An assessment of bait availability, utilization and management guidelines in Eastern Cape estuaries.

By

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Abstract

Aspects around the management of benthic soft sediment bait organisms, with special focus on the mud prawn (*Upogebia africana*) of eastern Cape estuaries was investigated. The recreational linefishery of the Gamtoos estuary was described, and compared to previous studies. Target fish species was identified, and a large dependency on bait sourced from estuaries needed for the capture of these species was noted, especially for spotted grunter (*Pomadasys commersonnii*). A comparison between bait use, success and the natural diet of target fish species was also made. The structure and distribution of sediments in the old channel mud banks was described and compared with historical data. The influence of sediments on mud prawn distribution was investigated, but no significant interactions were found at the study site. The impacts of once-off pumping and digging events, and monthly trampling on the sediments and mud prawn population was studied over a 7-month period. Initial removal rates as well as recovery time varied significantly between the two collection methods, while the largest decline in prawn numbers (to zero) with no recovery visible after seven months was caused by trampling. All disturbances caused some alteration in sediment composition, but not to such an extent that the sediments became unfavorable for mud prawns. Trampling did, however, result in the compaction of sediments to such a degree that prawns could not construct burrows. Issues around current removal quotas of bait species as well as the creation of a small-scale commercial (SSC) bait selling operation at Swartkops estuary were critically evaluated, and suggestions for the future removal rates of mud prawns based on production export calculations were made. The distribution, size, sex ratios and number of gravid females occurring along a tidal gradient as well as along horizontal gradient of the mud bank during growth (January – March) and reproductive (September – October) periods was investigated. Changes in the distribution of females between the two study periods were significant, while the distribution of reproductively active females were closely linked to the low water mark (Lower tidal levels). Females occurring in this zone were also significantly larger than females occurring towards the back of the study site. Some minor changes along the horizontal gradient were also observed. The sediment composition of the mud bank was found not to play a role in this distribution, leading to the suggestion that exposure to ebb and flood tide currents could influence female prawn distributions. Management recommendations based on these observations were made.

KEYWORDS: Gamtoos estuary, Swartkops estuary, Estuaries, mud prawn, *Upopegia africana*, sand prawn, *Callianassa kraussi*, pencil bait, *Solen capensis*, bait collection, bait digging, exploitation, conservation, recreational fishing, ecosystem approach, estuarine management.

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1. Introduction

Although the richness of benthic macrofauna of estuarine soft sediments, as well as their role in nutrient cycling have been well documented in certain estuaries (Allanson *et al*. 2000; Baird and Ulanowicz 1993; Hanekom *et al.* 1988; Cockroft and Tomalin 1987; Hodgson 1987; Hodgson *et al.* 2000a), baseline data on the standing stocks and reproductive success of many of these species do not exist for many of the large Eastern Cape estuaries. Continued sampling of well-studied systems also reveals complex community dynamics that is as yet poorly understood (Turpie 2002). Current management effort on the control of removal rates of these species are based on inadequate information without specific knowledge of distribution, standing stocks, recruitment patterns or sensitivity to exploitation of these species. Ongoing research has produced publications on various aspects of the physical and geological characteristics of estuaries, such as chemical processes and water quality, biology, ecology, energy flow and system modelling, but the relationship between estuary functions, species richness, human activity and management effort is not well understood.

The exploitation of invertebrate species used as bait by recreational and subsistence fishers take place in virtually all estuaries along the South African coast. This practice is particularly prevalent in those estuaries within or close to densely populated areas, or systems that attract large numbers of holiday makers/visitors. Bait populations in an estuary such as the Swartkops is under sustained exploitation whereas in other systems (e.g. the Kromme and Gamtoos estuaries) exploitation of these resources are more seasonal in nature. It has been shown that popular bait organisms, such as the mud prawn (*Upogebia africana*) and sand prawn (*Callianassa krausii*), are also key species in the food web of eastern Cape estuaries, and that they play an important role in the transfer of energy to higher trophic guilds (Baird 1988; Baird & Ulanowicz 1993). Surveys by Hanekom, Baird & Erasmus (1988) have shown that prawn species comprise up to 80% of the inter- and sub-tidal macrofauna. Because of their abundance and value as bait species, they are extensively used by recreational and subsistence fishers in many estuaries along the coast, and are thus subject to exploitation. It has become clear that excessive exploitation of these species not only threaten their own survival, but also their habitat and those predators dependent on them for energy.

Currently, the following groups of estuarine invertebrates are exploited as bait in Eastern Cape estuaries:

Two thalassinid prawns, namely mud prawn which dominates the muddy inter- and sub-tidal reaches (Hanekom 1980), and sand prawn, occurring in the more dynamic sandy inter- and sub-tidal mouth region as well as sandy sections of the upper reaches (McLachlan and Grindley 1974). Both species prefer non-vegetated sediments. The mud- and sand prawn together comprises approximately 82% and 11% of the bulk of benthic macrofaunal biomass in the Swartkops estuary (Hanekom *et al.* 1988). Other species used include the bivalves *Solen capensis and S. cylindraceus* (pencil bait), and polychaetes such as bloodworm (*Arenicola sp*.) and tapeworm *Polybrachiorhynchus dayi. Solen capensis* occurs in the intermediate zone between the sandy mouth and muddy lower reaches. In the Swartkops estuary, this sand-mud interface zone is only a few hundred metres wide (McLachlan and Grindley 1974). The smaller bivalve, *Solen cylindraceus*, occurs in high numbers in the muddy creeks of the Swartkops estuary, is not heavily exploited. Together the two *Solen* species constitutes less than 3% of the macrobethic biomass of the Swarkops estuary (Hanekom *et al*. 1988). Polychaetes, such as bloodworm and tapeworm have been heavily exploited in the past and are currently present in very low numbers or absent from many estuaries in the eastern Cape. Data on standing biomass and exploitation rate is not commonly available for these species. Gaigher (1979) found bloodworm to occur close to the mouth regions of the Breede River estuary, where medium sand particles (0.5 – 0.25 mm diameter) dominate the sediments. Neither McLachlan and Grindley (1974) or Hanekom *et al*. (1988) made any mention of the larger polychaetes during their detailed description of the macrobenthic fauna of soft substrata in the Swartkops estuary, suggesting that populations are either absent, present in very low numbers, or highly localised.

It has been estimated that during the early nineties about 4 000 kg dry mass (or about 1.7 million individuals) of mud prawn were collected per annum in the Swartkops estuary (Martin 1991a; Hanekom & Baird 1992). Wynberg (1991) estimated that the disturbance caused by high intensity collection of prawns using prawn pumps could result in a 25% reduction in prawn densities. Hanekom & Baird (1992) estimated that about 13% of the annual somatic production of the mud prawn is consumed by birds, about 5% by predatory fish, about 2% by bait collectors, while an additional mortality of about 18% (of new somatic production) is inflicted on the population through habitat disturbance during the collection process. The numbers of mud prawns consumed, collected and destroyed per annum are in the order of 28

million individuals. Judging by present day collection activities and destructive sampling methods (e.g. spades, garden forks, prawn pumps, etc.) the mortality may even be higher. In a habitat assessment of the Swartkops estuary published in 2000 (van Driel 2000) the Swartkops estuary was given a score of 58 out of 100, or a class D estuary. Excessive bait collection is listed as one of the factors seriously impacting on the estuary.

The geographic distribution and size of benthic macrofaunal populations in turn depends on the volume of freshwater throughput, sediment characteristics and macroflora distribution. While exploited species such as mud prawn and sand prawn have wide salinity tolerances (4 – 24 and 2 – 30 respectively) (Hanekom 1989), these species are still adversely affected by medium flood events (corresponding to a flood event with a frequency of between 1 in 5 to 1 in 10 years). Hanekom (1989) reported a 49 % and 28% reduction in the numbers of mud- and sand prawn populations of the upper and middle reaches of the Swartkops estuary immediately after a medium flood episode during 1975. No reductions in numbers of mud prawn were recorded from the lower reaches of the estuary, suggesting that these populations were able to tolerate flood conditions in these regions of the estuary. In the populations that experienced reductions in numbers, it was small (mud prawn) or small and medium (sand prawn) sized individuals that were displaced from burrows. Increases in the number of spotted grunter (*Pomadasys commersonnii*) captured during gill net surveys with both prawn species in their stomach contents was reported after the flood (Hanekom 1989). Pencil bait on the other hand, did not display any osmoregulatory ability and a 93% mortality rate was recorded after the flood (Hanekom 1989). Allanson *et al.* (2000) described changes in macrofaunal distributions and biomass as well as presence or absence of *Zostera* beds and associated fauna in the Knysna estuary.

Changes in distribution that took place over a 50-year period were ascribed to changes in sediment distribution, a conclusion supported by the findings of Marker (2000). Sedimentation in estuaries can be affected by wave action alone (Reddering and Esterhuysen 1984) but are also governed by fresh water inputs (Reddering and Scarr 1990b: Cooper 1993). Reduced freshwater supply not only diminishes the ability of the main channel to scour sediments in the mouth of the estuary (Turpie 2002), but also increases the deposition of marine sediments in estuaries. Reduced tidal prisms, as well as slower flow of freshwater into an estuary reduces the fine sediment load brought into the estuary by rivers. This, coupled to an increase in marine sediments present in the estuary during periods of low freshwater inflow, alters the

typical sediment distribution as described by Reddering and Scarr (1990b). Under flood conditions, fine particles are suspended and deposited closer to the mouth than under normal tidal flow conditions. It was noted (Hanekom 1989) that under these conditions, prawn numbers declined markedly when fine particle (< 63 µm) content of the sediments increased above 20%.

The management of macrofaunal species targeted by bait collectors is therefore inherently linked to freshwater flow and associated sediment distribution patterns. It also became clear that the influence of sediment movement and composition as well as freshwater volume and velocity is not uniform throughout entire systems and among all bait species. Furthermore, evidence has been presented that within species, populations and various size classes from different reaches of an estuary react differently to the same disturbance. The variation in mortality rates due to disturbance events displayed by various species indicate that the required standing stocks needed to maintain populations of the target bait species in different regions of an estuary will differ. The value of mud- and sand prawn populations from the lower reaches of an estuary, where recreational activity is concentrated (Daniel 1994) becomes apparent, as well as the risk of over-exploiting pencil bait stocks due to their vulnerability to episodic floods, which may cause mass mortality of the species.

These considerations have lead to the conclusion that it is imperative to link the management of estuarine benthic macrobenthos to the management of other species as well as to estuarine processes. Such an adjustment will bring estuarine management in South Africa in step with management strategies currently employed elsewhere in the world. In the U.S.A., the conservation of estuarine biodiversity falls under two large programmes, namely the National Estuarine Research Reserve System (NERRS) responsible for habitat protection, and the National Estuary Program (NEP) responsible for water quality management (Clark et *al.* 2002). In the UK, estuaries are managed by means of a host of conservation bodies responsible for different levels of protection, but where the overall aim is the conservation of estuarine fauna and flora through site safeguarding, ameliorating existing damage through sensitive management and pollution control (Clark et *al.* 2002). A wide range of management options is also available to legislators in Australia, where protected areas are managed as marine and estuarine protected areas (MEPAS). Areas can be protected from minor management controls to a total ban on all forms of exploitation. Usually, different levels of protection are present in

a single system; providing areas of exploitation as well as refuge zones were no human activity is allowed (Clark et *al.* 2002).

Turpie (2002) suggests that where an in-depth knowledge of a system is lacking, the maintenance of physical and chemical health of the estuary must be a priority, and that the conservation of species should involve the identification and active management of conspicuous umbrella species. An umbrella species in this context was defined by Turpie (2002) as an high profile species or a species occurring in high numbers, and where management efforts able to conserve these species would also lead to the successful management of a large number of species inhabiting the same environment in smaller or less well described numbers and distributional patterns. This approach assumes that the conservation of systems needed to support these umbrella species would result in the conservation of the other taxa until such a time as the biodiversity of the system is better studied. It is possible to determine key as well as conspicuous benthic macrofaunal species from previous studies on biodiversity in Eastern Cape estuaries, as well as the habitat type preferred by these species. From the data presented in this study, coupled with historical data, levels of utilisation of these species by humans, as well as their importance in energy flow cycles can be determined. By studying past and present trends in fishing activity, key fish species, either in numbers present in a system or as a priority ranking in fishery utilisation, can be identified. This information can serve as baseline data required to implement management decisions based on the principles listed above.

With the revision of the South African fisheries policy in 1998, the Marine Living Resources Act No. 18 was promulgated, advocating the following principles (Branch 2002):

- ✓ Sustainable development;
- ✓ Equitable access to resources, with attention given to the needs of subsistence fishers, and
- ✓ Stability of the industry

The current policy, therefore, is a combination of protecting the needs of poor people relying on marine resources for food or income, while still ensuring sustainable use of these resources (Branch 2002). Due to the perception that resources held at sea, and therefore by assumption also in estuaries, are common property, access rights have become one of the most pressing issues worldwide (Van der Elst *et al.* 1992). The ideal system of access rights will achieve

social acceptance, sustainable utilisation of resources and optimal economic returns (Van der Elst *et al.* 1992).

The objectives of this study are to provide some answers and baseline information of bait exploitation and related management issues in two typical Eastern Cape estuaries. For management purposes, the most commonly targeted estuarine invertebrate bait species can act as umbrella species as an interim measure until a better understanding of species distribution, numbers and system functioning needs have been formulated and the principles of the conservation of biodiversity are in place. In order to gather as much information as possible on the various aspects of estuarine bait management, including environmental factors that influence bait abundance and distribution, current utilisation patterns by human users as well as natural predators, and the sensitivity of the estuarine environment to these perturbations, the following key questions related to bait collection activities were investigated:

- ✓ Which species are exploited for bait?
- ✓ What are the standing stocks of these species, what are their rate of production, time of reproduction and recruitment back into the estuary?
- ✓ How much of their production are utilized by natural predators, where do they fit in the food web, and how much is removed by bait diggers?
- ✓ To what degree is the habitat damaged by collection, and how long does it take for the disturbed areas to become re-colonized?
- ✓ How much can safely be removed by bait collectors without damage to the stocks and their environment?
- ✓ What are the advantages of designated areas for exploitation, or the possibilities of rotational bait gathering in different geographical areas in an estuary?

2. Study sites

Due to the estuary's proximity to Port Elizabeth, as well as the current level of legal and illegal bait collection taking place, the Swartkops estuary was used only for the observation of illegal bait collection activity (Bait digging). During the study period, bait diggers was most active in the Tipper's creek area (Fig. 3). Due to their inapproachability, most observations on these activities were made from a vehicle parked next to the estuary in this area. The disturbance experiment and time-interval transects were moved to the relatively secure and less disturbed Gamtoos estuary.

2.1 The Gamtoos River estuary

The Gamtoos estuary discharges into St. Francis Bay, 55 km west of Port Elizabeth along the Eastern Cape coast between latitude 33° 58' south and longitude 25° 01' east. The permanently open estuary is tidal to approximately 20 km inland from the mouth (Pierce and Schumann 1997), and has a catchment area of ± 34 500 km^2 (Reddering and Scarr 1990a). Apart from the Gamtoos River, the Kouga, and the Groot Rivers also drain through the estuary (Heydorn and Grindley 1981). The mouth in its current position (Fig. 1) is permanently open, although periodic closure did occur during the 1960's when the inlet was located further to the northeast (Reddering and Scarr 1990a).

Mudflats are poorly developed in the narrow main channel of the estuary from the tidal head to 1 km from the mouth, where a sandy flood-delta has developed (Marais 1982). The silty sand banks on the middle and upper reaches of the estuary are mostly vertical (Reddering and Esterhuysen 1984) and mudflats in the estuary range on average between 10 – 30 m in width (Reddering and Scarr 1990a). The estuary is relatively shallow, averaging between 2.5 and 3.5 m in the lower reaches and 0.5 and 1.5 m in the upper reaches (Pearce and Schumann 1997). The abandoned mouth is not connected to the ocean any more except for occasion intrusions during storm conditions, but is still connected to the main channel and thus remains tidal.

The old channel opens into the main channel 1.4 km above the current mouth, and contains extensive mud and sand flats (Fig. 1). The Gamtoos estuary is a flood-dominant system, with wind and wave action as well as longshore currents resulting in the deposition of large volumes of marine sediments in the lower 1.3 km of the system, causing the extensive flood-tidal delta in the mouth (Pearce and Schumann 1997). The flood-tidal delta is a complex system of active

and abandoned channels, scoured out by periodic freshwater floods. Under low freshwater discharge conditions, sand build-up from longshore currents results in an eastward migration of the mouth and can result in mouth closure (Pearce and Schumann 1997). Although the three dams that have been built in the catchment buffers the effects of floods in the Gamtoos river (Marais 1982), major floods still occur. Freshwater floods cut a channel through the westward end of the sand barrier formed parallel to the wave fronts formed through sediment build-up (Reddering and Esterhuysen 1984).

Sedimentation patterns in the Gamtoos estuary is described by Reddering and Scarr (1990b) as displaying two main styles. During periods of fair weather, sediment deposition is dominated by marine tidal action and aeolian action in the adjacent dune field, depositing sand in the mouth of the estuary. Tide-induced deposition of clay particles derived from the catchment also takes place. During flood conditions, beds are eroded, changing the sedimentation in the estuary. Erosion dominates, although some localised sediment accumulation can still take place. The Groot river is also responsible for transporting a large amount of fine silt from the Karoo into the estuary, which is deposited in the mouth region (Heydorn and Grindley 1981). Whitfield (1995) considered the estuary to be in a fair condition, but expressed concern over the deteriorating quality and quantity of freshwater input due to extensive agricultural activity along the river catchment and basin.

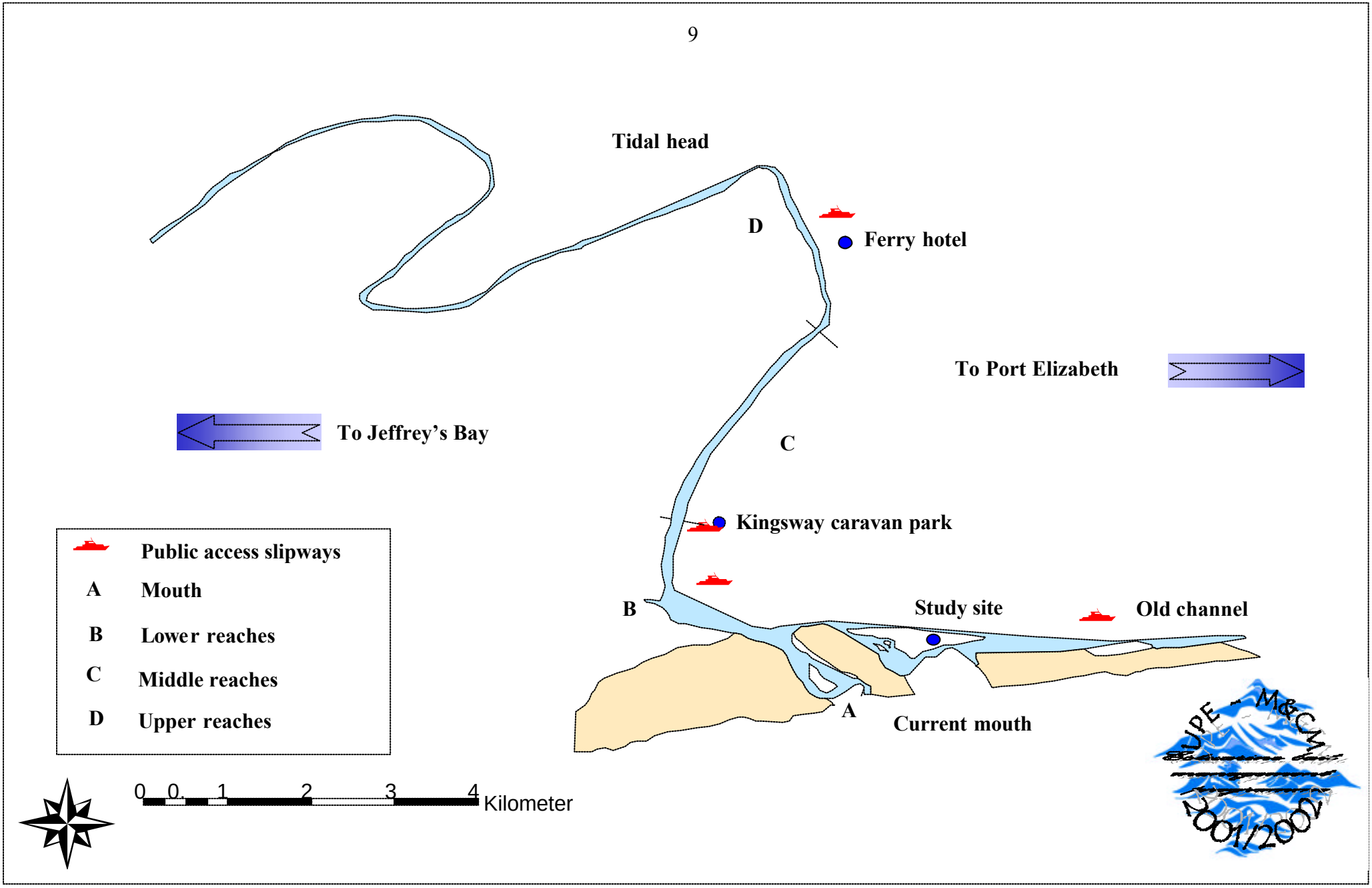

Figure 1. Map showing the Gamtoos river estuary, placement of slipways, study site, areas of relevance referred to in the text as well as boundaries of the different zones of the estuary (Modified from GIS map supplied by the Botany Dept., U.P.E.).

The study area where the disturbance experiment and sample transects was situated was the lagoon side of the largest mudflat located in "blind arm" or old channel of the estuary in the form of an disturbance experiment and line transects (Fig. 2).

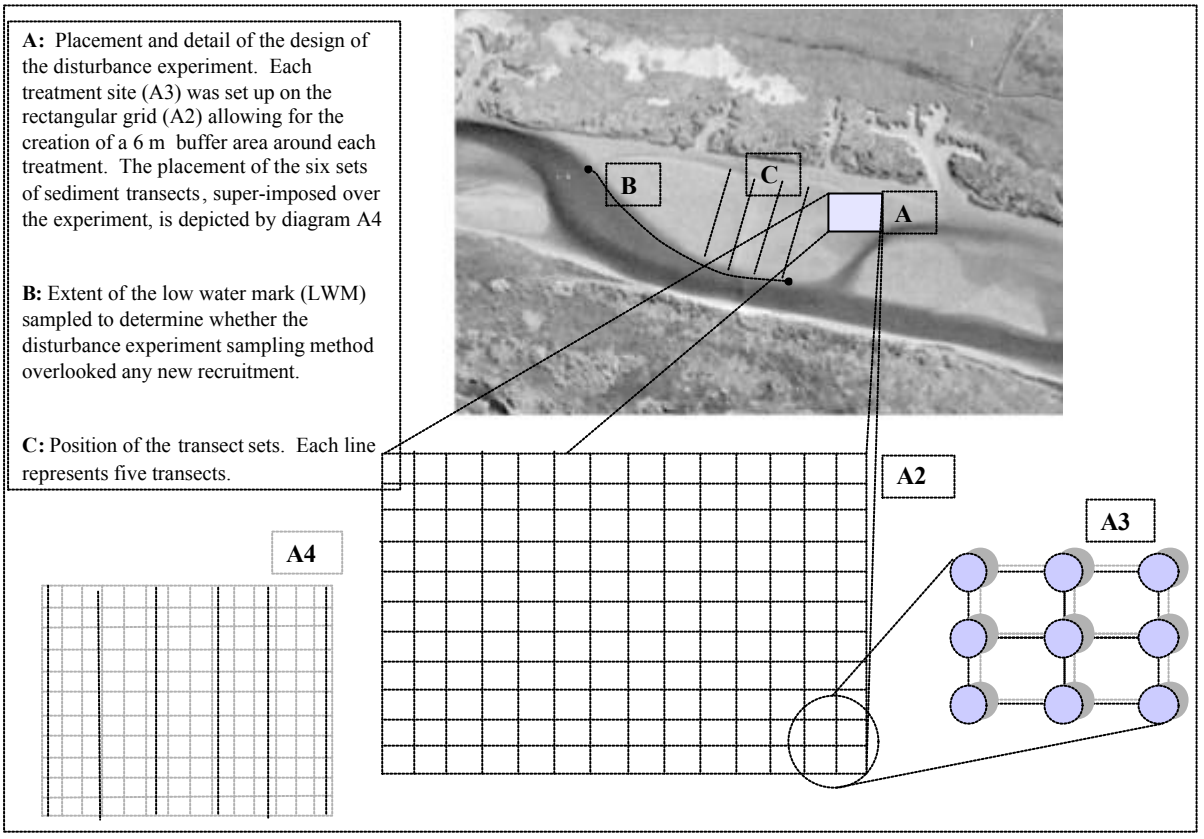

Figure 2. Layout of different sampling and experimental sites on the old channel mud bank selected to serve as a study area.

2.2 The Swartkops River estuary

The Swartkops estuary (33°52'S, 25°38'E) has its main catchment in the Groot Winterhoek mountains, from where the Swartkops and Elands rivers feed into the estuary (Reddering and Esterhuysen 1981). The Swartkops river was dammed approximately 40 km from the mouth through the construction of the Groendal dam (Marias and Baird (1980). The estuary, described as a small, shallow, temperate, turbid, well-mixed estuary (Baird and Winter 1992), is surrounded by residential and industrial developments. It enters Algoa bay approximately 10 km North-east of Port Elizabeth (Melville-Smith and Baird 1980). Although a causeway constricts the mouth at its present location, it remains permanently open (Reddering and Esterhuysen 1988). The overall length of the estuary is 14 km, with the causeway at Perseverance constricting the movement of saline water and thus determining the position of the head of the estuary (Winter 1990).

McLachlan (1972) divided the estuary into four regions based on sediment types. These were the mouth, lower, middle and upper reaches (Fig. 3). The mouth region, which extends for a kilometre upstream, is characterised by large sand banks, except for a rocky stretch in front of the Amsterdamhoek residential area (Hanekom 1980). The lower reaches of the estuary is characterised by extensive supra-tidal salt marshes (Melville-Smith and Baird 1980; Winter 1990) of 1.8 – 2.4 km^2, as well as extensive inter-tidal flats of similar extent. These species rich inter-tidal flats were described (Hanekom 1980; Winter 1990) as fringed by salt marshes and extensive beds of *Zostera capensis.* Colloty *et al.* (2000) estimated the original extent of the salt marshes (intertidal and supratidal) to be 255 ha, but this had declined to 170 ha by 1996 due to development. Only an estimated 5 ha of the original 40 ha of supratidal salt marsh remain. Recent human activities, as well as variations in freshwater throughput have impacted on the extent of both the marshes and the *Zostera* beds. The lower reaches, stretching from Amsterdamhoek to Brickfields, have substrate comprising of a mixture of sand and mud. The relief of the estuary remains low from the mouth to the brickfields area (middle reaches of the estuary) where it changes to a high relief with steep sided banks (Reddering and Esterhuysen 1988), typified by narrower inter-tidal zones with finer and more compact sediments (Hanekom 1980). The upper reaches, consisting of narrow channels with steep banks, reach until just northeast of Perseverance, and is typified by course sand mixed with various amounts of silt.

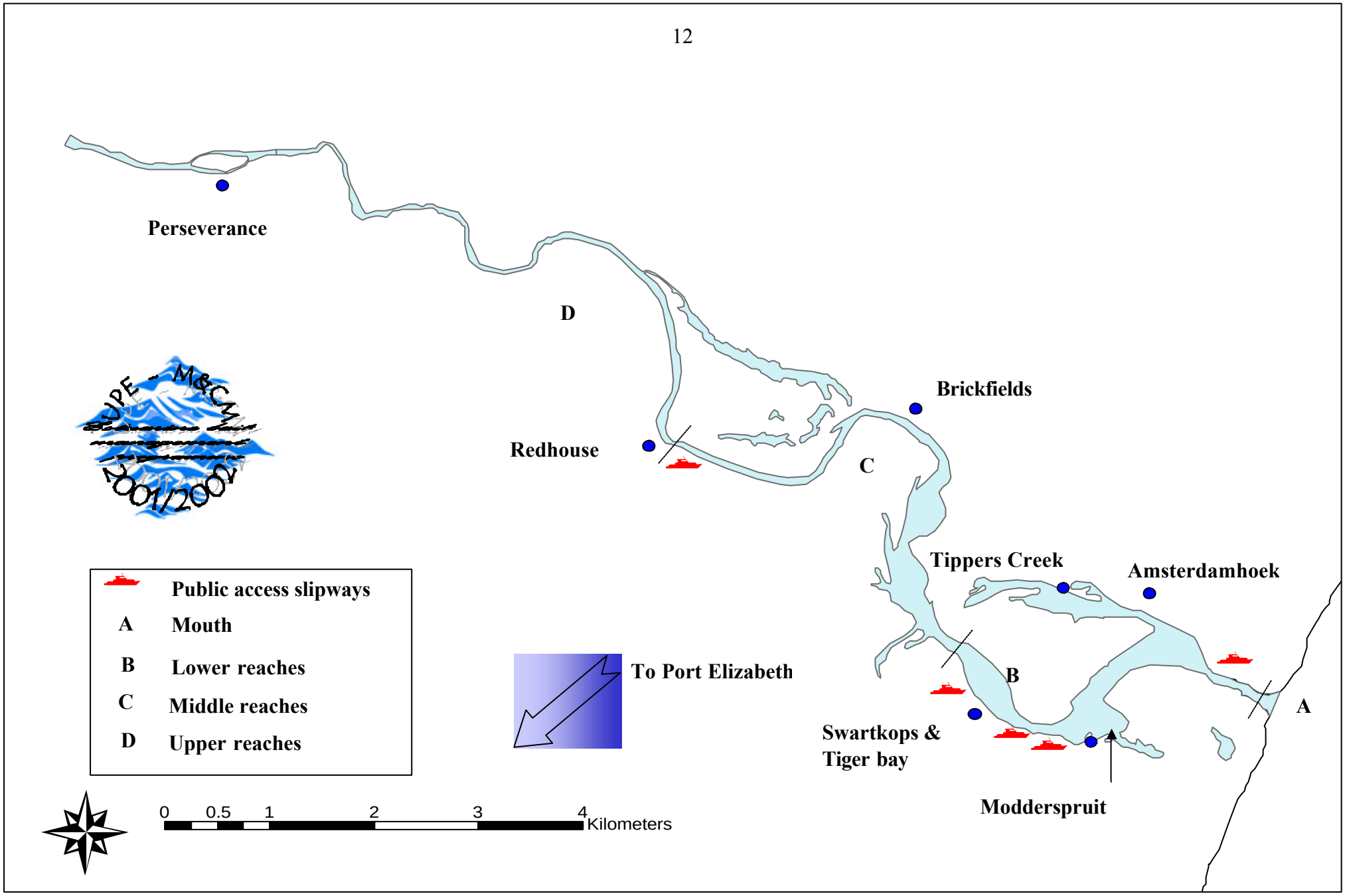

Figure 3. Map showing the Swartkops river estuary, placement of slipways, areas of relevance referred to in the text as well as boundaries of the different zones of the estuary (Modified from GIS map supplied by the Botany Dept., U.P.E.).

3. The recreational linefishery of selected Eastern Cape estuaries.

3.1 Introduction

Various studies (Baird *et al.* 1996, Brouwer *et al.* 1997; Pradervand 1998; Pradervand and Baird 2002) have investigated trends in the estuarine linefishery, and came to the following conclusions: Estuaries close to large urban centres experience greater angling effort than more remote systems, week-end fishing levels are much higher than effort during week days, and generally white anglers (73.5%) still dominate the industry. When anglers were questioned about preferred estuaries for fishing (Swartkops estuary or the more distant Sundays estuary), the majority preferred the Sundays estuary over the Swartkops estuary, citing the relative pristine state of the former estuary as the main reason (Baird *et al.* 1996). A further assumption that can be made is that anglers visit estuaries that are within their reach, but would prefer to be fishing in relatively pristine systems. The majority of boat anglers, which comprise 80% of Gamtoos estuary anglers, are not affiliated to clubs. A further 15% of the angling population are white recreational anglers, with only about 5% of the estuaries' fishing population being subsistence users from the local community (Wood 2002).

It is well documented (Pradervand 1998; Pradervand and Baird 2002) that many of the larger estuarine systems in the Eastern Cape support different fish assemblages, with anglers targeting a single or a few species that are locally abundant in each system (Daniel 1994). Even though this variation occurs, a large proportion of current total catch are comprised of only four
species, namely spotted grunter (*P. commersonnii*), Cape stumpnose(*Rhabdosargus holubi*), dusky kob (*Argyrosomus japonicus*) and white seacatfish (*Galeichthys* sp.) (Pradervand and Baird 2002). The Gamtoos estuary has a rich large-fish component, with dusky kob, spotted grunter, leervis (*Lichia amia*), white steenbras (*Lithognathus lithognathus*) and white seacatfish comprising the bulk of the biomass (Marais 1983b). Currently, anglers specifically target kob, spotted grunter and white steenbras, while all other recreational activities such as skiing, power boating and the use of jet-skis are prohibited or severely curtailed, meaning that most water-based activities in this estuary is aimed solely at the exploitation of its living resources (Wood 2002). Mean CPUE as well as numbers of fish caught (Marais and Baird 1980) from the Swartkops and Sundays estuaries for kob and spotted grunter over time does not vary to a large degree, suggesting that seasonal abundance will not influence anglers' catches (Daniel 1994).

Variation in catches here was ascribed to variation in angler effort over the study period. As bait species and availability is also similar between systems, it can be assumed that fishing activity, and therefore also bait usage, will differ between estuaries in relation to the composition of fish stocks only.

Fishing methods vary from estuary to estuary, but overall shore based angling is the dominant method employed, with exceptions being estuaries situated at holiday destinations such as the Kromme-, Gamtoos- and Sundays estuaries, where boat-based anglers exceed shore-based fishing (Pradervand and Baird 2002). About 659 boats were registered for fishing in the Gamtoos estuary, compared to 1014 for the Kowie, 1454 for the Kromme and 994 for the Sunday's estuary (Wood 2002). The lowest number of registered boats were for the Gamtoos estuary, but it has to be kept in mind that all other forms of boat use apart from fishing is banned on this estuary.

Pradervand (1998) in his study of eight eastern Cape estuaries, stated that 93.7% of estuarine anglers used bait in the following percentages: bloodworm 0.2%, mud prawn 37.5%, sardines or pilchard (*Sardinops sagax*)19.1%, pencil bait 10%, squid or chokka (*Loligo vulgaris*) 9%, fish bait 8.2% and sand prawn 9%, with the rest of catches made with lures, flies and other minor bait forms. The most commonly used form of fish bait was mullet (*Mugilidae*). The level of prawn usage (46.5% in total) is similar to those obtained by Wynberg (1991) for the Langebaan lagoon. Here, 55% of anglers questioned used sand- and mud prawn only, and 35% used sand prawn exclusively. Only 6% on anglers used bait other than the two prawn species on a regular basis. Sand prawn is preferred above mud prawn due to a different suite of target fish species and/or variations in regional fishing conditions.

The link between bait usage and target fish species can be taken further, to the point where the management of fishing activity and bait removal is merged with the common objective of sustainability. Therefore it is important to determine the bait usage patterns as well as target fish species preference of anglers. In the event of a situation where the sustainability of a fish species comes under consideration, the management of the preferred bait organism used should also be part of the conservation efforts. Conversely, the over-exploitation of an estuarine bait species could not be addressed without linking reductions in allowable bag limits of the target fish species for which the bait is harvested to begin with. The objective of this chapter was to determine current fishing trends in the Gamtoos estuary, specifically the type and amount of

bait used by fishermen. The amount of bait organisms sourced from the Gamtoos estuary in relation to total fishing activity as well as to individual target species catch results was also investigated. These results can then be compared to gill net and angler catch data as well as stomach content analyses collected from nearby systems such as the Swartkops and Sundays estuaries to form a clear picture of the relationship between the bait and fish assemblages of the estuaries, angler preference and catch results.

3.2 Methods

Although the validity of data obtained from fishing competitions has been questioned due to the discarding of non-target species during fishing activity (Pradervand and Baird 2002), records from competitions provide a substantial amount of data, which is invaluable if their limitations are borne in mind. The data collected at the Gam-1000 fishing competition held during September - October 2001 at the Gamtoos estuary, however, had a scoring system based on the weight of total catch without elevating the value of specific species. The data obtained therefore is seen as representative of the total catch in the estuary over a 5-day period. Data was collected at the weigh-in point of the Gam-1000 fishing competition on the official catch cards supplied by the Western District municipality in exchange for the use of the data obtained. Record was made of species of fish caught, total length of fish and bait used. Total fishing time was also recorded. Every fishing record completed by an angler at the weigh-in point was captured as an "outing". Numbers or total mass of bait species used during the competition was not quantified. Records from the competition were combined with data sourced From Pradervand (1998) and Wood (2002), from where similarities and differences in catch composition and bait usage can be analysed.

The key questions for this chapter are:

- ✓ To determine trends in the contribution of each bait species to the total amount of bait used in Eastern Cape estuaries, and to describe angler preferences.
- ✓ To note any similarities between target fish species, their natural diet and bait used to fish for these species in Eastern Cape estuaries, as well as the relative abundance of the fish and bait species and the implications of levels of availability of bait organisms.
- ✓ To compare current rates of exploitation and CPUE with historical data.

3.3 Results

From Fig. 4 it can be seen that bait sourced from the Gamtoos estuary itself dominates usage patterns. Mullet, used specifically to target large kob, was used in 36.4 % of outings, while sand- and mud prawn were used in 22% and 21% of outings respectively. Unspecified prawn was used in 8% of outings, bringing the total use of prawn bait to 51%. Combining data from all fishing outings indicate that 93% of invertebrate and fish bait used over the 5-day period was sourced from the estuary; with 50.5% of fishing outings recorded using invertebrate bait collected from Gamtoos mud and sand banks.

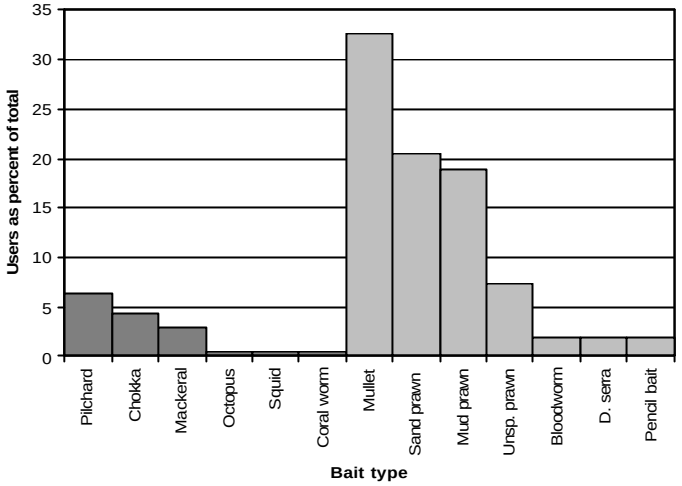

Figure 4. Breakdown of bait usage as recorded during the Gam-1000 fishing competition. Dark shaded bars are bait sourced from a marine origin; light shaded bars represent bait collected in the estuary.

Fig. 5 illustrates the bait used in catches of the two most sought-after target species, kob and spotted grunter during the fishing competition. Note that grunter is caught almost exclusively (87%) with estuarine prawn as bait. Kob catches are reported as *Argyrosomus* sp. since the exact species was not verified during the competition. As about 99.7% of kob occurring in Eastern Cape

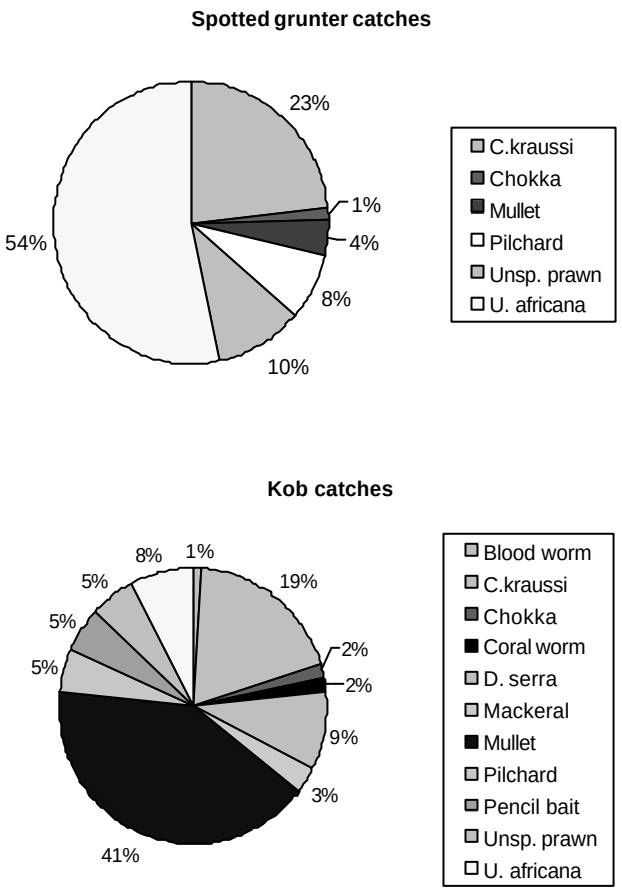

Figure 5. Comparison between bait used in catches of kob and spotted grunter during September 2001.

estuaries are *A. japonicus* (Griffiths and Hecht 1993), it can be assumed that most if not all kob reported are of this species. The kob catches can be divided further into size classes, as most of the fish caught with fish bait were above 55 cm in length, while those caught with other bait types mostly average between 40 cm and 55 cm (Table 2). There is obviously a clear relationship between bait used and preferred target species as well as the average size of target species captured (this will be discussed later in more detail).

A total of 14 fish species was recorded during the competition, but with the majority (90.86%) of the catch dominated by a small number of target or abundant species. As can be seen in Table 1, kob catches was the highest at 56.23%, followed by spotted grunter with 24.93% of the catch, and white seacatfish at 9.7%. The first two species were target species, whilst white seacatfish is not targeted but features in catch results due to its abundance.

Table 1. List of species caught during the Gam-1000 fishing competition as well as their contribution to total catch. Data on catches reported on by Pradervand (1998) and Wood (2002) are supplied for comparison.

	% of total recorded catch			
Species caught	1996 - 1997	Sept. 2001	Nov. 2000	Nov. 2001
White seacatfish	3.37	9.7	33.7	-
Chelidonichthys sp. (gurnard)	-	1.39	-	-
Spotted grunter	34.27	24.93	1.54	50.47
A. berda (river bream)	0.56	0.55	-	-
White steenbras	6.18	0.55	-	7.48
L. mormyrus (sand steenbras)	-	0.28	-	-
Cape stumpnose	7.3	4.16	-	-
Unspecified eel	-	0.55	-	-
Kob	42.13	56.23	66.15	41.12
Leervis	4.49	0.55	1.54	0.93
M. cephalus (flathead mullet)	-	0.28	-	-
T. fuscomaculata (blackspotted electric ray)	-	0.28	-	-
Diamond ray	-	0.28	-	-
Total catch recorded	*178*	*361*	*65*	*121*
Number of anglers	-	*89*	*20*	*132*

The average size, numbers of fish caught as well as CPUE for recorded selected species are given in Table 2. CPUE is predictably lower for species where only a few individuals were caught. The overall CPUE for white seacatfish, spotted grunter and kob is similar, ranging from 0.070 to 0.075 fish angler^{-1} h^{-1}. When the catches of kob and grunter are sub-divided into groups according to organisms were used as bait, it can be seen that, with the exception of immature kob caught using white mussel (*Donax serra)* as bait, the CPUE for both species is the highest when prawn species were used.

For kob this result can be due to angler and target species selectivity, as the average kob caught with mullet was nearly 20 cm larger than kob caught with prawns. Larger kob is less common in the estuary and would thus be caught at a lower CPUE.

Table 2. Numbers of fish caught, CPUE (fish angler $^{-1}$ h $^{-1}$), average length cm (TL) of selected species caught during the Gam-1000 fishing competition as well as standard deviations (in parentheses) for overall as well as per bait used catches recorded. Standard deviations not calculated for catches below 5 individuals.

Species	Numbers	CPUE	Average length (mm)
White seacatfish	35	0.070 (0.061)	33.89 (6.98)
Spotted grunter (overall)	90	0.073 (0.052)	41.66 (11.53)
Spotted grunter (mud prawn)	38	0.080 (0.032)	41.45 (11.51)
Spotted grunter (sand prawn)	19	0.062 (0.029)	42.21 (11.9)
Gurnard	4	0.042 (0.0002)	55.50
Kob (overall)	203	0.075 (0.076)	53.06 (19.6)
Kob (mullet)	72	0.058 (0.040)	63.68 (20.97)
Kob (est. inverts)	72	0.076 (0.055)	46.24 (13.66)
Kob (*D. serra*)	21	0.30 (0.336)	39.81 (7.46)
Cape stumpnose	14	0.084 (0.054)	21.79 (6.31)
White steenbras	2	0.042 (0.0002)	36.50

An interesting result is the CPUE for kob using white mussel as bait. Only 21 fish were caught (10.3% of total catch) using white mussel as bait, but it yielded the highest CPUE of all bait types that were successful in catching kob 0.30 (±0.336) fish angler $^{-1}$ h $^{-1}$. The average size of kob caught with white mussel was 39.81 cm (± 7.46 cm), suggesting that only immature individuals were selecting this bait. For spotted grunter, where a large proportion of the catch was made with the two prawn species, mud prawn not only yielded a higher CPUE (0.80 compared to 0.62 of sand prawn) but also yielded twice the amount of grunter that were caught using sand prawn. The average size of spotted grunter caught with the two prawn species fell within the same size range.

