-related disturbance in shallow regions and the resources available. We concentrated on detecting differences to the shoot and leaf densities, and leaf length of *Zostera capricorni* because these variables would most likely be affected by the passage of a commercial haul net. A pilot study in Botany Bay was carried out to develop the sampling methods and data arising from this study were used in power and cost-benefit analyses to assist in designing the sampling.

As hauling has been carried out over decades, any long-term impacts should be correlated with significant differences between seagrass variables at sites where hauling has and has not occurred. With this in mind, we sampled the shoot and leaf densities, and leaf length of *Zostera capricorni* at one hauled site and six control (unhauled) sites in each of nine estuaries (Wallis Lake, Port Stephens, Lake Macquarie, Tuggerah Lakes, Botany Bay, Lake Illawarra, St. Georges Basin, Burrill Lake and Wallaga Lake). This sampling was carried out in Winter 1996 and repeated in Summer 1997.

The instantaneous (short-term) effects of hauling were also assessed via studies carried out in Botany Bay in Winter 1996 and Summer 1997. This research involved the use of commercial nets at Silver Beach and an experimental net at unhauled sites in the Towra Point Aquatic Reserve. In addition to the normal sampling, we tagged seagrass leaves with white orthodontic rubber bands to examine the ability of seagrass leaves to survive the effects of hauling.

To assist in the interpretation of these results we examined estuary-wide, annual hauling effort data for the period 1984 to 1996 obtained from the catch and effort database maintained by NSW Fisheries. The average annual hauling effort differed among estuaries as expected, but more importantly, the nine estuaries could be combined into three groups each separated by an order of magnitude of hauling effort. Because this does not account for the differing amounts of hauling ground available across all the estuaries, the analyses incorporating nominal hauling effort were only exploratory. No obvious linear trends (increases or decreases) in the annual hauling effort over the period 1984 to 1996 were evident in Wallis Lake, Lake Macquarie, Tuggerah Lake, Botany Bay, Burrill Lake and Wallaga Lake. In contrast, there was a decrease in hauling effort in

Lake Illawarra and St George's Basin and a increase in effort in Port Stephens over the same period.

Hauling did not result in the total removal of *Z. capricorni* from any site, but was correlated with differences to the shoot and leaf densities, and length of the leaves at some sites in Winter and Summer. Plots of each of these variables (i.e. 18 means per plot for each seagrass variable) showed the following patterns at the hauled site. Shoot density greater in 7 and less in 10, whereas leaf density was greater in 6 and less in 10, of the possible 18 ratios. Finally, leaf length was greater in 3 and less in 14, of the possible 18 ratios. The large natural variation among control sites reduced the realised statistical power and led to ambiguity in the interpretation of the statistical tests (analyses of variance) when non-significant.

Of the six major analyses, only leaf length in Winter 1996, was correlated with significantly shorter leaves of *Zostera capricorni* (20% on average) at the hauled sites. The differences in leaf length between the hauled and control sites varied among estuaries with reductions of 17 - 39% occurring in all estuaries except Port Stephens and Wallaga Lake where the means did not differ significantly. Significant increases in shoot and leaf density also occurred during the Winter 1996 at the hauled sites in Lake Macquarie and Botany Bay.

In Summer 1997, there were no significant changes present across all estuaries, but insufficient power (i.e. power = 0.80) was realised in the statistical analyses. The only significant differences correlated with hauling over *Zostera capricorni* were evident in Port Stephens and St. George's Basin. In Port Stephens, the leaf length was significantly reduced by 56% despite the increased growth rates of *Zostera capricorni*. In St. George's Basin, the *Zostera capricorni* leaves remained lower at the hauled site in Jewfish Bay, representing a 73% difference compared to the average of the controls. This occurred in spite of the fishing closure in Jewfish Bay (St George's Basin) over the period October to May.

No instantaneous (short-term - i.e. over 3 days) impacts on *Zostera capricorni* were detected using the commercial and experimental haul nets in Botany Bay. Neither net had any significant effects on shoot and leaf densities, leaf-lengths or the persistence of seagrass leaves after 1-3 individual hauls of the net.

In summary, the significant reduction in leaf length in Winter correlated with hauling over *Zostera capricorni* beds was followed by recovery over the growth period in Spring/Summer. The differential hauling effort could possibly alter this pattern of putative impact as the hauled site in estuaries with highest levels of nominal effort were correlated with significant increases in shoot and leaf densities in Winter. These increases in shoot and leaf densities may be a mechanism that the seagrass uses to compensate for the reductions in leaf length. Finally, given that sampling was only carried out in one Winter and one Summer, it is not certain whether the pattern of hauling-related reduced leaf length in Winter and recovery in Summer would be evident in other years. A further study will be needed to test this assertion.

Previous research has shown that seagrass beds are important as sites for recruitment of fish and macro-invertebrates. Furthermore field studies in which the shoot/leaf densities and leaf lengths were experimentally reduced in excess of 30% resulted in significant reductions in the abundance and richness of fish recruits and macro-invertebrates. Given that the possible hauling-induced reduction in seagrass length during winter had an average of 20%, the possible increase in shoot/leaf density at such locations, and the large areas in most estuaries where hauling is not permitted/possible, any impact on recruitment whilst untested, is unlikely to be major.

Despite the often large variations among control sites and estuaries (ie these factors accounted for most of the variation), the sampling detected significant differences correlated with hauling in some estuaries and in some seasons. Unfortunately, the lack of power in many of the tests reduced the number of few firm conclusions that can be made. Consequently, it is recommended that further research be done to document:

(1) the physical effects of hauling on seagrass beds via a long-term, large-scale, field experiment involving industry and staff (research and management) from NSW Fisheries.
(2) whether the measured differences and similarities in *Zostera* variables persist over a longer time by repeating the study;
(3) the site specific hauling effort in estuaries along the NSW coast;
(4) whether hauling impacts on other seagrass species (e.g. *Posidonia*), and
(5) the percentage of seagrass area in estuaries where hauling occurs in relation to possible effects on fish/invertebrate recruitment.

With such information it would then be possible to interpret the combined results in relation to our existing knowledge of seagrass beds and the fisheries dependent on them, and provide long-term recommendations concerning the ecologically sustainable management of hauling over seagrass beds.

BACKGROUND

Previous research has shown that seagrass beds are important as sites for the recruitment of fish and macro-invertebrates. Furthermore, field experiments in which the shoot/leaf densities and leaf lengths of several seagrass species were reduced resulted in significant reductions to the species richness and abundances of fish and macro-invertebrates living amongst the seagrass. Given that the recruitment of fish and macro-invertebrates to seagrass beds is important for the maintenance of the estuarine and coastal (offshore) commercial and recreational fisheries, any ecologically significant alterations to seagrass abundance via hauling are clearly of importance to industry and the public alike.

A letter from Ocean Watch was tabled at the NSW Fishing Industry Research Advisory Committee (FIRAC) meeting of 28 October, 1994. The letter requested that the NSW FIRAC consider commissioning a project assessing the effects of fishing on seagrass beds. In view of this, a research proposal was prepared by the NSW Fisheries Research Institute. The proposal received strong support from the NSW FIRAC and was recommended to FRDC with funding for one year to be provided from the NSW trust fund. This was accepted by FRDC and the project commenced in February 1996. A further application to FRDC to allow the field sampling to be repeated was successful and the project was extended for a further six months.

NEED

The need for this project was recognised for a number of reasons. First, over recent years the fishing industry has realised the need to demonstrate that its activities are environmentally sustainable. Second, the Fisheries Management Act 1994 has upgraded the habitat protection provisions (see Sections 204 and 205) to provide for greater control over activities that can affect aquatic habitats, incuding seagrass beds. Third, there has been no research on hauling on seagrass beds in Australia or elsewhere in the world, and thus there is, at present, no scientific evidence to either support or refute the claims that hauling causes physical damage to seagrass beds. Fourth, the multi-use nature of estuaries has resulted in inevitable clashes between various interest groups and hauling has been repeatedly implicated by anglers, conservation groups and other commercial fishers as one of the major causes of seagrass loss in Australian estuaries (Ruello & Henry, 1977). Fifth, the substantial declines of seagrass in some of the estuaries in NSW has been documented in a number of studies (e.g. Larkum & West, 1990; Walker & McComb, 1992; Hamdorf & Kirkman, 1995) and the release of the State of the Marine Environment Report has highlighted the importance of this issue.

OBJECTIVES

The aim of the project is to identify whether there are any physical effects of hauling on seagrass beds, and if so, to indicate the directions of further research. It was deemed necessary to:

1. identify whether the effects of estuary hauling on seagrass meadows is identifiable at the estuary level,
2. assess the 'within-estuary' impacts of hauling, if any, on seagrass shoot and leaf density, and leaf length,
3. interpret the results in relation to known information on the utilisation of the seagrass habitat by fish,
4. recommend what further studies need to be done if effects are detected.

1. INTRODUCTION

1.1 ESTUARIES: A MULTIPLE-USE COASTAL RESOURCE

Estuaries and lagoons (coastal lakes) are common features in NSW especially in the central and southern coastal regions, and provide ideal conditions for the growth of extensive seagrass beds. The relatively calm waters of estuaries often contain abundant seafood readily accessible to humans. Consequently, early human settlers in Australia showed a preference for these regions and this is readily exemplified by the many Aboriginal middens that are found around the foreshores of estuaries (for details see Bell & Edwards, 1980). More recent urbanisation of estuaries can be linked directly to the development of ports and townships for trade and the shelter of coastal shipping. Today, estuaries support large urban populations with approximately 60% of Australia's population living in cities and towns surrounding estuaries (Yapp, 1986; Fairweather, 1990). Commercial fishing in estuaries in NSW has raised concerns especially as large numbers of juvenile fish are taken as by-catch (*sensu* Saila, 1983). For example, Kennelly *et al.* (1992) have shown that significant numbers of juvenile snapper and mulloway are caught by the estuarine prawn-trawl fishery. The land surrounding estuaries also has multiple-uses (Bell & Edwards, 1980), with areas zoned for industrial, commercial, urban, recreational and conservation purposes. Consequently, estuaries are also subjected to an increasing level of anthropogenic disturbances (e.g. waste disposal & dredging) leading to inevitable habitat destruction (Fairweather, 1990; Rieman & Hoffmann, 1991; Otway *et al.*, 1995; Skilleter, 1995). This has lead to a multitude of management issues requiring multi-disciplinary scientific research and broad-based socio-economic studies to identify, where possible, the causes and solutions to many of the problems facing managers in all levels of government.

1.2 SEAGRASS BEDS AND ASSOCIATED COMMUNITIES

The ecological importance of seagrass beds has been widely documented with respect to primary productivity (West & Larkum, 1979; Larkum *et al.*, 1984; Hillman *et al.*, 1989), biodiversity (Bell *et al.*, 1988; Bell & Pollard, 1989; Potter *et al.*, 1990; Gray *et al.*, 1996; Jenkins *et al.*, 1997) and as a nursery for juvenile fish (Pollard, 1984; Bell *et al.*, 1984; Bell *et al.*, 1987; Potter *et al.*, 1990; Worthington *et al.*, 1991; McNeill *et al.*, 1992; Jenkins *et al.*, 1995). Unfortunately, damage to, and loss of seagrass habitat in shallow coastal waters has also been commonly reported worldwide (Kirkman, 1978; Cambridge *et al.*, 1986; King & Hodgson, 1986; Coles *et al.*, 1989; Shepherd *et al.*, 1989; Larkum & West, 1990; Walker & McComb, 1992; den Hartog 1994; Short & Wyllie-Echevarria, 1996).

In NSW, the majority of the ecological research on seagrasses has been carried out in estuaries within 200 km of Sydney and in particular Lake Macquarie (e.g. Wood, 1959; King, 1986; King & Hodgson, 1986), Tuggerah Lake (e.g. King & Barclay, 1986;), Botany Bay (e.g. West & Larkum, 1979; Pollard, 1984; Larkum *et al.*, 1989), Port Hacking (e.g. Kirkman *et al.*, 1982), Lake Illawarra (e.g. Harris *et al.*, 1979; Evans & Gibbs, 1981;) and Jervis Bay (e.g. Worthington *et al.*, 1991; McNeill, 1994; Fitzpatrick & Kirkman, 1995). This research has shown that the seagrasses exhibit substantial spatial and temporal variation in abundance (i.e. shoot/leaf density, leaf length & area of bed) among individual beds and, within and among estuaries. Furthermore, several authors (e.g. Harris *et al.*, 1979; Larkum *et al.*, 1984) have shown that seagrasses in NSW's estuaries undergo a growth cycle in which the shoot/leaf density and leaf length vary depending on the time of year. This is generally characterised by a period of die-back in Winter resulting in reduced shoot/leaf densities, and leaf length. This is then followed by a growth period from late Spring to Summer over which time maximal shoot and leaf densities, and leaf length are attained.

1.3 ANTHROPOGENIC IMPACTS ON SEAGRASS BEDS

1.3.1 NON-COMMERCIAL FISHING RELATED IMPACTS

1.3.1.1 Worldwide

A wide range of human activities have been identified as being directly or indirectly responsible for loss of seagrass throughout the world (Thayer *et al*., 1975; Short & Wyllie-Echevarria, 1996 for reviews). The effects of urban development and run-off along the coastal fringe and in the catchment of estuaries has been the most commonly implicated anthropogenic cause for large-scale, long-term seagrass loss. For example, light reduction due to increases in turbidity (King & Hodgson, 1986; Shepherd *et al*., 1989), or increased epiphytism (Cambridge *et al*., 1986; den Hartog, 1994), has been identified as the probable cause in some cases, while damage and loss resulting from dredging and reclamation has been suggested in others (Coles *et al*., 1989; Larkum & West, 1990). Other more localised causes of damage to seagrass beds include propellers of boats (Zieman, 1976), mooring chains (Walker *et al*., 1989) and recreational bait-digging (Ruello & Henry, 1977).

1.3.1.2 In Australia

In Australia, the decline of seagrass beds has been well documented (Kirkman, 1978; Larkum & West, 1983; Larkum & West, 1990; Walker & McComb, 1992; Hamdorf & Kirkman, 1995) and has, in most cases, been attributed to reductions in light availability resulting from anthropogenic activities (see reviews by Shepherd *et al*., 1989; Walker & McComb, 1992). The disposal of sewage can also markedly reduce the abundance of seagrass to the point where areas become barren and show no signs of recovery (e.g. Shepherd & Cannon, 1989; Larkum *et al*., 1989; Keough & Jenkins, 1995). Damage to and the loss of seagrass can also result in changes to the faunal community within these habitats (Bell & Westoby, 1986a, b; Bell & Pollard, 1989; Edgar, 1990, 1992; Connolly, 1994, 1995), and this may ultimately lead to permanent reductions in species richness of the fauna associated with the seagrass.

1.3.2 COMMERCIAL FISHING RELATED IMPACTS

1.3.2.1 Worldwide

Commercial fishing has long been suspected as a cause of long- and short-term damage to seagrass beds and benthic communities in general (Dayton *et al*., 1995). Damage to beds of *Zostera marina* resulting from trawling, dragging and 'kicking' (using a boat propellor to plough through the sediment) for shellfish has been documented in the USA (Fonseca *et al*., 1984; Peterson *et al*., 1987). Oyster cultivation using racks has also been shown to have a deleterious impacts on *Z. marina* (Everett *et al*., 1995; Short & Wyllie-Echevarria, 1996). Demersal fish trawling is known to cause a variety of impacts to benthic communities and much has been published on the subject (e.g. Caddy, 1973; De Groot, 1984; Jones, 1992; and Dayton *et al*., 1995 for a review). Less is known about the effects of trawling on seagrass, despite this the majority of studies report detrimental outcomes. For example, damage to *Posidonia* beds in the Mediterranean Sea has been attributed to regular otter trawling (Peres & Picard, 1975).

Beach-seining usually targets demersal fish species, but there are no chains or otter-boards which can cause serious damage to the sea bed. Despite this, the net remains in contact with the substratum and has the potential to remove non-targetted organisms. However, a recent study in

South Africa (Lamberth *et al*., 1995) has presented strong, correlative evidence showing that seining on open ocean beaches has no major impacts on sessile benthic communities.

1.3.2.2 In Australia

The hauling of a seine net (hereafter hauling) is a common method used by commercial fishers in estuaries in NSW and throughout Australia. In NSW, the exact size of haul nets vary considerably, but the regulations of NSW Fisheries Management Act, 1994 place certain restrictions on net dimensions. In spite of this, nets used in some NSW estuaries exceed 1000 m in total length ensuring that a wide area of habitat is swept by the net. The fishing operation, *per se*, is relatively simple and fishers generally set the net over the stern of a small boat which moves along a semi-circular path starting and finishing on or near the shore. Nets are slightly negatively buoyant due to a weighted lead-line, but are kept stretched (vertically) by the float-line. The hauling process is often assisted by the use of motorised winches and the net is landed on the shore or to a 'back-net' in shallow water. Underwater observations of the nets while they are being hauled, indicate that the leadline remains in contact with the substratum leaving characteristc "trails" in the sediment. When the net strikes seagrass, the leadline rises up and passes over the shoots and leaves: pushing them over in the direction in which the net is travelling. Given the fact that the nets are in regular contact with the seabed, and that hauling grounds and seagrass beds (especially those comprising *Zostera capricorni*) overlap, it would clearly be prudent to take a precautionary approach (e.g. Gray, 1990) and regard hauling as potentially damaging technique in the absence of any contrary scientific evidence.

1.4 ASSESSING THE IMPACTS OF HAULING ON SEAGRASS BEDS

1.4.1 BACKGROUND

The ecological literature has many examples where researchers have not taken a precise and critical approach to their science (see reviews by Connell, 1974, 1975; Eberhardt, 1978; Underwood, 1981, 1986; Hurlbert, 1984; Underwood & Denley, 1984). This has been most likely due to the desire of ecologists to see their science "progress" (*sensu* Kuhn, 1970) and in doing so, achieve the status of an "exact" science similar to that of archetypal physics (but see Heisenberg, 1958). If science is to progress, it is essential that a study should formulate and define its hypotheses as precisely as possible (Green, 1979; Dayton & Oliver, 1980), consider all alternative hypotheses (*sensu* Feyerabend, 1975), and ensure that the hypotheses are tested by adopting the most appropriate experimental protocols (see Popper, 1959, 1963; Underwood, 1981; Hurlbert, 1984; Underwood, 1990). Studies formulated in this manner, especially those concerned with the assessment of the effects of fishing, will hopefully avoid the tendency to implicitly or explicitly verify rather than critically test the hypotheses under contention (Dayton & Oliver, 1980) and thus, provide a sound basis for responsible management and environmentally sustainable practices.

A large proportion of recent marine research is also compromised through poor experimental design. The common problems encountered were little or no replication (for details see Connell, 1974; Eberhardt, 1978; Underwood, 1981; Hurlbert, 1984), pseudoreplication (for details see Hurlbert, 1984), errors in computation or interpretation of analyses (for details see Underwood, 1981), and finally, the lack statistical power to detect changes (for details see Bernstein & Zalinski, 1983; Sweatman, 1985; Cohen, 1988; Andrew & Mapstone, 1987; Peterman, 1990). Consequently, the discovery of studies with adequate replication, no pseudoreplication, and the use of controls has often been the exception rather than the rule. The net result of poor experimental design is an inability to critically assess the degree and/or magnitude of impact. In financial terms, the inadequacies of experimental design can be translated directly into an improper use of, or in some circumstances a complete waste of limited funds. Therefore, it is crucial from scientific, management and economic points of view to ensure that any research programme is based on the best possible sampling design given the prevailing financial and logistic constraints.

1.4.2 CONSEQUENCES OF TYPE I AND TYPE II ERRORS FOR MANAGEMENT

Decisions about environmental impacts, be they correct or incorrect, have important consequences for management (Bernstein & Zalinski, 1983; Cohen, 1988; Andrew & Mapstone, 1987; Peterman, 1990; Fairweather, 1991; Mapstone, 1995). For example, inferring impact may result in the imposition of restrictions on or a complete cessation of the activity in question. This may have considerable repercussions if people's livelihoods (i.e. incomes) are at stake. If the inference was incorrect and there was no impact (i.e. an 'α' or Type I error has occurred - Table 1.1), then unnecessary hardship would have been imposed. In contrast, if no impact was inferred, then there is evidence for supporting the continuation of the activity in question. However, if this inferrence was made in error and an impact has occurred, but was not detected (i.e. a 'β' or Type II error has occurred - Table 1.1), then further environmental damage may ensue prior to detection. For example, damage and/or loss of seagrass can cause a reduction in: sediment stability, primary productivity, nutrient regeneration, and recruitment and abundances of fish and macro-invertebrates. Moreover, the latter can have serious implications for commercial and recreational fisheries.

Table 1.1 The four outcomes of a statistical test and the relationships between the acceptance and rejection of the null hypothesis (H_0) and Type I and Type II errors (modified from Toft & Shea, 1983; Peterman, 1990).

		CONCLUSION FROM MONITORING	
		Impact (H_0 False)	No Impact (H_0 True)
BIOLOGICAL REALITY	Impact (H_0 False)	**Correct Decision** - impact detected	**Type II (β) error** - impact not detected - false sense of security
	No Impact (H_0 True)	**Type I (α) error** - non-real impact detected - false alarm raised	**Correct Decision** - no impact detected

To date, most studies concerned with the impacts of fishing (see reviews of Hutchings, 1990; Dayton *et al.*, 1995) have been preoccupied with Type I errors because these will generally result in the restriction of an activity and may cause socio-economic hardship. By convention, the Type I error-rate (the probability of incorrectly concluding that an impact has occurred) has been set at $\alpha = 0.05$. Put simply, it means that there is a 1 in 20 chance of concluding that a fishing-related impact has occurred when, in reality, it has not. In contrast, Type II errors (i.e. incorrectly concluding that impacts have not occurred) have largely been ignored, a matter which should be of some concern (Fairweather, 1991; Otway, 1992, 1995). This is especially so in the assessment of impacts of anthropogenic activities including those arising from the variety of fishing techniques. Type II errors will arise from monitoring programmes with poor sensitivity and will, in general, be disastrous for the environment because managers may be lulled into a false sense of security and fail to initiate appropriate mitigating actions (Fairweather, 1991; Otway *et al.*, 1995; Otway *et al.*, 1996). Consequently, careful, pro-active management will require the balancing of the risk of errors against their associated costs (Mapstone, 1995).

If an impact of hauling on seagrass is detected, there are often several ways that a management agency can take action. In NSW the relevant management authority is NSW Fisheries which operates under the Fisheries Management Act 1994. The Act provides several ways of mitigating such an impact and these include:

(1) modifications to gear under the Seagrass Habitat Protection Plan,

(2) spatial and/or temporal fishing closures could be implemented under Section 8 of the Regulations to prevent fishing over seagrass.

Modifications to gear and/or spatial and/or temporal fishing closures could confine fishing activities to sites devoid of seagrass and such action might reduce catches and thus the income of fishers using haul nets. To offset possible losses in income, the fishers would likely turn to other fishing techniques. For example, many fishers in the NSW Estuary General Restricted Fishery possess endorsements to use several (up to 11) fishing techniques including: meshing, prawning and trapping. Consequently, these management actions could result in increased effort and catches of other species not normally caught in large quantities in haul nets. Increased fishing effort and larger catches via other fishing methods might then necessitate additional management action including: additional monitoring, revision of management plans, etc. The implementation of these management options would likely impose additional monetary costs and these would have to be met by the department. As a direct consequence, it will be important to maintain the Type I error-rate at the conventional $\alpha = 0.05$ to guard against additional costs to the department and undue hardship to commercial fishers.

If no impact is inferred incorrectly, then there is the likelihood, as discussed above, that further damage may occur prior to detection. However, previous studies (e.g. Larkum & West, 1990) have shown that *Zostera capricorni* can recover from quite large natural disturbances and thus if a Type II error is made, there is still a possibility that the seagrass bed will recover without management intervention. Recognising the need to ensure statistically powerful tests of impact and the ability of *Zostera capricorni* to recover from physical disturbances led us to opt for a less conservative Type II error-rate of $\beta = 0.20$.

1.4.3 DETECTION OF IMPACT

Disturbances of prolonged duration have been referred to as 'Press' disturbances, whereas those occurring over short periods of time have been referred to as 'Pulse' disturbances (Bender *et al.*, 1984). Impacts arising from these may be evident as sustained (long-term) changes or episodic (short-lived) alterations to abundance or any other variable under consideration (Fig. 1.1). Furthermore, if the frequency of pulse disturbances is high, then the net result may be a sustained (press) impact (Fig. 1.2). From a management point of view, many short-term impacts will not require intervention because the system is able to recover in due course (Underwood, 1989, 1992; Otway, 1995; Otway *et al.*, 1995; Otway *et al.*, 1996). However, some short-term impacts may produce flow-on effects in other (interacting) systems and these may require further mitigating actions by management.

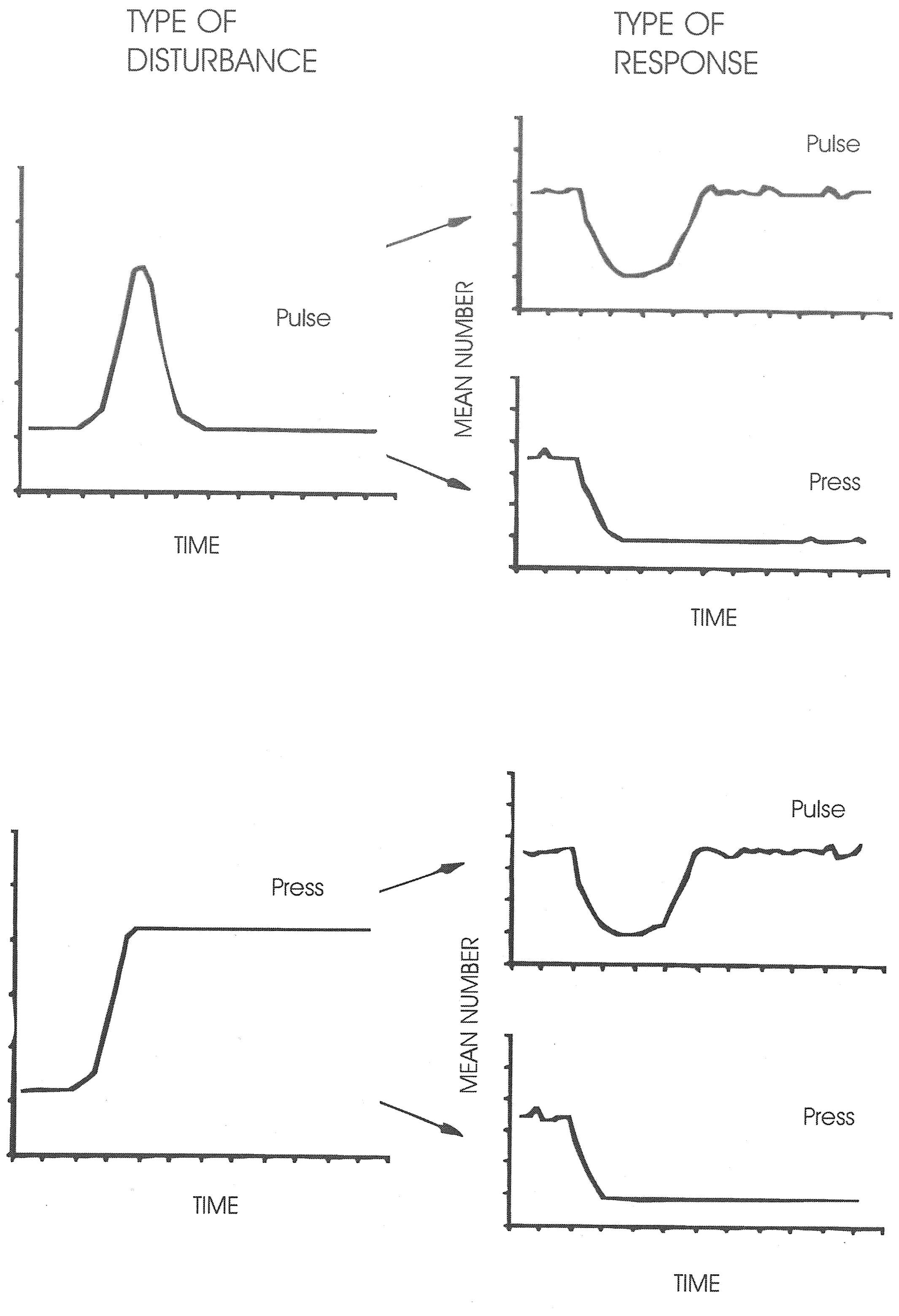

Figure 1.1 'Press' and 'Pulse' disturbances and associated impacts arising from these are evident as sustained (long-term) changes or episodic (short-lived) alterations to abundance or any other variable under consideration (After Bender et al., 1984). Note, increases in abundance, etc. may also occur, but are omitted from the figure for simplicity.

