Fish Use of Subtropical Saltmarsh Habitat

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FISHERIES RESEARCH & DEVELOPMENT CORPORATION

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School of Environmental and Applied Science,
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NON TECHNICAL SUMMARY

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OBJECTIVES:

1. To determine which fish species, in what abundance, directly use saltmarsh flats in subtropical east coast waters.

2. To compare the use by fish of vegetated and unvegetated (saltpan) habitats on the marsh flats.

3. To make clear recommendations to fisheries and coastal managers about the impacts on fisheries of human activities affecting saltmarsh habitat and the direction of future research.

NON TECHNICAL SUMMARY:

Saltmarshes are a major habitat in subtropical estuaries in Australia. They occur high in the intertidal zone, and are characterised by low vegetation interspersed with unvegetated patches (saltpans). Saltmarshes can potentially contribute to fisheries production in two ways. Plant production on the marsh may support food webs that sustain fisheries species in other parts of the estuary. Fish may also use saltmarsh directly as a habitat when it is inundated at high tide. This project tackled the second of these possibilities.

Whilst the possible value of saltmarsh to fisheries has begun to be recognised by coastal managers in Australia, saltmarshes continue to be destroyed by reclamation for urban and agricultural projects. Even where saltmarshes are being retained, they are poorly protected from the impacts of human activities. Grazing by cattle, use of off-road vehicles and altered drainage regimes for insect pest control can affect the extent and type of saltmarsh vegetation. Coastal managers faced with decisions about the values of saltmarsh habitat to fisheries urgently require information about the use of saltmarshes by fish.

Previous work on fish associated with saltmarshes in Australia relied on sampling in creeks that drain the marsh as the tide retreats. This, however, provided no evidence for whether fish actually visited the intertidal marsh flats that constitute the main area of the

marsh, nor for the way fish used different parts of the marsh. The only information available about this was from marshes in North America, where two of the main factors influencing fish abundance were the distance onto the marsh from subtidal water and the presence or absence of vegetation. Prior to the current study, it was not known how those results would apply to Australian marshes given that in North America, saltmarshes are lower in the intertidal and are inundated more frequently.

To achieve the objectives of the project, fish were sampled on the inundated flats of three saltmarshes spread across southeast Queensland, viz. Eden Island in southern Moreton Bay, Meldale in Pumicestone Passage in northern Moreton Bay, and Theodolite Creek in Hervey Bay. Fish were sampled on each marsh for two years, in winter and summer. Peak high tides that fully inundate the marsh occur at night in winter and during the day in summer. Comparisons between seasons were not intended, and they would be confounded with differences in the time of day at which samples were taken. Rather, sampling was done at different times of year to ensure results were broadly representative of the ways fish use saltmarshes. All sampling was done using 25 m^2 buoyant pop nets of 1 mm mesh size, set whilst the marsh was emergent and released remotely at high tide. Netting typically occurred over four days on each marsh at each period, with between 28 and 60 nets released, and with new netting sites selected on each sampling day.

The first objective was to determine which species actually occurred on subtropical saltmarsh flats. The project provides the first scientific evidence in Australia for the extent of use of subtropical saltmarsh flats by fish. The richness and abundance of fish on the marsh flats was at times surprisingly high (total of 41 fish species, maximum density almost 1 fish/m^2), and exploited fisheries species (e.g. bream, whiting, mullet, garfish, banana prawns) were prevalent without dominating catches numerically. The most common fish were small species such as perchlets and gobies, of no direct economic importance. Fish were found far onto the marsh flats, even to the furthest extent of sampling, up to 500 metres onto the marsh. An outstanding feature of this study is that results come from three saltmarshes spread across subtropical Queensland, sampled in both winter and summer. This is a more extensive sampling program than in previous saltmarsh studies around the world, and results can be considered a reliable guide to the types of fish that use subtropical saltmarsh habitat in Queensland.

The second objective was to compare fish use of vegetated and unvegetated marsh habitat. The presence of vegetation was shown to have remarkably little relationship with fish abundance and species richness. Nor did fish density differ between the two most common vegetation types, short saltcouch grass, *Sporobolus virginicus,* and the taller bush, *Suaeda australis*, although species richness was higher at times in *S. australis*.

The success in meeting objectives in the first year of sampling allowed a refinement of the objectives during the second year (of this two year project). The distribution of fish on saltmarshes was found to be most strongly influenced by proximity to intertidal, mangrove-lined feeder creeks, with more species and more individuals near to creeks than further away. This was more important than distance onto the marsh from subtidal water. The number of species and number of individuals was also related to water depth on some occasions, although the nature of this relationship varied in direction and strength. On the Meldale saltmarsh, where the habitat has been altered for mosquito control, the presence of artificial drains (runnels) was found to have an influence on fish assemblages secondarily to the proximity to feeder creeks.

The third original objective was to provide advice to coastal and fisheries managers about the value of saltmarsh as fisheries habitat. The project has provided original, reliable and essential information for managers, and is being widely disseminated to agencies in relevant regions. The project successfully met the original objectives and provided additional information about fish use of saltmarshes that will help in managing impacts on coastal fisheries habitat.

Evidence of fish use of saltmarsh flats in other regions of Australia is urgently needed. It is recommended that the momentum generated by the current project be built upon by establishing a project examining fish use of saltmarshes in several regions of Australia, using the expertise developed here in collaboration with state and territory based fisheries research agencies.

KEYWORDS: saltmarsh, fish, prawns, fish habitat, estuary

1.0 Background

Saltmarshes might be important to fisheries production either because juvenile fish use marsh habitat directly for food and/or protection from predators, or because plant production on the marsh is transported elsewhere in the estuary and fuels a detrital food web that supports fish. This project examined the former role, that of direct use of marsh habitat by fish. Most ecological knowledge of saltmarshes comes from studies in the USA. These studies have mostly been aimed at elucidating the energy flux within lower marshes and between marshes and the open water of an estuary (Talbot & Able 1984); fish are typically sampled in open water adjacent to the marsh (e.g. Rakocinski *et al*. 1992). Sampling of fish in higher marshes, which are inundated for short periods on high tides only, is extremely difficult. It has been shown, however, that fish use high marsh areas, and that, although fewer species occur there, the high marshes act as nursery areas for larval and juvenile fish (Kneib & Wagner 1994). All of this work has been undertaken in vegetated habitat.

In Australia, saltmarshes occupy the zone landward of mangroves high in the intertidal part of estuaries and are dominated by short vegetation such as saltcouch (*Sporobolus*) (Adam 1990). Therefore, results of ecological studies of low marshes in the northern hemisphere with stands of tall cordgrass (*Spartina*), which are inundated more frequently and for longer periods than marshes in Australia, should not simply be applied to the Australian marshes. Results of studies in high marshes in the northern hemisphere (e.g. Talbot & Able 1984; Kneib & Wagner 1994) are more likely to apply in Australia, although the presence of mangrove forests on the seaward side of many Australian marshes might still render results inapplicable.

There are very few studies of fish from saltmarshes in Australia. In the subtropical region of south-east Queensland a tidal creek draining marsh flats was netted on receding tides (Morton *et al*. 1987). Along with Gibbs' (1986) work in temperate NSW, this showed for the first time that a tidal saltmarsh creek in Australia was used by fish, including juveniles of economically important species such as mullet, bream and whiting. A distinctly different fish community with little presence of commercial species was sampled from semi-permanent pools remaining after the marsh drained, but it is not known whether this difference was due to the use of a different collecting technique (Morton *et al*. 1988). Juveniles of economically important species such as barramundi were also caught entering a creek supplying tidal water to a saltmarsh near Darwin in tropical Australia (Davis 1988). Assemblages of fish caught in permanent pools on the marsh flat differed from those in the creek, with a relatively high number of juveniles of barramundi. Again, it is not known whether this difference might have been due to the different sampling method used. The studies cited above of fish associated with saltmarshes indicate the beginnings of an attempt during the mid-1980s to determine the importance of marsh habitat, large areas of which were being degraded and destroyed. Unfortunately no further work was done, even though degradation of saltmarshes continued.

2.0 Need

Most saltmarsh habitat consists of marsh flats inundated at high tide but emergent at other times. Prior to the present project, the only sampling of fish from these flats in Australia was preliminary work on a marsh flat in southern Australia (Connolly *et al*. 1997). The work used a novel netting method, a buoyant pop net (Connolly 1994a), which allows fish to be sampled quantitatively from a marsh flat whilst inundated at high tide. The method had been tested successfully in vegetated (saltcouch) and unvegetated (saltpan) habitat in southeast Queensland, and was used to sample fish in the current project.

Despite legislation requiring that the preservation of saltmarshes be considered prior to developments that could harm their ecological integrity, saltmarshes continue to be destroyed and altered (Connolly & Bass 1996). Part of the rationale for encouraging the conservation of saltmarshes has been their assumed importance as fish habitat, especially for juveniles of economically important species (Hyland & Butler 1989). This role needs demonstrating, with a view to strengthening demands that saltmarsh habitat be retained in the face of increasing urbanisation.

Apart from direct loss of saltmarshes through urban development in southeast Qld and northern NSW, several other human activities are destroying or degrading saltmarshes. Anthropogenic changes to saltmarshes can result in loss of vegetation through changes in drainage regimes and salinity levels (Ruiz *et al*. 1993). While maps have been produced showing loss of saltmarshes in subtropical Australia (Hyland & Butler 1989), loss of vegetation from extant marshes has not been catalogued, despite the massive changes in drainage regimes, modification of marshes to control mosquitoes, grazing by stock, and use of marshes by off-road vehicles.

Debate about the role of vegetation in structuring fish communities of intertidal and subtidal habitats other than saltmarshes has been based on numerous comparisons of vegetated and unvegetated habitats (e.g. in seagrass meadows, Connolly 1994b, and reviewed in Bell & Pollard 1989; in mangroves, Laegdsgaard & Johnson 1995). In these habitats vegetated areas tend to have higher abundances and greater species richness. No attempt has been made in Australia to consider the role of vegetation in determining fish abundances on saltmarshes, although North American work on marshes lower in the intertidal zone has shown a greater abundance of fish and prawns in vegetation (Zimmerman & Minello 1984).

This proposal takes the first step towards determining the importance of saltmarsh habitat to fisheries by examining whether fish directly use inundated saltmarsh flats and whether vegetation plays a role in determining how many fish go there.

3.0 Objectives

The original proposal listed the following objectives:

1. To determine which fish species, in what abundance, directly use saltmarsh flats in subtropical east coast waters.

2. To compare the use by fish of vegetated (saltcouch) and unvegetated (saltpan) habitats on the marsh flats.

3. To make clear recommendations to fisheries and coastal managers about the impacts on fisheries of human activities affecting saltmarsh habitat and the direction of future research.

During the study the specific aims were altered for different marshes, especially in the second year's sampling, after discussions with QDPI and QDEH and with permission from FRDC. The final aims are best described under the four sections that are then used throughout this report.

3.1 Year 1, Meldale and Theodolite marshes: Vegetated vs unvegetated habitat and distance onto marsh

Over the first year at these marshes, the aims were kept similar to the original objectives.

Aim 1. To determine which fish species, in what abundance, directly use saltmarsh flats in southeast Queensland.

Aim 2. To compare the use by fish of vegetated and unvegetated (saltpan) habitats on the marsh flat.

Aim 3. To determine the relationship of water depth and distance onto a saltmarsh with species richness and fish density.

3.2 Years 1 & 2, Eden marsh: Sporobolus vs Suaeda habitat and distance onto marsh

At Eden Island unvegetated habitat is uncommon, and this is typical of saltmarshes in southern Moreton Bay. It was therefore decided to compare fish abundances between the two main vegetation types, short saltcouch grass, *Sporobolus virginicus*, and taller bushes of *Suaeda australis*.

Aim 1. To determine which fish species, in what abundance, directly use saltmarsh flats in southeast Queensland.

Aim 2. To compare the use by fish of *Sporobolus* and *Suaeda* habitats on the marsh flat.

Aim 3. To determine the relationship of water depth and distance onto a saltmarsh with species richness and fish density.

3.3 Year 2, Meldale marsh: Runneled vs unrunneled habitat and distance from feeder creek

The Meldale marsh has been modified as part of a mosquito reduction program that involves shallow, spoon-shaped drains (runnels) being created to drain deep pools that remain on the marsh after the tide recedes. Runneling is widespread across subtropical saltmarshes, and Qld Dept. Environment & Heritage (now known as Qld EPA) was concerned about the effects of runneling on non-target organisms such as fish. As an initial step towards developing a major program to determine the effects of runneling on fish, it was decided to sample fish alongside runnels and distant from runnels. The other main influence on the Meldale marsh suspected from the first year's sampling was that of a mangrove-lined feeder creek that supplies water to the marsh flat.

Aim 1. To determine which fish species, in what abundance, directly use saltmarsh flats in southeast Queensland.

Aim 2. To compare fish abundances alongside runnels and distant from runnels, on a marsh modified by runneling to reduce mosquito abundances.

Aim 3. To compare fish abundances on the marsh flats near and far from a mangrove-lined creek.

3.4 Year 2, Theodolite marsh: Shallow vs deep water and distance from feeder creek

In the first year's sampling, vegetation was not found to influence fish densities at Theodolite, nor was distance onto the marsh important. Rather, water depth arose as a likely influence on fish densities, along with proximity to the main mangrove-lined feeder creek.

Aim 1. To determine which fish species, in what abundance, directly use saltmarsh flats in southeast Queensland.

Aim 2. To compare fish abundances in shallow and deep water on the marsh (i.e. at high and low elevation).

Aim 3. To compare fish abundances on the marsh flats near and far from a mangrove-lined creek.

4.0 Methods

4.1 Vegetated vs unvegetated habitat and distance onto marsh (Meldale & Theodolite year 1)

Study sites and timing of sampling

Fish were sampled on two subtropical saltmarshes in southeast Queensland, at Meldale in northern Moreton Bay (27° 5′ S, 153° 9′ E) and Theodolite Creek in Hervey Bay (25° 10′ S, 152° 25′ E) (Fig. 4.1.1). The two marshes were chosen because they are not grazed by cattle, have relatively easy access for sampling, and are far apart (250 km). The study site at Meldale covers an area of 16 ha and the site at Theodolite covers 15 ha. Tidal flows at Meldale drain into a large creek which drains into Pumicestone Passage, an estuarine component of Moreton Bay. The Theodolite marsh drains into a much smaller estuary, consisting of one shallow creek adjacent to the marsh and another creek that drains directly into Hervey Bay. Meldale is 15 km from open waters and Theodolite is 2 km from open waters.

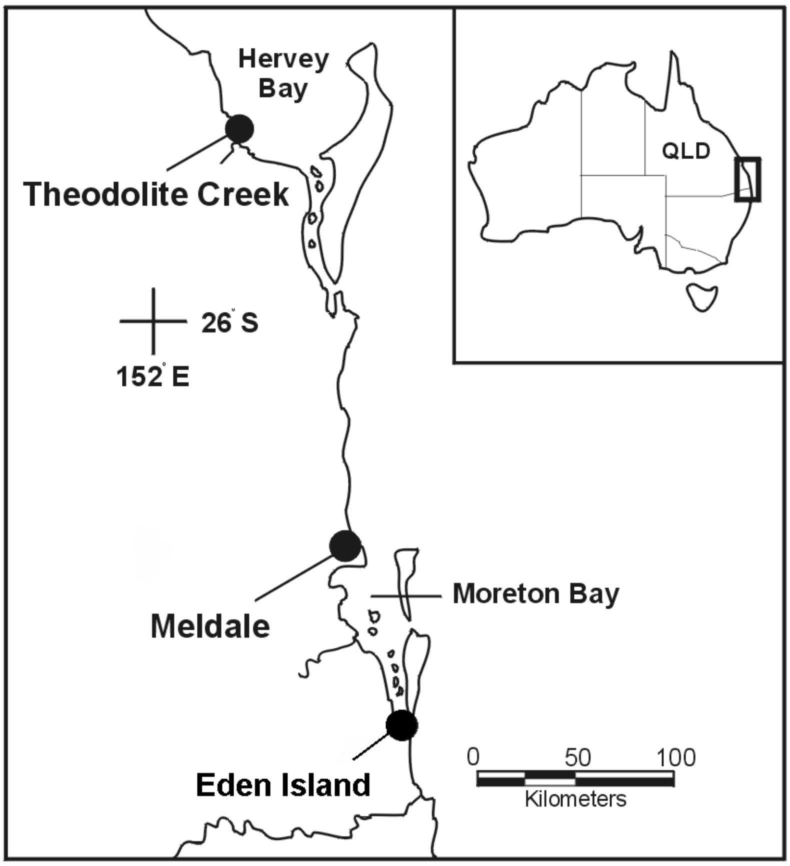

Figure 4.1.1. The three marsh locations sampled throughout the study

A short turf of beaded glasswort, *Sarcocornia quinqueflora*, and patches of saltcouch grass, *Sporobolus virginicus*, dominated the vegetation at Meldale. A succulent bush, *Halosarcia* sp., dominated the vegetation at Theodolite creek. Single mangrove trees of *Avicennia marina* and *Rhyzophora stylosa* occurred on both marshes. Sizes of vegetated and unvegetated patches that were sampled ranged from 0.02 ha to 1.7 ha and 0.003 ha to 1.0 ha respectively. Both marshes consist mainly of vegetated and unvegetated intertidal flats with occasional semi-permanent pools and mangrove-lined feeder creeks.

Tides within the study area are semi-diurnal with amplitudes ranging up to 2.1 m (Meldale) and 3.1 m (Theodolite). Marshes are completely inundated only on the highest of spring high tides, in sets of approximately 4 days. On a yearly basis, the percentage of time subtropical Queensland marshes are completely submerged is approximately 1%, with strong seasonality; it ranges from 0% in autumn and spring to 3% in summer and winter (Connolly 1999). During high tide sets, marshes are completely inundated for an average of 17% of the time, although they are partially inundated for a much greater time.