When studying the percentage contribution to catch made by the different bait types (Table 3), the following observations can be made. Apart from the generalist feeding behaviour of kob, taking all ten bait species listed, mud- and sand prawn and mullet (sourced from the Gamtoos estuary) dominates percentage contribution to catch of target species. Sand prawn was taken by seven different species, mullet by six and mud prawn by five species. A breakdown of the percentage contribution to the catch of the different fish species (Table 3) reveals that the only non-estuarine bait type that was successful for a wide range of angling fish species (6) was the pilchard. The only estuarine bait species that was not responsible for capturing a range of fish species was pencil bait.

Table 3. Percentage contribution to catch by different bait types used during the Gam-1000 survey. Numbers in brackets indicate number of fish caught.

Percentage contribution of various bait organisms to fish species caught

Species caught	**Bloodworm**	Sand prawn	**Chokka**	**Coral worm**	**White mussel**	**Mackeral (*S. japonicus*)**	**Mullet**	**Pencil bait**	**Pilchard**	**Unsp. prawn**	**Mud prawn**
White seacatfish	-	40.63 (13)	9.37 (3)	-	-	-	6.25 (2)	-	15.63 (5)	6.25 (2)	21.88 (7)
Spotted grunter	-	23.37 (18)	1.29 (1)	-	-	-	3.90 (3)	-	7.79 (6)	10.39 (8)	53.25 (41)
Gurnard	-	20 (1)	-	-	-	-	40 (2)	-	-	20 (1)	20 (1)
kob	1.08 (2)	18.92 (35)	1.62 (3)	1.62 (3)	9.19 (17)	3.24 (6)	41.08 (76)	5.40 (10)	4.86 (9)	5.41 (10)	7.57 (14)
leervis	-	-	-	-	-	-	33.33 (1)	-	66.66 (2)	-	-
River bream	-	50 (1)	-	-	-	-	50 (1)	-	-	-	-
Sand steenbras	-	100 (3)	-	-	-	-	-	-	-	-	-
Cape stumpnose	-	-	-	-	-	-	-	-	-	-	100 (8)
S. salpa (strepie)	-	-	-	-	-	-	-	-	-	100 (1)	-
White stumpnose	-	33.33 (1)	-	-	-	-	-	-	33.33 (1)	33.33 (1)	-
Number of fish caught	**2**	**72**	**7**	**3**	**17**	**6**	**85**	**10**	**23**	**23**	**71**

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Mullet, the most frequently used bait, yielded the most fish. The majority (89.4%) of the catch was kob (average length of 63.68 cm ±20.97). Sand prawn, used in roughly half the amount of trips than mullet, yielded the next largest overall catch, followed by mud prawn with a similar yield (in number of fish). The second largest number of kob was caught using sand prawn (19%) whilst mud prawn yielded the largest number of spotted grunter (54%). The kob caught using sand and mud prawn (46.24 cm ±13.66) were notably smaller than those caught on mullet, averaging 63.68 cm (±20.97).

3.4 Discussion

3.4.1 Contribution to catch of bait species

As mentioned above (Chapter 2.1), the Gamtoos estuary is renowned as a kob-fishing destination, a feature that also manifests in the observed bait use characteristics. Pradervand (1998) listed mud prawn as the most commonly used bait type in the Eastern Cape, but during this study, it was used in only 18.93% of outings, compared to the eastern Cape average of 37.5% (Pradervand 1998). Mullet, the preferred bait of most anglers who target larger kob, was the most frequently used bait during this survey, featuring in 32.52% of outings as compared to 8.2 % of outings reported by Pradervand (1998). The complete lack of the use of lures (and therefore also the high incidence of mullet use) to catch large kob, which has been reported to be as high as 43.3% of anglers interviewed (Pradervand and Baird 2002) is due to the rules of the fishing competition. Whereas lures are most commonly trolled behind boats fishing in the main channel, fishing from moving vessels was prohibited for the duration of the competition to accommodate the large amount of anglers participating.

Sand prawn usage also exceeded mud prawn usage at the Gamtoos estuary, although the difference is small. Of the other common bait types listed by Pradervand (1998), pencil bait, chokka and pilchard were less frequently used, with the use of bloodworm slightly higher during this survey as compared to earlier studies. The general trend, as can be expected from competitive anglers, is that the anglers surveyed selected fewer bait types than the average user group, and focussed on bait that would yield good catches rather than selecting for availability of bait species (Fig. 4).

When assessing the performance of the different bait types, the numbers of fish caught matches the preference of anglers to a large degree. When comparing number of fishing outings per

bait group used with fishing success, mud prawn, although not the most frequently used bait, performed the best. Used 13.59% less frequently than mullet (Fig. 4), mud prawn yielded only 4.39% less fish than mullet (Table 3). Sand prawn was used in 12.13% less outings than mullet, but also had a better yield, only 4% less than kob. The overall trend, however, is that mullet caught what the angler was targeting, namely large kob. The yield of smaller individuals and catches of other species was spread amongst the other bait types. Mud prawn can also be singled out as the best bait for spotted grunter (Fig. 5), supporting similar claims cited from literature (Daniel 1994; Pradervand 1998). The catchability of spotted grunter reported by other authors (Marais and Baird 1980) is supported by this study, as it is the most popular invertebrate bait used during the study and is also the preferred prey of the species.

3.4.2 Contribution to catch of target species

Dusky kob remains the main target species for anglers in the Gamtoos estuary, and is also the species that has the smallest amount of variability in contribution to catch between studies (Table 1) of all reported species listed in Table 3. Whilst reported spotted grunter catches range between 1.54% and 50.47% of total catch (Table 1), kob numbers remain between 41% and 66% of catches reported. It can therefore be safe to assume that the presence or absence of kob in the estuary will determine the amount of secondary target species captured more than angler selection.

Table 4. A comparison between catch composition and total catch for selected species caught in the Swartkops estuary for the periods 1972-78 and 1988-93 (Modified from Baird *et al*. 1996).

	Contribution to catch (%)		Numbers caught			
Species	**1972 - 78**	**1988 - 93**	**1972 - 78**	**1988 - 93**	**Reduction N**	**Reduction %**
P. commersonnii	87.3	85.5	8973.567	1176.48	7797.087	86.89%
L. lithognathus	3.3	3	339.207	41.28	297.927	87.83%
A. japonicus	2.4	1.9	246.696	26.144	220.552	89.40%
E. machnata	1.9	2.2	195.301	30.272	165.029	84.50%
L. amia	2.6	0.8	267.254	11.008	256.246	95.88%
P. indicus	1.2	0.3	123.348	4.128	119.22	96.65%
P. saltatrix	0.7	0.3	71.953	4.128	67.825	94.26%
Other	0.6	2	61.674	27.52	34.154	55.38%
Totals	**10279**	**1376**	**10279**	**1320.96**		

It can be seen from Table 4 that even though the composition of angler's catches have stayed the same over nearly two decades and gill net and angler CPUE for the two periods are also similar, the actual numbers of fish caught for all the major target species has decreased by over 80%. All target species comprising the bulk of anglers catches in eastern Cape estuaries, and

which featured prominently in the catch of Gamtoos anglers such as spotted grunter, kob and Cape stumpnose decreased in numbers by over 85%.

The overall as well as per species CPUE recorded during the Gam-1000 was considerably higher than the data presented by Wood (2002) for angler inspections undertaken by WDC inspectors (Table 1). The overall CPUE during the competition was 0.069 fish.angler^{-1}.h^{-1}, compared to 0.00722 fish.angler^{-1}.h^{-1} recorded during inspections. Kob CPUE was 0.075 fish.angler^{-1}.h^{-1} during the competition. This is considerably higher than WDC data reported by Wood (2002), where an average CPUE of 0.00478 fish.angler^{-1}.h^{-1} was recorded for 2000, and 0.00019 fish.angler^{-1}.h^{-1} for 2001. Both data sets were also collected during angling competitions. Pradervand (1998) lists a CPUE of 0.4 fish.angler^{-1}.h^{-1} recorded for the Gamtoos estuary during his study (Table 1). This is still much lower than the competition data, but not as low as the WDC data. The difference in CPUE is most likely caused by the fact that the fishing competition rules encouraged the report of all catches, as weight of catch was not used as a scoring criterium. The use of lures, comprising a large part of effort on which CPUE data was calculated by Pradervand (1998) was also prohibited during the competition. Pradervand (1998) reported that CPUE for artificial bait is lower than for natural bait. Anglers that did not catch anything would also not have been surveyed during the competition. The CPUE calculated for 2000 (Wood 2002) was based on the catches of 20 anglers, whereas a cumulative total of 132 anglers were sampled during 2001. The results reported here are based on 361 catch declarations made by 96 different anglers over a 6-day period (29 September – 4 October 2002).

Although Pradervand (1998) recorded the lowest CPUE for spotted grunter in the Gamtoos estuary (0.03 fish.angler^{-1}.h^{-1}), catches during the Gam-1000 was very close to kob CPUE at 0.073 fish.angler^{-1}.h^{-1}. The other species that had catches high enough to calculate a reliable CPUE was white seacatfish, with a CPUE of 0.07 fish.angler^{-1}.h^{-1}. Pradervand (1988) does not list CPUE figures for this species, and the CPUE supplied by Wood (2002) is very low, underlining the fact that the species is commonly discarded and not declared. The high number of white seacatfish in anglers catches was most likely influenced by the large volume of anglers using mullet as bait. Pradervand (1998) reported that this bait, intended for kob, was often taken by white seacatfish in stead.

3.4.3 Target fish species, their natural diet and bait success

Although the biomass of mullet in the Gamtoos estuary is expected to be highly variable, some correlations can be made between the natural diets of some of the preferred target species, the biomass of these species and the percentage contribution to catch recorded for these species. Data on the biomass of the prawn species in the Gamtoos estuary is not available, but Hanekom (1980) estimated that mud prawn comprised 82% of total macrofaunal biomass in the Swartkops estuary, followed by sand prawn at 11% and the two *Solen* species at a combined biomass of 3%. The equal use by anglers of the two prawn species in their angling effort (22% for sand prawn and 21% for mud prawn) thus created a situation where fish were presented with higher numbers of sand prawn than what are normally available to them.

Daniel (1994) reported that stomach content analyses of spotted grunter caught in gill nets in the Swartkops estuary revealed that crustacea comprised 97.1 % IRI (importance rating index) of the fishes' diet, with crustacea in the diet of fish from the Sundays estuary scoring 92.4%. Small amounts of mullet as well as bloodworm were also recorded. In both systems *Upogebia* dominated the diet of spotted grunter due to the lower biomass of sand prawn and the relative inaccessibility of sand prawn caused by their deeper burrows (Daniel 1994). Marais (1984) also list mud prawn as the most important prey species of spotted grunter. Interestingly, while Daniel (1994) reported that crustacea made up 97% of spotted grunter stomach content, an earlier study performed by Van der Westhuizen and Marais (1977) found that crustacea formed only 67% of the diet, with Polychaeta (21%) and Mollusca (12%) also contributing significantly to the diet. Although CPUE during the Gam-1000 was the highest for mud prawn as bait, the average size fish caught with different bait types did not vary greatly

Assuming that the diet of spotted grunter in the Gamtoos estuary will be similar to those sampled in the Swartkops estuary, the fact that 23% of all spotted grunter caught during the Gam-1000 were caught using sand prawn suggested that spotted grunter deviated from its natural mud prawn diet in an opportunistic manner. This assumption is strengthened by the observation that a further13% of catches were made with bait items either absent or present only in very low numbers in stomach content analyses. Such an ability to switch diet in relation to prey availability is in line with requirements for species living in inherently unstable environments such as estuaries (Whitfield 1980). Even though spotted grunter displayed an ability to alter its feeding behaviour during this study, it should be remembered that the majority of anglers using mullet or pilchard as bait would be likely to use lures under non-

competition conditions, as reported by Pradervand and Baird (2002). This shift would most likely strengthen the link between spotted grunter and mud prawn as a preferred bait organism. Anglers targeting spotted grunter interviewed at the Swartkops estuary used a wide range of bait but also focussed on mud prawn. Bait sellers (illegal) also seem to focus on mud prawn (pers. obs.), although large amounts of pencil bait have been seen on sale during sampling trips. For the duration of the Gam-1000 fishing competition, 33.3% of the top grunter catches were made using sand prawn and 44.4% using mud prawn. In total 54% of catches of grunter were made using mud prawn, and only 23% by using sand prawn. It seems therefore, that although sand prawn is used more often than mud prawn, it is less effective in catching both large spotted grunted and numbers of spotted grunter.

Kob stomach content analysis performed by Daniel (1994) is indicative of an opportunistic predator with a wide-ranging diet, depending on food availability. A total of 36 different prey species were identified, including 15 different fish species. Fish was therefore described as the principle diet of kob in the Swartkops as well as the Sundays estuary, comprising 84% to almost 89% of the species' diet (Daniel 1994). As not all the consumed species could be identified, Daniel (1994) could not determine all the fish prey species with absolute certainty, but concluded that *Gilchristella aestuarius* was the main prey in both estuaries sampled. Talbot (1982) described the species in the Swartkops estuary to be a very abundant estuarine species, found predominantly in the middle reaches of the estuary. During reproduction (August – May) *G. aestuarius* migrates towards the upper reaches of the estuary where they spawn. Mullet species as well as mud prawn did occur in the stomach contents of kob, but in very low numbers. Sand prawn and pencil bait was not recorded by Daniel (1994) in the diet.

The natural diet of dusky kob can therefore be described as mainly piscivorous, dominated by *G. aestuarius* and containing various other species in low numbers. The fact that fish bait was responsible for the capture of 49% of the dusky kob reported during the study is therefore not surprising. The fact that many bait items of marine origin was also readily taken can be related to the fact that dusky kob occurs in estuaries as well as the adjacent surf zone (Griffiths 1997), and would therefore be accustomed to feeding on species such as *Donax*, squid and coral worm. The high success rate of sand prawn (19% of reported catch, see Table 3) is interesting, as it was not recorded in the stomach contents of dusky kob caught in the Sundays or the Swartkops estuaries, even though sand prawn does occur in both the systems (Daniel 1994). It must therefore be concluded that the feeding habit of dusky kob excludes it from including

burrowing species in its natural diet, but that it will readily accept these species when offered to it in the water column. The relative success of different baits used during the survey is thus related directly to the amount of anglers using the bait type (frequency of use) due to the presence of species feeding opportunistically.

3.4.4 Relative abundance of bait and fish species

As with most of the other key questions, target species and catch ratios vary from estuary to estuary, and therefore also the bait organisms used. Comparing information presented by various authors on the ichthyfuana of the major Eastern Cape estuaries, some similarities between estuary structure and fish abundance can be made. Short, shallow estuaries with extensive mud flats, sand banks, salt marshes and *Zostera* beds include the Swartkops and the Kromme estuaries. These systems can have very different fish assemblages due to sediment characteristics (Marais 1983a). The Kromme sediments have a much lower mud content than the Swartkops, resulting in a decrease in feeding substrate for mullet and burrowing substrate for mud prawn. As can be expected, spotted grunter occurs in much lower numbers in the Kromme (4% of numbers caught compared to 17% in the Swartkops estuary). Numbers of white seacatfish and kob, which occur in the sandy mouth and middle reaches, are not affected by the lack of muddy substrate.

Historical data sets (older than 50 years) on the distribution of fish and macrofuana do not occur for most Eastern Cape estuaries. An exception is the dataset of fish species in the Swartkops estuary collected by Gilchrist in 1918. At that time, Cape stumpnose was the most abundant species (45.5%) followed by flathead mullet (26.3%), other mullet groups (8%), white steenbras (7.5%), kob (3.6%) white seacatfish (3.1%), spotted grunter (2.4%), elf (2.3%) and leervis (0.9%). Eight other species made up the rest of the catch (Marais and Baird 1980). By the late 70's, spotted grunter was the dominant angling species caught by anglers during the period 1972 - 1978 in the Swartkops estuary (87%), followed by white steenbras, dusky kob and leervis. At that time, spotted grunter comprised 19% of total fish numbers recorded during gill net surveys (Marais and Baird 1979). As five Mugilidae species comprised the bulk (42% of total numbers) of fish caught in gill net surveys (Marais and Baird 1979), the decline of elf in the estuary over the previous 60 years is difficult to explain. The decline of Cape stumpnose, a generalist feeder utilising estuarine macrophytes, molluscs and crustacea (De Wet and Marais 1990) in anglers' catches is also hard to explain. Juveniles enter estuaries and spend at least their first year in the system, where they grow rapidly. Beckley (1983) found

that juvenile Cape stumpnose dominated fish samples (12% of total catch) taken from Zostera beds in creeks of the middle reaches of the Swartkops estuary on a year-round basis. These species tend to return to the sea at a size of approximately 150 mm (Beckley 1983). Factors other than prey availability and nursery habitat seem to influence the numbers of elf and Cape stumpnose caught in recent times.

Both the Kromme and the Swartkops (smaller clear-water systems) are, however, poorer in fish life than the Sundays and Gamtoos estuaries (Marais 1983b), which are characteristically channel-like, turbid and containing a pronounced salinity gradient from head to mouth (Marais 1983a).

The fish assemblage of the Gamtoos and Sundays estuaries were found to be very similar (Marais 1983b), again due to factors that control prey availability. These two systems are characterised by frequent flooding, resulting in relatively small mud flats and *Zostera* beds. Beckley (1983) demonstrated that the extensive Swartkops *Zostera* beds played an important role in the reproductive cycle of fish breeding in the shallow marine environment, whereas the role in mud banks to provide habitat for mullet and mud prawn has already been demonstrated. While leervis and mullet species dominated species recorded by Marais (1983a) in the Kromme estuary, mullet, kob and white seacatfish was the most abundant species recorded in the Gamtoos estuary (Marais 1983b). Mullet also dominated the catches in the Sundays estuary. Flooding was also found to reduce the numbers of fish present in the two turbid estuaries (Marais 1983b). Kob was recorded in highest densities in the middle reaches of the estuary, which is where Talbot recorded the highest densities of its main prey, *Gilchristella aestuarius*, in the Swartkops estuary (Marais 1983b). The total distribution of kob was from the mouth region to a point further than the tidal head of the estuary. Leervis numbers recorded were also the highest at the head of the estuary, while white seacatfish and spotted grunter were most abundant in the mouth and middle reaches respectively (Marais 1983b).

Compared to gill net surveys, the catch composition of anglers differs in many respects. Pradervand and Baird (2002), Pradervand (1998), Baird *et al.* (1996) and Daniel (1994) lists spotted grunter as the dominant species in the catches of recreational anglers in Eastern cape estuaries including the Swartkops and Sundays estuaries, followed by dusky kob. Marais and Baird (1980) list angler catch composition for the Swartkops estuary as follows: spotted grunter 87%, followed by Cape stumpnose, kob and leervis. Sixty years prior to this study,

Cape stumpnose was the most abundant species in the Swartkops estuary, followed by dusky kob, spotted grunter and elf (Marais and Baird 1980). The results obtained for target species during the Gam-1000 competition is similar to data presented in gill net catch surveys of the Gamtoos estuary. It was found that kob made up 56.23 % of the total catch, followed by spotted grunter, 24.93%, Pradervand (1998) reported catches for the same species as 42.13% and 34.13% of total catch respectively. White seacatfish is as common in angler's catches as it is in gill-net survey results, but is not regarded as a target species by sport anglers.

While it is indicated by some anglers interviewed that kob and spotted grunter are specifically targeted, other interviewees as well as some published reports relate levels of catches to the relative dominance of the target species in the estuaries and bait use. Although not quantified, Daniel (1994) rates mud- and sand prawn as the most important bait species in the Swartkops and Sunday's estuaries. Pradervand (1998) made a distinction between game fish species such as leervis, skipjack or springer (*Elops machnata*) and elf (*Pomatomus saltatrix*), for which catches were higher when lures or flies were used, and grunter, kob, stumpnose and other lesser-caught species for which bait are more successful. Personal observations also indicate that spotted grunter is targeted in the Swartkops estuary. In the Gamtoos estuary, results from a recent fishing competition showed that the majority of anglers target kob. Large individuals were almost always caught using mullet as bait, whereas smaller individuals were caught on most types of bait used during the competition. Spotted grunter was the second most abundant species targeted, with mud- and sand prawn being used most often. During the competition, live bait (mullet) was used most often, followed by sand and mud-prawn. Four records of pencil bait and bloodworm were made during the competition, suggesting that these are not used frequently by Gamtoos estuary fishermen.

For most Eastern Cape estuaries, mud prawn is the predominant bait organism collected, followed by sand prawn and pencil bait. Although pencil bait (*Solen capensis)* is regularly recorded as a desired bait organism, it is present in relatively low numbers during biomass investigations, which limits the amount of historical data available that can serve in statistical comparisons. While Hanekom *et al.* (1988) estimated that *Solen capensis* and *S. cylindraceus* together constitute 3% of macrobenthic biomass, McLachlan (1974) was unable to conduct any statistical analysis on numbers and physical parameters of *S. capensis*, and in stead worked on the smaller *S. cylindraceus* occurring in larger numbers. The two species occur in different reaches of the estuary (sandy areas of the lower reaches and muddy creeks of the middle

reaches respectively) and making assumptions on *S. capensis* based on *S. cylindraceus* data is therefore impossible.

3.4.5 User groups

Data on the activity of subsistence bait users in the Knysna estuary indicate that this user group is responsible for the majority of prawns collected (Hodgson *et al.* 2000b). Subsistence fishing is not quantified all that well in Pradervand (1998), who estimated that less than 5% of fishers surveyed in the Eastern Cape through questionnaires as subsistence fishers. It is likely that the actual numbers of subsistence anglers vary between estuaries, being higher in estuaries near urban centres such as the Swartkops estuary. The rest of the estuarine fishing sector is comprised of recreational anglers, of which 63.7% on average (Pradervand 1998) operate from boats.

Prior to the banning of the use of off-road vehicles on Eastern Cape beaches, the coastal zone was rates as the most popular recreational resource in the country (Sowman 1987), and recreational angling was regarded as a growing industry (Smale and Buxton 1985; Hecht 1990). It has also been shown that increased leisure activity in an area can result in social upliftment (Van der Elst *et al.* 1997). With the reduction in fishing effort along the shore due to the banning of off-road vehicles on beaches, it can be expected that the recreational component will increase dramatically in estuaries, further emphasising the need for appropriate management of the resources exploited by recreational and subsistence fishers.

3.5 Conclusions

3.5.1 Trends in the contribution of bait species to bait use in Eastern Cape estuaries, and angler preferences.

From the results of this as well as previous surveys, it became very clear that there is a direct link between target species, angling success, and bait sourced directly from the estuary. Angler preference in bait use indicated that over 90% of bait used came from the Gamtoos estuary, with 50% sourced from the sand- and mud banks. The highest CPUE, the largest average size of catch as well as the majority of spotted grunter catch was made using mud- and sand prawn. The largest percentage of kob caught during the contest was caught using mullet as bait, but anglers using prawn and bivalve species in targeting kob and other species also had the highest CPUE during the survey.

These results are not representative of the all Eastern Cape estuaries due to the variation in species composition in channel-like and short, clear systems, but are indicative of trends in bait use. The general trend is that the amount of prawn species utilised as bait is directly proportional to the level of angler selection for spotted grunter (where species are targeted). The use of all other estuarine bait species is much lower, and seems to be related either to their perceived value as a bait for relatively abundant species such as *Solen*, or to availability for rarer species such as bloodworm.

In theory, a large section of recreational anglers, excluding those targeting spotted grunter, could have virtually the same fishing success as present without the use of prawns sourced from an estuary. It can be concluded that all the other target species, or frequently caught species are either opportunistic feeders or fish predators. These species can therefore be targeted, with high success, through the use of lures, fish, squid and all other types of bait on sale today. The removal of prawn species from recreational activity where grunter is not targeted would also safeguard immature individuals of dusky kob from recruitment over-fishing as described by Griffiths (1997).

Most other bait species, however, are only marginally effective at catching spotted grunter. During the Gamtoos fishing survey, 87% of spotted grunter catches were made using sand- and mud prawn. Currently, spotted grunter is the preferred target species of recreational anglers in the Swartkops, Kariega, Sundays, Kowie and Kromme estuaries in the Eastern Cape (Pradervand 1998). A reduction in the amount of mud prawns used by anglers becomes necessary, it can only be achieved by reducing the angling effort directed at spotted grunter. A reduction in angler activity should also not be considered as a distant prospect only. Baird *et al.* (1996) noted that although the contribution to catch (percentage, not number of fish) of spotted grunter present in anglers catches between the period 1972- 78 and 1988-93 dropped only about 2%, from 87.3% to 85.5%, a serious reduction in actual numbers of fish caught were recorded (86.89%). The numbers of all the other popular estuarine species caught during the study of Baird *et al.* (1996) declined in the same manner (80 – 90% in about a decade) even though angler activity increased.

Estuaries that have a large contingent of subsistence users, such as the Swartkops estuary, will have to re-consider exempting subsistence users from many size restrictions and quotas. This user-group fishes almost exclusively with mud prawn in the Swartkops estuary (Pers. obs.),

and most of their catch is retained. The results from this study indicate that mud prawn and bivalve bait is highly effective at catching small dusky kob. Although the current legal size limit is 40cm, this is well below the size at which 50% maturity is reached (Griffiths 1997), suggesting that uncontrolled removal of this size class fish will increase the risk of recruitment over-fishing. Griffiths (1997), suggests that due to the 40 cm size limit currently enforced, the species has already been over-fished, making the protection of immature individuals of dusky kob a management priority. The amount of dusky kob retained by subsistence anglers in all Eastern Cape estuaries need to be determined and included in the analysis of total annual catch used in managing the resource.

Thus, if it were required to manage bait resources or important estuarine fish species through control of angling activity, angler preference would have to be shifted away from a species currently targeted by the majority of estuarine anglers in the case of spotted grunter, and away from prawn species as a bait source in the case of the other target fish species.

3.5.2 Target fish species, natural diet and bait used in Eastern Cape estuaries, as well as the relative abundance of the fish and bait species.

The general trend for recreational anglers is to target the most abundant fish species of a particular estuary, such as dusky kob in the Gamtoos estuary and spotted grunter in the Swartkops estuary. Although most fish species captured displayed opportunistic feeding behaviour to varying degrees, the bait species used to target these fish also happen to be both estuarine of origin, and the most abundant species in the estuaries used. Mullet species make up the highest number of small fish netted in the Gamtoos estuary, while mud prawn and sand prawn are the two dominant benthic species in the Swartkops estuary. As fish and crustacea make up the bulk of dusky kob and spotted grunter diet respectively, it can also be concluded that angling success can be attributed to a high degree of overlap between offered bait and the natural diet of target species. The only exception seem to be immature dusky kob, which deviated from the natural diet reported and selected a large variety of invertebrate species offered. The conclusion can therefore be drawn that if one of the aims of dusky kob management becomes the exclusion of immature individuals from catches to prevent recruitment over-fishing; a limitation on the use of estuarine bait species would be a logical approach.

The extra-ordinarily high numbers of spotted grunter in the catches of anglers from both these systems compared to the numbers and biomass calculated for the estuaries from gill net surveys, however, suggests that the angling effort directed at this species far exceeds its relative abundance. At the Gamtoos estuary, where spotted grunter was the second most common species in the catch by number (24.93% of the catch), Marais (1983b) recorded spotted grunter at a mean of 0.016% of the large fish species over a 3-year period. As the Gamtoos estuary is also characterised by narrower inter-tidal areas supporting smaller populations of mud prawn, the perceived pressure on the bait resources is much greater under normal use conditions.

The Gamtoos estuary is also prone to flooding on a more regular basis than the Swartkops estuary. As the effects of flooding on mud prawn populations have proven to be severe, the management of the prawn population at the Gamtoos estuary should be directed at maintaining a large enough standing biomass at all times to prevent population numbers to drop to a critically low level after flooding. A further conclusion is that the similarity between spotted grunter diet and preferred bait of anglers affords resources managers with a straightforward control mechanism for the exploitation of both resources. Catch effort can be controlled through prawn removal control, and the pressure on prawn stocks can be managed through bag limits on spotted grunter.

3.5.3 Current rates of exploitation and CPUE compared with historical data.

It is not within the scope of this study to speculate whether the estuarine recreational linefishery has experienced the same degree of over-fishing, followed by a shift in target species, as described for inshore commercial linefisheries (Brouwer 1997; Pilford and Pampallis 1993; Fielding *et al.* 1994). Many marine line fishermen interviewed in an earlier study (Unpublished data) felt that elf numbers and average size had declined, although the species still contributed in large numbers (up to 16% of total monthly catch) for the period 1998 – 2000 (Jooste 2000). The fact that elf catches have declined in estuaries suggests that factors other than over-fishing could be involved. The same can be said for Cape stumpnose, which have been shown to be present in high numbers as juveniles in the Swartkops estuary *Zostera* beds. The common dietary items of both species are also still common in the Swartkops estuary, although stomach content analyses done on spotted grunter between 1972 and present show a large decrease in the amount of Mollusca and Annelida consumed. It could

be tentatively concluded that over-utilisation or physical changes in the estuary might have altered the composition of benthic macrofauna over the past few decades.

Another sign of changing angler behaviour is the perceived desirability of more remote estuaries as angling destinations. Marais (1983b) reported that it was surprising that the Gamtoos estuary, so rich in large fish species, was attracting so little angling attention. Ten years later, the estuary had become the premier destination for kob fishing and a highly popular angling destination. This can be interpreted either as the exploration of new fishing grounds as the number of anglers increase and utilization pressure builds up in systems close to urban centres, or as a sign that systems such as the Swartkops estuary are in a decline, and anglers are seeking out new, better fishing grounds. A worrying trend, underlined by Pradervand (1998), is the relatively high CPUE recorded during fishing competitions. Although some suggestions were put forward in this study to explain some of the differences in catch data and fishermen effort, it has to be concluded that fishing competitions, especially week-long events such as the Gam-1000, puts a large amount of pressure on estuarine fish and invertebrate resources. As Pradervand (1998) concluded that mortality rates are still high for released specimens caught during light-tackle events, even contests where fish are weighed and released have the capacity to cause high mortality rates of fish occurring in low numbers in an estuary. As the amount of bait used is not affected by the treatment of the fish after a catch, and as many forms of artificial bait are illegal or selected against during these competitions due to their low CPUE, it must also be concluded that protracted fishing competitions places a heavy burden on estuarine invertebrate bait resources. If every angler reporting either mud- or sand prawn as bait used collected 50 prawns per day as is legally allowed, the total amount of prawns removed during the competition amounted to 4800 individuals in one week.

As long as the current levels of fishing pressure remain at their present levels, the amount of bait sourced from estuaries and specifically estuarine sediments will remain high. At this point in time, it would be wise to re-evaluate the approach to the recreational user group. Pradervand (1998) and Daniel (1994) have already highlighted the need to reduce the negative associations the public can harbour towards recreational, but specifically boat-based anglers. Protracted fishing competitions resulting in the discarding of fish after weigh-in creates the impression of a wasteful industry. An increase in the amount of anglers supporting catch and release fishing is also requested. With the closure of beaches to 4-wheel drive vehicles, it should be obvious to assume that the user group affected by this legislation, if intent on

continuing their recreational angling, will increase the levels of angling pressure in estuaries. If anglers who use estuaries purely as a form of relaxation or sport, and need not supplement their economic situation by their fishing, they should not have any difficulty in accepting a change in the way bait resources are managed.

3.6 Management recommendations

- Although the results obtained from the Gamtoos estuary study is not representative of the entire province due to the variation in the fish species component of different estuaries, it is clear that there is a high degree of reliance among estuarine recreational anglers on bait sourced from muddy and sandy sediments as well as juvenile mullet. This study have demonstrated that with the exception of spotted grunter, all other targeted fish species can be captured at a similar CPUE using bait other than estuarine invertebrates. Active attempts to steer anglers away from the use of estuarine bait species when not targeting grunter could reduce the pressure on the bait resource without detracting from the anglers fishing enjoyment.

- The management of mud- and sand prawn exploitation is very closely linked to the targeting of spotted grunter by the recreational fishing sector. From a management point of view, the control of removal rates of either prawns or grunter should be linked during decision-making processes. In simplified terms, pressure on prawn resources will remain in estuaries where spotted grunter is a target species. Conversely, control over the amount of grunter removed per annum can also be attained by manipulating the amount of prawns available for removal by recreational anglers.

- Unless the behaviour of sport anglers are changed to include the use of commercial bait, artificial lures and flies, or are curtailed with stricter bag limits on fish that is specifically targeted with prawn species as bait, the pressure on the estuarine invertebrate populations will remain high. The recent closure of beaches to four-wheel drive vehicles will more than likely increase the pressure on estuarine resources, thus increasing the need for closer inspection of current removal rates and monitoring of the number of bait permit holders.

- Although angler catch contribution is similar to species abundance, the catch percentage of many preferred target fish species such as spotted grunter and kob, deemed to be in a

decline in many eastern Cape estuaries, is far greater than these species' relative abundance as calculated from gill-net surveys. This suggests that these species are heavily targeted, especially during prolonged fishing competitions. It is doubtful whether, from a resource management point of view, week-long contests, involving nearly a hundred anglers and resulting in the capture of over 350 fish should be allowed to take place on a regular basis.

4. The sediments, current flow and topography of the Gamtoos estuary study site

4.1 Introduction

During the preparation of the disturbance experiment it was noted that the particle size structure of the top 40 to 50 cm of the mud bank varied across horizontal and vertical gradients. This variation appeared to be related to tidal flow, velocity and current patterns. As a large difference in sediment structure (particle size distribution) could have a possible impact on the distribution of mud prawns, the sediment of the top 40 cm of mud along six transects located within the experimental area was sampled and described. The distribution of a prawn population in relation to the mouth of the estuary and current movement, as well as the type of sediment occurring at the site have been shown to influence their fitness. Hanekom & Erasmus (1989) described two distinct populations of mud prawn in the Swartkops estuary – one consisting of stunted individuals, and the other of large prawns. Females from the stunted population in the middle reaches of the estuary had a well defined spring and summer breeding cycle, with a calculated reproductive output of 332 kJ $m^{-2}y^{-1}$ and a reproductive biomass ratio (Pr/B) of 0.26. Females from the lower reaches of the estuary were characterised by larger individuals and had a longer breeding season resulting in three broods per annum with a calculated reproductive output of 1331 kJ $m^{-2}y^{-1}$ and a reproductive biomass ratio (Pr/B) of 0.53. Female to male ratios were higher in the lower reaches of the estuary, and ovigerous females had a larger overall carapace length. This tendency is in line with the observation of Hanekom and Erasmus (1988) that the average size of prawns decreased from the mouth towards the upper reaches of the estuary due to decreases in suspended food particles transported by marine flood tides. The inflow of sea water into the old channel is often impeded by the ebb tide outflow from the lagoon. It is therefore very likely that the old channel and lagoon, receiving restricted and diluted flood tide flow, does not receive as much nutrients as areas in the main channel that is a similar distance from the mouth of the estuary, thus limiting the fitness of the population.

If it is at all possible, the current sedimentary state as well as sedimentary history of an estuary should be considered when planning the management of species dependent on the sediments for survival. Despite the implication of its name, mud prawns need a relatively high component of coarse material in the sediments in order to construct and maintain its burrows (Hill 1967; Wooldridge 1968). Various authors (Hanekom *et al.* 1988; Hodgson 1987;

Hodgson *et al*. 2000a) have described the optimum habitat (highest biomass as well as production) for mud prawn to be the muddy inter-tidal reaches of the middle reaches of estuaries with a sediment composition roughly as follows: MDϕ: 2.6; mean % subsieves: 16.7; mean shear strength: 49g.cm^{-2}; mean N content: 0.40 mg.g^{-1}. It was noted (Hanekom 1989) that as soon as the fine particle (< 63 µm) content of the sediments increased above 20%, prawn numbers declined markedly. Hill (1967) observed that prawns were unable to burrow in course sediments due to continuous burrow collapse, and that prawns located in very fine sediments spent more time clearing their burrows than prawns in intermediate mud. Thus mud prawn requires an intermediate sediment state consisting of a sand/silt mixture, suggesting that their ideal habitat is the section of the estuary that receives sediments from marine and fluvial origin. Reddering and Esterhuysen (1984) described the deposition of muddy sediments in an estuary as a relatively quiet water process, taking place at the freshwater/salty estuarine water interface. This statement has various management implications. The freshwater/estuarine water interface is dependent on the amount of freshwater input the estuary receives, which in turn influences the depth of the estuary mouth through ebb tide scouring (Allanson *et al.* 2000; Marker 2000). The position of mud banks, although on a long time scale, has the potential to shift in relation to freshwater input into the estuary, as this affects the extent of marine sand penetration.

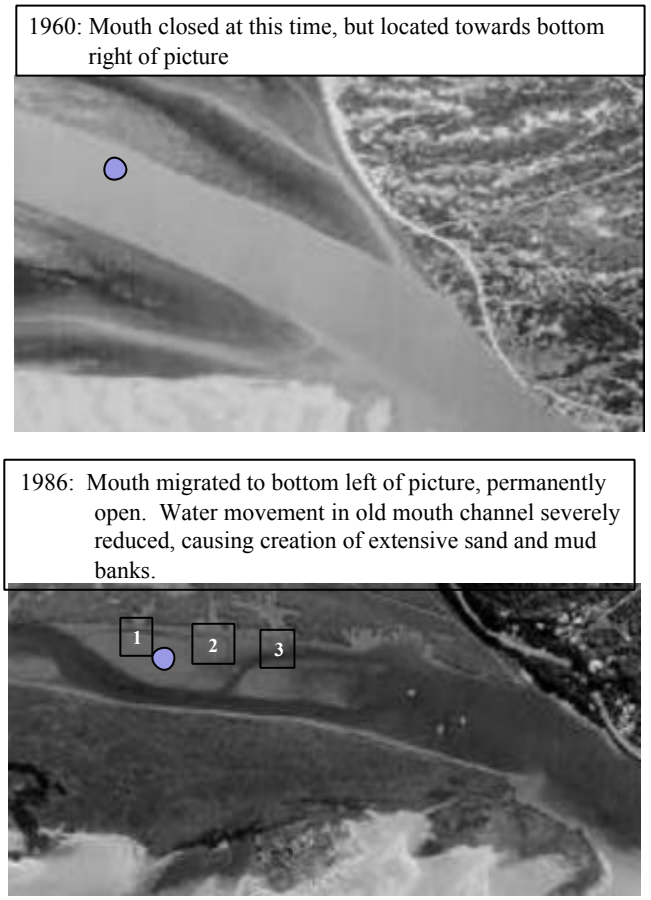

Figure 6. A comparison between the condition of the study site (blue dot) between 1960 and 1990. Numbers 1 – 3 indicate the positions of freshwater creeks that have formed in the vicinity of the study site.

Historical data for the distribution of sediments and related estuarine species does not exist for the Gamtoos estuary. It can be seen from Fig. 6, however, is that the estuary is capable of undergoing large-scale changes in mouth and lower estuary morphology. The study site, currently over 160 m wide and more

than 200 m long, did not exist in 1960 as is clear from the two photographs (Fig. 6). These changes, although over a period of 30 years, will affect benthic species distribution in the Gamtoos estuary.

Such changes in the distribution of sediments and related benthic fauna have been summarised by Allanson *et al.* (2000) for the Knysna lagoon. The current sediment and benthic macro-faunal distributions was compared with those recorded by Day *et al.* as cited by Allanson *et al.* (2000), and in most cases linked changes in species composition over the time period to changes in sediment composition of the estuary. Increased sediment loads due to bad agricultural practices and increased urban settlements in the catchment resulted in a general fining of sediments (Allanson *et al.* 2000), whilst physical characteristics such as salinity have remained relatively unchanged. Inter-tidal sediments have become more suitable for settlement by many species not recorded in 1952, as well as causing an increase in numbers of individuals of species previously recorded in the muddy zones. At the same time, sediments of the lower estuary western shore (Leisure Isle) have changed from muddy to sandy. Species present in 1954 were *Zostera* beds and mud prawn as well as associated amphipods and isopods, but these have not been recorded in the present study. The sediment and species characteristics of the eastern shore of Leisure Isle mud with (*Zostera* beds and mud prawn) is still as described by Day *et al.* in 1954 (Allanson *et al.* 2000). The area where mud has been replaced by sand is directly opposite the mouth of the estuary, and it can therefore be concluded with some certainty that these sediments have been deposited under the influence of flood tides, as it resembles the sediment distribution described by Reddering and Scarr (1990b) for the Gamtoos estuary. Marker (2000) suggested that this might be the case, attributing sand movements to wave refraction and reduced freshwater input, but also warns that the patterns observed could be cyclic.

Therefore, as seen in the case of the Knysna estuary, changes in sediment and species distribution can occur without decreasing species richness or diversity. From a management point of view this raises some questions. Firstly, at what point do changes in sediment input, freshwater flow and sediment dynamics become detrimental to the system, and secondly, if benthic macrofaunal populations are to be considered as mobile over time, what management action should be taken in respect to protected areas within an estuary? The demarcation and management of key conservation areas for species thus becomes a dynamic process, requiring constant re-evaluation of prevailing conditions to determine whether a species has only shifted

its distribution, or whether it is under threat due to loss of suitable habitat. The fact that sediment movement in estuaries can also be cyclic (Marker 2000) only serves to further complicate the scenario.

The muddy sediments in the old channel of the Gamtoos estuary provide an ideal study area in which to assess the influence of muddy sediment deposition on a mud prawn population. The position of the mouth is very dynamic. In its current position the mouth is permanently open, although periodic closure did occur during the 1960's when the inlet was located further to the northeast (Reddering and Scarr 1990a). This channel finally closed in 1978 (Reddering and Esterhuysen 1984), cutting the abandoned mouth off from the ocean except for occasional intrusions during storm conditions. The old channel or "blind arm" is still connected to the main channel and thus remains tidal. Sedimentation patterns in the old channel are therefore different to the rest of the estuary. The latter was described by Reddering and Scarr (1990b) as dominated by marine tidal action and aeolian action in the adjacent dunefield, depositing sand in the mouth of the estuary. Tide-induced deposition of clay particles derived from the catchment also takes place, and should take place at a faster rate in the calm waters of the old channel. The most up to date description of the sediments of the old channel is provided by Reddering and Esterhuysen (1984). Although no information is available on the benthic macrofauna that occurred at this site, current sediment patterns can be related to historical data to determine whether any significant changes has taken place, and whether these changes could impact on mud prawn habitat requirements.

As the experimental plot was extensive, (even though situated more towards the back of the mudflat) a wide range of sediment conditions was incorporated. This included a zone close to a side channel, a basin and surrounding flats where sediments tended to be relatively fine-grained. By incorporating sediment analysis into the experiment, a sediment distribution profile was generated, facilitating for the quantification of the influence (if any) that the sediments could have on the distribution and density of mud prawn populations or the recovery rate of disturbed areas.

The objectives for this chapter are:

- ✓ To describe the physical environment of the study site.
- ✓ To relate the results of study site sediment analyses to ideal mud prawn habitat descriptions from literature, and to propose what possible influences the environmental factors described could have on the study population.

4.2 Methods

4.2.1 Estuary classification

In order to locate suitable study sites, but also to determine the general composition of the inter-tidal and sub-tidal areas of the estuary, a survey of the estuary was undertaken during two days of spring low tide during September 2001. The sediment composition and structure, vegetation cover, width of the inter-tidal area and dominant species present were described. As the estuary was sampled during a low tide, the upper reaches of the estuary was only navigable to a point 200 m above the Ferry hotel, where-after the river was to shallow for the boat to travel any further and sampling was halted.

4.2.2 Sediment characteristics and analysis

In June 2002, core samples of the top 40 cm of sediments along 6 transects, set up 20 m apart within the disturbance experiment, were taken at 10 m intervals. As compaction of the samples almost always took place, the core obtained was usually in the region of 32 – 35 cm in length, but was representative of the sediments to a depth of 40 cm. The cores were collected using a 45 cm long thin-walled stainless steel pipe (wall thickness 1.5 mm) with an inside diameter of 23 mm. The removed cores were divided into 4 equal sections of approximately 10 cm each. The samples were dried at 60 ºC for 15 hours, where after the samples were loosened with a mortar and pestle prior to being sieved through a set of Kingtest stainless steel laboratory test sieves with mesh diameters ranging from .500 mm to 63 µm on a log – based scale (5 sieves in the Udden-Wentworth scale). A receiver below the 63 µm sieve collected the very fine sediments in the sample. Particle sizes on the mud bank in general were fine, thus the use of 1 mm and 2 mm diameter sieves were not required. Once individual samples were sieved and divided into size classes, each size class was weighed on a Scaltec SBA 52 balance (d = 0.01 g) balance. The different size classes were then noted as a percentage of the total weight of the 10 cm sub-sample from a core. The results obtained were also compared to a similar study performed by Reddering and Esterhuysen (1984). Sediment distributions were plotted on Krig

maps using Surfer32 for visual analyses, and analysed statistically using the Factorial ANOVA functions and post-hoc tests of Statistica 6.0 (at 95% confidence intervals).

