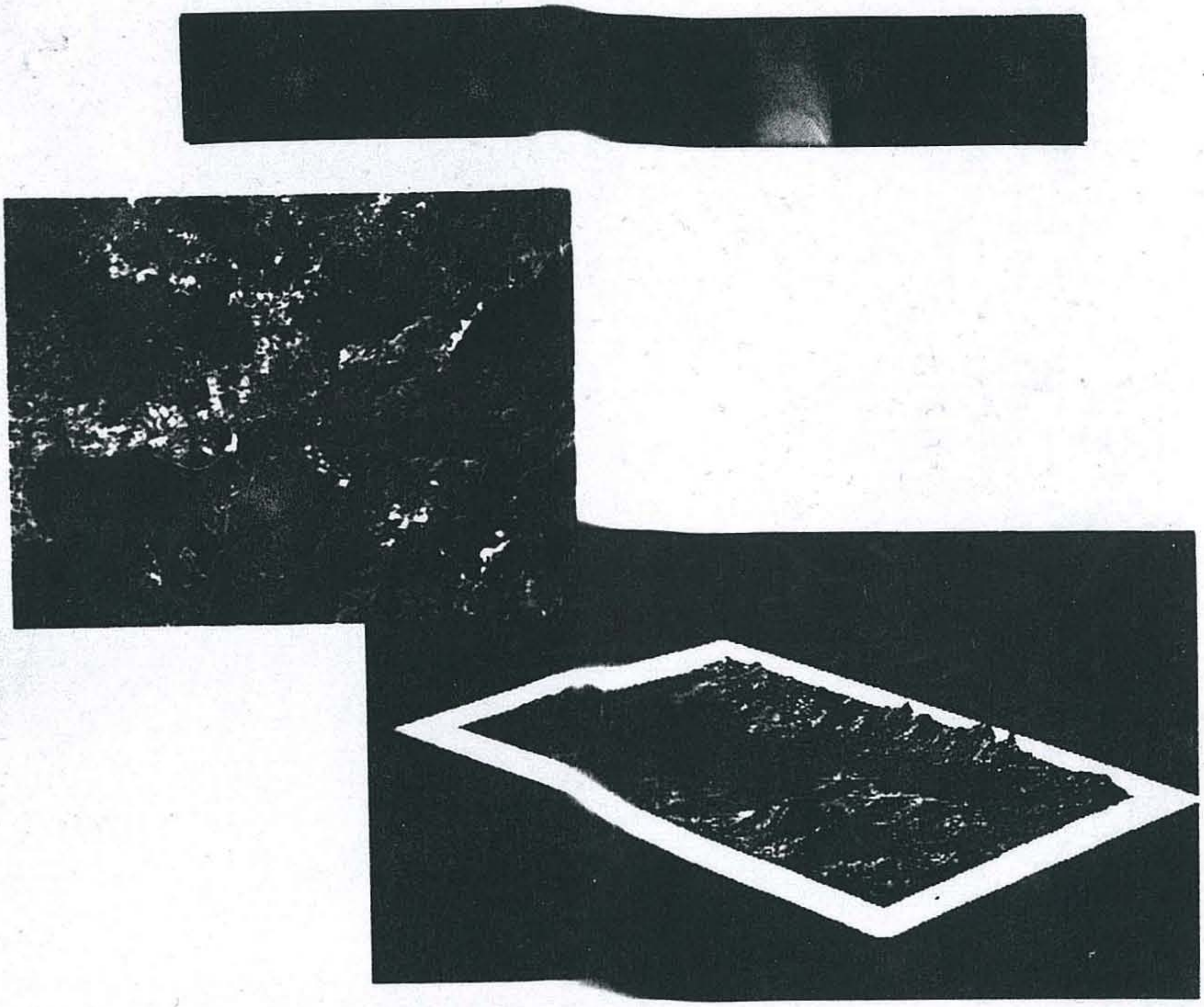
SHENZHEN RIVER REGULATION OFFICE OF MUNICIPAL GOVERNMENT

# ENVIRONMENTAL IMPACT ASSESSMENT STUDY ON SHENZHEN RIVER REGULATION PROJECT



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*Shenzhen River Regulation Office of Municipal Government*

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# FINAL EIA STUDY REPORT (III)

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# APPENDIX 10 ECOLOGY

## A10.1 INTERNATIONAL CONVENTIONS RELEVANT TO THE PROJECT IN TERMS OF HABITAT AND WILDLIFE PROTECTION

### A10.1.1 The Ramsar Convention

Article 1 of the Convention defines wetlands as 'areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six metres.' Thus all wetland habitats in the Deep Bay area, including man-made fish ponds and *gei wais*, and the mangroves, inter-tidal flats and open water areas of Deep Bay are 'wetlands' under the Ramsar definition.

The Convention requires contracting Parties to designate at least one wetland within its territory for inclusion in a 'List of Wetlands of International Importance'. In March 1995 the Hong Kong government announced that it would designate the Mai Po/Inner Deep Bay area as a Romsar site. The criteria for selection of wetlands for inclusion in the List were last revised at the Fourth Conference of the Parties in 1990. The Deep Bay wetlands qualify for designation on the following criteria:

*Criterion 1(d)*

'it is an example of a specific type of wetland, rare or unusual in the appropriate biogeographical region'.

- Deep Bay supports the sixth largest area of mangrove in China.
- Deep Bay supports one of the largest areas of reed bed in southern China

*Criterion 2(a)*

'it supports an appreciable assemblage of rare, vulnerable or endangered species or subspecies of plant or animal, or an appreciable number of individuals of any one of these species'.

- Deep Bay supports ~1% or more of the <u>world</u> population of:

| | | |
|---|---|---|
| Dalmatian Pelican | *Pelecanus crispus* | ~ 1% |
| Black-faced Spoonbill | *Platalea minor* | 24% |
| Asiatic Dowitcher | *Limnodromus semipalmatus* | ~ 1% |
| Spotted Greenshank | *Tringa guttifer* | 10% |
| Saunders' Gull | *Larus saundersi* | 5% |

- Deep Bay supports ~1% or more of the <u>flyway</u> population of (East Asia/Australia flyway population estimates after Watkins 1993):

| | |
|---|---|
| Lesser Sand Plover | *Charadrius mongolus* |
| Greater Sand Plover | *Charadrius leschenaultii* |
| Grey Plover | *Pluvialis squatarola* |

| | |
|---|---|
| Curlew Sandpiper | *Calidris ferruginea* |
| Broad-billed Sandpiper | *Limicola falcinellus* |
| Black-tailed Godwit | *Limosa limosa* |
| Greenshank | *Tringa nebularia* |

- Deep Bay also supports the largest number of Cormorants *Phalacracorax carbo* recorded wintering in East Asia (Perennou *et al.* 1994).

***Criterion 2(d)***

'it is of special value for one or more endemic plant or animal species or communities'.

- Deep Bay is the 'type locality' for at least 19 invertebrate species new to science (Lee 1993).

Article 3 of the Convention states: 'The Contracting Parties shall formulate and implement their planning so as to promote the conservation of the wetlands included in the List, and as far as possible the wise use of wetlands in their territory'.

Furthermore, Article 4 states: Each Contracting Party shall promote the conservation of wetlands and waterfowl by establishing nature reserves on wetlands, whether they are included in the List or not, and provide adequately for their wardening.

Article 5 states: The Contracting Parties shall consult with each other about implementing obligations arising from the Convention especially in the case of a wetland extending over the Territories of more than one Contracting Party or where a waterway is shared by Contracting Parties. They shall at the same time endeavour to coordinate and support present and future policies and regulations concerning the conservation of wetlands and their flora and fauna.

The provisions and requirements of the Ramsar Convention have played a significant role in determining the requirements for the present EIA study, and provide a framework for assessment of the acceptability of the project on ecological grounds.

### A10.1.2 The Bonn Convention

The basic objective of the Bonn Convention is to protect migratory species. This is achieved through two sub-objectives. The first of these is to provide strict protection for species listed in Appendix I, which consists of migratory species in danger of extinction throughout all or a significant portion of their range. The Convention seeks to protect Appendix I species by imposing strict conservation obligations on Parties that are "Range States".

The second sub-objective is to persuade Range States to conclude agreements for the conservation and management of Appendix II species. Migratory species are eligible for Appendix II either if they have an unfavourable conservation status and require international agreements for their conservation or if they have a conservation status which would significantly benefit from international cooperation. At the present time there are no such agreements which are relevant to Hong Kong or the People's Republic of China.

Those species which occur in the Deep Bay area which currently are listed in Appendix I of the Bonn Convention are:

| | |
|---|---|
| Dalmatian Pelican | *Pelecanus crispus* |
| Chinese Egret | *Egretta eulophotes* |
| Oriental White Stork | *Ciconia boyciana* |
| Relict Gull | *Larus relictus* |
| Saunders' Gull | *Larus saundersi* |

Article II.4. states: "Parties that are Range States of a migratory species listed in Appendix I shall endeavour:

a) to conserve and, where feasible and appropriate, restore those habitats of the species which are of importance in removing the species from danger of extinction;

b) to prevent, remove, compensate for or minimize, as appropriate, the adverse effects of activities or obstacles that seriously impede or prevent migration of the species".