The work in this section consisted of two sampling periods at each marsh, one in winter (Meldale, June 1997; Theodolite, August 1997) during night time high tides (full moon phase) and the other in summer (Meldale, January 1998; Theodolite, March 1998) during daytime high tides (new moon phase). For each sampling period, the number of sampling days was determined by the number of high tides sufficient to completely inundate the marsh. For both the winter and summer sampling periods, the Meldale marsh was sampled for 4 days and Theodolite was sampled for 3 days.

Important note: The high tides that inundate saltmarshes in subtropical Australian waters occur only at night in winter (and usually on full moon phase), and only during the day in summer (usually on new moon phase). The differences in fish use between winter and summer cannot, therefore, be separated from any influence of sampling in night and day (or different moon phase), and it is not the intention of this work to compare fish use between summer and winter. Rather, by sampling at two times of year, it is intended to give as broad a view as possible of the fish using saltmarsh flats.

Fish collections

The spatial extent of inundation at each marsh was estimated by inspecting vegetation type and observing inundation events prior to the study. This area of inundation was designated as the study area within which fish were sampled. Fish were captured using a series of floorless, buoyant pop nets (Fig. 4.1.2). Nets consisted of four walls of 1mm diameter mesh (5 m long × 1 m high) which, when installed, form a square sitting flush with the marsh surface. The time required for two people to install a net was 90 minutes (including the time to disassemble a net and transport it to the next sampling site), and this was done during low tide. At slack high tide, the nets were released, surfacing within two seconds of deployment and enclosing an area of 25 m^2. Nets were positioned so that fish would be channelled towards one corner as the tide retreated. Following net release, fish were collected with hand held dip nets. To mitigate against predation by scavengers, pop nets were revisited frequently until the area had drained, after which a final visual check of the enclosed area was made as species of Gobiidae occasionally remained in tiny depressions. All fish were identified, counted and measured to the nearest millimetre using total length (TL).

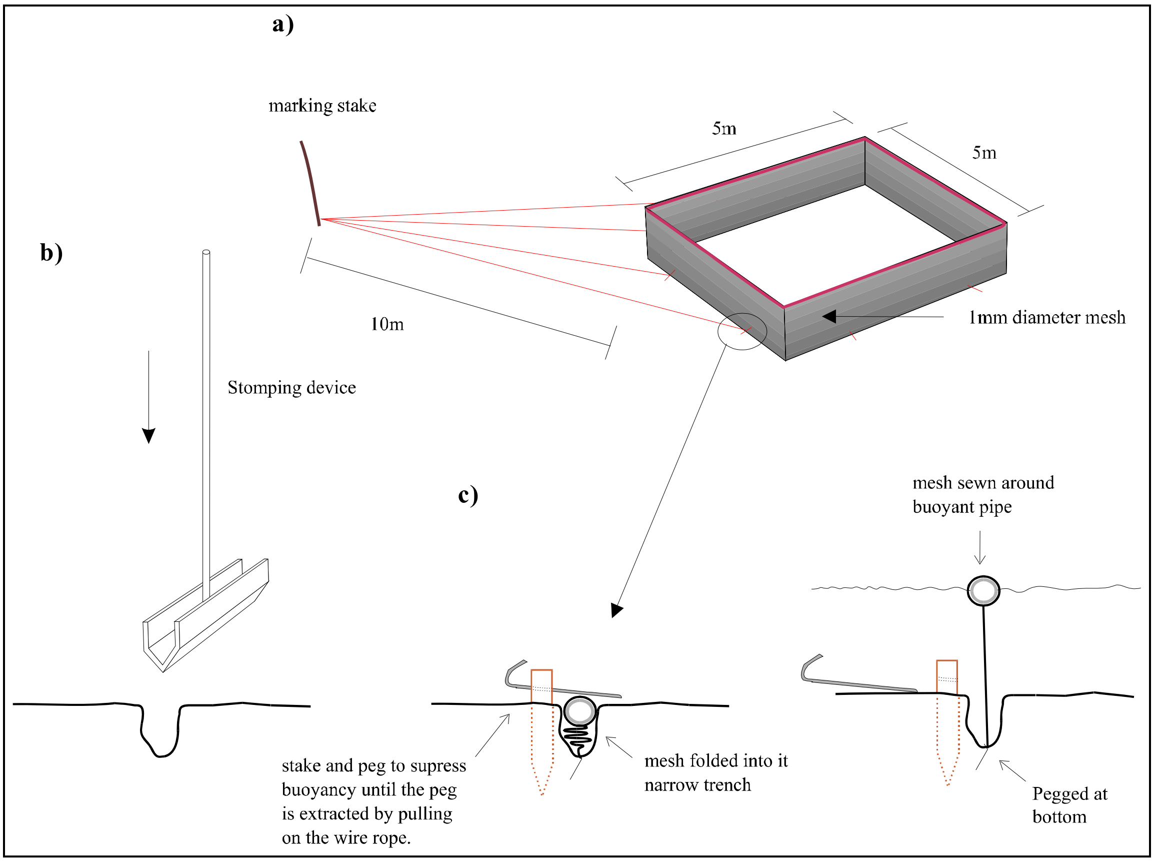

Figure 4.1.2. Pop net design and triggering device. a) full construction when deployed; b) stomping device to create trench; c) triggering device set up prior to net release (left) and after the net has been released at high tide. Modified from Moussalli & Connolly (1998).

Comparisons of fish assemblages in vegetated and unvegetated habitat were made using a paired sampling design. This design limits the influence of factors that were not investigated in the present study (e.g. proximity to mangroves and day of release), that may have confounded the comparison of vegetated and unvegetated habitat. Vegetated and unvegetated patches were sampled by placing a pair of nets at each site, one in each habitat, no further than 25 m apart. Sites were selected so as to represent the inundated marsh flats (covering approximately 16 ha at Meldale and 15 ha at Theodolite) and to sample at several distances onto the marsh where both habitats occurred. Placement of nets at sites, within habitat patches, was done randomly but with compliance to the 25 m maximum separation criterion. An approximately equal number of sites was chosen in each of three strata ranging from alongside subtidal water to the terrestrial edge of the marsh (410 m from subtidal water at Meldale, 200 m at Theodolite). These distance strata were used purely to ensure sites were placed at a range of distances onto the marsh and were not, therefore, used as a treatment in data analysis. The Meldale summer sampling period was only sampled up to 320 m because tidal heights were lower than predicted during this period. Nets were moved to new sites after each collection day. The actual day on which a particular site was sampled was chosen so that a broad spread of sites was achieved each day. A total of 14 paired samples was taken at each sampling period at Meldale, 18 paired samples were taken at Theodolite in winter and 21 pairs were taken at Theodolite in summer.

Distance onto the marsh was measured as distance from sites to the nearest seaward edge of the marsh. Distances were obtained from aerial photos. The scale on an aerial photo was ground-truthed, and the sites then located on the aerial photo. Water depth (± 1 cm) at each net, and water temperature (± 1°C) and salinity (± 0.5‰) at each paired site, were measured after both nets in each pair were released (Table 4.1.1). The average height of vegetation in vegetated plots is shown in Table 4.1.1.

Table 4.1.1. Physico-chemical characteristics at each marsh for each sampling period. Salinity and temperature entries are means (SE) for each sampling period. Vegetation heights are a range of averages at vegetated plots. V = vegetated, U = unvegetated.

		Depth range		Height of vegetation	Salinity	Temperature
Location	Season	V (cm)	U (cm)	Range (cm)	(‰)	(ºC)
Meldale	Winter	4-28	5-43	5-18	16 (0.4)	16 (0.1)
	Summer	4-19	6-22	6-15	27 (0.7)	33 (0.6)
Theodolite	Winter	7-63	11-56	3-16	28 (2.0)	19 (0.2)
	Summer	19-72	28-70	5-13	30 (0.8)	27 (0.3)

Data analysis

Each sampling event was analysed separately due to the differences in the timing of sampling (i.e. month of sampling and diurnal stage). Wilcoxon's paired-sample test was used to determine any differences between vegetated and unvegetated habitats in the variables listed below. This non-parametric test was used because the paired data typically did not have normally distributed differences. The ranking of the differences involved in this test also prevents the often large differences obtained for schooling species from obscuring patterns in non-schooling species. The variables analysed were species richness (no. of species/25 m^2) and the density (individuals/100 m^2) of : 1) all species combined, 2) all species excluding the dominant species, and 3) selected other species considered common enough to analyse (occurring in ≥ 4 nets), including the dominant species. At Meldale the individual species analysed were *Mugilogobius stigmaticus* for winter and summer, *Ambassis marianus* (dominant species), *Acanthopagrus australis*, *Gobiopterus semivestitus* and *Tetractenos hamiltoni* for winter only, and *Pseudogobius* sp. and *Sillago maculata* for summer only. At Theodolite in winter, *A. australis* (dominant species), *A. marianus* and *M. stigmaticus* were analysed and in summer *Atherinomorus ogilbyi* (dominant species) was analysed. Analysis of the density with the exclusion of the dominant species was not done for Theodolite in winter as the number of fish was too low to make useful comparisons between the two habitats. Length-frequency distributions were compared between vegetated and unvegetated habitat using Kolmogorov-Smirnov tests for species with at least 10 individuals in each habitat for any sampling period. Two species from the Meldale winter sampling period, *A. marianus* and *G. semivestitus,* and one species, *A. ogilbyi,* from the Theodolite summer sampling period were able to be analysed.

Multiple regressions were used to test the relationship of the independent variables distance onto the marsh and water depth with species richness and fish density. The aim was to determine whether either of the independent variables alone or the two in combination were good predictors of species richness or fish density. Vegetated and unvegetated habitats were analysed separately in case fish assemblages were influenced by depth and distance differently in each habitat. Regressions were done on log $(x + 1)$ transformed data as this transformation made the residuals more even when plotted against the independent variables. The density variables that were analysed were: 1) all species combined, 2) all species excluding the dominant species, and 3) individual species that occurred in at least four nets in a particular habitat. At Meldale in winter these were *Ambassis marianus* and *Gobiopterus semivestitus* in both habitats, and *Mugilogobius stigmaticus* and *Tetractenos hamiltoni* in vegetated habitat. No species were analysed individually for the summer sampling period. At Theodolite, *Atherinomorus ogilbyi* was the only species able to be analysed, and this was in vegetated habitat for the summer sampling period only.

4.2 Suaeda vs Sporobolus habitat and distance onto marsh (Eden year 1 & 2)

Study sites and timing of sampling

Sampling was done on saltmarsh flats at Eden Island (27° 45′ S, 153° 25′ E) in Moreton Bay, southeast Queensland (see Fig. 4.1.1 in Section 4.1). Four intertidal drainage channels, fringed by mangroves, fed water onto the marsh. A substantial proportion of water, however, flooded directly onto the marsh from the main subtidal channel. The saltmarsh flats often extended to the subtidal channel, with only small areas of the banks being fringed by stands of mangroves (*Avicennia marina*, *Rhyzophora stylosa*) at the immediate study site. This marsh was chosen because of its extensive area (approximately 31 ha), minimal anthropogenic impacts and the types of dominant vegetation that occurred on this marsh. The two main types of saltmarsh vegetation on Eden Island, *Suaeda australis* and *Sporobolus virginicus,* are characteristic of the vegetation on other saltmarshes in southern Moreton Bay. Saltpans were absent, although small ephemeral pools existed on the marsh and this was also representative of saltmarshes in southern Moreton Bay. Single mangrove trees that had saltmarsh abutting the base of the trunk were included as areas available for sampling. Eden Island is 6 km from open waters.

Sizes of *Suaeda* and *Sporobolus* patches that were sampled ranged from 0.02 ha to 1.7 ha and 0.003 ha to 1.0 ha respectively. The tidal regime at Eden Island is similar to that described in Section 4.1 for the Meldale marsh. Eden Island was sampled at four periods, winter and summer over the two years of the overall project [year 1, winter – July 1997, summer – February 1998; year 2, winter – June 1998, summer – January 1999]. Each sampling period ran for four consecutive days, sampling on the night time high tide in winter and the daytime high tide in summer (see special note about the rationale for this in Section 4.1).

Fish collections

The same methods used in Section 4.1 for determining the area of inundation (study area) were used in this study. The netting technique used to sample fish and the methods used for identifying, measuring and preserving fish were also the same as in Section 4.1 for all four sampling periods. Comparisons of fish assemblages in two different vegetation types, short saltcouch grass (*Sporobolus virginicus*) and the taller succulent bush (*Suaeda australis*) were made at all four sampling periods.

For the first two sampling periods (winter & summer, year 1), comparisons of fish assemblages in these two habitats were made using the same paired sampling design as in Section 4.1. Sampling was again done at several distances onto the marsh. Distances were greater than in Section 4.1, ranging up to 476 m. In year 1, a total of 60 nets (30 pairs) were released in winter, and in the summer sampling period 56 nets (28 pairs) were released.

In the second year, sampling was undertaken on a reduced spatial scale, down from approximately 31 ha used in year 1 to approximately 4 ha. This change was designed to reduce the effects of habitat heterogeneity, presumed to be a major contributor to the highly variable fish densities on all three marshes (Eden, Meldale, Theodolite) in year 1. This would allow more confidence in our statistical comparisons (i.e. higher statistical power). In the second year, comparisons of fish assemblages between *Suaeda* and *Sporobolus* were made using a two-factor design. The two factors were vegetation type and distance onto the marsh. Nets in each vegetation type were no longer paired, which allowed for more flexibility in the placement of nets in patches and consequently a larger area within a patch could potentially be sampled. The unpaired design resulted in less control for the influences on fish assemblages not investigated in the present study. Reducing the spatial scale of sampling, however, was considered likely to limit these influences by reducing habitat heterogeneity within each vegetation type.

The influence of distance onto the marsh on fish assemblages in the second year of sampling was examined by sampling at two distance ranges onto the marsh (0-50 m band, 100-150 m band). Results from the first year of sampling led us to believe that, on a large spatial scale, fish were influenced by many variables that were not measured in the present study, such as proximity to mangroves and drainage channels. To limit these influences the question about distance onto the marsh was asked on a smaller spatial scale, with more intensive sampling within this smaller area. These distance bands were also chosen to represent two types of saltmarsh habitats; deep marsh areas near to subtidal water and shallow areas further onto the marsh, where currents from subtidal channels are weak. In the first year of sampling, rather low densities were found far onto the marsh at times, and sampling in the second year was therefore focussed no further than 150 m from subtidal water.

In year 2, over the four day sampling periods, 44 nets were deployed in winter (11 in each combination) with 56 nets (14 nets in each combination) deployed in summer. On each collection day, the number of samples within each vegetation type-distance combination was similar. Within the two distance bands, patches of *Suaeda* and

Sporobolus were interspersed to the extent that their distribution permitted. Water depth (± 1 cm), water temperature (± 1°C) and salinity (± 0.5‰) were recorded at all four sampling periods using the procedures described in Section 4.1. In year 2, water depths ranged from 20-45 cm in the near distance band and 17-30 cm in the far distance band. The average height of vegetation in *Suaeda* and *Sporobolus* plots is shown in Table 4.2.2.

Table 4.2.2. Physico-chemical characteristics of the marsh for each sampling period. Salinity and temperature entries are means (SE) for each sampling period. Vegetation heights are the range of averages at these plots.

	Depth range		Salinity	Temperature	Height of vegetation	
Sampling period	*Suaeda* (cm)	*Sporobolus* (cm)	(‰)	(ºC)	*Suaeda* (cm)	*Sporobolus* (cm)
Winter, yr 1	8-29	7-33	22.0 (0.3)	16.0 (0.2)	27-50	12-21
Summer, yr1	9-30	7-27	33.0 (0.5)	29.3 (0.4)	17-37	10-22
Winter, yr 2	18-45	17-42	33.9 (0.4)	18.3 (0.3)	26-39	10-19
Summer, yr2	23-48	23-49	32.8 (0.4)	26.0 (0.2)	20-24	12-20

Data analysis

Sampling periods were analysed separately due to the differences in timing and diel stage of sampling. The same approach to data analysis used in comparing fish assemblages from vegetated and unvegetated habitats in Section 4.1 was used for the first year sampling periods here. In the first winter and summer sampling period the following variables were tested using a Wilcoxon test: species richness (no. of species/25 m^2) and the density (individuals/100 m^2) of, 1) all species combined, 2) all species except the dominant species (*Ambassis jacksoniensis*), and 3) selected species considered common enough to analyse (occurring in ≥ 4 nets). The individual species analysed were *A. jacksoniensis, Acanthopagrus australis* and *Mugilogobius stigmaticus* for both sampling periods, *Torquigener pleurosticta* in winter and *Ambassis marianus, Pseudogobius sp.* and *Valamugil georgii* in summer. Length-frequency distributions of selected species were tested for differences between *Suaeda* and *Sporobolus* habitats using Kolmogorov-Smirnov tests (See Section 4.1 for decision criteria on selection of species). These species were *A. jacksoniensis* for the first winter and summer sampling periods and *M. stigmaticus* in winter.

The multiple regression analyses described in Section 4.1 were used for the first winter and summer sampling periods. Species richness and the density variables listed above (in Wilcoxon description) were analysed with distance onto the marsh and water depth to determine whether either of the independent variables alone, or the two in combination, were good predictors of species richness or fish density. Species analysed individually were *Ambassis jacksoniensis* (dominant species) in both habitats at both periods, *Mugilogobius stigmaticus* in both habitats in winter, *Acanthopagrus australis* in *Suaeda* in winter, and *Pseudogobius* sp. and *Valamugil georgii* in *Sporobolus* in summer.