4.2.3 Current patterns and velocities

As the rate of flow over the mud bank was for the most part too slow to measure with the standard equipment and the water too shallow to use large floats, it was decided to calculate current velocity using the sediment composition of the study site as an indicator. During a sampling trip to the experimental study site, the flooding time and pattern were noted for the mud flat. An attempt was also made to calculate current velocities over the study site by using the typical sediment distribution obtained from the sediment analyses performed.

4.3 Results

4.3.1 Sediment characteristics

Fig. 7 illustrates that the percentage contribution of large particles (≥ 500 µm) sampled from 1984 to present remained very low, suggesting that marine sediments are not deposited on the site in large amounts. While the amount of medium to coarse sand (250 - 500 µm) have decreased by less than 2% and 1% in top and bottom samples respectively between 1984 and present, the percentage of fine sand (125 to 250 µm) have decreased by 14. 3% and 9.6% in top and bottom samples respectively since 1984. Coupled with this decrease in medium to fine sand is an increase in sediments smaller than 0.125 mm of 16.4% and 10.31% in top and bottom samples respectively.

The topography of the study site was determined by sediment deposition from currents feeding onto the mud bank near the salt marsh fringe as well as the current moving past the front of the mud bank into the lagoon (Fig. 8). The result of this pattern of deposition is a slightly saucer-shaped mud bank due to the small berm consisting of

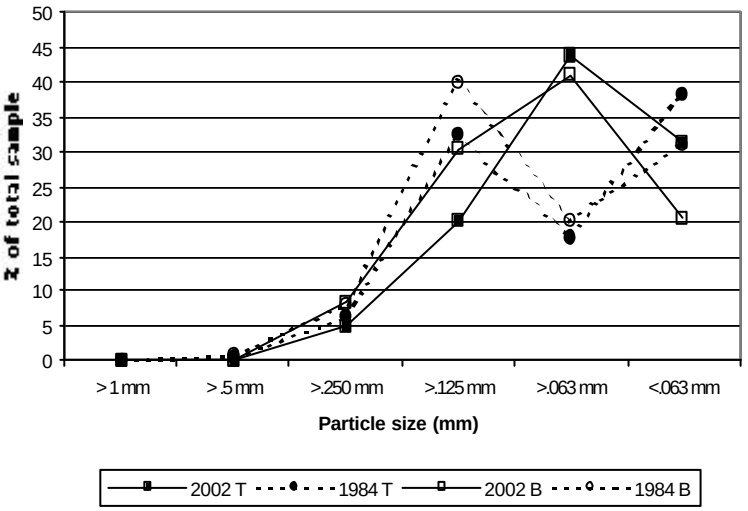

Figure 7. A comparison between sediment sizes recorded in 1984 and during the present study. Samples marked T were collected at the surface, whereas samples marked B originated from 40 cm below the surface.

coarser sediments accumulated at the low water mark, and the deposition of silty sediments from slower moving fresh waters' input towards the high water mark. The saucer-shaped characteristic of the bank is most pronounced on the lagoon side of the bank (transects C – E), where the overall length of the mud bank exceeds 160 m. As the mud bank decreases in width towards the main channel (see Fig. 2), this feature becomes less pronounced (Transect A). Overall variation in elevation across the entire surveyed area never exceeded 20 cm.

The bank topography obviously influences water movement during tidal cycles. Water enters and flows off the bank through a channel at transect E, from where the basin is flooded until the rising tide spills over the berm at the LWM and enters the basin from feeder channels at the high tide level. Drainage follows the same pattern in reverse; thus the centre of the bank can remain submerged for most of the tidal cycle. If the tide does not recede below the lowest point of the mud bank behind the berm, such as during storm conditions, the mud bank is not exposed, even during a spring low tide.

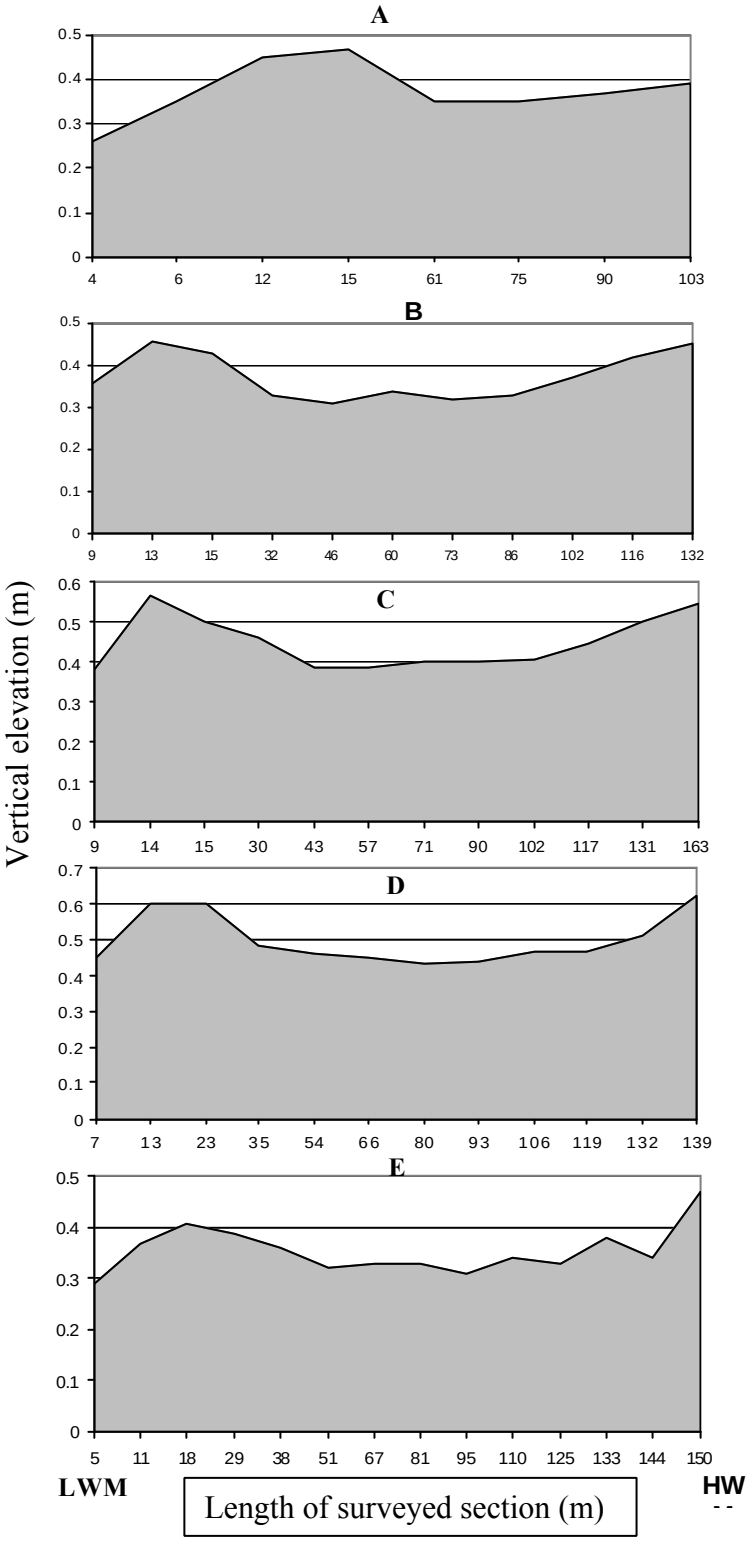

Figure 8. Profile of the mud bank on which study was conducted. Transects were surveyed at 20 m intervals perpendicular to the LWM. The survey was started next to the disturbance experiment (Transect E), working towards the main channel (Transect A).

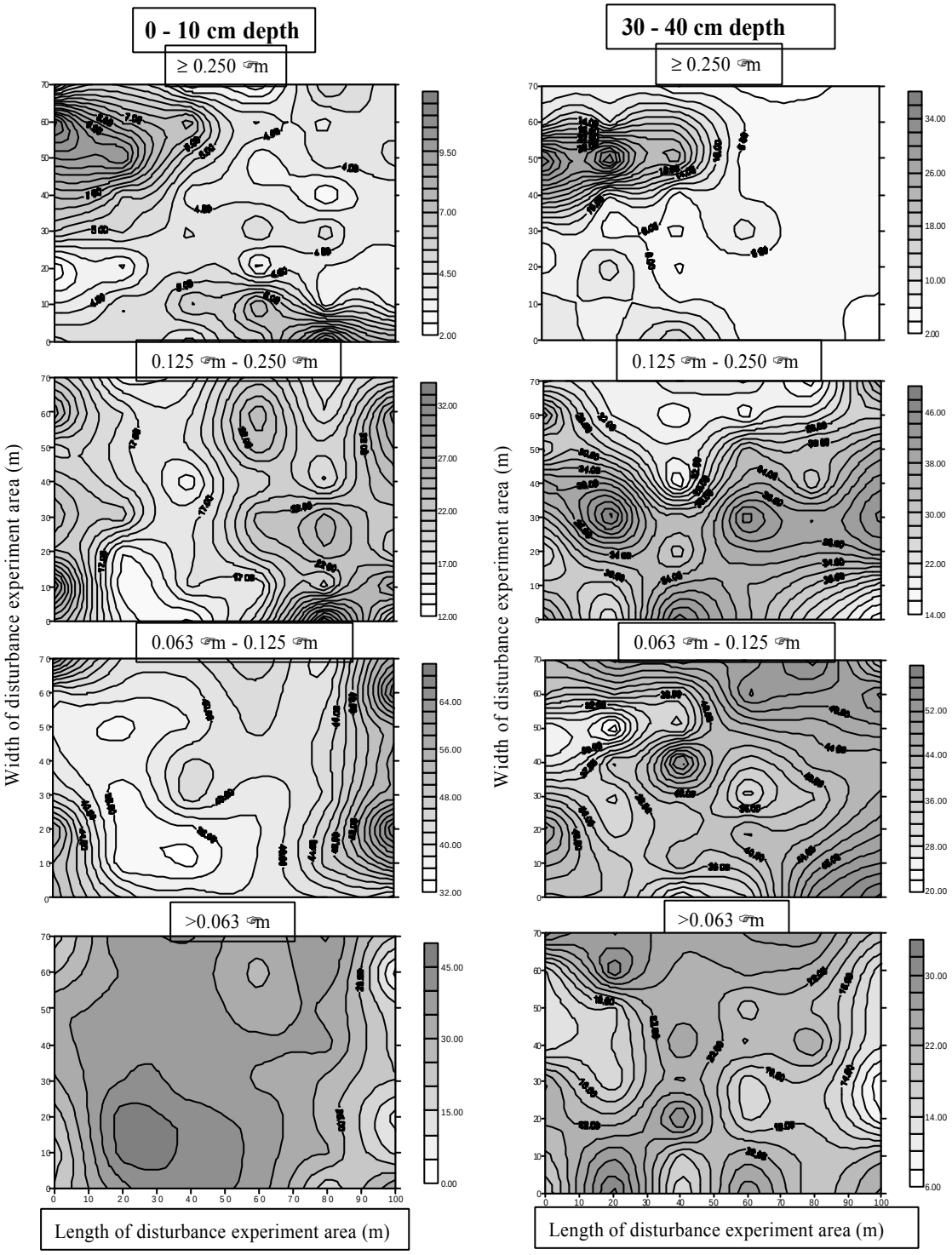

Figure 9. Percentage of different size sediment groups of the Wentworth scale present in the sediments of the top 10 cm of the study area compared to those at a depth of 30 – 40 cm. The X-axis of the individual figures is orientated towards the LWM, while the Y-axis is orientated towards the main channel.

The entire sediment profile of the disturbance experiment is presented in Appendix A. For the purposes of the results, only results from the top 10 cm and the bottom 30 – 40 cm of all the cores will be presented graphically (Fig. 9). At the surface of the sampled area, the ≥ 250 µm particles (medium sand) occur in highest concentrations at the front left hand corner of the plot

where flood tide water first spills onto the bank, and the back right hand side of the plot, where one of the back feeder channels enter the plot. Sediments of the size range 125 µm - 250 µm (fine sand) are concentrated on the right half of the plot, and occurs in slightly higher percentages at the back of the plot. The 63 µm - 125 µm sediments (very fine sand) has very much the same distribution pattern as the previous size class, apart from a small concentration in the top left corner of the plot, where a smaller feeder channel enters.
The sediments are also found more to the right hand extremes of the plot as compared to fine sand. The finest silt and clay component, of a size smaller than 63 µm, has a totally different distribution. Percentages are highest in the back left area of the plot, with reduced concentrations towards the front and right hand side of the plot.

As particle size distribution were analysed at depth intervals of 10 cm, a gradual shift in size distributions can be observed from the surface to the final depth interval (30 – 40 cm) which shows the clearest shift in sediment distribution. Here, medium sand is heavily concentrated towards the left front side of the plot. Fine sands are evenly spread along the middle horizontal axis of the plot, occurring in very low concentrations at the front and slightly higher concentrations at the back of the plot. Very fine sand has a relatively even distribution, but shows some degree of increased concentration towards both the front and back of the right hand boundary of the plot. Silt distribution is also relatively even, with some increased concentrations at the centre and to the left of the plot. Factorial ANOVA analysis of the sediment compositions of the sites, when analysed comparing distance from main channel to distance from LWM, as well as depth yield significant differences in sediment distribution, although low p-values suggest that the result should be treated with some caution. Thus, the analysis of the sediments was broken down to a particle range at a time tested against tidal height and distance from channel, tidal height and depth as well as depth and distance from channel. The results obtained indicated that significant differences between sediment particle distributions did not occur on a uniform basis. Graphs of significant interactions are presented in Appendix B. The various interactions tested are summarised in Table 5.

Table 5. Summary of results from Factorial ANOVA's performed to test for variation in sediment distribution in the experimental site. A tick mark indicates the occurrence of a significant difference detected (at 95% confidence intervals).

Sediment category	Tidal elevation vs. Distance to channel			Distance to channel vs. Depth			Tidal elevation vs. Depth		
	T	Di	T&Di	Di	De	Di&De	T	De	T&De
Medium sand	✓	✓	✓	✓	✓		✓	✓	
Fine sand	✓	✓		✓	✓		✓	✓	
Very fine sand	✓	✓	✓				✓		
Silt and clay	✓			✓			✓	✓	✓

The statistical analysis supports the visual analysis of the Krig diagrams. Medium and fine sand is responsible for the greatest amount of variation in the study site, while silt and clay have the most uniform distribution. All sediment classes vary significantly along tidal gradients, whether compared to distance to the main channel or to sediment depth. Medium sand, fine sand and silt and clay have significant interactions between tidal elevation and distance to main channel, while no significant interactions occur between distance to channel and sediment depth. The only significant interaction between tidal elevation and sediment depth occurs with silt and clay particles. Overall, sediment distribution at depth is least influenced by distance to the main channel, while tidal elevation, both at depth and in relation to distance to the main channel, seem to influence sediment distributions the most.

Post hoc (Tukey) tests were also performed to identify the sample(s) responsible for the significant differences. In most cases the significant interactions were the result of multiple samples, and are therefore a true reflection of the sediment composition of the mud bank. Exceptions to this statement, where only a small number of samples were responsible for the variations detected, are: Tidal level vs. distance to channel, medium sand category, distance to channel vs. depth, medium sand category and tidal level vs. depth, medium sand. The same samples were not always responsible for the significant differences noted, underlining the concentrated nature of medium sand distribution.

The results of the estuary survey are presented in Appendix C. Sections of the inter-tidal area from mouth to upper reaches was described and numbered as soon as a change in structure or substrate was observed. Altogether, 21 different site descriptions relating to vegetation, sediments and slope was recorded as well as 15 different substrate conditions. The only areas where the inter-tidal area exceeded 20 m in width were at the blind arm and mouth regions of

the estuary. As can be expected, sand prawn was the dominant species in the mouth and lower reaches up until the blind arm connection with the main channel on the east bank and the steep sided cliff face occurring on the west bank lower reaches. Mud prawn numbers were highest on the two mud banks either side of the blind arm channel as well as the east bank lower reaches, where the inter-tidal area was greater than the middle and upper reaches. Prawn numbers were also high around the muddy creek entering the estuary on the west bank just above the cliff face. Above this point, the estuary becomes steep-sided, the inter-tidal area becomes very narrow and prawn numbers drop to medium to low densities with the exception of the area around the Kingsway slipway, where the inter-tidal zone is wider and local residents enforce a no-take rule. Prawn numbers are low all the way above the N2 causeway, but they are to be found, together with some sand prawns, on the coarser river-derived sediments deposited at the tidal head. As can be expected from a channel-like estuary such as the Gamtoos, the sub-tidal populations of prawn are relatively limited. Nowhere is the extent of sub-tidal populations greater than the inter-tidal, with the majority of sub-tidal stocks being narrower than 5 m in width. The majority of areas that have a sub-tidal stock wider than 5 m is located in the lower and middle reaches of the estuary, and are located in areas where the estuary profile widens, at creek or side channel inflows or where point bars have developed in river bends. The only areas within normal distribution ranges where no prawns were found were in areas where road fill has caused rubble build-up in the inter-tidal zone, rocky areas below a cliff face, or where the estuary has undercut the bank and no inter-tidal zone exists. An exception is at the Ferry hotel, where a 200m stretch in front of the hotel and camping site was devoid of life, while prawns were located on either side of the hotel grounds.

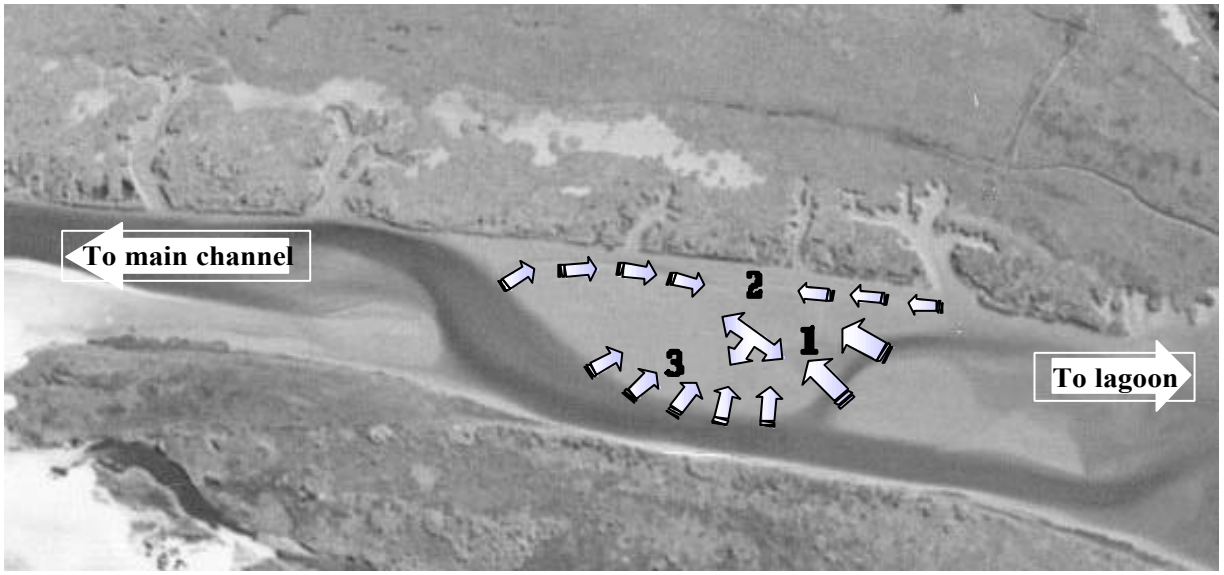

Figure 10. Section of an aerial photograph showing the experimental site with arrows depicting water movement over the mud bank. Numbers 1 – 3 indicate the sequence of flooding during the flood tide.

4.3.2 Current pattern

As described earlier, the mud bank in the old channel floods and drains in a distinctive pattern caused by the topography of the bank (Fig 10). As water rises during the flood tide, the small berm along the low water mark prevents flooding of the bank except at point 1, where a channel has been formed onto the bank. Water first fills the basin formed in the centre of the bank until the rising water reaches the back feeder-channels at point 2. At this point, the basin begins to fill up from water flowing in all three channels. Rising water finally over-tops the berm from right to left, rapidly flooding the remainder of the bank. The whole process takes place relatively fast due to the low relief of the entire bank. Flooding is normally completed in 40 minutes. Draining takes much longer, especially if water flowing out of the lagoon is restricted at the main channel connection due to rough sea conditions. After exposure of the berm, drainage takes place via the three channels, until the lowering water level exposes the two back channels. From this point on, the entire bank drains via the main channel at point 1, which is only about two meters wide and about 30 – 40 cm deep. Due to the single drainage point and constricted outflow, the central basin area is still submerged more than an hour after the front of the bank has been exposed. The degree to which the central area is exposed depends entirely on the speed at which the lagoon drains.

The fact that the sedimentary history of the site was so diverse, not only at depth intervals but also across tidal gradients makes the calculation of current velocities almost impossible. The sediments are always poorly sorted, suggesting that different current speeds are involved with sediment dispersal over time as well as within a single tidal cycle.

4.4 Discussion

4.4.1 The physical environment of the study site.

The results from sediment analyses indicate that the concentration of fine particles present in the blind arm sediments have undergone a marked increase in the last 18 years (Fig 7). This increase can be attributed in part to changing ebb and flood dynamics in the estuary as well as changes in the position of the estuary mouth since the 1960's (Reddering and Esterhuysen 1984). The increased input in suspended sediments as a result of agricultural practices in the catchment and around the estuary most likely also had an influence on the sediments. The formation of three freshwater creeks above the study site (Fig. 6) resulting in fine particle deposition during periods of freshwater flow over the study site further contributed to the

increase in volume of fine particles deposited at the site. The shape of the study site (Fig. 8) suggests that the majority of the sediment load transported by the currents is deposited relatively soon after water flows over the bank, causing the build-up of medium-grained sediments at the LWM and HWM and a basin dominated by finer sediments. The only deviation from this pattern is caused by the drainage channel on the lagoon side of the bank, where flood tide inputs formed a fan of medium sediments, as shown by the sediment particle analysis presented (Fig. 9). Although this description suggests that the sediment particle size distribution patterns in the study site should be fairly uniform, particle size analysis have highlighted the high variability of sediment composition along tidal level as well as depth, and to a lesser degree from the lagoon side to the channel side of the site (Fig. 9). This indicates that the sediment deposition pattern has not been uniform over time. Changes in current position and velocity over time as well as during periods of high and low water flow could be responsible for this variability. At a depth of 40 cm, the finest component of the sediments comprised 20.3% of the sediment volume, compared to 31.4% at the surface (Fig.9). It must be kept in mind that gravitational pull from current flow as well as bioturbation by burrowing macrofauna normally move fine sediments from the surface to the deeper layers (Reddering and Esterhuysen 1984), increasing the fine sediment component at depth. It can therefore be assumed that original deposition levels were below 20.3%. The increase in the fine sediment component towards the surface underlines the fact that current velocity over the site is decreasing.

4.4.2 Study site analyses, ideal mud prawn habitat and possible influences of environmental factors on the study population.

The mud bank itself has only started forming since the migration of the mouth to the current position and the full closure of the previous mouth, less than 30 years ago, and continue to undergo changes. Wind-blown sand from the adjacent dune field, sediment input from the muddy creeks above the mud bank and from normal estuarine sedimentation continue to fill the old channel. This will most likely result in the ultimate silting up of the old arm, returning the estuary to the typical channel-like shape it normally has. Reddering and Scarr (1990a) stated that the depth of the old channel at the vicinity of the confluence with the main channel was approximately 1 m at low tide. During this study the depth was found to be considerably less. Several longitudinal sandbars have formed near the confluence, and several small muddy islands in the old channel are exposed during low tide. The overall depth at low tide was not measured, but was estimated to range between 40 and 60 cm. The ultimate fate of the blind

arm implies that the standing biomass of mud prawn is also going to experience a serious reduction. The survey conducted here indicated that the majority of the wide (more than 10 m) inter-tidal areas are related to the old channel (Appendix. C). The wide mud banks either side of the old channel and the associated widening of the inter-tidal area either side of the channel for ± 100 m will not persist if the channel is silted up. This leaves about 500 m of muddy inter-tidal (points 12, 14, 15, 16, 17, 21, 22 and 23 in Appendix C) in the lower reaches wider than 5 m and containing medium to high densities of prawn comprising the most productive section of the population.

The population of the disturbance experiment is currently not situated in ideal sediments as defined by Wooldridge (1968) and Hanekom (1989). Fine sediment (silt and clay) particle percentages exceeded 20% at all depth increments sampled, averaging 27.6% for the entire study area. As this percentage exceeds the critical level noted by (Hanekom 1989), lower numbers of prawns could be expected. As long as the fresh water creeks are present above the mud bank, this situation will persist. The freshwater input can have a further negative effect on mud prawn. Hanekom (1989) noted a 49% mortality rate in the mud prawn populations of the Swartkops estuary middle reaches after a medium intensity flood, suggesting that mud prawn are sensitive to sediment conditions as well as salinity fluctuations. Mud and sand prawn are able to osmoregulate between wide salinity ranges, and it was found that the mortality was caused by the displacement of stunned but live prawns from their burrows (Hanekom 1989). No dead prawns or population decreases was noted in the lower reaches of the estuary, suggesting that the unfavourable conditions have decreased sufficiently for mud prawn to survive. As the Gamtoos estuary is prone to flooding, it can be expected that the mortality rates described by Hanekom (1989) could also apply to the Gamtoos estuary after flooding. As the mud prawn population in this system is already smaller than that of the Swartkops estuary, it can be concluded that the mud prawn population in the Gamtoos estuary is more at risk due to the smaller suitable habitat and frequent flooding events. By implication, the prawns are therefore also more vulnerable to over-exploitation.

4.5 Conclusions

When the standing biomass, or distribution and richness of any resource is evaluated, the simplest method available to scientists is a comparison of current figures with historical data. Any changes observed can then be compared to shifts in utilisation patterns to determine future management strategies. This is, however, a highly simplified explanation of the process. In the management of any resource there is a multitude of complicating factors that had to be taken into consideration. In the management of sedimentary macrobenthos, few other external factors play such a monumental role in their distribution and health as catchment land use. Although the estuaries studied will only suffer from reduced fresh water flow in extreme cases (that result in mouth closure), the degradation of land in the catchment have a direct role in influencing the volume and size of suspended matter imported into the system. This change in sediment input, in turn, will result in changes in sediment distribution that will have the same influence on the distribution of benthic organisms as described for the Knysna estuary (Hodgson *et al*. 2000).

The dynamics of freshwater inflow, the area of an estuary dominated by sea water flood inputs and the resulting sediment characteristics have been well documented, (Allanson *et al.* 2000; Marker 2000; Reddering and Scarr 1990b; Reddering and Esterhuysen 1984). The effects of a change in the controlling current dynamics of an estuary has also been described (Marker 2000). Cooper (1993) in his description of an East Coast estuary resembling the Gamtoos estuary (narrow, confined river-dominated estuary) described sedimentation patterns as cyclical, altering between periods of build-up and severe floods. The sediment patterns of an estuary, as well as the nutrient state of the estuary, is directly governed by the management of the river catchment. It is therefore not surprising that a reduction in freshwater flow is listed as one of the most pressing concerns of estuarine managers (Turpie 2002). Concurrent with a reduction in freshwater flow is an increase in marine dominated sedimentation in estuaries. The influence of this shift in sedimentation patterns is not well described, but most likely will favour those infaunal species that prefer coarse sediments (Turpie 2002). As the deposition of muddy sediments takes place at the freshwater/salty estuarine water interface (Reddering and Esterhuysen 1984), it can be assumed that under reduced freshwater flow, the area dominated by marine sediments will intrude deep into the lower reaches of the estuary, and could ultimately result in mouth closure. The area where muddy sediments are deposited will also shift away from the normal position, suggesting that a species such as mud prawn, which

prefers a mixture of muddy and sandy sediments to burrow into, will experience a shift in ideal habitat away from the lower reaches of the estuary. Although not currently quantified, an angler who has been active in the Swartkops estuary since 1987 have reported that the recent intrusion of marine sand into the lower reaches has passed zones recorded by Hanekom (1980) as ideal mud prawn habitat, and that some sections of the estuary is shallow enough to wade across at high tide. Bad agricultural practices also lead to the shallowing of some major East Coast estuaries. In 1884, the Umfolozi mouth was deep enough to accommodate a navy frigate, which measured the depth of the mouth to between 3 and 4 fathoms (Harrison (1976). Extensive sugar cane farming and vegetation clearing has changed the sediment load of the river to such an extent that the mouth could be waded at low tide in 1995 (pers. obs.).

The negative impacts of reduced freshwater inflow is not only limited to the distribution of sediments in an estuary. Allanson and Read (1995) as well as Grange *et al.* (2000) have shown that restricting freshwater input severely impacts on the productivity of the eastern Cape estuaries studied. These estuaries switched from a micro-algal based energy source during normal cyclic water flow conditions to a detritus-based system under controlled flow conditions. In terms of the Gamtoos estuary, a closing of the old channel would be the result on natural processes, but would cause a shift away from the broad inter-tidal regions, which will most likely result in a marked decrease in standing biomass. This underlines the fact that the management of estuarine bait species is inextricably linked to catchment management, again underlining the need to bring estuarine management policies in line with international management strategies based on the management of the entire system as a unit as described by Clark *et al.* (2002).

As sand prawn and pencil bait colonise the more dynamic sandy sections of an estuary, and as sand prawn has a distribution that stretches into shallow marine bays (Cockroft and Tomalin 1987), their continued presence under current exploitation levels seem to be more secure. As collection pressure on sand prawn is lower than mud prawn (see previous chapter), and their ability to cope with flood events are better than mud prawn (only 28% mortality recorded compared to 49% of mud prawn after a medium intensity flood) the need for active intervention is perceived to be less than for mud prawn.

4.6 Management recommendations

- ✓ The management of mudprawn populations cannot be approached without the incorporation of catchment management and freshwater flow maintenance into a management plan.

- ✓ The mud prawn habitat is dynamic, and although large scale changes does not occur without the aid of major perturbations such as floods, medium (10 – 20 years) and long term (20 + years) changes in sedimentation patterns have been documented in other estuaries and observed during this study. In formulating a management plan for mud prawn, it should therefore also be kept in mind that any zonation that is carried out, for instance open and closed areas, requires frequent re-evaluation of the habitat.

- ✓ For the purpose of managing mud prawn in the Gamtoos estuary, it should be accepted that the population occupying the old channel is more than likely of a temporary nature. The populations of mud prawn supported by sediments associated with the old channel, however, constitutes a large percentage of the current standing biomass of the species. Levels of exploitation of bait species found in the muddy sediments as well as fish catches of species, such as spotted grunter, should therefore be managed cautiously to avoid generating a level of exploitation that cannot be maintained if the old channel disappears.

5. Gamtoos estuary disturbance experiment

5.1 Introduction

The exploitation of estuarine resources has received considerable attention in the past, for example fish stocks by recreational fishers (Pradervand 1998, Baird *et al.* 1996, Pradervand & Baird 2002), the utilisation of invertebrate species by natural predators such as birds and fish (Martin 1991a, Hanekom & Baird 1992) and by bait collectors (Wynberg 1991; Wynberg and Branch 1994; Hodgson *et al.* 2000b). Disturbance can be the result of physical, biological and anthropogenic processes, but the overall implication of past studies on the fauna of estuarine soft sediments is that associated benthic species including mud prawn were perceived to be resilient to disturbance. Recent studies (Wynberg 1991; Cretchley 1996) have demonstrated the contrary, demonstrating that the effects of disturbance can have lasting effects on sediment structure and associated trophic guilds (Wynberg and Branch 1994). The previous chapters of this study have also demonstrated a link between the utilisation of other estuarine resources such as fish species and benthic macrofauna. It has been shown that mud prawn and sand prawn are key species in the food web of eastern Cape estuaries, and that they play an important role in the transfer of energy to higher trophic guilds (Baird 1988; Baird & Ulanowicz 1993). The disturbance associated with mud prawn collection therefore also has effects beyond a single species. Hodgson *et al.* (2000b) reported that mud prawns are responsible for increases in sediment oxygenation and mineralisation, and can have diverse effects on micro-algae, bacteria and meiofauna. An over-exploitation of mud prawn therefore also has negative effects on those species that benefit from mud prawn activity (Hodgson *et al.* 2000b).

Surveys by Hanekom, Baird & Erasmus (1988) have shown that prawn species comprise up to 80% of the inter- and sub-tidal macrofauna, while Martin (1991a) and Marais (1984) reported that mud- and sand prawn are the preferred prey for many bird and carnivorous fish species in eastern Cape estuaries. Hanekom & Baird (1992) estimated that about 13% of the annual somatic production of the mud prawn is consumed by birds, about 5% by predatory fish, about 2% by bait collectors. The levels of utilisation of mud and sand prawn by man are similar for other estuaries (Wynberg and Branch 1994; Cretchley 1996). The exploitation of invertebrate species used as bait by recreational and subsistence fishers takes place in virtually all estuaries, especially in those estuaries within or close to densely populated areas, or systems that attract

large numbers of holiday makers/visitors. It can therefore be assumed that the biomass removed annually by all sectors of the estuarine fishing industry do not reach excessively high unsustainable levels. The question of bait collection management should therefore be a concern for all estuarine managers, with special emphasis on the collection method employed.

Wynberg (1991) described a removal experiment where extensive digging and pumping of an area had more serious knock-on effects than the original number of prawns removed. Original removal rates were close to 10% of standing biomass (46 – 49% of mud prawn numbers present), but resulted in a decline in numbers of about 70%, resulting in a secondary or cumulative mortality effect of 500%. The recovery rate of such a disturbance was also more protracted than expected (Wynberg and Branch 1994). Cretchley (1996) listed digging as having a far greater effect on prawn populations than numbers removed alone. The compacting of sediments as a result of the large-scale disturbance is listed as one of the major factors delaying prawn recovery (Cretchley 1996; Wynberg and Branch 1994). Forbes (1998) in an assessment of the impact of bait collector traffic on mud banks of the Sunday's estuary also noted a drop in prawn numbers due to sediment compaction. Hanekom and Baird (1992) with a similar approach, determined that the removal of 2% of annual somatic production resulted in an additional mortality of about 18% (of new somatic production) on the population through habitat disturbance during the collection process. It is therefore deemed important to start considering disturbance related mortality when assessing acceptable levels of prawn removal.

A comparison between the removal rates listed in the study by Cretchley (1996) and the rate of production and recruitment suggests that current bait collection levels are matched many times over. Wooldridge and Loubser (1996) studied mud prawn larval release rhythms in the Gamtoos and Swartvlei estuaries. During sampling in the Gamtoos estuary in December 1990, minimum stage 1 larval density recorded was 50 m^{-3}, and the maximum over 5000 m^{-3} on a single tidal cycle. Numbers for the Swartvlei estuary was generally lower, but is was calculated that at post spring ebb tides (3 days), 53 9711 stage 1 larvae were exported whilst 20 0280 post-stage larvae were imported during the post neap tides (3 days). Currently, data on settlement and recruitment success is not available for the Gamtoos estuary. In the Knysna estuary, the average juvenile recruitment rate was 24 m^{-2} per month, with peak rates recorded in the lower reaches (31 m^{-2} per month) (Cretchley 1996). Comparing mean recruitment rates to exploitation levels per annum, Cretchley (1996) determined that recruitment was five times

higher than numbers of prawns removed (excluding knock-on effects). An interesting management dilemma related to reproduction and recruitment is that it is not always the same site that is responsible for peaks in both processes. Cretchley (1996) found that the peak number of larvae releases occurred in the middle reaches, where the highest density of ovigorous females was also recorded. Closed seasons as well as protected areas will have to be considered for both processes if they occur in different reaches of the estuary and at different times of the year. The overall situation is, however, that only a fraction of the annual reproductive output needs to survive in order to maintain current levels of biomass.

In order to maintain this current standing biomass in un-degraded estuaries, or to restore standing biomass and production levels to a desirable level in degraded estuaries, the impact of collection on the habitat, especially human traffic (trampling) and illegal digging, must be taken into account when planning removal rates. The maintenance of healthy breeding stock in a relatively limited area of each estuary should be able to ensure the sustainable use of estuarine bait species, on condition that utilised habitats are not degraded to such an extent that recruitment fails. The concern of this study, assuming that current reported removal rates are sustainable, is therefore not to attempt to quantify current levels of biomass removals from Eastern Cape estuaries, but to focus on the effects that the collection of bait can have on the remaining standing stocks as well as the habitat of the targeted species.

Historical and current management of bait exploitation in South African estuaries are based on the control of effort (TAC in the form of bag limits) without taking into account that the numbers of users continue to increase, or that the subsistence industry should also be formalised in order to quantify their annual consumption. The combined effects of trampling, sediment disturbance and bait removal are also not considered as a management priority. As steps are also currently being taken to legalise the commercial exploitation of bait resources by subsistence collectors, care should be taken to understand the cumulative effects of bait collection on the environment. It is therefore the assumption of this study that a better management strategy for mud- and sand prawn utilisation would be formalised to determine the maximum amount of standing biomass that can be allocated to human use, to determine the amount of damage caused by collection activities and to limit these to such an extent that natural ecosystem processes are not severely impacted on by bait collection. Managing for ecosystem functioning is therefore seen as a desired outcome of such an approach.

In this chapter a new calculation for maximum yield, based on balancing production levels with ecosystem component requirements and export capacity will be proposed.

The objectives of this chapter are:

- ✓ To describe the response of a mud prawn population to a single disturbance, simulating either mild pumping or digging to a depth of 40 cm.
- ✓ To describe the response of a mud prawn population to a monthly trampling episode.
- ✓ To make management recommendations on the issues of method of removal as well as intensity of human activity in mud prawn habitat.

5.2 Methods

5.2.1 Disturbance experiment

The aim of this experiment was to simulate human traffic, as well as current legal and illegal bait collection methods, and to monitor the effects that these disturbances had on a mud bank. The experiment was designed to determine the impact of bait collection through the use of a prawn pump and a spade, as well as the human traffic associated with monthly bait collection. After the initial collection disturbance and during the ongoing trampling disturbance, the recovery or decline of the population was quantified to describe, if possible, the impact of user activity on recruitment.

The disturbance experiment was located on a landward mud bank towards the middle of the blind arm, or old mouth, of the Gamtoos river estuary (refer to Fig. 1&2). The site was selected for its isolation and extent of tidal flat, allowing for the treatments to be set up in rows along horizontal and vertical gradients. This design will hopefully aid in the analyses of the influence of distance to low water mark and tidal dynamics on the recovery of disturbed sites. The experimental area, consisting of three treatments and controls totalling 180 circular 1 m^2 area plots, was positioned as far away from the main channel as possible in an attempt to reduce the risk of interference from bait collectors as far as possible. Although the placement of the experiment thus does not include the part of the population deemed most productive, bait collectors have been encountered on numerous re-sampling trips collecting bait from the front of the mud flat that would have been part of the experiment. No signage warning people about the experiment was erected, as it was deemed that this would increase the risk of interference.

The sample site was rectangular; 12 rows wide and 15 rows long spaced 6 m apart (Table 6). The experiment was implemented in December 2001. As sampling introduces a further disturbance, a treated plot can only be re-sampled once, thus enough treatments must be generated to allow for undisturbed recovery until a single re-sampling episode at the end of the experimental period. The experiment was therefore relatively extensive, consisting of 45 replicates of each treatment and a control, with a planned duration of nine months for the experiment. Five plots of each treatment (trample, dig and pump) and controls were re-sampled monthly. Although the experimental sites were laid out in a planned rectangular grid, allowing for a buffer area of six metres in either direction between sites, the placement of individual treatments as well as plots selected for follow-up sampling was randomised using the random number generation function of Microsoft Excel 97.

Table 6. Layout and placement of disturbance experiment plots. Treatments were placed in the centre of each block, allowing for a sufficient buffer area between adjacent sites. P = pumping, D = digging and T = trampling

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	P5	P4	P3	T3	C4	D3	P2	C3	C2	T2	P1	C1	T1	D2	D1
2	T11	D4	P8	C7	C6	P7	T10	T9	C5	T8	T7	P1	T6	T5	T4
3	C50	C10	D11	P9	D10	C9	T14	D8	C8	D9	D7	D6	T13	T12	D5
4	D14	T18	D13	C18	C17	C16	C15	C14	C13	C12	D12	T17	P10	T16	T15
5	P15	D20	C24	D19	D18	P14	C20	C19	D17	P13	P12	D16	D15	P11	T19
6	C25	P19	D22	T24	P18	C24	D21	C23	C22	P17	T23	T22	P16	T21	T20
7	D28	D27	D26	C27	P23	D25	D24	D23	P22	P21	C26	T26	T25	P20	T49
8	D33	C29	T33	T32	T31	D32	T29	T30	D31	D30	C28	P24	D29	T28	T27
9	T37	C34	D49	C33	C32	C31	D36	P26	P25	T36	C30	D35	T35	D34	T34
10	P33	D39	P32	C38	D38	P31	C37	P30	C36	C35	P29	P28	P27	D37	T38
11	D41	P39	C41	T42	P38	P37	P36	P35	C40	C39	P34	T41	D40	T40	T39
12	P45	P44	C45	D44	P43	T44	C44	C43	D43	C42	P42	P41	D42	P40	T43

The first two treatments, namely digging and pumping, were carried out in such a way as to best simulate the time per area spent on prawn collection by bait collectors observed during the planning phase of the experiment. In the digging sites, the area of the circular plot was marked out. A larger, square area surrounding the circle was then excavated with a spade to a depth of 40 cm, corresponding both to the approximate depth of a fork or spade blade, and to the depth at which Hanekom (1980) determined that more than 80% of the mud prawn occurring in the site will be located. Excavated mud were placed in a plastic crate with a 1.5 mm stainless steel mesh bottom, and searched for prawn (the same size that would have been collected by bait users). For the prawn pumping simulation, the plot area was marked out and five spots inside the area pumped out to a depth of 40 – 50 cm using a stainless steel prawn pump and the same

sieve crate mentioned for the digging simulation. Pumping was relatively light; ceasing when no further prawns were encountered and before the sediments around the pumped area started collapsing. All the mud removed was returned into source sites after prawns were removed. All the prawns removed from the plots were measured from the base of the carapace to the tip of the rostrum using a stainless steel calliper accurate to 0.1 mm, sexed and females in berry noted. Broken prawns were listed, sexed and sized as far as possible. The prawns were returned to the mud bank away from the study area.

The trampling treatment differs from the previous two treatments in that the effect of prolonged human disturbance was studied. To attain this objective, all sites that have not been re-sampled in a given month were trampled again. Thus the final five sites re-sampled at the end of the experiment were trampled nine times during the duration of the experiment. Square areas slightly larger than the plot area were marked out and trampled thoroughly, but without removing any prawns.

Plate 1. Relocating marked plots using the Excalibur 1000 hand-held metal detector (Photo by J.M. Jooste).

The marking of the experimental area posed several problems. If every plot was marked even with a central pin or rod only, the site would have remained highly visible. This was undesirable as previous studies carried out in the Gamtoos river area by colleagues suffered endlessly from tampering with markers. As the capital outlay involved with this study was significant, it was decided to protect the site as far as possible by developing an invisible marking technique. Due to the small size and high density of plots, standard modern methods of site location such as Global Positioning System (GPS) would not have been accurate enough. Cornelius *et al.* (1994) states that due to the military sensitivity of the system, 95% of positions obtained are only within 100 m of the true position. Even though more accurate GPS models have seen the light since this study (1 – 2 m accuracy), 30 cm either side of the centre of the studies' plots would have resulted in the sampling of untreated areas. The solution of pinpointing hidden sites lay in the

use of a metal detector. Although four poles marked the outer perimeter of the study area, only a 30 mm stainless steel washer inserted at the landward side of the plot after treatment marked each plot. The washer, engraved on both sides with the treatment code, was placed between 10 and 15 cm away from the edge of the treatment, approximately 10 cm below ground level. The metal detector used was a Minelab Excalibur 1000. The waterproof detector incorporates 17 search frequencies in a broadband spectrum search and was found to be capable of detecting the washers at a depth exceeding 16 cm below the mud in tests. The depth at which the washers were inserted therefore allowed for at least 5 cm sediment build-up without the risk of losing the marker. For the 7-month duration of the experiment (continuous rough seas caused sufficient delays to call of the experiment two months prior to its maximum running time), only one plot could not be re-located. This plot was on the edge of the experimental area, and it appeared as if some bait collecting in that area damaged the site. Enough duplicate treatments were created in order to compensate for such eventualities, and therefore the experiment was not disrupted. After completion of the study, a return visit to the mud bank revealed that a holidaying boat user had lost his sense of direction, and caused extensive damage to the site in an attempt to re-locate the main channel. Fortunately for all involved the experiment was completed, but this event highlighted the difficult conditions under which estuarine research has to be conducted.