In the case of those migratory waterfowl species which use the Deep Bay wetlands as a feeding area, a reduction in feeding opportunities could impede the ability of the birds to migrate, and thus be in contravention of the intent of Article II.4.b.

## A10.2 HONG KONG STATUTES AND GUIDELINES RELEVANT TO ECOLOGICAL RESOURCE PROTECTION

### A10.2.1 The Forests and Countryside Ordinance, Cap. 96

This Ordinance provides for the protection of forests (any area of Crown land covered with selfgrown trees) and plantations (any area of Crown land which has been planted with trees or shrubs or sown with the seeds of trees or shrubs). It thus covers all mangroves within the Hong Kong part of the project area, as well as the vegetation on the hills at Seung Ma Lei Yue.

Under Section 16, fires may not be lit 'in or near any forest, plantation or area of open countryside', unless it is 'reasonable in all circumstances' and 'all reasonable steps have been taken to prevent the fire from damaging or endangering anything growing in the forest, plantation or area of open countryside'. Thus fires at work sites for the project must be strictly controlled and no open fires should be allowed.

Section 21 states:

'Any person who, without lawful authority or excuse, in any forest or plantation

(a) cuts grass, removes turf or earth, rakes pine needles;
(b) plucks or damages any bud, blossom or leaf of any tree, shrub or plant;
(c) [not relevant]
(d) fells, cuts, burns or otherwise destroys any trees or growing plants; shall be guilty of an offense'.

Thus, all engineering works within the Hong Kong part of the Project Area which involve the removal of mangroves or other vegetation in 'forests' and 'plantations', within the meaning of this Ordinance, must be conducted in accordance with a special permit issued in writing by the Director of Agriculture and Fisheries under Section 23. However, as a general practice the Agriculture and Fishery Department advise that permission for tree felling will be granted by the Land Authority.

Regulation 2 of the Forestry Regulations provides for the protection of certain local wild plant species, it being an offense to offer for sale or to be in possession, custody or control of any portion of a protected species. All orchids are listed and at least one species (*Zeuxine strateumatica*) has been recorded at Mai Po.

### A10.2.2 The Town Planning Ordinance, Cap. 131

The Town Planning Ordinance was amended in 1991 to include the majority of the Territory of Hong Kong. The Ordinance does not have specific conservation requirements but the Plans which are prepared under Section 3(1)(b) may include areas which are designated as Sites of Special Scientific Interest (SSSI). Until the Ordinance was amended in 1991 SSSI designation had been an administrative tool for site protection with no legislative support. The amended Ordinance now provides for SSSI as a statutory landuse, with activities within such sites being restricted to those listed in the 'notes' attached to such plans. It should be noted, however, that at present not all SSSIs which have received administrative designation have been incorporated into Development Permission Area plans.

Table 10.2.1 Lists SSSIs within the Inner Deep Bay Area.

| Location | Date of Designation | OZP |
|---|---|---|
| Mai Po Marshes/Lut Chau | 15 Sept 1976 | S/YL-MP/1 |
| Tsim Bei Tsui | 10 Jan 1985 | S/YL-LFS/1 |
| Tsim Bei Tsui Egretry | 5 Jan 1989 | S/YL-LFS/1 |
| Mai Po Village Egretry | 16 Feb 1979 | S/YL-MP/1 |
| Inner Deep Bay | 18 March 1986 | S/YL-LFS/1 |
| Lok Ma Chau Egretry | * | |

* proposed, awaiting designation

### A10.2.3 The Wild Animals Protection Ordinance, Cap. 170

This Ordinance provides for the protection of species listed in the Second Schedule. Of those species recorded in the Deep Bay area, the following are fully protected in Hong Kong:

| | |
|---|---|
| bats | *Chiroptera* spp. |
| Chinese Pangolin | *Manis pentadactyla* |
| Chinese White Dolphin | *Sousa chinensis* |
| Crab-eating Mongoose | *Herpestes urva* |
| Javan Mongoose | *Herpestes javanicus* |
| Small Indian Civet | *Viverricula indica* |
| Otter | *Lutra lutra* |
| Leopard Cat | *Felis bengalensis* |
| all birds | Aves |
| terrapins | Testudines |
| Burmese Python | *Python molurus* |

Furthermore, the nests and eggs of protected species (all birds and selected reptiles) are protected (Section 5). Any civil engineering works which will 'remove, injure, destroy or wilfully disturb' any nest or egg of a protected wild animal can only be undertaken in accordance with a permit in writing issued under Section 15 by the Director of Agriculture and Fisheries. Any structures to be dismantled which contain bat colonies also require a permit under Section 15 since bats are likely to be killed.

Section 13 of the Ordinance provides for the control of access to areas specified in the Sixth Schedule. The Mai Po Marshes are currently listed and access is restricted.

### A10.2.4 The Fisheries Protection Ordinance, Cap. 171

This Ordinance is 'to promote the conservation of fish and other forms of aquatic life within the waters of Hong Kong and to regulate fishing practices and to prevent activities detrimental to the fishing industry' (preamble).

The Ordinance provides for Regulations to prohibit the use of explosives and fish poisons, such substances being listed in the Schedule. The Fisheries Protection Regulations enable enforcement of these prohibitions.

Provision may also be made for other conservation activities, such as the control of mesh size, the protection of spawning areas and the conservation of oysters and oysterbeds; however, no such regulations exist at present.

Thus, although the Shenzhen River Regulation Project may adversely impact fisheries within Deep Bay, the current legislation provides no controlling mechanism for such activities.

### A10.2.5 The Environmental Guidelines for Planning in Hong Kong

These "provide guidance for including environmental considerations in the planning of both public and private developments. [They apply] both to the planning of any permanent or temporary uses which will have potential to cause significant changes to the biophysical environment or which are sensitive to environmental impacts".

Section 5.3.14 is relevant to the Shenzhen River Regulation Project. It states: 'Nature Reserves and Sites of Special Scientific Interest (SSSI). These areas should be adequately protected from the effects of pollution and from the diversion of natural flows'.

### A10.2.6 The Deep Bay Guidelines for Dredging, Reclamation and Drainage Works

These guidelines were developed as part of the Deep Bay Environmental Management Review (ERL 1991). The guidelines address various issues including:

- site selection
- appropriate methods of working
- environmental site investigation needs
- environmental constraints, criteria and monitoring requirements
- design procedures, including assessment of impacts and selection of mitigation measures
- specific conditions of contract and performance specifications to be applied to Deep Bay projects

Some of the Deep Bay Guidelines have now been superseded, in particular those relating to 'contaminated sediments' and standards for water quality (Mott MacDonald 1991).

Those Sections of the Guidelines which are of particular relevance to the Shenzhen River Regulation Project with respect to flora and fauna include:

*Special Measures Zone (SMZ)*

'Normally, no works will be permitted within the Inner Deep Bay Special Measures Zone (SMZ);....In [those cases where works are unavoidable] the works should be designed to minimise land-take and programmed so as not to occur during the migratory-bird over-wintering period (November to March). ...In addition, works should preferably not take place outside normal working hours (0700 hours to 1900 hours on the same day)'. The wording for the Special Conditions of Contract is given in Section 5.2.1. of the Guidelines.

*Dumping in Deep Bay*

'All Works should be designed on the general assumption that no surplus material (i.e. surplus to the requirements of the permanent works) from dredging can be dumped in Deep Bay'.

## A10.3 PRC RELEVANT STATUTES AND BILATERAL MIGRATORY BIRD AGREEMENTS

### A10.3.1 Wildlife Protection Law of the PRC

According to Chapter 2 Provision 12 an environmental impact assessment should be submitted by the developer for construction projects which potentially result in adverse impacts on wildlife habitat protected by national or local regulations. In the approval process the Environmental Protection Department should consult the wildlife protection agencies at the same administrative level.

### A10.3.2 PRC Wildlife Protection Implementation Regulations

According to Chapter 2 Provision 10 preventive measures should be taken by relevant institutions and individuals to preclude potential risk of adverse impacts on wildlife protected by national or local regulations.

### A10.3.3 PRC Guidelines for Nature Reserves for Forests and Wildlife Species

According to Provision 11 the natural environment and natural resources in nature reserves should be managed solely by the administrative organization of nature reserves. Without permission of the Ministry of Forestry or the provincial, autonomous regional, or municipal administrative department of forests no institution or individual is allowed to enter the nature conservation area to establish institutions or construct facilities.

### A10.3.4 PRC Nature Reserve Regulations, Provision 32

Any construction facility is prohibited in core areas and buffer zones of nature reserves. Construction facilities which may cause environmental pollution, resource destruction, or landscape damage in the experimental areas are also inhibited; pollutants discharged from other construction projects in the experimental areas should obey national or local standards. Time tables should be set up for effluent control for those existing facilities in the experimental area if the effluents discharged exceed national or local standards; mitigation measures must be taken for any damage.

Other construction projects surrounding nature reserves should not damage the environmental quality of nature reserves; any damage must be rectified within a definite time.

Time tables for the rectification will be set up by appropriate administrations authorized by relevant laws and regulations. The responsible enterprises and institutions must accomplish rectification within the specified time.