For the second year sampling periods, a two-factor analysis of variance was used to examine whether species richness and fish density differed between the two vegetation types (*Suaeda* and *Sporobolus*) and two distances onto the marsh (near and far). The same types of fish density variables analysed in the first winter and summer sampling periods were used here. These were the density (indiv./100 m^2) of: 1) all species combined, 2) all species except the dominant species (*Ambassis jacksoniensis*), and 3) selected common species. Individual species analysed were *A. jacksoniensis*, *Mugilogobius stigmaticus, Gobiopterus semivestitus* and *Calamiana* sp. Data were log *(x + 1)* transformed prior to ANOVA tests so that the interaction term provided a test of proportional differences rather than magnitudinal differences (Hurlbert & White 1993). If a significant interaction was found, post hoc Tukeys tests were carried out, in which case differences between levels of the factor being tested were done for each level of the other factor separately. For the winter sampling period and the summer sampling period in year 2, differences in the length-frequency distributions of *A. jacksoniensis* between *Suaeda* and *Sporobolus,* and near and far distance bands were tested using Kolmogorov-Smirnov tests. No other species had sufficient sample sizes for analysis.

4.3 Runneled vs unrunneled habitat and distance from feeder creek (Meldale year 2)

Study sites and timing of sampling

The study site was part of the same marsh at Meldale, as shown in Section 4.1, Fig. 4.1.1. The tidal regime for this marsh is described in Section 4.1. Within the specific sampling area used here, a succulent turf of glasswort, *Sarcocornia quinqueflora,* dominated the vegetation, *Suaeda australis* occurred commonly, and *Sporobolus virginicus* occurred occasionally. There were two sampling periods, the first in winter (May 1998) on night time high tides, and the second in summer (December 1998) on daytime high tides. Fish were sampled for four consecutive days at both periods, at times when high tides were sufficient to completely inundate the marsh.

Fish collections

Fish were sampled, collected and measured as described in Section 4.1, using buoyant pop nets. Water depth (± 1 cm), temperature (± 1°C) and salinity (± 0.5‰) were recorded at each netting site after the net had been released. Water depth averaged 21.8 cm in winter and 25.7 cm in summer. Mean temperatures were 17.9°C in winter and 28.5°C in summer, and salinity averaged 28.4‰ and 30.5‰ for the winter and summer sampling period, respectively.

Fish assemblages were compared from vegetated areas of the marsh that were alongside runnels, and distant from runnels, and at near and far distances from a shallow, mangrove-lined feeder creek that supplied water to and drained the marsh. Nets were placed near to (5-10 m) and far from (40-60 m) the feeder creek. Within these near and far distance bands, nets were also placed alongside (nearest edge 0.5 m) and distant from (30 m) three runnels, which run approximately perpendicular to the feeder creek. This orthogonal design allowed comparisons between the two habitats, alongside runnel and distant to runnels, to be made at both near and far distances from the feeder creek. Areas that were sampled near to the creek were always deeper (at any one period) than those far from the creek, and within each distance band, the water depth of areas alongside, and distant from runnels, were similar. Depth ranges were: near creek, runneled habitat 25-47 cm; near creek, unrunneled habitat 21-48 cm; far from creek, runneled habitat 6-26 cm; far from creek, unrunneled habitat 8-26 cm.

Important note: The terms runneled and unrunneled habitat will be used hereafter to specify areas alongside runnels and distant from runnels, respectively.

For the winter sampling period, 44 pop nets were deployed, 11 in each combination of habitat type (runneled and unrunneled habitat) and distance (near and far) from feeder creek. For the summer sampling period, 48 nets were deployed, 12 in each combination. In both sampling periods, an even number of nets in each habitat/distance combination was deployed on each of the four nights.

Data analysis

A two-factor analysis of variance was used to examine whether species richness and fish density differed between runneled and unrunneled habitat, and at two distances from the feeder creek (near and far). The variables analysed were species richness (no. of species/25m^2) and the density (indiv./100 m^2) of: 1) all species combined, 2) all species except the dominant species and 3) selected species considered common enough to analyse (occurring in ≥ 5 nets). Individual species analysed for the winter period were *Acanthopagrus australis, Ambassis jacksoniensis, Ambassis marianus* (dominant), *Arrhamphus sclerolepis, Calamiana* sp., *Mugilogobius stigmaticus, Pseudogobius* sp., *Tetractenos hamiltoni* and *Torquigener pleurosticta*. Species analysed individually in summer were *Calamiana* sp. (dominant), *Gerres subfasciata, Mugilogobius stigmaticus, Pseudogobius* sp. and *Sillago maculata*. Data were log *(x + 1)* transformed prior to ANOVA tests so that the interaction term provided a test of proportional differences rather than magnitudinal differences on raw data (Hurlbert & White 1993). If a significant interaction was found, post hoc Tukeys tests were carried out, in which case differences between levels of the factor being tested were done for each level of the other factor separately. Length-frequency distributions between the levels of each of the two factors, habitat and distance, were compared using Kolmogorov-Smirnov tests for species where enough individuals occurred to make a useful test. The criterion for testing was that at least 10 individuals must occur in the two levels being tested. For the second winter sampling period, species able to be analysed were *A. marianus, M. stigmaticus* and *Pseudogobius* sp. In summer, *Calamiana* sp., *G. subfasciata* and *M. stigmaticus*. were analysed.

4.4 Shallow vs deep water and distance from feeder creek (Theodolite year 2)

Study sites and timing of sampling

The study site was part of the same marsh at Theodolite, as shown in Section 4.1, Fig. 4.1.1. The tidal regime for this marsh is described in Section 4.1. Vegetation at the specific sampling area used here was as described for the whole marsh in Section 4.1. The first sampling period was done early in winter (May 1998) on night time high tides, and the second sampling period was done in summer (February 1999) on daytime high tides. Fish were sampled for four consecutive days at both periods, at times when high tides were sufficient to completely inundate the marsh.

Fish collections

Fish were sampled, collected and measured as described in Section 4.1, using buoyant pop nets. Water depth (± 1 cm), temperature (± 1°C) and salinity (± 0.5‰) were recorded at each netting site after the net had been released. Mean temperatures were 22.5°C in winter and 27.9°C in summer, and salinity averaged 41.0‰ and 30.2‰ for the winter and summer sampling period, respectively.

Fish assemblages were compared from vegetated areas of the marsh at two elevations, high and low, and at near and far distances from a shallow, mangrove-lined feeder creek that supplied much of the water to the marsh. When inundated, the high and low elevation areas are covered by shallow and deep water depths, respectively, and hereafter the two types of habitat will be referred to as shallow and deep areas. Nets were placed near to (< 25 m) and far from (90-120 m) the feeder creek. Within these near and far distance bands, nets were also placed in either shallow or deep areas. There was a degree of natural interspersion of shallow and deep areas in both the near and far zones, and the design took advantage of this feature of the marsh. Within shallow and deep areas, actual netting sites were randomly placed. At any one period, water depths at deep sites were always greater than at shallow sites (Fig. 4.4.2). The orthogonal design allowed comparisons of fish assemblages occurring in different water depths to be made at both near and far distances from the feeder creek.

For the winter sampling period, 36 pop nets were deployed, 9 in each combination of depth (shallow and deep) and distance (near and far) from feeder creek. For the summer sampling period, 48 nets were deployed, 12 in each combination. In both sampling periods, an approximately even number of nets in each habitat/distance combination was deployed on each of the four nights.

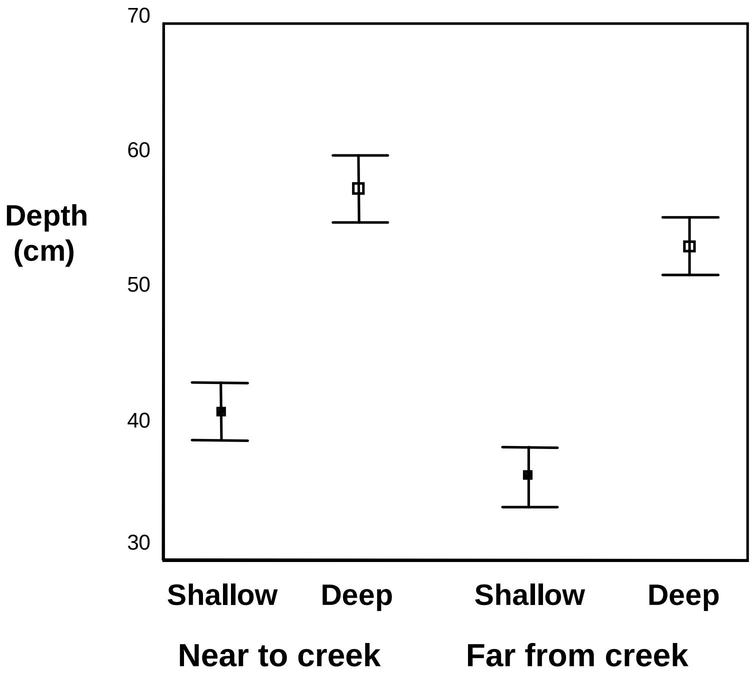

Figure 4.4.2. Water depths (mean ± SE) at near and far distances from a feeder creek, at shallow and deep sites, for the summer sampling period at Theodolite in year 2.

Data analysis

A two-factor analysis of variance was used to examine whether species richness and fish density differed between shallow and deep water depths, and at two distances from the feeder creek (near and far). The variables analysed were species richness (no. of species/25m^2) and the density (indiv./100 m^2) of: 1) all species combined, 2) all species except the dominant species, and 3) selected species considered common enough to analyse (occurring in ≥ 5 nets). Individual species analysed for the winter period were *Acanthopagrus australis, Ambassis marianus* (dominant), *Atherinomorus ogilbyi, Craterocephalus mugiloides,* and *Valamugil georgii.* Species analysed individually in summer were *A. australis*, *Atherinomorus ogilbyi* (dominant), *Mugilogobius stigmaticus* and *Tetractenos hamiltoni.* Data were log $(x + 1)$ transformed prior to ANOVA tests so that the interaction term provided a test of proportional differences rather than magnitudinal differences (Hurlbert & White 1993). Length-frequency distributions between the levels of each of the two factors, habitat and distance, were compared using Kolmogorov-Smirnov tests for species where enough individuals occurred to make a useful test. The criterion for testing was that at least 10 individuals must occur in the two levels being tested. For the winter sampling period, species able to be analysed were *A. marianus,* and *A. ogilbyi*. In summer, *A. ogilbyi* was the only species able to be analysed.

5.0 Results

5.1 Vegetated vs unvegetated habitat and distance onto marsh (Meldale & Theodolite year 1)

Overall densities and species composition

From 56 pop nets released at Meldale, 396 fish of 15 species from 9 families were caught, with 55% of nets catching fish. From 78 nets released at Theodolite, 181 fish of 21 species from 13 families were caught, with 50% of nets catching fish. Different species were numerically dominant at the two marsh sites. *Ambassis marianus* and *Gobiopterus semivestitus* numerically dominated the winter catch at Meldale, representing 50% and 31% of the catch respectively. For the summer sampling period, *A. marianus* (41%) and *Tetractenos hamiltoni* (12%) were numerically dominant (Table 5.1.1). At Theodolite in winter, the catch was dominated by *Acanthopagrus australis* (24%) with *A. marianus* and *Mugilogobius stigmaticus* also contributing 19% each to total catch. In summer, *Atherinomorus ogilbyi* dominated strongly, representing 74% of the catch (Table 5.1.2). With the exception of *A. australis,* these species were present as juveniles and adults. Fourteen of the 23 species caught are of economic importance, either recreationally, commercially or both. Refer to Appendix 3 for an indication of which species are of economic importance, and the common names for all fish species. These exploited species comprised 34% of the total catch. All exploited species occurred as juveniles; species of Sparidae, Mugilidae and Hemiramphidae also occurred as subadults. Species that were represented by only a single individual at a sampling period were omitted from Tables 5.1.1 and 5.1.2. At Meldale in winter, *Ambassis jacksoniensis* and *A. ogilbyi* were excluded from Table 5.1.1. *Acentrogobius viridipunctatus*, *Myxus elongatus* and *Torquigener pleurosticta* for the Theodolite winter sampling period, and *Herklotsichthys castelnaui*, *Pseudogobius* sp., *Scomberoides lysan*, *Sillago maculata* and *T. hamiltoni* for the summer sampling period were excluded from Table 5.1.2.

Table 5.1.1. Summary of species richness and fish densities at Meldale for winter (W) and summer (S). The units for species richness and density are given in parentheses under the variable types. Uncommon species are not listed (see text). Overall = habitats combined, D = mean density, % = % of total fish abundance at that period. d = dominant species at that period.

		Overall		Vegetated	Unvegetated
Species	Season	D	%	D	D
Species richness	W	2.0		2.1	1.8
(no. of species/25 m^2)	S	0.8		0.6	1.1
Density					
(indiv./100 m^2)					
Acanthopagrus australis	W	0.7	2	0.6	0.9
	S	0.3	3	-	0.6
Ambassis marianus [d]	W	23.3	50	32.3	14.3
	S	5.0	41	-	9.1
Arrhamphus sclerolepis	W	0.3	1	-	0.6
	S	0.4	4	-	0.9
Atherinomorus ogilbyi	W	-	-	-	-
	S	1.0	5	-	1.1
Gerres subfasciata	W	0.4	1	-	0.9
	S	1.0	9	-	2.0
Gobiopterus semivestitus	W	14.4	31	17.1	11.7
	S	1.0	6	-	1.4
Liza argentea	W	0.3	1	0.3	0.3
	S	-	-	-	-
Mugilogobius stigmaticus	W	3.4	7	6.3	0.6
	S	1.0	8	0.6	1.1
Pseudogobius sp.	W	0.3	1	0.6	-
	S	1.0	8	0.9	0.9
Pseudomugil signifer	W	0.3	1	0.6	-
	S	-	-	-	-
Sillago maculata	W	0.4	1	0.3	0.6
	S	0.6	5	0.3	0.9
Tetractenos hamiltoni	W	0.9	2	1.1	0.6
	S	1.0	12	2.0	0.6
Torquigener pleurosticta	W	0.4	1	0.6	0.3
	S	-	-	-	-
Total (all species)	W	45.5		59.7	31.1
	S	11.1		3.7	18.6
Dominant species	W	22.1		27.4	16.9
excluded	S	6.6		3.7	9.4

Table 5.1.2. Summary of species richness and fish densities at Theodolite for winter (W) and summer (S). The units for species richness and density are given in parentheses under the variable types. Uncommon species are not listed (see text). Overall = habitats combined, D = mean density, % = % of total fish abundance at that period. d = dominant species at that period.

		Overall		Vegetated	Unvegetated
Species	Season	D	%	D	D
Species richness	W	0.5		0.6	0.5
(no. of species/25 m^2)	S	0.9		1.0	0.8
Density					
(indiv./100 m^2)					
Acanthopagrus australis	W	0.6	24	0.7	0.4
	S	0.5	3	0.8	0.2
Ambassis marianus	W [d]	0.4	19	0.7	0.2
	S	0.2	1	0.4	-
Arrhamphus sclerolepis	W	-	-	-	-
	S	0.3	2	0.2	0.4
Atherinomorus ogilbyi	W	-	-	-	-
	S [d]	11.3	74	20.2	2.5
Gerres subfasciata	W	-	-	-	-
	S	0.9	6	1.1	0.6
Gobiopterus semivestitus	W	-	-	-	-
	S	0.5	3	-	1.0
Hyporhamphus quoyi	W	-	-	-	-
	S	0.2	1	-	0.4
Liza argentea	W	0.2	10	0.4	-
	S	-	-	-	-
Mugil cephalus	W	0.2	10	-	0.4
	S	-	-	-	-
Mugilogobius stigmaticus	W	0.4	19	0.4	0.4
	S	-	-	-	-
Selenotoca multifasciata	W	-	-	-	-
	S	0.3	2	-	0.6
Terapon jarbua	W	-	-	-	-
	S	0.2	1	0.4	-
Tetractenos hamiltoni	W	0.2	10	-	0.4
	S	-	-	-	-
Valamugil georgii	W	-	-	-	-
	S	0.4	3	-	0.8
Total (all species)	W	2.4		2.4	2.2
	S	15.2		23.8	6.7
Dominant species	W	1.8		1.8	1.8
excluded	S	3.9		3.6	4.2

Comparisons of species richness and composition from vegetated and unvegetated habitats

At Meldale, the total number of species caught in vegetated habitat was 10 in winter and 4 in summer, and in unvegetated habitat, the total number of species was 12 in winter and 10 in summer. Of the species caught in both sampling periods at Meldale, *Atherinomorus ogilbyi* and *Gerres subfasciata* were specific to unvegetated habitat, *Mugilogobius stigmaticus*, *Sillago maculata* and *Tetractenos hamiltoni* occurred in both habitats, and no species was unique to vegetated habitat. At Theodolite, *Acanthopagrus australis* occurred in both habitats and no species was unique to either habitat over both sampling periods. No significant difference in species richness (per 25 m^2) was demonstrated between vegetated and unvegetated habitats for any of the four sampling periods (see Table 5.1.3 for the Wilcoxon results and Tables 5.1.1 and 5.1.2 for the means in each habitat).

Comparisons of density and sizes from vegetated and unvegetated habitats

At Meldale, the highest mean fish density (59.7 indiv./100 m^2) was recorded in vegetated habitat in winter, and the lowest (3.7) was recorded in vegetated habitat in summer (Table 5.1.1). At Theodolite the highest density (23.8) was recorded in vegetated habitat in summer and the lowest (2.2) was recorded in unvegetated habitat in winter (Table 5.1.2). Over all four sampling periods, significant differences in fish density between vegetated and unvegetated habitats were detected for just two species (Table 5.1.3). At Meldale in winter, the density of *Mugilogobius stigmaticus* was significantly higher in vegetated habitat, as was *Atherinomorus ogilbyi* at Theodolite in summer (see Table 5.1.3 for the Wilcoxon results and Tables 5.1.1 and 5.1.2 for the means in each habitat). Of the pairs of nets where fish were caught in at least one habitat, *M. stigmaticus* had five pairs with the higher density in vegetated habitat and zero pairs with higher density in unvegetated habitat. For *A. ogilbyi*, eight pairs had the higher density in vegetated habitat and two pairs in unvegetated habitat.

Table 5.1.3. Results of Wilcoxon paired-sample test (given as probability, p) comparing species richness and density between vegetated and unvegetated habitats for the Meldale and Theodolite winter (W) and summer (S) sampling periods. For mean paired differences between habitat types, catch in vegetated habitat is greater than unvegetated habitat except where the difference is negative. The units for mean paired difference and effect size are given in parentheses under the variable types. d = dominant species at that period. * = p < 0.05.