Plate 2. Views of sample site after treatments have been completed. The pole visible in the foreground is one of four remaining markers demarcating the outer boundary of the experiment (Photo by J.M. Jooste).

Sampling of treated plots took place once a month over the best spring low tide. Plots selected randomly for sampling were located using the metal detector. A sampling cylinder with an area of 1 m^2, made of perforated 1.5 mm stainless steel, was then inserted into the centre of the treated plot as deep as possible but always exceeding 40cm. The mud inside was then removed and any prawns located then analysed as described earlier. At the start of the experiment, mud samples were also collected from randomly selected plots. These samples were to be analysed for

occurrence and density of mud prawn larval recruit and juvenile stages. Originally, 5 replicates from 15 plots of each treatment type and controls were identified, but due to tidal constraints not all samples were taken. The mud sample consisted of a core sample 10 cm deep taken with a prawn pump and inserted into a 350 ml honey jar. All samples were preserved in a 15% formalin solution and stored in a cold room until analysis. During follow-up sampling, it was decided to reduce sampling to 4 replicates at 4 treated sites and controls for a six-month period. This was done in order to speed up processing as well as to reduce sampling time (Due to the low elevation of the mud flat and the nature of tidal flow, some plots can remain inaccessible during a spring low tide, especially during stormy weather, where wave action at the mouth can severely restrict tidal outflow). For the purposes of relating prawn densities obtained to environmental parameters such as sediment structure, duration of tidal exposure as well as strength of tidal action, the flow of water during ebb and flood tides was mapped, and compared to current velocities previously calculated. The position of three freshwater inflow points above the sample site was also noted. During the re-sampling process it was noted that only a couple of small prawns under 8 mm carapace length were encountered. To determine whether these prawns are overlooked during sampling or if recruitment was very low on the particular mud flat, a small once-off survey was conducted with a 1mm diameter sieve box. Initial probing samples with a prawn pump as well as sediment excavations at 5 m intervals, starting at the LWM in front of the disturbance experiment, located only 2 individuals below 10 mm carapace length, and only one below 8 mm. Both prawns, one located with each sampling method tested, were located within 5 m of the LWM. It was therefore decided to sample the area just above the LWM at 25 m intervals, starting at the lagoon side of the mud bank and working towards the channel side. A circular sampling ring with an area of 1 m^2 was inserted into the mud and excavated to a depth of 30 cm. All the sediments were sieved through a 1 mm mesh box. Prawns removed were sexed if above 10 mm carapace length, otherwise they were noted as juvenile.

Data analyses were performed in the following ways: The numbers of prawns removed by pump and by spade from the experimental site was compared to the numbers of prawns re-located during re-sampling by performing a paired sample t-test. The results of this test was then subjected to 1-tailed t-tests to determine whether the numbers of prawns re-sampled were significantly larger or smaller than the original treatment samples. The average size and number of prawns removed at the onset of the experiment for the two different treatments was determined and tested using an ANOVA to determine if the results differed significantly. To

determine the recovery rate over time between treatments, average number of prawns re-located as well as average carapace length was calculated and plotted using Excel and trendlines were fitted to the data points. The results were also tested using the ANOVA package of Statistica 6.0. To test whether there is a statistically significant link between prawns of different sexes and sizes located during the start of the experiment and the distribution of coarse sediments, simple correlations were performed in Statistica 6. Average numbers of males and females recorded, as well as average carapace length (mm) of males and females per site was correlated with the 250 µm sediment component of the 30 – 40 cm section of sediment cores described in the previous chapter.
To determine whether the treatments had a lesser or greater influence on a sex group or size class at different tidal levels, average male and female carapace lengths as well as numbers during re-sampling were calculated and plotted on a Krig-diagram using Surfer32. Results were also statistically analysed.

5.2.2 Sediment characteristics and analysis

During the treatment of the plots some variation in sediment composition was noted, and as a large difference in sediment structure (particle size distribution) could have a possible impact on the distribution of mud prawn, the sediment of the top 40 cm of mud along six transects located within the experimental area was described. By incorporating sediment analysis into the experiment, a sediment distribution profile was generated, facilitating for the quantification of the influence (if any) that the sediments could have on the distribution and density of mud prawn populations. It would then also be possible to compare sediments prior to disturbance to sediments from disturbed areas.

Therefore, core samples of the top 40 cm of sediments along 6 transects, set up 20 m apart within the exclusion experiment, were taken at 10 m intervals. The analysis of the removed core samples was described in detail in Chapter 4. The sediment profile generated at the start of the disturbance experiment was also compared with a second set of samples removed at the 6-month interval of the experiment. In order to investigate any possible changes to sediment layers or overall composition, sets of sediment samples consisting of 4 replicate cores taken from three plots each of the digging, pumping and trampling treatments were taken prior to the six month samples being taken. These cores were analysed in the same way as explained for the initial sediment descriptions. In order to compare the results from the two data sets, four cores from the original grid samples closest to the 6-month interval samples were assigned to

each treated sample, and compared using a Factorial ANOVA. Of the 32 original cores assigned to treated cores for comparison, 4 were assigned to more than one treated plot due to the close proximity of some of the randomly selected plots. This is not seen as a major compromise and should not have any serious impact on the results.

5.2.3 Biomass comparisons

A continual data set of mud prawn biomass for the Swartkops estuary does not exist, making it virtually impossible to detect any changes in biomass. A reliable dataset for the biomass and distribution of mud prawn exists in the form of a study completed over 20 years ago by Hanekom (1980). A follow-up study was performed in 2000 (Gerber, unpublished data), but due to different sample plot sizes and sample areas used in the two samples, as well as the very large difference in biomass recorded by Gerber (unpublished data) in the latter study, a statistical comparison between the two studies was not attempted. Instead, it was decided to compare the prawn densities recorded relative to the other sites surveyed, which would generate an importance ranking for each site relative to the other sites surveyed in each study. By comparing the rank of each site between the two studies, it can be determined whether any site has undergone a large change in importance rating, which would suggest a serious decline in numbers.

5.3 Results

Table 7 summarises the numbers of prawns removed from the study site while employing the collection methods described previously. Although the two collection methods yielded similarly sized male and female prawns, the numbers of prawns removed during the digging treatments was much higher than during pumping treatments.

Table 7. Average size and number of prawns removed from pumping and digging treatments during the start of the experiment. Numbers in brackets are standard deviations.

Treatment	Sex	Avg. carapace length (mm)	Avg. no's per site
Pumping	Male	15.56 (1.79)	0.89 (0.97)
Digging	Male	15.64 (1.66)	3.93 (3.12)
Pumping	Female	15.48 (1.57)	1.26 (1.47)
Digging	Female	15.08 (0.97)	5.18 (3.71)

As no prawns were removed during initial trampling treatments, comparisons are not made at the commencement of the experiment.

The high variation in standard deviation of numbers of prawns per site from both collection methods suggest a high degree of natural variation in prawn distribution, but it can still be concluded that the mortality (removal) rates from a digging disturbance is much greater than for pumping to the same depth. This variability had a marked influence on the statistical analysis of average numbers recorded from sites of the two different treatments. Testing the assumptions of the ANOVA with Statistica 6 (Using Hartley F-max, Cochran C and Bartlett Chi-sqr. tests) revealed very low p-values, thus requiring log-transformations before a Factorial ANOVA could be performed. Graphs of statistically significant results are presented in Appendix D.

The results of this test revealed significant differences in numbers removed between pumping and digging as well as between male and female removals. Average carapace length was not log-transformed, although the p-value recorded was relatively low. The only significant difference recorded using a Factorial ANOVA was between male and female carapace length recorded, with the size prawns removed by the different treatments not being significantly different.

The data in Fig. 11 is a summary of the average number as well as average size (mm) of prawns recorded per month for the different treatments as well as the control sites over a period of 7 months. It is clear that digging and trampling had a

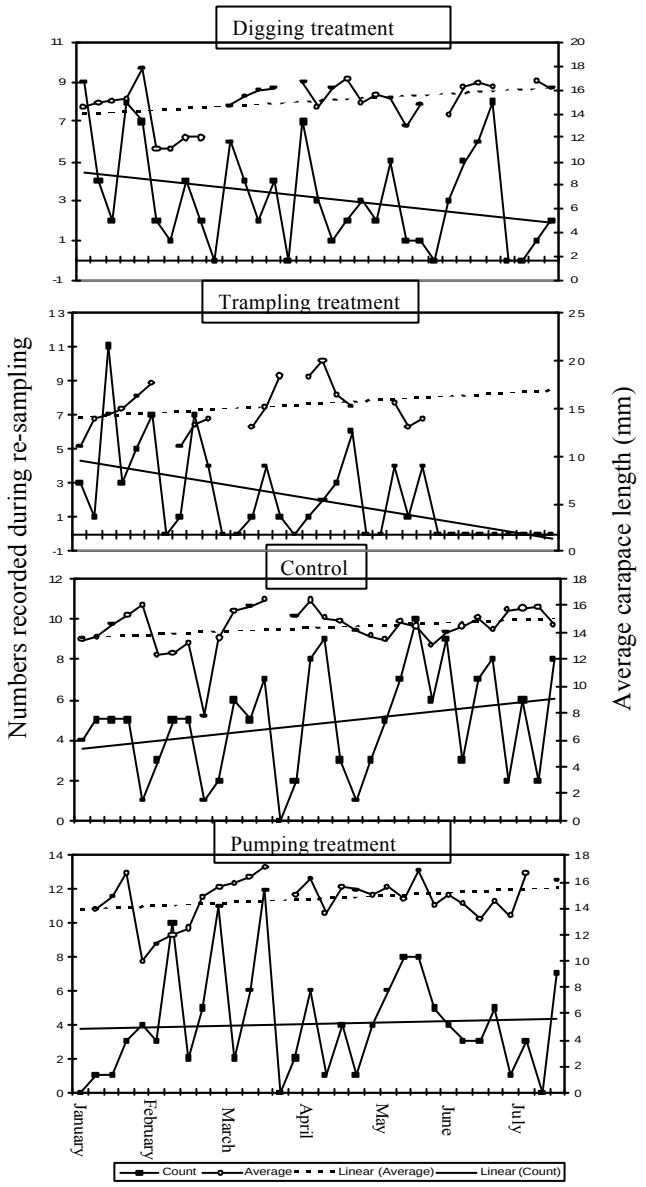

Figure 11. Effects of different disturbances on the mud prawn population of the study site over a 7-month period.

far more serious effect on prawn numbers than pumping. While average number of prawns in the control sites increased steadily over the study period, prawn numbers in the digging treatments were clearly declining while prawns disappeared altogether from trampled sites after May. The response in the pumped sites seems to be neutral to the disturbance, suggesting that numbers were only slightly depressed by the treatment. As recruitment was poor throughout the study site, the possible influence of the disturbances on new recruits cannot be determined. It is interesting to note, however, that although prawn numbers from the digging and trampling treatments show a definite decline, the average size of prawns present in the treated and control sites remained relatively similar (Digging: 16.5 mm, Control: 15.46, Trample 15.01 and Pumping 14.72) throughout the 7-month period. Only the digging treatment had a greater average carapace length than the control sites, while the smallest average size was recorded in the pumping treatment. Again, a high degree of natural variability within months and treatments can be observed.

The initial number of prawns removed during the preparation of the digging and pumping treatments differed, with more prawns originally removed from digging treatments. The effect that the original disturbance had on the recovery rate of prawn numbers over time is represented in Fig. 12. The number of prawns that remained behind or migrated into digging plots for the duration of the study period, and re-sampled during follow-up sampling was notably lower than pumping treated sites. In total,

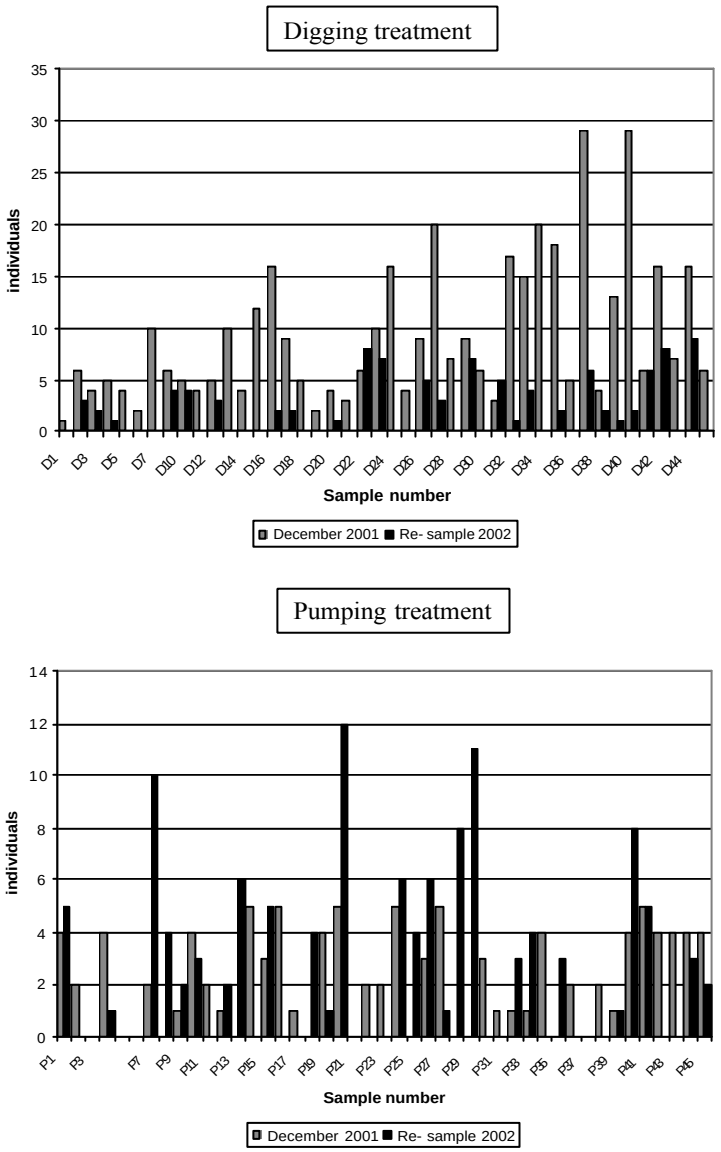

Figure 12. Numbers of prawns removed from treated sites (December 2001) compared to numbers encountered when the sites were re-sampled.

the number of prawns re-sampled in the digging sites equated to 32% of the initial removals, while the number of prawns present in pumped sites was 185% of the original removal. Performing pair t-tests on the two data sets (t-test for independent samples) yielded a significant difference between prawn numbers located during treatment and subsequent re-sampling ($t = 4.97$ for digging and $t = -3.043$ for pumping samples, $\propto = 0.05$). Due to the low p – values obtained ($P \leq 0.001$) a Mann-Whitney rank sum test was also performed on both samples. A statistically significant difference was also detected for digging as well as pumping treatments. Following this result, the difference between prawn numbers found during re-sampling and at the inception of the study (treatment preparation) was subjected to a 1-tailed t-test, where H_0: The difference between numbers of prawns removed with the two different sampling methods and the numbers of prawns removed during monitoring is ≥ 0 (no difference). The results indicated that the hypothesis is accepted for the pumping treatment ($t = 2.51$, critical $t = -1.705$), but rejected for the digging treatment ($t= -4.7$, critical $t = -1.705$). Comparing the distribution of average carapace lengths recorded from prawns removed during the preparation of treatments (Fig. 13) and the sediment profile generated for the study site, some similarities emerge. Variation between both male and female sizes recorded is relatively small, but for both sexes the largest prawns were located at the bottom left hand corner of the plot. This grouping not only corresponds with the distribution of coarse sediments at depth reported in Fig. 9, but is also the closest to the inflow of the

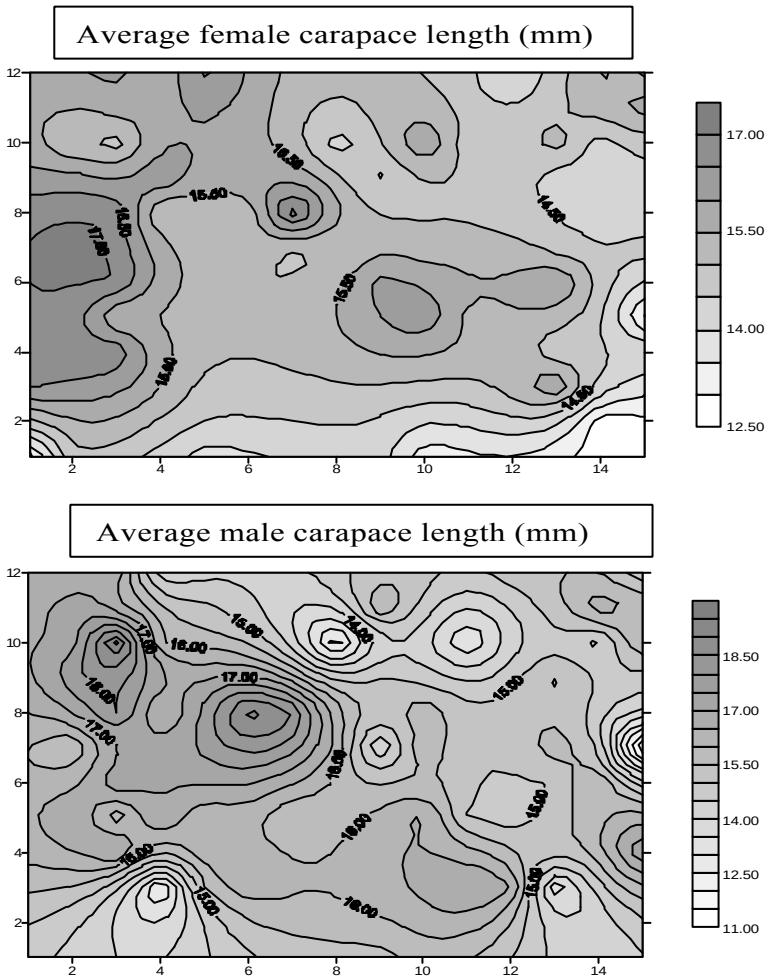

Figure 13. Graphic representation of the distribution of average carapace lengths (mm) recorded during the preparation of digging and pumping treatments in December 2001.

main current flooding the bank as described in the previous chapter. When studying the distribution of male and female prawn numbers removed at the onset of the study presented in Figure 14, it becomes immediately apparent that although the distribution of both sexes show some relation to the distribution of coarse sediments in the study area, the trend is more evident in female distributions. The concentration of prawns in the top left corner of the study site is clearest in the digging results, as a higher number of prawns were sampled. The high female to male ratio during the study (≈ 2:1) also influenced the accuracy with which male prawn distributions could be determined. Testing both the distributions of prawn size and numbers against sediment size distributions with the aid of a simple correlation yielded the following results: All correlations were negative, except for female average carapace length.

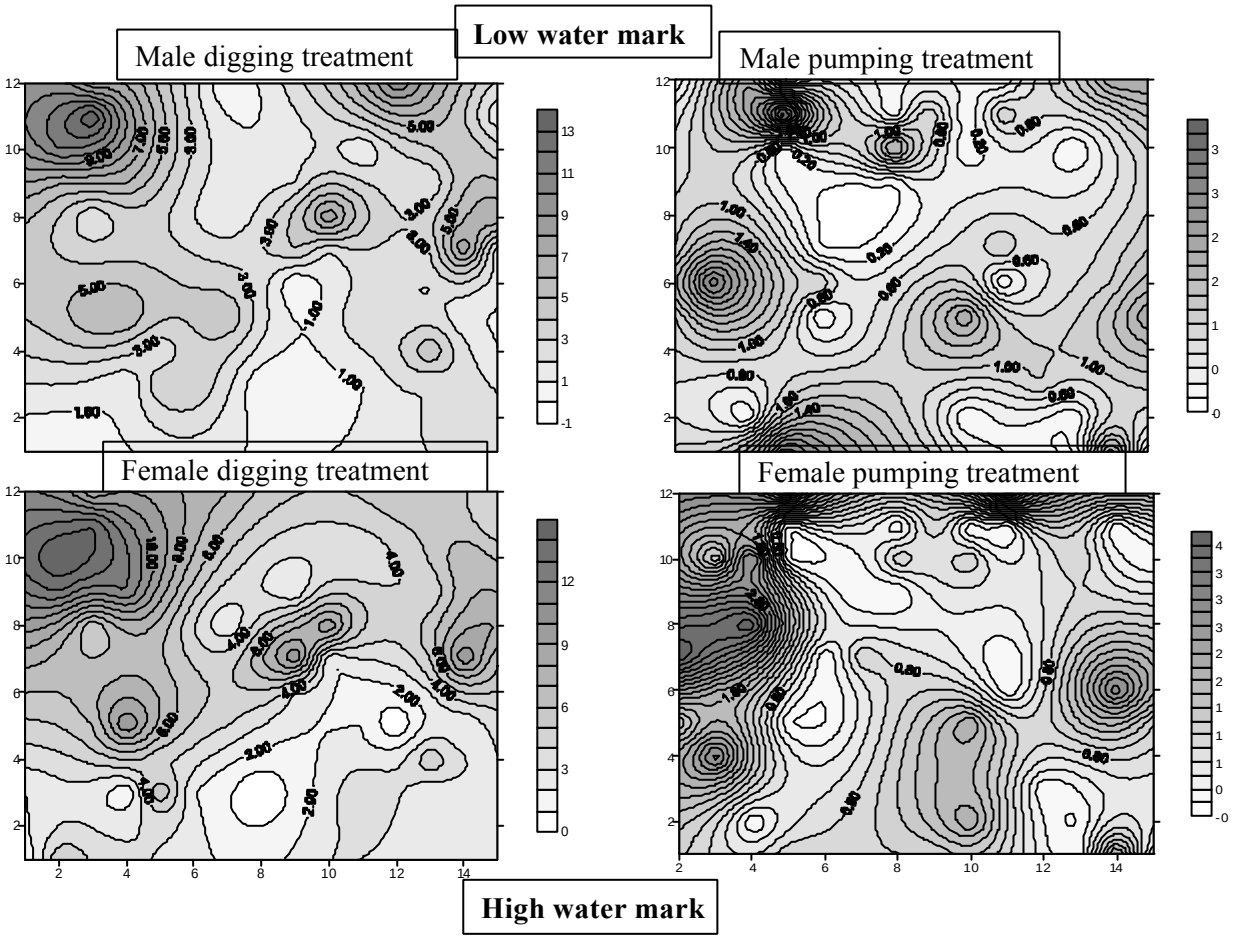

Figure 14. Graphic representation of the distribution of the numbers of prawns removed from pumping and digging treatments in December 2001. Due to the significant difference between numbers of prawns collected with the two methods, the results for each treatment is plotted separately.

Correlation results are located in Appendix D. No significant correlation was found between coarse sediment distribution and prawn numbers or average prawn size. Male and female

numbers as well as carapace length was tested against digging treatments only due to the higher yield of prawns from this treatment. The data obtained from the once-off recruitment survey performed to double-check the disturbance experiment sampling gear accuracy indicated that recruitment did not take place uniformly along the mud flat low tide mark (Fig 15). Juvenile prawns comprised more than 60% of the total number of prawns recorded only in one sample, 300 m away from the disturbance experiment. Total percentage of juveniles recorded per sample averaged 32% for the entire survey, and 46.4% in samples that contained juvenile prawns. The overall trend was for the numbers of juvenile prawns to decrease from the channel side of the mud flat towards the lagoon side, with no juveniles detected within 150 m of the experimental area.

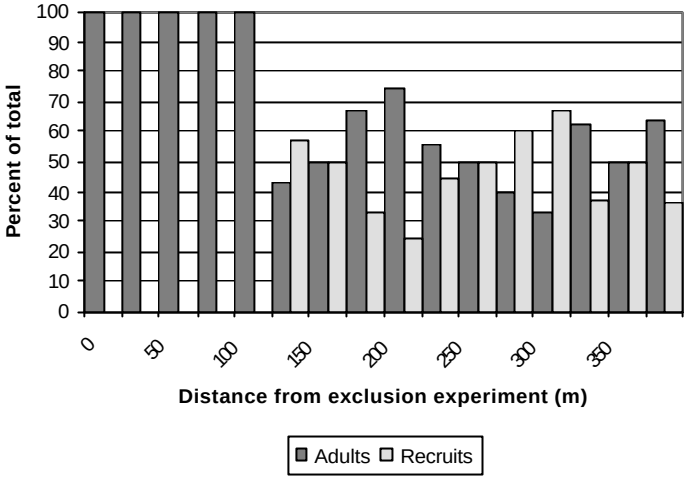

Figure 15. Distribution of juvenile prawns along a 400 m stretch of the mud bank LWM. The point 0 on the x-axis is closest to the lagoon, and the point 350 closest to the channel.

Table 8. Results obtained by performing Factorial ANOVA's on sediment size class percentages of samples collected at the start of the experiment and corresponding samples taken from disturbed sites after 6 months (P = pumping, T = trampling and D = digging). Tick-marks indicate significant differences, while filled blocks indicate tests with very low p-values.

		P16	P2	P5	T1	T19	T32	D1	D28	D49
Treatment	≥ 500 µm				✓	✓				
	250 – 500 µm	✓		✓	✓	✓		✓	✓	✓
	125 – 250 µm	✓		✓		✓		✓		
	63 – 125 µm				✓		✓	✓		
	< 63 µm	✓		✓	✓	✓	✓			
Depth	≥ 500 µm									
	250 – 500 µm					✓		✓		
	125 – 250 µm	✓			✓	✓	✓		✓	✓
	63 – 125 µm					✓			✓	
	< 63 µm	✓	✓			✓	✓	✓	✓	✓
Treatment & depth	≥ 500 µm									
	250 – 500 µm				✓					
	125 – 250 µm									✓
	63 – 125 µm				✓					
	< 63 µm				✓					

A large amount of the sediment cores collected from treated sites after the 6-month interval were significantly different to the sediments collected from the same sites at the inception of the study (Table 8). In total, 46.7% of particle groups tested were significantly different, but if it is taken into consideration that the largest size class was mostly absent from many samples and only tested where located, results indicate that 52.8% of sediment classes were significantly different after the treatment period. Considering only the ANOVA between time interval samples (Treatment), it can be seen that trampled sites were affected the most, with 66.6% of sediment groups undergoing significant change, followed by very similar results for digging (33.3%), and pumping (40%). Of the more common sediment classes, the most significant differences were recorded for the 250 – 500 µm category, where 77.7% of samples experienced significant changes. In the digging treatment, all three sites experienced significant changes in the percentage contribution of this particle group, while 2 out of 3 in each of the other treatments were significantly different. The 63 – 125 µm sediment category, also the most abundant in sediment composition, experienced the least amount of significant change during the 6 – month period. Graphs depicting changes in sediment distribution are presented in Appendix E. Some generalisations can be reached in terms of sediment category fluctuations where significant differences were recorded. Sediments normally present in low volumes, such as the medium sand (250 – 500 µm) and fine sand (125 – 250 µm) declined in volume in all samples except sample T19 and P16 respectively. In pumping and digging treatments, very fine sand (63 – 125 µm) as well as silt and clay (< 63 µm) particles increased in contribution to the samples. In trampled sites, all significant changes in silt and clay particles were the result of declines in volume, while very fine sand were measured at increased levels. The large amount of significant differences (64.8% of significant differences also with high p-values) obtained in the depth category is more than likely as a result of the disturbance of the initial stratification characteristics of the mud bank. Between tests, analysing differences between T0 and T6 – month treatments yielded the largest amount of significant differences, followed by sediment characteristics tested against the depth from which the sample came. Significant interactions between treatment and depth were few, and mostly associated with the T1 sample.

Table 9. A comparison between number of mud prawns per square meter recorded in two different Swartkops studies, as well as the rank in terms of numbers recorded in the different sites. The 2000 data is taken from Gerber (Unpublished data), while the 1980 data is from Hanekom (1980).

Site description	2000		1980	
	Prawns m^2	Rank	Prawn m^2	Rank
Tippers creek	20.77	1	276.67	3
Tippers island	9.82	4	276.67	3
Modderspruit	8.13	5	309.00	1
Opp. Modderspruit	7.44	6	-	6
Opp. Yacht club	12.90	3	221.00	5
Above bridge	18.23	2	280.00	2

As can be seen from the results of the comparison between the two Swartkops estuary mud prawn biomass data sets in Table 9, the lower reaches of the mud prawn distribution has seen some marked changes in prawn densities. Only the area above the N2 bridge remained unchanged in terms of both studies' ranking. The most popular fishing site and the area where a large proportion of fishing effort is concentrated is Modderspruit. This site has declined from a top ranking in 1980 to second last in 2000. An interesting observation is the fact that Hanekom (1980) did not record any prawns on the banks opposite Modderspruit, while Gerber (unpublished data) did record mud prawn, albeit at the lowest densities of all sites studied. It cannot be determined from this comparison if the drop in biomass between the two studies is in fact correct, or if it is due to the sampling technique employed by Gerber (unpublished data).

5.4 Discussion

Due to the absence of new recruits in the study area, all attempts to quantify the effect that the simulated disturbances have on recruitment success were aborted. The results will therefore be discussed only in terms of the influence of the treatments on adult prawns present during the study.

5.4.1 The impact of digging, pumping and trampling on the mud prawn population

Initial investigations have indicated a difference in preference for bait species between systems and between user groups. Subsistence bait users at the Swartkops estuary target mud prawn, while bait sellers target both prawn species, worm species and pencil bait. Bait sellers predominantly use spades and forks as a means of collection. Their activities pose a dual threat, namely the large-scale removal of species on which ecosystem functioning depends as well as the large-scale disturbance of mud banks. In a habitat assessment of the Swartkops estuary, (van Driel 2000) a score of 58 out of 100, or a class D estuary is assigned, with excessive bait collection listed as one of the factors seriously impacting on the system. Sand prawn has been removed to such an extent in the past that during a recent MSc study conducted in the Swartkops estuary study sites had to be shifted in order to locate sand prawn. As extensive stocks of sand prawn occur sub-tidally in the sheltered south-western shore of Algoa bay (Cockroft and Tomalin 1987), the risk of extinction from estuarine systems is not as great as for purely estuarine species such as the mud prawn, polychaetes and pencil bait.

The results of removal rates obtained using conservative pumping and digging methods indicate that there is a far greater initial disturbance caused by bait removal through digging (Table 7). The significant differences recorded between the two sexes are not related to the two removal techniques, and will be discussed in the next chapter. The amount of prawns removed through digging not only severely lowers the biomass remaining on the mud bank, but also negatively impacts on the remaining prawns. Both impacts will be discussed in detail.

Bait digging has been illegal for a long period of time, but law enforcement in this regard has been problematic since the user group responsible for the majority of digging effort is bait sellers. Since the inception of the Marine Living Resources Act (No. 18, 1998) the right of this user group to have equitable access to the bait resource has been recognised (Branch 2002), but

efforts to steer the group away from destructive collection methods have been lacking until recently.

The initial loss of numbers from digging treatments did not recover over the entire period, whilst numbers in the pumping and control sites showed a slow and a steady increase respectively (Fig. 11 & 12). Statistical analyses indicated that the numbers of prawns re-sampled in digging plots were significantly lower than the original number removed, while sampling pumped sites revealed a significantly higher number of prawns present than removed during the preparation of the treated plots. As the treated sites were relatively small, it was considered possible for prawns from adjacent untreated areas to migrate into the disturbed sites to occupy the new open space created, but this did not seem to happen. Two possible explanations can be given. Firstly, it can be suggested that it is not a behavioural trait of adult prawn to move from their burrows into a new area, or alternatively, the disturbance altered the treated sites in such a manner that it was not possible to re-colonise the sites.

Although prawns can often be observed moving across mud banks when the inter-tidal zone is flooded, the recovery rate recorded in the pumped sites suggests that prawn migrations into sites where prawns were removed did not occur on a large scale or in a short period of time. As the pumping treatment caused minimal damage to the site compared to digging, it is not highly likely that the site was altered to such a degree that prawns did not want to occupy the vacated space. It is also assumed that the prawns not removed during the pumping exercise were not detrimentally affected by the once-off event. When the re-sampled numbers of prawn from pumped sites are plotted over time, the linear increase in numbers are very small, suggesting that there is not a ordered increase in the numbers of prawn detected over time. As the results have indicated that prawn numbers are highly variable across the study site, no relationship can be found between position of treated sites, recovery time and numbers of prawn re-sampled. It would appear that the numbers of prawn re-sampled from treated sites are more likely to be a function of the percentage of prawn removed from the original standing stock of the site during treatment, and the extent of damage to the site.

The continued presence of the prawns not removed during pumping (in some cases higher than in control sites) would suggest that these assumptions are correct. It can therefore be accepted that for the duration of this study (7 months), the serious reductions in prawn biomass caused by a single digging event persisted, with numbers of prawns from this treatment continuing to

decline at the termination of the study. Numbers of prawns re-sampled totalled 63.6% of the number removed during treatment (Fig. 12), with the majority of prawns in the re-sampled category being located in the early months of the study, suggesting that the disturbance was responsible for ongoing mortality or migrations. Sites pumped conservatively, however, did not show a decline in numbers, even though exactly the same amount of prawns in total was removed from the treated sites as was re-sampled during the study. Digging yielded 27% more prawns than pumping, but yielded 36.4% fewer prawns during re-sampling. This drop in yield would more than likely have increased if the experiment was designed to run for a longer time period, but yielded enough results to underline the unsustainability of digging. In terms of numbers, an average of 24.6 prawns/m^2 was removed from sites in the digging experiment, compared to 5.63 prawns/m^2 from the pumped sites. This suggests that the prawn population is able to sustain the removal of a relatively high percentage of standing biomass under specific conditions.

The results of this study are in line with the effects of prawn collection described by Wynberg (1991). In a similar experiment conducted in the Western Cape, extensive digging and pumping of an area had more serious knock-on effects than the original number of prawns removed. It was estimated that the disturbance caused by high intensity collection of prawns removed 6.7 and 13.1% of prawns respectively, but resulted in a decline in numbers of about 70%, translating to a 25% decrease in density. Judging by present day collection activities and destructive sampling methods (e.g. spades, garden forks, prawn pumps, etc.) in sections of the Swartkops estuary, the mortality may even be higher.

From personal observations made during the measurement of removed prawns, it was concluded that both digging and pumping was a relatively abrasive process, as a large amount of prawns removed were damaged. A sizeable amount of removed prawns that did not appear to have any external injuries died before being returned to the mud bank, or appeared to be relatively immobile when returned. The disappearance of prawns from trampled sites within 5 months (thus after 5 relatively intensive trampling episodes) seem to support the assumption that mud prawn are susceptible to excessive abrasion during any collection method or during human traffic over a mud bank. Damage also appeared to be higher during the summer growth period, as many prawns sampled had soft exoskeletons.

If it is assumed that all imports and exports of prawn were equal during the study, it can be concluded that mortality rates from the pumping treatment was the lowest, followed by digging and trampling treatments. The mortality from trampling was by far the greatest, reaching 100% after five months (Fig. 11). This is a serious decline in numbers, considering that no prawns were removed from trampled sites prior to treatment. The increase in numbers of prawns in control sites, as well as the recovery seen in pumped sites is an indication that the population as a whole was not in decline during the study, and that the declines noted in digging and trampling treatments was caused by the introduced disturbances. The high mortality rates observed in collected prawns makes it very likely that the abrasive effect of digging and trampling was responsible for a large percentage of the declines noted in both treatments. Under normal conditions, the effect of trampling and pumping cannot be separated. It can therefore be assumed that the total mortality rates of prawns exposed to heavy utilisation would not be as low as determined in this experiment due to the continued cumulative effects of traffic and pumping.

It should therefore be necessary to re-evaluate previously published data on removal rates of prawn if disturbance mortality was not considered. For example, Hanekom & Baird (1992) estimated that about 2% of annual production in the Swartkops estuary was removed by bait collectors, while an additional mortality of about 18% (of new somatic production) is inflicted on the population through habitat disturbance during the collection process. The removed production during the early nineties, when converted to numbers (without associated mortality) was estimated to be about 4 000 kg dry mass (or about 1.7 million individuals) of mud prawn per annum (Martin 1991a; Hanekom & Baird 1992). A generalisation that can be made from the studies of Hanekom and Baird (1992) as well as Wynberg (1991) is that when the effects of bait collection on mud prawn is factored into removal rates, bait removal can cause a further 25% reduction in standing biomass or consume another 18% of annual somatic production.

Wynberg and Branch (1994) reported that the recovery of extensively pumped and trampled sites was also more protracted than expected, lasting18 months. It was concluded that the associated compaction of sediments was responsible for this recovery delay. Forbes (1998) came to the conclusion that even medium traffic along a mud bank could cause decline in prawn numbers due to sediment compaction. The finding of the trampling experiment seems to concur with the findings of these two studies. The Gamtoos study site sediments were extremely fine and loose at the onset of the study, causing the person doing the trampling work

to sink about 50 cm into the mud within seconds. Due to the compactability of clay, the depth to which a person sank into trampled plots was gradually reduced until only the top 10 cm of the plots was still soft. It was nearly impossible to force the steel sampling ring into the trampled site, and totally impossible to dig into it by hand. No burrows were visible in the compacted sediments, suggesting that it was not possible for any organism to penetrate the sediments. The assumption can therefore be made that continued trampling associated with a high collector presence would compact the mud bank to such a degree that immigration from unaffected areas adjacent to heavily utilised mud banks would not take place successfully. This assumption has some serious repercussions for management options related to bait collection. If collection areas and no-take areas were zoned in an estuary, the size of the area in which human activity is allowed would have to be able to sustain the cumulative effect of intensive prawn removal and human traffic. It is highly likely that these collection zones will become badly degraded relatively quickly depending on size and utilisation intensity, thus possibly necessitating the generation of short-term rotational collecting zones to prevent long-term damage.

In the previous chapter it was reported that a significant degree of variation occurred in the distribution of sediments along tidal as well as depth gradients in the study site. The results obtained from correlating average male and female size (Fig. 13) as well as numbers to the sediment characteristics of the sample plots indicate that the distribution of prawns was not affected by the sediment characteristics of the mud bank. This finding concurs with Hanekom (1980) who tested various environmental and physical parameters that could impact on prawn distribution and fitness. The fact that a weak similarity can be observed between prawn number and average size increases and the position of the highest densities of medium sand does however, have some significance. It has been demonstrated in the past (Hanekom 1980; Hanekom and Erasmus 1989) that the single factor with the most influence over mud prawn distribution and fitness is exposure to the marine flood tide water borne nutrients. This influence will be discussed in further detail in the next chapter, but as marine currents are also responsible for the deposition of the medium sand component of the study site it is not entirely coincidental that some improvement in prawn numbers or average size was observed near the medium sand deposits.

5.5 Conclusions

The general patterns that emerge from well-studied systems is that the total number of prawns removed per annum, as well as from specific collection hotspots within the prawns distribution range, fall well within acceptable levels of sustainability (Wynberg 1991; Cretchley 1996; Hanekom and Baird 1992; Tomalin and Fielding 1993). From the data recorded on the reproductive capacity of mud prawns (Wooldridge and Loubser 1996) and the rate of larval recruitment later, it can be concluded that a relatively high exploitation rate can be supported **on condition** that these processes are not adversely affected during exploitation.

The data obtained from disturbance experiment in the Gamtoos estuary indicates that mud prawn, although resilient in the face of natural perturbations such as floods, cannot withstand an abrasive disturbance event such as digging and trampling. Data presented by other authors support this conclusion (Wynberg and Branch 1994; Forbes 1998). The fact that prawns took a long time to return to sites heavily disturbed by bait diggers (B. Seale, pers. com.) and the poor link between prawn densities and normal sediment distribution in the muddy reaches of estuaries (Hanekom and Erasmus 1988) seem to support this assumption. Digging for prawn, although illegal, persists in the Swartkops estuary on a large scale despite recent efforts by M & CM to formalise the selling industry and convert collectors to the use of prawn pumps. Concerned anglers involved with the Swartkops Trust have also conveyed observations of dwindling prawn populations in areas frequented by lure and fly anglers. Gerber (unpublished data) noted these declines in the lower reaches, specifically Modderspruit, as well. As prawn exploitation in these areas were not any different to the rest of the estuary, and away from the sites recently exploited by bait diggers, the decline can more than likely also be the result of the high levels of trampling experienced by the site.

The poor recruitment event on the Gamtoos estuary study site, apart from serving as a reminder that recruitment failures do occur and underline the need for continued monitoring of mud prawns in heavily exploited areas, made the detection of impacts on larvae and juveniles impossible. As larvae and small juveniles occupy the top 2 – 10 cm of the mud bank during early development, it can be assumed that sediment disturbance during and immediately after recruitment will have at least the same impact as has been demonstrated for the adult population, if not greater.

To conclude, it must be stressed that current knowledge on the size and needs of the three different estuarine bait user groups, namely recreational, small-scale commercial and recreational, is poor. Information on standing stocks and production rates is also dated. There is an urgent need to fill the knowledge gaps, as well as introduce continual monitoring systems. Without the information listed above, the management of sustainable exploitation of mud prawn will be almost impossible.

5.6 Management recommendations

- ✓ A quota system (daily bag limits) managing TAC only without considering the number of users that have access to the resource (thus amount of trampling associated with the removal of 50 prawns per user) is possibly unwise. In an over-exploited system, the problem of trampling-related mortality will be exacerbated by the low standing biomass. Search time will be lengthened and thus traffic on the already pressurised population will increase. From a disturbance point of view, the controlled sale of mud prawn could reduce the number of people on mud banks. Under specific conditions, a SSC bait industry can thereby reduce the amount of trampling related damage (i.e. prawn mortality and compaction of mud) in mud prawn habitat.
- ✓ Closed areas or seasons can be considered during reproduction and recruitment peaks, but some problems will have to be overcome. First, a 2 – 3 month window will be sufficient to protect females in berry, but new recruits are vulnerable for a considerably longer period of time. If recruits settle in the same areas of an estuary from where peak reproductive effort occurs, attempts to protect adults as well as recruits could result in the closure of large sections of the estuary for the period August to April each year. This period would more than likely be undesirable to all user groups. The best protection for new recruits is a reduction of human traffic on prime mud prawn habitat. As female reproductive production is spread over a large section of mud prawn distribution, only sections of the inter-tidal region of the lower and/or middle reaches of an estuary (depending on standing stocks) have to be protected to ensure reproduction at sustainable levels. Secondly, a balance between users and access areas will have to be attained. Leaving only a small area of access to users will result in the rapid degradation of exploitable sites. Recruitment is also lower in the extremities of mud prawn distribution, suggesting that these areas will take longer to recover from stock depletion if large sections of the lower reaches are closed for collection. A potential

outcome of this exploitation pattern is the reduction of mud prawn range until only protected sites contain sizeable populations.

- ✓ Ideally the reproductive output, recruitment success and needs of different user groups (in terms of production) of the mud prawn population of individual estuaries need to be determined. An estimation of the percentage of annual production required to match these exports as well as exports to natural predators of mud prawn can then be made. From this calculation, the percentage of the current female population needed to achieve the desired production levels can be determined. The proportion of the best sites in terms of reproductive output that contains this number of females can then be afforded the required level of protection for the duration of peak reproductive activity. Recruitment rates thereafter must also be monitored to determine if the desired production level was attained. Due to the natural variability of reproduction and recruitment and periodic perturbations such as floods and drought, the calculations of desired reproduction levels would have to be relatively robust.
- ✓ At this point it is also crucial that collection related mortality be factored into the requirements of the bait users. Calculations presented in this chapter indicate that the cumulative effects of bait collection can easily result in the over-exploitation of stocks. When it becomes apparent that current levels of exploitation exceed annual production, effort control in the form of bag limit reductions or access reductions will have to be implemented. It is also important that habitat damage due to other estuarine recreational activities such as bank, fly and lure fishing be factored in to management efforts. It is important to manage and quantify all activities that damage standing stocks of mud prawn, not only direct bait collection damage.

6. Mud prawn distribution along tidal gradients

6.1 Introduction

From previous studies (Hanekom 1980; Cretchley 1996; Hodgson et al. 2000a) it can be concluded that mud prawn populations are not distributed evenly within an estuary in terms of standing biomass or average size. Mud prawns are generally most abundant in the lower and middle reaches of the eastern Cape estuaries with a sub-tidal distribution determined by the scouring strength of ebb and flood tide currents (Hodgson 1987; Cretchley 1996; Hanekom 1980). What could be of interest is to determine if any distribution changes can be observed along a tidal gradient within a single population. If such zoning occurs within sites as well as within the four reaches of the estuary, the variation has to be noted as it would influence the calculation of standing stocks as well as influence the management of areas deemed to support key mud prawn populations.