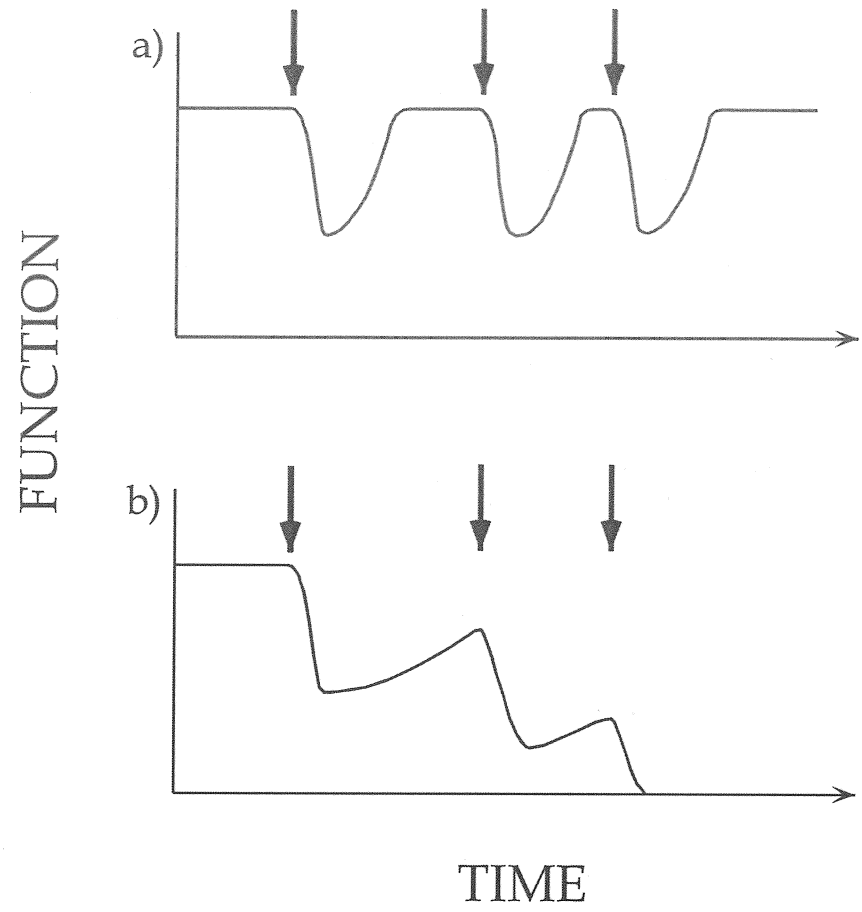

Figure 1.2 'Pulse' disturbances (arrows) resulting in (a) episodic (short-lived) changes to abundance followed by recovery, and (b) a sustained (long-term) alteration because disturbances occur at a frequency that does not permit recovery.

The passage of a haul net (i.e. a ‘pulse’ disturbance), over seagrass beds may result in a short-term, or ‘pulse’, response (Figs. 1.1 and 1.2). However, frequent pulse disturbances to the seagrass beds, as would be the case at established commercial hauling grounds, would likely result in a press response (Figs. 1.1 and 1.2). Whatever the outcome, it would be reasonable to expect that if commercial hauling does have an impact on seagrass beds, it would most likely be detected as changes in: (1) the area of the seagrass bed, (2) the shoot and leaf density of the seagrass, and (3) the leaf length of the seagrass.

Ideally, a study assessing the physical effects of hauling on seagrass beds would require a long-term, large-scale, field experiment involving industry and staff (research and management) from NSW Fisheries. The experiment would need replicate sites with and without hauling to be sampled contemporaneously over at least 2 years in the 'before' and 'after' periods. A design of this nature would then enable an unequivocal assessment of possible impacts. However, it is highly likely that such an experiment would be restricted to a few estuaries and not be able to incorporate different levels of hauling effort because of the overall cost.

Given the restricted funds and the time constraints associated with this study we restricted the study to eelgrass, *Zostera capricorni* (Aschers.) and adopted an alternative approach. We used a design that could be done in the absence of any 'before' data, ensured contrasts of hauled and non-hauled (control) sites and permitted a range of estuaries to be sampled. However, such an analysis is potentially confounded in that it is not possible to be absolutely sure that impacts detected are a result of the disturbance under investigation. Thus the possibility that another external source could have been responsible for possible impacts would still remain. The sampling design adopted provided a powerful means of overcoming this source of confounding and this is discussed in detail in Section 2.5.2.

1.4.4 DEGREES OF IMPACT AND MANAGEMENT DECISIONS

Previous research based on manipulative field experiments (e.g. Bell & Westoby, 1986; Edgar, 1990, 1992; Edgar & Robertson, 1992; Connolly, 1994, 1995) has shown that a range of reductions in the shoot/leaf density and leaf length seagrass causes reductions in the abundances and numbers of species of fish and macro-invertebrates (see example in Fig. 1.3). Clearly, physical changes to seagrass beds are ecologically important and have implications for the estuarine and coastal (offshore) commercial and recreational fisheries given the linkages among the various life-history stages and their associated habitats (Bell & Worthington, 1993).

The objective of the NSW Fisheries Habitat Protection Plan No. 2 (Seagrasses) is "to ensure there is no net loss of seagrasses within the coastal and estuarine waters of NSW," and thus any substantial departure from this may necessitate management action. The broad strategies for achieving the plan's objective are also identified and include "regulating developments/activities that cause direct and indirect damage to seagrasses......". Furthermore, under **Section 7.9 Fishing**, the plan states that "research on the short-term effects of hauling on live seagrass suggests that it causes no significant damage." The plan also states that "where a particular fishing gear type is shown to damage seagrasses, its impact will be required to be ameliorated by phasing in gear modifications in the management plan for that fishery. Where gear modifications to prevent damage to seagrass cannot be implemented, the fishing technique will normally be phased out." Consequently, management may be interventionist and impose spatial and/or temporal fishing closures. Alternatively, managers might opt for a 'watching brief' and initiate further studies to clarify which of several competing management strategies would be the most appropriate to mitigate the impacts (i.e. to ensure the objectives of Habitat Protection Plan No. 2 are met) under the existing and future socio-economic climates. Finally, examples of these differing approaches in relation to the management of seagrasses can be found in a recent study by Smith *et al.* (1997).

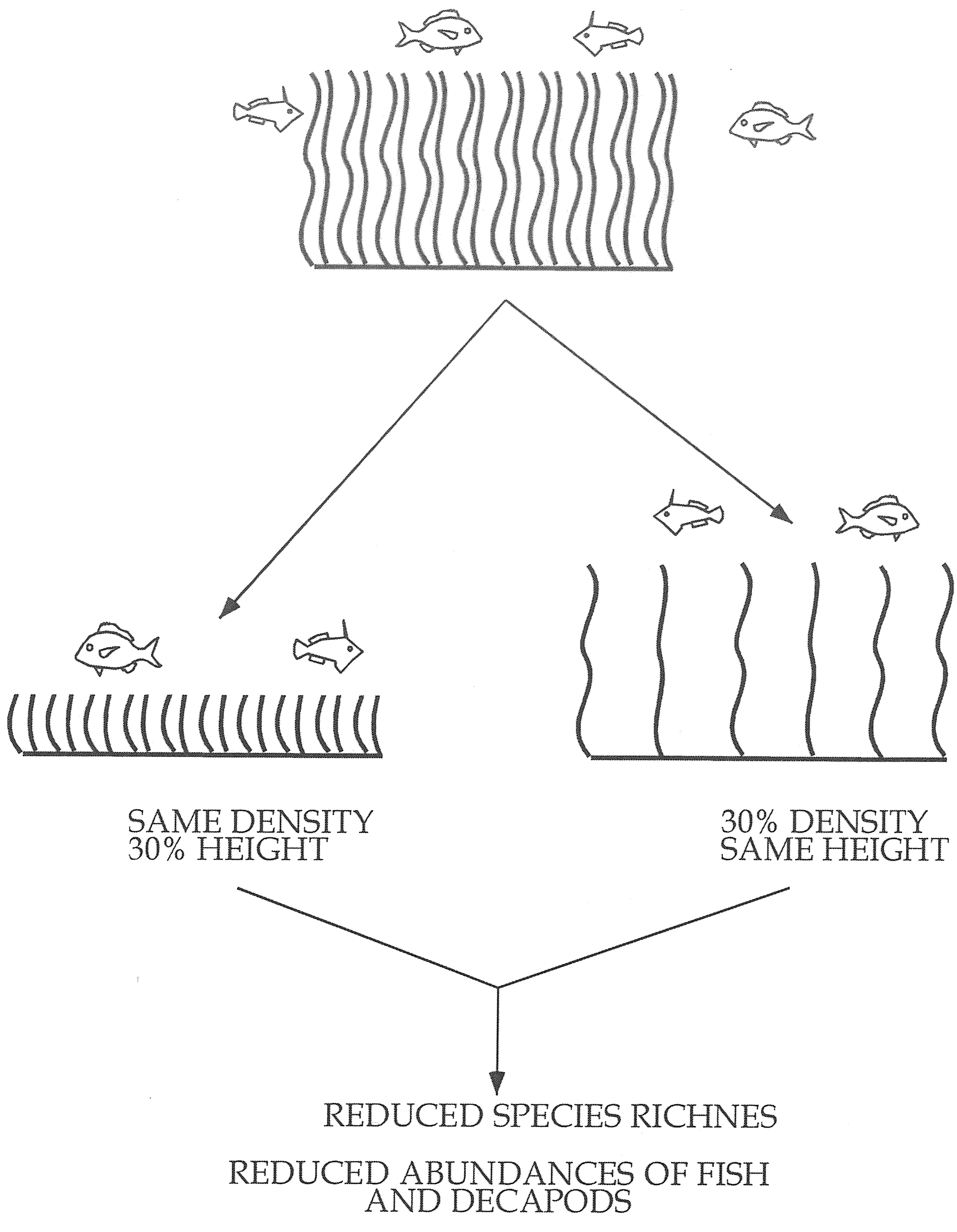

Figure 1.3 Diagramatic summary of the results of experimental manipulations of the shoot density and leaf length of *Zostera capricorni* and its effects on the species richness and abundances of juvenile fish and decapods (After Bell & Westoby, 1986).

2. METHODS

2.1 DESK-TOP STUDY

2.1.1 INTRODUCTION

The aim of the desktop study was to assess whether there is a change in the area of seagrass beds at hauled and control sites by using aerial photographs.

2.1.2 METHODS

The spatial extent of seagrass beds in estuaries was documented in an extensive survey carried out in 1981-84 (West *et al.*, 1985) using aerial photographs and Central Mapping Authority 1: 25,000 topographic maps. As the previous study was "ground-truthed" its results provide a baseline for this study. Information from industry and NSW Fisheries compliance officers was used to identify sites in estuaries where hauling occurs. It was envisaged that aerial photographs from 1985 onwards would be examined for the coverage of seagrass at hauled and control sites.

2.1.3 RESULTS

Site inspections in Lake Macquarie, Botany Bay, St George's Basin and Wallaga Lake showed that the cover of seagrass had changed so dramatically that the baseline data of West *et al.*, (1985) are outdated for the estuaries chosen and use of these data would have most likely led to erroneous conclusions. For example, in St George's Basin the bed of *Zostera capricorni* that was located from Sanctuary Point to Basin View (see Map I8, page 113 in West *et al.*, 1985) is now completely absent. The area lost represents 20% of the total cover of seagrass documented by West *et al.*, (1985). In contrast, site inspections at Wallaga Lake showed there is now an extensive bed of seagrass along the northern shore near the bridge. There was no seagrass present at this site when West *et al.* (1985) carried out their estuarine inventory. Similar results have also been obtained as part of water quality studies carried out by the NSW Environment Protection Authority (Scanes, pers. comm.).

2.1.4 DISCUSSION AND CONCLUSIONS

With such large changes in the distribution of seagrass in estuaries over the past decade it is clear that the survey done by West *et al.* (1985) needs to be repeated prior to its use in this or other impact-related studies. To base any assessment of the physical effects of hauling on seagrass beds on the West *et al.* (1985) baseline and recent aerial photographs would likely produce erroneous results. The use of aerial photographs also poses a number of analytical problems. First, it does not allow replication and thus estimates of within site variation. Moreover, as the same area must be sampled on each occasion, the data will be spatially and temporally dependent (correlated) and thus violate the assumption of independence required for parametric and non-parametric statistical analysis (Scheffé, 1959; Hollander & Wolfe, 1973; Snedecor & Cochran, 1980; Underwood, 1981). Statistical analysis of the data would require that a large number of sites be sampled to permit random sub-sampling to generate data for analysis. This approach would be further confounded by inconsistencies in effort, spatial variation in the temporal trajectories of seagrass abundance (for further discussion Weins, 1984; Bunn, 1986; Underwood, 1992; Otway *et al.*, 1996b), clarity of the water and hence the quality of the aerial photograph, natural progradation (movement) of the seagrass bed (Larkum *et al.*, 1989; Larkum & West, 1990), and a variety of other factors. For example, the disposal of sewage can markedly reduce the abundance of seagrass (Shepherd & Cannon, 1989; Larkum *et al.*, 1989; Keough & Jenkins, 1995) and as there are numerous sewage and stormwater outfalls in NSW estuaries (Otway, 1995b; and Table 4 in West *et al.*, 1985), any changes in the extent of seagrass beds could also be due to many other factors including the disposal of sewage or stormwater.

We decided to abandon the desktop study in favour of a detailed, field-based survey for a number of reasons. First, the distribution and abundance of seagrass exhibited marked changes in various estuaries. Second, it was highly likely that the data arising from the aerial photographs would not fulfill the necessary assumptions for statistical analysis, third, it would be highly unlikely that a detailed history of events could be established for more than a few sites, and fourth, numerous other anthropogenic disturbances occur in estuaries and many of these can affect seagrasses thus confounding the results of a study based on aerial photographs.

Consequently, the vast majority of this report comprises the methods and results of the two field surveys carried out in Winter 1996 and Summer 1997, and the short-term experiments carried out in Botany Bay.

2.2 GENERAL SAMPLING TECHNIQUES

2.2.1 FIELD PROCEDURES

2.2.1.1 Seagrass Sampling

Zostera capricorni beds were sampled destructively using a shovel to cut around the shoots, rhizomes and roots within a specified area. The "turf" of seagrass (underlying sediments included) was then removed with the shovel, placed in a plastic bag and sealed. After all replicates had been collected from the site, each replicate sample (turf) was placed in a seive and washed to remove the sediments. The washed shoots, rhizomes and roots were then placed in plastic bag with clean seawater, sealed and placed in ice for return to the laboratory. While this sampling technique is destructive, it proved to be the most cost-effective and accurate given the time constraints. Furthermore, we believe that this approach is also environmentally acceptable for two main reasons. First, the amount of seagrass removed would be extremely small relative to that present at each site and overall in the entire estuary. Second, *Zostera capricorni* readily recovers from short-term, natural disturbances (Larkum & West, 1990) that occur at much larger spatial scales.

The cost-effectiveness of sampling using quadrats of 3 different sizes (0.0625 m^2, 0.10 m^2 and 0.25 m^2) was evaluated in an initial mensurative experiment near the Caltex wharf in Botany Bay. The 0.0625 m^2 quadrat was found to be as efficient and precise as the remaining two sizes and as previous studies (e.g. Larkum *et al.*, 1984; Inglis & Lincoln Smith, 1995) found similar results, the 0.0625 m^2 quadrat was used in all subsequent sampling.

2.2.1.2 Tagging of Seagrass

Individual *Zostera capricorni* leaves were tagged with white orthodontic rubber bands. The tags were applied to the leaves approximately 2 cm from the tip of each leaf. This was done by placing a leaf inside a transparent, plastic tube with the orthodontic rubber bands stretched around the external surface of the tube. A single rubber band was then allowed to slide off the tube and contract around the leaf. This process was repeated until sufficient leaves had been tagged.

2.2.1.3 Experimental Haul Net

The experimental haul net was similar in construction to commercial nets, but was much shorter with a total length of 95 m. The net had 40 m long wings, a 15 m long centre piece and a drop of 5 m. The lead-line was weighted with lead of a similar size and number compared to commercial nets. The net was set by boat and retrieved manually to the intertidal area. In doing so, the lead-line dragged over the seagrass bed and simulated the action of a commercial haul net in shallow water at the point of landing.

2.2.2 LABORATORY PROCEDURES

The rinsed shoots, rhizomes and roots were refrigerated until they were processed. The shoots were carefully removed from the rhizomes and roots, and placed in groups according to the number of leaves (per shoot) present. The frequencies of shoots with 2, 3, 4 , etc. leaves were then recorded and the total density of shoots and leaves calculated. Varying numbers of shoots were then retained (in proportion to the frequencies of the number of leaves per shoot) to ensure that the lengths of 45 randomly-chosen leaves would be obtained. The lengths were measured to the nearest 1 mm and used to calculate the mean leaf length for the quadrat.

2.2.3 STATISTICAL PROCEDURES

2.2.3.1 General Statistical Approach

The majority of data obtained in this study were analysed by univariate analyses of variance. Preliminary tests for homogeneity of variances were done using Cochran's Test (Winer, 1971) and when variances were heterogeneous data were transformed using the procedures outlined by Scheffé (1959), Snedecor & Cochran (1980) and Underwood (1981).
Post-hoc removal of terms in the original model was also done, where possible, to provide more powerful tests of the remaining sources of variation. These pooling procedures followed the recommendations of Winer (1971) and Underwood (1981) and are in line with the arguments developed by Bozivich *et al.* (1956) and Green & Tukey (1960). *A priori* comparisons between treatment means arising from a 2-way interaction were done using non-orthogonal contrasts as described in Sokal and Rohlf (1969). *Post-hoc* comparisons among means were done using Student-Newman-Keuls (SNK) tests (Snedecor & Cochran, 1980). Finally, the statistical analyses used for particular aspects of the study are described in detail in Section 2.5.

2.2.3.2 Power Analyses

The power of a statistical test is dependent on: (1) the effect-size (ES) to be detected, (2) the number of replicate samples, (3) Type I error-rate 'α', and (4) the appropriate estimate of variation, and linked to the probability of a Type II error via the relationship: Power = $(1 - \beta)$. The effect-size (Cohen, 1988; Fairweather, 1991) is a change that is considered to be of practical (ecological) importance to detect in an experiment. In more specific terms, it is a standardised difference between treatments (Winer, 1971) and in this study it is the standardised difference between the means of the impacted (sites of hauling) and control sites. However, in many situations it is not possible to postulate a critical effect-size *a priori* because of a lack of information about the system. In such cases, a range of effect sizes can be postulated and the power to detect these can be calculated under constraints imposed by funding, etc. (see Otway *et al.*, 1996a for an example). This was not the case in this study as previous research (e.g. Bell & Westoby, 1986; Edgar, 1990, 1992; Edgar & Robertson, 1992; Connolly, 1994, 1995) has shown that a range of reductions in the shoot/leaf density and leaf length of seagrass results in lowered abundances and fewer species of fish and macroinvertebrates. Consequently, we concentrated on detecting 30 - 50% differences between the mean Hauled and Control treatments for shoot and leaf density, and leaf length as changes of this magnitude would have ecologically important consequences.

When only 2 treatments (i.e. Hauled vs Control) are compared, the *F*-test will have the form:

$$F_{\text{Treatments}} = 1 + \lambda.$$

If the null hypothesis,

$$H_0 : \text{Treatment}_{\text{Control}} = \text{Treatment}_{\text{Hauled}} = 0$$

is true, then it follows that $\lambda = 0$, and F will be distributed as a central F. When the null hypothesis is false (i.e. the Treatments differ), then $\lambda = 0$ and the F distribution will be distributed as a non-central F. Hence, the calculation of power of an F-test for a fixed effect is based on the non-central F distribution and commences with the calculation of the non-centrality parameter, λ. The non-centrality parameter was calculated using standard formulae (e.g. Winer, 1971) and these were modified as necessary for the asymmetrical analyses. The probability of Type II error (β) and hence the power of the test (i.e. equal to $1 - \beta$) for effect sizes ranging from 30 - 50% was then obtained using the SAS procedure,

$$\Pr \{F_{(1,\, l-1),\, \lambda} \geq F_{\alpha,\, (1,\, l-1),\, 0}\} \geq (1 - \beta), \text{ for } \alpha = 0.05,\ \beta = 0.20.$$

where:

> $F_{(1,\, l-1),\, \lambda}$ is a random variable distributed as non-central F with 1 and l-1 df, and non-centrality parameter λ, and
> $F_{\alpha,\, (1,\, l-1),\, 0}$ is the upper α percentage point of a central F with 1 and l-1 df.

We adopted $\alpha = 0.05$ and $\beta = 0.20$ as our respective, nominal Type I and Type II error-rates for reasons discussed earlier (see Section 1.4.2). With $\beta = 0.20$, our nominal power will be $1 - \beta = 0.80$ which is considered to be reasonable for statistical tests in marine ecological work (Sweatman, 1985; Peterman, 1990; Fairweather, 1991).

A priori power analyses used information obtained from: (1) the Pilot Study (see Section 2.3), or (2) the subsequent field sampling carried out in Winter 1996. The terms with similar components of variation were used as surrogates for the MS denominator for the *a priori* power analyses. *Post-hoc* power analyses were, of course, done using the same mean square as required for the *F*-test. *A priori* and *post-hoc*, when necessary, analyses were used to calculate power for the tests of impact on shoot/leaf density and leaf length, and the persistence of seagrass leaves. The terms examined for power included:

(1) H vs C (symmetrical and asymmetrical),
(2) Estuary x H vs C,
(3) Effort x H vs C.

2.3 PILOT STUDY

2.3.1 INTRODUCTION

Prior to commencing the field sampling we carried out a pilot study to assist with the experimental design. In particular we wanted to identify:

(1) the costs of field sampling and laboratory processing,
(2) the number of replicate quadrats and leaves required for precision = 0.10,
(3) the natural, spatial variation in shoot and leaf density, and leaf height for inputs into *a priori* power calculations (see Section 2.2.3.2).

2.3.2 METHODS

The main pilot sampling was done east of the Caltex terminal at Silver Beach, Botany Bay. Sites chosen possessed well established beds of *Zostera capricorni* and were not subjected to commercial hauling. Sampling was done at 2 sites ≈ 100 m apart and at each site, 2 areas ≈ 5 m apart were identified. In each area, two replicate 0.0625 m^2 quadrats were placed at random (≈ 2 m apart) within the bed and the seagrass sampled in accordance with the protocol outlined in Section 2.2.1.1. This sampling design allowed the natural variation to be partitioned across the 3 spatial scales. The seagrass was taken back to the laboratory and processed in accordance with the protocol outlined in Section 2.2.2. The time taken to do the field sampling and laboratory processing was also recorded.

The data obtained were used to identify the minimum number of replicate quadrats and leaf measurements required to ensure precision of 0.10 and then analysed in more detail. The densities of *Zostera capricorni* shoots and leaves were analysed using 2-factor, nested analyses of variance (Table 2.1a) with the variation partitioned into that associated with differences between Sites, between Areas within Sites, and among individual replicate shoots (the residual variation). Leaf lengths were analysed using a 3-factor, nested analysis of variance (Table 2.1b) with the variation partitioned into that associated with differences between Sites, between Areas within Sites, between Quadrats within Areas and Sites, and among individual replicate leaves (the residual variation). Estimates of the variation between Sites were used in the calculation of the non-centrality parameter for subsequent *a priori* power analyses. Power was calculated in accordance with the methods in Section 2.2.3.2 and included several sampling strategies for all three variables. The degrees of freedom used in the power calculations were associated with: (1) a significant Treatments x Estuaries interaction, and (2) a non-significant ($P > 0.25$) Treatments x Estuaries interaction pooled with the Residual as described in Section 2.5.2.1.

2.3.3 RESULTS

The analyses indicated that a minimum of 2 replicate quadrats per site and between 45 and 60 leaves per quadrat would be required to ensure a precision of 0.10 for shoot and leaf densities, and leaf-length, respectively. The total time taken in the pilot study indicated that it would not be possible to sample and process any more than 45 samples within one week with 2 people. Clearly, with two teams of 2 people it would be possible to travel to and from two estuaries per week and, sample and process the seagrass from them.

Results for leaf density are not presented as the analyses (analysis of variance & power analysis) for shoot and leaf densities produced almost identical outcomes. Analyses of variance of shoot and leaf densities indicated that there was significant variation between

Table 2.1 Nested analyses of variance used to analyse: (a) shoot and leaf densities, and (b) leaf length of *Zostera capricorni* from the pilot study.

(a) Analysis of variance for shoot and leaf densities.

Source of variation	MS estimate	Denominator for *F*
MS Sites	$\sigma_e^2 + n\sigma^2A(S) + bn\sigma^2S$	MS Areas (Sites)
MS Areas(Sites)	$\sigma_e^2 + n\sigma^2A(S)$	MS Residual
MS Residual	σ_e^2	

(b) Analysis of variance of leaf length.