### A10.3.5 The National Protection List of Important Wild Animals

The following mammals which occur in the Shenzhen River catchment and Deep Bay area are listed among species to be protected in PRC (first class protection species are marked with *).

| | |
|---|---|
| Otter | *Lutra lutra* |
| Small Indian Civet | *Viverricula indica* |
| Chinese White Dolphin | *Sousa chinesis* |

The following birds which occur in the Shenzhen River catchment and Deep Bay are listed among species to be protected in PRC (first class protection species are marked with *).

| | |
|---|---|
| Black-necked Grebe | *Podiceps nigricollis* |
| Dalmatian Pelican | *Pelecanus (philippensis) crispus* |
| Reef Egret | *Egretta sacra* |
| Swinhoe's Egret | *Egretta eulophotes* |
| Oriental White Stork * | *Ciconia (ciconia) boyciana* |
| Black Stork * | *Ciconia nigra* |
| White Ibis | *Threskiornis (aethiopicus) melanocephalus* |
| Glossy Ibis | *Plegadis falcinellus* |
| White Spoonbill | *Platalea leucorodia* |
| Black-faced Spoonbill | *Platalea minor* |
| swan | *Cygnus* sp. |
| Mandarin Duck | *Aix galericulata* |
| Common Crane | *Grus grus* |
| Imperial Eagle * | *Aquila heliaca* |
| Black-shouldered Kite | *Elanus caeruleus* |
| Black Kite | *Milvus migrans* |
| White-bellied Sea Eagle | *Haliaeetus leucogaster* |
| Crested Goshawk | *Accipiter trivirgatus* |
| Marsh Harrier | *Circus aeruginosus* |
| Hen Harrier | *Circus cyaneus* |
| Pied Harrier | *Circus melanoleucos* |
| Japanese Sparrowhawk | *Accipiter gularis* |
| Besra | *Accipiter virgatus* |
| Horsfield's Goshawk | *Accipiter soloensis* |
| Grey-faced Buzzard-eagle | *Butastur indicus* |
| Buzzard | *Buteo buteo* |
| Spotted Eagle | *Aquila clanga* |
| Bonelli's Eagle | *Hieraaetus fasciatus* |
| Crested Honey Buzzard | *Pernis ptilorhnychus* |
| Serpent Eagle | *Spilornis cheela* |
| Osprey | *Pandion haliaetus* |
| Kestrel | *Falco tinnunculus* |
| Peregrine | *Falco peregrinus* |
| Hobby | *Falco subbuteo* |
| Saker Falcon | *Falco cherrug* |
| Little Whimbrel | *Numenius (borealis) minutus* |
| Spotted Greenshank | *Tringa guttifer* |
| Relict Gull * | *Larus relictus* |
| Greater Coucal | *Centropus sinensis* |
| Lesser Coucal | *Centropus bengalensis* |
| Rose-ringed Parakeet | *Psittacula krameri* |
| Short-eared Owl | *Asio flammeus* |
| Grass Owl | *Tyto capensis* |
| White-vented Needletail | *Hirundapus cochinchinensis* |

The following reptiles which occur in the Shenzhen River catchment and Deep Bay are listed among species to be protected in PRC.

| | |
|---|---|
| Water Monitor | *Varanus salvator* |
| Burmese Python | *Python molurus* |

### A10.3.6 Bilateral Migratory Bird Agreements

China has entered into a number of bilateral agreements to protect migratory birds. These include agreements with both Japan and Australia. Birds passing through the Deep Bay area are known to migrate to/from both of these countries (see, for example: Melville, D.S. and Galsworthy, A.C. 1993. Report on bird ringing in Hong Kong in 1992. *Hong Kong Bird Report* 1992:81-99) and thus these agreements are relevant in the context of this study. A list of birds occurring in the Deep Bay area protected under bilateral migratory bird agreements between China and Australia/Japan is given below.

Birds occurring in the Deep Bay area protected under bilateral migratory bird agreements between China and Australia/Japan

| | | |
|---|---|---|
| Black-necked Grebe | *Podiceps nigricollis* | J |
| Great Crested Grebe | *Podiceps cristatus* | AJ |
| Lesser Frigatebird | *Fregata ariel* | AJ |
| Bittern | *Botaurus stellaris* | J |
| Cattle Egret | *Bubulcus ibis* | J |
| Reef Egret | *Egretta sacra* | AJ |
| Great Egret | *Egretta albas* | AJ |
| Yellow Bittern | *Ixobrychus sinensis* | AJ |
| Schrenck's Bittern | *Ixobrychus eurhythmus* | J |
| Little Green Heron | *Butorides striatus* | J |
| Intermediate Egret | *Egretta intermedia* | J |
| Night Heron | *Nycticorax nycticorax* | J |
| Purple Heron | *Ardea purpurea* | J |
| Black Stork | *Ciconia nigra* | J |
| Glossy Ibis | *Plegadis falcinellus* | A |
| White Spoonbill | *Platalea leucorodia* | J |
| Black-faced Spoonbill | *Platalea minor* | J |
| Ruddy Shelduck | *Tadorna ferruginea* | J |
| Shelduck | *Tadorna tadorna* | J |
| Pintail | *Anas acuta* | J |
| Teal | *Anas crecca* | J |
| Baikal Teal | *Anas formosa* | J |
| Falcated Teal | *Anas falcata* | J |
| Mallard | *Anas platyrhychos* | J |
| Gadwall | *Anas strepera* | J |
| Wigeon | *Anas penelope* | J |
| Garganey | *Anas querquedula* | AJ |
| Shoveler | *Anas clypeata* | J |
| Common Pochard | *Aythya ferina* | J |
| Baer's Pochard | *Aythya baeri* | J |
| Tufted Duck | *Aythya fuligula* | J |
| Scaup | *Aythya marila* | J |
| Red-breasted Merganser | *Mergus serrator* | J |
| White-bellied Sea-eagle | *Haliaeetus leucogaster* | A |
| Marsh Harrier | *Circus japonica* | J |
| Hobby | *Falco subbuteo* | J |
| Japanese Quail | *Coturnix coturnix* | J |
| Watercock | *Gallicrex cinerea* | J |

| | | |
|---|---|---|
| Moorhen | *Gallinula chloropus* | J |
| Pheasant-tailed Jacana | *Hydrophasianus chirurgus* | A |
| Painted Snipe | *Rostratula benghalensis* | AJ |
| Little Ringed Plover | *Charadrius dubius* | A |
| Ringed Plover | *Charadrius hiaticula* | A |
| Lesser Sand Plover | *Charadrius mongolus* | AJ |
| Greater Sand Plover | *Charadrius leschenaultii* | AJ |
| Oriental Plover | *Charadrius veredus* | A |
| Lapwing | *Vanellus vanellus* | J |
| Grey Plover | *Pluvialis squatarola* | A |
| Pacific Golden Plover | *Pluvialis fulva* | AJ |
| Little Whimbrel | *Numenius (borealis) minutus* | A |
| Whimbrel | *Numenius phaeopus* | J |
| Curlew | *Numenius arquata* | AJ |
| Australian Curlew | *Numenius madagascariensis* | AJ |
| Black-tailed Godwit | *Limosa limosa* | AJ |
| Bar-tailed Godwit | *Limosa lapponica* | AJ |
| Spotted Redshank | *Tringa erythropus* | J |
| Redshank | *Tringa totanus* | AJ |
| Marsh Sandpiper | *Tringa stagnatilis* | AJ |
| Greenshank | *Tringa nebularia* | AJ |
| Green Sandpiper | *Tringa ochropus* | J |
| Wood Sandpiper | *Tringa glareola* | AJ |
| Nordmann's Greenshank | *Tringa guttifer* | J |
| Common Sandpiper | *Tringa hypoleucos* | AJ |
| Grey-rumped Sandpiper | *Tringa brevipes* | AJ |
| Terek Sandpiper | *Xenus cinereus* | AJ |
| Turnstone | *Arenaria interpres* | AJ |
| Swinhoe's Snipe | *Gallinago megala* | AJ |
| Pintail Snipe | *Gallinago stenura* | A |
| Common Snipe | *Gallinago gallinago* | J |
| Woodcock | *Scolopax rusticola* | J |
| Asiatic Dowitcher | *Limnodromus semipalmatus* | A |
| Red Knot | *Calidris canutus* | AJ |
| Great Knot | *Calidris tenuirostris* | AJ |
| Red-necked Stint | *Calidris ruficollis* | AJ |
| Long-toed Stint | *Calidris subminuta* | AJ |
| Temminck's Stint | *Calidris temminckii* | J |
| Sharp-tailed Sandpiper | *Calidris acuminata* | AJ |
| Dunlin | *Calidris alpina* | AJ |
| Curlew Sandpiper | *Calidris ferruginea* | AJ |
| Sanderling | *Calidris alba* | AJ |
| Spoon-billed Sandpiper | *Eurynorynchus pygmaeus* | J |
| Broad-billed Sandpiper | *Limicola falcinellus* | AJ |
| Ruff | *Philomachus pugnax* | AJ |
| Black-winged Stilt | *Himantopus himantopus* | J |
| Avocet | *Recurvirostra avosetta* | J |
| Red-necked Phalarope | *Phalaropus lobatus* | AJ |
| Grey Phalarope | *Phalaropus fulicarius* | AJ |
| Oriental Pratincole | *Glareola maldivarum* | AJ |
| Common Gull | *Larus canus* | J |