Hanekom and Erasmus (1989) as well as Hanekom and Baird (1992) demonstrated that the size differences as well as population size differences recorded, in turn, have a marked influence on the reproductive capacity of mud prawns from different regions of the Swartkops estuary. It was concluded that the single factor influencing mud prawn growth and fitness to the largest degree was exposure to nutrients carried mostly by the flood tide (Hanekom and Baird 1992). Baird et al. (1987) determined that although net transport of particulate material varied between tidal cycles regarding direction (import and export) and magnitude, the Swartkops estuary was a net exporter of suspended particulate material. Particulate concentrations were found to be higher during the ebb tide, with seven of the thirteen tides studied showing a net export of total suspended particulate material (TSPM). Export levels was greatest during spring and autumn, with most winter months showing net imports. Overall trends, however, were the net export of particulate organic material (POM), particulate inorganic material (PIM), particulate organic carbon (POC) from the breakdown of decaying organic material, and particulate organic nitrogen (PON). The biggest sources of particulate organic carbon were saltmarshes and from inter-tidal invertebrate production, resulting in the generation of 31% of the annual net export volume of POC. Total exports of suspended particulate organic and inorganic carbon, however, is relatively small compared to annual imports, (Baird and Winter 1992) suggesting that salt marshes act nominally as a sink for suspended POC and PIC, with the net flux of POC from the marshes taking place in the form of detritus. Seasonal trends were also identified in the distribution and source of nutrients in the Swartkops estuary (Winter

and Baird 1991). Phosphates were generally exported from the estuary during the year, except for the period July – September, where neap tides showed a continual import of phosphates. During this time, spring tides maintained the net export function. It was concluded (Winter and Baird 1991) that the salt marshes of the estuary was producing an excess of phosphates, and that the mud flats were absorbing phosphates at a greater rate during July – September than during the rest of the year. All forms of dissolved inorganic nitrogen (NH_4, NO_2 and NO_3) were imported into the Swartkops estuary, the majority of which is absorbed by the salt marshes (Baird and Winter 1992). The overall trends in nutrient cycling in the Swartkops estuary therefore appears to be that salt marshes act almost as isolated systems, recycling and retaining most of its own production, exchanging limited amounts of inorganic nutrients mostly through the marsh sediment-detritus system.

Wooldridge (1968) studied the burrowing ability of mud prawn, and determined that burrows can be constructed in substrates ranging in fine mud content up to 65% and not less than 4%. Outside this range, burrows are either silted up or collapse continually due to lack of cohesion (Hill 1967). The sediments at the back of the mud bank was studied during the exclusion experiment, and found to be within the range suitable for burrowing described by Wooldridge (1968) but above the 20% fine sediment levels described by Hanekom and Erasmus (1989) as causing declines in mud prawn numbers.

From a management point of view, it would be useful to understand the distribution of mud prawn along a tidal gradient on a mud bank as extensive as the study site. In the Gamtoos estuary, the mud banks of the old channel are the largest area of suitable mud prawn habitat in the lower reaches, and it would be tempting to manage the entire population as a single stock with generalised biomass calculated for the entire zone. Events important to the success and fitness of the species, such as reproduction and recruitment, have been demonstrated to vary in intensity between sites (Cretchley 1996; Hanekom and Erasmus 1989; Hanekom and Baird 1992). It is therefore safe to assume that it is also possible that variations contributing towards reproductive output can occur within a site if the range is extensive enough.

The study site in the Gamtoos estuary afforded this project with the opportunity to collect information valuable to further refine current knowledge on mud prawn distribution within a single site. The width of the mud bank in the blind arm made it possible to investigate the distribution of prawns in a population from the lower reaches along a tidal gradient as wide as

160 m. Information obtained from such a study can be used to determine whether the most important sections of an estuary in terms of mud prawn biomass and reproductive activity can be divided further along tidal gradients to pinpoint zones of prime prawn habitat within their optimal habitat range. This chapter of the study was undertaken to determine whether any part of the population on a specific site reproduces at a higher rate, and could therefore benefit from management actions such as closed seasons or restricted access. If smaller zones of a population, such as those exposed to optimum sedimentary and tidal flow regimes are responsible for a significant percentage of reproductive activity, these zones would be identified during the study. From a management point of view, this information can be applied to plan closed areas or closed seasons based on the zonation of prawn distribution.

The objectives of this study therefore are:

- ✓ Describe the sediments at the low water mark of the study site.
- ✓ Assess the distribution of male and female prawns along tidal gradients during a low reproductive as well as a high reproductive period.
- ✓ Assess the distribution of females in berry along tidal gradients.

6.2 Methods

The experiment, in the form of five 100 m transects sampled at 5 m intervals, was carried out in January and March 2002, with follow- up samples taken from the same location during September and October 2002. The first sample set coincided with the post-reproductive period of mud prawns, while the second set was scheduled during peak reproductive activity of mud prawn in the Gamtoos estuary (Loubser 1992). The study area was located on the same mud bank as chosen for the exclusion experiment, covering and area of ± 1 ha directly adjacent to the disturbance experiment. The transects began at the low water mark, with the 0 m mark determined by the first occurrence of mud prawn burrows. Generally, a sandy, compacted zone devoid of burrows was located on the berm described earlier, necessitating the use of mud prawn burrows as the 0 m mark. At 5 m intervals, five points were taken within a $1m^2$ circle and pumped into a sieve box using a stainless steel prawn pump. Prawns were removed to a depth of 50 cm. As prawn density was not to be analyzed, no methods of standardizing effort other than number of points per sample and depth of removal were employed.

All prawns removed were measured from the base of the carapace to the tip of the rostrum using stainless steel calipers accurate to 0.1 mm, sexed and females in berry noted. Broken prawns were listed, sexed and sized if possible. Sediment samples was collected and analyzed in the same manner as performed for the description of the disturbance experiment at the onset of the study (See chapter 5).

The prawns were returned to the mud bank away from the study area. The results obtained were plotted onto Krig-maps using Surfer32 for visual inspection. Statistica 6 was used to perform Factorial ANOVAS on the combined data sets in order to determine any changes in population structure during and after the reproductive season, as well as between sexes and along tidal gradients. The statistical significance of variations in berry ratios obtained was investigated using regressions generated in Excel 97.

6.3 Results

Although no clear changes in population composition from the channel side to the lagoon side of the population can be detected using the Krig map (Fig 16), a clear decrease in prawn numbers and average carapace length of male as well as female prawns can be observed between the LWM and the HWM. Seasonal fluctuations in numbers and positions along the tidal gradient can also be observed.

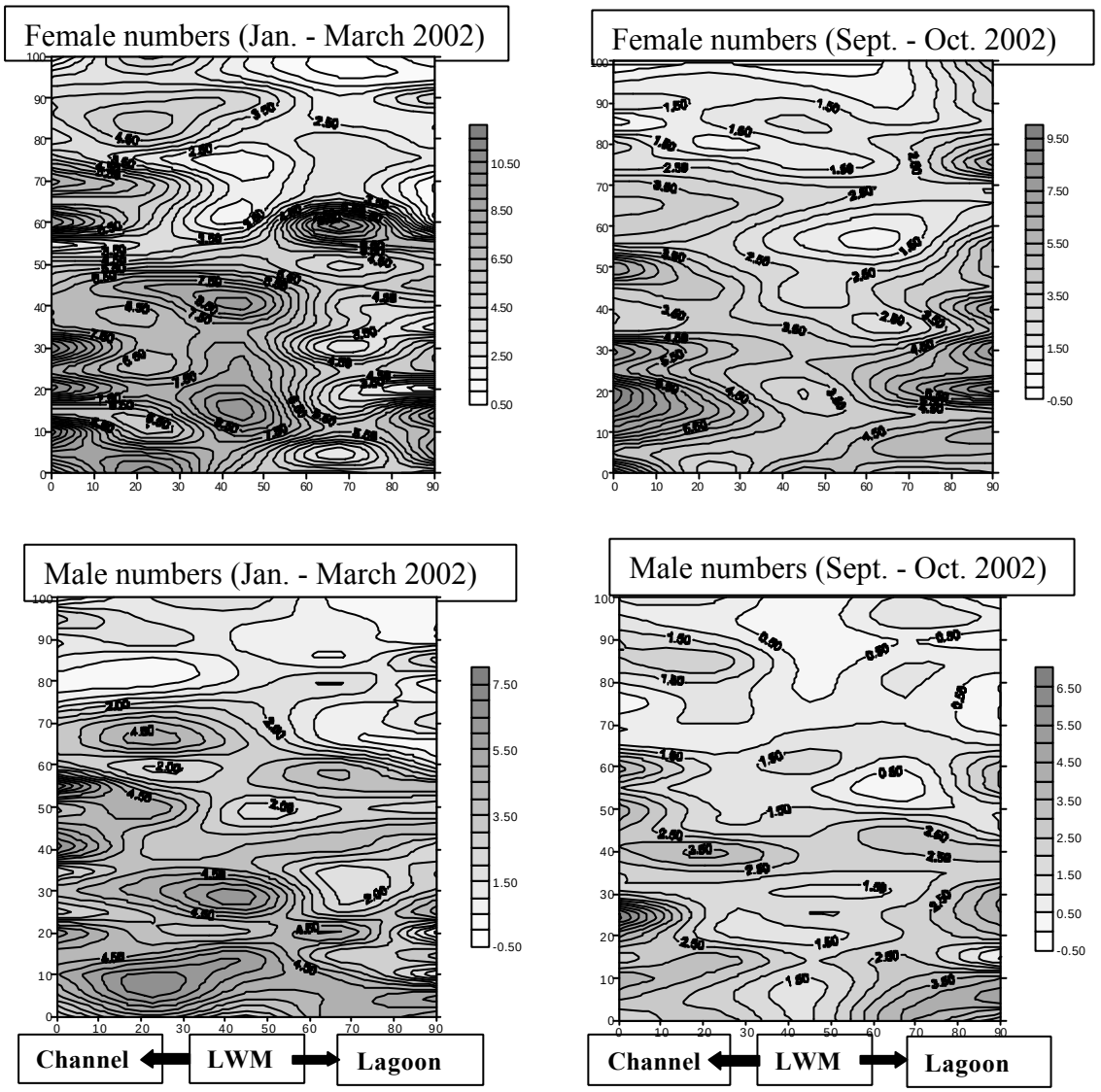

Figure 16. Distribution of prawn numbers from LWM (0) towards the HWM (100) and from a point nearest to the channel (0) towards the lagoon (100) during periods of low (January – March) and High (September – October) reproductive activity.

Graphs of all statistically significant results obtained are presented in Appendix F. The number of females and males recorded during the study was analyzed untransformed at first, but more reliable results were obtained after the values were log-transformed and analyzed again using a Factorial ANOVA. For female numbers recorded during the period January to March (low reproductive period) significant differences were recorded between transect sets as well as along the tidal gradient (distance from LWM). Testing the assumptions of the test, however, indicated that the p-value was low. Male numbers were significantly different (with high p-value) only when testing for between-relations of transect sets and tidal gradient. The results for the same tests performed during the period September – October (high reproductive activity) yielded almost identical results. The only change was in male numbers, where significant differences were recorded for tidal gradient as well as between transects and tidal height. Post hoc tests for both seasons and both sexes indicated that a large number of samples were responsible for the differences recorded.

When comparing average female and male carapace length between seasons and transects, the following significant differences were recorded: during January – March, average female size was significantly different for transects as well as along tidal gradients, although p-values obtained were again low. Average male size significantly different along tidal gradients as well as between transects and tidal gradient. The p-value obtained for this test was also higher than for female tests. Identical results were obtained for the period September – October.

The seasonal variation in prawn population characteristics is presented in more detail in Fig 17. Here, Krig maps of transect set 1 averages were compared with transect set 3 averages, giving a graphic representation of sex and size distributions in a 50 m zone at 6-month intervals. Female size variations along the tidal gradient appear to be more distinct than male size variation, suggesting that the two sexes are impacted upon differently by the same environmental factors. An interesting result that can be seen in the last set of comparisons of Fig. 17 is the change in female/male rations observed during the study. Although the seasonal fluctuations in female and male numbers reported in Fig. 16 appears to be similar, a notable increase in the numbers of females had occurred towards the LWM, especially the front 30 m of mud bank. Before analyzing the variation in female to male ratios between the transect sets, Factorial ANOVA's were performed on the two months' transects within each set. Analyses of differences between the two sets sampled in January - March 2002, yielded significant differences between transect sets and individual transects (distance from channel). Post hoc

tests indicated that only a few samples were responsible for the variation. The p-value of the test was also very low. A significant difference was also detected between individual transects and distance to LWM. Again, it was only a few samples responsible for variation although the p-value was high. In the transect sets sampled during Sept. – Oct. 2002, there was no significant interaction between transect sets and individual transects, while significant differences were recorded for distance to LWM between transect sets and distance to LWM as well as individual transects and distance to LWM. The highest p-value was recorded for the latter significant difference, although post-hoc tests did not highlight any samples responsible for the variation. When the two transect set means are compared statistically, no significant differences are recorded between transect sets and individual transects, while tests between transect sets and distance to LWM as well as individual transects yield significant differences for distance to LWM. With the difference between individuals and distance to LWM again yielding a high p-value.

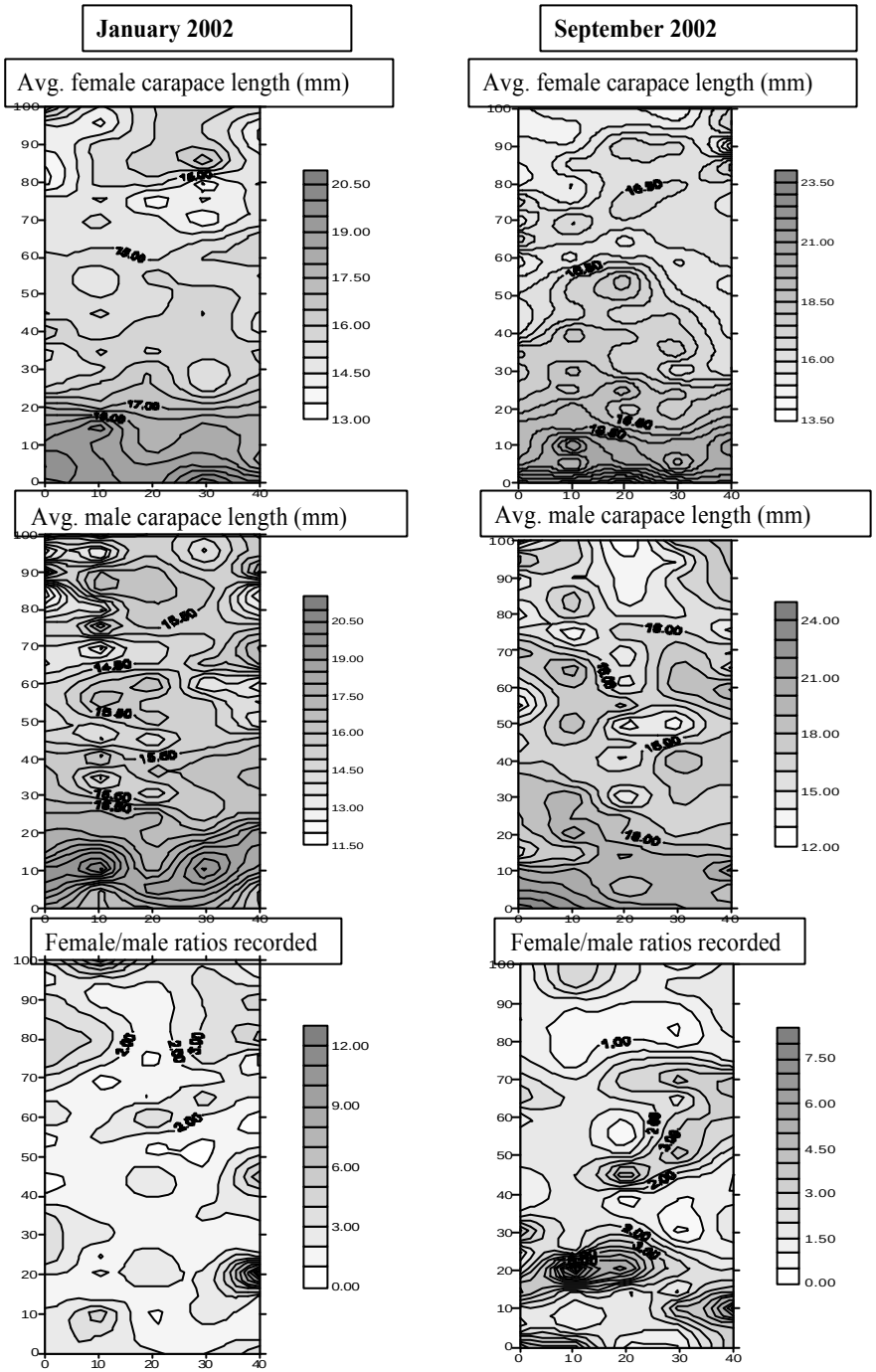

Figure 17. Distributions of average carapace length (mm) data as well as female/male ratios recorded for January and September 2002 in a single transect set.

The analysis of berry ratios focusses only on the period September – October 2002 (Fig. 18), as not enough females in berry was located in the earlier transect to perform any statistical analysis. Graph A represents the number of gravid females expressed as a percentage of the total number of females recorded. Although gravid females occur from the LWM to the top of the transect 100 m further towards the HWM, the largest percentage of gravid females are to be found in the first 30 – 40 m of the transect. The average size of gravid females also tend to increase towards the LWM, although the decrease in gravid females are less pronounced towards the HWM, occurring mostly within the first 20 – 30 m from the LWM. There does not appear to be any visible differences in the distribution of numbers or size classes from the channel side of the mud bank (0 on x-axis) and the lagoon side of the mud bank (90 on x-axis). Although Factorial ANOVA assumption tests on both numbers in berry and average carapace length indicate that low p-values are associated with the results, significant differences were obtained. When comparing the berry ratios obtained during September and October, the numbers of females in berry varied significantly on tidal height, but not between the two transect sets (months). Within the two transect sets sampled, a significant difference occurred on tidal hight but also not between transect sets. In both significant interactions, post hoc test revealed that the variation was a result of many samples, highlighting the significant difference occurring along tidal height.

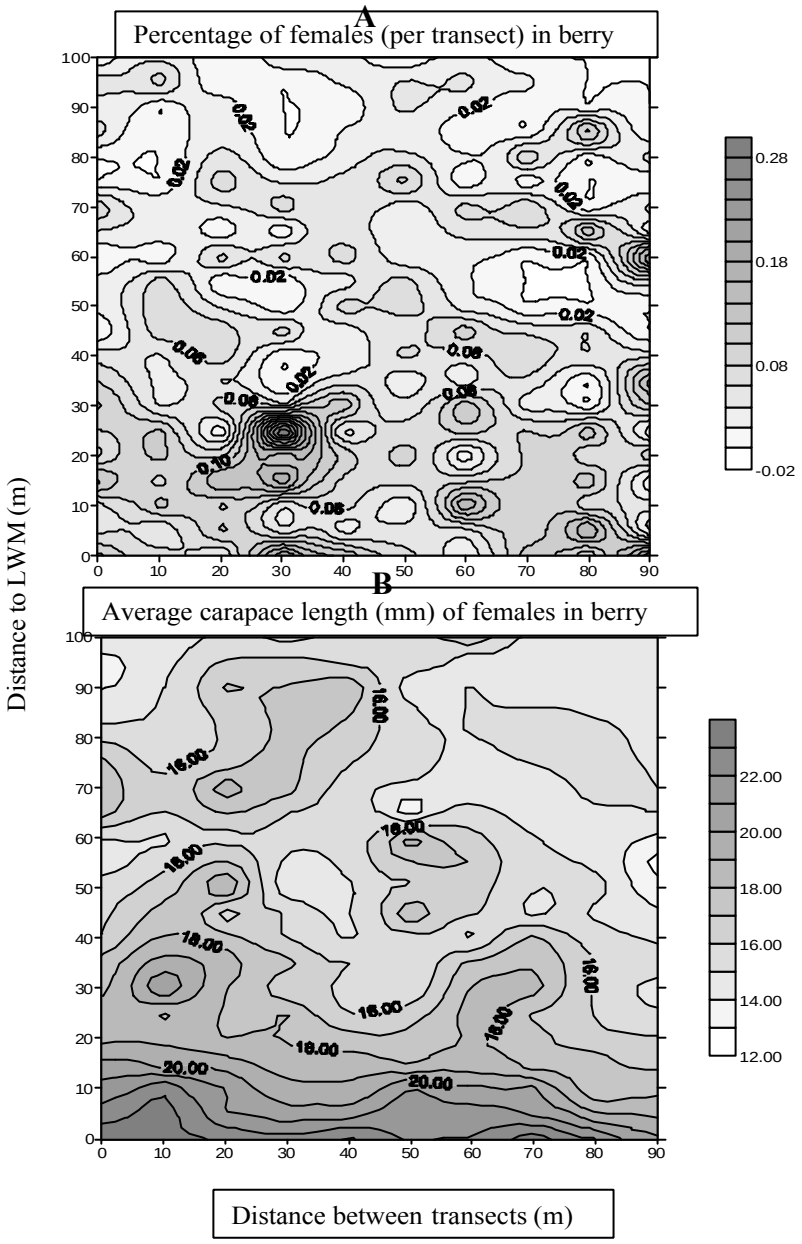

Figure 18. Graphic representation of the distribution of percentage females per transect in berry, as well as the average carapace length of females in berry for the period September (A) – October (B) 2002.

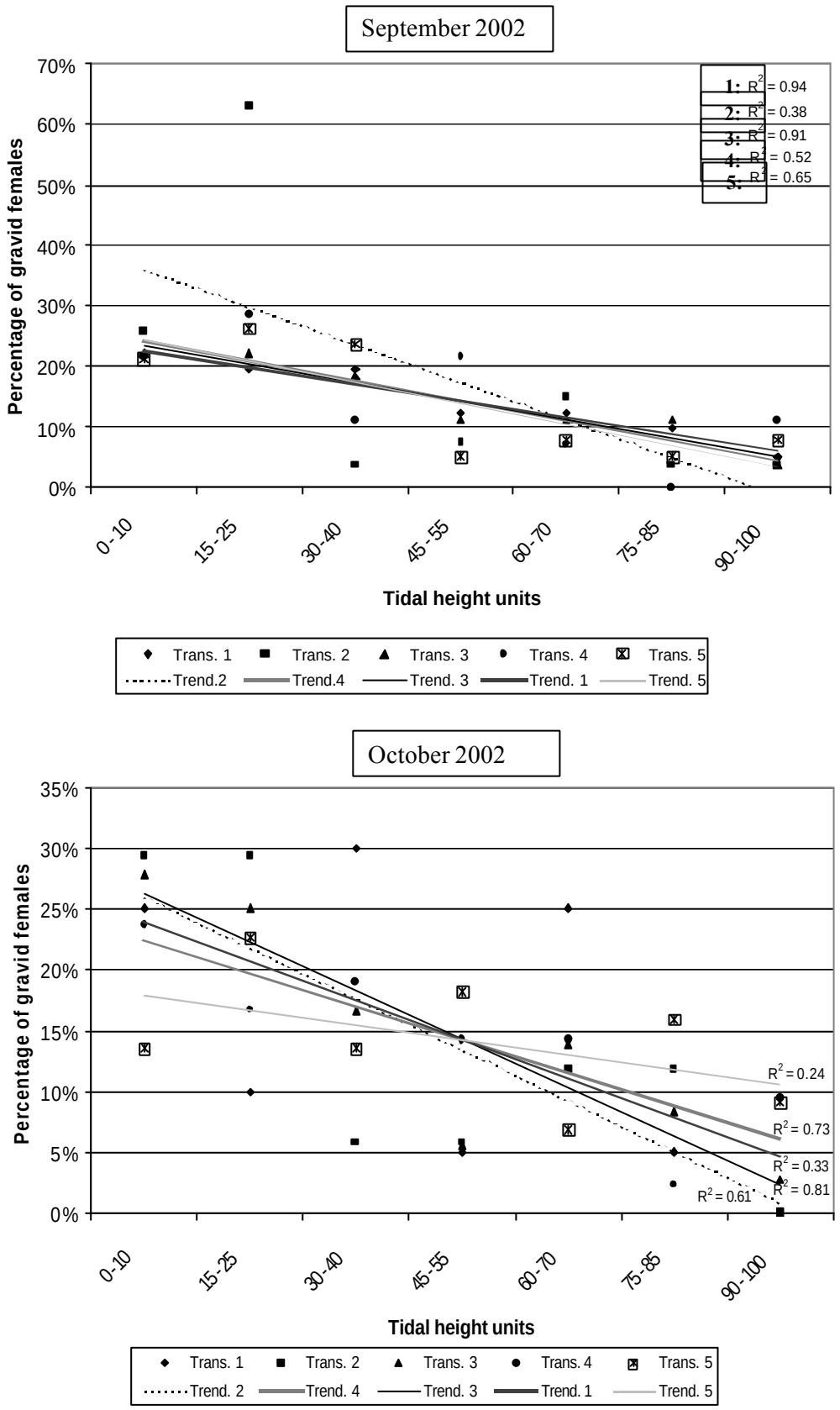

Figure 19. Berry percentages of individual transects grouped into 10 m tidal levels for the period September – October 2002. Due to the close proximity of trendlines in the September plot, R^2 – values have been moved to the top right corner of the diagram.

Following the results of ANOVA's performed on the berry data, the percentages of females in berry (as a function of the numbers of females from the tidal level only) was divided into 10 m tidal levels, graphed and fitted with trendlines in Excel. Months as well as individual transects were plotted separately in order to ascertain whether the trend observed in Fig. 18 is representative of all the transects performed. It can be seen (Fig. 19) that the numbers of gravid females in all ten transects studied during the peak reproductive periods of the mud prawn follow the same trend. The percentage of gravid females present in each individual transect as a function of all females recorded in the transect is considerably higher in the first two tidal units (Fig. 19). The fisrt two tidal units, representing the lower 25 m of the mud bank contained on average 55% of the gravid females of the transect set in September and 46% of the gravid females in October 2002. Again, no major differences in contribution were observed between the channel side and lagoon side of the mud bank. It can therefore be assumed that the trends described in Fig. 18 is representative of the entire mud bank. When the average size of females in berry were analyzed in the same manner reported above (Fig. 20), the differences in size of females in berry follows the same distribution patterns as numbers of females in berry. Although overall female carapace length across the tidal gradient was not found to be significantly different, p-values were relatively low for these tests. The breakdown of female distribution presented in Fig. 20 might throw some light on that result.

It was found that the females occurring in the first 25 m of the transect (0 – 25 m from LWM) was 17% larger than the rest of the females, and that those occurring in the first tidal level (0 – 10 m) were 24% larger than females present from 30 m to 100 m from the LWM. From this graph it is apparent that the variation occurring in the population is caused by a very small percentage of the population occurring in the first 25 – 30 m of the mud bank. The small number of significantly larger females would not have yielded high p-values in the ANOVA performed on the entire population. As far as reproductive output is concerned, it is clear that the front 30m (or ± 20%) of the mud bank contained the most important section of the population.

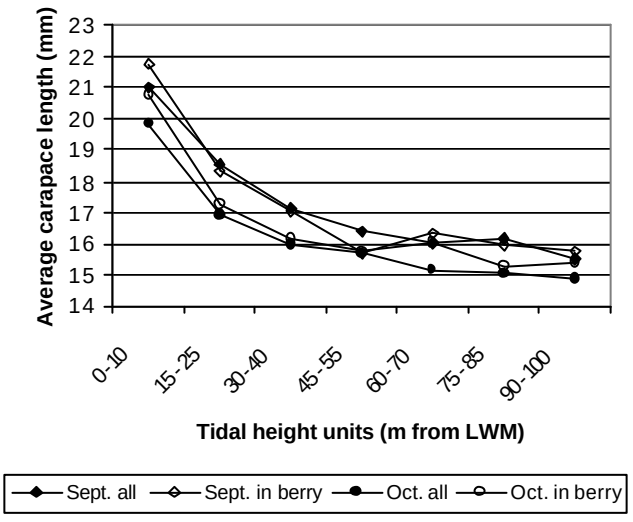

Figure 20. Comparison between the average carapace lengths of females in berry recorded during September and October 2002, at different tidal levels.

The results of prawn distributions thus far show a strong correlation with distance from the LWM, but the possible influence of sediments at the front of the mud bank has to be quantified to eliminate it as a causal factor. As can be seen in Fig. 21, the distribution of medium sand and silt and clay particles does not vary greatly over the first 40 m of the mud bank. Medium sand shows a decrease of about 1.2% over the first 20 m, but is not present in high enough volumes to cause burrow collapse. Silt and clay increases from 17.3% to 27.3% over the 40 m section, but never exceeds the limits of acceptability described by Wooldridge (1968). Silt and clay particles does, however, exceed the level of 20% of total composition listed by Hanekom (1980) as the point at which mud prawn numbers start to decline.

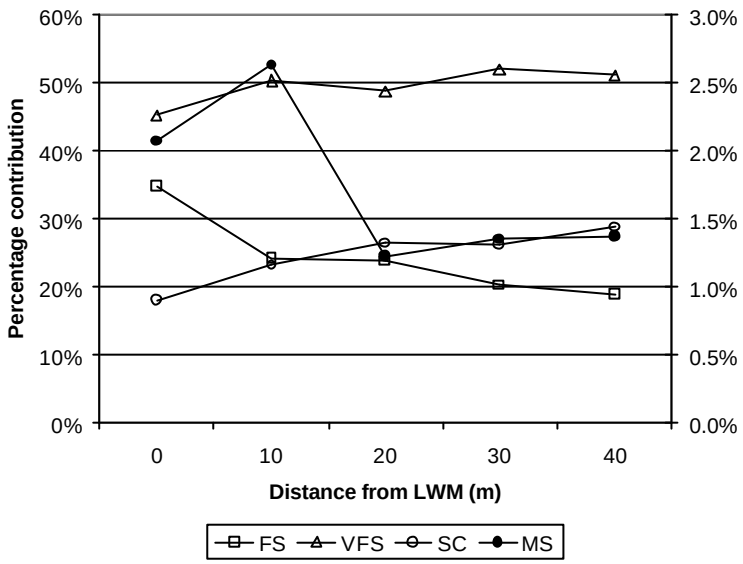

Figure 21. Distribution of sediments along the first 40 m of the study site. FS = fine sand, MS = medium sand, VFS = very fine sand and SC = silt and clay. Medium sand has been placed on a secondary y-axis due to its relatively low contribution to sample volume.

6.4 Discussion

In previous chapters, various aspects of ideal mud prawn habitat have been described. Variations in density and reproductive output have been described in different zones of estuaries studied, while the preferred sediment characteristics of the prawn as well as its osmoregulating capacity have been determined (Hanekom 1980). Ideal mud prawn habitat has to date been described as the inter-tidal and shallow sub-tidal areas of the lower and middle reaches of most estuaries (Cretchley 1996; Hanekom *et al.* 1988; Hodgson 1987). The results of this study indicates that the definition of the ideal mud prawn habitat can be further refined to include a per-site description of mud prawn distribution.

6.4.1 The distribution of male and female prawns along tidal gradients and channel length

As with the results of other experiments in the study site, a high degree of natural variation in prawn distribution and numbers was detected during sampling. This variation no doubt had a marked influence on the statistical analyses, where very few tests yielded acceptable p-values for the answers obtained. As the results of the post-hoc tests suggest that the significant differences obtained were as a result of a large percentage of the samples analysed, all significant differences obtained will be accepted as a true reflection of the state of the population in the study area, although the results should still be interpreted with caution.

Male and female mud prawns both displayed a tendency towards higher densities close to the LWM during periods of low as well as high reproductive activity (Fig. 16). The statistical analysis of male and female distributions indicated that slight differences occur between the two sexes. Females have a stronger tendency towards seasonal variations along tidal gradients, while some indication of directional changes in female population structure can also be found (Fig. 18). In male prawns, this pattern is only visible in the distribution patterns of the September – October 2002 samples (Fig. 17). The analysis of average carapace length data follows the same trends as described for numbers, increasing the likelihood that the distributional trends are described with accuracy. Hanekom and Erasmus (1989) suggested that the male contribution to reproduction effort is not as important as that of the female, and that the single most important limiting factor affecting mud prawn fitness is position on the mud bank in relation to nutrient input. Distribution patterns of dissolved nutrients described by Baird *et al.* (1987) Winter and Baird (1991) and by Baird and Winter (1992) suggests that although not all nutrients are sourced from the marine environment, peak spring flood tides

generally transport the largest amount of nutrients available in the estuary, although seasonal variations occur. From the distributional patterns observed on the Gamtoos study site it appears as if the females are influenced more by this limiting factor. The flooding patterns in the old channel does not follow a simple pattern, as the flow of the flood tide is dependent on the speed at which the lagoon water drains out of the channel at low tide. The residency time of water from previous flood tides was not determined, but no doubt has an influence on nutrient availability on the study site. Sampling was almost always cut short by the rising tide, resulting in a close observation of the changing tidal levels during the onset of the flood tide. On numerous occasions, especially during rough sea conditions, drainage on the ebb tide was impeded at the mouth and therefore a large volume of resident water would still be flowing out of the lagoon while the tide started rising again. Water level would rise on the study site, but with the current at the LWM still flowing out of the old channel. It is thus highly likely that the flood tide reaching the mud bank is diluted by resident lagoon water, especially at the lagoon end of the mud bank. There is therefore more than likely a correlation between prawn size, contribution to reproductive output and the amount of undiluted flood tide marine water that reaches different parts of the mud bank during a tidal cycle.

Testing the assumptions of the ANOVA's performed on male distribution data yielded much higher p-values for male data than for female, suggesting that there was much less variation within transects in male characteristics. Seasonal variation in male parameters was also less than in female (Fig. 16 & 17), suggesting that limiting factors – i.e. flood tide exposure had a bigger impact on the female population.

Some of the results obtained from this study can be used to support this argument. The results obtained from both male and female data analyses indicate that a degree of variation between individual transects as well as between transect sets were detected. This could tentatively be interpreted as slight variations along the channel, with the parameters studied changing slightly from the channel side to the lagoon side of the mud bank. The complex flooding pattern of the bank would in all probability also influence prawn fitness if flood tide exposure is significantly influenced during tidal cycles. A much clearer distribution pattern that emerged, however, is the variation from LWM to HWM. There is a clear and significant difference between male and female numbers as well as average carapace length at the LWM, with a visible drop in these factors taking place about 30 – 40 m away from the LWM. The analysis of sediment structure at this transition point indicated no drastic changes (Fig. 21), staying within the

acceptable parameters stipulated by Hanekom and Erasmus (1989), Hill (1967) and Wooldridge (1968). The drastic change in prawn numbers and size therefore cannot be linked to changes in sediment deposition, but rather support the assumption that it is determined by the current patterns on the mud bank.

In the Swartkops estuary, a large decrease in adult biomass has been detected starting in October, coinciding with the end of the reproductive activity. The drop in numbers slowly recover through summer as new recruits enter into the population (Hanekom *et al*. 1992). Such a reduction in biomass was also detected during the September – October sampling sessions. It would be expected, however, that if female reproductive effort is much greater than that of the male, mortality would be skewed towards females and that the September – October sex ratios should indicate a lowering of female numbers in relation to those of the male population. This, however, was not found in this study. Post-hoc tests indicate that the variation causing a significant difference between low and high reproductive effort is relatively small, and caused by only a limited number of samples. The ratios obtained during September-October indicated an increase in the numbers of females in the front 30 m of the transect during the same period as an overall drop in prawn numbers were recorded (Fig. 16). As high male mortality along the front of the mud bank coupled with female mortality at the back is highly unlikely, a more plausible explanation is that females displayed an active shift down the tidal gradient during peak reproductive activity. It is also highly likely that this concentration of female numbers observed in the front 30 m of the transects were responsible for the significant differences observed in sex ratios over the 10-month study period (Fig. 17).

6.4.2 The distribution of females in berry along tidal gradients

The results obtained in this study correspond with that of Loubser (1992), who stated that peak larval release rates in the Gamtoos estuary took place during October. During this study, the highest numbers as well as the largest females in berry were recorded in the front 30 – 40 m of the transects (Fig. 18 & 19). As statistical analyses did not show any significant differences in terms of individual transects or transect sets, it can be concluded that the high concentration of females in the front of sample transects more than likely occur along the entire mud bank. The highest concentration of females at the front of the mud bank corresponds with very low female numbers at the HWM. As mentioned before, this pattern is more than likely due to active female migrations along tidal gradients, and can be linked to reproductive strategy. Wooldridge and Loubser (1996) determined that peak larval release rhythms follow a semi-

lunar cycle synchronized to the time when high tide is crepuscular, which occurs after peak spring tidal amplitude. A position as low down on the mud bank as possible would therefore be advantageous to facilitate the export of larvae to the ocean. Evidence for such a migration during peak reproductive activity has been obtained from these results. Although the general trend observed during the analyses of transect data was that the front 30 – 40 m of the bank supported the most productive portion of the population, close inspection of the distribution of females in berry indicates that a much narrower section of the mud bank supports the prime reproductive stock of the mud bank. The average carapace length of females in berry is already much smaller at 35 m from the LWM, suggesting that reproductive capacity is already rapidly decreasing at 25 – 30 m from the LWM (Fig. 20).

Hanekom and Erasmus (1989) determined that the reproductive output of female prawns in the lower reaches of the Swartkops estuary was approximately three times higher than females in the middle reaches. The difference in average size between the females from these two sites were 6.1 mm carapace length (CL), with the average prawn from the lower and middle reaches measuring 21.2 ± 1.1 mm and 15.1 ± 1.3 mm CL respectively. A similar difference in carapace length was observed in the study population. The average size of a female in berry in the front 10 m of the mud bank was 21.27 ± 1.67 mm CL, while for the first 25m of the mud bank the average was 19.61 ± 2.31 mm CL. The average size of females in berry in the rest of the transects was 15.93 ± 1.54 mm CL. This difference, 3.68 mm CL if the average for the front 25 m is used, can be translated into approximately 200% the reproductive capacity of the rest of the mud bank. From a management point of view, the maintenance of this section of the population should be a priority, but would not be an easy task. The higher density of prawns is easily observable from surface signs such as burrow counts, and most bait collectors observed during the sampling sessions at the Gamtoos estuary targeted this narrow zone.

6.5 Conclusions

The data presented in this chapter have some important management implications. Although not all the variations in population structure observed in this study will be relevant to management, it has been demonstrated that differences exist between the distribution of male and female prawns along tidal gradients as well as over time. It has also been demonstrated that female to male ratios change during peak reproductive activity, and that this movement is more than likely due to female migration towards the low water mark. Sediment distribution

has been ruled out as an influencing factor, with marine flood tide dynamics put forward as the most likely limiting factor shaping the distribution patterns observed in the study population. All the different analyses performed, however, had one result in common. The front 20 – 30 m of the mud bank can be singled out as responsible for a sizable percentage of reproductive output, and it contains the highest number of prawns per unit area, as well as the largest prawns on the mud bank.

From literature reviews it has been determined that the lower reaches of eastern Cape estuaries support the largest and most productive mud prawn populations, with the middle reaches populations in some systems such as the Knysna estuary also contributing significantly to the maintenance of the prawn population. This study provides further evidence supporting the creation of a further division, namely the tidal gradient. Hanekom and Erasmus (1988) as well as Hodgson (1987) detected a decrease in prawn numbers from LWM to HWM in the Swartkops and Kariega estuaries, indicating that this observation is not unique to the Gamtoos estuary. From a management point of view, the results of this study have the following implications: Firstly, when the size of mud prawn populations are determined for management purposes, the entire area of extensive mud flats can not be considered as prime habitat. In effect, the old channel mud bank supports prime mud prawn numbers along less than 20% of its total width, and in much less of the total area. Bait collection in turn, is focused in that small section of the bank, rendering the reproductive capacity of the population of an extensive mud bank just as vulnerable to over-exploitation as that of an 20 m wide inter-tidal zone along the main channel of the estuary.

If the protection of mud prawn populations during the peak reproductive periods is a priority, bait collection effort should be diverted away from the low water mark. A further factor to consider is sub-tidal stocks of prawn. An option in the management of invertebrate populations that has been adopted in areas of high exploitation of coastal resources elsewhere in South Africa is to forfeit inter-tidal stocks if the sub-tidal population is deemed substantial enough to ensure the survival and recruitment of the species. Hanekom *et al.* (1988) found 22% of the sand – and mud prawn of the Swartkops estuary to occur sub-tidally, but found the lowest sub-tidal populations of mud prawn (15%) corresponding with the largest inter-tidal population in the muddy inter-tidal section of the lower estuary. Hill (1967) described the same type of distribution in the lower reaches of the Kowie estuary. Although Hill (1967) did not describe the characteristics of the channel sediments, he noted that in laboratory conditions,

prawns abandoned attempts to burrow in what he termed "muddy sands" as the burrows kept collapsing. Highest sub-tidal populations occurred in the mid- and upper reaches of the estuary where the scouring action of the current has abated to a large extent, allowing for the deposition of finer mud particles.

As the lower reaches of the Swartkops estuary contained both the most viable inter-tidal population and the smallest sub-tidal population, a cautious approach to the value of sub-tidal mud prawn stocks should be adopted as a key management option. The highest densities of sub-tidal prawns occur in areas where their production rates could not surpass those of the inter-tidal stocks, and at best should be seen as able to play a buffering role in case of inter-tidal over-exploitation.

A second management implication derived from this study is that the management of female numbers requires an adaptive management system. As females appear to be able to migrate along the tidal gradient on a seasonal basis, protected zones should be flexible enough to accommodate these movements. Female numbers appear to be most vulnerable during spring to early summer in the Gamtoos estuary, but this seasonality most likely does not apply to all estuaries. During this period, a sizable percentage of the adult female population occurs near the LWM, making them most at risk of over-exploitation.

The management strategy with the best returns for inter-tidal mud prawn populations would be a strategy that identifies the optimal habitats of the species and actively manages these during the peak reproductive periods for mud prawn in a particular estuary. To manage mud prawn populations, bait collection can either be directed away from these sites, or sections of habitat could be closed off to ensure sufficient recruitment. The period of closure, if deemed desirable, would not have to span the entire breeding cycle, as current evidence suggest that the period August to October shows the highest reproductive activity. From the calculations of Wooldridge and Loubser (1996) it can be assumed that annual successful reproductive output of a percentage of the entire mudprawn population could maintain healthy prawn populations across the species' distribution. Conflict with bait users can therefore be avoided by closing off sections of the lower reaches of an estuary for a few months only. In the case of the Gamtoos estuary, this period of closure could fall between August and November. A potential conflict with a user-group can occur during the September holiday period, which is a favorite time for angling clubs to hold extended fishing competitions. The undesirability of such

contests have been noted in previous chapters, but as an outright ban on such events is not likely in the near future, co-operation from competition anglers will have to be solicited. In estuaries with a large subsistence user group, closed seasons might be resisted (Branch *et al.* 2002b; Cockroft *et al.* 2002, Harris *et al.* 2002b), and may not be successful without incorporating the subsistence group into the co-management of the resource (Harris *et al.* 2002a).

6.6 Management recommendations

- ✓ All the different analyses performed on male and female prawn distribution had one result in common. The front 20 – 30 m (less than 20%) of the mud bank can be singled out as responsible for a sizable percentage of reproductive output, contains the highest number of prawns per unit area, as well as the largest prawns on the mud bank. The location of closed areas for reproductive as well as recruitment purposes should therefore be focused in this zone. Bait collection activity in turn, is also concentrated focused in this small section of the bank, rendering the reproductive capacity of the population very vulnerable. The restriction of human activity around the LWM in the lower and middle reaches of estuaries containing mud prawn populations should therefore be a very important management objective. Sediment distribution has been ruled out as an influencing factor, with marine flood tide dynamics put forward as the most likely limiting factor shaping the distribution patterns observed in the study population.
- ✓ When extensive mud prawn populations/habitats are identified for management purposes, the entire area of a mud flat cannot be considered as prime habitat. In effect, the old channel mud bank supports prime mud prawn numbers along less than 20% of its total width, and in much less of the total area. Calculations of standing stocks and available biomass must therefore be adapted to take this variation in density into account.
- ✓ Estuarine managers should adopt a cautious approach to the value of sub-tidal mud prawn stocks. Often the highest densities of sub-tidal prawns occur in areas where their production rates could not surpass those of the inter-tidal stocks, and at best should be seen as able to play a buffering role in case of inter-tidal over-exploitation.
- ✓ The management of female numbers requires an adaptive management system. Females appear to be able to migrate along the tidal gradient on a seasonal basis,

requiring flexible protected zones should to accommodate these movements. Female numbers appear to be most vulnerable during spring to early summer in the Gamtoos estuary, but this seasonality most likely does not apply to all estuaries. During this period, a sizable percentage of the adult female population occurs near the LWM, making them most at risk of over-exploitation.

- ✓ The management strategy with the best returns for inter-tidal mud prawn populations would be a system that identifies the optimal habitats of the species and actively manages these during the peak reproductive periods. During this time, bait collection can either be directed away from protected sites, or sections of habitat could be closed off to ensure sufficient recruitment. The period of closure, if deemed desirable, would not have to span the entire breeding cycle, as it can be assumed that annual successful reproductive output of a percentage of the entire mud prawn population could maintain healthy prawn populations across the species' distribution. Conflict with bait users can therefore be avoided by closing of sections of the lower reaches of an estuary for a few months only. In the case of the Gamtoos estuary, this period of closure could fall between August and November.