Source of variation	MS estimate	Denominator for F
MS Sites	$\sigma_e^2 + n\sigma^2Q(A(S)) + cn\sigma^2A(S) + bcn\sigma^2S$	MS A(S)
MS Areas(Sites)	$\sigma_e^2 + n\sigma^2Q(A(S)) + cn\sigma^2A(S)$	MS Q(A(S))
MS Quadrats(Areas(Sites))	$\sigma_e^2 + n\sigma^2Q(A(S))$	MS Residual
MS Residual	σ_e^2	

Table 2.2 Analysis of variance of untransformed data for the number of *Zostera capricorni* shoots obtained in the pilot study. The variance estimated by MS Sites was used in the calculation of power as described in the text.

Source of variation	df	SS	MS	*F*	*P*
Sites	1	144.5	144.50	0.162	0.726
Areas (Sites)	2	1780.0	890.00	8.790	0.034
Residual	4	405.0	101.25		
Total	7	2329.5			

Table 2.3 Analysis of variance of untransformed data for the length of *Zostera capricorni* leaves obtained in the pilot study. The variance estimated by MS Sites was used in the calculation of power as described in the text.

Source of variation	df	SS	MS	*F*	*P*
Sites	1	222267	222267.00	1.139	0.398
Areas (Sites)	2	390153	195076.50	6.606	0.054
Quadrats (A(S))	4	118125	29531.30	6.080	< 0.001
Residual	472	2292454	4856.89		
Total	479	3022999			

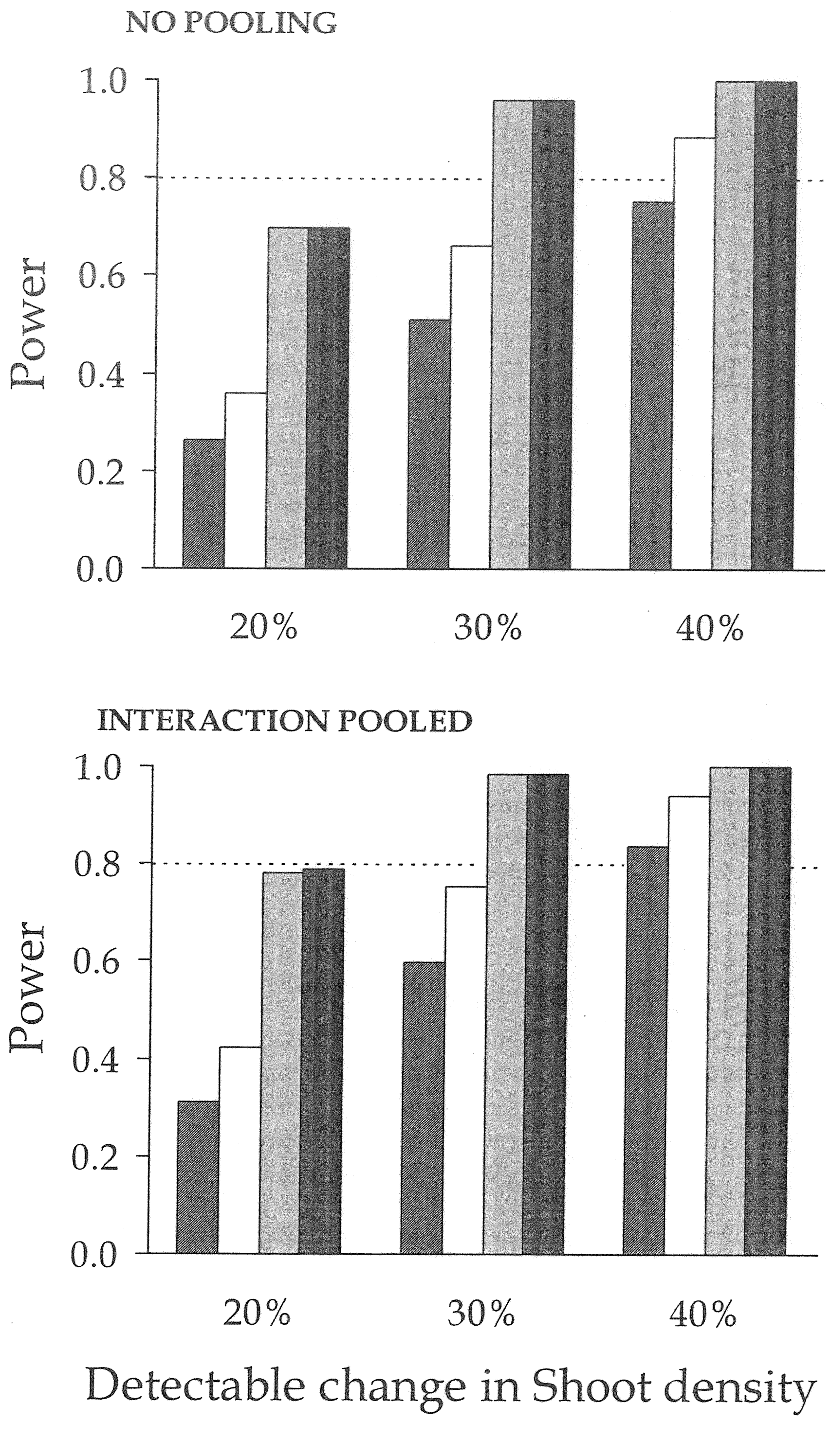

Figure 2.1 Predicted power associated with the detection of a 20%, 30% and 40% difference in shoot density of *Zostera capricorni* between hauled and control sites for various sampling design strategies (▨ 7 Sites, 2 Areas, 3 Quadrats; □ 7 Sites, 3 Areas, 2 Quadrats; ▨ 6 sites 1 Area, 7 Quadrats; ■ 7 sites, 1 Area, 6 Quadrats). Dashed line denotes minimum power of 0.80.

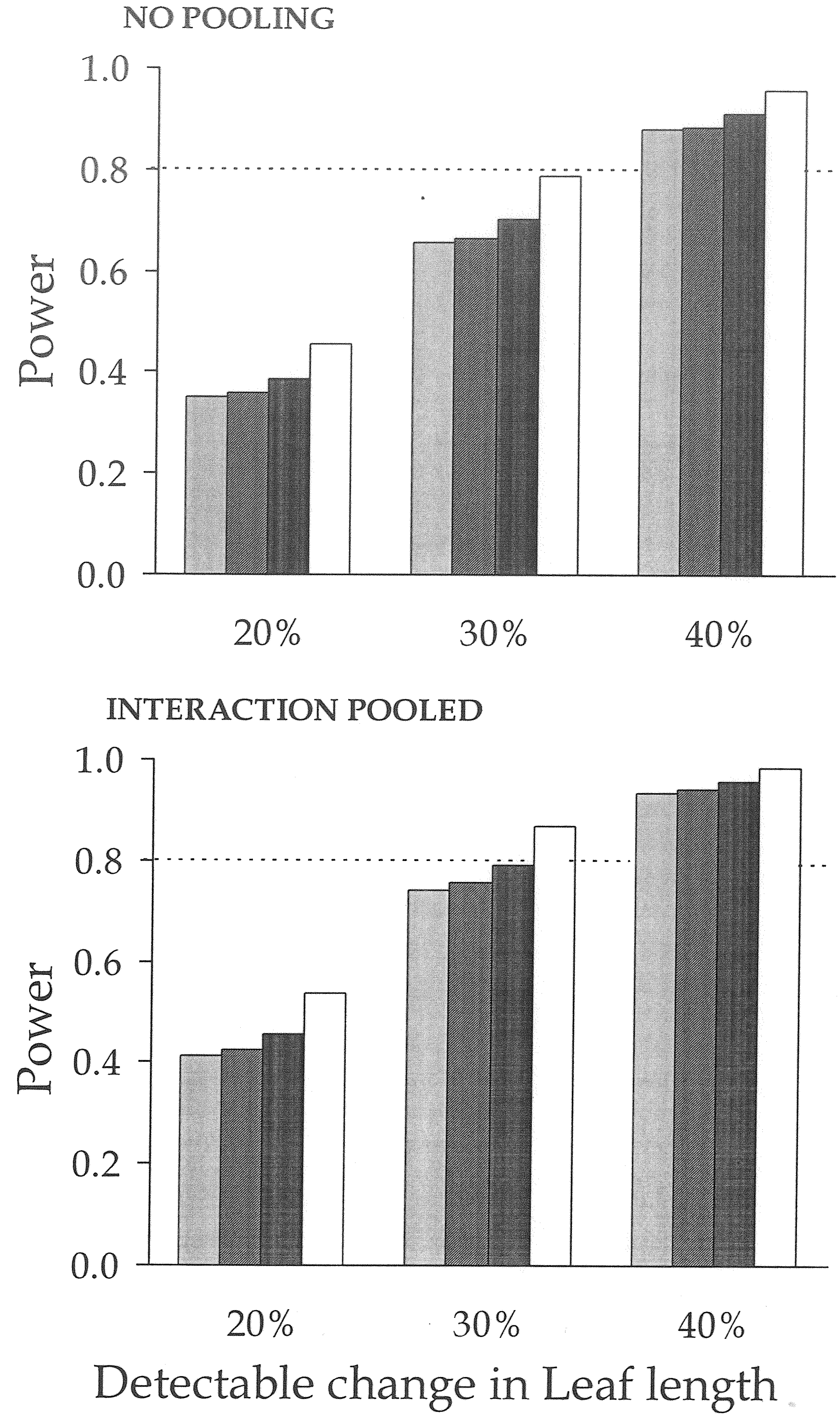

Figure 2.2 Predicted power associated with the detection of a 20%, 30% and 40% difference in leaf length of *Zostera capricorni* between hauled and control sites for various sampling design strategies (■ 7 Sites, 2 Areas, 3 Quadrats; □ 7 Sites, 3 Areas, 2 Quadrats; ■ 6 sites 1 Area, 7 Quadrats; ■ 7 sites, 1 Area, 6 Quadrats). Dashed line denotes minimum power of 0.80.

areas nested within Sites (e.g. Shoot density in Table 2.2). Leaf length exhibited a similar result with significant differences between the Quadrats nested within Areas and Sites (Table 2.3).

The results of the *a priori* power analyses for shoot density (Fig. 2.1) showed that the H vs C *F*-ratio (i.e. the Treatments term) should be able to detect a 30% change in density with power = 0.80. This could be achieved by using one of two sampling strategies. The first strategy would be based on sampling 6 Sites (1 Hauled & 5 Control sites) and 7 replicate quadrats per site in each of 9 estuaries. The second strategy would entail sampling 7 Sites (1 Hauled & 6 Controls) and 6 replicate quadrats per site in each of 9 estuaries. Furthermore, if the Estuaries x Treatment interaction was not significant at $P > 0.25$ and could be pooled with the residual (see Section 2.5.2.1), the resultant test with either sampling strategy above, should be able to detect an even smaller change (≈ 20%) with power = 0.80. The *a priori* power analyses for the Estuaries x H vs C *F*-ratio indicated that it should be possible to detect a 50% change in shoot density with power = 0.80 using a strategy based on sampling 7 Sites (1 Hauled & 6 Control sites) and 6 replicate quadrats per site in each of 9 estuaries.

The results of the power analyses for the length of *Zostera capricorni* leaves (Fig. 2.2) showed that the H vs C *F*-ratio should be able to detect close to a 30% change in leaf-length, with power = 0.80 using a strategy based on sampling 7 Sites (1 Hauled & 6 Control sites) and 6 replicate quadrats per site in each of 9 estuaries. Furthermore, if the Estuaries x Treatment interaction was not significant at $P > 0.25$ and could be pooled with the residual (see Section 2.5.2.1), the resultant test with either sampling strategy above, should be able to detect a change smaller than 30% with power = 0.80. The *a priori* power analyses also indicated that the Estuaries x H vs C *F*-ratio should be possible to detect a 50% change in leaf length with power = 0.80 using a strategy based on sampling 7 Sites (1 Hauled & 6 Control sites) and 6 replicate quadrats per site in each of 9 estuaries.

2.3.4 DISCUSSION

Clearly, the optimal sampling effort will be the one that is best able to meet the sampling requirements necessary for estimating changes in shoot and leaf density, and leaf-length. The power calculations showed that optimal sampling effort should be optimal with a strategy based on sampling 6 replicate quadrats in each of 7 Sites (1 Hauled & 6 Control sites) in each of 9 estuaries. The pilot study also indicated that a maximum of 45 samples could be sampled and processed within 1 week. By using two teams of 2 people it should be feasible to travel to and from two estuaries per week and, sample and processing the seagrass. This would enable sampling to be completed within a period of 2 months, allowing for unforseen difficulties and/or inclement weather. Finally, the sampling of 9 randomly-chosen estuaries provides: (1) increased statistical power for tests of impact, (2) the opportunity to generalise the results to hauled sites in other (unsampled) estuaries, and (3) a means of overcoming problems associated with differences in the configuration and operation of the hauling nets among estuaries and the various hauling crews.

2.4 DESCRIPTION OF STUDY SITES

2.4.1 WALLIS LAKE

This permanently-open lagoon is situated approximately 400 km north of Sydney (Fig. 2.3). The surrounding catchment (1420 km^2) has an average annual rainfall of 1250 mm and an estimated runoff of 450 m^3 x 10^6 (Bell & Edwards, 1980). The lagoon provides ideal conditions for the growth of seagrass which was estimated to cover ≈ 31 of the 86 km^2 of water (West *et al.* 1985). The towns of Foster and Tuncurry straddle the entrance to the estuary and are popular destinations for tourists. The estuarine waters provide good recreational fishing opportunities and also support commercial fishing and aquaculture activities. The most obvious commercial activities include: hauling, crab trapping (predominantly for blue swimmer crabs) and oyster growing.

2.4.2 PORT STEPHENS

This estuary (drowned river valley) is situated approximately 275 km north of Sydney (Fig. 2.3). The surrounding catchment (4950 km^2) is, at present, relatively undisturbed and has an average annual rainfall of 1230 mm providing an estimated runoff of 1480 m^3 x 10^6 (Bell & Edwards, 1980). The estuarine conditions support the growth of mangroves and seagrasses, the latter of which were estimated to cover ≈ 7 of the 205 km^2 of water (West *et al.* 1985). The towns of Nelson Bay and Shoal Bay, near the entrance, are popular destinations for tourists. The offshore waters provide for good game-fishing and as result, there is a substantial fleet of charter boats. The estuarine waters also provide good recreational fishing opportunities and support commercial fishing and aquaculture activities. Hauling and oyster growing are among the predominant commercial activities in Port Stephens.

2.4.3 LAKE MACQUARIE

This permanently-open lagoon is situated approximately 150 km north of Sydney (Fig. 2.3). The surrounding catchment (700 km^2) has an average annual rainfall of 1100 mm and an estimated runoff of 175 m^3 x 10^6 (Bell & Edwards, 1980). Apart from residential housing, development within the catchment also includes power stations and copper/zinc smelter. Numerous towns including Swansea, Toronto, and Belmont are located around the shores of the estuary and provide for tourists from Sydney and Newcastle. While the lagoon supports the growth of seagrass, which was estimated to cover ≈ 13 of the 115 km^2 of water (West *et al.* 1985), the construction and operation of the power stations (Vales Point, Wangi) and continued urban development have resulted in declines in seagrass cover (see Otway *et al.*, 1995 for a review). The estuarine waters also provide good recreational fishing opportunities and support commercial fishing and aquaculture activities. The northern section of the lake is, however, closed to all forms of commercial fishing and the most obvious commercial activities occurring in the southern section include: hauling, crab trapping (predominantly for blue swimmer crabs) and oyster growing.

2.4.4 TUGGERAH LAKE

This permanently-open lagoon is situated approximately 100 km north of Sydney (Fig. 2.3). The surrounding catchment (745 km^2) has an average annual rainfall of 1050 mm and an estimated runoff of 450 m^3 x 10^6 (Bell & Edwards, 1980). The estuary provides good conditions for the growth of seagrass which was estimated to cover ≈ 12 of the 70 km^2 of water (West *et al.*, 1985).

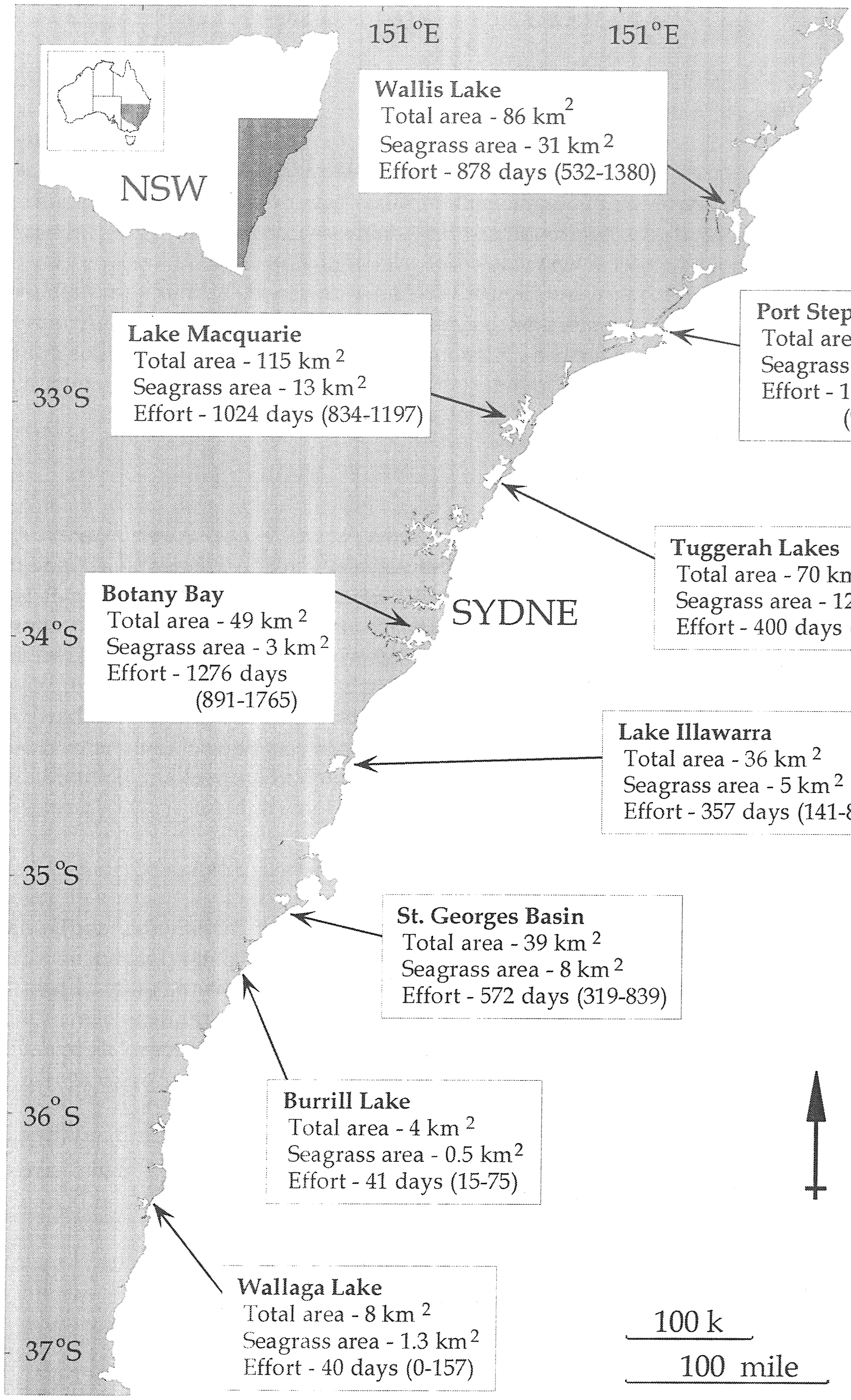

Figure 2.3 Map showing the location of the nine estuaries sampled to assess the impacts of hauling on seagrass, associated total seagrass area (West *et al.*, 1985) and the range in mean annual fishing effort (expressed as fisher days) over the period 1984 to 1996 (Pease & Scribner, 1993, 1994; Pease & Grinberg,1995).

The town of The Entrance sits at the mouth of the lagoon and is a popular destination for tourists. The continued urbanisation of surrounding environment the is likely to pose problems for the estuary in the near future. The estuarine waters provide good recreational fishing opportunities and support commercial fishing and aquaculture activities. The most obvious commercial activities include: hauling, crab trapping (predominantly for blue swimmer crabs) and prawning.

2.4.5 BOTANY BAY

This large, relatively shallow bay is situated approximately 12 km south of the Sydney CBD (Fig. 2.3). The surrounding catchment (1100 km^2) is highly urbanised and has an average annual rainfall of 1000 mm and an estimated runoff (including Georges River) of 520 $m^3 \times 10^6$ (Bell & Edwards, 1980). The Bay itself has undergone dramatic changes over the past 20 years as a result of industrial development, port and airport construction. While the bay supports the growth of seagrass, which was estimated to cover $\approx$ 3 of the 49 km^2 of water (West *et al.* 1985), the continuing construction and urban development have resulted in declines in seagrass cover (see Larkum & West, 1990 for a review). The bay and its foreshores provide major recreational amenities for the residents of Sydney with the waters providing recreational fishing opportunities. The bay also supports commercial fishing and aquaculture activities with hauling, prawn trawling and oyster growing the most obvious.

The Towra Point Aquatic Reserve is located on the southern side of Botany Bay and closed to all commercial fishing. The Aquatic Reserve was used for the manipulative field study examining the short-term effects of the experimental haul net on *Zostera capricorni*.

The other short-term experiment, involving commercial haulers, was done at Silver Beach which is also located on the southern side of Botany Bay. The beach slopes very gently from the shoreline to approximately 100 metres from shore where the water depth then drops steadily from 2 to 5m. Rock groynes penetrate out into the bay at 200 metre intervals along the length of the beach. Patchy beds of *Z. capricorni* exist at a range of depths from the low water mark to approximately 1.5 metres depth along the extent of the beach. Commercial hauling takes place regularly - from twice a day to once a fortnight - at certain suitable locations between groynes.

2.4.6 LAKE ILLAWARRA

This permanently-open lagoon is situated approximately 125 km south of Sydney (Fig. 2.3). The surrounding catchment (150 km^2) is urbanised and has an average annual rainfall of 1300 mm providing an estimated runoff of 75 $m^3 \times 10^6$ (Bell & Edwards, 1980). The estuary has undergone major changes over the past 20 years as a result of foreshore development, reclamation and dredging. While the bay supports the growth of seagrass, which was estimated to cover $\approx$ 5 of the 36 km^2 of water (West *et al.*, 1985), the continuing urban development has resulted in a decline in water quality and possible declines in seagrass cover. Towns such as Windang (at the entrance) and suburbs to the south of the lake are popular destinations for tourists from Sydney. Locally, the residents of Wollongong and Port Kembla use the recreational amenities provided along Lake Illawarra's foreshores and participate in water sports (sailing, windsurfing) and recreational fishing on the lake itself. The bay also supports commercial fishing with hauling and prawning the most obvious.

2.4.7 ST GEORGE'S BASIN

This estuary is situated approximately 265 km to the south of Sydney (Fig. 2.3). The surrounding catchment (390 km^2) has an average annual rainfall of 1200 mm providing an estimated runoff of 140 m^3 x 10^6 (Bell & Edwards, 1980). The estuarine conditions support the growth of mangroves and seagrasses, the latter of which were estimated to cover ≈ 7 of the 205 km^2 of water (West *et al.*, 1985). The town of Sussex Inlet is situated at the mouth of the estuary on the far south-western shore and is a popular destination for tourists. In contrast, the western and south-eastern shores are relatively undisturbed. The northern shores of the Basin have sustained substantial urbanisation over the past decade and this is most evident near the towns of Erowal Bay, Sanctuary Point and Basin View. These towns are also popular with tourists from Sydney during the summer months. The estuarine waters also provide for recreational fishing and numerous water sports (sailing, windsurfing & water skiing). Hauling is the most predominant commercial fishing technique carried within the Basin.

2.4.8 BURRILL LAKE

This intermittently-open lagoon is situated approximately 325 km south of Sydney (Fig. 2.3). The entrance to the lagoon was open throughout the duration of this study permitting tidal interchange of the water. The surrounding catchment (78 km^2) has an average annual rainfall of 1120 mm and an estimated runoff of 24 m^3 x 10^6 (Bell & Edwards, 1980). The lagoon provides ideal conditions for the growth of seagrass which was estimated to cover ≈ 0.5 of the 4 km^2 of water (West *et al.*, 1985). The town of Burrill Lake sits at the entrance to the estuary and is a popular destination for tourists. The estuarine waters provide good recreational fishing opportunities and a restricted amount of commercial hauling is also carried out.

2.4.9 WALLAGA LAKE

This intermittently-open lagoon is situated approximately 525 km south of Sydney (Fig. 2.3). The mouth of the lagoon was open throughout the duration of this study allowing tidal exchange of the water. The surrounding catchment (285 km^2) has an average annual rainfall of 940 mm and an estimated runoff of 24 m^3 x 10^6 (Bell & Edwards, 1980). The lagoon provides ideal conditions for the growth of seagrass which was estimated to cover ≈ 1.3 of the 8 km^2 of water (West *et al.*, 1985). The estuary is also a favoured spot for recreational fishing and a restricted amount of commercial fishing (hauling and gill-netting) is also carried out. Note that it is likely that the seagrass in Wallaga Lake is not *Zostera capricorni* as taxonomic examination of the flowers has suggested that is *Heterozostera tasmanica* (Scanes, pers. comm.). However, this is unlikely to pose any major problems for the study as the shoot/leaf morphologies of the two species are very similar.

2.5 EXPERIMENTAL DESIGNS AND ANALYSES TO DETECT IMPACTS

2.5.1 HAULING EFFORT

2.5.1.1 Source of Data

Information concerning fishing effort in the 9 estuaries was obtained from the NSW Fisheries catch and effort database (see Pease & Scribner, 1993, 1994; Pease & Grinberg, 1995 for details). However, the database only distinguishes differences between the estuarine and ocean haul fisheries from the 1984/1985 financial year onwards. Consequently, the analysis of effort was restricted to the period 1984 to 1996. Furthermore, effort data was only recorded on an estuary-wide basis and thus there is no information concerning hauling effort for individual sites.

2.5.1.2 Analysis of Hauling Effort

Differences in mean annual fishing effort among the 9 estuaries were examined by using the means of individual years as replicates in a single factor analysis variance. The temporal trends in fishing effort in each of the nine estuaries was examined by regressing the mean annual fishing effort for each year (commencing in 1984) against time (years 1 - 12). Intra-annual variation (i.e. at monthly intervals) in mean fishing effort was not examined statistically. Instead, means (± SE) for each month, pooled over the 12 years, were plotted and trends examined. Small standard errors associated with each of the monthly means would indicate that a similar pattern (trend) was occurring from year to year.