| | | |
|---|---|---|
| Herring Gull | *Larus argentatus* | J |
| Slaty-backed Gull | *Larus schistisagus* | J |
| Black-headed Gull | *Larus ridibundus* | J |
| Black-legged Kittiwake | *Rissa tridactyla* | J |
| Common Tern | *Sterna hirundo* | AJ |
| Little Tern | *Sterna albifrons* | AJ |
| Ancient Auk | *Synthliboramphus antiquus* | J |
| Oriental Cuckoo | *Cuculus saturatus* | AJ |
| Short-eared Owl | *Asio flammeus* | J |
| White-throated Needletail | *Hirundapus caudacutus* | AJ |
| Pacific Swift | *Apus pacificus* | AJ |
| Little Swift | *Apus affinis* | J |
| Sand Martin | *Riparia riparia* | J |
| Barn Swallow | *Hirundo rustica* | AJ |
| Red-rumped Swallow | *Hirundo daurica* | AJ |
| Asian House Martin | *Delichon dasypus* | J |
| Forest Wagtail | *Dendronanthus indicus* | J |
| Yellow Wagtail | *Motacilla flava* | AJ |
| Citrine Wagtail | *Motacilla citreola* | AJ |
| White Wagtail | *Motacilla alba* | AJ |
| Richard's Pipit | *Anthus richardi* | J |
| Olive-backed Pipit | *Anthus hodgsoni* | J |
| Pechora Pipit | *Anthus gustavi* | J |
| Red-throated Pipit | *Anthus cervinus* | J |
| Water Pipit | *Anthus spinoletta* | J |
| Ashy Minivet | *Pericrocotus divaricatus* | J |
| Tiger Shrike | *Lanius tigrinus* | J |
| Brown Shrike | *Lanius cristatus* | J |
| Black-naped Oriole | *Oriolus chinensis* | J |
| Chestnut-cheeked Starling | *Sturnus philippensis* | J |
| Red-tailed Robin | *Luscinia sibilans* | J |
| Siberian Rubythroat | *Luscinia calliope* | J |
| Siberian Blue Robin | *Luscinia cyane* | J |
| Red-flanked Bluetail | *Tarsiger cyanurus* | J |
| Daurian Redstart | *Phoenicurus auroreus* | J |
| Stonechat | *Saxicola torquata* | J |
| Siberian Thrush | *Zoothera sibiricus* | J |
| White's Thrush | *Zoothera dauma* | J |
| Grey-backed Thrush | *Turdus hortulorum* | J |
| Grey Thrush | *Turdus cardis* | J |
| Pale Thrush | *Turdus pallidus* | J |
| Eye-browed Thrush | *Turdus obscurus* | J |
| Dusky Thrush | *Turdus naumanni* | J |
| Short-tailed Bush Warbler | *Urosphena squameiceps* | J |
| Middendorf's Grasshopper Warbler | *Locustella ochotensis* | J |
| Lanceolated Warbler | *Locustella lanceolata* | J |
| Great Reed Warbler | *Acrocephalus orientalis* | AJ |
| Black-browed Reed Warbler | *Acrocephalus bistrigiceps* | J |
| Yellow-browed Warbler | *Phylloscopus inornatus* | J |
| Arctic Warbler | *Phylloscopus borealis* | AJ |
| Pale-legged Leaf Warbler | *Phylloscopus tenellipes* | J |

| | | |
|---|---|---|
| Eastern Crowned Warbler | *Phylloscopus coronatus* | J |
| Yellow-rumped Flycatcher | *Ficedula zanthopygia* | J |
| Narcissus Flycatcher | *Ficedula narcissina* | J |
| Mugimaki Flycatcher | *Ficedula mugimaki* | J |
| Blue-and-White Flycatcher | *Cyanoptila cyanomelana* | J |
| Sooty Flycatcher | *Muscicapa sibirica* | J |
| Grey-streaked Flycatcher | *Muscicapa griseisticta* | J |
| Brown Flycatcher | *Muscicapa latirostris* | J |
| Japanese Paradise Flycatcher | *Terpsiphone atrocaudata* | J |
| Ruddy Sparrow | *Passer rutilans* | J |
| Brambling | *Fringilla montifringilla* | J |
| Siskin | *Carduelis spinus* | J |
| Black-tailed Hawfinch | *Eophona migratoria* | J |
| Yellow-breasted Bunting | *Emberiza aureola* | J |
| Black-faced Bunting | *Emberiza spodocephala* | J |
| Japanese Yellow Bunting | *Emberiza sulphurata* | J |
| Chestnut-eared Bunting | *Emberiza fucata* | J |
| Rustic Bunting | *Emberiza rustica* | J |
| Little Bunting | *Emberiza pusilla* | J |
| Tristram's Bunting | *Emberiza tristrami* | J |
| Pallas's Reed Bunting | *Emberiza pallasi* | J |
| Reed Bunting | *Emberiza schoeniclus* | J |

These species are listed under:

(A) Agreement between the Government of Australia and the Government of the People's Republic of China for the Protection of Migratory Birds and Their Environment, and

(J) Agreement on the Protection of Migratory Birds and Their Habitats by the Governments of Japan and the People's Republic of China.

### A10.3.7 The Management Measures for Forests of Guangdong Province, Section 26

Natural reserves should be protected. Permission of relevant authorities is required for any special-aimed use of the resources within natural reserves.

### A10.3.8 The Environmental Management Regulations for Construction Projects in Guangdong Province, Section 4

Any decision on construction projects including their identification, layout, and siting should meet the environmental planning requirements. Consideration should be given to protecting and to enhancing the environmental quality of the whole area. Construction of projects which will cause environmental pollution and ecological damage to water source protection zones, natural reserves, and other special protection areas is prohibited.

### A10.3.9 Guangdong Provincial Implementary Detailed Regulations for Natural Reserves of Forest and Wildlife Species, Section 12

Natural environment and resources within the natural reserves should be managed by the administrative organization of nature reserves. Establishment of institutes or facilities is prohibited without approval of the Ministry of Forestry or the provincial authority of forest management.

## A10.4 EXPERIMENTAL STUDY ON SURVIVAL OF MANGROVE SEEDLINGS

### A10.4.1 Introduction

Mangroves are a type of intertidal vegetation community found on mudflats in tropical and subtropical areas. Mangroves play an important role in wind resistance and coastal protection. A flourishing mangrove grows on the mudflats of the intertidal zone of the Shenzhen River estuary. The mangroves scattered on either side of the river channel in the lower reaches and a portion of the mangroves in the estuary will be lost due to Stage 2 of the Shenzhen River dredging project. The planting of mangroves on either side of the new river channel will be an effective mitigation measure to compensate for the ecological impacts caused by loss of mangroves. This measure will bring advantages in the form of wind resistance, bank stabilisation, beautification of the environment and restoration of habitat. This study selected study sites along the upper, middle and lower reaches of the Shenzhen River to study the survival and growth of one-year-old seedlings of *Kandelia candel*, the dominant mangrove species, under varying environmental conditions. The purpose of the study, in accordance with the requirements of the inception report, was to clarify the various habitat conditions that influence the growth and development of mangrove seedlings. This study provides necessary background for the future replanting of mangroves along the channel banks.

### A10.4.2 Plantation Sites and Environmental Conditions

The Shenzhen River discharges into Deep Bay and receives tidal inflows daily. Soil conditions and salinity along the estuary shore are well suited to the growth of mangroves, and large areas of mangrove cover the shores at Mai Po, Hong Kong and Futian, Shenzhen. Shipping on the Shenzhen River is currently relatively busy, and the scouring action from waves raised by vessels may affect the development of replanted mangrove seedlings. Soil conditions along the Shenzhen River and salinity and pollution levels of the water may also affect survival of the seedlings. The three experimental sites (Figure A10.4.1) chosen for this study had the following characteristics:

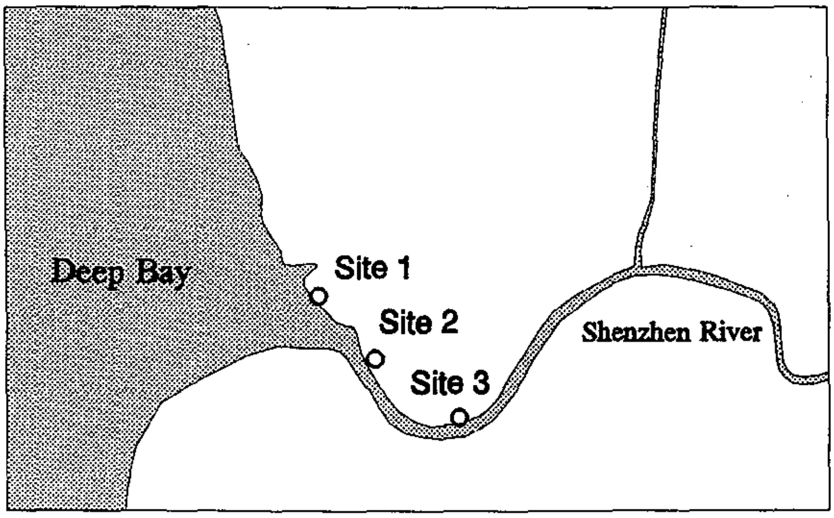


Figure A10.4.1 Experimental Sites

Site 1 (river mouth) was located in the vicinity of the Shenzhen River estuarine shore. Salinity here was relatively high, soil was heavily silted, and the level of water pollution was relatively low. Site 2 (middle reaches) was located approximately 200m upstream from the estuary. Salinity was similar to that at the estuary, as were pollution levels. Soil was mixed silt and lateritic soil. Site 3 (upper reaches) was located near Chegongmiao. The water here was relatively unaffected by seawater. Serious levels of domestic sewage from Shenzhen Municipality made the water here malodorous, while the soil was hard. All three sites were characterised by uneven terrain and a proliferation of weeds. All three sites were levelled and cleared of stones and rubbish prior to commencement of the experiment.