7. Rates of exploitation, subsistence issues and management recommendations

7.1 Removal rates, standing biomass and production rates

The extent and magnitude of standing stocks of bait populations have been obtained from published and unpublished literature, which will be augmented by current data analysis. One point of concern, however, is the influence that habitat change could have on the suitability of the data. Changes in the location and extent of suitable habitats, as well as the species that occupy these have been described in the previous chapter. These fluxes in species distribution will have obvious influences on management recommendations. Figures cited in most studies are those obtained by Hanekom (1980) for the Swartkops estuary. In this system, mud prawn comprises 82% of total macrofaunal biomass, and sand prawn 11%. The mean density and biomass of mud prawn was 218 ± 166 animals and 46 ± 40 $g.m^{-2}$ respectively (Hanekom *et al.* 1988). These density figures are higher than those obtained for the Kromme (121 ± 79 prawns m^{-2}) and Sundays estuaries (100 ± 70 prawns m^{-2}). Mud prawn dominates the middle reaches of estuaries, whereas sand prawn dominates the mouth and upper reaches. Hanekom *et al.* (1988) also quantified the numbers of both prawn species occurring sub-tidally. Mud prawn was found to occur at 68 % of sub-tidal transects compared to 73 % at inter-tidal transects, whilst sand prawn was found at 68% and 36% of the sub-tidal and inter-tidal transects respectively. The significance of these sub-tidal stocks for management purposes have been discussed in a previous chapter. Densities and biomass of sand prawn was calculated to be in the order of 104 ± 126 animals and 15 ± 17 $g.m^{-2}$ inter-tidally respectively, and 53 ± 85 animals and 8.5 ± 8.4 $g.m^{-2}$ sub-tidally respectively. These values are higher than those recorded (22 ± 29 prawns m^{-2}) by Du Preez (as cited in Hanekom *et al.* 1988) in the Sunday's estuary, but similar to figures obtained for the Knysna estuary.

The above-mentioned results on species' density differ from data obtained in the Western Cape. In the Langebaan Lagoon, the two prawn species account for approximately 48% of the total benthic biomass. Studies of the Kariega estuary indicated that sand prawn is present in the mouth region at a maximum density of 50 m^{-2}, whereas mud prawn dominates the lower reaches together with the sand-flat crab (*Cleistosoma edwardsii*), both reaching densities of between 100 and 150 m^{-2} (Hodgson 1987). Although mud prawn is also present in the middle reaches of the estuary, it is no longer a dominant species. In the Knysna estuary, mud prawns also have a lower to middle estuary distribution, but with the uppermost distribution characterised by fewer and smaller individuals (11.7 m^{-2}; 3.9$g.m^{-2}$ dry weight). The prawns

occupy 62% of the available inter-tidal area with an overall standing stock of 82.7 tonnes dry mass (Cretchley 1996).
The average inter-tidal density was 74 – 76 m^{-2}, with a biomass of 26 – 27 $g.m^{-2}$, whilst highest densities were 176.5 m^{-2} with a standing biomass of 65.3 $g.m^{-2}$ (Hodgson *et al.* 2000a). Sex ratios in the Knysna estuary did not vary significantly from a 1:1 ratio.

Data on removal rates of bait collectors are limited. Hanekom and Baird (1992) stated that recreational collectors remove 2% of annual somatic production annually from the Swartkops estuary. In Langebaan lagoon, bait collectors removed an estimated 3.2% of standing biomass (800 000 prawns) per annum from collection areas. In total, this was equal to below 0.01% of total standing biomass (Wynberg and Branch 1991). In the Knysna estuary, bait collectors removed 8.49% (1.858 x 10^6) of the standing stock of prawns annually (of six targeted collection areas), which translated to 0.85% of total standing biomass.

7.2 The subsistence fishery and mud prawn utilisation

Since the inception of the Marine Living Resources Act (No. 18, 1998) the recognition of access rights of subsistence users, many with a long history of resource utilization, was formally recognized (Branch *et al.* 2002a; Harris *et al.* 2002a). Prior to the inception of the act, the National fisheries development Committee (FPDC) made the following recommendation towards the subsistence sector of the fishing community: Subsistence users should be identified and licensed, different regulations could apply to this user group, they should be allowed to sell part of their catch (locally only) and specific zones within which they have preferential access rights could be established (Van der Elst *et al.* 1997).

The exploitation of estuarine bait resources, including sand- and mud prawn, pencil bait and polychaetes, play an important role in the livelihood of the subsistence fishers of the Swartkops estuary. Branch *et al.* (2002a) determined that 30% of South Coast subsistence fishers interviewed reported using estuarine invertebrates, in the majority of cases to target fish for consumption or sale. Pradervand (1998) lists only 3.4% of anglers interviewed in Eastern Cape estuaries as subsistence anglers, but due to the sampling method (questionnaires and telephone interviews) a large percentage of subsistence fishers were most likely overlooked. Of the six guidelines listed by Branch *et al.* (2002a) for the identification of subsistence fisher zones, at least four are likely to apply to the Swartkops estuary. These are: a high degree of dependence on the resource, a long history of using the resource, resources are in short supply

and competition exists between different user groups of the same resource. Previous investigations into angler activity in the Swartkops estuary has largely overlooked the subsistence sector, thus making it very difficult to determine the size of the user group at present as well as levels of resource use and needs. Any conclusions in this study on the needs of subsistence users in the Eastern Cape will have to be made based on studies done at the Knysna estuary.

In a study that incorporated subsistence users in a Southern Cape estuary, Cretchley (1996) was able quantify the amount of bait resources used by recreational and subsistence users in the Knysna lagoon. The bait collectors studied were divided into two user groups, namely recreational fishers removing ± 59 prawns per day, and subsistence fishers using ± 102 (double the legal quota) prawns per day. 77% of collectors were subsistence fishers, and accounted for 85% of prawns removed (Hodgson *et al.* 2000b). A large percentage (71%) of subsistence users felt that the daily quota was insufficient, while the majority of recreational anglers interviewed felt that the number was more than enough. The quantification of the subsistence user group would therefore not only require the determination of current numbers of anglers, but also their daily bait requirements.

7.2.1 Creating a small-scale commercial (SSC) bait selling industry at the Swartkops estuary

The suggestion that the use of limited commercial rights to uplift needy communities living near estuaries has been explored for a number of years. Cretchley (1996) suggested that the collection of bait for angling should be seen as part of the estuarine experience, and that the commercialisation of bait resources should be considered on a limited scale only. Branch *et al.* (2002b) describes a SSC operator as people with a history of involvement, working together or as individuals with the aim of making a profit out of the sale of high value or very abundant resources. These resources are managed through TAC or TAE, although management options listed include exemption from permit fees and/or zoning and preferential access to resources. A number of examples of possible SSC industries are listed by Branch *et al.* (2002b), excluding benthic estuarine macrofauna. The list should however be seen as guidelines only. Cockroft *et al.* (2002) identified bait exploitation as a potential new commercial avenue to explore. As most marine resources are fully exploited or over-exploited (Branch *et al.* 2002a), creating a new commercial venture should be approached with caution. It is on the basis of this assumption that the potential for limited commercial exploitation was investigated.

7.2.2 Possible areas of conflict

A decrease in the numbers of popular estuarine fish species has been demonstrated in a previous chapter, and as the exploitation of bait species goes hand in hand with fishing activity, the two resources should be dealt with as a single management priority. According to Harris *et al.* (2002a) sustainability is critical for the allowance of a SSC operation to exploit a resource. If the resource, in this case mud prawn and associated target fish species, cannot be exploited in a sustainable manner or without significant collateral environmental damage, it is not suitable for utilization in a SSC industry (or any other sector).

From the study performed by Cretchley (1996) it can be seen that subsistence users are able to be responsible for the removal of a much larger percentage of bait organisms than the recreational sector.

A hasty attempt to create a SSC bait industry could meet up with the same problems that the generation of subsistence abalone and rock lobster industries encountered. These ventures were unsuccessful because appropriate management and monitoring systems were not developed, and no market supply lines or support structures were established prior to quota allocations (Branch *et al.* 2002a). Poor communities benefited little from the exercise, which served only to create a loophole for increased poaching. At this point in time, it might be wise to re-consider the potential of a large scale SSC based on bait selling. Harris *et al*. (2002b) suggested that SSC opportunities exist where species are not targeted by commercial or recreational fishers. As the use of the bait species concerned form an integral part of the recreational fishing industry, the degree of user-overlap might be too significant to ignore. The authors further suggest the use of the Precautionary Principle where current biological data on the species is insufficient, thus no increase in fishing effort should be implemented until evidence exists that it would be sustainable. Even if species are deemed exploitable based on current information, they might not be so, requiring the monitoring of all user groups and the periodic review of any subsistence or SSC fisheries. Species should be removed from the exploitable list, or removal rates reduced if sustainability is threatened (Harris *et al.* 2002b).

A further potential source of difficulty for the management of an SSC bait industry is that it is recommended or suggested (Branch *et al.* 2002b; Cockroft *et al.* 2002, Harris et al. 2002a) that closed areas or seasons as well as bag limits or permit levels should not always apply to an SSC industry, and that SSC operators should have preferential access to the resource. Hauck *et al.* (2002) also reports that subsistence fishers interviewed in target groups feel that they should

have priority access rights to resources they exploit, not be subjected to recreational bag limits or denied access to areas zoned for recreational use. It is not within the scope of this study to find solutions to these issues, but it seems likely that conflict could arise between the different user groups as well as between managers and SSC operators. When the recreational sector pays to have access to the same resource, and when subsistence fishers rely on the same resource for survival, can the SSC operators demand first right of access? If a situation arises when decreasing stocks of bait species or associated target fish species requires management intervention in the form of closed seasons or reduced bag limits, a single user group cannot have continued rights of access reserved or protected. It has been stated by many authors (Branch *et al.* 2002b; Cockroft *et al.* 2002, Harris *et al.* 2002a; 2002b) that the sustainability of resource use must be ensured at all times. As closed seasons and bag limits are instituted to ensure sustainability, no user group should be given the power to demand access to a resource beyond the point of sustainable exploitation. It is also likely that in relatively short estuaries such as the Swartkops, zones of recreational and subsistence use of resources as well as areas deemed as valuable to the reproductive or recruitment success of mud prawn will overlap. It is therefore imperative to determine access rights and the efficiency of management control on all sectors prior to the formalisation of an SSC bait operation.

As only the recreational sector of the Swartkops estuary is relatively well quantified, the creation of a SSC should ideally be delayed until the total resource needs of the two other user groups at present exploitation rates have been determined. This sentiment is shared by Harris *et al.* (2002b) where it is advocated that the development of acceptable, practical and equitable solutions requires better information about the fishers involved as well as the resources used. The principles of shared decision making also need further exploration.

Prior to Marine and Coastal Management (M & CM) assuming control of the management of the Swartkops estuary, a small operation selling mud prawn from the Rod and Reel Club, employing about 10 bait collectors, existed. This practice was stopped by M & CM, but the collection and sale of bait organisms continued. In the last quarter of 2002, dialogue was initiated between M & CM, local law enforcement bodies, interested parties and bait sellers in order to investigate the possibility of legalising the practice. At last count (Dr A. Boyd pers. com.) 65 bait sellers have been recognised and their details documented. The question over the creation of an SSC is not whether current stakeholders deem it desirable, but rather if the estuary can sustain increases in recreational as well as subsistence fishers as well as 65 full-

time bait collectors. Clark *et al.* (2002) states that the management of subsistence (and by inference) and potential SSC operators along the East Coast should be prioritised, as resources are already under severe pressure. Harris *et al.* (2002b) defines a SSC operator as a person living close to the exploited resource, must have a history of involvement in the industry, and have a reliance on the industry for a living which must generate more than 75% of their total income. Branch *et al.* (2002a) investigated the income of fisher communities around South Africa, and determined that the average income of a fisher household in the Port Elizabeth area is R 735 per month. Therefore, if a generalised figure can be used to determine the income that should be derived from a SSC bait operation, 75% of R 735 is R 514,50. For the purposes of this discussion therefore, it is assumed that a bait seller will strive to earn at least R 500 per month from his efforts. The difference in numbers of collectors employed by the Rod and Reel club and those interviewed by M & CM officials in late 2002 suggests that a large component of potential SSC candidates do not conform to the definition given by Harris *et al.* (2002b). Clark *et al.* (2002) warns about the extent of opportunism in subsistence industries, underlining the need for clear definitions of subsistence fishers to ensure that only *bona fide* subsistence users are treated as such. The need is the same for the definition of a SSC operator. The temptation to list too many users as subsistence or SSC should also be avoided, as the needs of this user group should be balanced (and not exceed) against limits of sustainability of the resource on which they depend. Coastal resources can not be seen as a safe fallback during hard times, as it would most likely lead to over-exploitation (Clark *et al.* 2002).

7.2.3 Generating a formula to describe the potential SSC requirements

For the purposes of this exercise it is suggested that management control over commercial activity comes in the form of a modified total allowable catch (TAC). This is a commonly used management tool for small scale commercial operations (Cockroft *et al.* 2002) and should be relatively simple to implement if baseline information is maintained. The modification required for the suggested TAC is that current levels of biomass (prawns per square meter) be determined, and the potential area available for exploitation determined. The yield available to sellers would then be described as the biomass of mud prawn (production export) contained in an area deemed available for collection by legal means. It is important that collection related mortality should be incorporated into the TAC, as it has been estimated to be at least 25% of standing biomass where bait digging took place. Ignoring mortality rates such as these could rapidly lead to stock over-exploitation. Based on the amount of mud prawns available for the

SSC bait industry, the amount of individuals allowed access to the industry or the total potential income of sellers in the industry can be determined.

For the first scenario described below, a TAC will not be employed. In stead, a hypothetical desired annual income per seller would be used as the only controlling factor to determine the level of exploitation required. The current description of a SSC operator is relatively vague, therefore some general assumptions will be made in this exercise.

To determine the potential effort and participator limitations of a mud prawn SSC operation, the following parameters are required:

1. The desired income of the bait seller: For the purposes of this example, it will be assumed that a commercial operator would attempt to gain at least a living wage from his or her activity, thus a minimum required monthly income (R) of R500 is set. For the purposes of this calculation, incomes of R250, R500 and R750 will be used to calculate industry requirements.
2. The amount of effort of each seller: Currently, SSC bait sellers are allowed to remove 150 prawns per day. It is not possible at present to gauge the market parameters accurately, thus the actual number of prawns removed cannot be determined. The current recreational bag limit of 50 prawns, 100 prawns and the SSC bag limit of 150 prawns will be the units of sale in these calculations. A specific amount (b) of prawn units (X, set at 50, 100 and 150) will have to be sold to meet the seller's requirements.
3. The amount of selling opportunities: Not every day will be suitable for collection. Spring low tides corresponding with weekends and during holidays are arguably the best selling time, as a large amount social anglers will visit the estuary. During 2002, spring tides within 3 days either side of a Saturday occurred 13 times, while spring tides corresponding exactly with a weekend occurred nine times. It is assumed in this study that at least three days each during full moon and dark moon spring tide would provide sufficient customers (anglers). Using the figures above, 27 to 39 selling days corresponded with weekend spring low tides. This is less than four ideal selling days on average per month. For the purposes of this example, number of selling days (a) per month is set at six, which is considered to be above average, but if holidays and long weekends are taken into consideration, could be a realistic estimate.

The formula for the income of a single seller per month can then be written as:

$$R = a \times (bX)$$

If 6 selling opportunities are used monthly (amount of selling opportunities does not influence number of prawns sold, it is only introduced as an expected figure) to generated the desired income, here put forward as ≈ R 250, R 500 or R 750, the number of prawn (n) required per is expressed as:

$$n = \frac{R}{ab}$$

where b is the estimated value of a single prawn. The market price for mud prawn will have to compete with other commercially available bait sources. Pink prawn currently sells for R30 per 200g box; chokka at ± R35/kg, while the price of pilchard varies between R8,95 to R10,95/kg box. The average angler probably would use not more than 500 g of chokka per day, thus putting the price range for a day's bait somewhere between R10 and R 30 per day depending on the choice of bait. When prawns were sold at the Swartkops estuary Rod club, the average price was ± R5 per 50, which is currently also close to the asking price by bait diggers for prawn (R5 to R10 per 50, depending on selling conditions). The low value of prawns is immediately a cause for concern. Clark *et al.* (2002) lists commercial species as high value species, which mud prawn clearly is not. Even though minimum size or daily bag limits and closed seasons can be applied to operators in a mud prawn SSC (Cockroft *et al.* 2002), the amount of prawns required to satisfy income expectations could be too high. It is assumed that no angler will buy all 150 of a seller's daily quota, but will still buy in batches of 50. For the purposes of this example (Table 10) the price of 50 prawns is set at R25 for a maximum and at R5 for a minimum sale price at R5 increments. This price range therefore allows for the determination of the possible cost of a unit (50) of prawns compared to other bait types used by estuarine anglers. It is assumed that anglers will be deterred from buying mud prawn when the unit cost exceeds that of other commercial bait types, which sets the possible maximum price for a unit of prawns (50) at ≈ R25.

Table 10. Calculations of the number of prawns per day required by a SSC bait seller to meet hypothetical income levels (R) with variations in the number of possible selling days (a) in a month, as well as the possible value (in c) of a single prawn (b). Highlighted values are below 150 prawns per day, the maximum allowable take per seller per day at present.

Selling	Desired		Value per single prawn (b)			
days	income (R)	1 c	2 c	3 c	4 c	5 c
a = 4	**200**	500.00	250.00	166.67	125.00	100.00
a = 5	**200**	400.00	200.00	133.33	100.00	80.00
a = 6	**200**	333.33	166.67	111.11	83.33	66.67
a = 7	**200**	285.71	142.86	95.24	71.43	57.14
a = 8	**200**	250.00	125.00	83.33	62.50	50.00
a = 4	**300**	750.00	375.00	250.00	187.50	150.00
a = 5	**300**	600.00	300.00	200.00	150.00	120.00
a = 6	**300**	500.00	250.00	166.67	125.00	100.00
a = 7	**300**	428.57	214.29	142.86	107.14	85.71
a = 8	**300**	375.00	187.50	125.00	93.75	75.00
a = 4	**400**	1000.00	500.00	333.33	250.00	200.00
a = 5	**400**	800.00	400.00	266.67	200.00	160.00
a = 6	**400**	666.67	333.33	222.22	166.67	133.33
a = 7	**400**	571.43	285.71	190.48	142.86	114.29
a = 8	**400**	500.00	250.00	166.67	125.00	100.00
a = 4	**500**	1250.00	625.00	416.67	312.50	250.00
a = 5	**500**	1000.00	500.00	333.33	250.00	200.00
a = 6	**500**	833.33	416.67	277.78	208.33	166.67
a = 7	**500**	714.29	357.14	238.10	178.57	142.86
a = 8	**500**	625.00	312.50	208.33	156.25	125.00
a = 4	**600**	1500.00	750.00	500.00	375.00	300.00
a = 5	**600**	1200.00	600.00	400.00	300.00	240.00
a = 6	**600**	1000.00	500.00	333.33	250.00	200.00
a = 7	**600**	857.14	428.57	285.71	214.29	171.43
a = 8	**600**	750.00	375.00	250.00	187.50	150.00
a = 4	**700**	1750.00	875.00	583.33	437.50	350.00
a = 5	**700**	1400.00	700.00	466.67	350.00	280.00
a = 6	**700**	1166.67	583.33	388.89	291.67	233.33
a = 7	**700**	1000.00	500.00	333.33	250.00	200.00
a = 8	**700**	875.00	437.50	291.67	218.75	175.00

From these calculations it is clear that prawns cannot be sold at low cost when selling opportunities are limited. Even when the maximum perceived cost of 50 prawns (b = 0.5) are used, an income over R500 a month can only be attained at 8 selling days per month. Under no circumstances with the parameters used in this calculation was it possible to reach an income

over R700 per month with legal removal levels, while it seems more likely that at prices between R15 and R25 per 50 prawns, sellers are at best likely to earn between R300 and R500 per month. It must, however, also be kept in mind that a total of 70 SSC bait sellers have been given quotas at present. It is doubtful whether the entire group of sellers would be able to

operate at the same time or be able to generate a sizeable income under such competitive conditions. For the sake of calculating the number of prawns required to sustain the SSC bait industry, the income levels of Table 10 using up to 150 prawns per person per day will be used with a sliding scale of active sellers. Seasonal fluctuations in the market for mud prawn will occur, but it assumed that commercial operators would attempt to maintain income levels, setting effort in months (*m*) at 12. Using the total amount of potential sellers listed by M & CM, the number of sellers (*s*) is set at 70. The equation describing the income and prawns needed to sustain the industry is listed as:

$$Rms = a \times (bX)$$

The total amount of prawn per annum required to sustain a SSC under the parameters set above and using variations in numbers of active sellers are set out in Table 11.

Table 11. Calculations of the total number of prawns per annum required to sustain a SSC bait selling community under various operator level and prawn value scenarios. Note that only acceptable removal rates (below 150 per person per day) were used in these calculations.

			Desired income levels at different unit values (b) per prawn								
Sellers	***b = 0.2***	***b = 0.3***			***b = 0.4***				***b = 0.5***		
active	**R 200**	**R 200**	**R 300**	**R 200**	**R 300**	**R 400**	**R 200**	**R 300**	**R 400**	**R 500**	**R 600**
10	120000	80000	60000	60000	90000	120000	48000	72000	96000	120000	144000
20	240000	160000	240000	120000	180000	240000	96000	144000	192000	240000	288000
30	360000	240000	360000	180000	270000	360000	144000	216000	288000	360000	432000
40	480000	320000	480000	240000	360000	480000	192000	288000	384000	480000	576000
50	600000	400000	600000	300000	450000	600000	240000	360000	480000	600000	720000
60	720000	480000	720000	360000	540000	720000	288000	432000	576000	720000	864000
70	840000	560000	840000	420000	630000	840000	336000	504000	672000	840000	1008000

From Tables 10 & 11 it can be seen that a relatively high number of selling days as well as a market value close to those of other commercial bait species would be required to sustain the number of potential bait sellers permitted to operate in the SSC bait industry. The calculations presented here further assume that all prawns collected will find their way to a buyer. At maximum operating levels, this will imply that 20 160 angling trips per year or 1680 per month will make use of the bait on offer. Daniel (1994) estimated that an average of 121 recreational anglers visit the Swartkops estuary per weekends. Even if it assumed that the number of anglers have increased notably since his study, there will not be enough buyers on hand to ensure that every operator in the industry earns a living wage. The number of transactions, assuming that fishermen will be limited to 50 prawns per day, required to dispense of the

number of prawns listed in Table 11 is given in table 12. Highlighted results in Table 12 are values exceeding the monthly utilisation levels of the Swartkops estuary by recreational anglers as determined by Daniel (1994).

Table 12. Numbers of transactions per month required to reach calculated income goals for SSC operators.

Unit cost	Income level	Sellers						
		10	20	30	40	50	60	70
0.20	R 200	200	400	600	800	1000	1200	1400
0.30	R 200	133.33	266.67	400	533	666	800	933
	R 300	100	400	600	800	1000	1200	1400
0.40	R 200	100	200	300	400	500	600	700
	R 300	150	300	450	600	750	900	1050
	R 400	200	400	600	800	1000	1200	1400
0.50	R 200	80	160	240	320	400	480	560
	R 300	120	240	360	480	600	720	840
	R 400	160	320	480	640	800	960	1120
	R 500	200	400	600	800	1000	1200	1400
	R 600	240	480	720	960	1200	1440	1680

It is therefore relatively obvious that even enforcing the sale of the bait to every recreational angler visiting the estuary would not ensure the survival of all role-players currently in the bait selling industry. A more conservative estimate would appear to be that an opportunity exists for between 10 and 30 full-time sellers to earn ± R300 a month.

All the calculations listed above are based solely on removal rates, excluding secondary mortality rates caused by the collection process. It is crucial that the amount of mortality related to collection activity be calculated and incorporated into the TAC of the SSC industry. Therefore, provision must be made for the further loss of 25% of remaining biomass or 20% of annual somatic production (Wynberg 1991; Hanekom and Baird 1992).

7.3 Generating a removal formula for mud prawn

7.3.1 Utilisation of bait species by natural predators and bait collectors

In order to assign a safe percentage of annual somatic production, it is important to determine the current energy requirements of natural predators of mud prawn as well as the role mud prawn play in nutrient cycling. Martin (1991b) lists 35 bird species that commonly feed in the Swartkops estuary. The 5 most dominant species are kelp gull (*Larus dominicanus*), grey plover (*Pluvalis squatarola*), whimbrel (*Numenius phaeopus*), Curlew sandpiper (*Calidris*

ferruginea)(migrants) and common tern (*Sterna hirundo*). These and other species feed predominately in the inter-tidal mud banks, where mud prawn constitute up to 80% of the prey mass consumed by the birds (Martin 1991b). The main fish predators of *U. africana* are spotted grunter, sea catfish and Cape moony (Hanekom *et al*. 1988). Major fish predators of *C. kraussi* are spotted grunter and white steenbras, whilst bird predators in the sandy regions include sanderling (*Calidris alba*) and white-fronted plover (*Charadrius marginatus*), although these two birds feed mainly on insects (Hanekom *et al.* 1988). *Solen* species are a small part of the diet of white steenbras and spotted grunter, whilst the extent of bird predation on these species is unknown.

Hanekom and Baird (1992) listed the annual consumption of mud prawn production (not standing biomass) by predators as follows - birds: 13%, fish: 5% and humans: 2% (4 000 kg dry mass or about 1.7 million individuals per annum). It is important to note that the human component listed here is based on the recreational industry. The subsistence sector was poorly quantified during the study, and most likely overlooked completely. Daniel (1994) reported that an average number of 27 subsistence anglers utilised the Swartkops estuary over weekends (18% of weekend fishermen). The number of subsistence anglers during the week was not determined. It is vital that the requirements of this user group be determined as soon as possible. For the purposes of this example, the ratio of recreational to subsistence users in the Knysna estuary (another Eastern Cape estuary close to a large urban settlement) will be used to determine possible exploitation rates. Using the data recorded by Cretchley (1996), it can be calculated that if the Swartkops estuary recreational sector is also responsible for 15% of the total annual removal of mud prawn (2% of annual somatic production), the subsistence users could be responsible for the removal of 11% of annual somatic production (± 9.6 million prawns per annum based on Hanekom and Baird (1992)).

Therefore, even before SSC removals are considered, it can be seen that a total of 31.33% of annual somatic production of mud prawns are potentially removed at present. Factoring in the effect of environmental damage and mortality related to bait collection (combining the two user groups gives a consumption level of 13%) determined by Hanekom and Baird (1992) to be 9% for every 1% production consumed, a further 120% of annual somatic production could be lost to human activity alone. Based on this estimation, the mud prawn population of the Swartkops estuary could already be over-exploited (an estimated total of 151% of annual somatic production if natural predators are included) at present levels of utilisation with the

addition of collection-related mortality. Although the study performed by Gerber (unpublished data) was not inclusive of all the sites studied by Hanekom (only seven sites were sampled) and the sample grid size used was very small (21 cm by 21 cm), it is the only current data available. It noted a decline in numbers in the most popular bait collecting and fishing areas, with only the population above the N2 bridge appearing to be relatively untouched by present day collection pressure. Fishermen interviewed and present at a stakeholders meeting conducted by M & CM during September 2002 were also of the opinion that prawn numbers were declining substantially in the lower reaches of the estuary.

Bait diggers have been active in the Tipper's creek area since the study by Gerber (pers. com.) and the effects of their digging has seriously reduced prawn numbers in this area (pers. obs.). It would therefore seem plausible that the decline noted in the site biomass rating recorded by Gerber (unpublished data) when compared to Hanekom (1980) could be correct, suggesting that current levels of utilisation is non-sustainable and causing a population decline.

Before quantifying the annual requirements of a potential SSC bait operation, it will have to be determined whether the potential sellers identified by M & CM are currently utilising mud prawns at subsistence levels (thus forming part of the consumption already listed) or if their requirements will require further annual allocations. Based on the calculations listed in this chapter, generating a completely new user group requiring at least 1 00 8000 prawns per year will require a further 1.3% of annual somatic production without incorporating mortality caused by collection. This may seem to be a relatively small addition, but should have been delayed until the current levels of utilisation and standing biomass have been quantified.

These calculations are only a rough attempt to quantify the requirements of each user group and natural predators, but indicate that a potential situation for over-exploitation already exists. The data on which these calculations are based, however, are dated, extrapolated from other studies or based on small sample sizes. The need to quantify consumption levels on a regular basis is highlighted by this scenario. Therefore it is a matter of utmost urgency that the current levels of biomass, production and utilisation levels are determined with accuracy prior to the full-scale implementation of an SSC bait selling industry.

7.4 Conclusions

7.4.1 The subsistence sector and possible SSC bait industry

The most immediate management action regarding the subsistence sector is to quantify, licence and formalise the subsistence fishery in the Swartkops estuary as well as all other systems in the eastern Cape where the usage patterns of this user group is poorly documented. Once the bait requirements of this group has been determined and combined with current removal rates from the recreational sector, the feasibility of a SSC bait industry can be properly investigated. Rushing into a decision regarding this issue will definitely have the same outcomes as warned against by Branch *et al.* (2002a). From the lessons learnt from other subsistence fisheries in South Africa, the incorporation of the subsistence sector into a co-management structure could be crucial for the successful implementation of any future management plan that would have an impact on the activities of this group. Other than many resources earmarked elsewhere in South Africa for the implementation of SSC programmes, mud prawn is currently exploited by recreational as well as subsistence fishers. Recreational anglers already pay to have access rights to the resource. Creating a third user group into the system could lead to tension over access rights, again necessitating the inception of co-management structures including members of all the user groups to promote new management plans.

From a resource management point of view, the creation of a SSC bait operation cannot be implemented at this stage, as up to date baseline exploitation and biomass data is lacking at present and is crucial to the planning phase of such an industry. It is the assumption of this study that the cautious approach advocated (Branch *et al.* 2002b; Cockroft *et al.* 2002, Harris *et al.* 2002a) to maintain sustainability will prevail during the planning phase of a SSC bait programme, and that the limits of sustainability (once established) will not be exceeded. Concern over the process thus far still remain pertaining to the following issues:

1. The short history of many of the bait seller associated with the Swartkops estuary. It is doubtful whether all the sellers identified in a recent fact finding survey by M & CM fit the description of a *bona fide* commercial operator as described by Clark *et al.* (2002).
2. The relatively low value of the resource, coupled with vague definitions of desired income and the number of potential sellers identified for the industry could result in the creation of unrealistic expectations of potential income. This could in turn lead to high levels of exploitation that could be hard to control after licences have been issued. The

examples given in the discussion indicate that over a million prawns per annum allocated to the SSC operators would still not guarantee a steady income for all the identified participants. If quota enforcement is not actively persued; a high unit price for prawns cannot be maintained and all the identified sellers in the industry strive for a steady income regardless of number of prawns removed, a situation can arise where ± 3 000 000 prawns per annum are removed for sale.

3. The potential market has not been properly quantified nor is it known at this stage what the pricing of mud prawn compared to other commercially available bait would be.
4. Interviews with many anglers confirm that the current sale of mud prawn goes hand in hand with the sale of other species, such as pencil bait, blood- and tapeworm. These species occur in such low numbers (Hanekom *et al.* 1988) that standing biomass could not be quantified previously. Clear indications will have to be given on which species are allocated to SSC operators, and the illegal sale of any other species should be dealt with better than at present.
5. Creating a SSC bait industry will result in a dependence on the maintenance of the market for bait. As determined in earlier chapters, numbers of the most commonly targeted estuarine fish species, the spotted grunter, is currently declining. It is possible that future management options for this and other fish species include serious bag limit reductions or even no take periods. The influence on a commercial bait selling population can be profound. It is worth investigating the future of estuarine fishing in detail before allowing individuals to start a SSC venture at Swartkops estuary.

7.5 Management recommendations

If all the criteria of sustainable utilisation can be met by a SSC bait industry, the following recommendations are made regarding its implementation:

- ✓ The requirements of estuary functioning are never to be compromised. Save removal rates should always be maintained and where baseline information is lacking, it should be acquired expediently.
- ✓ Measured deemed necessary for the management of mud prawn populations or related target fish species such as reduced bag limits, closed seasons or closed areas have to implemented in a co-management manner, but should be respected by all user groups. As the resource is confined to parts of an estuary with little chance of recovery if stocks

are removed completely, it should be considered as very sensitive to over-exploitation and no user group should be given access to closed areas or have exemption from bag limits.

- ✓ Feasibility studies to determine the size of the market need to be carried out, market supply lines need to be established to ensure that the sellers and the potential market are well co-ordinated to prevent wastage.

7.6 Review of management recommendations from preceding chapters

7.6.1 The recreational estuarine linefishery

- ✓ A high degree of reliance on bait sourced from muddy and sandy sediments as well as juvenile mullet is evident among estuarine recreational anglers. With the exception of spotted grunter, all other targeted fish species can be captured at a similar CPUE using bait other than estuarine invertebrates. Active attempts to steer anglers away from the use of estuarine bait species when not targeting grunter could reduce the pressure on the bait resource without detracting from the anglers fishing enjoyment.
- ✓ The management of mud- and sand prawn exploitation is very closely linked to the targeting of spotted grunter in the recreational fishing sector. In simplified terms, pressure on prawn resources will remain in estuaries where spotted grunter is a target species. Conversely, control over the amount of grunter removed per annum can also be attained by manipulating the amount of prawns available for removal by recreational anglers.
- ✓ The behaviour of sport anglers need to be changed to include the use of commercial bait, artificial lures and flies. Stricter bag limits on fish that is specifically targeted with prawn species as bait, such as spotted grunter, should also be considered to reduce the pressure on the fish species as well as estuarine invertebrate populations. The recent closure of beaches to four-wheel drive vehicles will more than likely increase the pressure on estuarine resources, thus increasing the need for closer inspection of current removal rates.
- ✓ The catch contribution of many preferred target fish species such as spotted grunter and kob, deemed to be in a decline in many eastern Cape estuaries, is far greater than these species' relative abundance as calculated from gill-net surveys. This suggests that these species are heavily targeted, especially during prolonged fishing competitions. It

is doubtful whether, from a resource management point of view, week-long contests, involving nearly a hundred anglers and resulting in the capture of over 350 fish should be allowed to take place on a regular basis.

7.6.2 Sediments and currents

- ✓ The management of mudprawn populations cannot be approached without the incorporation of catchment management and freshwater flow maintenance into a management plan.
- ✓ The mud prawn habitat is dynamic, and although large scale changes does not occur without the aid of major perturbations such as floods, medium (10 – 20 years) and long term (20 + years) changes in sedimentation patterns do occur. In formulating a management plan for mud prawn, it should therefore also be kept in mind that any zonation that is carried out requires frequent re-evaluation of the protected habitat.
- ✓ It should be accepted that the most population distributions are more than likely of a dynamic nature. Levels of exploitation of bait species found in the muddy sediments as well as catches of important fish predators, such as spotted grunter, should therefore be managed cautiously to avoid a level of exploitation that exceed production levels under variable sediment and therefore suitable habitat conditions.

7.6.3 Bait removal experiments

- ✓ Managing only TAC (daily quotas) without considering the number of users that have access to the resource is possibly unwise. In an over-exploited system, the problem of trampling-related mortality will be exacerbated by the low standing biomass. Search time will be lengthened and thus traffic on the already pressurised population will increase. From a disturbance point of view, the **controlled** sale of mud prawn could reduce the number of people on mud banks. Under specific conditions, a SSC bait industry can thereby reduce the amount of trampling related damage (i.e. prawn mortality and compaction of mud) in mud prawn habitat.
- ✓ Closed areas or seasons can be considered during reproduction and recruitment peaks. A 2 – 3 month window will be sufficient to protect females in berry, but new recruits are vulnerable for a considerably longer period of time. If recruits settle in the same areas of an estuary from where peak reproductive effort occurs, attempts to protect

adults as well as recruits could result in the closure of large sections of the estuary for the period August to April each year. This period would more than likely be undesirable to all user groups.

- ✓ The best protection for new recruits is a reduction of human traffic on prime mud prawn habitat. As female reproductive production is spread over a large section of mud prawn distribution, only sections of the inter-tidal region of the lower and/or middle reaches of an estuary (depending on standing stocks) have to be protected to ensure reproduction at sustainable levels.
- ✓ A balance between users and access areas will have to be attained. Leaving only a small area of access to users will result in the rapid degradation of exploitable sites. Recruitment is also lower in the extremities of mud prawn distribution, suggesting that these areas will take longer to recover from stock depletion if large sections of the lower reaches are closed for collection. A potential outcome of this exploitation pattern is the reduction of mud prawn range until only protected sites contain sizeable populations.
- ✓ Ideally the reproductive output, recruitment success and needs of different user groups (in terms of production) of the mud prawn population of individual estuaries need to be determined. An estimation of the percentage of annual production required to match these exports as well as exports to natural predators of mud prawn can then be made. From this calculation, the percentage of the current female population needed to achieve the desired production levels can be determined. The proportion of the best sites in terms of reproductive output that contains this number of females can then be afforded the required level of protection for the duration of peak reproductive activity. Recruitment rates thereafter must also be monitored to determine if the desired production level was attained. Due to the natural variability of reproduction and recruitment and periodic perturbations such as floods and drought, the calculations of desired reproduction levels would have to be relatively robust.
- ✓ It is crucial that collection related mortality be factored into the requirements of the bait users. The cumulative effects of bait collection can easily result in the over-exploitation of stocks. When it becomes apparent that current levels of exploitation exceed annual production, effort control in the form of bag limit reductions or access reductions will have to be implemented. It is important to manage and quantify all activities that damage standing stocks of mud prawn, not only direct bait collection damage. It is also

important that habitat damage due to other estuarine recreational activities such as bank, fly and lure fishing be factored in to management efforts.

7.6.4 Mud prawn distribution along tidal gradients

- ✓ All the different analyses performed on male and female prawn distribution had one result in common. The front 20 – 30 m of the mud bank can be singled out as responsible for a sizable percentage of reproductive output, contains the highest number of prawns per unit area, as well as the largest prawns on the mud bank. Sediment distribution has been ruled out as an influencing factor, with marine flood tide dynamics put forward as the most likely limiting factor shaping the distribution patterns observed in the study population.
- ✓ When extensive mud prawn populations are determined for management purposes, the entire area of mud flats cannot be considered as prime habitat. In effect, the old channel mud bank supports prime mud prawn numbers along less than 20% of its total width, and in much less of the total area. Bait collection in turn, is focused in that small section of the bank, rendering the reproductive capacity of the population very vulnerable. The restriction of human activity around the LWM in the lower and middle reaches of estuaries containing mud prawn populations should therefore be a very important management objective.
- ✓ Estuarine managers should adopt a cautious approach to the value of sub-tidal mud prawn stocks. Often the highest densities of sub-tidal prawns occur in areas where their production rates could not surpass those of the inter-tidal stocks, and at best should be seen as able to play a buffering role in case of inter-tidal over-exploitation.
- ✓ The management of female numbers requires an adaptive management system. Females appear to be able to migrate along the tidal gradient on a seasonal basis, requiring flexible protected zones should to accommodate these movements. Female numbers appear to be most vulnerable during spring to early summer in the Gamtoos estuary, but this seasonality most likely does not apply to all estuaries. During this period, a sizable percentage of the adult female population occurs near the LWM, making them most at risk of over-exploitation.
- ✓ The management strategy with the best returns for inter-tidal mud prawn populations would be a system that identifies the optimal habitats of the species and actively manages these during the peak reproductive periods. During this time, bait collection

can either be directed away from protected sites, or sections of habitat could be closed off to ensure sufficient recruitment. The period of closure, if deemed desirable, would not have to span the entire breeding cycle, as it can be assumed that annual successful reproductive output of a percentage of the entire mudprawn population could maintain healthy prawn populations across the species' distribution. Conflict with bait users can therefore be avoided by closing of sections of the lower reaches of an estuary for a few months only. In the case of the Gamtoos estuary, this period of closure could fall between August and November.

7.5 Overview

The results presented here illustrate the complex nature of resource management in estuarine systems. The conservation and management of bait resources (utilised by recreational and subsistence fishers) require a holistic approach and must be seen in the ecosystem context. The mud prawns, in particular, plays a key role in the energy flow network of estuaries (Baird and Ulanowicz 1993) and its management is of utmost importance. Previous authors have demonstrated the links between nutrient cycling, saltmarshes and the soft substratum inter-tidal zone of estuaries (Winter and Baird 1991; Baird and Winter 1992; Baird *et al.* 1987) where most of the targeted bait species occur. A clear link between the management of estuarine bait species and popular angling species occurring in eastern Cape estuaries was also demonstrated in this study. It is therefore crucial that a management strategy based on maintaining the integrity of the estuarine environment is developed in stead of attempting to manage closely related activities or species as single units with independently determined harvesting regulations. Bait removal, human traffic over mud- and sandbanks and related fishing activity have impacts beyond total annual removal rates. Human traffic has been identified in this and other studies as being at least as detrimental to the benthic macrofauna as the collection method employed. It has been demonstrated that a prawn population can be heavily reduced by wading pressure alone, a factor not currently taken into account when managing bait resources. Although it was not possible to study the damage caused by trampling and bait collection to new recruits, it is more than likely to be as severe as the damage observed in the adult population.

The fact that it is currently very difficult to quantify exactly the amount of bait organisms removed from estuaries emphasises the necessity not only for a strong management policy and

effective law enforcement capabilities. But for the design and implementation of **continued** monitoring systems to establish and maintain the baseline population and utilisation figures needed to accurately determine safe harvesting rates and suitable harvesting areas. To this end, the SSC bait industry created during the completion of this study need to be monitored extremely carefully. Other such ventures, such as the Sukhulu mussel harvesting project in Kwa-zulu Natal took years to develop. The number of harvesters involved with the bait selling industry at Swartkops is more than likely too large to be commercially sustainable. Together with the evidence of reduced prawn and fish stocks in the estuary presented here, could create further pressure on the estuary at a time where it would likely have been wiser to reduce pressure on the system until such a time as detailed baseline information on the status of important stocks was available. The sale of species such as blood- and tapeworm, sold illegally for years by the same collectors at inflated prices, and pencil bait removed by the bag-load need to be addressed to ensure that digging in muddy sediments and the over-exploitation of species not included in the SSC bait industry is stopped.

Ideal habitat for the most commonly exploited bait species can be identified, and as their reproductive cycles are known, closed periods for reproduction and recruitment can be implemented. These parameters, however, are unique to each system. Effective management would therefore require detailed surveys of individual systems. This study, as well as previous studies on mud prawn distribution, has shown that the inter-tidal zone of the lower reaches of the estuary, and in particular the area immediately above the LWM contains the largest populations of reproductively active females. This is, however, also the area targeted by bait collectors. Closing off sections of the population to allow for successful reproduction and recruitment can therefore be a viable management option in heavily utilised systems.

A complicating factor, however, is that the sediment distribution in estuaries is not fixed, and various studies have shown that species adapted to mud or sand shift in distribution in a response to a changing physical environment. The factors that have the biggest influence on sediment distribution, fresh water abstraction and land use in catchments are both land-based and out of the control of the estuarine manager. A holistic ecosystem approach, where all the factors influencing the health of the catchment, river and estuary is managed, should therefore be seen as of the utmost importance.

The bait species, as well as fish species targeted in estuaries have very important roles to perform in estuarine ecosystem functioning and energy pathways. Estuarine fish species are also under increasing pressure. Control over bait collection as well as fishing is required to ensure the continued functioning of estuaries in the Eastern Cape. The most detrimental activity observed in this study is digging for bait using a fork or spade. This activity, although illegal, is reaching catastrophic levels in estuaries close to urban centres, such as the Swartkops estuary. Digging, with associated increases in traffic over mud banks, not only increases the turbidity of estuarine waters, but also disturbs larger sections of mud bank for a longer period of time than any other fishing or bait collecting activity. As bait digging solely exists to provide in the illegal trade of polychaete bait species, there should be no reason why every management action possible should not be taken to end this practice.

Many of the bait species known to be preferred by anglers, such as pencil bait, blood- and tape worm, occur in such low numbers that a detailed analysis of their current biomass and response to disturbance would be nearly impossible. Management recommendation for these species is therefore also impossible to make based on the information contained in this report.

Finally, on the point of managing bait collection, it must be concluded that a change from a daily bag limit system to a system calculating removal rates based on somatic production and ecosystem requirements is long overdue. Whether 70 bait sellers or 210 new recreational anglers are added to the system is irrelevant to the issue at hand. Continually adding quota-holders to the pool of bait collectors will at some point tip the scale towards over-exploitation. Currently, the data available to management does not allow for the determination of a safe cut-off point to the number of people allowed into an estuary, or for the determination of damage caused by the collection or fishing presence of humans on the soft sediments of the system. Without continual monitoring systems, it is also debatable whether a decline in stocks will be detected at an early stage. Therefore, in order to manage bait collection in a pro-active manner, it is suggested that the bag limit system be changed to a program where yearly allowable removal rates are calculated as an ecosystem export based on the current production status of bait stocks. Collection mortality should always be factored into calculations, and the integrity of ecosystem functioning should be safeguarded by safeguarding the needs of natural predators and the functioning of the detritus nutrient cycle prior to the allocation of any collection quotas to a user group.

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Appendix A. Distribution of sediments in the top 40 cm of the disturbance experiment, located in the old channel of the Gamtoos estuary.