2.5.2 LONG-TERM IMPACTS

2.5.2.1 Impacts irrespective of Hauling Effort

Hauling has been carried out over decades, and while its short-term effects may be small relative to the natural variability in seagrass cover in any given year, the cumulative effects over longer periods of time might be discernible by sampling seagrass beds where hauling has occurred and comparing these data to similar beds where no hauling has been carried out. Sampling numerous, randomly-chosen estuaries provides the opportunity to generalise the results to hauled sites in other (unsampled) estuaries. Furthermore, it simultaneously overcomes problems associated with differences in the configuration and operation of the hauling nets among estuaries and the various hauling crews.

It is important to be aware of the locations of the hauled and control sites as proximity to the entrance may also affect seagrass shoot/leaf density and leaf-length. These may also influence the abundances of fish and the hauling location. Consequently, a similar hauled location in all estuaries might bias the results in an unforseen manner. To assess this the location of the hauled and control sites were tabulated (Table 2.4) in a clockwise direction from the mouth of each of the 9 estuaries. The relative location of the hauled site in each estuary was clearly not the same across all 9 estuaries. This variation in location of the hauled site across the 9 estuaries will likely prevent any substantial bias in the subsequent analyses.

Table 2.4 Location of the hauled and 6 control sites in clockwise direction relative to the mouth of each estuary for the 9 estuaries sampled in Winter 1996 and Summer 1997.

Estuary	Location of Hauled and Control Sites
Wallis Lake	C C C H C C C
Port Stephens	H C C C C C C
Lake Macquarie	C C H C C C C
Tuggerah Lake	C C C C C H C
Botany Bay	C C H C C C C
Lake Illawarra	H C C C C C C
St. George's Basin	H C C C C C C
Burrill Lake	C C C H C C C
Wallaga Lake	C C H C C C C

The *a priori* power analyses carried out in the Pilot Study (Section 2.3) indicated asymmetrical analysis of variance with 6 replicates at 1 hauled (putatively impacted) site and 6 control sites in each of 9 randomly-chosen estuaries should enable effect sizes of 30% or more to be detected with power equal to or greater than 0.80. These analyses also indicated that the tests of impact arising from an underlying 4-factor asymmetrical analysis of variance incorporating Winter and Summer as an additional factor would not have detected 30 - 50% differences in the means of the Hauled and Control treatments for shoot and leaf density, and leaf length. Consequently, analyses to detect the impacts of hauling on shoot and leaf densities, and leaf length in Winter 1996 and Summer 1997 were done separately.

A 3-factor asymmetrical analysis of variance (Table 2.5) formed the basis of the statistical analyses of the shoot and leaf densities, and leaf length at the hauled and control sites in the 9 estuaries chosen at random (see Section 2.3). The asymmetrical analysis of variance partitioned the variation into that associated with differences among Estuaries, Treatments, i.e. Hauled vs. Control (H v C), Sites within control treatment, the interaction of Estuaries and H vs C, and among individual replicate samples (the residual variation). In this design, evidence of the impact of hauling on seagrass is indicated in two ways. First, a significant Estuary x H vs C interaction shows that there is a potential impact, but it is not consistent across all the estuaries, i.e. the difference between the hauled site and the mean of the controls varies from estuary to estuary. Second, a significant H vs C term indicates that there is a potential impact and that it is consistent across all 9 estuaries.

As discussed earlier (see Section 2.2.3.2), it is important to ensure that the tests of impact have adequate power. *Post-hoc* pooling of non-significant terms provides an additional way of increasing the power of the tests for impact. If the Sites (Est x Control) term is not significant at $P = 0.25$, it can be pooled with the residual. The Est x H v C *F*-ratio would then have the MS Residual as the denominator and would have increased power. However, it is likely that the Sites

(Est x Control) term will be significant because it estimates the natural variation among control sites and thus it is unlikely that this approach could be used. However, if the Est x H v C interaction is not significant at $P = 0.25$, it can be pooled with the residual. This enables the power of the H v C *F*-ratio to be increased as the MS Sites (Est x Control) would then be used as the denominator. This procedure results in a test with 1 and 45 degrees of freedom giving substantially more power than the original test with 1 and 8 degrees of freedom. It is far more likely that this approach will be used.

Table 2.5 Asymmetrical analysis of variance for detecting the impacts of hauling on seagrass shoot and leaf density, and leaf length in the 9 estuaries. Note that there is one putatively impacted (hauled) site and 6 control sites in each estuary and sampling is done contemporaneously with 6 replicate quadrats per site on one occasion.

Source of variation	**df**	**Denominator for *F***
Estuaries = Est	8	MS Sites (Est x Control)
Hauled v Controls = H v C	1	MS Est x H v C
Est x H v C [2]	8	MS Sites(Est x Control)
Sites(Est x Control) [1]	45	MS Residual
Residual	315	
Total	377	

1. If the *F*-ratio for Est x H v C is not significant at $P = 0.25$ then pooling can be done and the denominator of the *F*-ratio for H v C becomes the MS Sites(Est x Control).

2. If the *F*-ratio for Sites(Est x Control) is not significant at $P = 0.25$ then pooling can be done and the denominator of the *F*-ratio for Est x H v C becomes the MS Residual.

It is important to note that while this design provides evidence of impact, it is not conclusive because of the absence of sampling before the disturbance i.e. the haul of a net. Thus, there is a chance, albeit small, that significant differences between the control and hauled treatments may have existed prior to hauling and have nothing whatsoever to do with the activities of commercial fishers. However, the use of numerous estuaries provides greater generality and certainty that impact is detected, especially when the H vs C term is significant. The likelihood of obtaining, by sheer chance alone, a consistent difference (e.g. H < C) across all 9 randomly-chosen estuaries would be 1 in 512 (i.e. $P = 0.002$). Hence, a significant H vs C term provides the best (almost unequivocal) evidence of impact in the absence of sampling before the hauling of a net over the seagrass.

The effects of hauling on shoot and leaf densities in individual estuaries were, on occasion, analysed using a 2-factor asymmetrical analysis of variance (Table 2.6). The analysis of variance partitioned the variation into that associated with differences between Treatments, i.e. Hauled vs. Control (H v C), Sites within control treatment, and among individual replicate samples (the residual variation). In this design, evidence of the impact of hauling on seagrass is indicated via a significant H vs C term. These analyses were done to assist in the interpretation of non-significant H vs C and Est x H v C terms with power less than 0.80.

Table 2.6 Asymmetrical analysis of variance for detecting the impacts of hauling on seagrass shoot and leaf density, and leaf length in one estuary. Note that there is one putatively impacted (hauled) site and 6 control sites sampled contemporaneously with 6 replicate quadrats per site.

Source of variation	df	Denominator for F
Hauled v Controls = H v C	1	MS Sites (Control)
Sites (Control) [1]	5	MS Residual
Residual	35	
Total	41	

1. If the F-ratio for Sites (Est x Control) is not significant at P = 0.25 then the denominator of the F-ratio for Est x H v C is the MS Residual.

2.5.2.2 Impacts in relation to Hauling Effort

The analysis of fishing effort (Section 3.1) showed that the 9 randomly-chosen estuaries could be separated into three groups each separated by an order of magnitude in the nominal mean annual fishing effort. This measure was not site-specific and therefore can only be used as an approximate measure. Hence, these analyses can only be considered exploratory. As the group with low fishing effort comprised only 2 estuaries (i.e. Burrill and Wallaga Lakes), two estuaries from each of the medium and high fishing effort groups were chosen at random. The data collected in these six estuaries during Winter 1996 and in Summer 1997 were then analysed (separately) using a 4-factor asymmetrical analysis of variance (Table 2.7). To detect the impacts of hauling on the shoot and leaf density, and leaf length of *Zostera capricorni* in estuaries subjected to high, medium and low levels of fishing effort the analysis partitioned the variation into that associated with differences among Effort, Estuaries nested in Effort, Treatments, i.e. Hauled vs Control, Sites within control treatment nested in Estuaries within Effort, the interactions of Estuaries and H vs C, Estuaries(Effort) and H vs C, and among individual replicate samples.

In this design, evidence of the impact of hauling on seagrass is indicated in three ways. First, a significant Estuary(effort) x H vs C interaction shows that there is a potential impact, but it is not consistent between the estuaries within hauling effort, i.e. the difference between the hauled site and the mean of the controls varies between estuaries within the same gross level of hauling effort. Second, a significant Estuary x H vs C interaction shows that there is a potential impact, but it is not consistent across all the estuaries, i.e. the difference between the hauled site and the mean of the controls varies from estuary. Third, a significant H vs C term indicates that there is a potential impact and that it is consistent across all 9 estuaries. Note that the latter two tests lack power and *post-hoc* pooling of non-significant terms will be the only way of increasing the power of the tests for impact. If the Sites(Estuaries(Effort)) x Control term is not significant at $P = 0.25$, it can be pooled with the residual. The Est x H v C F-ratio would then have the MS Residual as the denominator and would have increased power. However, it is likely that the Sites(Estuaries(Effort)) x Control term will be significant because it estimates the natural variation among control sites and thus it is unlikely that this approach could be used. However, if the Estuaries(Effort) x H v C interaction is not significant at $P = 0.25$, it can be pooled with the residual. This enables the power of the H v C and Estuaries(Effort) x H v C interaction F-ratios to be increased as the MS Sites(Estuaries(Effort)) x Control would then be used as the denominators. This procedure results in tests with respectively, 1 and 30, and 2 and 30 degrees of freedom giving substantially more power. It is likely that this approach will be used.

Table 2.7 Asymmetrical analysis of variance for detecting impacts of hauling on the shoot and leaf densities, and leaf length of *Zostera capricorni* in estuaries with high, medium and low levels of fishing effort (See text for details).

Source of variation	df	Denominator for *F*
Effort	2	MS Estuaries(Effort)
Estuaries(Effort)	3	MS Sites(Estuaries(Effort)) x C
H vs C	1	MS Estuaries(Effort) x H vs C
Effort x H vs C	2	MS Estuaries(Effort) x H vs C
Estuaries(Effort) x H vs C [1]	3	MS Sites(Estuaries(Effort)) x C
Sites(Estuaries(Effort)) x C	30	MS Residual
Residual	210	
Total	251	

1. If the *F*-ratio for Est x H v C is not significant at $P = 0.25$ and pooling is done, then the denominator of the *F*-ratio for H v C becomes the MS Sites(Est x Control).

2.5.3 SHORT-TERM IMPACTS

The small-scale experiment is clearly only able to assess the short-term (pulse *sensu* Bender *et al*., 1984, Underwood, 1992) effects in contrast to possible long-term (press) effects. However, with short-term changes quantified it might be possible to predict, with appropriate effort data, possible longer-term effects.

2.5.3.1 Impacts of the Experimental Net

The objectives of the field study using an experimental haul net were to assess the short-term effects on: (1) seagrass shoot/leaf density, (2) seagrass leaf length, and (3) the persistence of tagged seagrass leaves. A total of eight sites, each separate by ≈ 30 m, within a seagrass bed in the Towra Point Aquatic Reserve were identified. Treatments (Hauled, Control) were randomly assigned to the sites (i.e. 4 sites per treatment) in the experiment. Within each site, four 1 m^2 quadrats, spaced ≈ 2 m apart, were marked out using plastic ribbons in the corners. The entire process, i.e. hauling and associated sampling, was carried out over 4 consecutive days and was akin to commercial hauling practices.

Immediately prior to hauling with the experimental net, a 0.0625 m^2 sample of seagrass (collected as described in Section 2.2.1.1) was removed from within each marked quadrat and rinsed and stored as described in Section 2.2.1.1. After sampling the seagrass, ≈ 30 white orthodontic rubber bands were attached to leaves in a 0.0625 m^2 area in the middle of each marked quadrat to examine the persistence of seagrass under the experimental hauling regime. The net was then set by boat and retrieved manually so that the lead-line dragged over the seagrass bed until the point of landing on an intertidal sandflat. This hauling process was repeated three times in quick succession. After each haul, the number of tagged seagrass leaves caught in the net was recorded. After all 3 hauls had been completed a further 0.0625 m^2 sample of seagrass bed was removed and the number of tagged leaves remaining was recorded for each marked quadrat. All samples were then rinsed, etc. (see Section 2.2.1.1) and returned to the laboratory for processing.

The short-term effects of hauling with an experimental net on the shoot and leaf density was examined using a 3-factor analysis of variance. The analysis (Table 2.8) partitioned the total variation into that associated with differences between times (before & after), treatments (Hauled vs Control), among sites nested within treatments and their respective interactions. A 4-factor analysis of variance used to examine the short-term effects of hauling on the leaf length of *Zostera capricorni*. The analysis (Table 2.8) partitioned the total variation into that associated with differences from Before to After (Fixed), between Hauled vs Control (Fixed), among Sites nested within treatments and among Quadrats nested within sites and their respective interactions. The proportion of tagged leaves remaining intact in each quadrat was used to examine the persistence of seagrass under the experimental hauling. A two-factor analysis of variance was used to test for differences between treatments (Hauled vs Control) and among sites nested within treatments.

Table 2.8 Analysis of variance for assessing the short-term impacts of an experimental haul net on of the length of *Zostera capricorni* leaves. Note there were four 0.0625 m^2 quadrats in each of 4 hauled and 4 control sites sampled before and after hauling with the experimental net.

Source of variation	df	MS Denominator
B vs A	1	MS B vs A x Sites(H vs C)
H vs C	1	MS Sites(H vs C)
Sites(H vs C)	6	MS Quad(Sites(H vs C))
Quad(Sites(H vs C))	24	MS Residual
B vs A x H vs C	1	MS B vs A x Sites(H vs C)
B vs A x Sites(H vs C)	6	MS B vs A x Quad(Sites(H vs C))
B vs A x Quad(Sites(H vs C))	24	MS Residual
Residual	48	
Total	63	

2.5.3.2 Impacts of a Commercial Net

This field experiment using a commercial net had only one primary objective, that of assessing the short-term effects of hauling on the persistence of seagrass leaves. To do so, we took advantage of the fact that commercial hauling takes place regularly (up to twice a day) at certain locations between groynes on Silver Beach, Botany Bay.

One commercially hauled site (confirmed by discussions with local hauling crews) and five control sites were selected along Silver Beach. The control sites were chosen for their complete inaccessibility to commercial haul nets due to physical obstructions such as groynes, mooring pylons, etc. At each site, three 0.0625 m^2 quadrats, spaced ≈ 2 m apart, were marked out using plastic ribbons in the corners. In each quadrat, 50 seagrass leaves were tagged with white orthodontic rubber bands. The number of tagged seagrass leaves remaining intact was recorded for each quadrat in each site on each of three consecutive days thereafter. Prior to sampling, discussions with commercial fishers confirmed that hauling had taken place at the hauled site. Strong winds resulting in much wave-action and low visibility made sampling impossible after the third day.

The proportion of tagged leaves remaining intact in each quadrat was used to examine the short-term persistence of seagrass under the commercial hauling. A 2-factor asymmetrical analysis of variance (Table 2. 9) was used to test for differences between treatments (Hauled vs Control) and among control sites for each of the 3 days of the experiment. The power of test for impact, i.e. the H v C term, is very dependent on the number of control sites, but can be increased if *post-hoc* pooling is possible. If the Sites(Control) term is not significant at $P = 0.25$, it can be pooled with the residual. The H v C *F*-ratio would then have the MS Residual as the denominator and its associated 16 degrees of freedom. It is likely that the Sites(Control) term will be significant in most situations because it estimates the natural variation among control sites. Thus, it is unlikely that *post-hoc* pooling could be used to enhance the power of the test for impact.

Table 2.9 Asymmetrical analysis of variance for detecting the impacts of commercial hauling on the short-term persistence of *Zostera capricorni* leaves. Note that there is one putatively impacted (hauled) site and 5 control sites sampled contemporaneously with 3 quadrats of tagged leaves per site.

Source of variation	df	Denominator for *F*
Hauled v Controls = H v C	1	MS Sites (Control)
Sites (Control) [1]	4	MS Residual
Residual	12	
Total	17	

1. If the *F*-ratio for Sites (Est x Control) is not significant at $P = 0.25$ then the denominator of the *F*-ratio for Est x H v C is the MS Residual.

3. RESULTS

3.1 HAULING EFFORT

3.1.1 ANALYSIS OF HAULING EFFORT AMONG ESTUARIES

The mean annual hauling effort (expressed as fisher days) for the period 1984 to 1996 ranged from about 40 to 1680 days/annum across the nine estuaries (Table 3.1). While individual estuaries clearly differed, they could be combined into three groups each separated by an order of magnitude in the mean annual hauling effort. The first group comprised Port Stephens, Lake Macquarie and Botany Bay and had pooled mean annual hauling effort of 1,325.86 days/annum. In contrast, Wallis Lake, Tuggerah Lake, Lake Illawarra and St. George's Basin had pooled mean annual hauling effort of 551.56 days/annum. Finally, the third group comprised Burrill and Wallaga Lakes, with a mean annual hauling effort of 40.55 days/annum.

The differences in mean annual hauling effort among estuaries were examined more closely using the means of individual years as replicates in a single factor analysis variance (Table 3.2). This analysis showed that the annual hauling effort differed significantly among estuaries (Table 3.2a, analysis of variance, P <0.0001) and the pattern of differences was very similar to the three groups identified in Table 3.1 (i.e. each group separated by an order of magnitude in the mean annual hauling effort). Results of the SNK-test (Table 3.2b) showed that the mean annual fishing effort was greatest in Port Stephens which was significantly greater than Botany Bay which, in turn, was significantly greater than Lake Macquarie and Wallis Lake which did not differ. The mean annual hauling effort in all four of these estuaries was significantly greater than that in St. George's Basin, Tuggerah Lake and Lake Illawarra which did not differ significantly. Finally, fishing effort in these estuaries was, in turn, significantly greater than that in Burrill and Wallaga Lakes, which did not differ significantly.

There was a significant correlation between the area of an estuary and the mean annual hauling effort ($\sigma_s = 0.85$, $P < 0.01$). The correlation is likely the result of several (potentially interacting) factors, but does not assist with the assessment of impact because the hauling crews only operate at recognised hauling sites and do not fish the entire estuary. In addition, the variation among control sites for the seagrass variables estimated (e.g. shoot density, etc.) was not correlated with estuary size. Site-specific hauling effort would, however, be advantageous for the assessment of impact, but such information has not been collected to date.

3.1.2 ANALYSIS OF HAULING EFFORT OVER TIME

The mean annual hauling effort (expressed as fisher days) for the period 1984 to 1996 varied through time in each of the estuaries (Table 3.1), but showed no obvious linear trends in Wallis Lake, Lake Macquarie, Tuggerah Lake, Botany Bay, Burrill Lake and Wallaga Lake (Table 3.3, all regression slopes not significantly different from zero, P > 0.05). In contrast, there was a significant increase in the mean annual hauling effort in Port Stephens, and significant decreases in mean annual hauling effort in Lake Illawarra and St George's Basin (Table 3.3, all 3 regression slopes significantly different from zero, P < 0.05).

Examination of the intra-annual variation (monthly intervals) in mean hauling effort pooled over the 12 years (Fig. 3.1) showed few, if any, trends in all estuaries except Port Stephens and Botany Bay. In Port Stephens, hauling effort increased substantially from February to June. In Botany Bay, the fishing effort reflected seasonal patterns of change. Effort increased slowly over Spring, reaching a maximum in late Summer and then declined over Autumn reaching a

Table 3.1. Annual and overall mean hauling effort (days/annum) for the period 1984 to 1996 for the nine randomly chosen estuaries sampled to assess the physical effects of hauling on seagrass. Data from the NSW Fisheries catch and effort database (for details see Pease and Scribner, 1933, 1994; Pease and Grinberg, 1995)

FINANCIAL YEAR / ESTUARY	1984-1985	1985-1986	1986-1987	1987-1988	1988-1989	1989-1990	1990-1991	1991-1992	1992-1993	1993-1994	1994-1995	1995-1996	MEAN FOR ESTUARIES
WALLIS LAKE	532	633	879	1239	791	880	581	819	714	1380	1264	825	878.08
PORT STEPHENS	952	1023	1203	923	1498	1423	2684	2563	1975	2274	1886	1731	1677.92
LAKE MACQUARIE	942	1170	834	1046	1071	874	917	1059	1049	1197	1166	960	1023.75
TUGGERAH LAKES	274	326	634	465	445	483	441	75	179	245	652	576	399.58
BOTANY BAY	1086	1265	1174	1180	1136	1212	1765	1524	1487	1421	1170	891	1275.92
LAKE ILLAWARRA	244	802	538	463	676	395	141	327	159	215	175	144	356.58
ST GEORGES BASIN	625	799	766	443	501	762	839	681	320	325	319	484	572.00
BURRILL LAKE	33	44	24	15	50	36	49	75	45	51	35	31	40.67
WALLAGA LAKE	0	52	53	107	12	14	22	33	26	2	7	157	40.42

minimum in Winter. Finally, the relatively small standard errors for monthly means of hauling effort suggested that similar patterns occurred from year to year over the period 1984 to 1996.

Table 3.2 Analysis of the mean annual hauling effort (fisher days/annum) for the period 1984 to 1996 for Wallis Lake (WS), Port Stephens (PS), Lake Macquarie (LM), Tuggerah Lake (TL), Botany Bay (BB), Lake Illawarra (LI), St George's Basin (SG), Burrill Lake (BL) and Wallaga Lake (WL).

(a) Analysis of variance of untransformed data (variances heterogeneous).

Source of variation	df	MS	Percent variance	*F*	*P*
Estuaries	8	3778098	81.2	52.68	< 0.0001
Residual	99	71714	18.8		
Total	107		100.0		

(b) Results of SNK-test.

PS > BB > LM = WS > SG = TL = LI > BL = WL

Table 3.3 Linear regressions of estuary-wide hauling effort (fisher days/annum) on time (years: 1 - 12) for the period 1984 to 1996 for Wallis Lake, Port Stephens, Lake Macquarie, Tuggerah Lake, Botany Bay, Lake Illawarra, St George's Basin, Burrill Lake and Wallaga Lake.

Estuary	Regression Equation	r^2	*t* ($H_0 : b = 0$)	Trend	*P*
Wallis Lake	y = 660.61 + 33.46x	0.191	1.534	none	> 0.05
Port Stephens	y = 915.44 + 117.30x	0.476	3.014	increase	**< 0.05**
Lake Macquarie	y = 961.82 + 9.53x	0.083	0.950	none	> 0.05
Tuggerah Lake	y = 377.97 + 3.33x	0.004	0.209	none	> 0.05
Botany Bay	y = 1230.89 + 6.93x	0.011	0.339	none	> 0.05
Lake Illawarra	y = 625.33 - 41.35x	0.450	-2.860	decrease	**< 0.05**
St. George's Basin	y = 775.55 - 31.31x	0.327	-2.203	decrease	**< 0.05**
Burrill Lake	y = 33.30 + 1.13x	0.070	0.869	none	> 0.05
Wallaga Lake	y = 26.08 + 2.21x	0.028	0.539	none	> 0.05

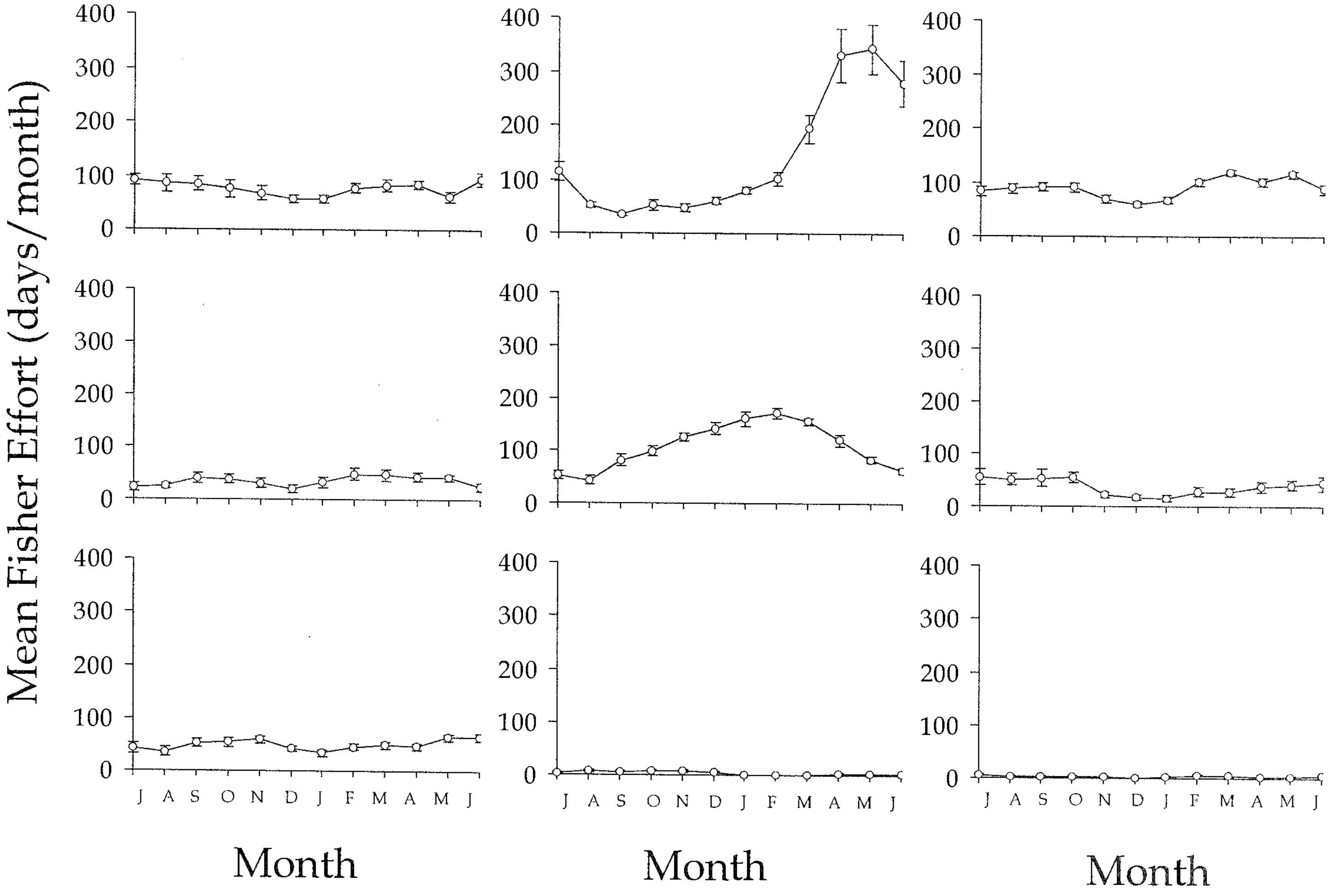

Figure 3.1. Mean (SE) monthly hauling effort (days/month) calculated as a pooled mean over the period 1984 to 1996 for the nine randomly-chosen estuaries sampled to assess the physical effects of hauling on seagrass. Data from the NSW Fisheries catch and effort database (see Pease and Scribner 1994, Pease and Grinberg 1995 for summaries).