	Season	Mean paired difference	p	Effect size	Power
Meldale					
Species richness	W	0.3	0.467	1.0	0.45
(no. of species/25 m^2)	S	-0.5	0.558	0.4	0.10
Density (indiv./100 m^2)					
All species	W	28.6	0.213	22.8	0.10
	S	-14.9	0.389	5.6	0.07
Dominant species excluded	W	10.5	0.332	11.1	0.16
	S	-5.7	0.389	3.3	0.09
Acanthopagrus australis	W	-0.3	0.655	0.4	0.08
Ambassis marianus [d]	W	18	0.767	11.6	0.07
Gobiopterus semivestitus	W	6	0.463	7.2	0.13
Mugilogobius stigmaticus	W	5.7	**0.043***	1.7	0.09
	S	-0.5	0.705	0.5	0.07
Pseudogobius sp.	S	0	1.000	0.5	0.09
Sillago maculata	S	-0.6	0.317	0.3	0.08
Tetractenos hamiltoni	W	0.5	0.317	0.2	0.08
Theodolite					
Species richness	W	0.1	0.272	0.3	0.14
(no. of species/25 m^2)	S	0.2	0.675	0.4	0.39
Density (indiv./100 m^2)					
All species	W	0.2	0.839	1.2	0.14
	S	17.1	0.073	7.6	0.10
Dominant species excluded	S	-0.6	0.623	2.0	0.37
Acanthopagrus australis [d]	W	0.3	0.705	0.3	0.08
Ambassis marianus	W	0.5	0.317	0.2	0.07
Atherinomorus ogilbyi [d]	S	17.7	**0.041***	5.7	0.07
Mugilogobius stigmaticus	W	0	1.000	0.2	0.09

Given the small number of Wilcoxon tests that were significant, it is worthwhile examining the power of those tests. The power of a Wilcoxon test is approximately 95% of the power in an equivalent paired-sample *t* test (Zar 1999). Since power cannot be calculated directly for Wilcoxon tests, power was estimated as 95% of the power of the equivalent paired sample *t* tests. For the paired *t* test the effect size is specified as the magnitude of the mean difference. For the tests between habitat types we considered it important to detect a departure from the null where the mean difference was at least 50% different to the overall mean (for that particular sampling period). For example, at Meldale in winter, the overall mean density (all species) was 45.5 indiv./100 m^2. Therefore the effect size is 22.8 indiv./100 m^2 (i.e. 50% of the overall mean). The chance of detecting a difference in density between habitat types at Meldale in winter with the effect size specified above was 0.10 ($\beta = 0.90$). Power of the Wilcoxon tests comparing fish densities amongst habitat types ranged from 0.07 to 0.37 (Table 5.1.3). The power of the Wilcoxon tests comparing species richness amongst habitat types ranged from 0.10 to 0.45 (Table 5.1.3). The low power of these tests may partly explain the lack of significant differences shown between vegetated and unvegetated habitats.

The length-frequency distributions of *Ambassis marianus* in vegetated and unvegetated habitats at Meldale in summer were found to differ significantly (KS test: p = 0.003). A higher proportion of juveniles (15-25 mm) were found in vegetated than unvegetated habitat (Fig. 5.1.1a). The length-frequency distribution of *Gobiopterus semivestitus* also differed significantly between habitat types (KS test: p = 0.02). A higher proportion of larger sizes (18-19 mm) occurred in vegetated habitat (Fig. 5.1.1b). No difference was detected between the length-frequency distributions of *Atherinomorus ogilbyi* in vegetated and unvegetated habitats for the Theodolite summer sampling period (KS test: p = 0.417, n = 106 in vegetated, n = 13 in unvegetated).

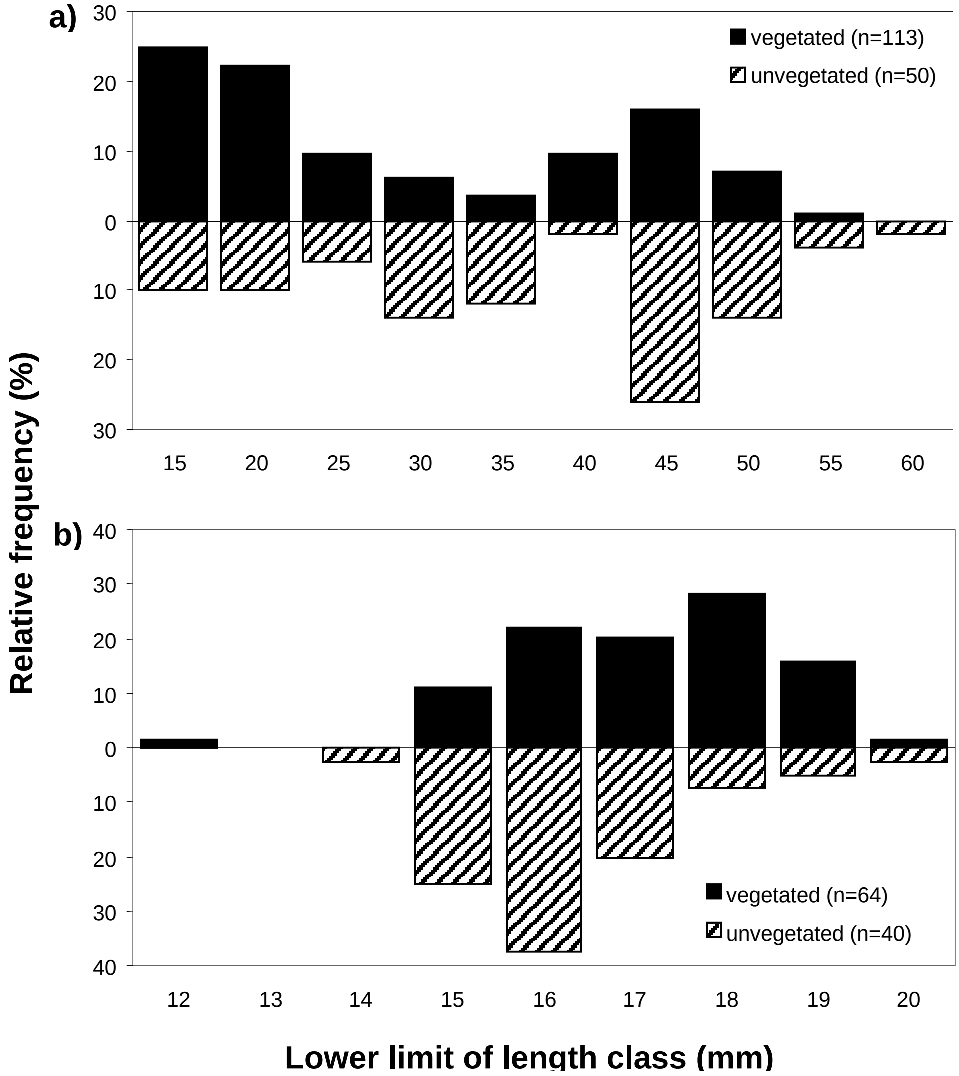

Figure 5.1.1. Length-frequency distributions in vegetated and unvegetated habitats for a) *Ambassis marianus* and b) *Gobiopterus semivestitus* for the Meldale winter sampling period in year 1.

Patterns in fish density with distance onto marsh and water depth

Fish occurred even at sites furthest from subtidal water, 413 m at Meldale and 201 m at Theodolite. At Meldale a number of species, for example *Ambassis marianus*, *Mugilogobius stigmaticus* and *Tetractenos hamiltoni*, were widely distributed on the marsh flat, in at least one habitat and one sampling period (Fig. 5.1.2). Also at Meldale a number of species were not found within the first 50 m onto the marsh, but occurred after this distance in both habitats (Fig. 5.1.2). At Theodolite, *Acanthopagrus australis* was caught in vegetated sites furthest onto the marsh in both sampling periods (Fig. 5.1.2).

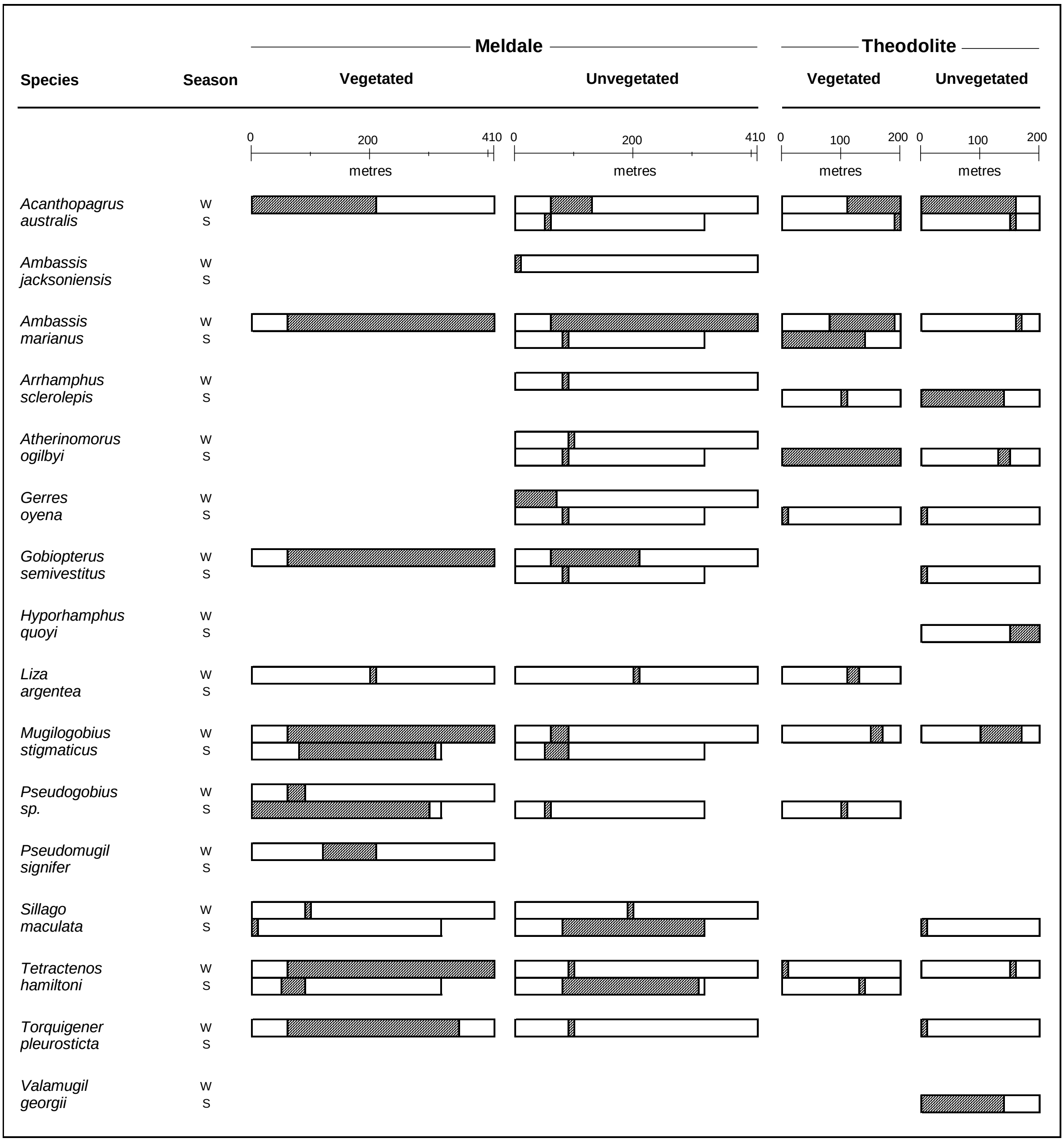

Figure 5.1.2. Distances onto the marsh for each species caught. Hatched areas represent the distance range of each species caught, rounded to the nearest 10 m. Species caught only in one net are excluded (8 species). The distances sampled at Meldale were 3-413 m (winter) and 3-321 m (summer) and at Theodolite were 3-201 m (winter) and 3-195 m (summer).

Within each sampling period at Theodolite, similar fish densities occurred at a range of distances onto the marsh and the relationships of species richness and fish density with the two independent variables, water depth and distance, were not significant ($n = 18$ in each habitat in winter, $n = 21$ in each habitat in summer, $p > 0.05$). The influence of water depth and distance onto the marsh on species richness and several density variables were found to be significant at Meldale (Table 5.1.4). At Meldale in winter, species richness was significantly related to water depth in both vegetated and unvegetated habitat, with higher numbers of species coinciding with deeper water depths (Fig. 5.1.3a). Of the significant relationships between fish density and distance and depth, water depth on its own was found to be the better predictor of fish density in all but one case (Table 5.1.4). Six of the eight significant relationships between density and water depth were in vegetated habitat with all but one from the winter sampling period. These variables were all positively related to water depth. An example of this relationship is shown in Figure 5.1.3b. The density of the variable, all species with the exclusion of *A. marianus*, in unvegetated habitat was better predicted by the combination of water depth and distance (Table 5.1.4). Density was positively related to depth and negatively related to distance onto the marsh (Fig. 5.1.3c, d). Even in this case, however, the amount of variance explained by the depth-distance combination increased only marginally when both variables were analysed in the multiple regression model as opposed to water depth as a single factor (Table 5.1.4).

It is worthwhile examining the power of the regression tests performed. For linear regression tests the effect size is specified as the correlation coefficient, *r* (Zar 1999). An *r* value of 0.55 was considered biologically meaningful (i.e. coefficient of determination (r^2) = 30%). The power of the tests mentioned above was 0.57 (β = 0.43) when n = 14 (Meldale winter and summer), 0.69 (β = 0.31) when n = 18 (Theodolite winter) and 0.77 (β = 0.23) when n = 21 (Theodolite summer).

Table 5.1.4. Summary of multiple regression analyses testing the influence of depth and distance on species richness and density in vegetated and unvegetated habitats at Meldale. Dependant variables that were not significant for at least one regression model were excluded (3 of these). r^2 entries are adjusted for the number of variables. ▸ ◂ significantly better predictor out of depth, distance and depth-distance combination. * = $p < 0.05$, ** = $p < 0.01$, *** = $p < 0.001$.

			Vegetated		Unvegetated	
Dependant variable	Independent variable	Season	r^2	p	r^2	p
Species richness	Depth-Distance	W	0.32	**0.047***	0.58	**0.004****
	Depth	W	▸**0.37**◂	**0.012***	▸**0.61**◂	**<0.001*****
	Distance	W	0.01	0.306	0.41	**0.008****
Density						
All species	Depth-Distance	W	0.28	0.065	0.42	**0.020***
		S	0.22	0.101		
	Depth	W	▸**0.32**◂	**0.020***	▸**0.47**◂	**0.004****
		S	▸**0.25**◂	**0.038***		
	Distance	W	0.04	0.241	0.29	**0.027***
		S	0.03	0.343		
Dominant species excluded	Depth-Distance	W	0.31	0.053	▸**0.54**◂	**<0.001*****
	Depth	W	▸**0.33**◂	**0.018***	0.52	**0.002****
	Distance	W	0.08	0.169	0.51	**0.003****
Gobiopterus semivestitus	Depth-Distance	W	0.18	0.133		
	Depth	W	▸**0.25**◂	**0.041***		
	Distance	W	0	0.404		
Mugilogobius stigmaticus	Depth-Distance	W	0.23	0.094		
	Depth	W	▸**0.29**◂	**0.027***		
	Distance	W	0	0.381		
Tetractenos hamiltoni	Depth-Distance	W	0.22	0.100		
	Depth	W	▸**0.29**◂	**0.028***		
	Distance	W	0	0.440		

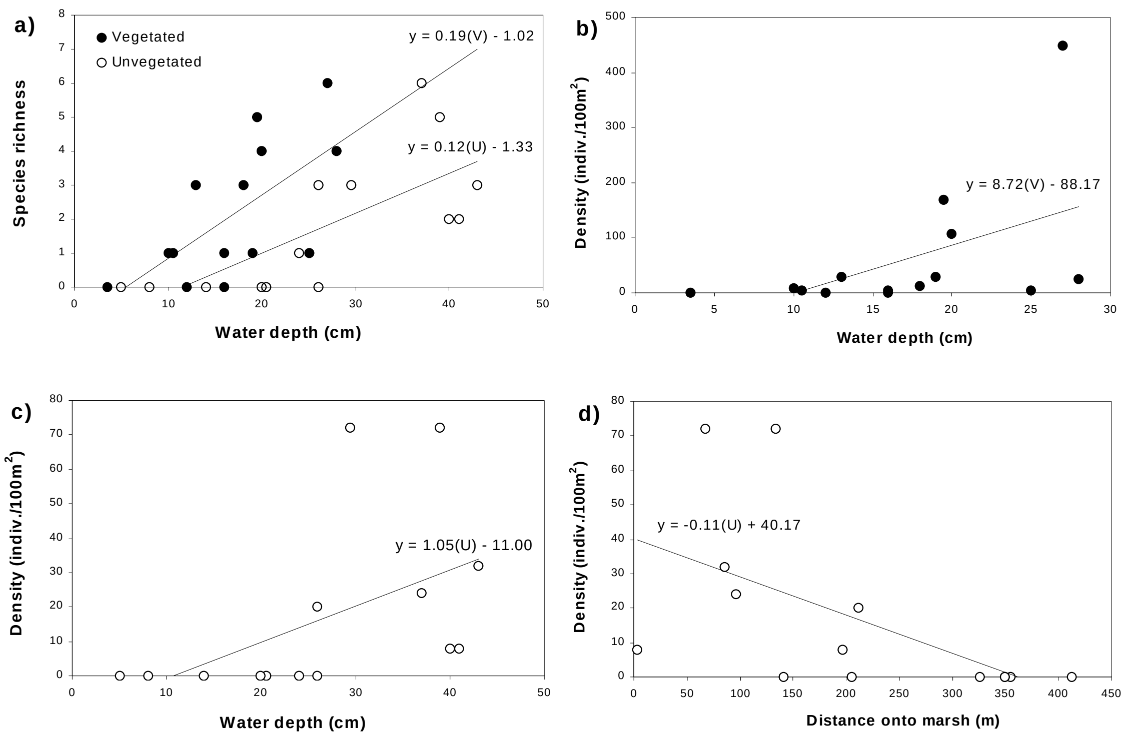

Figure 5.1.3. Relationships between species richness (no. of species/25 m^2) and fish density with water depth and distance onto the marsh at Meldale in winter: a) species richness in vegetated and unvegetated habitats with water depth; b) total fish density in vegetated habitat with water depth; and density, excluding the dominant species, in unvegetated habitat with c) water depth and d) distance onto the marsh.
V = independent variable (water depth or distance onto marsh) in vegetated habitat,
U = independent variable (water depth or distance onto marsh) in unvegetated habitat.