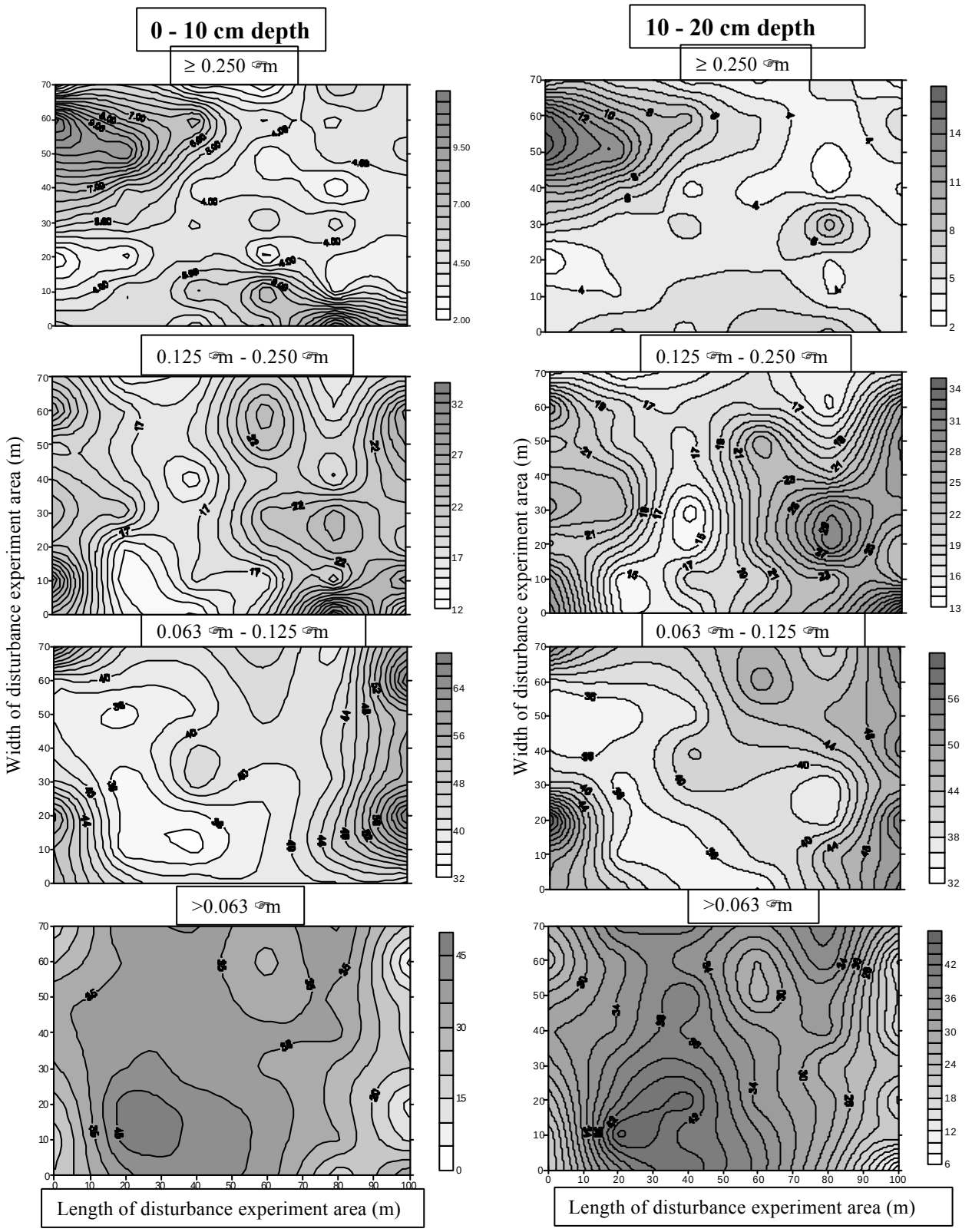


Figure A.1. Percentage of different size sediment groups of the Wentworth scale present in the sediments of the top 40 cm of the study area divided into 10 cm intervals. The X-axis of the individual figures is orientated towards the LWM, while the Y-axis is orientated towards the main channel.

Appendix A. Continued

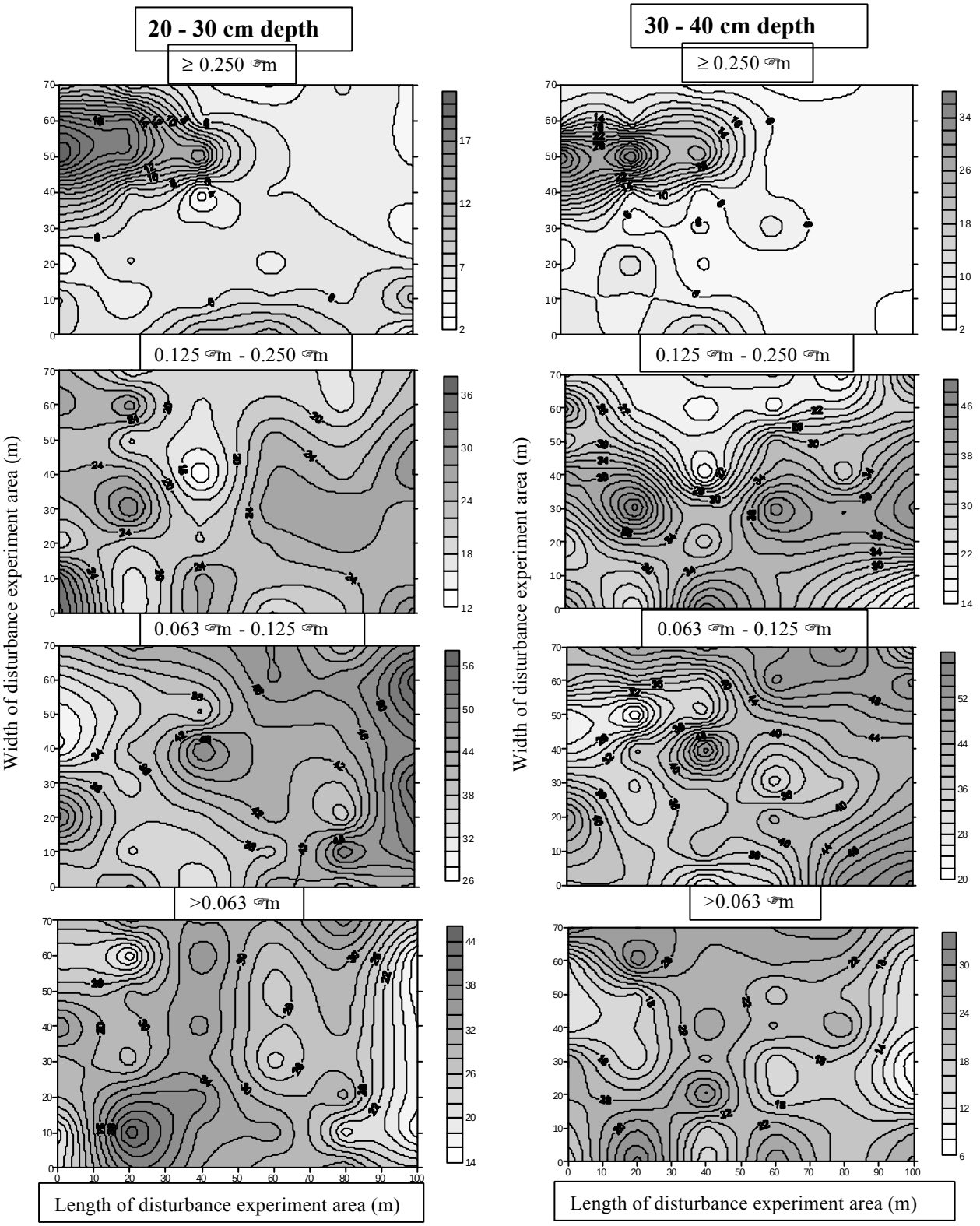


Figure A.1. Continued.

Appendix B. Graphs of results obtained from factorial ANOVA's performed on sediments removed at the onset of the disturbance experiment (T0), located in the old channel of the Gamtoos estuary.

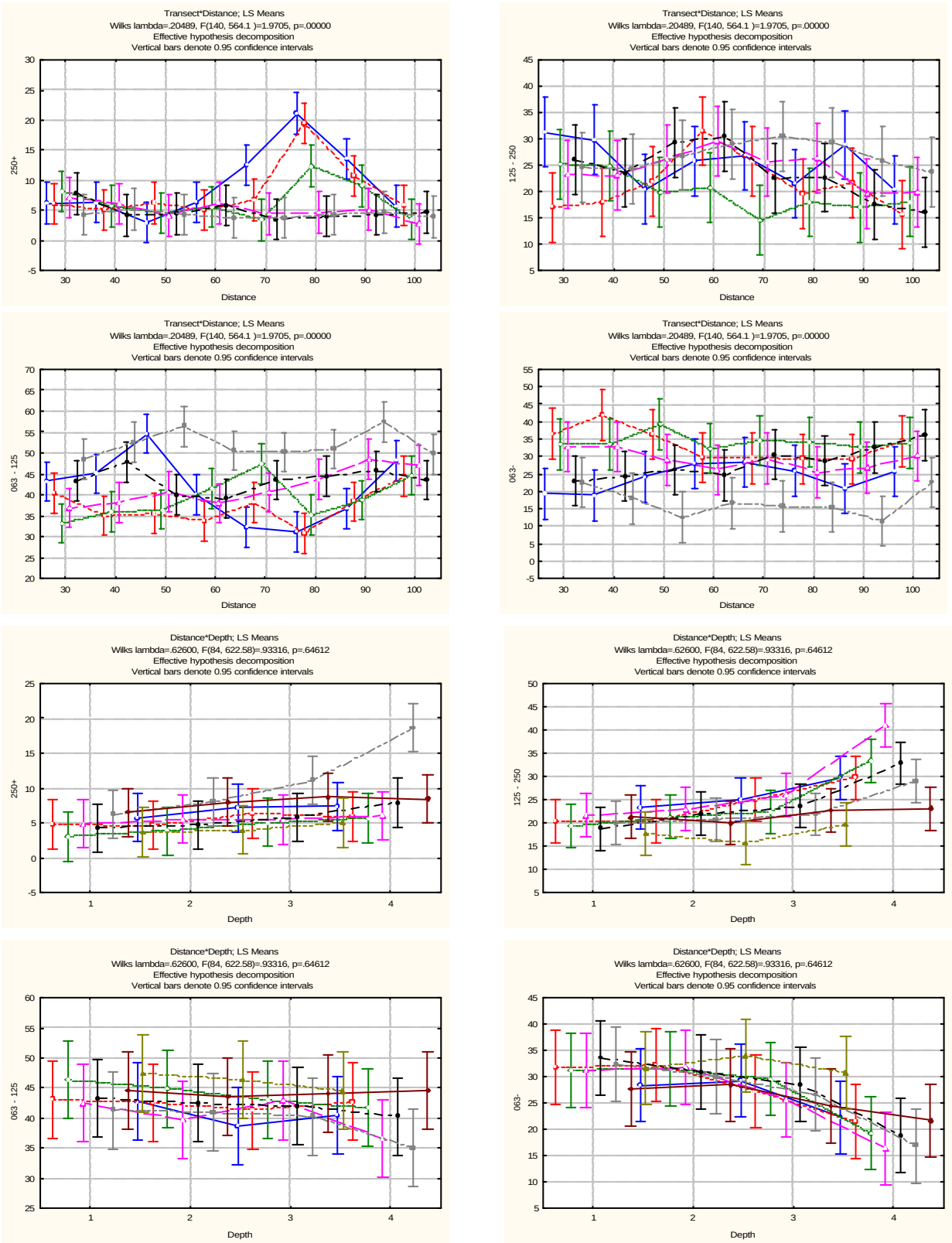
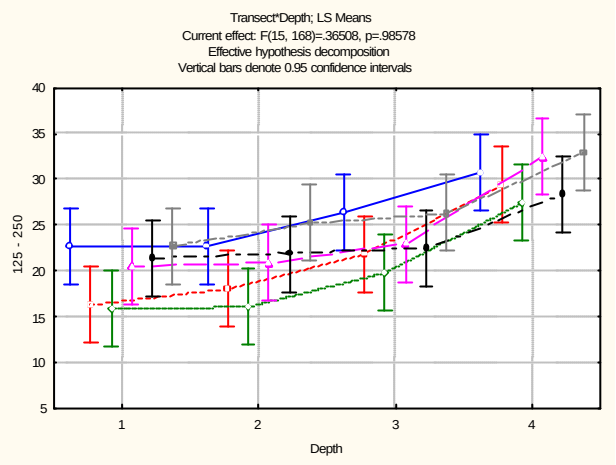
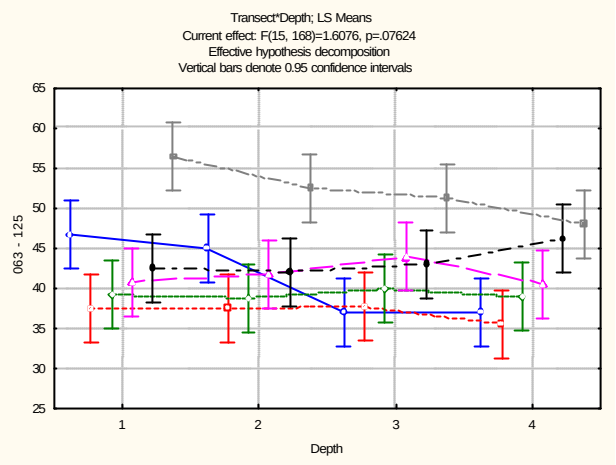


Figure B.1. Graphs of significant results of factorial ANOVA's performed on the T0 sediment transects, comparing distance from LWM, individual transects and depth of cores. 1 = 0 – 10 cm, 2 = 10 – 20 cm, 3 = 20 – 30 cm and 4 = 30 – 40 cm.

Appendix B. Continued





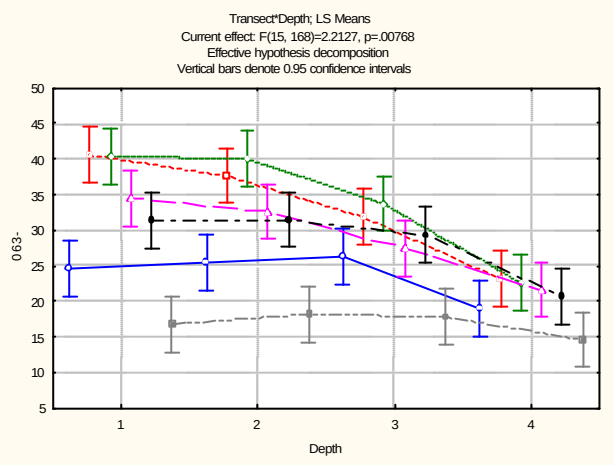


Figure B.1. Continued

Appendix C. Results of the inter-tidal classification of the Gamtoos estuary.

Table C.1. Classification of Gamtoos estuary inter-tidal and sub-tidal areas from the mouth to the upper reaches of the estuary.

Code	Description	Substrate	Slope	Width	Sub tidal	Dominant species	Numbers
1	Shallow bank, exposed during spring low, extensive	Sand	Shallow	+ 20 m	0 - 5 m	C. kraussi	Medium to high
2	Shallow bank, exposed during spring low, extensive	Sand	Shallow	+ 20 m	0 - 5 m	*C. kraussi*	High
3	Slip face of dune	Sand	Steep to intermediate	5 - 10 m	0 - 5 m	*C. kraussi*	Medium to low
4	Shallow flats, similar to 1 & 2 but much smaller	Sand	Shallow	10 - 20 m	0 - 5 m	*C. kraussi*	High
5	Slip face of dune	Sand	Steep	5 - 10 m	0 - 5 m	*C. kraussi*	Medium to low
6	Shallow flats, similar to 1 & 2 but much smaller	Sand	Shallow	10 - 20 m	0 - 5 m	*C. kraussi*	High
7	Long sandbank, not completely explored	Sand with some mud	Shallow to flat	10 - 20 m	0 - 5 m	*C. kraussi*	High
8	Shallow zone of mixed sandy and muddy sediments	Sand and mud	Intermediate to shallow	10 - 20 m	5 - 10 m	*C. kraussi* + *U. africana*	High
9	2 Mud banks on either side of blind arm mouth	Mud	Intermediate to shallow	10 - 20 m	5 - 10 m	*U. africana*	High
10	Undulating section of dune slip faces	Sand	Steep	0 - 5 m	0 - 5 m	*C. kraussi*	Low
11	Steep sided vegetated cliff edge with sandy base.	Sand, rock, boulders, pebbles	Steep	0 - 5 m	0 - 5 m	*C. kraussi*	Very low
12	Banks replacing cliffs, no large rocks	Sand with some pebbles	Intermediate	5 - 10 m	5 - 10 m	*U. africana*	High
13	Mud bank with some marsh vegetation towards back of inter-tidal	Mud	Intermediate	10 m	5 - 10 m	*U. africana*	High
14	Mud bank with some marsh vegetation towards back of inter-tidal	Mud	Intermediate	5 - 10 m	5 - 10 m	*U. africana*	High
15	Mud bank with some marsh vegetation towards back of inter-tidal	Mud	Intermediate	10 - 20 m	+ 10 m	*U. africana*	High
16	Mud bank with some marsh vegetation towards back of inter-tidal	Mud + debris	Intermediate	10 - 20 m	+ 10 m	*U. africana*	Medium to high
17	Tributary surrounded by salt marsh or steep-sided bank	Fine mud	Intermediate to shallow	0 - 5 m	+ 10 m	*U. africana*	High
18	Steep sided vegetated cliff edge with muddy base.	Mud + debris	Steep	0 - 5 m	0 - 5 m	*U. africana* + *C. kraussi*	Medium
19	More gently sloping bank, lower vegetation	Mud	Intermediate	0 - 5 m	0 - 5 m	*U. africana*	Medium to low
20	Steep sided vegetated cliff edge with muddy base.	Mud + fine silt, debris	Steep	0 - 5 m	0 - 5 m	*U. africana*	Low
21	Steep sided vegetated cliff edge with muddy base.	Mud	Intermediate	5 - 10 m	5 - 10 m	*U. africana*	High
22	Steep sided vegetated cliff edge with muddy base.	Mud	Intermediate	5 - 10 m	5 - 10 m	*U. africana*	High
23	Steep sided vegetated cliff edge with muddy base.	Mud	Intermediate	0 - 5 m	0 - 5 m	*U. africana*	High
24	Densely vegetated, steep edged bank	Mud + debris	Steep to intermediate	0 - 5 m	0 - 5 m	*U. africana*	Low
25	Densely vegetated, steep edged bank	Mud + debris	Steep	0 - 5 m	0 - 5 m	*U. africana*	Low
26	Densely vegetated, steep edged bank	Mud	Steep to intermediate	5 - 10 m	5 - 10 m	*U. africana*	High
27	Less densely vegetated, steep edged bank	Mud	Steep to intermediate	5 - 10 m	5 - 10 m	*U. africana*	Low
28	Densely vegetated, steep edged bank	Mud + construction rubble	Steep to intermediate	5 - 10 m	5 - 10 m	*U. africana*	Low
29	Sparsely vegetated, steeply eroded bank	Mud + some rock	Steep	0 - 5 m	0 - 5 m	No prawn	-

Table C.1 continued. Classification of Gamtoos estuary inter-tidal and sub-tidal areas from the mouth to the upper reaches of the estuary.

30	Sparsely vegetated, steeply eroded bank	Mud	Steep	0 - 5 m	0 - 5 m	*U. africana*	Low
31	Densely vegetated, steep edged bank	Boulders	Steep	0 - 5 m	0 - 5 m	No prawn	-
32	Densely vegetated, steep edged bank	Boulders + reeds	Steep	0 - 5 m	0 - 5 m	No prawn	-
33	Less densely vegetated, steep edged bank	Mud	Steep to intermediate	5 - 10 m	5 - 10 m	*U. africana*	Medium to low
34	Less densely vegetated, steep edged bank	Mud	Steep to intermediate	5 - 10 m	5 - 10 m	*U. africana*	Medium to low
35	Steep sided vegetated cliff edge with muddy base	Hard mud breaking of bank	Steep	0 - 5 m	0 - 5 m	No prawn	-
36	Shallow sloping bank with mixed sand and mud	Sand and mud	Intermediate to shallow	5 - 10 m	0 - 5 m	*U. africana* + *C. kraussi*	Medium to high
37	Extension of mud bank, but sediments muddy	Mud	Shallow	+ 20 m	0 - 5 m	*U. africana*	Medium to high
38	Channel bank shallow and extensive closing to steep, vegetated.	Mud, wind-blown sand	Intermediate to shallow	0 - 20 m	0 - 5 m	*U. africana*	Medium to high
39	Extensive mud flat, no or sparse covering of *Zostera*	Mud	Shallow to flat	+ 20 m	0 - 5 m	*U. africana*	Medium
40	Shallow bank fringed by steep bank of salt marsh	Mud	Shallow	5 - 10 m	0 - 5 m	*U. africana*	Medium to low
41	Shallow bank fringed by steep bank of dune vegetation	Mud, wind-blown sand	Intermediate to shallow	5 - 10 m	0 - 5 m	*U. africana*	Medium to low
42	Sandy embankment with muddy pebble creek mouth at lowest point	Sand with some mud	Intermediate to shallow	5 - 10 m	0 - 5 m	*C. kraussi*	Medium to high

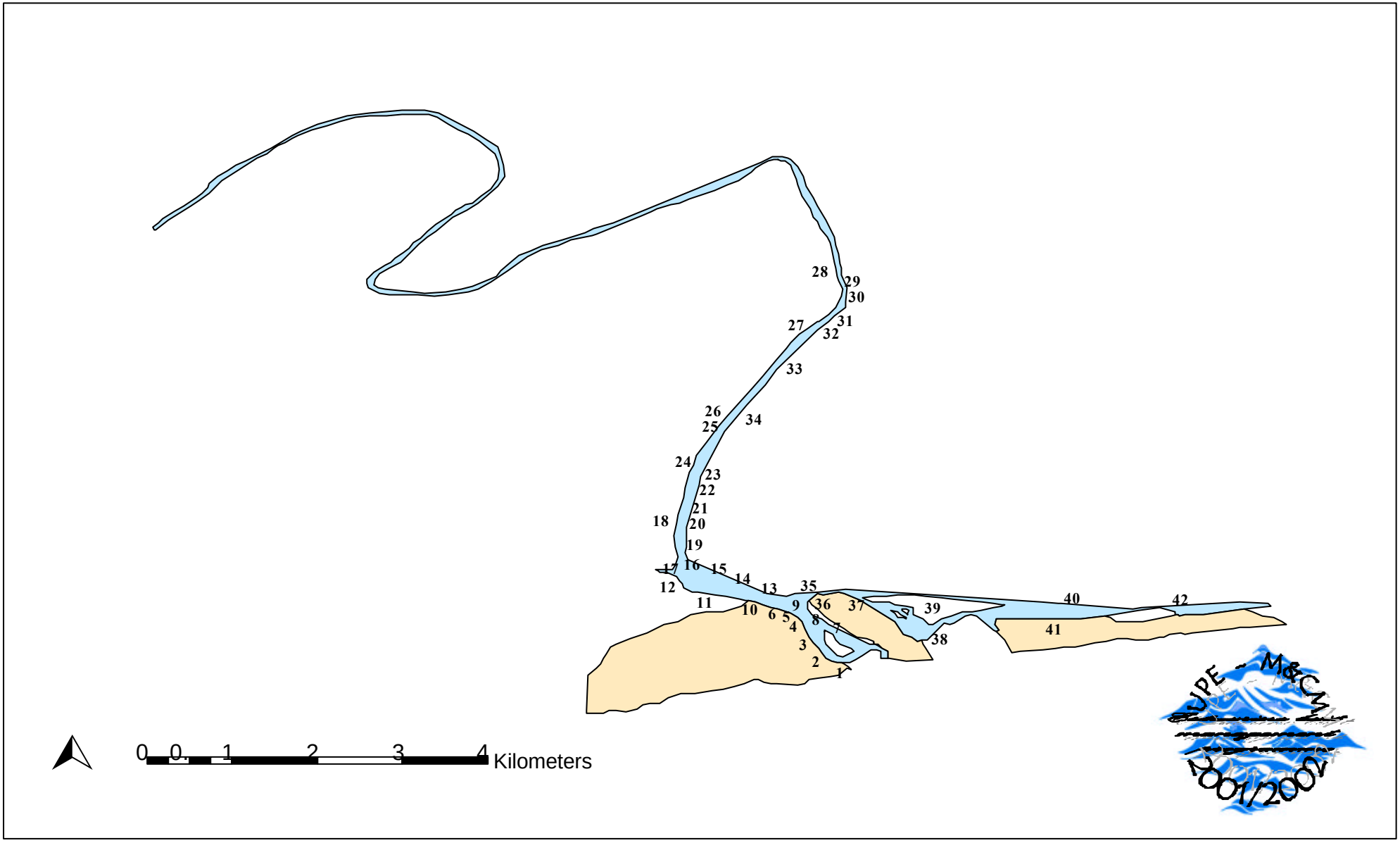


Figure C1. Location of the described inter-tidal areas in the Gamtoos estuary

Appendix D. Graphs of factorial ANOVA's performed on data obtained from pumping and digging treatments at the onset of the disturbance experiment, located in the old channel, Gamtoos estuary.

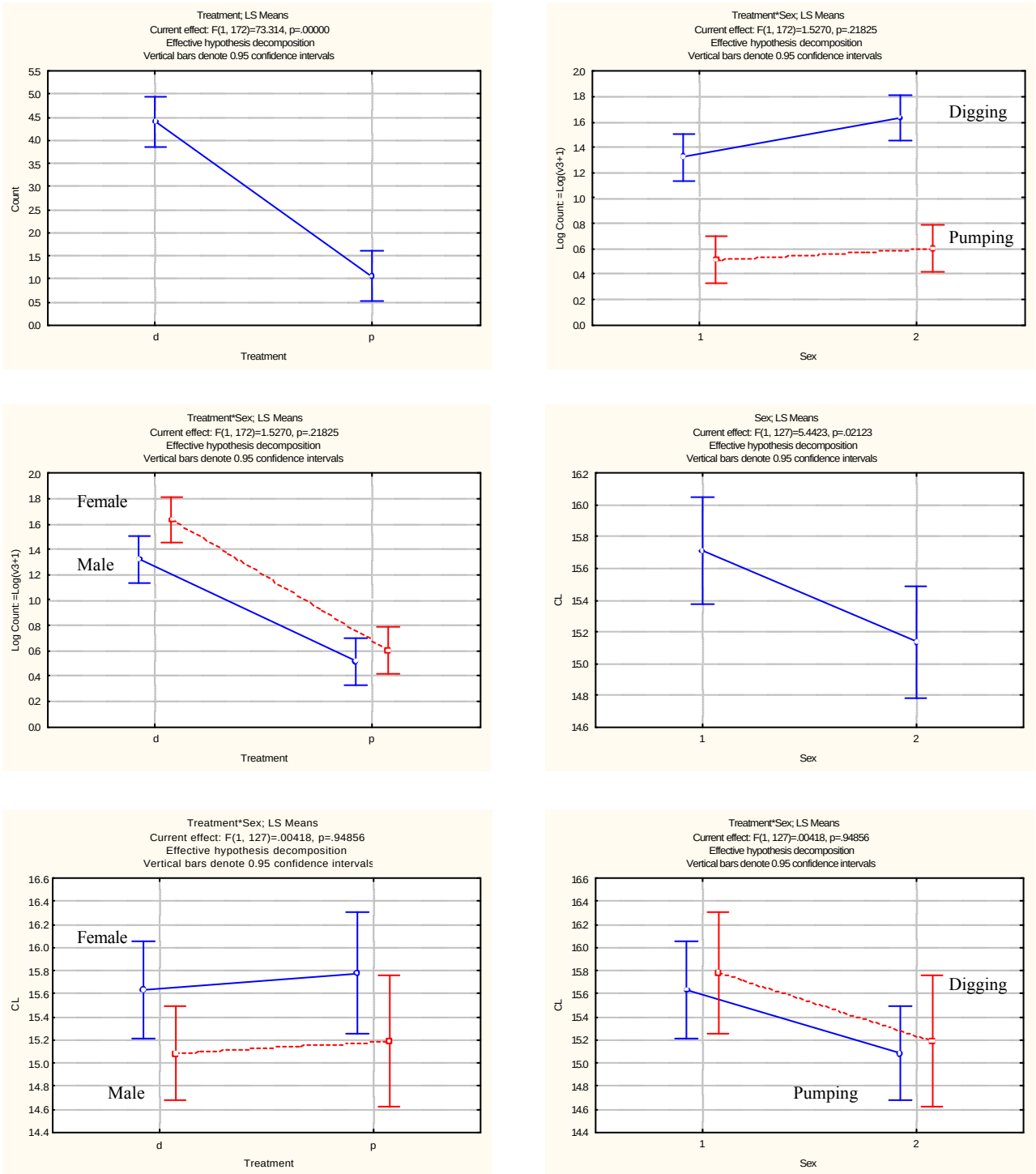
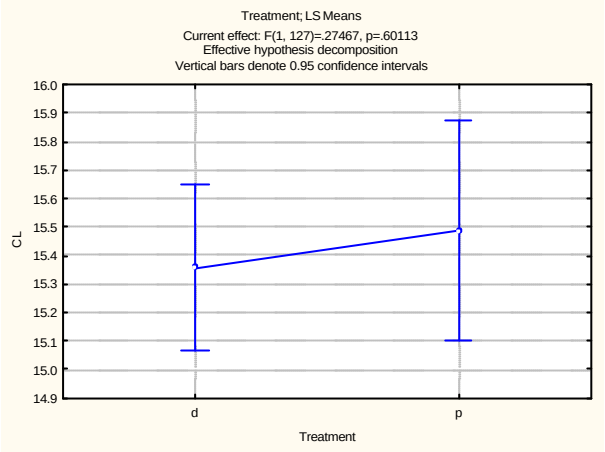
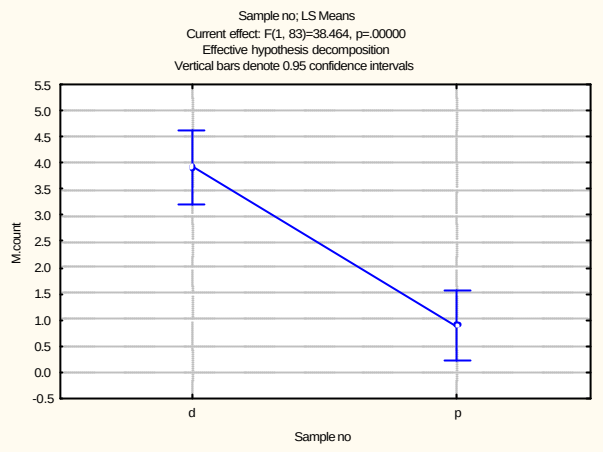


Figure D1. Plots of factorial ANOVA results performed on the data obtained from pumping and digging treatments at the onset of the disturbance experiment. D = digging, p = pumping, CL = carapace length, F = female, M = male, Sex 1 = male, Sex 2 = female.

Appendix D. continued.





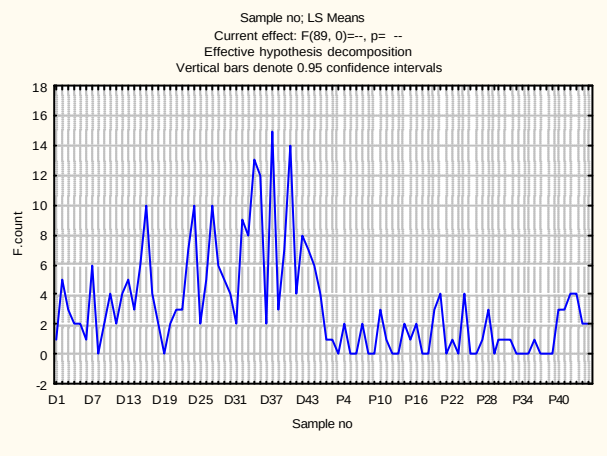


Figure D1. Continued.

Appendix D continued. Graphs of correlation analyses performed on sediments removed at the onset of the disturbance experiment (T0) and samples taken after 6 (T6) months in treated sites of the disturbance experiment, located in the old channel of the Gamtoos estuary.

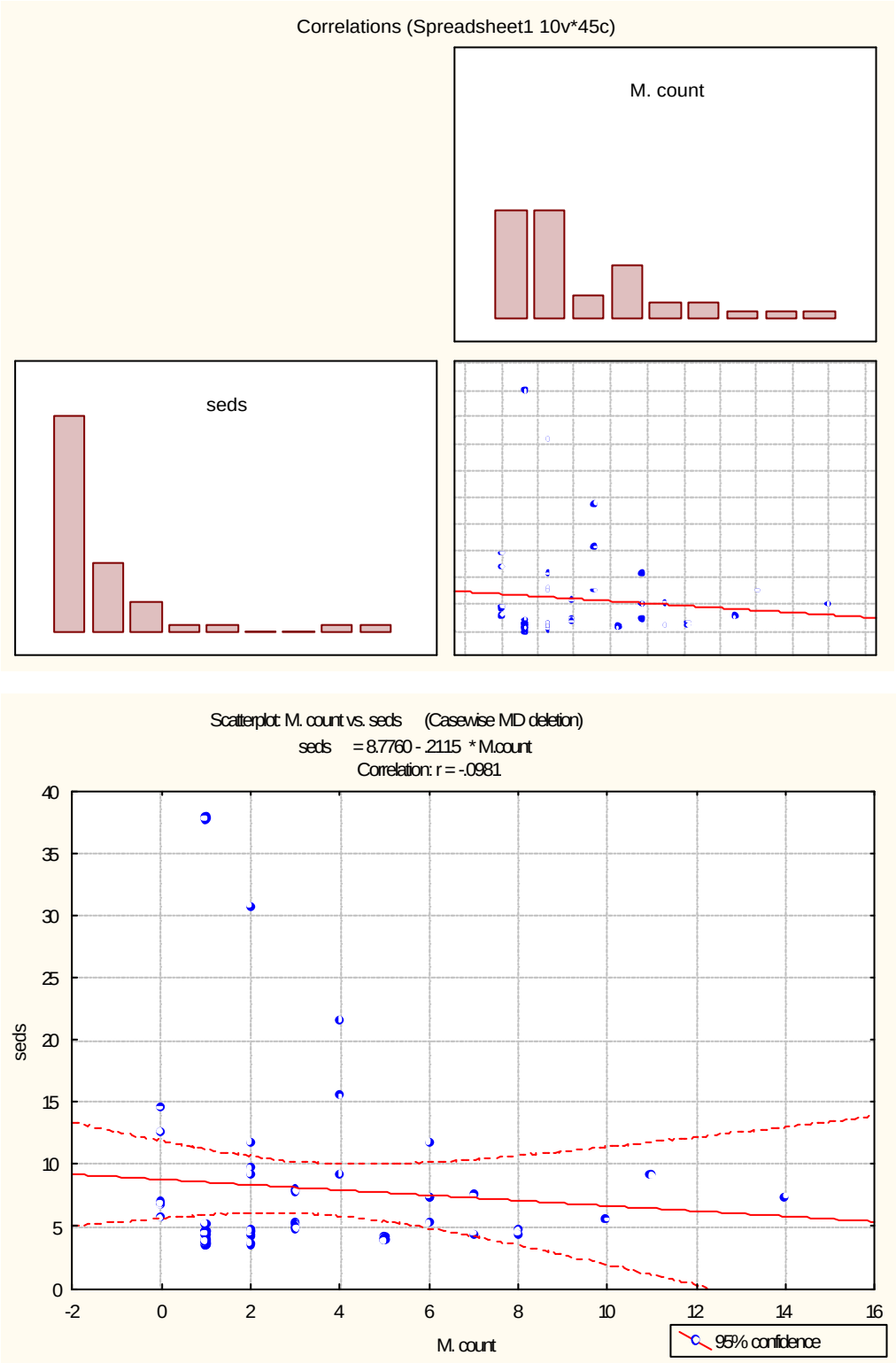
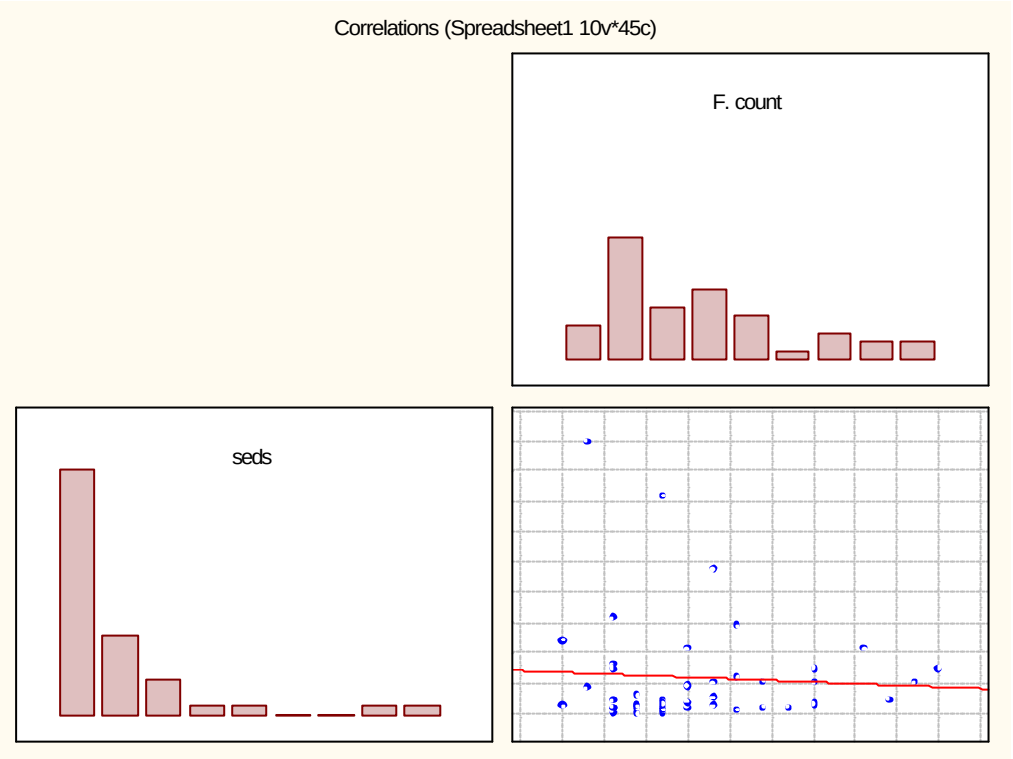


Figure D2. Results of correlations performed on numbers of males recorded during the start of the experiment, and the distribution of medium sand (250 µm – 500 µm)

Appendix D. continued.



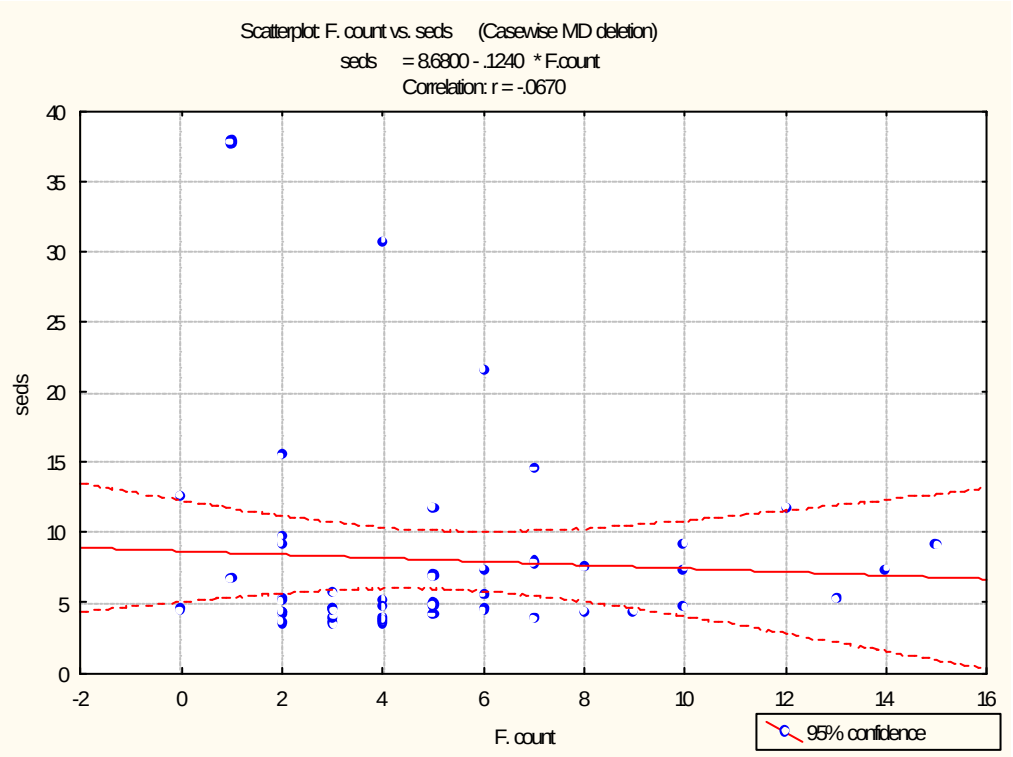


Figure D3. Results of correlations performed on numbers of females recorded during the start of the experiment, and the distribution of medium sand (250 µm – 500 µm)

Appendix E. Sediment composition of selected treated plots from the disturbance experiment at the start (T0) of the study and after six months (T6)

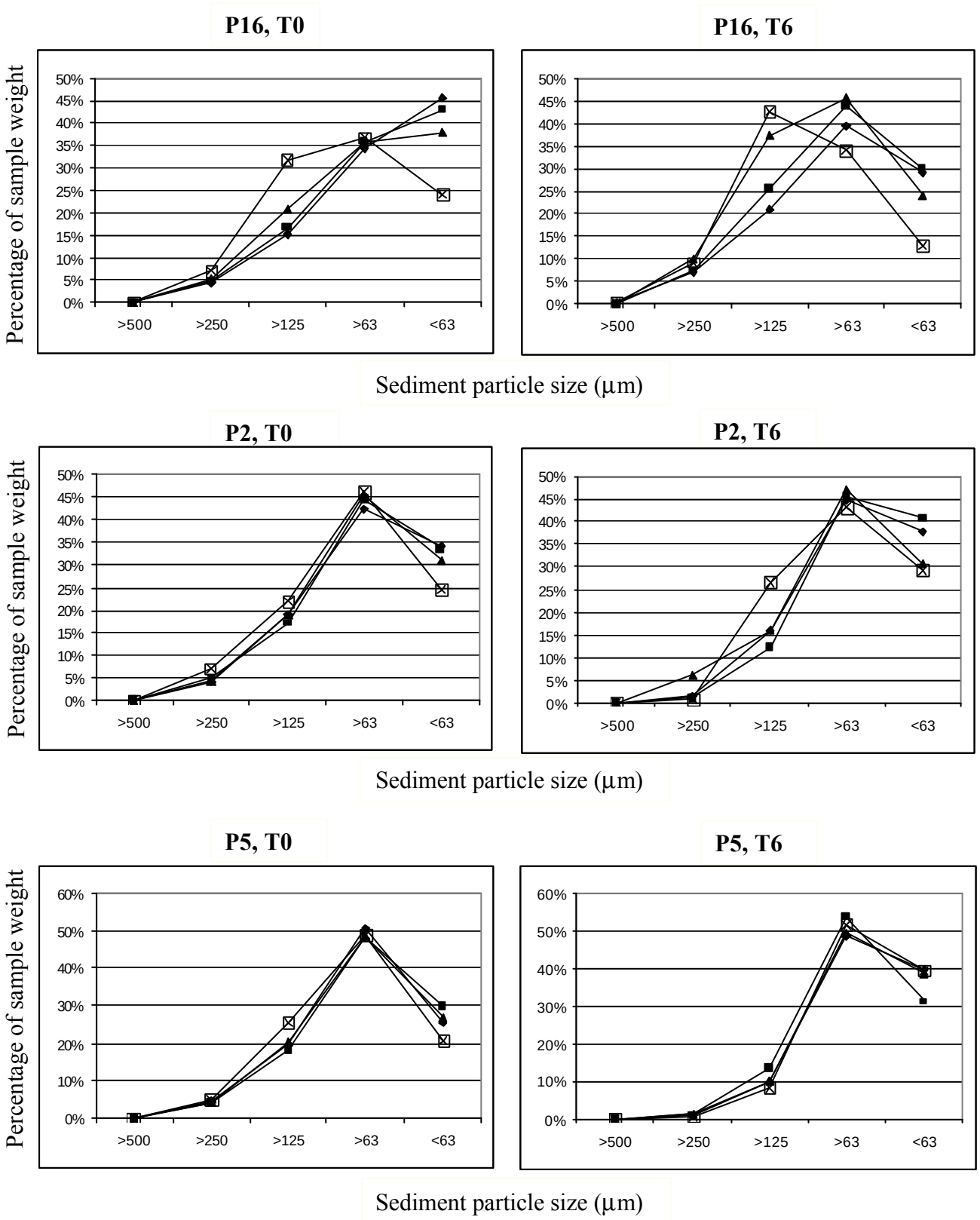


Figure E.1. Percentage contribution of particle sizes (Udden-Wentworth scale) to surface sediments of pumped sites at the start of the disturbance experiment (T0) and after six months (T6).