3.2 LONG-TERM IMPACTS

3.2.1 IMPACTS OF HAULING IRRESPECTIVE OF EFFORT

3.2.1.1 Shoot and Leaf Densities - Winter 1996

Zostera capricorni exhibited significant variation in shoot and leaf densities among estuaries and sites within individual estuaries during die-back in Winter (Figs. 3.2 & 3.3, Tables 3.4 & 3.7, analyses of variance, $P < 0.01$). During Winter most of the variation in shoot and leaf densities was accounted for by differences among sites within estuaries (45.2% and 41.8% for shoot and leaf density, respectively). Neither the Estuary x H vs C interaction nor the H vs C term were significant in the analyses of shoot and leaf density (Tables 3.4 & 3.7, analysis of variance, $P > 0.05$ and $P > 0.25$ for Estuary x H vs C and H vs C, respectively) suggesting that there was no consistent impact of hauling on shoot and leaf densities of *Zostera capricorni* across all nine estuaries. However, the realised power of the Estuary x H vs C interaction to detect 30 - 50% changes in mean shoot density between treatments in any given estuary was less than 0.40. Furthermore, inspection of the means in Figures 3.2 and 3.3, and the means of the hauled and control treatments (pooled across all 6 replicate sites) in each individual estuary (Tables 3.5 & 3.8) suggested that shoot and leaf densities of *Z. capricorni* differed between the hauled and control treatments in some estuaries. To assist in identifying whether these differences were statistically significant, the absolute value of the difference between the means of the hauled and control treatments divided by the mean of the control treatment was calculated and expressed as a percentage (Tables 3.5 & 3.8). Then, if the absolute value of the difference between the means of the hauled and control treatments divided by the mean of the control treatment for a given estuary was 70% or more, the data for the particular estuary was subjected to analysis of variance. To ensure the experiment-wise Type I error-rate was maintained at $\alpha = 0.05$, the Type I error-rate for the analyses (i.e. anova) of individual estuaries was adjusted using Bonferroni's inequality (Miller, 1966).

For shoot density, the absolute values of the difference between the means of the hauled and control treatments divided by the mean of the control treatment (expressed as percentage) were 93.1%, 75.9% and 75.9% for Lake Macquarie, Botany Bay and St. George's Basin, respectively (Table 3.5), and thus a separate analysis of variance was done for each estuary. Hauling was correlated with significantly greater shoot densities of *Z. capricorni* in Lake Macquarie and Botany Bay, respectively (Table 3.6a and b, analyses of variance, $P < 0.05$). While there was also a marked difference in the shoot densities of *Z. capricorni* at the control and hauled sites in St. George's Basin (Table 3.5), the analysis of variance (Table 3.6c) did not detect a significant difference. *Post-hoc* power analysis showed that the power to detect a 40% change in shoot density was less than 0.20. It is likely that the variation among control sites (i.e. 47.0% of the total variation in the analysis in Table 3.6c) was responsible for the low power of the H vs C *F*-test.

With leaf density, separate analyses of variance were only done for Lake Macquarie and Botany Bay because the differences were 83.0% and 84.0%, respectively (Table 3.8). Both analyses showed that hauling was correlated with significantly greater leaf densities of *Z. capricorni* (Fig. 3.3, Table 3.9a and b, analyses of variance, $P < 0.01$).

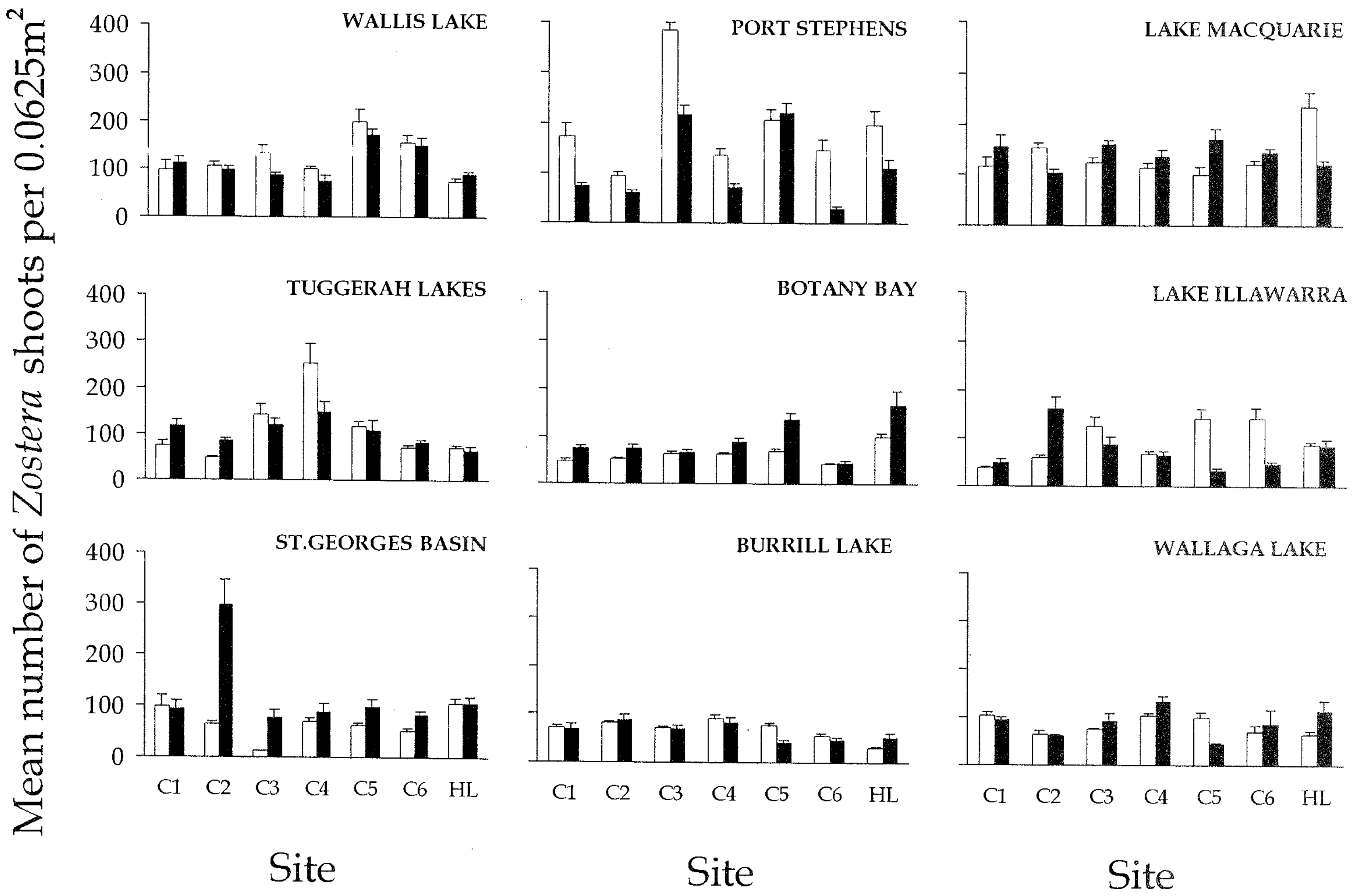

Figure 3.2. The mean (SE) density of *Zostera capricorni* shoots at one hauled site (HL) and six control sites (CL) in each of nine NSW estuaries sampled during the periods of die-back and growth in Winter 1996 (unshaded) and Summer 1997 (shaded), respectively.

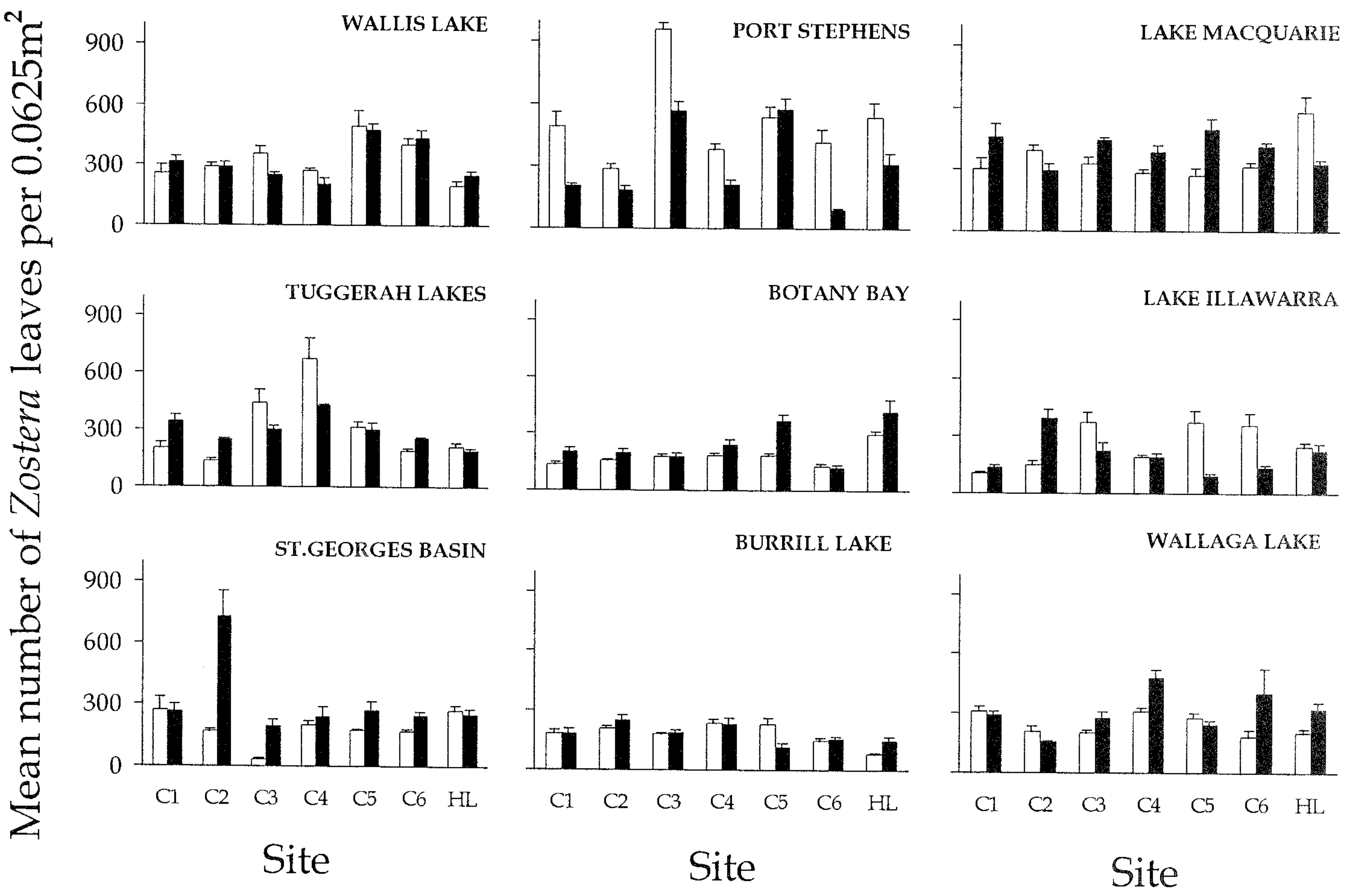

Figure 3.3. The mean (SE) density of *Zostera capricorni* leaves at one hauled site (HL) and six control sites (CL) in each of nine NSW estuaries sampled during the periods of die-back and growth in Winter 1996 (unshaded) and Summer 1997 (shaded), respectively.

Table 3.4 Asymmetrical analysis of variance of untransformed data for the density of *Zostera capricorni* shoots at one hauled site and six control (unhauled) sites in each of nine NSW estuaries sampled during the period of die-back in Winter 1996.

Source of variation	df	MS	Percent variance	*F*	*P*
Estuaries	8	74450.5	29.9	5.260	< 0.01
H vs C	1	372.3	0.0	0.024	> 0.25
Estuaries x H vs C	8	15740.0	0.9	1.112	> 0.10
Sites (Estuaries x C)	45	14155.4	45.2	12.340	< 0.01
Residual	315	1147.1	24.0		
Total	377		100.0		

Table 3.5 Mean density (per 0.0625 m^2) of *Zostera capricorni* shoots in the hauled and control treatments in all nine estuaries sampled during the die-back period in Winter 1996. Each control mean was calculated by pooling across all 6 replicate sites within an estuary.

Estuary	Treatment Mean		Change from Control	|H - C| / C (%)
	Hauled	Control		
Wallis Lake	73.8	132.1	- ve	44.13
Port Stephens	197.0	189.8	+ ve	3.79
Lake Macquarie	234.0	121.2	+ ve	**93.07**
Tuggerah Lake	71.3	117.3	- ve	39.22
Botany Bay	98.3	55.9	+ ve	**75.85**
Lake Illawarra	86.2	95.5	- ve	9.74
St. George's Basin	105.0	59.8	+ ve	**75.59**
Burrill Lake	29.0	73.2	- ve	60.38
Wallaga Lake	63.3	84.6	- ve	25.18

Table 3.6 Asymmetrical analyses of variance of untransformed data for the density of *Zostera capricorni* shoots at one hauled site and six control (unhauled) sites in (a) Lake Macquarie, (b) Botany Bay, (c) St. Georges Basin sampled during the period of die-back in Winter 1996. Type I error-rate adjusted to $\alpha = 0.02$ using Bonferroni's inequality to maintain the experiment-wise Type I error-rate at $\alpha = 0.05$.

(a)

Source of variation	df	MS	Percent variance	*F*	*P*
H vs C	1	65540.0	54.0	35.26	< 0.02
Sites (C)	5	1858.7	2.2	1.30	> 0.10
Residual	35	1433.6	43.8		
Total	41		100.0		

(b)

Source of variation	df	MS	Percent variance	*F*	*P*
H vs C	1	9277.1	48.6	12.97	< 0.02
Sites (C)	5	715.1	19.0	4.51	< 0.01
Residual	35	158.6	32.4		
Total	41		100.0		

(c)

Source of variation	df	MS	Percent variance	*F*	*P*
H vs C	1	10286.10	10.7	2.19	> 0.05
Sites (C)	5	4692.78	47.0	7.67	< 0.01
Residual	35	611.88	42.3		
Total	41		100.0		

Table 3.7 Asymmetrical analyses of variance of untransformed and $\log_{10}$ transformed data for the leaf density of *Zostera capricorni* at one hauled site and six control (unhauled) sites in each of nine NSW estuaries sampled during the period of die-back in Winter 1996.

Source of variation	Untransformed Data			Transformed Data		
	df	MS	Percent variance	MS	*F*	*P*
Estuaries	8	508854.9	31.6	1.0877	5.86	< 0.01
H vs C	1	4597.0	0.0	0.0030	0.01	> 0.25
Estuaries x H vs C	8	95105.5	0.6	0.2853	1.54	> 0.05
Sites (Estuaries x C)	45	87878.1	41.8	0.1856	12.88	< 0.01
Residual	315	8275.0	26.0	0.0144		
Total	377		100.0			

Table 3.8 Mean density (per 0.0625 m^2) of *Zostera capricorni* leaves in the hauled and control treatments in all nine estuaries sampled during the die-back period in Winter 1996. Note each control mean was calculated by pooling across all 6 replicate sites within an estuary.

Estuary	Treatment Mean		Change from Control	$\frac{\|H - C\|}{C}$ (%)
	Hauled	Control		
Wallis Lake	198.0	344.3	- ve	42.5
Port Stephens	536.0	513.3	+ ve	4.4
Lake Macquarie	581.0	317.5	+ ve	**83.0**
Tuggerah Lake	210.0	326.3	- ve	35.6
Botany Bay	295.0	160.3	+ ve	**84.0**
Lake Illawarra	246.0	254.3	- ve	3.3
St. George's Basin	268.0	167.6	+ ve	59.9
Burrill Lake	77.5	183.3	- ve	60.1
Wallaga Lake	201.0	243.5	- ve	17.5

Table 3.9 Asymmetrical analyses of variance of untransformed and $\log_{10}$ transformed data for the density of *Zostera capricorni* leaves at one hauled site and six control (unhauled) sites in (a) Lake Macquarie, and (b) Botany Bay sampled during the period of die-back in Winter 1996. Type I error-rate adjusted to $\alpha = 0.025$ using Bonferroni's inequality to maintain the experiment-wise Type I error-rate at $\alpha = 0.05$.

(a)

Source of variation	Untransformed Data			Transformed Data		
	df	MS	Percent variance	MS	*F*	*P*
H vs C	1	357833.4	48.4	0.327	14.22	< 0.01
Sites (C)	5	11245.3	1.0	0.023	1.46	> 0.10
Residual	35	10055.7	50.6	0.016		
Total	41		100.0			

(b)

Source of variation	Untransformed Data				
	df	MS	Percent variance	*F*	*P*
H vs C	1	93074.2	59.7	24.29	< 0.01
Sites (C)	5	3831.4	10.4	3.09	< 0.05
Residual	35	1240.9	29.9		
Total	41		100.0		

3.2.1.2 Shoot and Leaf Densities - Summer 1997

During the summer growth period a large majority of the variation in shoot and leaf densities (Tables 3.10 & 3.11) was accounted for by differences among sites within estuaries (58.5 and 54.0% for shoot and leaf density, respectively). Commercial hauling was not correlated with significant alterations to the density of *Z. capricorni* shoots and leaves as the Estuary x H vs C and H vs C *F*-ratios were not significant (Tables 3.10 & 3.11, analyses of variance, all terms $P > 0.05$). Moreover, neither term accounted for any of the percentage variance explained by the model for the analyses of shoot and leaf density (Tables 3.10 & 3.11). Despite this, an inspection of the means (Figs. 3.2 and 3.3) showed that there were greater shoot and leaf densities of *Z. capricorni*

Table 3.10 Asymmetrical analysis of variance of untransformed data for the density of *Zostera capricorni* shoots at one hauled site and six control (unhauled) sites in each of nine NSW estuaries sampled during the period of growth in Summer 1997.

Source of variation	df	MS	Percent variance	*F*	*P*
Estuaries	8	23727.6	6.2	1.671	> 0.05
H vs C	1	1.2	0.0	0.001	> 0.25
Estuaries x H vs C	8	7362.0	0.0	0.519	> 0.05
Sites (Estuaries x C)	45	14196.2	58.5	10.949	< 0.01
Residual	315	1296.5	35.3		
Total	377		100.0		

Table 3.11 Asymmetrical analysis of variance of untransformed (variances heterogeneous) data for density of *Zostera capricorni* leaves at one hauled site and six control (unhauled) sites in each of nine NSW estuaries sampled during the period of growth in Summer 1997.

Source of variation	df	MS	Percent variance	*F*	*P*
Estuaries	8	196453.3	9.6	2.115	> 0.05
H vs C	1	12139.0	0.0	0.261	> 0.25
Estuaries x H vs C	8	46424.0	0.0	0.500	> 0.05
Sites (Estuaries x C)	45	92897.8	54.0	9.874	< 0.01
Residual	315	9408.1	36.4		
Total	377		100.0		

Table 3.12 Mean density (per 0.0625 m^2) of *Zostera capricorni* shoots in the hauled and control treatments in the 9 sampled in Summer 1997. Each control mean was calculated by pooling across all 6 replicate sites within an estuary.

Estuary	Treatment Mean		Increase or Decrease from Control	$\frac{\lvert H - C \rvert}{C}$ (%)
	Hauled	Control		
Wallis Lake	89.7	115.0	Decrease	22.0
Port Stephens	109.0	111.1	Decrease	1.9
Lake Macquarie	121.0	145.3	Decrease	16.7
Tuggerah Lake	66.2	109.6	Decrease	39.6
Botany Bay	165.0	80.8	Increase	**104.2**
Lake Illawarra	84.3	73.9	Increase	14.1
St. George's Basin	106.0	122.3	Decrease	13.3
Burrill Lake	53.0	65.4	Decrease	19.0
Wallaga Lake	112.0	84.0	Increase	33.3

Table 3.13 Mean density (per 0.0625 m^2) of *Zostera capricorni* leaves in the hauled and control treatments in the 9 sampled in Summer 1997. Each control mean was calculated by pooling across all 6 replicate sites within the estuary.

Estuary	Treatment Mean		Change from Control	$\frac{\lvert H - C \rvert}{C}$ (%)
	Hauled	Control		
Wallis Lake	252.0	328.2	Decrease	23.2
Port Stephens	315.0	306.4	Increase	2.8
Lake Macquarie	329.0	415.0	Decrease	20.7
Tuggerah Lake	189.0	310.3	Decrease	39.1
Botany Bay	413.00	217.8	Increase	**89.6**
Lake Illawarra	223.0	192.0	Increase	16.1
St. George's Basin	248.0	322.8	Decrease	23.2
Burrill Lake	146.0	183.3	Decrease	20.3
Wallaga Lake	318	303.7	Increase	4.7

at the hauled site compared to the control sites in Botany Bay. The absolute value of the difference between the means of the hauled and control treatments divided by the mean of the control treatment for the densities of shoots and leaves were 104.2% and 89.6%, respectively (Tables 3.12 and 3.13) suggesting a significant differences. Individual analyses of variance of data from Botany Bay showed that hauling was correlated with a significantly greater shoot density of *Z. capricorni* (Table 3.14, analysis of variance, $P < 0.05$). The leaf densities at the hauled and control treatments were not significantly different (Table 3.15, analysis of variance, $P > 0.05$), but power of 0.80 was not realised in the analysis.

Table 3.14 Asymmetrical analysis of variance of untransformed data for the density of *Zostera capricorni* shoots at one hauled site and six control (unhauled) sites in Botany Bay, sampled during the growth period in Summer 1997. Test-wise Type I error-rate is equivalent to the experiment-wise Type I error-rate of $\alpha = 0.05$ for a single estuary.

Source of variation	df	MS	Percent variance	*F*	*P*
H vs C	1	362464.0	30.6	63.80	< 0.01
Sites (C)	5	5681.3	27.0	4.82	< 0.01
Residual	35	1178.2	42.4		
Total	41		100.0		

Table 3.15 Asymmetrical analyses of variance of untransformed and $\log_{10}$ transformed data for the density of *Zostera capricorni* leaves at one hauled site and six control (unhauled) sites in Botany Bay sampled during the growth period in Summer 1997. Test-wise Type I error-rate is equivalent to the experiment-wise Type I error-rate of $\alpha = 0.05$ for a single estuary.

Source of variation	Untransformed Data			Transformed Data		
	df	MS	Percent variance	MS	*F*	*P*
H vs C	1	196840.0	26.1	0.429	2.98	> 0.05
Sites (C)	5	40555.6	33.9	0.144	10.08	< 0.01
Residual	35	6661.4	40.0	0.014		
Total	41		100.0			

3.2.1.3 Leaf Length - Winter 1996 and Summer 1997

Zostera capricorni exhibited significant variation in leaf length among estuaries, and sites within individual estuaries over the period of die-back in Winter 1996 and Summer 1997 (Fig. 3.4 and Tables 3.16 & 3.18, analyses of variance, $P < 0.01$) with 81.4% of the variation in leaf length accounted for by differences among estuaries (34.2%) and sites within estuaries (47.2%). During the Summer growth period 79.4% of the variation in leaf length was accounted for by differences among estuaries (29.4%) and sites within estuaries (50.0%).

In Winter 1996, the Estuary x H vs C interaction was not significant (Table 3.16, analysis of variance, $P > 0.25$) indicating that the differences between treatments were consistent among estuaries. More importantly however, the H vs C term was significant (Table 3.16, analysis of variance, $P < 0.05$) and comparison of the means indicated that hauling was correlated with a 20% reduction in the length of *Zostera capricorni* leaves, on average, across the nine estuaries. On inspection of the means (Table 3.17) it was clear that reductions in leaf length varied from 38.9% to 16.8% across the nine estuaries.

In Summer 1997, the Estuary x H vs C interaction was significant (Table 3.18, analysis of variance, $P < 0.05$) indicating that the differences between treatments were not consistent among estuaries. Non-orthogonal contrasts, as described by Sokal and Rohlf (1969), were then used to compare the treatment means for individual estuaries and interpret the interaction. The contrasts (Table 3.19) showed that the mean length of *Zostera capricorni* leaves had been significantly reduced by 55.8% and 72.8% in Port Stephens and St. George's Basin, respectively when sampled in Summer 1997. The change at St. George's Basin represented a further (38.5%) reduction in leaf length from Winter 1996 to Summer 1997. It is also important to note that the power of these contrasts was only adequate enough to detect large (> 50%) differences between the treatment means. Comparisons of the means in Table 3.19 clearly shows an obvious trend towards reductions in leaf length at the hauled site in all estuaries except Lake Illawarra and Tuggerah Lake.

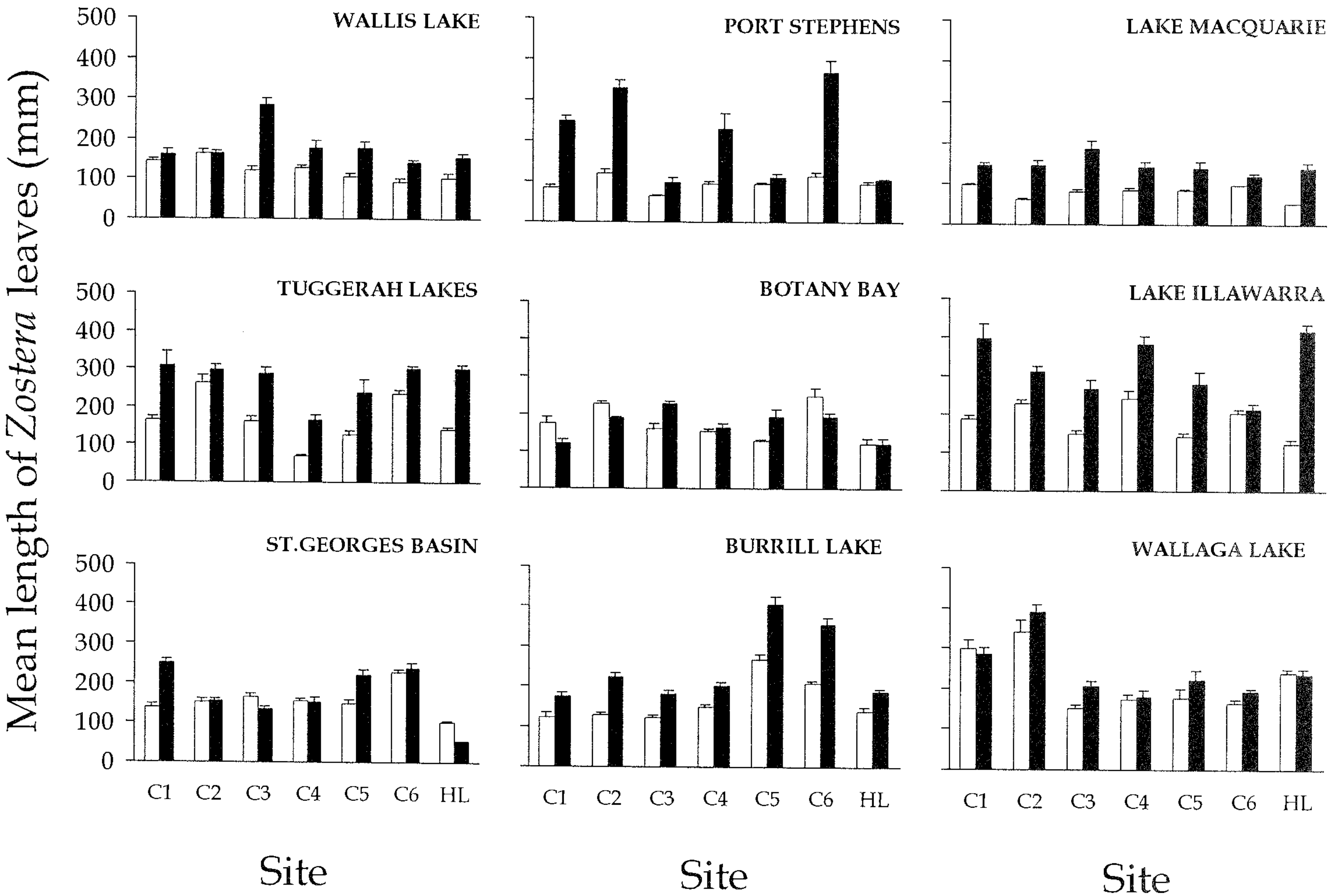

Figure 3.4. The mean (SE) length of *Zostera capricorni* leaves at one hauled site (HL) and six control sites (CL) in each of nine NSW estuaries sampled during the periods of die-back and growth in Winter 1996 (unshaded) and Summer 1997 (shaded), respectively.