5.2 Suaeda vs Sporobolus habitat and distance onto marsh (Eden year 1 & 2)

Overall densities and species composition

At Eden Island, 26 fish species of 14 families were caught (Table 5.2.1). Thirteen of these species were economically important, with *Acanthopagrus australis* being the only species to occur in all four sampling periods. Exploited species contributed 4% of the catch, and were mainly represented by juveniles; species of Belonidae, Hemiramphidae, Mugilidae and Sparidae also occurred as sub-adults (Sparidae was also represented by adults). In year 1, 269 fish were caught in the winter sampling period and 544 fish were caught in the summer sampling period. In year 2, 141 fish and 1313 fish were caught in winter and summer, respectively. *Ambassis jacksoniensis* dominated the catch numerically in both years, ranging from 56% to 93% of the catch, with the highest percentages occurring in the summer sampling periods (Table 5.2.1 & 5.2.2). For the winter sampling periods, two species of Gobiidae, *Mugilogobius stigmaticus* and *Gobiopterus semivestitus*, were the next most abundant species. In summer, *Ambassis marianus* was the next most abundant species in year 1and *Valamugil georgii* was the next most abundant species in year 2.

Comparisons of species richness and composition from Suaeda and Sporobolus (year 1)

All species caught in more than one net for a particular sampling period in year 1 (10 of the 11 species) were caught in both habitats, except *Mugil cephalus*, which occurred only in *Suaeda* (Table 5.2.3). For both the winter and summer sampling periods in year 1, species richness (per 25 m^2) was significantly higher in *Suaeda* habitat.

Comparisons of density and sizes from Suaeda and Sporobolus (year 1)

Fish were variably distributed on the marsh with, very few differences in fish density between the two vegetation types (Table 5.2.3). When significant differences were detected, higher densities were found in *Suaeda* (*e.g. Acanthopagrus australis*, Table 5.2.3). Statistical power of the performed Wilcoxon tests ranged from 0.07 to 0.36, indicating that chances of detecting differences in densities between vegetation types for the specified effect size were low (Table 5.2.3).

The size distributions of *Ambassis jacksoniensis* differed between vegetation types in both the winter and summer sampling periods in year 1. In winter, the smallest size classes (15-20 mm) of *A. jacksoniensis* were present only in *Suaeda* (KS test: $p = 0.018$, Fig. 5.2.1a). In summer, *Sporobolus* had a more even size distribution than *Suaeda*, with small, medium and large sizes having approximately the same frequency (Fig. 5.2.1b). A higher proportion of medium-sized individuals (26-34 mm) occurred in *Suaeda*, and a higher proportion of the small size classes (8-25 mm) occurred in *Sporobolus* (KS test: $p < 0.001$). No other significant differences in size distributions were detected.

Table 5.2.1. Summary of fish densities (no. of indiv./100 m^2) in *Suaeda* and *Sporobolus* habitats for the winter (W) and summer (S) sampling periods in year 1. Overall = habitats combined, D = mean density, % = % of total fish abundance in that period. d = dominant species at that period.

		Overall		*Suaeda*	*Sporobolus*
Species	Season	D	%	D	D
Acanthopagrus australis	W	0.6	3	1.1	0.1
	S	0.4	1	0.4	0.3
Ambassis jacksoniensis [d]	W	12.9	72	16.1	9.7
	S	31	80	46.9	15.1
Ambassis marianus	W	-	-	-	-
	S	2.4	6	3.6	1.1
Arenigobius caninus	W	-	-	-	-
	S	0.1	0.2	-	0.1
Blenniidae (unident. sp.)	W	-	-	-	-
	S	0.1	0.2	0.1	-
Gerres subfasciata	W	-	-	-	-
	S	0.1	0.2	0.1	-
Gobiopterus semivestitus	W	1.1	6	1.7	0.4
	S	1	3	0.3	1.7
Liza argentea	W	0.1	1	-	0.3
	S	-	-	-	-
Liza subviridis	W	-	-	-	-
	S	0.2	1	0.4	-
Mugil cephalus	W	0.2	1	0.4	-
	S	-	-	-	-
Mugilogobius stigmaticus	W	2.3	13	2.8	1.9
	S	2.1	5	3.1	1.0
Myxus elongatus	W	0.1	1	0.1	0.13
	S	-	-	-	-
Pseudogobius sp.	W	-	-	-	-
	S	0.8	2	0.9	0.7
Pseudomugil signifer	W	0.3	2	0.4	0.1
	S	0.1	0.2	0.1	-
Torquigener pleurosticta	W	0.3	2	0.3	0.3
	S	0.1	0.2	-	0.1
Valamugil georgii	W	-	-	-	-
	S	0.7	2	1.3	0.1
Total (all species)	W	17.9		22.9	12.9
	S	38.9		57.3	20.4
Dominant species excluded	W	5.0		6.8	3.2
	S	7.9		10.4	5.3

Table 5.2.2. Summary of species richness (no. of species/25m^2) and fish densities (no. of indiv./100 m^2) in *Suaeda* and *Sporobolus*, and at near and far distances onto the marsh for the winter and summer sampling period in year 2. Overall = habitats combined, D = mean density, % = % of total fish abundance in that period. d = dominant species at that period.

	Winter						Summer					
	Overall		*Suaeda*	*Sporobolus*	Near	Far	Overall		*Suaeda*	*Sporobolus*	Near	Far
Species	D	%	D	D	D	D	D	%	D	D	D	D
Acanthopagrus australis	0.2	1	0.2	0.2	-	0.4	0.6	0.6	-	1.1	0.3	0.9
Ambassis jacksoniensis [d]	7.2	56	9.6	4.7	2	12.4	87.4	93.1	102.6	72.1	110.9	63.9
Ambassis marianus	0.2	1	0.4	-	-	0.4	0.8	0.8	1.1	0.4	0.9	0.7
Arrhamphus sclerolepis	0.1	1	-	0.2	-	0.2						
Atherinomorus ogilbyi	0.2	1	0.4	-	-	0.4						
Calamiana sp.	0.7	6	0.2	1.3	1.1	0.4						
Favonigobius sp.	0.1	1	-	0.2	-	0.2						
Gerres subfasciata	0.5	4	0.9	-	-	0.9	0.1	0.2	-	0.3	0.1	0.1
Glossogobius biocellatus							0.1	0.2	-	0.3	0.3	-
Gobiopterus semivestitus	1.8	14	2.4	1.3	-	3.6	0.1	0.2	-	0.3	-	0.3
Hyperlophus vittatus							0.8	0.8	-	1.6	1.6	-
Mugilogobius stigmaticus	1.6	13	1.5	1.8	1.6	1.6	1.4	1.4	1.0	1.7	0.7	2.0
Pseudogobius sp.							0.1	0.1	-	0.1	0.1	-
Pseudorhombus arsius							0.1	0.1	-	0.1	0.1	-
Sillago maculata							0.1	0.1	-	0.1	0.1	-
Sphyraena obtusata							0.1	0.1	-	0.1	0.1	-
Torquigener pleurosticta	0.3	2	-	0.5	0.5	-						
Tylosurus gavialoides							0.1	0.2	0.3	-	-	0.3
Valamugil georgii							2.1	2.2	3.6	0.6	2.6	1.6
Total (all species)	12.8		15.5	10.2	5.3	20.4	93.8		108.6	79.0	117.9	69.7
Dominant species excluded	5.6		5.8	5.5	3.3	8.0	6.4		6.0	6.9	7.0	5.9
Species richness	1.3		1.4	1.2	1.9	0.7	1.5		1.3	1.8	1.2	1.8

Table 5.2.3.. Results of Wilcoxon paired-sample test (given as probability, p) comparing species richness and density in *Suaeda* and *Sporobolus* for the winter (W) and summer (S) sampling periods in year 1. For mean differences between habitat types, catch in *Suaeda* is greater than *Sporobolus* for all entries. The units for mean paired difference and effect size are given in parentheses under the variable types. d = dominant species at that period. * = p < 0.05, ** < 0.01.

	Season	Mean paired difference	p	Effect size	Power
Species richness	W	0.7	**0.008****	0.7	0.78
(no. of species/25 m^2)	S	0.5	**0.034***	0.7	0.72
Density (no. of indiv./100 m^2)					
All species	W	10	**0.031***	9.0	0.36
	S	36.9	0.262	19.5	0.13
Dominant species excluded	W	3.6	0.064	2.5	0.22
	S	5.1	**0.041***	4.0	0.27
Acanthopagrus australis	W	1.0	**0.008****	0.3	0.14
	S	0.13	0.705	0.2	0.08
Ambassis jacksoniensis [d]	W	6.4	0.073	6.5	0.32
	S	31.8	0.559	15.5	0.11
Ambassis marianus	S	2.5	0.216	1.2	0.10
Gobiopterus semivestitus	W	1.3	0.465	0.55	0.07
Mugilogobius stigmaticus	W	0.9	0.320	1.15	0.15
	S	2.1	0.299	1.05	0.09
Pseudogobius sp.	S	0.2	1.000	0.4	0.08
Pseudomugil signifer	W	0.3	0.317	0.15	0.08
Torquigener pleurosticta	W	0	1.000	0.15	0.08
Valamugil georgii	S	1.2	0.066	0.35	0.09

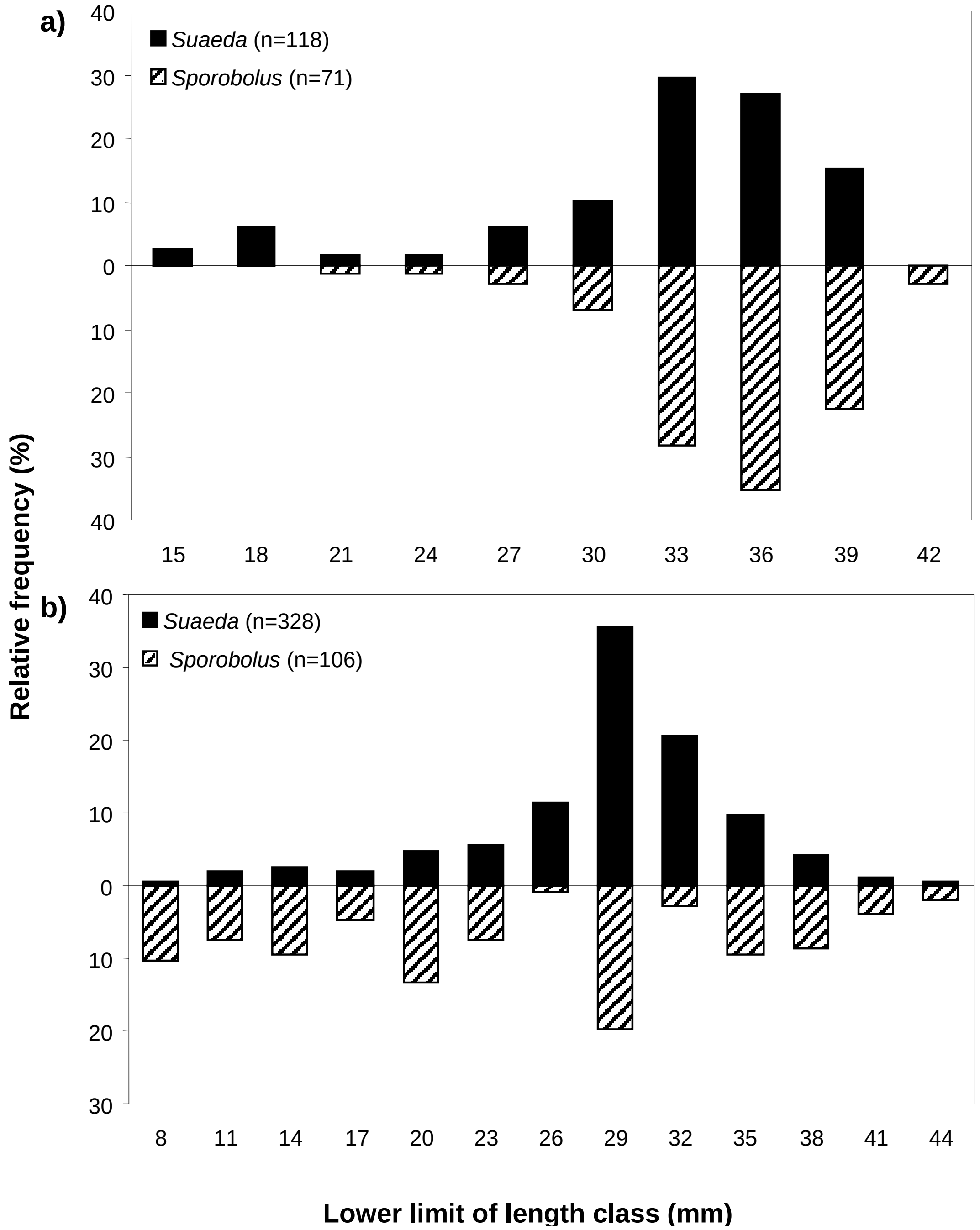

Figure 5.2.1. Length-frequency distributions of *Ambassis marianus* in *Suaeda* and *Sporobolus* for year 1 in the a) winter and b) summer sampling period.

Patterns in fish density with distance onto the marsh and water depth (year 1)

Fish occurred at sites furthest onto the marsh in both sampling periods, and many species were widely distributed on the marsh flat, in both vegetation types (*e.g. Ambassis jacksoniensis* & *Mugilogobius stigmaticus*, Fig. 5.2.2). In both periods *Acanthopagrus australis* was found at distances further onto the marsh in *Suaeda* than in *Sporobolus*. *Gobiopterus semivestitus* was not found within the first 40 m onto the marsh, but occurred after this distance in both habitats at both sampling periods (Fig. 5.2.2).

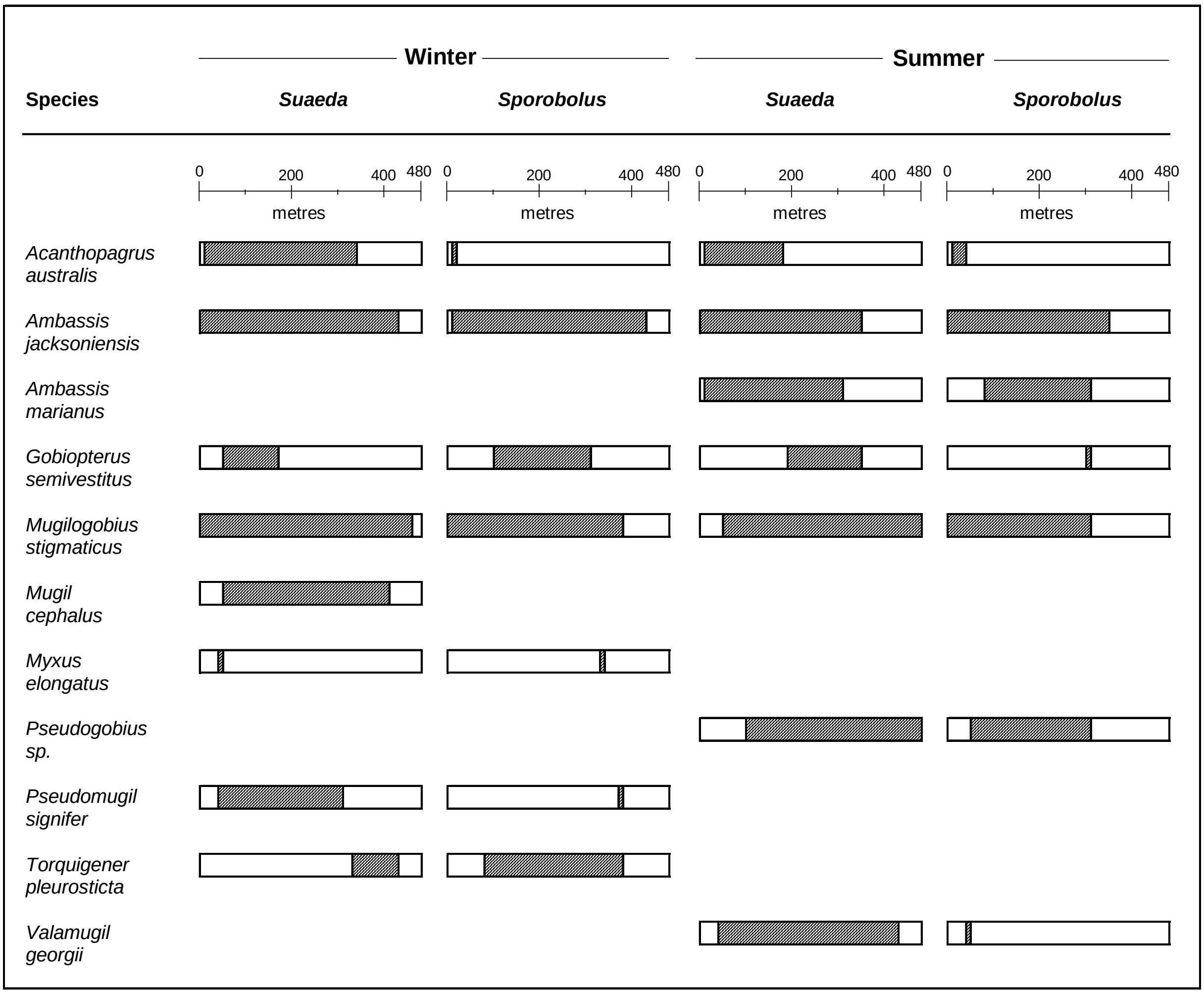

Figure 5.2.2. Distances onto the marsh for each species caught. Hatched areas represent the distance range of each species caught, rounded to the nearest 10 m. Species only caught in one net are excluded (5 species). The distance sampled at winter and summer in year 1 was 3-476 m.