### A10.4.3 Planting Methods, Planting Density and Study Period

*K. candel* seedlings of normal growth, approximately 40cm in height, were selected for planting. The rootball transplantation method was employed. Planting density was 0.5 x 0.5m. In order to assess the influence of wind and waves on seedling survival, plantings at each site were divided into three groups of 200 seedlings each, to test three experimental conditions (full, partial and no buffer) related to wave buffering. Buffers were constructed of bamboo lengths approximately 50cm in length and 5cm in width.

Plantation of *K. candel* seedlings was carried out between 25 and 28 March 1994. The observation continued for three months, through the end of June. Observations were made on the 10th, 20th and 30th of each month. The main point of interest was the survival rate and growth of seedlings under different experimental conditions at each site.

### A10.4.4 Results

#### A10.4.4.1 Survival and growth of *K. candel* seedlings at each site under various experimental conditions

*Upper reaches*

Table A10.4.1 Survival Rates of *K. candel* Seedlings under Different Experimental Conditions in the Upper Reaches over Three Months (%)

| Month | No buffer | Partial buffer | Full buffer |
|---|---|---|---|
| April | 92.5 | 96.5 | 98.0 |
| May | 39.0 | 65.0 | 64.6 |
| June | 12.5 | 14.0 | 50.0 |

Table A10.4.1 shows that at the end of April, one month after plantation of *K. candel* seedlings, overall survival rate was fairly high. Differences in survival among the three experimental subgroups were not strongly marked; the difference in survival rates between the full-buffer group and the no-buffer group was only 5.5%, and between the fully buffered group and the partially buffered group only 1.5%. Data for May show a noticeably lower survival rate among the non-buffered group as opposed to the partially and fully buffered groups. By the end of June, the mortality rate in the non-buffered group was far higher than that in the fully buffered group. Seedling survival in the fully buffered group was 36% higher than in the partially buffered group and 37.5% higher than in the non-buffered group. The survival rate for fully buffered seedlings was 4 times that of non-buffered seedlings and 3.37% that of partially buffered seedlings. These results clearly demonstrate the utility of the buffer.

*Middle reaches*

Table A10.4.2 Survival Rates of *K. candel* Seedlings under Different Experimental Conditions in the Middle Reaches, 200m above estuary (%)

| Month | No buffer | Partial buffer | Full buffer |
|---|---|---|---|
| April | 88 | 91 | 91 |
| May | 57 | 62 | 61 |
| June | 26 | 51.5 | 58 |

Table A10.4.2 shows significant mortality at this site during the first month of observation, specifically a mortality rate 5-7% higher than that at the upper reaches site. The three experimental conditions at this site showed a difference of 3% in survival rates. Fairly high mortality rates were recorded for all three experimental conditions during the second month of observation, ranging from 29-37%. Survival rates for fully buffered and partially buffered seedlings were roughly 10% higher than that for non-buffered seedlings. By the third month, the mortality rate for the non-buffered group had risen by 31% over the month before, while mortality in the partially buffered and fully buffered groups rose only 11% and 3% respectively over the same period. The survival rate of the fully buffered group of seedlings was 2.23 times that of the non-buffered group and 1.13 times that of the partially buffered group. Again, the protective utility of the buffers was noticeable.

*Lower reaches*

Table A10.4.3 Survival Rates of *K. candel* Seedlings under Different Experimental Conditions in the Lower Reaches, in Shenzhen River estuary (%)

| Month | No buffer | Partial buffer | Full buffer |
|---|---|---|---|
| April | 89 | 91 | 90 |
| May | 59 | 63 | 64 |
| June | 27.5 | 38.5 | 56.5 |

The situation at this site was essentially the same as at those in the middle and upper reaches. Results for the first month of observation showed a marked disparity, with survival rates nearly the same as those for the middle reaches. More mortality followed in the second month, with mortality rates 26-30% higher than those for the first month. The survival rate for the fully buffered group was only 5% higher than that for the non-buffered group. This relatively slight difference was increased in the third month of observation; at this point the survival rate of the non-buffered group fell 32% and that of the partially buffered group fell 25%, while the survival rate of the fully buffered group fell only 8% as compared with the second month. The survival rate of the fully buffered group of seedlings was 1.47 times that of the partially buffered group and twice that of the non-buffered group. Once again, the protective utility of the buffers was noticeable.

A comparison of the *K. candel* seedling survival rates for the three experimental sites under the different experimental conditions showed that survival rates decreased little in the first month following planting, while mortality rates were high in the second and third months. Data for all three sites testify that survival rates of fully buffered seedling are perceptibly higher than those for partially buffered seedlings and considerably higher (an average of 30% higher) than those for non-buffered seedlings. The effect of the full buffer was particularly significant in assuring the survival of seedlings at the experimental site on the upper reaches of the river, where the channel is narrow and the wave effect from passing vessels correspondingly great.

### A10.4.4.2 Comparison of seedling survival under different experimental conditions at different sites after three months

Table A10.4.4 Overall Comparison of Survival Rates of *K. candel* Seedlings at Different Experimental Sites under Different Experimental Conditions (%)

| Site | No buffer | Partial buffer | Full buffer | Average |
|---|---|---|---|---|
| Upper reaches | 12.5 | 14.0 | 50.0 | 25.5 |
| Middle reaches | 26.0 | 51.5 | 58.0 | 45.2 |
| Lower reaches | 27.5 | 38.5 | 56.5 | 40.8 |
| Average | 22.0 | 34.7 | 54.8 | |

Table A10.4.4 shows that three months after plantation of *K. candel* seedlings, the average survival rates were as follows: 45.2% at the middle reaches site, 40.8% at the lower reaches (estuary site), and 25.5.% at the upper reaches site. Among the three different experimental conditions, the highest overall survival rate occurred among the fully buffered seedlings, an average of 54.8%. The overall average survival rate for partially buffered seedlings was 34.7%, while that for non-buffered seedlings was 22.0%. An inspection of the interrelationship between surviving seedling numbers and length of survival on the one hand and the different experimental conditions on the other shows that the most rapid decline in number of surviving seedlings occurred among the non-buffered groups (see Fig. A10.4.2, estuary site). All three experimental conditions shared one characteristic: mortality rates increased considerably after 20 May. Seedlings at the middle and upper reaches sites displayed a similar phenomenon.

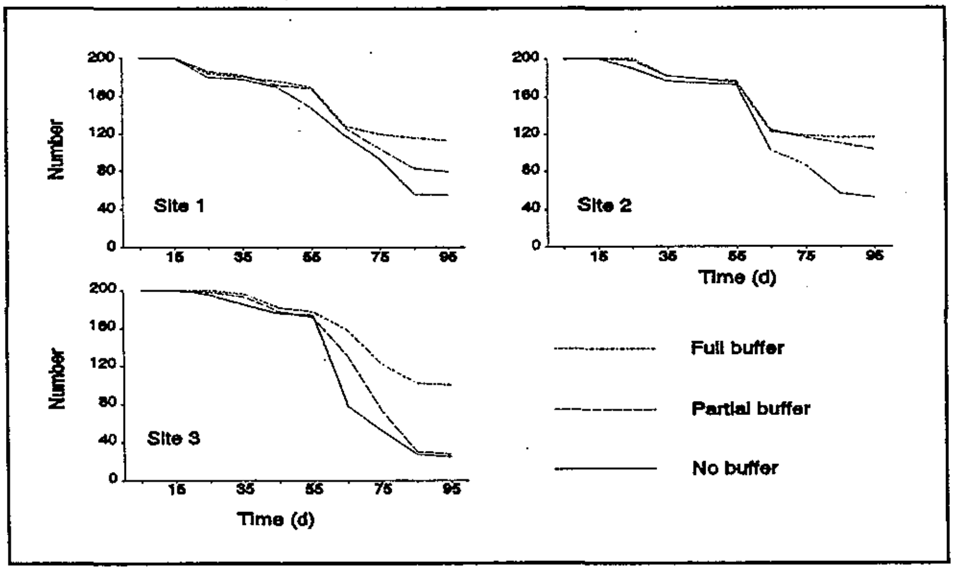


Fig. A10.4.2 Numbers of Surviving *K. candel* Seedlings at Different Times at the Estuary Experimental Site

### A10.4.5 Discussion

The results of this study show differential survival among *K. candel* seedlings at different experimental sites and under different experimental conditions. Among the three experimental sites, seedling survival rates were higher at the middle reaches site, followed by the estuary site and finally the upper reaches site. Lower survival at the estuary may be the result of wind and wave effects, which affect seedling survival to some extent. Severe water pollution and the freshwater flow of the river in the upper reaches, added to the narrowness of the river channel at this point and the effect of waves caused by passing vessels, contributed to lower seedling survival at the upper reaches site.