Table 3.16 Asymmetrical analyses of variance of untransformed and log_{10} transformed data or the length of *Zostera capricorni* leaves at one hauled site and six control (unhauled) sites in each of nine NSW estuaries sampled during Winter 1996.

Source of variation	Untransformed Data			Transformed Data		
	df	MS	Percent variance	MS	*F*	*P*
Estuaries	8	81767.63	34.2	0.7917	8.68	< 0.01
H vs C	1	43927.00	2.6	0.4234	8.37	< 0.05
Estuaries x H vs C	8	4499.25	0.0	0.0506	0.55	> 0.25
Sites (Estuaries x C)	45	14103.31	47.2	0.0912	16.21	< 0.01
Residual	315	756.56	16.0	0.0056		
Total	377		100.0			

Table 3.17 Mean length (mm) of *Zostera capricorni* leaves in the hauled and control treatments (pooled across all nine estuaries) sampled during the die-back period in Winter 1996. Note, the control mean for each estuary was obtained by pooling across the 6 replicate sites.

Estuary	Treatment Mean (mm)		Change from Control	|H - C| / C (%)
	Hauled	Control		
Wallis Lake	102.1	125.3	- ve	18.5
Port Stephens	94.7	94.8	no change	0.1
Lake Macquarie	51.2	83.8	- ve	38.9
Tuggerah Lake	139.8	169.1	- ve	17.3
Botany Bay	120.9	181.9	- ve	33.5
Lake Illawarra	125.4	190.6	- ve	34.2
St. George's Basin	101.4	162.9	- ve	37.8
Burrill Lake	137.7	165.6	- ve	16.8
Wallaga Lake [1]	239.7	216.2	+ ve	10.9
Overall Mean	123.7	154.5	- ve	20.0

1 Difference is not significant.

Table 3.18 Asymmetrical analyses of variance of untransformed and $\log_{10}$ transformed data for the length of *Zostera capricorni* leaves at one hauled site and six control (unhauled) sites in each of nine NSW estuaries sampled during the period of growth in Summer 1997.

	Untransformed Data			Transformed Data		
Source of variation	**df**	**MS**	**Percent variance**	**MS**	***F***	***P***
Estuaries	8	139636.63	29.4	0.5618	5.30	< 0.01
H vs C	1	50727.00	0.7	0.5623	2.47	> 0.05
Estuaries x H vs C	8	31019.88	0.7	0.2278	2.15	< 0.05
Sites (Estuaries x C)	45	28660.89	50.0	0.1060	16.74	< 0.01
Residual	315	1728.27	19.2	0.0063		
Total	377		100.0			

Table 3.19 Mean length of *Zostera capricorni* leaves in the hauled and control treatments in all nine estuaries sampled during the growth period in Summer 1997. Each control mean was calculated by pooling across all 6 replicate sites.

Estuary	**Treatment**		**Change from Control**	**|H - C| / C (%)**	**Mean Square (H vs C)**	***F***	***P***
	Hauled	**Control**					
Wallis Lake	152.64	183.42	- ve	16.8	0.02	0.19	> 0.05
Port Stephens	101.98	230.72	- ve	**55.8**	0.45	4.25	**< 0.05**
Lake Macquarie	140.16	146.13	- ve	4.1	0.01	0.09	> 0.05
Tuggerah Lake	300.76	265.75	+ ve	13.2	0.02	0.19	> 0.05
Botany Bay	122.16	180.61	- ve	32.4	0.08	0.75	> 0.05
Lake Illawarra	417.06	307.99	+ ve	26.2	0.12	1.13	> 0.05
St. George's Basin	51.80	190.12	- ve	**72.8**	1.58	14.91	**< 0.05**
Burrill Lake	187.17	256.25	- ve	27.0	0.07	0.66	> 0.05
Wallaga Lake	234.59	245.27	- ve	4.4	0.00	0.00	> 0.05

3.2.2 IMPACTS OF HAULING IN RELATION TO HAULING EFFORT

3.2.2.1 Hauling Effort - Implications for Analyses of Impact

The mean annual fishing effort for the period 1984 to 1996 clearly identified three groups of estuaries each separated by an order of magnitude in the mean annual fishing effort. Group 1 comprised Port Stephens, Lake Macquarie and Botany Bay, group 2 comprised Wallis Lake, Tuggerah Lake, Lake Illawarra and St. George's Basin, and group 3 comprised Burrill and Wallaga Lakes. The analyses of impact in relation to hauling effort were based on a partially nested, partially orthogonal 4-factor asymmetrical analysis of variance with factor 1: Effort (Low, Medium, High), factor 2: Estuaries nested within Effort (Low - Wallaga & Burrill Lakes; Medium - Lake Illawarra, Tuggerah Lake; High - Botany Bay, Lake Macquarie), factor 3: Hauled vs Control, and factor 4: Sites nested within Control treatment (i.e. asymmetrical). As these measures of hauling effort were not site-specific, the analyses can only be considered exploratory.

It is important to note that the *F*-tests to detect impact (Effort x H vs C and H vs C, see Table 3.20 etc.) lack power unless the effect size is large because there are few degrees associated with the mean squares. However, was sometimes possible to eliminate terms from the model via *post-hoc* pooling procedures (see later and for details of pooling Bozivich *et al*., 1956; Green & Tukey, 1960; Winer, 1971) which increased the power of these tests.

3.2.2.2 Shoot and Leaf Densities - Winter 1996

During the period of die-back in Winter, *Zostera capricorni* exhibited significant variation in shoot and leaf densities among control sites within individual estuaries in different levels of fishing effort (Tables 3.20 & 3.22, analyses of variance, $P < 0.01$) and this accounted for 35.5% and 37.8% of the total variation in the analyses of shoot and leaf densities, respectively. Moreover, as there were no consistent patterns evident among the control sites within estuaries with differential hauling effort (i.e. Low: Wallaga & Burrill Lakes; Medium: Lake Illawarra, Tuggerah Lake; High: Botany Bay, Lake Macquarie), it is likely that the differences were due to spatial and temporal variation in the processes affecting the persistence of seagrass.

Examination of the means in Figure 3.5 suggested that the high levels of effort in Botany Bay and Lake Macquarie were correlated with increased densities of *Zostera capricorni* shoots and leaves at hauled sites compared to controls. The initial tests of this hypotheses (i.e. the Effort x H vs C interactions in Table 3.20 & 3.22) had few degrees of freedom and lacked power. However, the test of the effects of differential hauling effort was made more powerful as the Estuaries(Effort) x H vs C interaction was not significant in both analyses (Tables 3.20 & 3.22, analyses of variance, $P > 0.25$) and could be pooled. This resulted in a new *F*-ratio for the Effort x H vs C interaction, namely: MS Effort x H vs C / MS Sites (Estuaries(Effort)) x Control, a test with 2 and 30 degrees of freedom. These tests were significant (Table 3.20 & 3.22, analyses of variance, $P < 0.05$) indicating that differential hauling effort was correlated with changes in the shoot and leaf densities of *Zostera capricorni*. Non-orthogonal contrasts of the hauled versus control sites for each of the three levels of fishing effort for the densities of *Zostera capricorni* shoots and leaves (Tables 3.21 & 3.23) confirmed the patterns observed in Figure 3.5 with the high levels of effort in Botany Bay and Lake Macquarie correlated with significantly greater densities of shoots (≈ 88% on average) and leaves (≈ 83% on average) at hauled sites compared to controls.

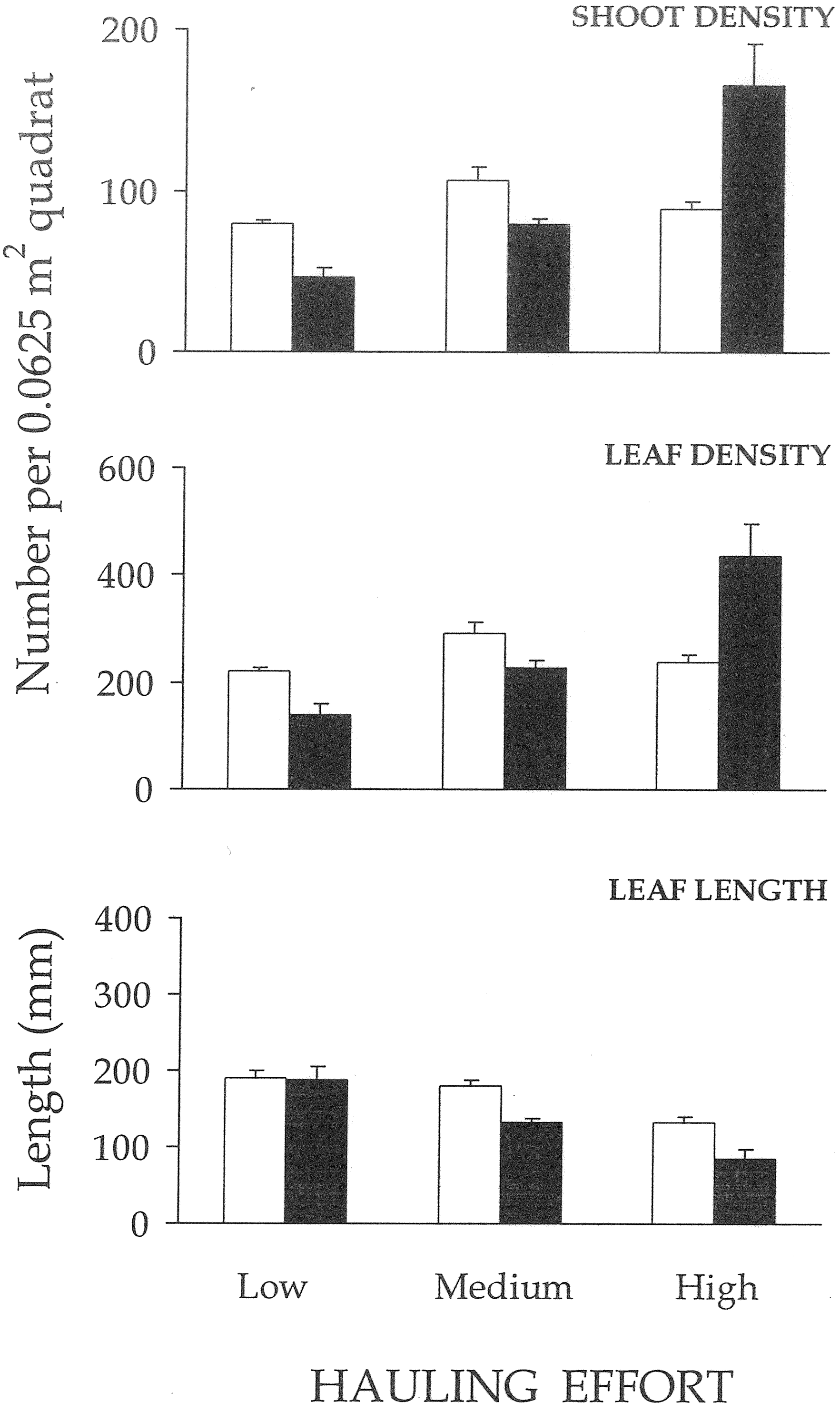

Figure 3.5. The mean (SE) shoot and leaf density, and leaf length of *Zostera capricorni* at hauled (shaded) and control (unshaded) sites in six NSW estuaries subjected to three different levels of fishing effort (Low: Wallaga & Burrill Lakes; Medium: Lake Illawarra, Tuggerah Lake; High: Botany Bay, Lake Macquarie) sampled during the period of die-back in Winter 1996.

Table 3.20 Asymmetrical analyses of variance of untransformed and log $\log_{10}$ transformed data for the density of *Zostera capricorni* shoots at one hauled site and six control (unhauled) sites in each of six NSW estuaries subjected to three different levels of fishing effort sampled during Winter 1996.

Source of variation	Untransformed Data			Transformed Data		
	df	MS	Percent variance	MS	*F*	*P*
Effort	2	20253.85	0.0	0.0124	0.28	> 0.25
Estuaries (Effort)	3	43286.50	23.6	0.0449	6.30	< 0.01
H vs C	1	1050.00	0.0	0.0013	0.20	> 0.25
Effort x H vs C	2	39891.05	13.4	0.0386	5.96	> 0.05
Est (Effort) x H vs C	3	5862.10	0.0	0.0065	0.91	> 0.25 [a]
Sites (Est(Effort)) x C	30	8465.39	35.5	0.0071	10.39	< 0.01
Residual	210	965.28	27.5	0.0007		
Total	251		100.0			

[a] With *post-hoc* pooling of the Estuaries (Effort) x H vs C term as $P > 0.25$, the new *F*-ratio for Effort x H vs C is given by: MS Effort x H vs C / MS Sites (Estuaries(Effort)) x Control with 2 and 30 degrees of freedom. $F = 0.0386 / 0.0071 = 5.44$, $P < 0.01$.

Table 3.21 Non-orthogonal contrasts of the hauled versus control sites for each of the three levels of fishing effort for the density of *Zostera capricorni* shoots sampled during the period of die-back in Winter 1996. Log $\log_{10}$ transformed means are pooled across estuaries nested within levels of effort and the MS Sites (Estuaries(Effort)) x Control was used as the denominator for *F* (i.e. MS = 0.0071) giving a test with 1 and 30 degrees of freedom.

Effort	Treatment	Mean	X	MS	*F*	*P*
Low	Hauled	0.22	2.66	0.257	3.62	> 0.05
	Control	0.27	19.44			
Medium	Hauled	0.28	3.36	0.010	1.41	> 0.05
	Control	0.31	22.32			
High	Hauled	0.35	4.20	0.050	**7.04**	**< 0.05**
	Control	0.29	20.88			

Table 3.22 Asymmetrical analyses of variance of untransformed and $\log_{10}$ transformed data for the density of *Zostera capricorni* leaves at one hauled site and six control (unhauled) sites in each of six NSW estuaries subjected to three different levels of fishing effort sampled during die-back in Winter 1996.

	Untransformed Data			Transformed Data		
Source of variation	**df**	**MS**	**Percent variance**	**MS**	***F***	***P***
Effort	2	129169.50	0.0	0.2368	0.32	> 0.05
Estuaries (Effort)	3	262213.67	19.7	0.7513	5.47	< 0.01
H vs C	1	11041.00	0.0	0.0002	0.001	> 0.25
Effort x H vs C	2	251336.00	12.8	0.6359	5.54	> 0.05
Est (Effort) x H vs C	3	28971.33	0.0	0.1147	0.83	> 0.25 [a]
Sites (Est(Effort)) x C	30	61914.07	37.8	0.1374	9.79	< 0.01
Residual	210	7165.96	29.7	0.0140		
Total	251		100.0			

[a] With *post-hoc* pooling of the Estuaries (Effort) x H vs C term as $P > 0.25$, the new F-ratio for Effort x H vs C is given by: MS Effort x H vs C / MS Sites (Estuaries(Effort)) x Control with 2 and 30 degrees of freedom. $F = 0.6359 / 0.1374 = 4.62$, $P < 0.05$.

Table 3.23 *A priori* contrasts of the hauled versus control sites for each of the three levels of fishing effort for the density of *Zostera capricorni* leaves sampled during the period of die-back in Winter 1996. Log transformed means are pooled across estuaries nested within levels of effort and the MS Sites (Estuaries (Effort)) x Control was used as the denominator for F (i.e. MS = 0.1374) giving a test with 1 and 30 degrees of freedom.

Effort	Treatment	Mean	X	MS	*F*	*P*
Low	Hauled	2.14	25.68	0.410	2.98	> 0.05
	Control	2.34	168.48			
Medium	Hauled	2.36	28.32	0.110	0.80	> 0.05
	Control	2.46	177.12			
High	Hauled	2.64	31.68	0.700	**5.09**	**< 0.05**
	Control	2.38	171.36			

3.2.2.3 Leaf Length - Winter 1996

During the Winter die-back period, *Zostera capricorni* exhibited significant variation in leaf length among control sites within individual estuaries in the different levels of fishing effort (Table 3.24, analysis of variance, $P < 0.01$) and this accounted for 51.8% of the total variation explained by the analysis. Moreover, as there were no consistent patterns evident among the control sites within estuaries with differential hauling effort (i.e. Low: Wallaga & Burrill Lakes; Medium: Lake Illawarra, Tuggerah Lake; High: Botany Bay, Lake Macquarie), it is likely that the differences were due to spatial and temporal variation in the processes affecting the persistence of *Zostera capricorni*.

Examination of the means in Figure 3.5 suggested that the high levels of effort in Botany Bay and Lake Macquarie were responsible for decreases in the length of *Zostera capricorni* leaves. With the *post-hoc* pooling of the Estuaries(Effort) x H vs C interaction (Table 3.24, analysis of variance, $P > 0.25$), tests of the effects of differential hauling effort (i.e. the Effort x H vs C interaction & the H vs C term) were made more powerful as both were tested over the MS Sites (Estuaries(Effort)) x Control: a test with 30 degrees of freedom in the

Table 3.24 Asymmetrical analyses of variance of untransformed and $\log_{10}$ transformed data for the length of *Zostera capricorni* leaves at one hauled site and six control (unhauled) sites in each of six NSW estuaries subjected to three different levels of fishing effort sampled during die-back in Winter 1996.

	Untransformed Data			**Transformed Data**		
Source of variation	**df**	**MS**	**Percent variance**	**MS**	***F***	***P***
Effort	2	93208.00	1.3	0.9187	1.00	> 0.05
Estuaries (Effort)	3	87193.73	27.9	0.9165	8.11	< 0.01
H vs C	1	31763.00	2.2	0.2932	9.19	> 0.05 b
Effort x H vs C	2	6889.85	0.6	0.1006	3.15	> 0.05
Est (Effort) x H vs C	3	4057.10	0.0	0.0319	0.28	> 0.25 a
Sites (Est(Effort)) x C	30	19036.85	51.8	0.1130	18.66	< 0.01
Residual	210	945.10	16.2	0.0061		
Total	251		100.0			

a With *post-hoc* pooling of the Estuaries (Effort) x H vs C term as $P > 0.25$, the new *F*-ratio for Effort x H vs C is given by: MS Effort x H vs C / MS Sites (Estuaries(Effort)) x Control with 2 and 30 degrees of freedom. $F = 0.1006 / 0.1130 = 0.89$, $P > 0.25$.

b With *post-hoc* pooling of the Estuaries (Effort) x H vs C term as $P > 0.25$, the new *F*-ratio for H vs C is given by: H vs C / MS Sites (Estuaries(Effort)) x Control with 1 and 30 degrees of freedom. $F = 0.2932 / 0.1130 = 2.59$, $P > 0.05$.

denominator. However, neither test was significant (Table 3.24, analysis of variance, both $P > 0.05$) suggesting that differential hauling effort was affecting the length of *Zostera capricorni* leaves. Despite the increases in degrees of freedom, neither test had sufficient power to detect a 30% change in leaf length with a Type II error-rate of 0.20.

3.2.2.4 Shoot and Leaf Densities - Summer 1997

During the period of growth in Summer, *Zostera capricorni* exhibited significant variation in shoot and leaf densities among control sites within individual estuaries in different levels of fishing effort (Tables 3.25 & 3.26, analyses of variance, $P < 0.01$) and this accounted for 28.1% and 25.2% of the total variation in the analyses of shoot and leaf densities, respectively. There were also no consistent patterns present among the control sites within estuaries with differential hauling effort. It is likely that the observed differences were due to spatial and temporal variation in the processes affecting the persistence of *Zostera capricorni*.

Examination of the means in Figure 3.6 suggested that the differential levels of fishing effort across the six estuaries had not affected the densities of *Zostera capricorni* shoots and leaves. This was confirmed by the analyses as neither the Effort x H vs C interaction nor the H vs C terms were significant (Tables 3.25 & 3.26, analyses of variance, all terms $P > 0.25$) indicating that differential hauling effort was not affecting shoot or leaf densities. The power of these tests was not questioned because both *F*-ratios were less than one and the terms could have been eliminated from the model via *post-hoc* pooling.

Table 3.25 Asymmetrical analysis of variance of untransformed data (variances heterogeneous) for the density of *Zostera capricorni* shoots at one hauled site and six control (unhauled) sites in each of six NSW estuaries subjected to three different levels of fishing effort sampled during Summer 1997.

Source of variation	df	MS	Percent variance	*F*	*P*
Effort	2	34753.10	3.8	1.42	> 0.05
Estuaries (Effort)	3	26362.87	18.7	4.73	< 0.01
H vs C	1	1508.00	0.0	0.11	> 0.25
Effort x H vs C	2	5480.15	0.0	0.39	> 0.25
Est (Effort) x H vs C	3	13915.80	7.5	2.50	> 0.05
Sites (Est(Effort)) x C	30	5577.08	28.1	5.03	< 0.01
Residual	210	1108.30	41.9		
Total	251		100.0		

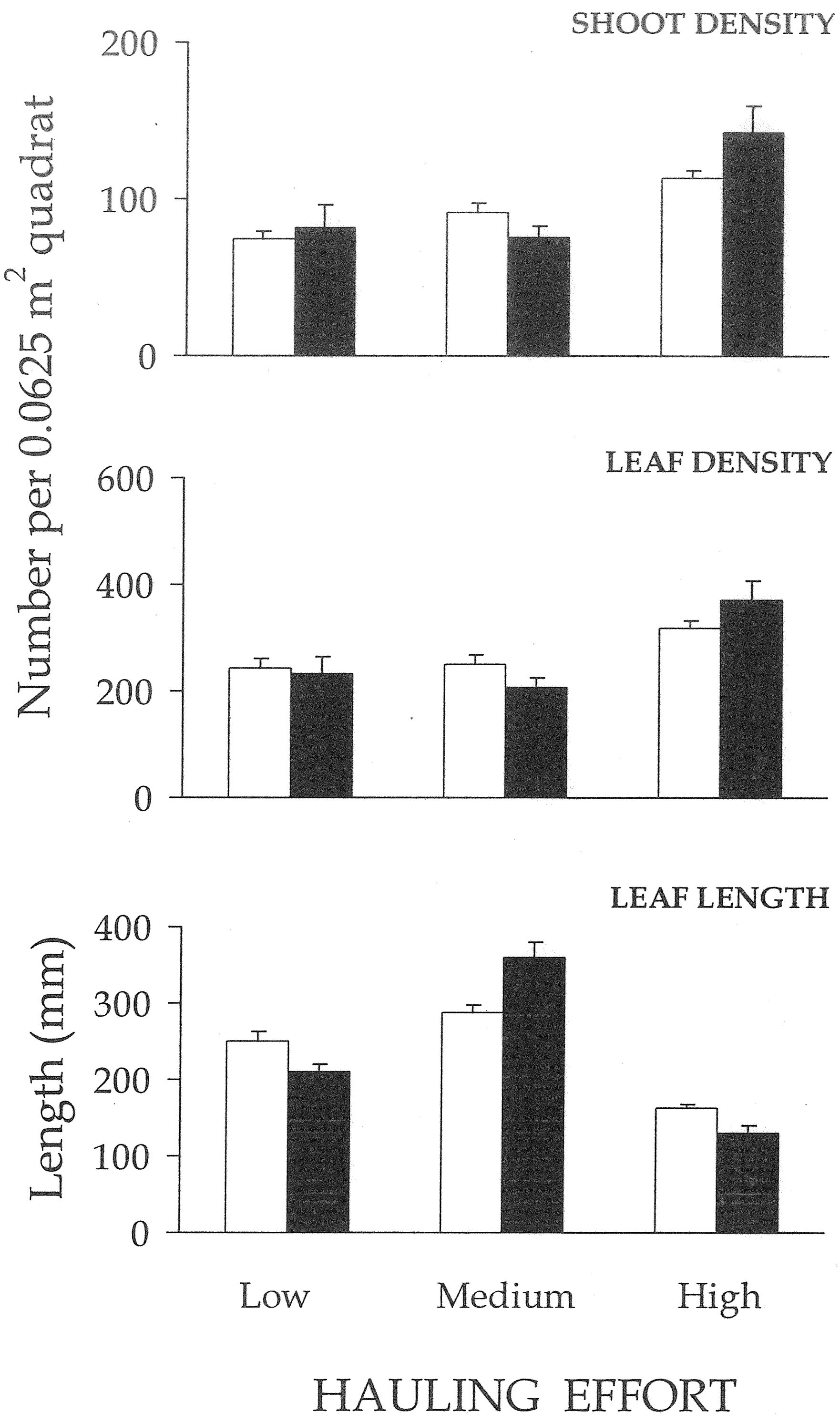

Figure 3.6. The mean (SE) shoot and leaf density, and leaf length of *Zostera capricorni* at hauled (shaded) and control (unshaded) sites in six NSW estuaries subjected to three different levels of fishing effort sampled during the period of growth in Summer 1997.

Table 3.26 Asymmetrical analysis of variance of untransformed data (variances heterogeneous) for the density of *Zostera capricorni* leaves at one hauled site and six control (unhauled) sites in each of six NSW estuaries subjected to three different levels of fishing effort sampled during the period of growth in Summer 1997.