The strongest relationship detected for both periods in year 1 was that species richness and fish density were better predicted by water depth (Table 5.2.4). Higher numbers of species and densities coincided with deeper water depths, and an example of this relationship is given in Figure 5.2.3a. Although the combination of depth and distance was frequently the better predictor of fish density, the combination explained only a marginally higher amount of variance (r^2) in fish density than depth on its own (Table 5.2.4). An example of the relationship between fish density and distance onto the marsh is given in Figure 5.2.3b. Only *Ambassis jacksoniensis* was better predicted by distance alone, and this was only in *Suaeda* and only in summer (Table 5.2.4). The density of *A. jacksoniensis* was negatively related to distance onto the marsh. Power of the regression tests was high. With an r value specified as 0.55 ($r^2 = 0.30$), power was 0.91, when n = 30 (winter period) and 0.88, when n = 28 (summer period).

Comparisons of species richness from *Suaeda* and *Sporobolus* (year 2)

In the winter sampling period differences in species richness depended on the distance onto the marsh. Within the near distance band, species richness did not differ between vegetation types, but within the far distance band species richness was significantly higher in *Suaeda* (Table 5.2.5). In the summer sampling period similar numbers of species were found in both vegetation types, regardless of the distance onto the marsh (Table 5.2.5).

Comparisons of densities and sizes from *Suaeda* and *Sporobolus* (year 2)

In both periods from year 2, fish density differed little between *Suaeda* and *Sporobolus* (Table 5.2.5). Of the variables that were significantly different in winter, the most prominent result was that, within the far distance band, *Suaeda* had higher fish densities than those in *Sporobolus* (Table 5.2.5). Also, in summer, the density of *Acanthopagrus australis* was higher in *Sporobolus*, regardless of distance onto the marsh (p = 0.004, n = 22), and this pattern is opposite to that found in year 1, where higher densities of this species occurred in *Suaeda.* No other variables differed significantly for the summer sampling period.

Power for the 2-way ANOVA was calculated for each of the main factors (distance and vegetation). For the 2-way ANOVA, effect size is specified as the difference between the means (Zar 1999). I considered it important to detect a difference between means equivalent to 50% of the overall mean for that particular sampling period. For example, the overall mean density (all species) in winter was 12.8 indiv./100 m^2. Therefore the effect size is 6.4 indiv./100 m^2. The chance of detecting a difference in fish density among means with the effect size specified above was 0.83. The power for each of the ANOVA tests ranged from 0.09-0.83 in winter and 0.13-0.40 in summer.

Differences in the size distributions of *Ambassis jacksoniensis* between the two vegetation types were detected only in the summer sampling period, and this was only within the far distance band (KS test: p = 0.007, n = 204 in *Suaeda*, n = 243 in *Sporobolus*). A higher proportion of large-sized individuals of this species (33 mm-43 mm) was found in *Suaeda*.

Table 5.2.4. Summary of multiple regression analyses testing the influence of depth and distance on species richness and density in each habitat for year 1. Dependant variables that were not significant for at least one regression model were excluded (5 of these). r^2 entries are adjusted for the number of variables. ▶ ◀ significantly better predictor out of depth, distance and depth-distance combination. * = p < 0.05, ** = p < 0.01, *** = p < 0.001.

			Suaeda		*Sporobolus*	
Dependent variable	Independent variable	Season	r^2	P	r^2	P
Species richness	Depth-Distance	W	▶ 0.30 ◀	0.003**	0.15	0.014*
		S	0	0.533	0.17	0.036*
	Depth	W	▶ 0.30 ◀	0.001**	▶ 0.17 ◀	0.014*
		S	0	0.300	▶ 0.20 ◀	0.010*
	Distance	W	0.11	0.040*	0.05	0.116
		S	0	0.818	0.05	0.140
Density						
All species	Depth-Distance	W	▶ 0.36 ◀	0.001**	▶ 0.20 ◀	0.018*
		S	0	0.480	▶ 0.17 ◀	0.037*
	Depth	W	0.23	0.004**	0.19	0.009**
		S	0.02	0.226	0.15	0.022*
	Distance	W	0.28	0.001**	0.10	0.047*
		S	0	0.400	0.12	0.037*
Ambassis jacksoniensis	Depth-Distance	W	▶ 0.53 ◀	<0.001***	0.25	0.007**
		S	0.18	0.031*	0.06	0.189
	Depth	W	0.42	<0.001***	▶ 0.27 ◀	0.002**
		S	0.10	0.056	0.06	0.105
	Distance	W	0.33	<0.001***	0.05	0.113
		S	▶ 0.20 ◀	0.009**	0.05	0.128

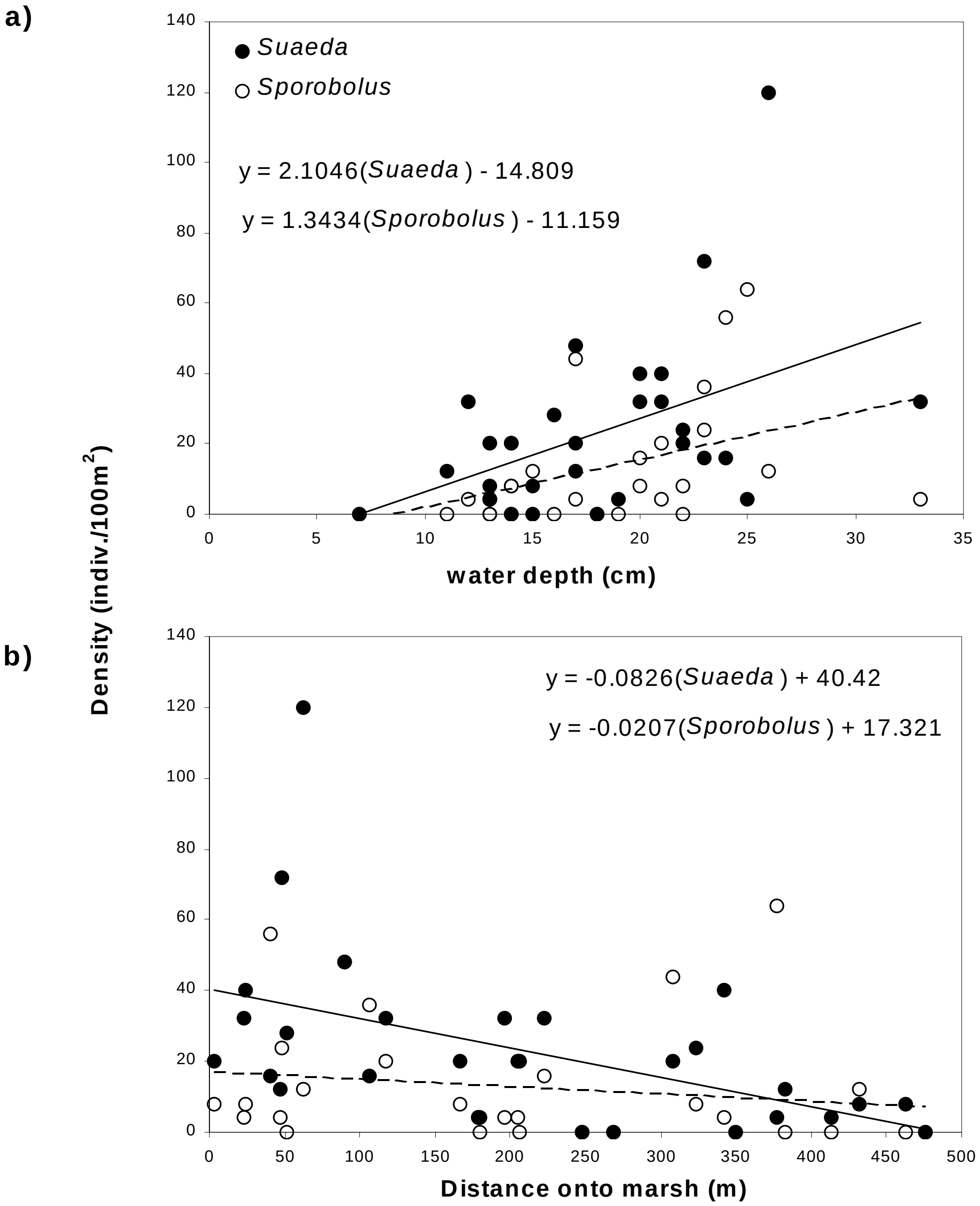

Figure 5.2.3. Relationships between fish density (all species combined) and a) water depth and b) distance onto the marsh in *Suaeda* and *Sporobolus* for the winter sampling period in year 1. Continuous fitted line represents *Suaeda* and broken fitted line represents *Sporobolus*. In regression equations, *Suaeda* = the independent variable in *Suaeda* habitat and *Sporobolus* = the independent variable in *Sporobolus* habitat.

Table 5.2.5. Summary of results of 2-way ANOVA in year 2 (given as probability, p) and subsequent Tukey procedure testing for differences between vegetation type and distance on the marsh for species richness and fish density. Su = *Suaeda*, Sp = *Sporobolus*, N = near and F = far onto the marsh. Comparisons of fish density from the summer period are not shown. d = dominant species in winter period. * = p < 0.05, ** = p < 0.01, *** = p < 0.001.

Variable	Factor	p	Pairwise comparisons
Species richness (no. of species/25 m^2)			
Winter, yr 2	Vegetation	0.386	N: Su = Sp F: Su > Sp
	Distance	**<0.001*** **	Su: N = F Sp: N > F
	Interaction	**0.004** **	
Summer, yr 2	Vegetation	0.744	
	Distance	**0.009** **	F > N
	Interaction	0.102	
Density (no. of indiv./100 m^2)			
All species	Vegetation	0.618	N: Su < Sp F: Su > Sp
	Distance	**<0.001*** **	Su: N = F Sp: N > F
	Interaction	**0.001** **	
Dominant species excluded	Vegetation	0.833	N: Su = Sp F: Su > Sp
	Distance	0.115	Su: N = F Sp: N > F
	Interaction	**0.008** **	
Ambassis jacksoniensis [d]	Vegetation	0.979	
	Distance	**<0.001*** **	N > F
	Interaction	0.053	
Calamiana sp.	Vegetation	0.415	
	Distance	0.115	
	Interaction	0.115	
Gobiopterus semivestitus	Vegetation	0.542	
	Distance	**0.024***	N > F
	Interaction	0.542	
Mugilogobius stigmaticus	Vegetation	0.592	
	Distance	0.701	
	Interaction	0.346	

Comparisons of densities and sizes from near and far distances onto the marsh (year 2)

Differences in species richness between near and far distances onto the marsh were observed in both periods. For the winter sampling period, within *Sporobolus,* higher numbers of species were found in the near distance band, but within *Suaeda*, species richness was similar in both distance bands (Table 5.2.5). In summer, however, higher numbers of species were found far onto the marsh, irrespective of the vegetation type (Table 5.2.5).

Fish densities differed between near and far distance bands only in the winter sampling period. The most prominent pattern for this period was that higher densities occurred within the near distance band (*e.g. Ambassis jacksoniensis*), although, as for species richness, this difference occasionally depended on the type of vegetation. When an interaction was detected, fish densities were similar between near and far distances onto the marsh within *Suaeda*, whereas within *Sporobolus,* higher densities occurred in the near distance band (Table 5.2.5).

Differences in the size distributions of *Ambassis jacksoniensis* between near and far distances onto the marsh were detected only in the summer sampling period. In both vegetation types, higher proportions of small-sized individuals (13 mm-26 mm in *Suaeda* & 10 mm-28 mm in *Sporobolus*) were found within the far distance band (KS test: $p = 0.011$ in *Suaeda*, $n = 512$ in near, $n = 204$ in far; $p < 0.001$ in *Sporobolus*, $n = 261$ in near, $n = 243$ in far).

5.3 Runneled vs unrunneled habitat and distance from feeder creek (Meldale year 2)

Overall densities and species composition

At Meldale in year 2, 19 fish species from 11 families were caught (Table 5.3.1). Nine of these species were of economic importance, five of which occurred in both sampling periods. Exploited species contributed 15% to total catch, and were represented by juveniles; species of Mugilidae, Sparidae and Hemiramphidae also occurred as sub-adults. For the winter sampling period, 701 fish (63.7/100m^2) of 16 fish species were caught, with the catch dominated numerically by *Ambassis marianus* (55%) and *Mugilogobius stigmaticus* (23%). The banana prawn, *Penaeus merguiensis*, was also very abundant at this sampling period (24.7/100m^2). For the summer sampling period, 372 fish (31.0/100m^2) of 16 species were caught, with the catch dominated numerically by *Calamiana* sp. (41%), *Gerres subfasciata* (23%) and *M. stigmaticus* (18%). This is the first record of species of the genus *Calamiana* from Moreton Bay, and is probably a newly recorded and certainly undescribed species of fish (Johnson 1999).

Comparisons of species richness and species composition from habitats and distances from creek

For both sampling periods, irrespective of habitat type, a significantly higher number of species occurred near to the feeder creek (see Table 5.3.2 for winter & Table 5.3.3 for summer). Differences in species richness between runneled and unrunneled habitat only existed in winter and these differences depended on the distance from the creek. A significantly higher number of species was found in unrunneled habitat, far from the creek. Near to the creek, however, species richness did not differ between the two habitat types (Table 5.3.2).

Mugilogobius stigmaticus was the only species to occur in all four combinations of the two factors, distance from creek and habitat type, in both sampling periods. Within each sampling period, some species were specific to particular combinations, although this may have reflected the low abundances of these species. Of the species that were abundant (occurring in ≥ 10 nets, combining periods), three never occurred in runneled habitat, far from the creek in both periods. These species were *Sillago maculata*, *Arrhamphus sclerolepis* and *Acanthopagrus australis*.

Comparisons of densities and sizes from habitats and distances from creek

In both sampling periods the overwhelming pattern was that for most species, significantly higher densities were found near the creek (see Table 5.3.2 for the winter results, see Table 5.3.3 for the summer results). Only *Torquigener pleurosticta* was more common far from creek, and then only in unrunneled habitat and only in winter. Differences between runneled and unrunneled habitat were generally weaker than differences with distance from creek. No differences between runneled and unrunneled habitat were found in summer. In winter, *Ambassis jacksoniensis* was more abundant in unrunneled habitat, regardless of distance from creek. An interaction between habitat type and distance from the creek was detected for several variables in the winter sampling period. For these variables, higher densities occurred in unrunneled habitat far from the creek but not near the creek. Power for the 2-way ANOVA ranged from 0.13-0.71 in winter and 0.10-0.63 in summer. Given that the power range was similar in winter and summer, the lack of differences detected in summer cannot be explained by a lack of statistical power at this period.

For the winter sampling period, the size distributions of *Ambassis marianus* and *Mugilogobius stigmaticus* differed between runneled and unrunneled habitats, near to the creek. These species had lower proportions of small individuals in runneled habitat. For example, the smallest (< 30 mm) size classes of *M. stigmaticus* were absent in runneled habitat, near to the creek (KS test: $p = < 0.001$, see Figure 5.3.1a for sample sizes). Also, the size distributions of *Ambassis marianus* differed between near and far distances from the creek, within unrunneled habitat (KS test: $p < 0.001$, see figure 5.3.1b for sample sizes). Individuals less than 24 mm did not occur far from the feeder creek in this habitat (Fig. 5.3.1a). No other significant differences in size distributions were detected in winter. For the summer sampling period, *Gerres subfasciata* was the only species to have different size distributions among habitat/distance combinations. In unrunneled habitat, a much higher proportion of small individuals (8 mm–14 mm) and fewer of the larger size classes (15 mm-68 mm) occurred far from the creek, relative to near the creek (KS test: $p = < 0.001$, $n = 21$ in near, $n = 47$ in far).

Table 5.3.1. Summary of species richness (no. of species/25m^2) and density (no. of indiv./100 m^2) in runneled (R) and unrunneled (U) habitat, and at near and far distances onto the marsh from a feeder creek. Overall = habitats combined, D = mean density, % = % of total fish abundance (not applicable for *Penaeus merguiensis*). d = dominant species at that period.