Comparing the different experimental conditions, it is noted that seedling survival was highest, an average of 50%, under fully buffered conditions. It should be noted, however, that seedling survival rates recorded over the course of this study were relatively low. This indicated that planting mangroves along the banks of the estuary was more difficult than planting on the mudflat areas of the bay. Also due to insufficient funds the protective measures available for field testing were, insufficient to adequately buffer the mangroves and were less comprehensive than originally planned. It is predicted that seedling survival rates would be considerably higher if "bag seedlings" were employed and if management were enhanced. Experimental results from studies at Futian show that survival rates for planted "bag seedlings" can surpass 90%. In addition, there is an issue of selection of tree species. The roots of *K. candel* are succulent, break easily, and do not readily regenerate following breakage. This increases the difficulty of achieving survival. Based on experience at Futian National Nature Reserve, it is expected that survival rates would be greatly increased by the addition of some *Aegiceras corniculatum* as a companion species in reforestation.

## A10.5 MANGROVE SURVEY AT FUTIAN

### A10.5.1 INTRODUCTION

The ecosystem of Shenzhen River, its estuary, and Deep Bay is a wetland of international importance, with the Neilingding-Futian National Nature Reserve and Mai Po being the core part. It is an integrated ecosystem, where mangrove seaweeds and phytoplankton are the primary producers, zooplankton and benthic animals the primary or secondary consumers, birds and pelagic fish are the ultimate consumers, and microbes function as decomposers.

The mangrove is of particular importance in the intertidal ecosystem between the land and the sea. It plays a leading role in stabilizing the estuary ecosystem, increasing the biodiversity, and providing a habitat of dwelling and reproduction for birds, insects, fishes, invertebrates and microbes, and there exists a complex food web with consumers in all classes.

This area and its surrounding environment provide a living and feeding habitat for birds. These birds include waterfowl, and raptors counted to nearly one hundred species, and includes a number of international endangered species. Because other coastal habitats in South China have been destroyed, the wetland habitats of Shenzhen river have become more and more important for migratory birds.

Benthic and aquatic fauna are the main food of the waterfowl, and these organisms depend on, both autochthomas and autochthonons organic inputs.

Any disruption of the link among these three subsystems will influence the whole ecosystem. This investigation is a baseline survey on birds, mangrove and benthic invertebrates. The survey considers the ecosystem as a whole, and provides additional information required to better understand the ecosystem.

### A10.5.2 Methodology

The area, forest types, forest structure and species composition of the vegetation at futian were determined in a mangrove survey. A ground survey was undertaken from February to March 1994, in which four transects perpendicular to coastline were studied (Figure A10.5.1). Methodology of transects information for the following parameters was collected.

- Species(s)
- Height(Ht)
- Diameter at breast height(dbh): Taken at 1.3m above ground level for trees with dbh>2cm. Trees which branched below breast height were treated as several stems, and the parameters of each branch were recorded. The number was recorded for small trees (dbh<2cm), shrubby plants and seedlings. The transects continued to the seaward limit of the mangal.
- Leaf area index(LAI): By sampling survey, the leaf area index of *Kandelia candel*, *Aegiceras corniculatum* and *Avicennia marina* was measured respectively.
- Map of vegetation distribution (MVD): The distributions of various mangrove communities were marked on in a map with the scale of 1:10,000 by field surveying the whole Futian Nature Reserve. The measured parameters of mangrove communities can be employed to compare the different mangrove communities and baseline date of environmental impact assessment.

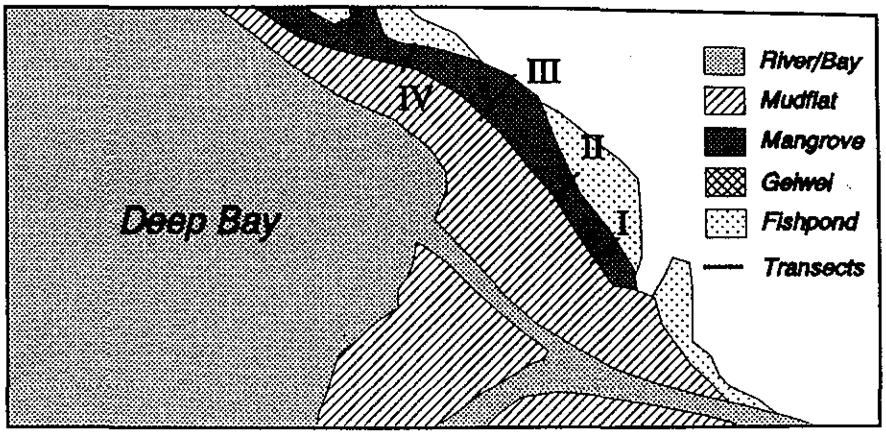


Figure A10.5.1 Mangrove survey transects

The parameters recorded are as follows:

- Types of mangrove communities
- Forest area in the Reserve
- Species distribution along the transects and in the Reserve
- Numerical species composition along the transects
- Tree density
- Mean stand diameter at breast height and basal diameter
- Importance value of each plant species in the transects
- Vegetation map for Futian Nature Reserve

## A10.5.3 Results

### A10.5.3.1 Types of mangrove communities

After thorough survey and analysis, the mangrove communities in Futian Nature Reserve can be divided into six community types:

1) *Kandelia candel* forest. Quadrats of *K. candel* forest appeared in four transects. Taking a sample of one quadrat from each transect, the statistical result are shown in Table A10.5.1.

Table A10.5.1 Results of *K. candel* forest quadrats analysis in Futian ($5x5m^2$ x 4 quadrats)

| Sp. | No | Occ | DBH($cm^2$) | Rel Ab(%) | Rel Freq(%) | Rel Dom(%) | Sign | Rank |
|---|---|---|---|---|---|---|---|---|
| K.c. | 110(47)* | 4 | 28373 | 79.7 | 36.4 | 82.6 | 198.7 | 1 |
| A.c. | 12(5) | 4 | 1968 | 8.7 | 36.4 | 5.7 | 50.8 | 2 |
| A.m. | 13 | 1 | 3702 | 9.4 | 9.0 | 10.8 | 29.2 | 3 |
| B.g. | 3 | 2 | 302 | 2.2 | 18.2 | 0.9 | 21.3 | 4 |

* Here and in the following tables, figures in brackets indicate seedling counts

* Here and in the following tables, K.c = *K. candel*, A.c. = *A. corniculatum*, A.m. = *A. marina*, B.g. = *B. gymnorrhiza*, A.i. = *A. ilicifolius*, D.t. = *D. trifoliata*;

The Table A10.5.1 shows that: in *K. candel* forest, the relative abundance and relative dominance of *K. candel* was high and its importance value shows it has absolute predominance. There were also small numbers of *A. corniculatum* and *A. marina* or *Brugiera gymnorrhiza* but

*K. candel* seedlings dominated. In addition, *Acanthus ilicifolius* formed a scrub layer. The degree of the forest cover was 90-100%. In some quadrats, there was *Derris trifoliata* (height 4.5-5.0m) accompanying.

2) *Avicennia marina* forest. *A. marina* forest grows in the outer edge of transect I (hereafter referred to as T1), transect II (hereafter referred to as T2) and the central section of transect III (hereafter referred to as T3). Taking four quadrats for analysis, the results are shown in Table A10.5.2.

Table A10.5.2 Results of *A. marina* forest quadrats analysis in Futian (5x5m$^2$, x 4 quadrats)

| Spp | No | Occ | DBH(cm$^2$) | Rel Ab(%) | Rel Freq(%) | Rel Dom(%) | Sign | Rank |
|---|---|---|---|---|---|---|---|---|
| A.m. | 49 | 4 | 32582 | 80.3 | 44.5 | 96.0 | 220.8 | 1 |
| K.c. | 7(12) | 3 | 920 | 11.5 | 33.3 | 2.9 | 47.7 | 2 |
| A.c. | 5(39) | 2 | 377 | 8.2 | 22.2 | 1.1 | 31.5 | 3 |
| A.i. | 72 | 1 | | | | | | |

The Table A10.5.2 shows that the relative dominance of *A. marina* in this community was higher than the other species but it produced no seedlings. Though there were not many trees of *K. candel* and *A. corniculatum* in the quadrats, they dominated the seedling, compliment succession of the community, the *K. candel* forest or *K. candel* + *A. corniculatum* forest may take the place of *A. marina*, The cover-degree of the community was over 80% and height of the trees was 3.5-4.5m. This community developed in the middle and seaward parts.

3) *Aegiceras corniculatum* forest. *A. corniculatum* forest could only be seen in T3 and transect IV (hereafter referred to as T4). Taking a sample of four quadrats for analysis, and the results are shown in Table A10.5.3.