Source of variation	df	MS	Percent variance	*F*	*P*
Effort	2	183283.00	0.0	0.52	> 0.25
Estuaries (Effort)	3	351363.00	32.2	8.16	< 0.01
H vs C	1	11.00	0.0	0.001	> 0.25
Effort x H vs C	2	26766.00	0.0	0.30	> 0.25
Est (Effort) x H vs C	3	90254.87	4.9	2.10	> 0.05
Sites (Est(Effort)) x C	30	43052.63	25.2	5.01	< 0.01
Residual	210	8599.55	37.7		
Total	251		100.0		

3.2.2.5 Leaf Length - Summer 1997

During Summer, the mean length of *Zostera capricorni* leaves exhibited significant variation among control sites within individual estuaries in different levels of fishing effort (Table 3.27, analysis of variance, $P < 0.01$) and this accounted for 36.7% of the total variation in the analysis. There were also no consistent patterns present among the control sites within estuaries with differential hauling effort. It is likely that the observed differences were due to spatial and temporal variation in the processes affecting the persistence of *Z. capricorni*.

Examination of the means in Figure 3.6 suggested that the differential levels of fishing effort across the 6 estuaries had not affected the length of *Zostera capricorni* leaves. The Estuaries(Effort) x H vs C interaction was not significant (Table 3.27, analysis of variance, $P >$ 0.25) indicating that there were no differences between replicate estuaries within the 3 levels of fishing effort. With the *post-hoc* pooling of the Estuaries(Effort) x H vs C interaction, the test of the effects of differential hauling effort, i.e. the Effort x H vs C interaction, was tested over the MS Sites(Estuaries(Effort)) x Control: a test with 2 and 30 degrees of freedom. This test was not significant (Table 3.27, analysis of variance, $P > 0.10$) indicating that differential hauling effort was not affecting the length of *Zostera capricorni* leaves. However, despite of the *post-hoc* pooling the power of the latter test to detect an effect-size of 40% was only 0.25, i.e. much less than a nominal 0.80. Nevertheless, as the treatment means (Fig. 3.6) did not exhibit any marked trends we conclude that differential hauling effort did not affect the length of *Zostera capricorni* leaves.

Table 3.27 Asymmetrical analyses of variance of untransformed and $\log_{10}$ transformed data for the length of *Zostera capricorni* leaves at one hauled site and six control (unhauled) sites, in each of six NSW estuaries subjected to three different levels of fishing effort sampled during Summer 1997.

Source of variation	Untransformed Data			Transformed Data		
	df	MS	Percent variance	MS	*F*	*P*
Effort	2	410386.00	42.4	1.5693	21.29	< 0.05
Estuaries (Effort)	3	24671.69	0.0	0.0737	0.99	> 0.25
H vs C	1	0.00	0.0	0.0050	0.14	> 0.25
Effort x H vs C	2	40206.50	3.9	0.1169	3.39	> 0.05
Est (Effort) x H vs C	3	9986.33	0.0	0.0345	0.46	> 0.25 [a]
Sites (Est(Effort)) x C	30	25691.62	36.7	0.0743	12.19	< 0.01
Residual	210	1849.92	17.0	0.0061		
Total	251		100.0			

[a] With *post-hoc* pooling of the Estuaries (Effort) x H vs C term as $P > 0.25$, the new F-ratio for Effort x H vs C is given by: MS Effort x H vs C / MS Sites (Estuaries(Effort)) x Control with 2 and 30 degrees of freedom. $F = 0.1169 / 0.0743 = 1.57$, $P > 0.10$.

3.3 SHORT-TERM IMPACTS

3.3.1 IMPACTS WITH AN EXPERIMENTAL HAUL NET

3.3.1.1 Shoot and Leaf Densities

A priori power analyses were used to identify the replication required to detect 40% changes in shoot and leaf densities of *Zostera capricorni* with power equal to or greater than 0.80 (i.e. a Type II error-rate of 0.20) given a Type I error-rate of $\alpha = 0.05$. It was estimated that by using a design with 4 replicate samples from each of 4 sites within each treatment (Hauled & Control) collected before and after hauling with an experimental net, it should be possible to detect an effect size of 40% with power equal to 0.84 and 0.79 for shoot and leaf densities, respectively.

As expected, there was significant variation in the shoot and leaf densities of *Zostera capricorni* among sites within the Hauled and Control treatments (Tables 3.28 & 3.29, analyses of variance, $P < 0.01$). This variation was most probably due to spatial fluctuations in shoot density because the temporal sampling (i.e. Before & After) was carried out only a few hours apart and the protocol demanded sampling without replacement. Examination of the means in Figures 3.7 and 3.8 suggested that hauling the experimental net caused little, if any, damage to the seagrass bed. This was confirmed by the analyses as neither the B vs A x H vs C interaction nor the B vs

A x Sites(H vs C) interaction were significant (Tables 3.28 & 3.29, analyses of variance, $P > 0.25$ and 0.10, respectively in both analyses). This clearly indicated that there were no short-term effects of hauling on the density of *Zostera capricorni* shoots and leaves. Finally, the power of these tests was not questioned for two reasons. First, the *F*-ratio for the B vs A x H vs C interaction was less than 1.00 and could have been eliminated from the model via *post-hoc* pooling. Second, while the B vs A x Sites(H vs C) interaction was not significant (i.e. $P > 0.10$) and could not be eliminated from the model, the variation contributed to the analysis was most likely attributable to spatial fluctuations (as discussed above) rather than to effects of hauling.

Table 3.28 Analysis of variance of the density of *Zostera capricorni* shoots in 0.0625 m^2 quadrats (n = 4) in each of 4 hauled and 4 control sites sampled before and after hauling with an experimental net (Cochran's test, $P > 0.05$).

Source of variation	df	SS	MS	*F*	*P*
B vs A	1	2956.64	2956.64	0.856	> 0.25
H vs C	1	102.52	102.52	0.008	> 0.25
Sites(H vs C)	6	81626.40	13604.40	5.566	< 0.01
B vs A x H vs C	1	206.64	206.64	0.060	> 0.25
B vs A x Sites(H vs C)	6	20726.82	3454.47	1.413	> 0.10
Residual	48	117325.44	2444.28		
Total	63	222994.46			

Table 3.29 Analysis of variance of the density of *Zostera capricorni* leaves in 0.0625 m^2 quadrats (n = 4) in each of 4 hauled and 4 control sites sampled before and after hauling with an experimental net (Cochran's test, $P > 0.05$).

Source of variation	df	SS	MS	*F*	*P*
B vs A	1	18056.60	18056.60	0.764	> 0.25
H vs C	1	2743.14	2743.14	0.027	> 0.25
Sites(H vs C)	6	602496.00	100416.00	6.098	< 0.01
B vs A x H vs C	1	8122.52	8122.52	0.344	> 0.25
B vs A x Sites(H vs C)	6	141777.00	23629.50	1.435	> 0.10
Residual	48	790459.20	16467.90		
Total	63	222994.46			

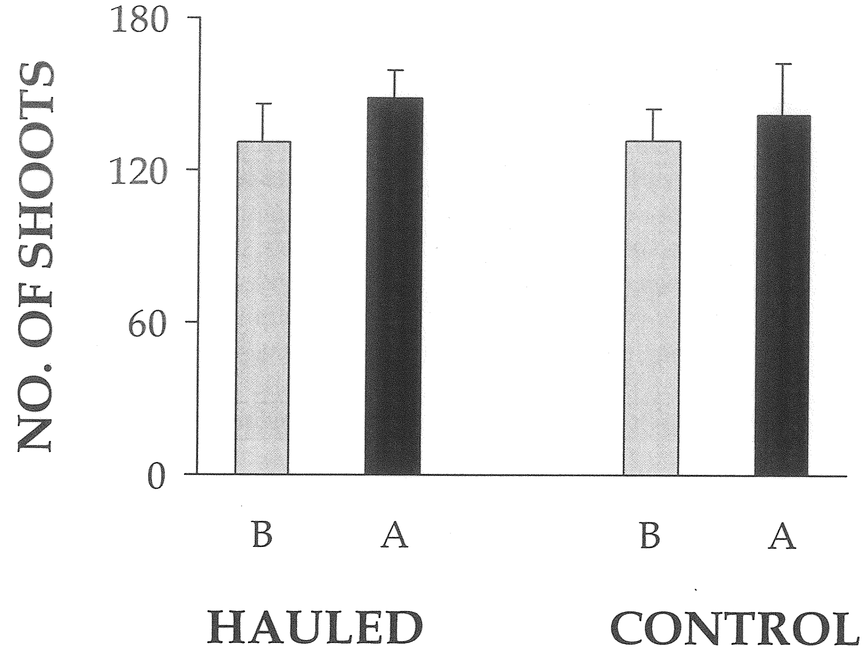

Figure 3.7 The mean (SE) density of *Zostera capricorni* shoots (in 0.0625 m^2 quadrats) in the hauled and control treatments (n = 16, i.e. pooled across sites within each treatment) before and after hauling with the experimental net.

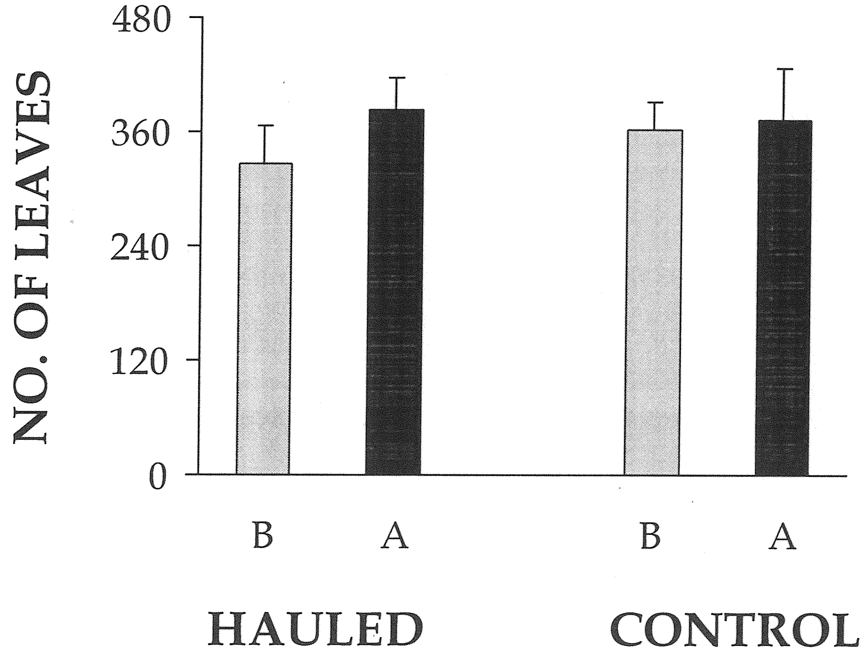

Figure 3.8 The mean (SE) density of Zostera *capricorni* leaves (in 0.0625 m^2 quadrats) in the hauled and control treatments (n = 16, i.e. pooled across sites within each treatment) before and after hauling with the experimental net.

3.3.1.2 Leaf Length

A priori power analyses were also used to identify the replication required to detect a 40% change in length of *Zostera capricorni* leaves with power equal to or greater than 0.80 (i.e. a Type II error-rate of 0.20) given a Type I error-rate of $\alpha = 0.05$. It was estimated that by also using a design with 45 replicate samples from each of 4 quadrats in each of 4 sites within each treatment (Hauled & Control) collected before and after hauling with an experimental net, it should be possible to detect an effect size of 6% with power equal to 0.89.

As expected, there was significant variation in the length of *Zostera capricorni* leaves among quadrats in the sites within the Hauled and Control treatments (Table 3.30, analysis of variance, $P < 0.01$). This variation was most likely attributable to local (spatial) fluctuations in leaf length because the temporal sampling (i.e. Before & After) was separated by just a few hours and the protocol demanded sampling without replacement. The means in Figure 3.9 suggested that hauling the experimental net resulted in little or no damage to the seagrass bed. This was confirmed by the analysis as neither the B vs A x H vs C interaction nor the B vs A x Sites (H vs C) interaction were significant (Table 3.30, analysis of variance, both $P > 0.25$). This clearly indicated that there were no short-term effects of hauling on the length of *Zostera capricorni* leaves. Finally, the power of these tests was not questioned as the *F*-ratios for both interactions could have been eliminated from the model via *post-hoc* pooling. However, differences in leaf length from Before to After were detected in some of the quadrats nested within the Sites and Treatments (Table 3.30, analysis of variance, $P < 0.01$). SNK tests showed that just over half (56%) of all quadrats sampled in both treatments exhibited significant reductions in mean leaf length after hauling the experimental net. However, as these were distributed evenly across both treatments, there was no strong evidence to suggest that hauling had any effect on the length of *Z. capricorni* leaves. Finally, it is likely that the observed differences were due to spatial fluctuations rather than to effects of hauling.

Table 3.30 Analysis of variance of the length of *Zostera capricorni* leaves in 0.0625 m^2 quadrats in each of 4 hauled and 4 control sites sampled before and after hauling with an experimental net. Variances homogeneous after $\log_{10}$ transformation (Cochran's test, $P > 0.05$).

Source of variation	df	SS	MS	*F*	*P*
B vs A	1	0.0809	0.0809	0.507	> 0.25
H vs C	1	0.5956	0.5956	0.548	> 0.25
Sites(H vs C)	6	6.5255	1.0876	1.951	> 0.10
Quad(Sites(H vs C))	24	13.3796	0.5575	17.762	**< 0.01**
B vs A x H vs C	1	0.0549	0.0549	0.344	> 0.25
B vs A x Sites(H vs C)	6	0.9567	0.1594	1.158	> 0.25
B vs A x Quad(Sites(H vs C))	24	3.3039	0.1377	4.386	**< 0.01**
Residual	48	88.3848	0.0314		
Total	63	113.2820			

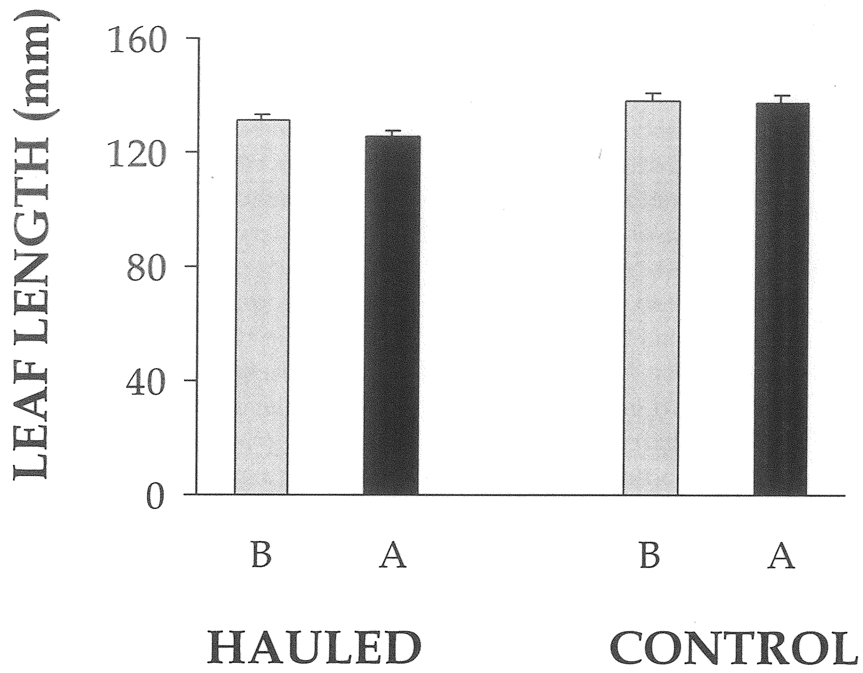

Figure 3.9 The mean (SE) length of *Zostera capricorni* leaves in the hauled and control treatments (n = 720, i.e. pooled across sites within each treatment) before and after hauling with the experimental net.

3.3.1.3 Persistence of Seagrass Leaves

A priori power analyses were also used to identify the replication required to detect a 20% change in the proportion of tagged *Zostera capricorni* leaves with power equal to or greater than 0.80 (i.e. a Type II error-rate of 0.20) given a Type I error-rate of $\alpha = 0.05$. It was estimated that by using a design with 30 tagged leaves in each of 4 quadrats, at each of 4 sites within each treatment (Hauled & Control) counted before and after hauling with an experimental net, it should be possible to detect an effect size of 10% with power equal to 0.79 or alternatively, an effect size of 20% with power equal to 0.99.

There was no significant variation in the proportion of tagged *Z. capricorni* leaves remaining in the sites within the Hauled and Control treatments (Fig. 3.10 and Table 3.31, analysis of variance, $P > 0.25$). With the *post-hoc* pooling of the Sites(H vs C) term the test of the effects of hauling was made more powerful as the H vs C term was tested over the MS Residual: a test with 1 and 30 degrees of freedom. This test was not significant (Table 3.31, analysis of variance, $P > 0.25$) indicating that hauling did not affect the persistence of *Zostera capricorni* leaves, at least over the short-term. Finally, the experimental haul net was searched thoroughly for tagged leaves, but none were found.

Table 3.31 Analysis of variance of the length of *Zostera capricorni* leaves in 0.0625 m^2 quadrats in each of 4 hauled and 4 control sites sampled before and after hauling with an experimental net. Variances homogeneous after arcsine transformation, (Cochran's test, $P > 0.05$).

Source of variation	Transformed Data				
	df	SS	MS	*F*	*P*
H vs C	1	0.0170	0.0170	0.760	> 0.25
Sites (H vs C)	6	0.1330	0.0222	0.839	> 0.25 [a]
Residual	24	0.6382	0.0266		
Total	31	0.7890			

[a] With *post-hoc* pooling of the Sites(H vs C) term as $P > 0.25$, the new *F*-ratio for H vs C is given by: MS H vs C / MS Residual with 1 and 30 degrees of freedom. $F = 0.0170 / 0.0257 = 0.661$, $P > 0.25$.

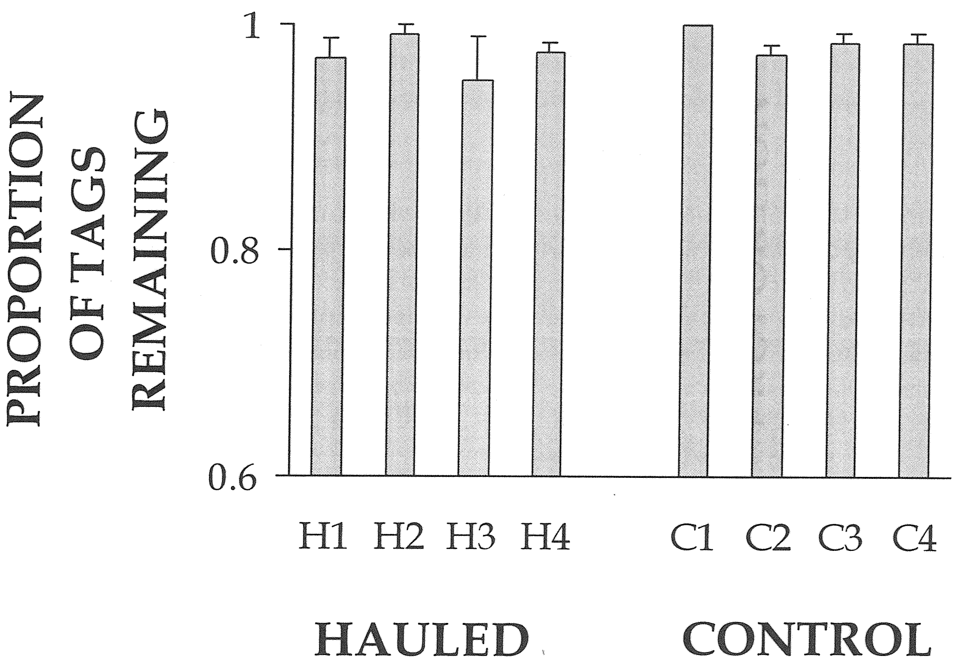

Figure 3.10 The mean (SE) proportion of tagged *Zostera capricorni* leaves remaining in each of the 4 hauled and 4 control sites. Hauling was carried out with an experimental net (see Methods for details).

3.3.2 IMPACTS WITH A COMMERCIAL HAUL NET

3.3.2.1 Persistence of Seagrass Leaves

A priori power analysis was used to identify the replication required to detect a 20% change in the proportion of tagged *Zostera capricorni* leaves with power equal to or greater than 0.80 (i.e. a Type II error-rate of 0.20) given a Type I error-rate of $\alpha = 0.05$. It was estimated that by using a design with 50 tagged leaves in each of 3 quadrats, in each of 6 sites (1 hauled and 5 controls), it should be possible to detect an effect size of 10% with power equal to 0.79 or alternatively, an effect size of 20% with power equal to 0.99.

The proportion of tagged seagrass leaves persisting differed significantly among control sites on days 1 and 2 (Table 3.32, Fig. 3.11). More importantly, there were no significant differences in the proportions of tagged seagrass leaves remaining at commercially hauled site compared to the mean of the control sites (Table 3.32, Fig. 3.11). However, after the third day a significantly smaller proportion tagged seagrass leaves were found at the control sites compared to the commercially hauled site (Table 3.32). This result clearly shows that hauling was not affecting the density of tagged leaves and that there was ample statistical power to detect very small changes analyses (Fig. 3.11).

Finally, two of the five control sites could not be sampled on the third day due to high turbidity which persisted over the following days. We had intended to monitor for at least 5 days, but the high turbidity spread to all sites and sampling on subsequent days was prevented.

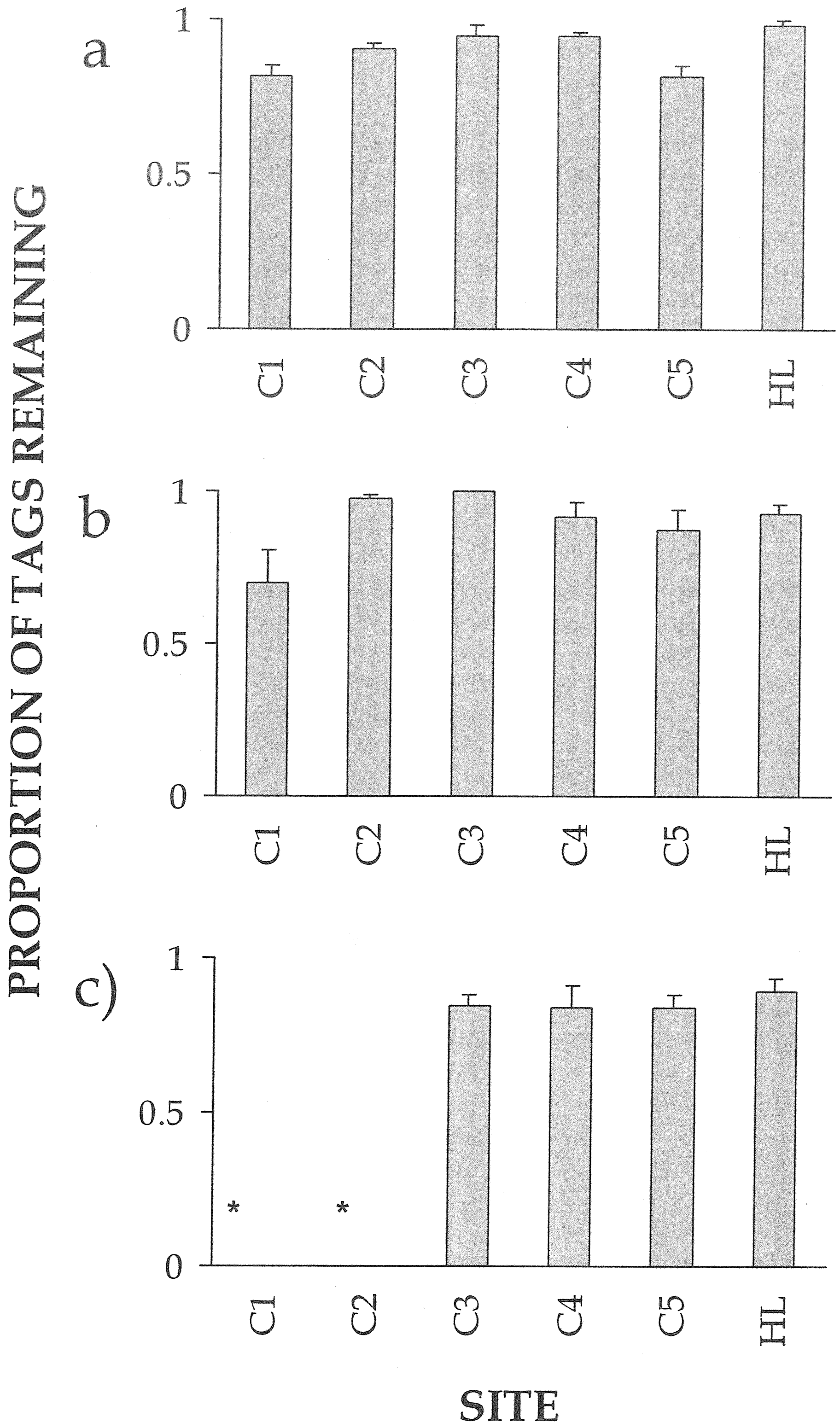

Figure 3.11 The mean (SE) proportion of tagged *Zostera capricorni* leaves remaining in the hauled and 5 control sites on (a) day 1, (b) day 2 and (c) day 3 at Silver Beach, Botany Bay. Hauling was carried out each day by commercial fishers (see Methods for details). Asterisk denotes sampling prevented because of high turbidity.

Table 3.32 Asymmetrical analyses of variance of the proportion of tagged *Zostera capricorni* leaves (per quadrat) remaining at the commercially hauled site and 5 control sites on (a) day 1, (b) day 2 and (c) day 3 at Silver Beach, Botany Bay. Note analysis on day 3 (c) only has 3 control sites because sampling at the remaining 2 control sites was prevented by high turbidity. Variances were homogeneous (Cochran's test, $P > 0.05$).

(a)

Source of variation	Untransformed Data				
	df	SS	MS	*F*	*P*
H vs C	1	0.0224	0.0224	1.628	> 0.05
Sites (C)	4	0.0550	0.0138	5.954	< 0.01
Residual	12	0.0277	0.0023		
Total	17	0.1052			

(b)

Source of variation	Untransformed Data				
	df	SS	MS	*F*	*P*
H vs C	1	0.0027	0.0027	0.062	> 0.25
Sites (C)	4	0.1718	0.0429	4.561	< 0.05
Residual	12	0.1130	0.0094		
Total	17	0.2874			

(c)

Source of variation	Untransformed Data				
	df	SS	MS	*F*	*P*
H vs C	1	0.0055	0.0055	128.400	< 0.01
Sites (C)	2	0.0001	0.0000	0.006	> 0.25
Residual	8	0.0606	0.0076		
Total	11	0.0662			

4. DISCUSSION

4.1 HAULING EFFORT

The detailed analysis of the mean annual hauling effort (expressed as fisher days/annum) differed significantly among estuaries, and despite this, the 9 individual estuaries could be combined into three groups each separated by an order of magnitude in the mean annual hauling effort. These groups were, respectively: Port Stephens, Lake Macquarie and Botany Bay (magnitude of hauling effort = 1000's days/annum); Wallis Lake, Tuggerah Lake, Lake Illawarra and St. George's Basin, (magnitude of hauling effort = 100's days/annum); and Burrill and Wallaga Lakes (magnitude of hauling effort = 10's days/annum). Unfortunately, it was not possible to examine site-specific hauling effort as the necessary data have not been collected to date. Data on site-specific hauling effort would, however, permit a more precise assessment of any possible impact and hence enable more cost-beneficial management.