	Winter						Summer					
	Overall		R	U	Near	Far	Overall		R	U	Near	Far
Species name	D	%	D	D	D	D	D	%	D	D	D	D
Acanthopagrus australis	1.6	2.6	1.3	2	2.9	0.4	0.3	1.1	0.7	-	0.7	-
Ambassis jacksoniensis	0.9	1.4	-	1.8	0.9	0.9	0.1	0.3	0.2	-	0.2	-
Ambassis marianus	35.3 [d]	55.3	30.9	39.6	44.9	25.6	1.8	5.6	3.5	-	3.5	-
Arenigobius frenatus									0.2	-	0.2	-
Arrhamphus sclerolepis	1.4	2.1	1.1	1.6	2.7	-	0.1	0.3	-	0.2	0.2	-
Atherinomorus ogilbyi	0.2	0.3	-	0.4	0.4	-						
Calamiana sp.	1.5	2.3	2	0.9	2.7	0.2	12.8 [d]	41.1	12	13.5	19.7	5.8
Gerres subfasciata	0.1	0.1	-	0.2	0.2	-	7.2	23.1	3	11.3	6.3	8
Gobiopterus semivestitus	0.2	0.3	-	0.4	0.4	-	0.4	1.3	0.3	0.5	-	0.8
Herklotsichthys castelnaui	0.1	0.1	-	0.2	0.2	-						
Liza argentea							0.1	0.3	0.2	-	-	0.2
Mugilogobius stigmaticus	14.4	22.5	13.6	15.1	24.9	3.8	5.5	17.7	6.3	4.7	5.3	5.7
Penaeus merguiensis	24.7		17.1	32.4	48.9	0.5						
Pseudogobius sp.	4.7	7.4	6.4	3.1	9.5	-	1.1	3.5	1.5	0.7	1.7	0.5
Pseudomugil signifer	0.2	0.3	0.2	0.2	-	0.4						
Sillago maculata	0.6	1.0	0.7	0.5	0.7	0.5	0.8	2.7	1.3	0.3	1.5	0.2
Tetractenos hamiltoni	1.1	1.7	1.6	0.5	1.6	0.5	0.3	0.8	0.5	-	0.2	0.3
Torquigener pleurosticta	1	1.6	0.4	1.6	0.4	1.6	0.2	0.5	0.2	0.2	-	0.3
Tylosurus gavialoides							0.3	0.8	-	0.5	0.2	0.3
Valamugil georgii	0.5	0.9	0.4	0.7	0.5	0.5	0.2	0.5	0.3	-	0.3	-
Total (all species)	63.7		58.5	68.9	92.9	34.5	31.0		30.2	31.8	39.8	22.2
Dominant species excluded	28.4		27.6	29.3	48.0	8.9	18.2		18.2	18.3	20.2	16.3
Species richness	3.3		2.7	4.0	4.6	2.1	2.2		2.5	2.0	2.7	1.8

Table 5.3.2. Summary of **winter** results of 2-way ANOVA (given as probability, p) and subsequent Tukey procedure testing for differences between runneled and unrunneled habitat and distance from creek for species richness and density. R = runneled habitat, U = unrunneled habitat, N = Near, F = Far. d = dominant species at that period. * = p < 0.05, ** = p < 0.01, *** = p < 0.001.

Variable	Factor	p	Pairwise comparisons
Species richness	Habitat	**0.003****	N: R = U F: U > R
(no. of species/25 m^2)	Distance	**<0.001*****	R: N > F U: N > F
	Interaction	**0.004****	
Density (no. of indiv./100 m^2)			
All species	Habitat	**0.019***	N: R = U F: U > R
	Distance	**<0.001*****	R: N > F U: N = F
	Interaction	**0.021***	
Dominant species excluded	Habitat	**0.006****	N: R = U F: U > R
	Distance	**<0.001*****	R: N > F U: N > F
	Interaction	**<0.001*****	
Acanthopagrus australis	Habitat	0.218	
	Distance	**0.001****	N > F
	Interaction	0.965	
Ambassis marianus [d]	Habitat	0.052	
	Distance	**0.040***	N > F
	Interaction	0.112	
Arrhamphus sclerolepis	Habitat	0.997	
	Distance	**0.001****	N > F
	Interaction	0.997	
Ambassis jacksoniensis	Habitat	**0.002****	U > R
	Distance	1.000	
	Interaction	1.000	
Calamiana sp.	Habitat	0.147	
	Distance	**0.002****	N > F
	Interaction	0.408	
Mugilogobius stigmaticus	Habitat	0.245	
	Distance	**<0.001*****	N > F
	Interaction	0.677	
Penaeus merguiensis	Habitat	0.284	
	Distance	**<0.001*****	N > F
	Interaction	0.354	
Pseudogobius sp.	Habitat	0.997	
	Distance	**<0.001*****	N > F
	Interaction	0.997	
Tetractenos hamiltoni	Habitat	0.384	N: R > U F: R = U
	Distance	0.384	R: N > F U: N = F
	Interaction	**0.005****	
Torquigener pleurosticta	Habitat	**0.048***	N: R = U F: U > R
	Distance	**0.048***	R: N = F U: F > N
	Interaction	**0.001****	

Table 5.3.3. Summary of **summer** results of 2-way ANOVA (given as probability, p) testing for differences between runneled and unrunneled habitat and distance from creek for species richness and density. N = Near, F = Far. d = dominant species at that period. * = $p < 0.05$, ** = $p < 0.01$.

Variable	Factor	p	Pairwise comparisons
Species richness (no. of species/25 m^2)	Habitat	0.285	
	Distance	**0.040***	N > F
	Interaction	0.240	
Density (no. of indiv./100 m^2)			
All species	Habitat	0.872	
	Distance	**0.036***	N > F
	Interaction	0.927	
Dominant species excluded	Habitat	0.736	
	Distance	0.593	
	Interaction	0.633	
Calamiana sp. [d]	Habitat	0.709	
	Distance	**0.002****	N > F
	Interaction	0.576	
Gerres subfasciata	Habitat	0.114	
	Distance	0.377	
	Interaction	0.169	
Mugilogobius stigmaticus	Habitat	0.399	
	Distance	0.777	
	Interaction	0.218	
Pseudogobius sp.	Habitat	0.325	
	Distance	**0.047***	N > F
	Interaction	0.451	
Sillago maculata	Habitat	0.280	
	Distance	0.071	
	Interaction	0.071	

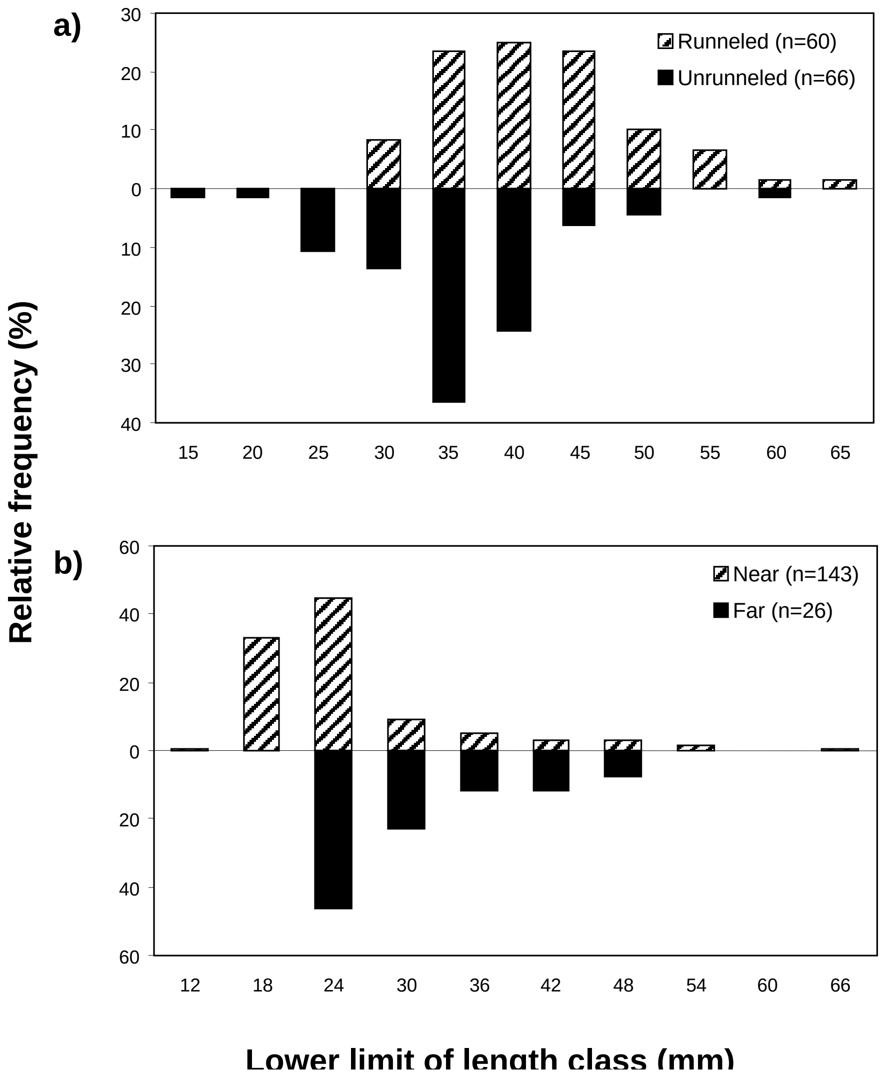

Figure 5.3.1. Length-frequency distributions of a) *Mugilogobius stigmaticus* in runneled and unrunneled habitats, near to the feeder creek, and b) *Ambassis marianus* at near and far distances from the feeder creek, in unrunneled habitat at Meldale.

5.4 Shallow vs deep water and distance from feeder creek (Theodolite year 2)

Species composition

At Theodolite in year 2, 20 species from 11 families were caught (Table 5.4.1). Eleven of these species were of economic importance, four of which occurred in both periods. Exploited species contributed 45% to total catch, and were mainly represented by juveniles; species of Mugilidae, Sparidae, Atherinidae, Lutjanidae and Scatophagidae also occurred as sub-adults. For the winter sampling period, 245 fish (27.2/100m^2) of 12 species were caught, with the catch dominated numerically by

Ambassis marianus (63%) and *Atherinomorus ogilbyi* (21%). In the summer sampling period, 95 fish (7.9/100m^2) of 13 species were caught, with the catch dominated numerically by *Atherinomorus ogilbyi* (45%), *Mugilogobius stigmaticus* (18%), *Liza argentea* (13%) and *Acanthopagrus australis* (6%).

Comparisons of species richness and species composition from different water depths and distances from creek

For the winter sampling period, significantly higher numbers of species were found near to the creek, and in shallow areas, and there was no significant interaction between these two factors (see Table 5.4.2). In summer, however, species richness was greatest in deep areas, and no difference was detected between near and far distances from the creek (Table 5.4.3). As for winter, there was no significant interaction between the two factors, depth and distance from the creek.

Atherinomorus ogilbyi was the only species to occur in all four combinations of the two factors, distance from creek and water depth, in both sampling periods. In the winter period, *Ambassis marianus*, and in the summer sampling period, *Mugilogobius stigmaticus* occurred in all four combinations of the two factors. For both periods, *Acanthopagrus australis* never occurred in deep areas, far from the creek. Also in winter, *Craterocephalus mugiloides* occurred at near and far distances from the feeder creek, but only in shallow areas.

Comparisons of densities and sizes from different water depths and distances from creek

For the winter sampling period, five of the seven variables analysed for differences in fish density were significant (see Table 5.4.2). There was a striking pattern for individual species and for the total catch; greater densities were found in shallow areas and near the creek, with no interactions. In the summer sampling period, however, no significant differences were detected, for any of the density variables, between shallow and deep areas, or between near and far distances from the creek (see Table 5.4.3). Power for the 2-way ANOVA ranged from 0.13-0.88 in winter and 0.12-0.35 in summer. Power in summer was substantially lower than in winter, which may partly explain the lack of significant differences shown in fish densities at this period.

The size distributions of *Atherinomorus ogilbyi* and *Ambassis marianus* in the winter sampling period, and *A. ogilbyi* in the summer sampling period, did not differ between shallow and deep areas of the marsh. Comparisons of size distributions between near and far distances from the creek were also not significant (KS test: all tests: $p > 0.05$).

Table 5.4.1. Summary of species richness (no. of ind./25m^2) and fish density (no. of indiv./100 m^2) in shallow and deep areas, and at near and far distances from a feeder creek. Overall = factors combined, D = mean density, % = % of total fish abundance in that sampling period. d = dominant species at that period.

	Winter						Summer					
	Overall		Shallow	Deep	Near	Far	Overall		Shallow	Deep	Near	Far
Species	D	%	D	D	D	D	D	%	D	D	D	D
Acanthopagrus australis	0.8	2.9	1.3	0.2	1.3	0.2	0.5	6.3	0.7	0.3	0.7	0.3
Ambassis jacksoniensis	0.1	0.4	0.2	-	0.2	-						
Ambassis marianus	17.2 [d]	63.3	23.6	10.9	23.6	10.9						
Arothron manillensis							0.1	1.1	-	0.2	0.2	-
Atherinomorus ogilbyi	5.8	21.2	8.4	3.1	8.0	3.6	3.6 [d]	45.3	2.8	4.3	3.3	3.8
Craterocephalus mugiloides	0.8	2.9	1.6	-	0.9	0.7						
Gobiopterus semivestitus							0.1	1.1	-	0.2	0.2	-
Liza argentea							1.0	12.6	-	2.0	-	2.0
Liza subviridis	0.3	1.2	0.4	0.2	0.7	-						
Lutjanus russelli	0.1	0.4	-	0.2	0.2	-						
Mugilogobius sp.							0.1	1.1	-	0.2	-	0.2
Mugilogobius stigmaticus							1.4	17.9	1.0	1.8	1.5	1.3
Periophthalmus argentilineatus	0.1	0.4	-	0.2	-	0.2						
Pomatomus saltatrix							0.1	1.1	-	0.2	-	0.2
Sillago ciliata							0.1	1.1	-	0.2	-	0.2
Selenotoca multifasciata							0.2	2.1	-	0.3	-	0.3
Tetractenos hamiltoni	0.3	1.2	0.4	0.2	0.4	0.2	0.4	5.3	0.2	0.7	0.3	0.5
Terapon jarbua	0.4	1.6	0.4	0.4	0.4	0.4	0.1	1.1	-	0.2	-	0.2
Torquigener pleurosticta	0.1	0.4	0.2	-	0.2	-						
Valamugil georgii	1.1	4.1	0.9	1.3	1.3	0.9	0.3	4.2	0.2	0.5	0.2	0.5
Total (all species)	27.2		37.6	16.9	37.3	17.1	7.9		4.8	11.0	6.3	9.5
Dominant species excluded	10.0		14.0	6.0	13.8	6.2	4.3		2.0	6.7	3.0	5.7
Species richness	2.3		2.8	1.8	2.9	1.7	0.9		0.6	1.3	0.9	1.0

Table 5.4.2. Summary of **winter** results of 2-way ANOVA (given as probability, p) and subsequent Tukey procedure testing for differences between water depth and distance from creek for species richness and fish density. N = Near, F = Far, S = Shallow and D = Deep. d = dominant species at that period. * = p < 0.05, ** = p < 0.01.

Variable	Factor	p	Pairwise comparisons
Species richness (no. of species/25 m^2)	Depth	**0.006****	N > F
	Distance	**0.003****	S > D
	Interaction	0.976	
Density (no. of indiv./100 m^2)			
All species	Depth	**0.007****	N > F
	Distance	**0.002****	S > D
	Interaction	0.860	
Dominant species excluded	Depth	**0.014***	N > F
	Distance	**0.041***	S > D
	Interaction	0.080	
Acanthopagrus australis	Depth	0.060	
	Distance	0.060	
	Interaction	0.300	
Ambassis marianus [d]	Depth	**0.047***	N > F
	Distance	**0.001****	S > D
	Interaction	1.000	
Atherinomorus ogilbyi	Depth	**0.044***	S > D
	Distance	0.100	
	Interaction	0.640	
Craterocephalus mugiloides	Depth	**0.020***	S > D
	Distance	0.670	
	Interaction	0.670	
Valamugil georgii	Depth	0.630	
	Distance	0.630	
	Interaction	0.360	

Table 5.4.3. Summary of **summer** results of 2-way ANOVA (given as probability, p) and subsequent Tukey procedure testing for differences between water depth and distance from creek for species richness and fish density. N = Near, F = Far, S = Shallow, D = Deep. d = dominant species at that period. * < 0.05.

Variable	Factor	p	Pairwise comparisons
Species richness (no. of species/25 m^2)	Depth	**0.019***	S < D
	Distance	0.899	
	Interaction	0.099	
Density (no. of indiv./100 m^2)			
All species	Depth	0.059	
	Distance	0.850	
	Interaction	0.180	
Dominant species excluded	Depth	0.070	
	Distance	0.460	
	Interaction	0.130	
Acanthopagrus australis	Depth	0.560	
	Distance	0.270	
	Interaction	0.560	
Atherinomorus ogilbyi [d]	Depth	0.850	
	Distance	0.510	
	Interaction	0.860	
Mugilogobius stigmaticus	Depth	0.260	
	Distance	0.730	
	Interaction	0.730	
Tetractenos hamiltoni	Depth	0.160	
	Distance	0.640	
	Interaction	0.160	

6.0 Discussion

6.1 Vegetated vs unvegetated habitat and distance onto marsh (Meldale & Theodolite year 1)

This study over two sampling periods at two marshes approximately 200 km apart, gives conclusive evidence for widespread use of saltmarsh flats by fish. Many species were caught on the marsh flats, the key families being: Ambassidae, Gobiidae, Gerridae, Sparidae, Mugilidae, Hemiramphidae and Atherinidae. More than half of the species caught are of direct economic importance, and several of these species were common without dominating the catch numerically. Only at Theodolite in the winter period was one of the exploited species dominant, when *Acanthopagrus australis* was the most common species in a very small total catch. At other times and places, the most abundant species were small species, such as perchlets and gobies, that spend their entire life in estuaries. Typically one or two of these small species contributed 50-90% of the total fish abundance at any one period. Numerical dominance by one or two species is a common feature of other subtropical estuarine habitats in Australia (e.g. saltmarsh creeks, Morton et al. 1987; mangroves, Morton 1990) and of saltmarsh habitat in the northern hemisphere (Talbot & Able 1984, Kneib & Wagner 1994).

At both marshes, fish were widely distributed across the marsh flat, although at highly variable densities. Fish occurred even to the furthest extent of sampling, 410 m at Meldale and 200 m at Theodolite and it was not only the small, estuarine-resident species that were found far onto the marshes. Juveniles and subadults of larger species considered estuarine-marine (part of life history spent outside estuaries) were also caught at sites distant from subtidal water. In North America studies of the influence of distance onto the marsh found estuarine-marine species such as species of mullet (*Mugil* spp) typically traveled only a few metres onto the marsh, whereas estuarine-resident species were caught at all distances (Kneib 1991, Rakocinski *et al.* 1992, Rozas 1992, Baltz *et al.* 1993, Kneib & Wagner 1994, Peterson & Turner 1994). It is worth noting that all of these studies sampled no further than 90 metres onto the marsh, much less extensively than in the present study.