Table A10.5.3 Results of *A. corniculatum* forest quadrats in Futian (5x5m$^2$, x 4 quadrats)

| Sp. | No | Occ | DBH(cm$^2$) | Rel Ab(%) | Rel Freq(%) | Rel Dom(%) | Sign | Rank |
|---|---|---|---|---|---|---|---|---|
| A.c. | 142(28) | 4 | 40447 | 88.2 | 50 | 84.2 | 222.4 | 1 |
| K.c. | 19(2) | 4 | 7585 | 11.8 | 50 | 15.8 | 776 | 2 |
| A.g. | 37 | 2 | | | | | | |
| A.i. | 36 | 1 | | | | | | |

The Table A10.5.3 shows that the forest was numerically dominated by *A. corniculatum,* and sub-dominated by *K. candel.* There are no *A. marina* and *B. gymnorrhiza* appearing in this community. The forest was regenerating well. In addition, *D. trifoliata* and *A. ilicifolius* occurred. The forest height was 2.5-4.5m.

4) *Kandelia candel* + *Aegiceras corniculatum* forest. This forest was distributed in all the transects except T1. The results of four quadrats analysis are shown in Table A10.5.4.

The Table A10.5.4 shows that in this forest, the relative dominance of *K. candel* was higher than that of *A. corniculatum,* but the relative abundance values of the two species were about the same. The forest was regenerating well. *B. gymnorrhiza* was observed occasionally. There was still a number of *A. ilicifolius* and *D. trifoliata* in this forest. Cover-degree of this community was near 100%.

Table A10.5.4 *K.candel* + *A. corniculatum* forest quadrats in Futian ($5x5m^2$, x 4 quadrats)

| Sp. | No | Occ | DBH($cm^2$) | Rel Ab(%) | Rel Freq(%) | Rel Dom(%) | Sign | Rank |
|---|---|---|---|---|---|---|---|---|
| K.c. | 53(43) | 4 | 15490 | 48.6 | 44.5 | 75.0 | 188.1 | 1 |
| A.c. | 55(76) | 4 | 4808 | 50.5 | 44.5 | 23.3 | 118.3 | 2 |
| B.g. | 1(2) | 1 | 345 | 0.9 | 11.0 | 1.7 | 13.6 | 3 |
| A.i. | 50 | 2 | | | | | | |
| D.t. | 24 | 2 | | | | | | |

5) *Aegiceras corniculatum* + *Kandelia candel* forest. The forest was distributed in all the transects except, Results of the analysis described above shown in Table A10.5.5.

Table A10.5.5 *A. corniculatum* + *K candel* forest quadrats in Futian ($5x5m^2$, x 4 quadrats)

| Sp. | No | Occ | DBH($cm^2$) | Rel Ab(%) | Rel Freq(%) | Rel Dom(%) | Sign | Rank |
|---|---|---|---|---|---|---|---|---|
| A.c. | 138(52) | 4 | 20147 | 22.6 | 36.4 | 52.1 | 161.1 | 1 |
| K.c. | 46(15) | 4 | 17079 | 24.2 | 36.4 | 44.1 | 104.7 | 2 |
| A.m. | 4 | 2 | 1122 | 2.1 | 18.2 | 2.9 | 23.2 | 3 |
| B.g. | 2(1) | 1 | 339 | 1.1 | 9.0 | 0.9 | 11.0 | 4 |
| A.i. | 253 | 1 | | | | | | |

The Table A10.5.5 shows that in this forest, the importance value of *A. corniculatum* was more than 50% and its relative dominance was similar to that of *K. candel*. The forest was noted for a higher relative abundance of *A. corniculatum* and good regeneration. There were a large number of *A. ilicifolius* and several *A. marina* and *B.gymnorrhiza* in this community.

6) Small *Acanthus ilicifolius* community. *A. ilicifolius* grew vigorously in the mud beach of the creek or near the seashore. It was flowering during this survey. This small community was surrounded by *Panicum repens* and *Cynodon dectylon* etc., with a height of 90cm and density of 10 plants/$m^2$.

### A10.5.3.2 Forest area in Futian National Nature Reserve

Based on the four transects data, community distribution information and the vegetation map filled by field survey, it is estimated that the area of mangrove in Futian Nature Reserve is 42.5 ha. Moreover, there are 18.8 ha of *gei wai* bunds with partial distribution of mangrove and 5.4 ha of *K. candel* newly planted in middle beach. Thus, the total mangrove forest area is 66.7 ha, which constitutes 30% of the total present area of 304 ha (Huang, 1985) in Futian Nature Reserve.

### A10.5.3.3 Species distribution along transects in Futian National Nature Reserve

The mangrove species occurring in Futian Nature Reserve are *K. candel* (L.) Druce, *B. gymneorhiza* (L.) Savigny, *A. corniculatum* (L.) Blanocoe, *A. marina* (Forsk.) Vierh, *A. ilicifolius* Linn. and *Excoecaria agallocha* Linn. Of these, *E. agallocha* was not found in the transects. Mangrove associates are *Acrostichum aureum* L., *Thespesia populnea* (L.) Engl., and *Pluchea indica* (L.) Less. Of these, *A. aureum* was only seen at the landward side, *T. populne* and *P. indica* were recorded formerly (Huang, 1985) but were not recorded in this survey. *Derris trifoliata* (accompanying species) was a common sight in the forest.

In T1, T2 and T3, 5 mangrove and accompanying species were found in this survey, Of the accompanying species, *D. trifoliata* was not found in T4. *K. candel* was the dominant species in the quadrats at the high shore with *A. corniculatum*, A. ilicifolius, *D. trifoliata*, and a few *B. gymnorrhiza* also occurring. In the quadrats of mid-tide zone, 5 mangrove species were found frequently. In the lower tide zone, only *A. marina*, *K. candel* and *A. corniculatum* were found, and most of the *K. candel* was replanted individuals (Table 10.5.6). *A. ilicifolius* mainly grew in mud bank of creeks or near the seashore.

Table A10.5.6 Integrated information of the mangrove survey in Futian National Nature Reserve

| Tra. | Dis. | Species composition(%) | | | | | Forest Structure | |
|---|---|---|---|---|---|---|---|---|
| | | Density (n/100m²) | K.c. | A.c. | A.m. | B.g. | Basal Coverage (cm²/5x5m²) | Mean DBH(cm) |
| T1 | 5 | 9600 | 96 | 0 | 0 | 4 | 593 | 5.6 |
| | 25 | 6400 | 100 | 0 | 0 | 0 | 333 | 5.1 |
| | 45 | 17200 | 81 | 14 | 0 | 5 | 883 | 5.1 |
| | 65 | 8800 | 59 | 14 | 23 | 4 | 1071 | 7.9 |
| | 85 | 4400 | 0 | 0 | 100 | 0 | 879 | 10.1 |
| | 105 | 3200 | 0 | 0 | 100 | 0 | 1289 | 14.3 |
| T2 | 5 | 10400 | 42 | 54 | 0 | 4 | 740 | 6.0 |
| | 25 | 12000 | 50 | 20 | 23 | 7 | 1087 | 6.8 |
| | 45 | 7600 | 53 | 26 | 16 | 5 | 713 | 6.9 |
| | 65 | 15200 | 18 | 74 | 8 | 0 | 1115 | 6.1 |
| | 85 | 6800 | 0 | 29 | 71 | 0 | 715 | 7.3 |
| T3 | 5 | 13600 | 56 | 44 | 0 | 0 | 516 | 4.4 |
| | 25 | 9200 | 0 | 100 | 0 | 0 | 280 | 3.9 |
| | 45 | 19600 | 20 | 74 | 2 | 4 | 682 | 4.2 |
| | 65 | 21600 | 46 | 54 | 0 | 0 | 972 | 4.8 |
| | 85 | 7600 | 26 | 42 | 32 | 0 | 615 | 6.4 |
| | 105 | 23600 | 19 | 81 | 0 | 0 | 697 | 3.9 |
| | 125 | 9200 | 39 | 61 | 0 | 0 | 244 | 3.7 |
| | 145 | 10000 | 28 | 0 | 72 | 0 | 555 | 5.3 |
| | 165 | 13600 | 71 | 0 | 29 | 0 | 901 | 5.8 |
| | 185 | 3600 | 100 | 0 | 0 | 0 | 298 | 6.5 |
| | 205 | 1600 | 100 | 0 | 0 | 0 | 158 | 6.8 |
| | 225 | 2000 | 100 | 0 | 0 | 0 | 261 | 8.0 |
| | 245 | 2000 | 80 | 0 | 20 | 0 | 323 | 9.0 |
| | 265 | 800 | 100 | 0 | 0 | 0 | 99 | 7.8 |
| T4 | 5 | 10400 | 54 | 46 | 0 | 0 | 591 | 5.4 |
| | 25 | 12400 | 13 | 87 | 0 | 0 | 2838 | 10.8 |
| | 45 | 16800 | 98 | 2 | 0 | 0 | 981 | 5.5 |
| | 65 | 18800 | 34 | 66 | 0 | 0 | 964 | 5.1 |
| | 85 | 19200 | 8 | 92 | 0 | 0 | 1052 | 5.3 |
| | 105 | 27600 | 6 | 94 | 0 | 0 | 1064 | 4.4 |
| | 125 | 22400 | 23 | 77 | 0 | 0 | 1168 | 5.2 |
| | 145 | 11200 | 3 | 86 | 11 | 0 | 871 | 6.3 |

### A10.5.3.4 Species distribution along the transects

The species distribution along the transects are shown in Figure A10.5.2. All the 4 transects exhibit a clear zonation pattern. From west to east along the beach, *A. corniculatum* increased from 14% to 100% in the second quadrat of T3. In T4, the mean proportion of *A. corniculatum* amounted to 69%. In T1, T2 and T4, the proportion of species increased or deceased gradually among different quadrats, and there was a transition between the zones, i.e. in the fourth quadrat of T1, the proportion of *K. candel* was 59%, and the *A. marina* was 23%, but in T3, the situation was more complicated: 3 dominant species constituted 8 clear zones which were the *K. candel* + *A. corniculatum* forest, *A. corniculatum* forest, *A. corniculatum* + *K. candel* forest, *A. marina* forest, *A. corniculatum* + *K. candel* forest, *K. candel* + *A. corniculatum*, forest, *A. marina* forest, *K. candel* forest in the clear order of the list.