The variation among control sites for the seagrass variables estimated (e.g. shoot density, etc.) was not correlated with estuary size. This indicates that the size of any given estuary was not a confounding effect in the analyses. The significant correlation between estuary size and mean annual estuary-wide hauling effort over the period 1984 to 1996 is possibly due to several, interacting factors. These include: a range of biological events (e.g. the "mullet run"), the human populations surrounding the estuaries, and the number of crews working in a given estuary.

In any given estuary, the pattern of mean monthly hauling effort was similar from year to year over the period 1984 to 1996. Intra-annual variation only showed pronounced trends in Port Stephens where hauling effort increased substantially from January to June and was probably due to the targeting of sea mullet and bream (Virgona pers. comm.). In Botany Bay, the hauling effort changed seasonally with a slow increase over Spring, reaching a maximum in late Summer and then declining over Autumn to a minimum in Winter.

4.2 LONG-TERM IMPACTS

Hauling was correlated with differences in the shoot and leaf densities, and length of the *Zostera capricorni* leaves at some sites and in some seasons. Plots of shoot and leaf densities, and leaf length for the hauled and control sites for all estuaries in winter 1996 and summer 1997 (Figs. 4.1 - 4.3, with 18 means for each seagrass variable) showed the following patterns at the hauled site. Shoot density at the hauled site was greater in 7 and fewer in 10 of the Hauled/Control ratios (Fig. 4.1). Leaf density was greater in 6 and fewer in 10, of the possible 18 Hauled/Control ratios. In contrast, the leaf length of *Zostera capricorni* was greater in 3 and fewer in 14, of the possible 18 Hauled/Control ratios.

The often large natural variation among control sites, especially during summer 1997, reduced the realised power of the statistical tests. This led to ambiguity in the interpretation of some of the statistical tests when non-significant. Of the six major analyses, only in Winter 1996, was hauling correlated with significantly shorter (20% on average) *Zostera capricorni* leaves across the 9 estuaries. The differences in leaf length between the hauled and control sites varied among estuaries with Port Stephens and Wallaga Lake exhibiting no change, and reductions of 17 - 39% occurring in the remaining estuaries. Significant increases in shoot and leaf densities also occurred during the die-back period in Winter 1996, but these were restricted to the hauled sites in Lake Macquarie and Botany Bay. It is possible that the increases in shoot and leaf density of *Zostera capricorni* were a response to the high levels of hauling effort combined with the reduction in leaf length. These correlative changes (putative impacts) were detected over and

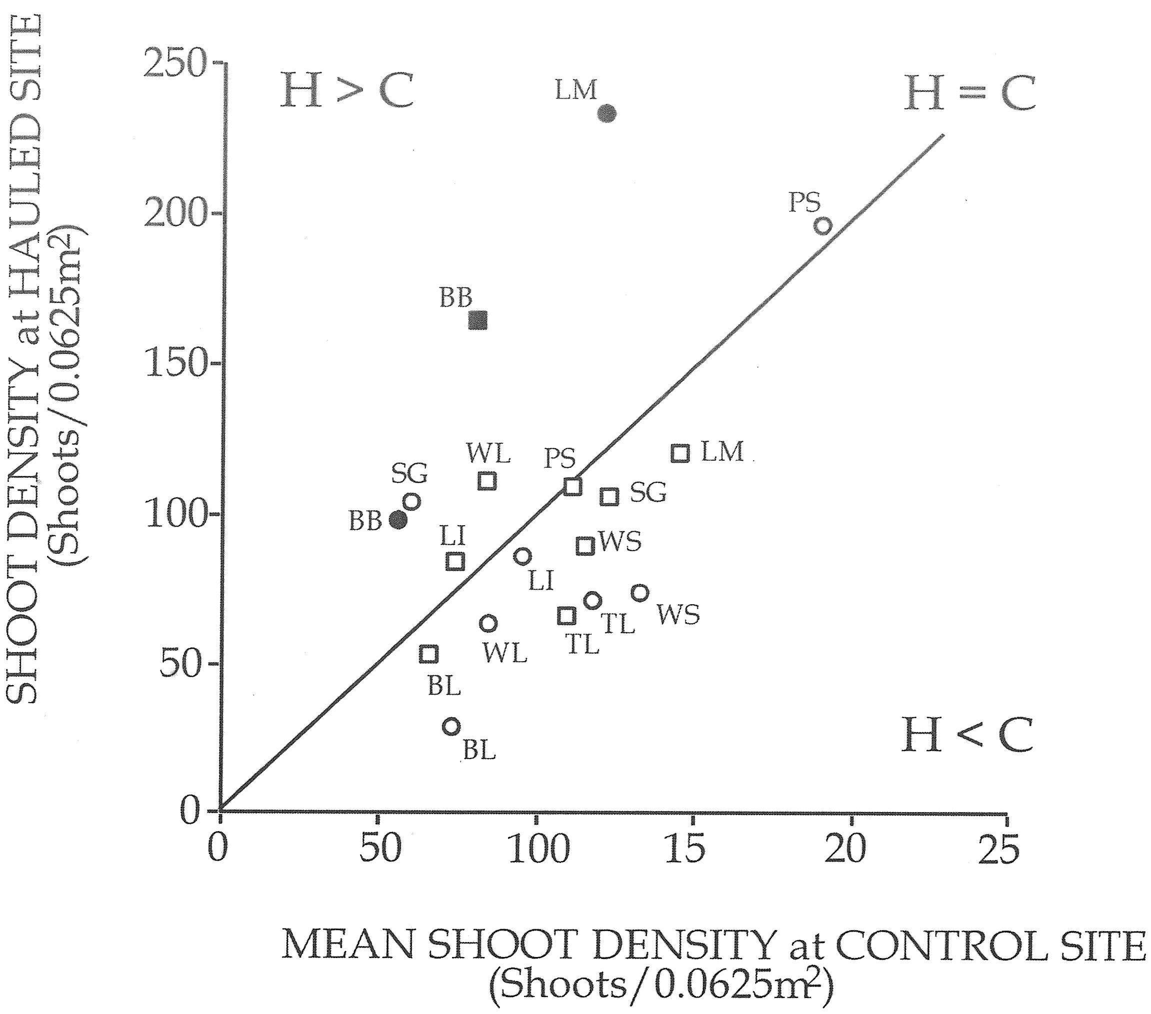

Figure 4.1 Plot of the mean of the hauled treatment versus the mean of the control treatment for the density of *Zostera capricorni* shoots (per 0.0625 m^2) in Wallis Lake (WS), Port Stephens (PS), Lake Macquarie (LM), Tuggerah Lake (TL), Botany Bay (BB), Lake Illawarra (LI), St George's Basin (SG), Burrill Lake (BL) and Wallaga Lake (WL) in Winter, 1996 (O) and Summer, 1997 (□). Note, n = 6 replicate samples were collected from each of the single hauled site and six control sites. Shading of a point indicates that the hauled and control treatments were significantly different in the associated analysis of variance.

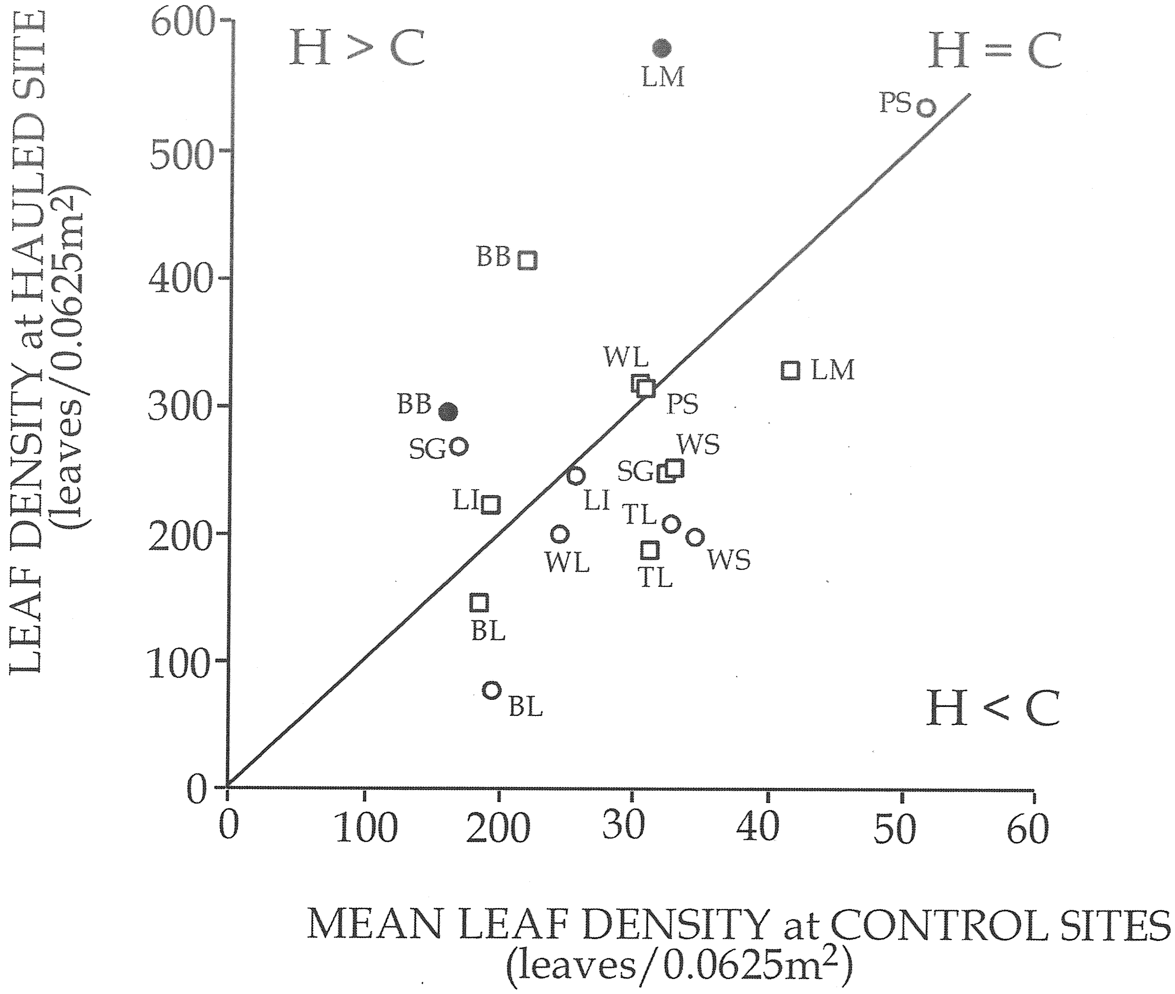

Figure 4.2 Plot of the mean of the hauled treatment versus the mean of the control treatment for the density of *Zostera capricorni* leaves (per 0.0625 m^2) in Wallis Lake (WS), Port Stephens (PS), Lake Macquarie (LM), Tuggerah Lake (TL), Botany Bay (BB), Lake Illawarra (LI), St George's Basin (SG), Burrill Lake (BL) and Wallaga Lake (WL) in Winter, 1996 (O) and Summer, 1997 (□). Note, n = 6 replicate samples were collected from each of the single hauled site and six control sites. Shading of a point indicates that the hauled and control treatments were significantly different in the associated analysis of variance.

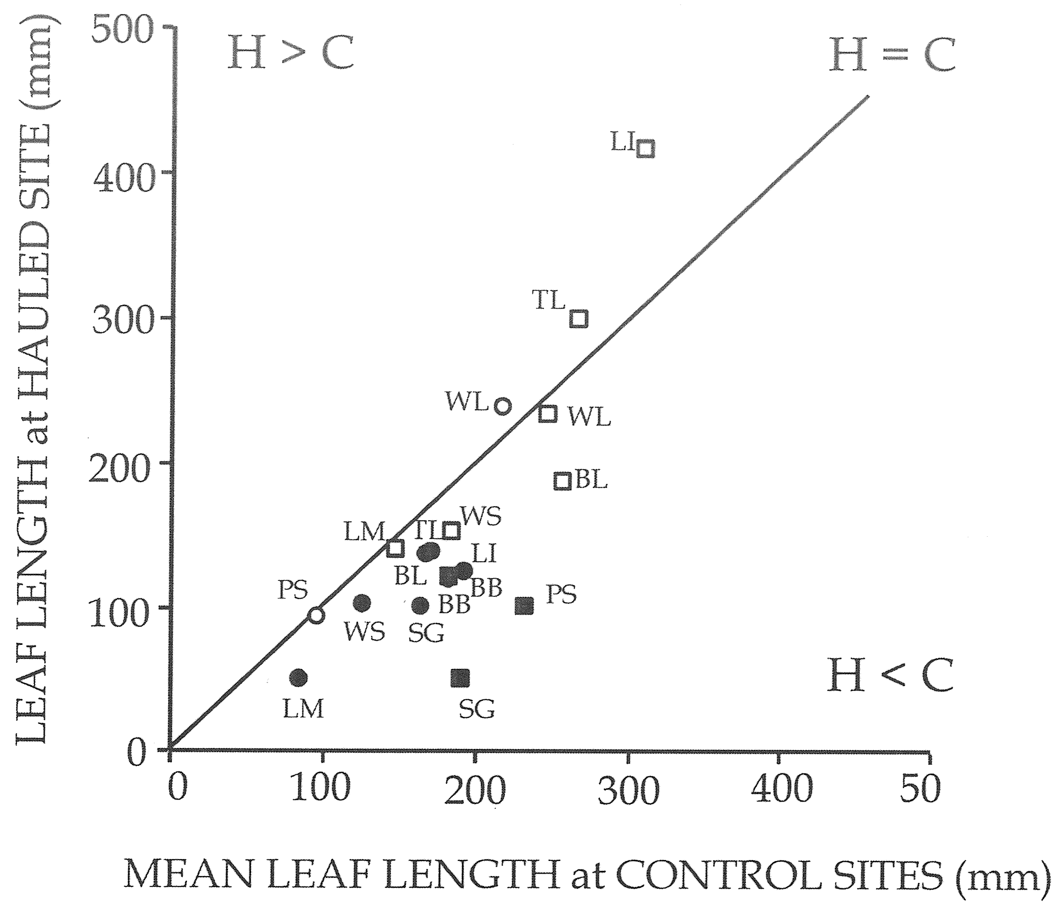

Figure 4.3 Plot of the mean of the hauled treatment versus the mean of the control treatment for the length of *Zostera capricorni* leaves (mm) in Wallis Lake (WS), Port Stephens (PS), Lake Macquarie (LM), Tuggerah Lake (TL), Botany Bay (BB), Lake Illawarra (LI), St George's Basin (SG), Burrill Lake (BL) and Wallaga Lake (WL) in Winter, 1996 (O) and Summer, 1997 (□). Note, n = 6 replicate samples were collected from each of the single hauled site and six control sites. Shading of a point indicates that the hauled and control treatments were significantly different in the associated analysis of variance.

above the naturally-occurring period of reduced growth and die-back in which *Zostera capricorni* shoot and leaf densities and leaf-lengths decline (for details see Harris *et al.*, 1979; Larkum *et al.*, 1984).

Significant differences correlated with hauling over *Zostera capricorni* were also evident in Summer 1997, but these only occurred in Port Stephens, St. George's Basin and Botany Bay. In Port Stephens, leaf length was significantly reduced by 55.8% compared to the controls despite the increased growth rates of *Zostera capricorni*. In St. George's Basin, the mean length of *Zostera capricorni* leaves remained significantly shorter at the hauled site in Jewfish Bay and the difference was equal to a 72.8% reduction compared to the mean of the controls. This occurred in spite of the fishing closure in Jewfish Bay over the period October to May, inclusive. Finally, the significant increase in the shoot density of *Zostera capricorni* at the hauled site in Botany Bay persisted through to Summer 1997. This may be related to the continually high levels of hauling effort which further increased over the Spring/Summer period (Fig. 3.1).

Using the exploratory analyses of estuary-wide (i.e. not site-specific), mean annual hauling effort to assess the effects of hauling over seagrass suggested that during Winter 1996, the estuaries with high levels of effort (i.e. Botany Bay and Lake Macquarie) had significantly greater shoot and leaf densities ($\approx$ 88% on average) in hauled seagrass beds. No other analyses were significant, but power of 0.80 was not realised in these tests. Hence, little can be concluded.

4.3 SHORT-TERM IMPACTS

There were no detectable short-term (instantaneous) impacts on *Zostera capricorni* in Botany Bay. Neither the experimental net nor a commercial haul net had any significant effects on shoot and leaf densities, leaf-lengths or the persistence of seagrass leaves.

4.4 IMPLICATIONS FOR SEAGRASSES

4.4.1 ZOSTERA CAPRICORNI

Hauling did not result in the total removal of *Zostera capricorni* from any site as all the sites sampled had seagrass present when the sampling was repeated in Summer. However, hauling crews were observed (e.g. in St. George's Basin) hauling over areas where seagrass was present (see West *et al.*, 1985), but is now absent. Inferring cause and effect (i.e. impact) from such anecdotal evidence should be avoided because numerous other anthropogenic disturbances can cause declines in seagrass. For example, light reduction due to increases in turbidity (King & Hodgson, 1986; Shepherd *et al.*, 1989; Walker & McComb, 1992), or increased epiphytism (Cambridge *et al.*, 1986; den Hartog, 1994), dredging and reclamation (Coles *et al.*, 1989; Larkum & West, 1990), propellers of boats (Zieman, 1976), mooring chains (Walker *et al.*, 1989) and recreational, bait-digging (Ruello & Henry, 1977), shellfish harvesting (Fonseca *et al.*, 1984; Peterson *et al.*, 1987), oyster cultivation (Everett *et al.*, 1995; Short & Wyllie-Echevarria, 1996) and the disposal of sewage (Shepherd & Cannon, 1989; Larkum *et al.*, 1989; Keough & Jenkins, 1995), have all been identified as causes of declines in seagrass abundance.

Most of the major analyses were non-significant (but see discussion on power below). Even when significant differences were found the average magnitude of the putative impacts of hauling on shoot and leaf densities and leaf lengths of *Zostera* were less than the 30% level determined as ecologically significant. It is important to recall, however, that the statistical analyses examining the differences in the seagrass beds adopted Type I and Type II error rates of $\alpha = 0.05$ and $\beta = 0.2$ respectively. Moreover, the expected power of 0.8 was not realized in several estuaries. This limits the conclusions that can be made from non-significant results.

If there are any long-term impacts of hauling on shoot and leaf densities, leaf lengths for *Zostera*, these would most likely result from the cumulative effects of small, albeit non-significant changes. Therefore, we would predict that variations in hauling frequency should result in different impacts. The analyses incorporating mean estuary wide nominal effort detected differences at the highest effort sites but only for leaf and shoot density and only in winter. Nonetheless this relationship should be explored further using site specific hauling effort.

Overall, the pattern of differences appeared to be one in which hauling was correlated with significantly reduced leaf length in Winter and this was followed by subsequent recovery in some estuaries in Spring/Summer (as illustrated in Fig. 4.4). The hauled site in estuaries with highest levels of mean annual estuary-wide fishing effort had significantly greater shoot and leaf densities of *Zostera capricorni* compared to the controls, and this may represent a compensatory process. Given that sampling was only carried out in one Winter (die-back period) and one Summer (growth period), it is not clear whether the pattern of significant hauling-related reduced leaf length in Winter and a subsequent recovery in Summer would be evident in other years. Further sampling will be necessary to test this and other hypotheses.

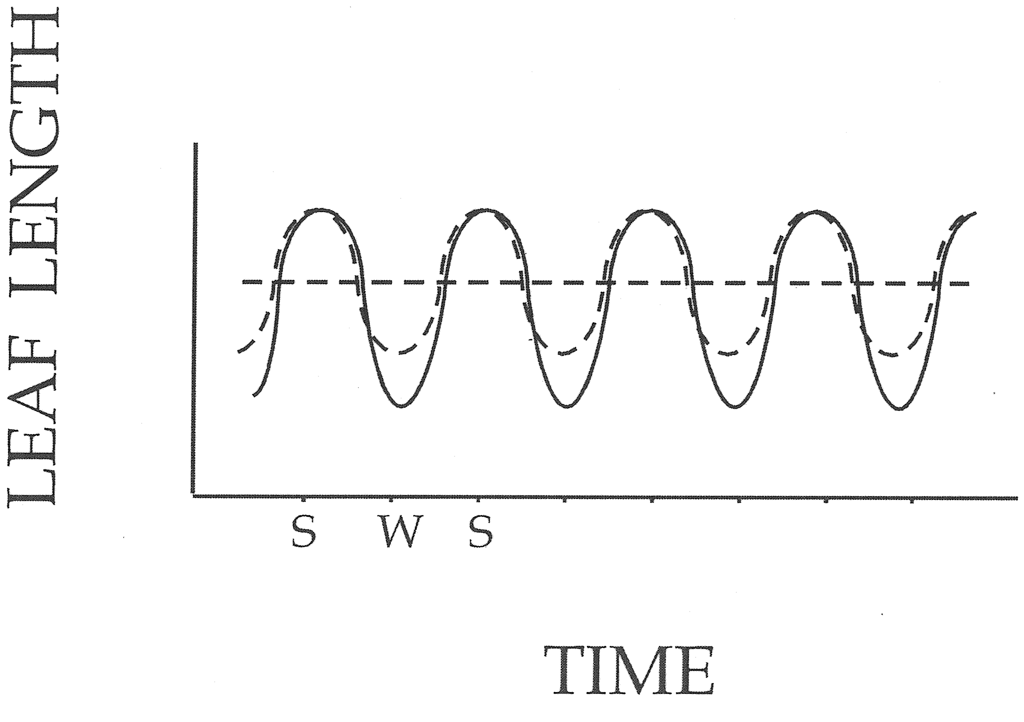

Figure 4.4 Possible cyclic pattern of long-term impacts of hauling on the length of *Zostera capricorni* leaves with reductions occurring in Winter followed by recovery in Summer. Temporal changes in leaf length at the hauled site (unbroken line) and mean of control sites (broken line).

4.4.2 *POSIDONIA AUSTRALIS*

As the study focused on *Zostera capricorni*, we cannot make any conclusive statements concerning the effects of hauling on *Posidonia australis*. However, given that hauling was correlated with changes to *Zostera capricorni* and the fact that *P. australis* does not recover from many anthropogenic disturbances (e.g. Larkum *et al.*, 1989), it would appear prudent, if not crucial, to investigate the possible impacts of hauling on *P. australis*.

4.5 IMPLICATIONS FOR FISH AND INVERTEBRATES IN SEAGRASS

Previous research (e.g. Pollard, 1984; Bell *et al.*, 1984; McNeill *et al.*, 1992; Gray *et al.*, 1996) has shown that seagrass beds act as sites for fish recruitment and as nursery habitats for juvenile fish and macro-invertebrates. Furthermore, field experiments with *Zostera capricorni* and *Posidonia australis* in NSW (Bell & Westoby, 1986a), *Zostera muelleri* in South Australia (Connolly, 1994, 1995) and *Amphibolis antarctica* and *Zostera muelleri* in Western Australia (Edgar, 1990, 1992; Edgar & Robertson, 1992) in which the shoot/leaf densities and leaf lengths were manipulated (i.e. reduced in density and/or length) resulted in significant reductions in species richness and abundances of fish and macro-invertebrates living amongst the seagrass. The sampling carried out in this study was specifically designed to detect changes of similar magnitude, that is, changes of a size that would precipitate ecologically important changes to species richness and abundances of fish and macro-invertebrates. Clearly, such changes would have implications for the estuarine and coastal (offshore) commercial and recreational fisheries given the linkages among the various life-history stages and their associated habitats (Bell & Worthington, 1993). This study has shown that a possible hauling-induced reduction in seagrass length of 20% occurred during winter (and persisted through to summer in a few estuaries) but there were also increases in the shoot and leaf densities at some hauled sites during this period. Much of the recruitment for fish and invertebrates occurs in seagrass beds in spring-summer period. To fully understand the impact of such interactions would necessitate documenting how this combination affected recruitment on a local scale, the relationship with site-specific hauling effort and the spatial extent of such areas compared to the total seagrass area. For example, even if a reduction in recruitment occurs in a few local areas, this may be insignificant from a management perspective if there are sufficient areas of unhauled seagrass elsewhere in the estuary.

5. BENEFITS

This study has, to our knowledge, provided the first assessment of the physical effects of hauling on seagrass in Australia. The results will benefit all stakeholders in fisheries using this gear by contributing information on the environmental effects of the fishing gear. An understanding of these effects will enable steps to be taken to ensure sustainability in the long-term.

6. FURTHER DEVELOPMENT

The sampling techniques developed in this study could be applied to similar studies elsewhere in Australia. As stated earlier, it would be prudent to investigate the longer-term impacts of hauling on seagrass *per se* and include *Posidonia* sp. as this seagrass does not recover from many anthropogenic disturbances. Any future study should also assess the possible impacts on the recruitment of fish and macro-invertebrates.

7. CONCLUSIONS AND RECOMMENDATIONS

It is clear that the documented declines in seagrass beds throughout the world (e.g. Thayer *et al.*, 1975; Cambridge *et al.*, 1986; den Hartog, 1994; Short & Wyllie-Echevarria, 1996) and in Australia (e.g. Kirkman, 1978; Larkum & West, 1983; Larkum & West, 1990; Walker & McComb, 1992; Hamdorf & Kirkman, 1995) have raised concerns at a national level. It would appear prudent therefore, if not imperative, to investigate the longer-term impacts of hauling on seagrass *per se* (*Zostera* and *Posidonia* sp.), and the possible impacts on the recruitment of fish and macro-invertebrates. Consequently, it is recommended that further research be done to document:

(1) the physical effects of hauling on seagrass beds via a long-term, large-scale, field experiment involving industry and staff (research and management) from NSW Fisheries. Such an experiment would need replicate sites with and without hauling to be sampled contemporaneously over at least 2 years in the 'before' and 'after' periods. A design of this nature would then enable an unequivocal assessment of possible impacts. However, it is highly likely that such an experiment would be restricted to a few estuaries and not be able to incorporate different levels of hauling effort because of the overall cost,
(2) whether the differences and similarities on *Zostera capricorni* persist over a longer term by repeating this study,
(3) the site-specific hauling effort,
(4) whether hauling causes impacts on *Posidonia australis*, and
(5) the percentage of seagrass area over which hauling occurs.

It would then be necessary to:

(1) interpret the results of such research in relation to our existing knowledge of seagrass beds and the fisheries dependent on them, and
(2) provide recommendations concerning the short and long-term management of hauling over seagrass beds.

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APPENDIX 1 INTELLECTUAL PROPERTY

INTELLECTUAL PROPERTY

No patentable inventions nor processes were developed as part of this project. NSW Fisheries and the FRDC retain the right to publish scientific papers and other public domain literature emanating from this project.

APPENDIX 2 STAFF

STAFF

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