At Meldale and Theodolite, the presence or absence of vegetation had a surprisingly weak relationship with species richness and fish density. The evidence from North American saltmarshes studies (e.g. crustaceans, Zimmerman & Minello 1984; fish, Rozas & Odum 1987) and other estuarine habitats in Australia (e.g. seagrass, reviewed in Bell & Pollard 1989; mangroves, Laegdsgaard & Johnson 1995) shows that species composition and densities are very different in vegetated and unvegetated habitats. Since Australian saltmarshes are inundated for much shorter periods than North American saltmarshes, and seagrass and mangroves in Australia, the lack of influence of vegetation in the present study might be related to the short time the habitat is available to fish.

In the present study, water depth was found to have stronger relationships with fish assemblages than distance onto the marsh from subtidal water. These relationships, however, were mainly in the winter sampling period and only at Meldale. Higher numbers of species and higher densities of several species coincided with deeper water depths. No comparative studies linking water depth (or elevation in intertidal zone) with fish assemblages at a single time can be found from other saltmarshes. It has been noted several times, however, that greater water depths resulting from seasonally higher tides are associated with increased fish densities and species richness on saltmarsh flats in North America (Zimmerman & Minello 1984, Rozas & Odum 1987) and in a saltmarsh creek in subtropical Australia (Morton *et al.* 1987). Such evidence led Rozas (1995) to conclude that greater water depths may facilitate use of vegetated marshes by fish and that the hydrology of a marsh is a major controlling factor in the accessibility and utilization of marshes by fish.

6.2 Suaeda vs Sporobolus habitat and distance onto marsh (Eden year 1 & 2)

The fish fauna at Eden Island was characterised by species from the families Ambassidae, Gobiidae, Mugilidae and Sparidae. As at Meldale and Theodolite, the fauna was dominated numerically by one or two small, estuarine-resident species, always including *Ambassis jacksoniensis* which contributed up to 94% of the total catch. Again, however, half of the species caught were of direct economic importance.

As for Meldale and Theodolite, a number of fish species were widely distributed on the marsh flat. These species included estuarine-resident fish (e.g. *Mugilogobius stigmaticus, Ambassis jacksoniensis, Torquigener pleurosticta*) and juveniles of estuarine-marine species (e.g. *Valamugil georgii*).

The most consistent difference in fish assemblages between *Sporobolus* and *Suaeda* habitat was for species richness rather than fish density. Species richness was higher in *Suaeda* than *Sporobolus* at three of the four sampling periods over the two years. *Suaeda* vegetation consists of tall, sparse bushes, with leaf cover mainly high on the bush. Thus there is ample space among lower parts of the bush for fish to penetrate this habitat. *Sporobolus* vegetation, on the other hand, consists of short, often dense tufts of grass, leaving little open space within this vegetation type. It seems likely that the higher species richness in *Suaeda* might result from this habitat being more easily penetrated by fish on the rising tide. The period when species richness was not greater in *Suaeda* (summer, year 2) was characterised by exceptionally high tides driven by strong winds. At this period, the time during which fish could swim over the top of *Sporobolus* vegetation would have been much greater. The patterns of differences in fish density between *Suaeda* and *Sporobolus*, although less marked than for species richness, also tend to support an interaction between water depth and vegetation differences. Of the few differences detected in fish density between *Suaeda* and *Sporobolus*, none was in the period with exceptionally high tides. Even at other periods, *Sporobolus* tended to have higher densities only in deeper water. The only comparison of nekton between different saltmarsh vegetation types found in the literature is that by Rozas and Reed (1993) in North America. They found two species of killifish (*Fundulus* spp) to be more abundant in *Distichlis spicata* marsh, two species of shrimp (*Penaeus* spp) to be more abundant in hummocky *Spartina alterniflora* and four other common species to have similar abundances in both vegetation types. Since the two habitats sampled by Rozas and Reed (1993) occur at different elevations, the influence of vegetation and elevation on nekton densities cannot be separated in their study.

6.3 Runneled vs unrunneled and distance from feeder creek (Meldale year 2)

Once again the fish fauna was dominated by one or two small species, but with several exploited species also being common. The presence of juvenile banana prawns in large numbers in winter was a notable feature of this work.

The strongest pattern at this marsh was that species richness and the densities of several species were higher near to the mangrove-lined feeder creek. Some of the highest densities found during the entire project, including banana prawns at 0.5 prawns/m^2, were found alongside the creek at this marsh. This apparently strong influence of proximity to an intertidal creek has not been assessed in North American studies on salt marshes. There, research has focussed mainly on distance onto the marsh from open water, a term describing subtidal channels or open areas (Minello *et al.* 1994, Peterson & Turner 1994). The emphasis on distance onto the marsh from intertidal mangrove-lined creeks in the present study has not been attempted elsewhere. *Torquigener pleurosticta* was the only species found to have higher densities far from the creek, and this was in unrunneled habitat only. It was noticed during the study that individuals of this species move onto the marsh flat at the front of the incoming tide, pushing far onto the marsh, in very shallow water.

The influence of runneling was weaker than that of proximity to creek, with very few differences in fish densities or richness between runneled and unrunneled habitat. There was a trend for some species to be more abundant away from runnels (e.g. *Ambassis jacksoniensis*). In winter, two species (*Ambassis marianus, Mugilogobius stigmaticus*) had higher proportions of small individuals distant from runnels, near to the creek. Although fish were sampled at high tide in the absence of currents, any strengthening of currents associated with runnels on the rising or falling tide may affect fish. Also, any effect runnels have on currents may affect sediment characteristics and this could itself influence fish use on the marsh flat.

On an incoming tide runnels are inundated earlier than the marsh flats, and fish may use these runnels to access the marsh flat early on the incoming tide (when the flats themselves are too shallow to access). Since fish were sampled only at high tide, the influence of runneling on fish may have been underestimated in this study.

The process of runneling for pest control is only practiced in Australia (Dale *et al*. 1993), and this is the first study investigating the influence of runneling on saltmarsh fish assemblages. The possible influence of runnels found here will help to plan future work examining runneling effects.

6.4 Shallow vs deep water and distance from feeder creek (Theodolite year 2)

Again in this sampling period the fish fauna at Theodolite was dominated by small, estuarine-resident species, yet with more than half of the species caught being economically important.

Patterns in species richness and fish density varied between sampling periods. In winter, higher numbers of species and the densities of several species occurred in shallow areas of the marsh, and near to the intertidal feeder creek. This pattern of a profusion of small fish in very shallow estuarine water has previously been linked with decreased predation pressure. Ruiz *et al.* (1993) demonstrated, using tethering experiments, that predation mortality of small fish was greatest in water deeper than 70 cm. At this stage it is too speculative to consider predation rates in different water depths in the current study, but it would be worth considering the importance of predation in future studies. In the summer sampling period in the present study, a higher number of species was found in deeper water, and fish density did not differ between water depths, nor between distances from the feeder creek. Work is needed in the future to determine why patterns of fish abundance vary among sampling periods.

6.5 Overall Discussion

The project provides the first scientific evidence in Australia for the extent of use of subtropical saltmarsh flats by fish. Species richness and abundance of fish on the marsh flats was at times surprisingly high (total of 41 fish species, maximum density around 1 fish/m^2), and exploited fisheries species (e.g. bream, whiting, mullet, garfish, banana prawns) were prevalent without dominating catches numerically. The most common fish were small species such as perchlets and gobies, of no direct economic importance. Tropical species such as *Selenotoca multifasciata, Craterocephalus mugiloides* and *Terapon jarbua* occurred at Theodolite, but did not occur on the southern marshes, Meldale and Eden Island. Fish were found far onto the marsh flats, even to the furthest extent of sampling, up to 500 metres onto the marsh. An outstanding feature of this study is that results come from three saltmarshes spread across southeast Queensland, sampled in both winter and summer. This is a more extensive sampling program than in previous saltmarsh studies anywhere in the world, and results can be considered a reliable guide to the types of fish that use subtropical saltmarsh habitat in Queensland.

In comparing fish use of vegetated and unvegetated marsh habitat, the presence of vegetation was shown to have remarkably little relationship with fish abundance. Nor were there major differences in fish densities between the two most common vegetation types, short saltcouch grass, *Sporobolus virginicus,* and the taller bush, *Suaeda australis*.

The distribution of fish on saltmarshes was found to be most strongly influenced by proximity to intertidal, mangrove-lined feeder creeks, with more species and more individuals near to creeks than further away. This was more important than distance onto the marsh from subtidal water. The number of species and number of individuals was also related to water depth on some occasions, although the nature of this relationship varied in direction and strength. On the Meldale saltmarsh, where the habitat has been altered for mosquito control, the presence of artificial drains (runnels) was found to have an influence on fish assemblages secondarily to the proximity to feeder creek.

In drawing overall conclusions about relationships between fish densities and features of the marsh flats, it must be noted that the patterns of fish abundance varied markedly between sampling periods on any one marsh. This study cannot determine whether that variability is due to sampling at different seasons, times of day, or moon phases, since all three factors were necessarily conflated by the nature of the tidal cycles. There is a lot of evidence that the depth of water, not only at different elevations on the marsh but also at the same elevation at different tidal heights, influenced fish abundance and composition. The influence of water depth may have obscured any influence of vegetation. The interaction between elevation, tidal height and vegetation type would be worth pursuing in future studies.

The project has provided original, reliable and essential information for coastal and fisheries managers, and is being widely disseminated to agencies in relevant regions. Evidence of fish use of saltmarsh flats in other regions of Australia is urgently needed. It is recommended that the momentum generated by the current project be built upon by establishing a project examining fish use of saltmarshes in several regions of Australia, using the expertise developed here in collaboration with state and territory based fisheries research agencies.

Within subtropical waters, as well as sampling saltmarsh flats themselves, future research should also be directed towards sampling saltmarsh habitats simultaneously with adjacent intertidal and subtidal habitats. There is already some evidence that the fish species occurring on saltmarshes are the same as those in adjacent mangrove forests (Moussalli & Connolly 1998), yet other species (e.g. *Pelates sexlineatus*) common in shallow seagrass meadows have never been recorded from saltmarshes. The work should be aimed at determining the proportion of individuals of a particular species that visit the inundated saltmarshes. This would provide another perspective on the importance of saltmarsh relative to other estuarine habitats.

7.0 Benefits

This project provides the first scientific evidence in Australia for the extent of use of subtropical saltmarsh flats by fish. Whilst further work is needed to determine the relative importance to fisheries production of saltmarshes compared with other estuarine habitats, this project has shown that numerous commercial and recreational fish species are common on subtropical saltmarshes. This result will be of great benefit to coastal habitat managers and reinforce the importance of conserving and protecting saltmarsh habitat. Saltmarsh habitat continues to be reclaimed and degraded in Australia, so conservation, protection and restoration are important. Every effort is being made to disseminate the results to fisheries and management agencies, with approximately equal benefits expected for commercial and recreational fishing sectors. Inshore subtropical fisheries for estuarine fish species and banana prawns are the most direct beneficiaries.

The lack of data about fish use of saltmarsh flats in all areas of Australia may result in the information from this report being used in other regions of Australia. The information is best used, however, where it has most scientific relevance and the flow of benefits should be as predicted in the original proposal, to states with substantial subtropical saltmarsh conservation issues, viz. about 80% to Queensland fisheries and 20% to NSW fisheries.

8.0 Further development

The results of this project are already being disseminated widely among coastal managers and fisheries agencies responsible for subtropical waters. The results of this research can best be extended by continuing the research into different regions of Australia, in particular in tropical waters. This project received media coverage around Australia in 1998, after which requests for information about fish use of saltmarshes were received from several government and non-government sources in NSW, Qld, NT and WA. There was particularly strong demand for information about saltmarsh as fisheries habitat from tropical areas, where saltmarshes are actually more extensive than in temperate waters (though this is not widely known) and are currently facing an increase in urban development applications. It is recommended that a project be developed in the future to determine fish and prawn use of saltmarshes in several regions of Australia. A project across states and territories would be best, using the expertise developed at Griffith University in the current project, in collaboration with state and territory based fisheries agencies.

9.0 Conclusion

This project successfully met the original objectives and provided additional information about fish use of saltmarshes that will help in managing impacts on coastal fisheries habitat.

The first objective was to determine which species actually occurred on subtropical saltmarsh flats. The project provides the first scientific evidence in Australia for the extent of use of subtropical saltmarsh flats by fish. The diversity and abundance of fish on the marsh flats was at times surprisingly high, and exploited fisheries species (e.g. bream, mullet, whiting, garfish, banana prawns) were prevalent without dominating catches numerically. The most common fish were small species such as perchlets and gobies, of no direct economic importance. Fish were found far onto the marsh flats, even to the furthest extent of the sampling, up to 500 metres onto the marsh. An outstanding feature of this study is that results come from three saltmarshes spread across southeast Queensland, sampled in both winter and summer. This is a more extensive sampling program than in previous saltmarsh studies around the world, and results can be considered a reliable guide to the types of fish that use subtropical saltmarsh habitat in Queensland.

The second objective was to compare fish use of vegetated and unvegetated marsh habitat. Evidence from saltmarsh research in North America and from work in other estuarine habitats in Australia pointed to vegetation being a major influence on fish assemblages. However, this was not found to be the case here. The presence or type of vegetation was shown here to have remarkably little relationship with fish abundance.

The success in meeting objectives in the first year of sampling allowed a refinement of the objectives during the second year (of this two year project). The distribution of fish on saltmarshes was found to be most strongly influenced by proximity to intertidal feeder creeks, with more species and more individuals near to creeks than further away. This was more important than distance onto the marsh from subtidal water. The number of species and number of individuals was also related to water depth at times, although the nature of this relationship varied in direction and strength. On the Meldale saltmarsh, where the habitat has been altered for mosquito control, the presence of artificial drains (runnels) was found to have an influence on fish assemblages secondary to the proximity to feeder creek. Some fish species were found to be more abundant away from the runnels.

The third original objective was to provide clear advice to coastal and fisheries managers about the value of saltmarsh as fisheries habitat. The project has provided original, reliable and essential information for managers, and is being widely disseminated to agencies in relevant regions (Qld, NSW). The information was keenly sought even before the final results were known.

Evidence of fish use of saltmarsh flats in other regions of Australia is urgently needed. It is recommended that the momentum generated by the current project be built upon by establishing a project examining fish use of saltmarshes in several regions of Australia, using the expertise developed here in collaboration with state and territory based fisheries research agencies.

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Appendix 1 – Intellectual property

This project provides the first scientific evidence in Australia for the extent of use of subtropical saltmarsh flats by fish. Its main use will be in improving coastal management decisions about conservation and protection of estuarine fish habitat. The results of this work are best disseminated to coastal managers directly, a strategy being pursued by the Principal Investigator, with no direct financial gain to be made. Where coastal development proposals involve saltmarsh habitat, the results of this project are applicable to, and potentially valuable to, the proponents of the development, environmental consultants and all levels of governments. Currently, however, no immediate prospects for financial gain from this project are known by the Principal Investigator, and the recommended strategy remains one of wide and public dissemination of results with a view to those results being available to all parties in any decision over coastal habitat conservation.

Appendix 2 – Staff

The following is a list of staff that were involved in this project.

Principal Investigator

Dr Rod Connolly

Paid Staff

Rodney Duffy (GU)
Bonnie Thomas (GU)
Dave Vance (peer reviewer, CSIRO)
Rowena Warne (GU)

Voluntary Staff

Karen Flynn
Michaela Guest
Mathew Harvey
Brenda Healey
Mark Miller
Karen Rudkin
Suzanne Round

Appendix 3 – Complete list of species caught on saltmarshes during this study, with common names and family names. * = exploited species.

Species	Common name	Family
Acanthopagrus australis *	Yellowfin bream	Sparidae
Acentrogobius viridipunctatus		Gobiidae
Ambassis jacksoniensis	Port Jackson glassfish	Ambassidae
Ambassis marianus	Ramsay's glassfish	Ambassidae
Arenigobius caninus		Gobiidae
Arenigobius frenatus	Half-bridled goby	Gobiidae
Arothron manillensis	Narrow-lined toadfish	Tetraodontidae
Arrhamphus sclerolepis *	Snub-nosed garfish	Hemiramphidae
Atherinomorus ogilbyi *	Ogilby's hardyhead	Atherinidae
Calamiana sp.		Gobiidae
Craterocephalus mugiloides		Atherinidae
Favonigobius sp.		Gobiidae
Gerres subfasciata *	Common silver belly	Gerridae
Glossogobius biocellatus	Estuary goby	Gobiidae
Gobiopterus semivestitus	Glass goby	Gobiidae
Herklotsichthys castelnaui *	Southern herring	Clupeidae
Hyperlophus vittatus *	Sandy sprat	Clupeidae
Hyporhamphus quoyi *	Short-nosed garfish	Hemiramphidae
Liza argentea *	Tiger mullet	Mugilidae
Liza subviridis *	Flat-tail mullet	Mugilidae
Lutjanus russelli *	Moses perch	Lutjanidae
Mugil cephalus *	Sea mullet	Mugilidae
Mugilogobius stigmaticus	Mangrove goby	Gobiidae
Mugilogobius sp.		Gobiidae
Myxus elongatus *	Sand mullet	Mugilidae
Periophthalmus argentilineatus	Mudskipper	Gobiidae
Pomatomus saltatrix *	Tailor	Pomatomidae
Pseudogobius sp.		Gobiidae
Pseudomugil signifer	Pacific blue-eye	Atherinidae
Pseudorhombus arsius *	Large-toothed flounder	Bothidae
Scomberoides lysan *	Double-spotted queenfish	Carangidae
Selenotoca multifasciata *	Striped butterfish	Scatophagidae
Sillago ciliata *	Sand whiting	Sillaginidae
Sillago maculata *	Winter whiting	Sillaginidae
Sphyraena obtusata *	Striped sea-pike	Sphyraenidae
Terapon jarbua *	Crescent perch	Terapontidae
Tetractenos hamiltoni	Common toadfish	Tetraodontidae
Torquigener pleurosticta	Banded toadfish	Tetraodontidae
Tylosurus gavialoides *	Stout longtom	Belonidae
Unident. sp.		Blenniidae
Valamugil georgii *	Fantail mullet	Mugilidae