Appendix E. Continued

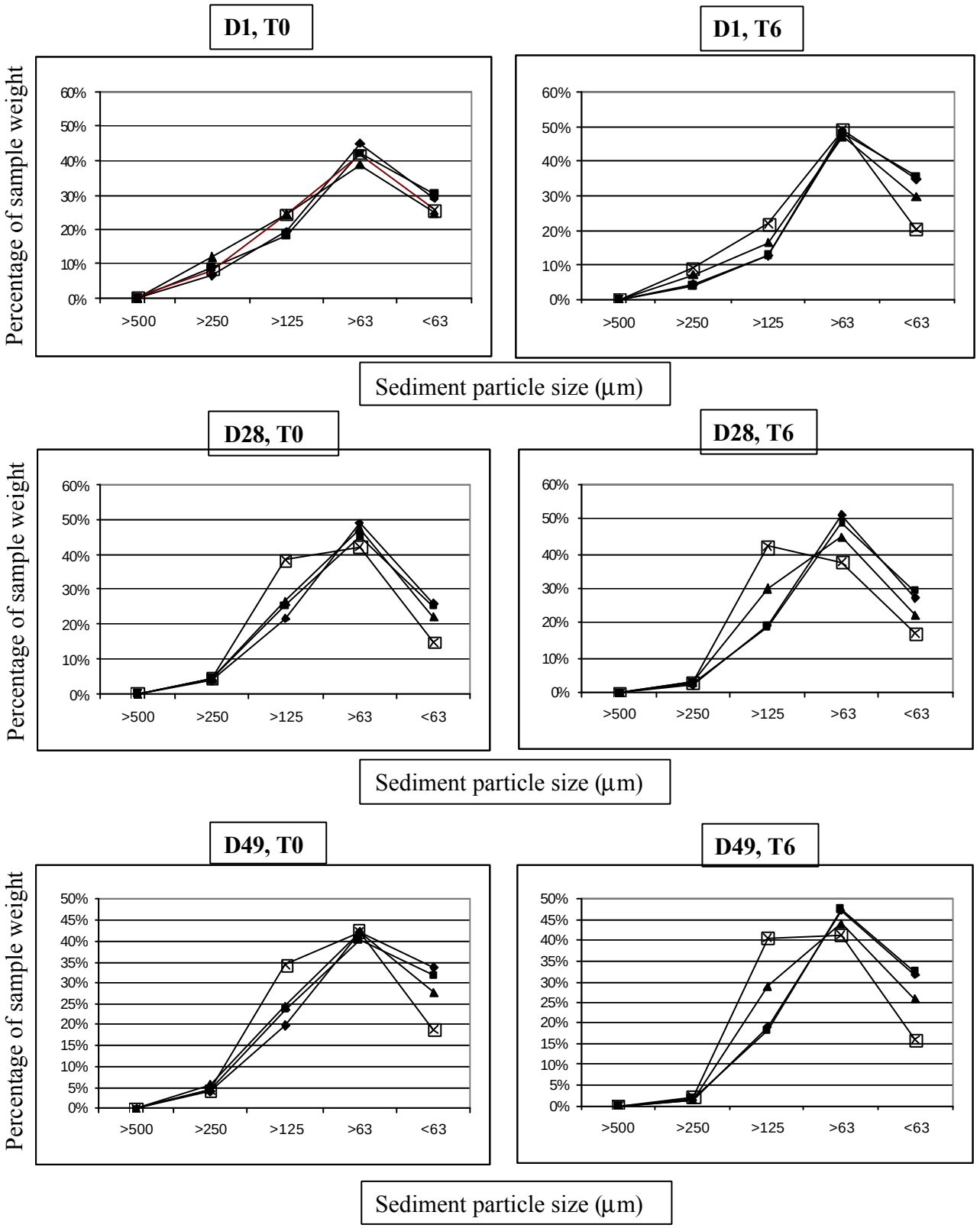


Figure E.2. Percentage contribution of particle sizes (Udden-Wentworth scale) to surface sediments from digging treatments at the start of the disturbance experiment (T0) and after six months (T6).

Appendix E. Continued

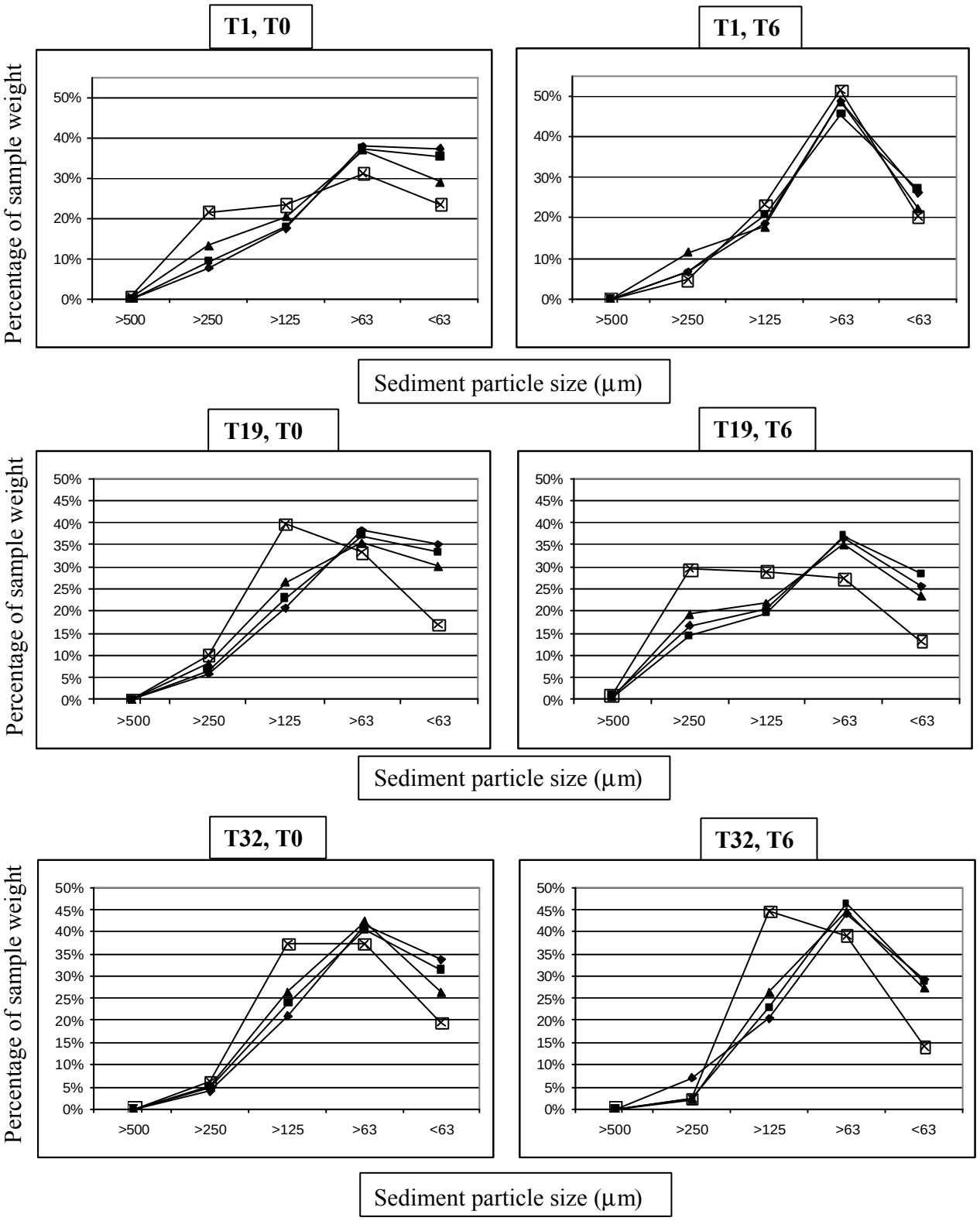


Figure E.3. Percentage contribution of particle sizes (Udden-Wentworth scale) to surface sediments from trampled sites at the start of the disturbance experiment (T0) and after six months (T6).

Appendix E continued. Graphs of results obtained from factorial ANOVA's performed on sediments removed at the onset of the disturbance experiment (T0) and samples taken after 6 (T6) months in treated sites of the disturbance experiment, located in the old channel of the Gamtoos estuary.

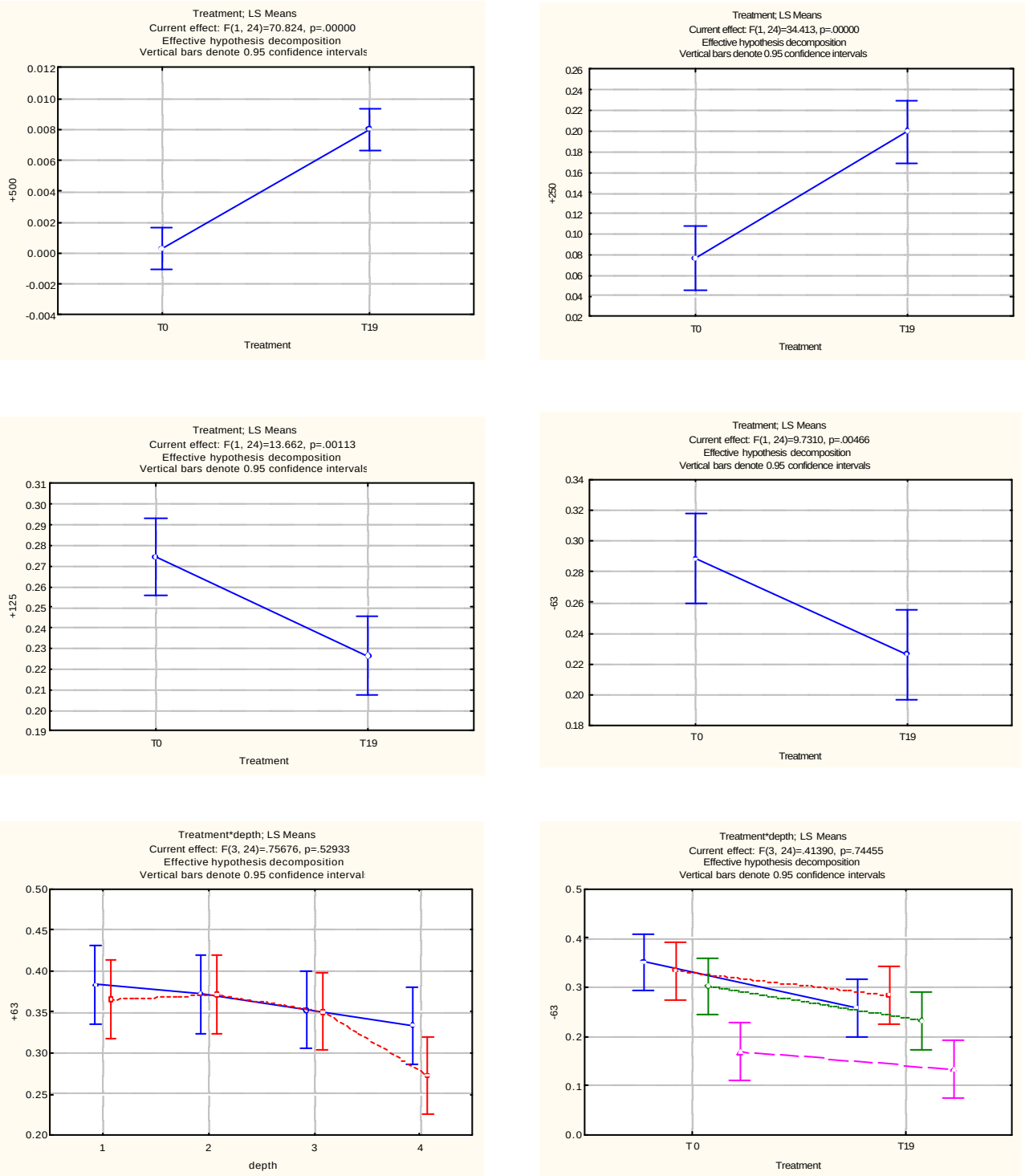
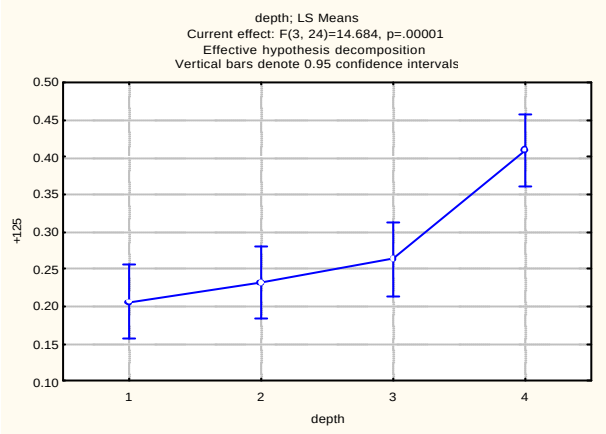
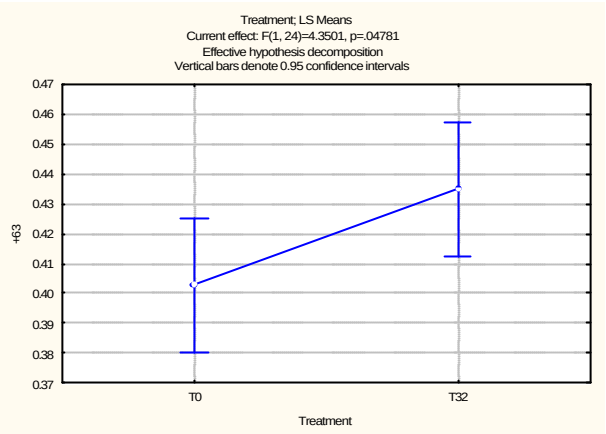
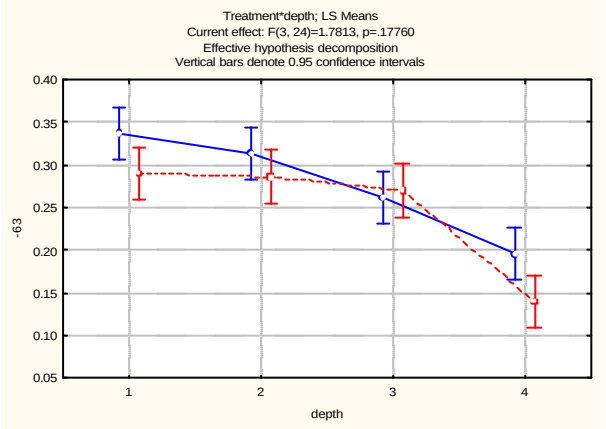


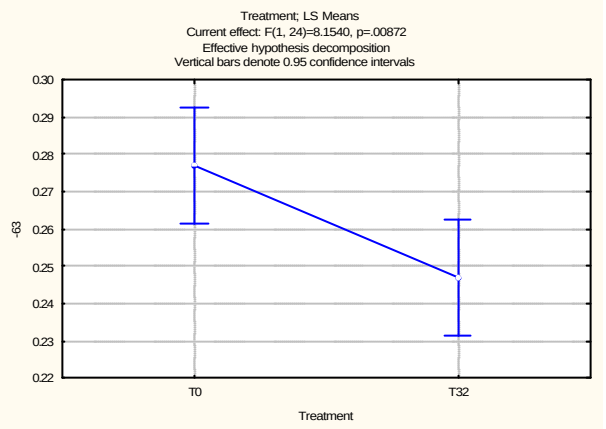
Figure E.4. Results of factorial ANOVA's performed on sediment cores taken from the experimental site at the start of the study (T0) and sediment cores taken six months into the experiment. T = trampling, P = pumping and D = digging. Figures 1 – 4 represents depths at 10 cm intervals, with 1 = 0 – 10 cm and 4 = 30 – 40 cm. Y-axis values represent sediment classes. +500 = ≥ 500 µm, +250 = 250 µm – 500 µm, + 125 = 125 Φm – 250 µm, +63 = 63 µm – 125 µm and –63 = = 63 µm.

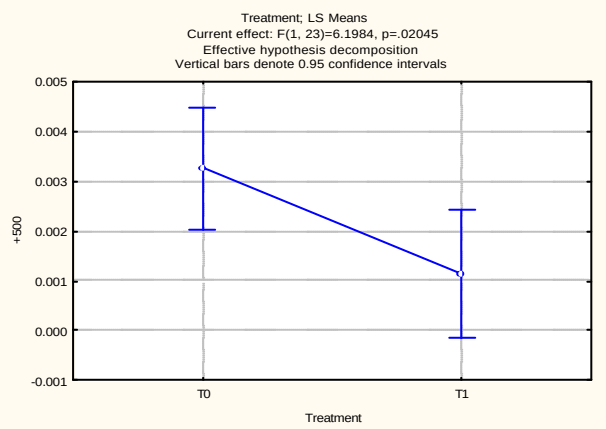
Appendix E continued.

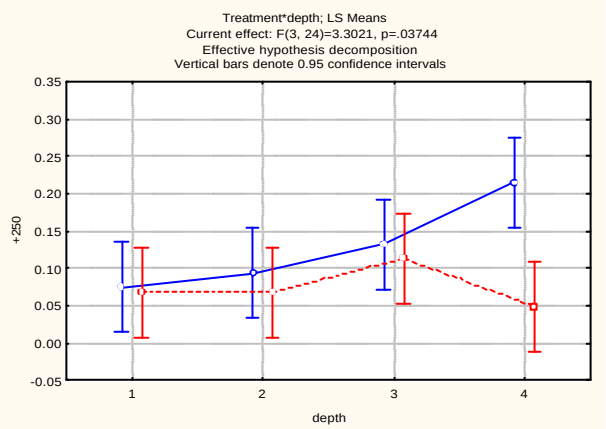


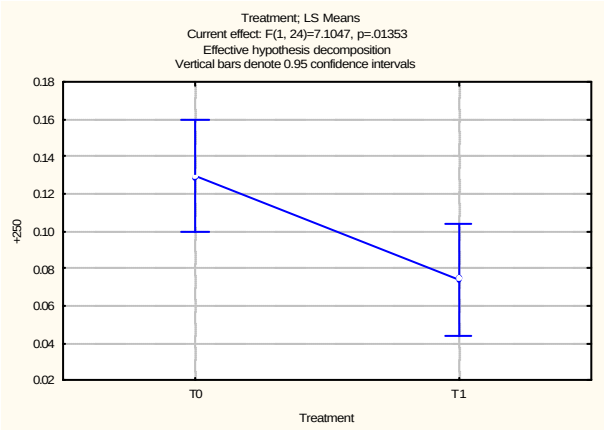












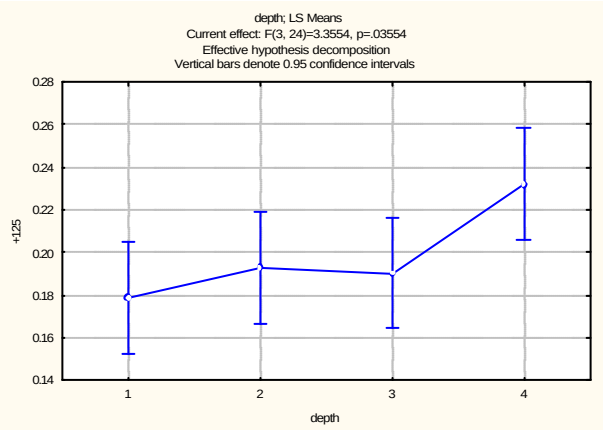
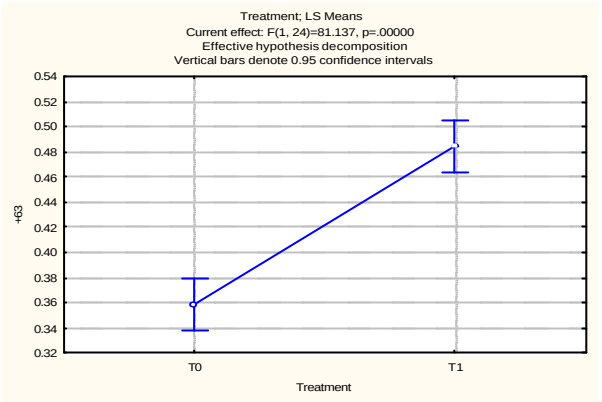
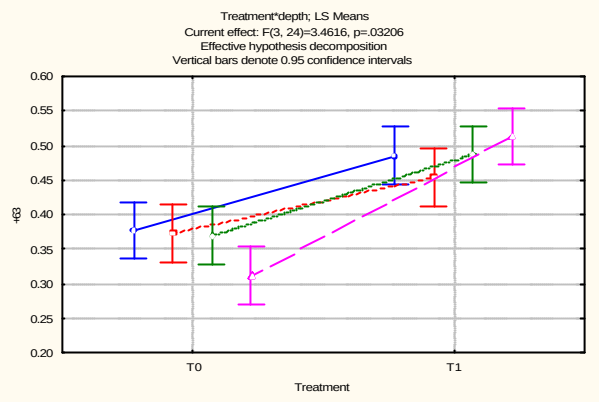
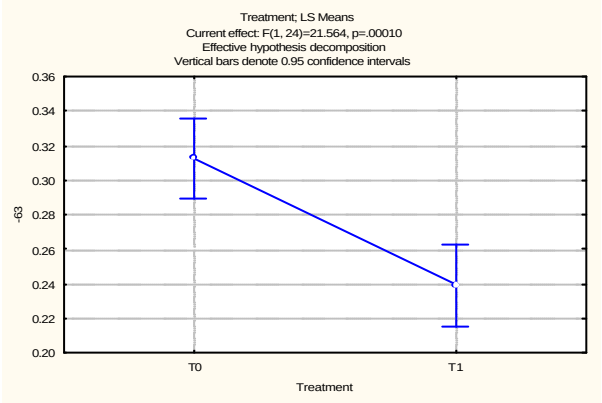


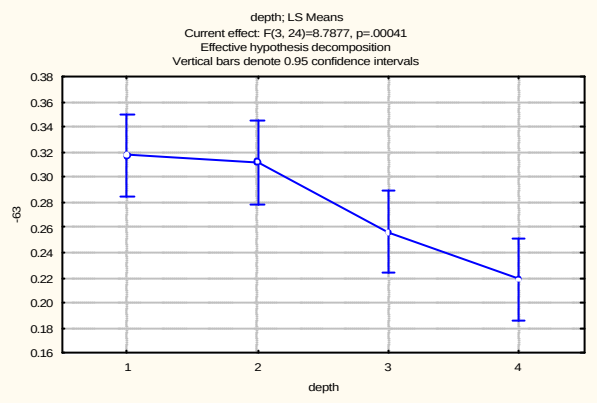
Figure E.4. Continued

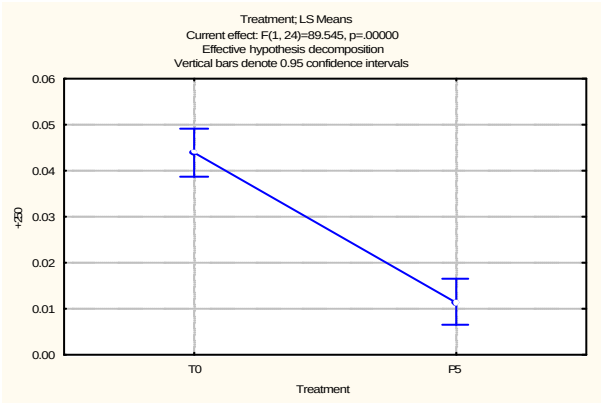
Appendix E. Continued

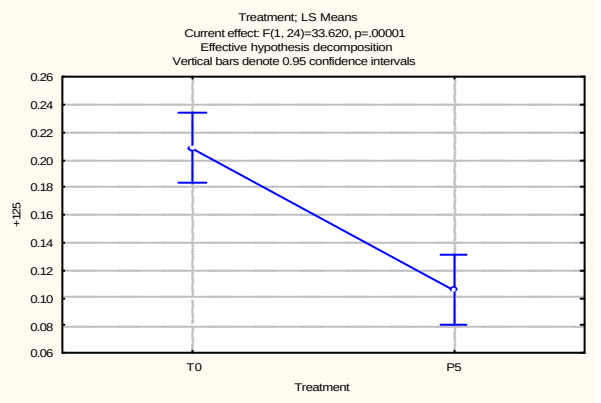


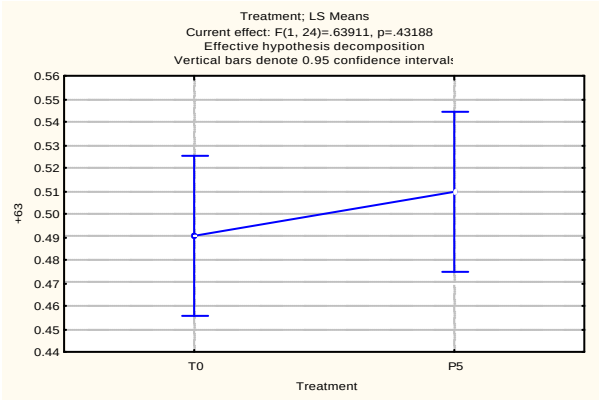












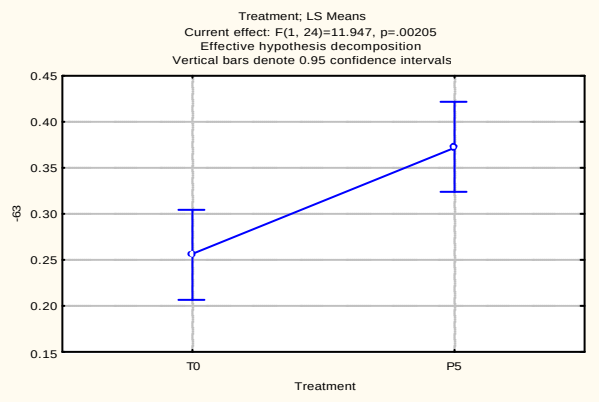


Figure E.4. Continued

Appendix E. Continued

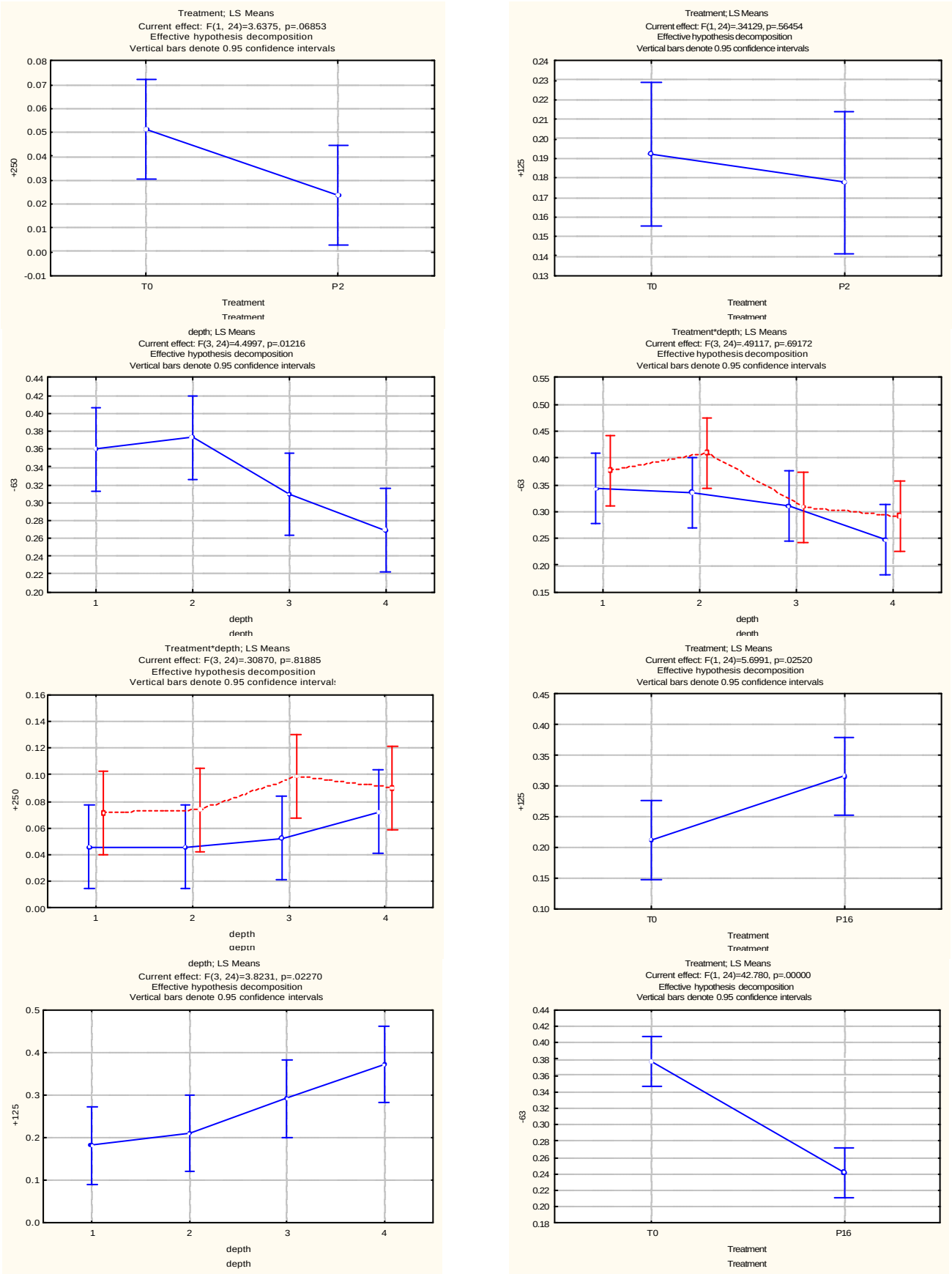


Figure E.4. Continued

Appendix E. Continued

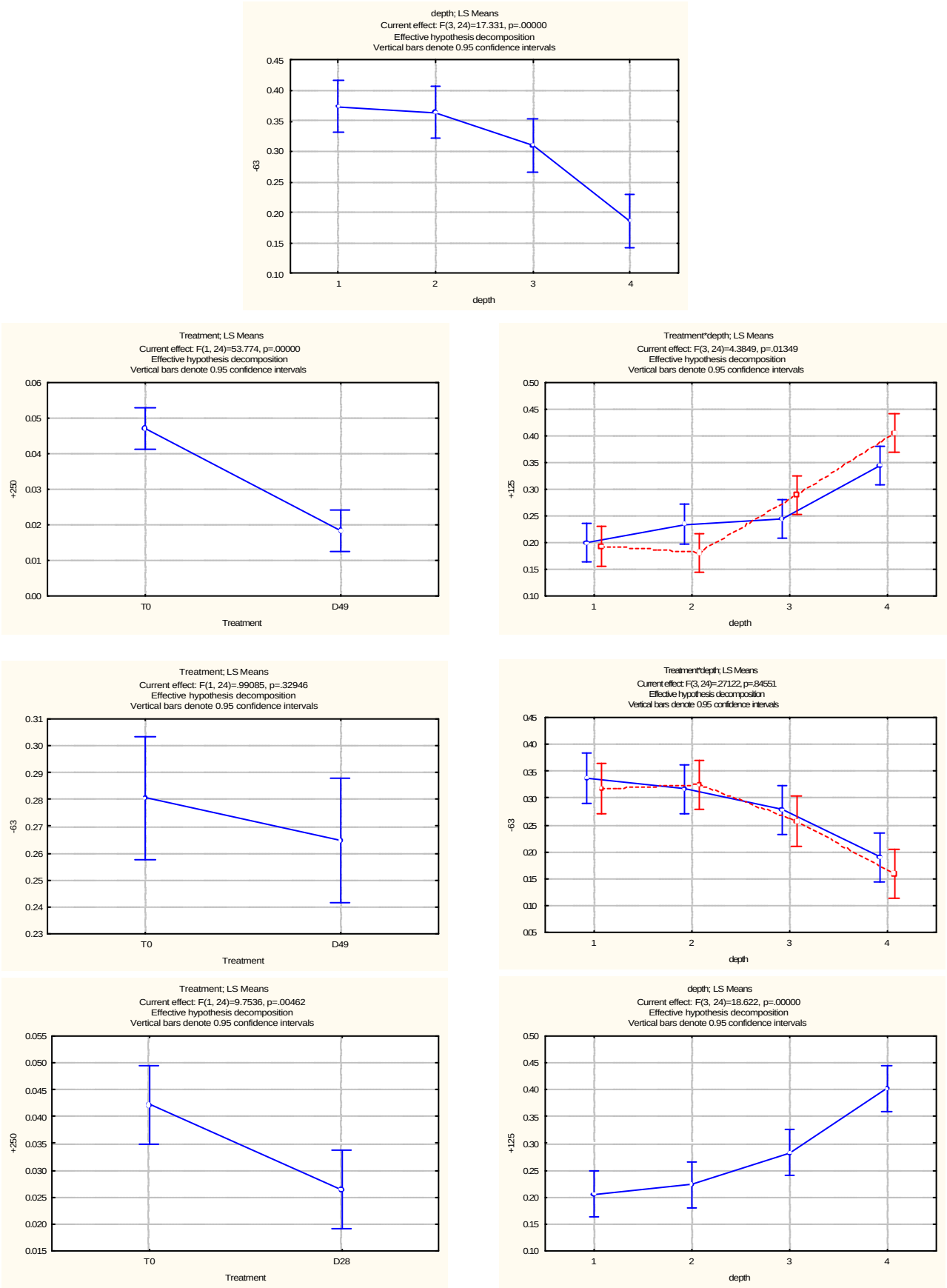


Figure E.4. Continued

Appendix E. Continued

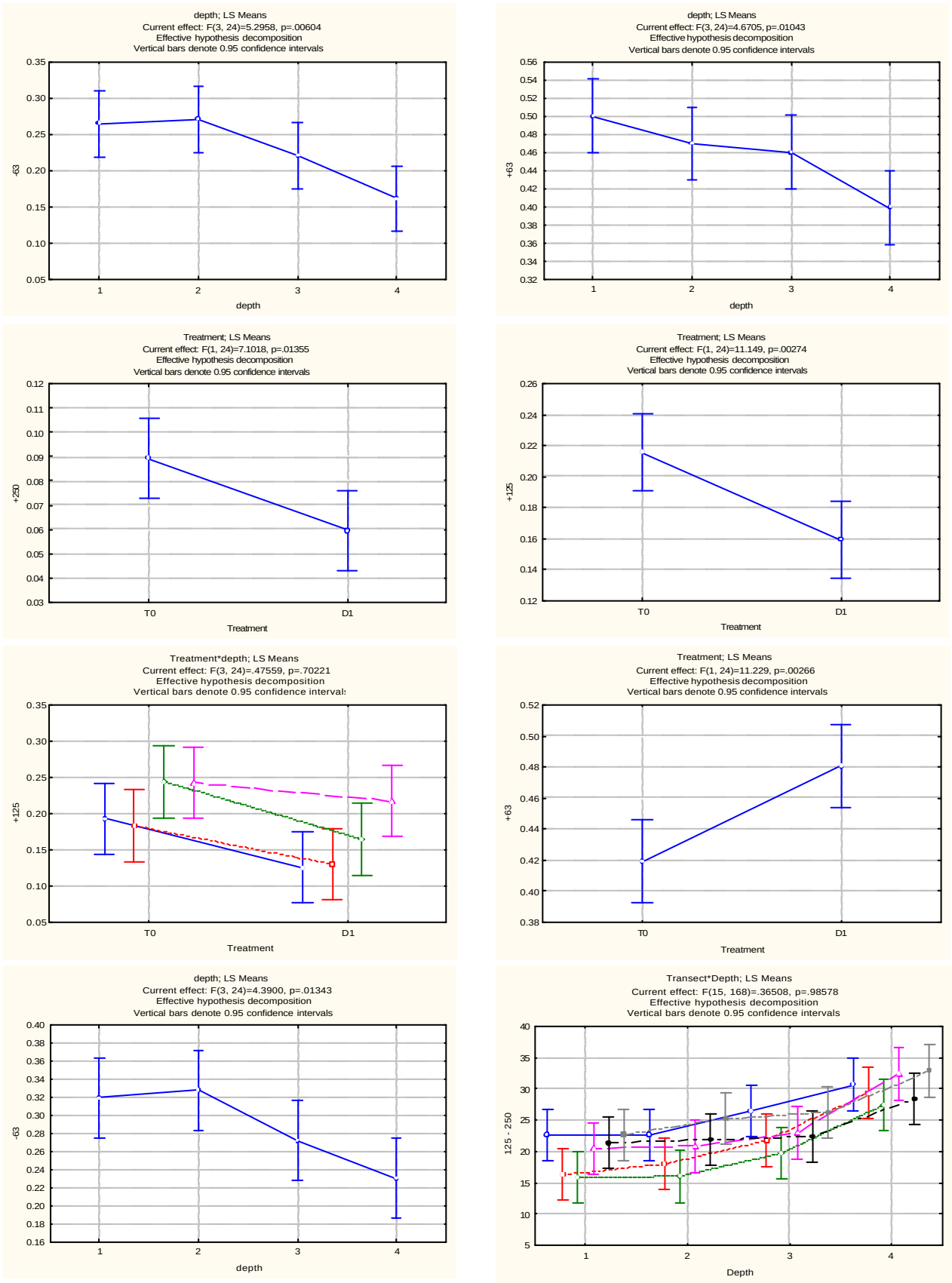
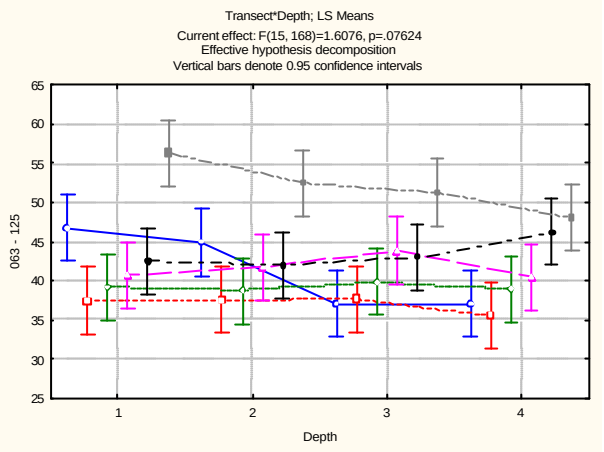


Figure E.4. Continued

Appendix E. Continued



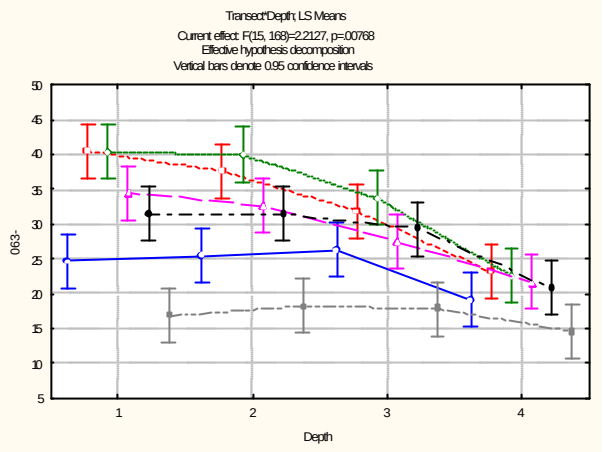


Figure E.4. Continued

Appendix F. Graphs of results obtained from factorial ANOVA's performed on data obtained from line transects performed in the old channel of the Gamtoos estuary.

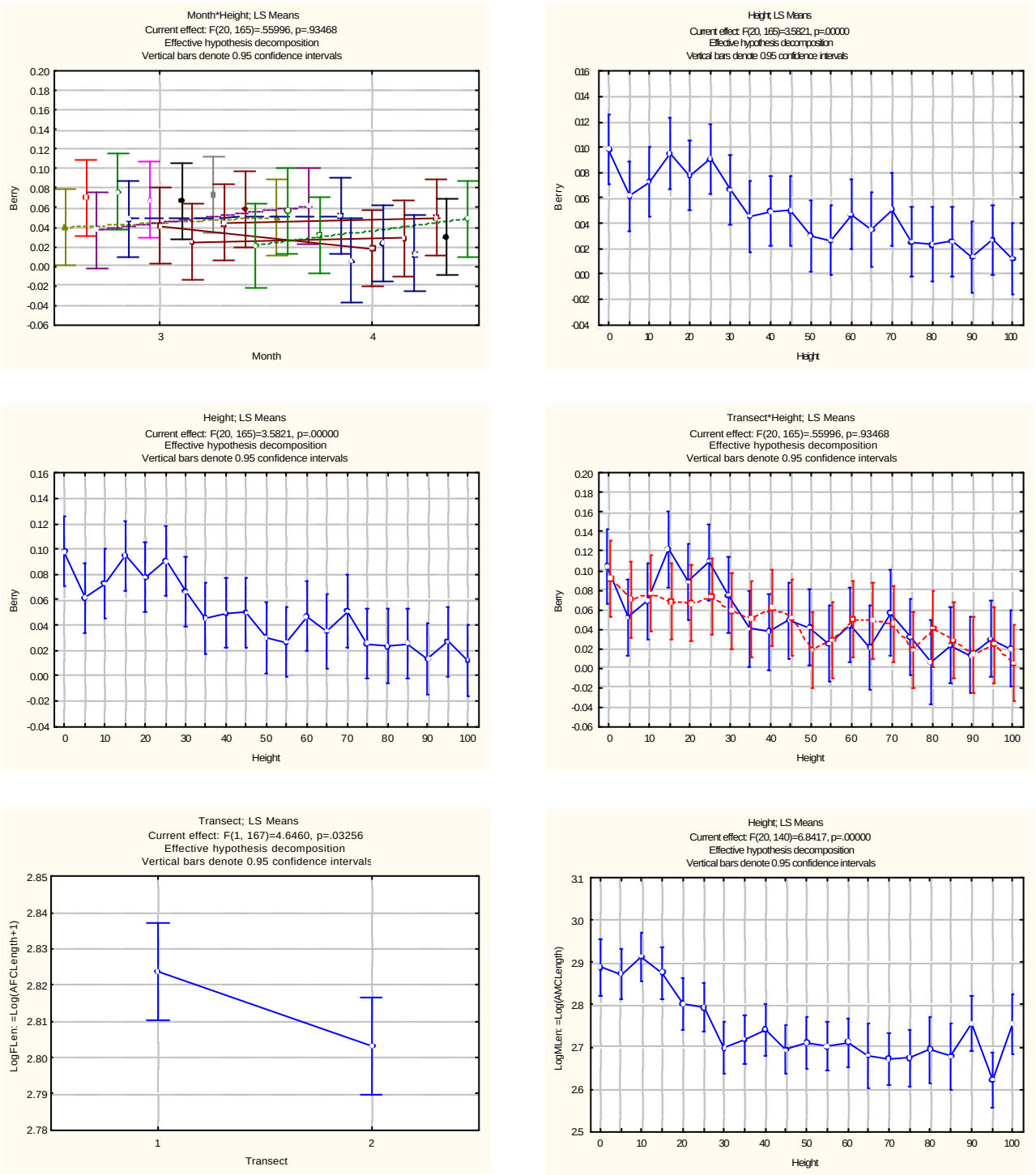
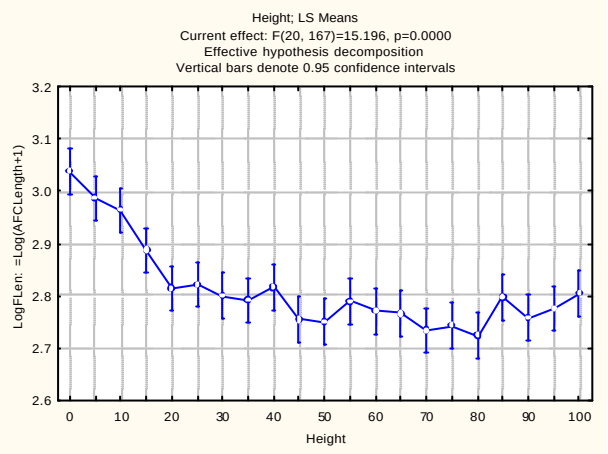


Figure F.1. Plots of factorial ANOVA results performed on the line transect sets obtained from the old channel mudbanks during high reproductive activity. Month 3 = September, 4 = October, Transect 1 = September, transect 2 = October, Height = distance from LWM (m).

Appendix F. continued.



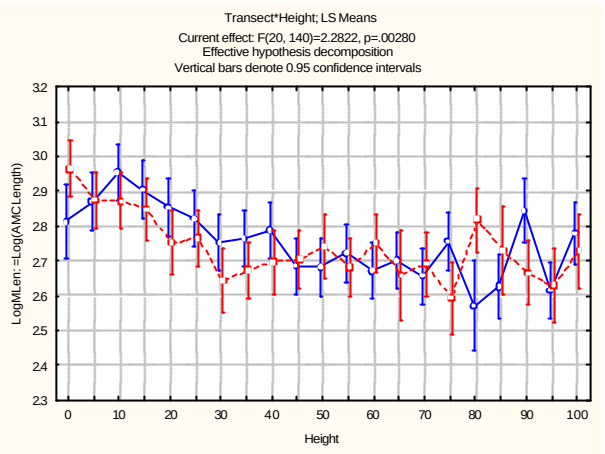


Figure F.1. Continued