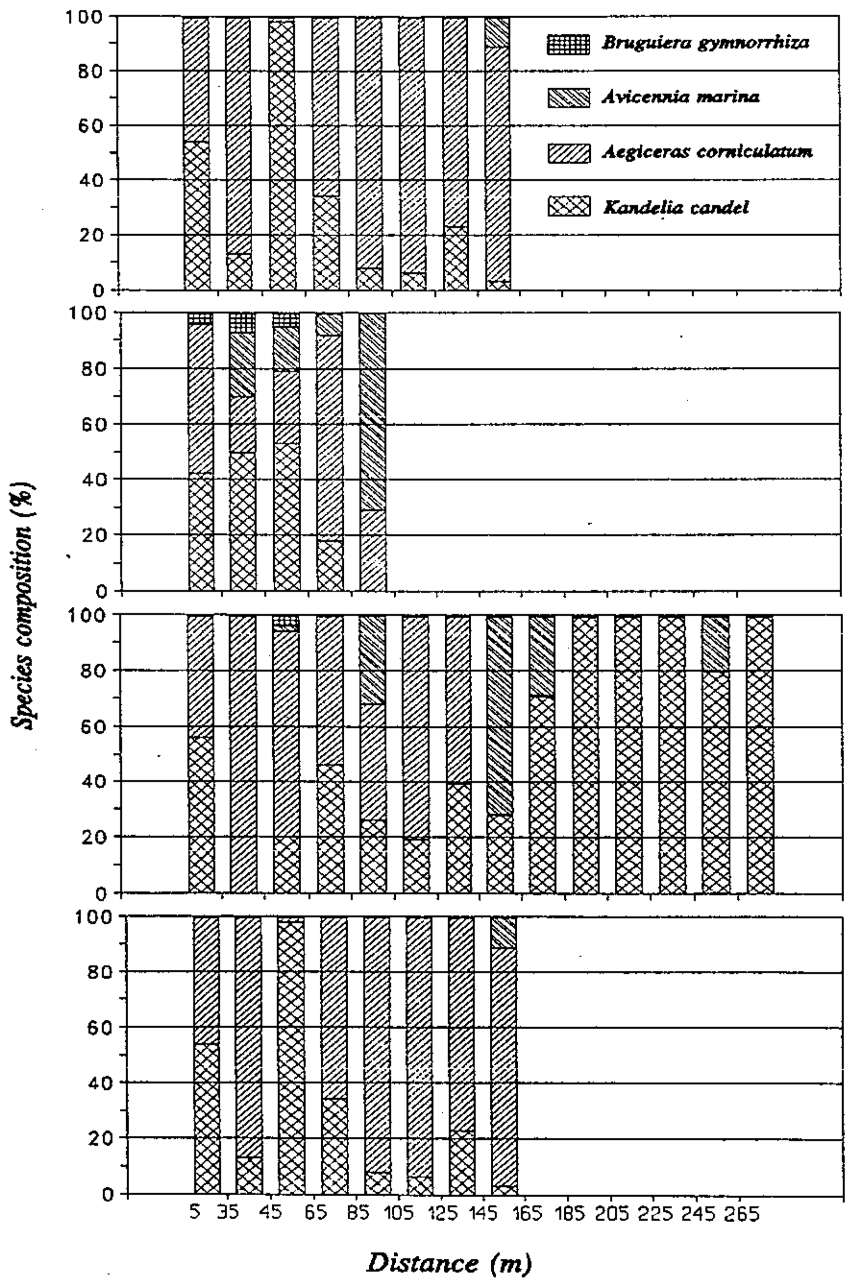


Figure A10.5.2 Mangrove species distribution at Transects 1-4

### A10.5.3.5 Tree density

Tree density(trees/ha) varied in different communities. It is lowest in *A. marina* forest (only 32-100 in./100m²) , such as in the fifth and sixth quadrats of T1. It is 64-200 in *K. candel* forest in all transects, and nearly 300 in *A. corniculatum* forest such as the sixth quadrat of T4. The dbh of *A. ilicifolius* was less than 2cm, while its density could reach 200 (shown in Table A10.5.6).

### A10.5.3.6 Mean stand dbh and basal diameter

As indicated in Figure A10.5.3, the mdbh of stand in T3 was the lowest at 5.75cm. The mdb h in all transects increased gradually from high tide zones to low tide zones such as T1, and varied from 5.6cm to 14.3cm. It varied less in T2.

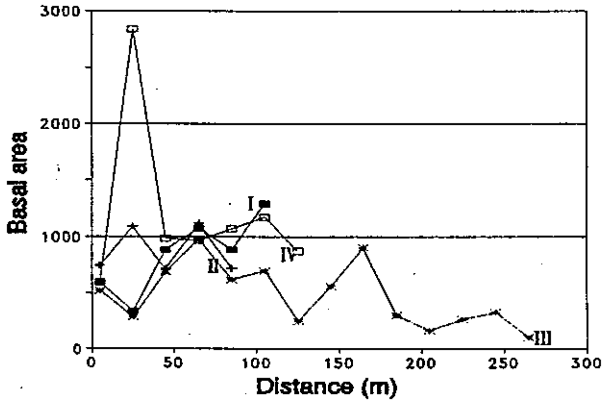


Figure A10.5.3 Basal diameter at transects I-IV

As indicated in Figure A10.5.4, the basal diameter in different quadrats varied greatly, and depended on the dominant species of quadrat (or forest). It was 1289cm²/quadrat in *A. marina* forest, which was larger than the others, and that of the *A. corniculatum* pure forest was 280cm²/quadrat, which was the smallest. The Basal diameters of *A. corniculatum* forests and *K. candel* forests were usually small, except in the second quadrat of T4.

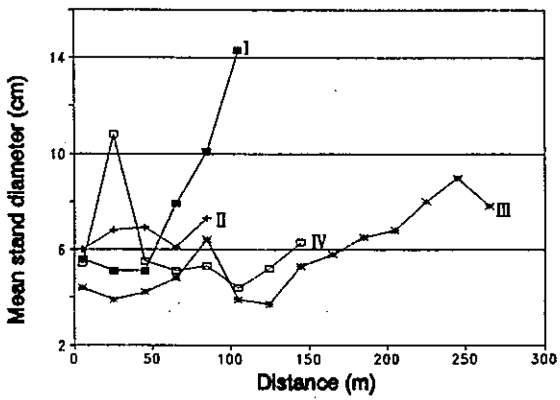


Figure A10.5.4 MDBH of stand at transects I-IV

### A10.5.3.7 Importance value

As indicated in Table A10.5.7, and Figure A10.5.5 which refers to T4, the importance value(I.V.) of *A. corniculatum* was the biggest(176.1), and *K. candel* was the second. In the other three transects, the importance values of *K. candel* were the biggest (T1:159.6; T2:132.55; T3:163.3). In T1, the I.V. of *A. marina* was the second (94.3). In T3, the I.V. order of the species was the same as in T2, the first was *K. candel.*, the second was *A. corniculatum*, the third *A. marina*, and the fourth *B. gymnorrhiza*.

Table A10.5.7 Results of the transects carried out at the Futian Mangrove Nature Reserve

| Tr.* | Sp.** | No. (N/t) | Occ. | dbh (cm²) | Rel.Ab. (%) | Rel.Freq. (%) | Rel.Dom.(%) | Sign. | Rank |
|---|---|---|---|---|---|---|---|---|---|
| T1 | K.c. | 114(27)% | 4(3) | 23261 | 73.0 | 39.9 | 46.7 | 159.6 | 1 |
| | A.m. | 24(0) | 3(0) | 24847 | 15.4 | 30.0 | 49.9 | 94.3 | 2 |
| | A.c. | 9(0) | 2(0) | 1212 | 5.8 | 19.9 | 2.4 | 28.1 | 3 |
| | B.g. | 9(5) | 1(1) | 495 | 5.8 | 10.2 | 1.0 | 16.0 | 4 |
| | A.i. | 116 | 4 | | | | | | |
| | D.t. | 32 | 2 | | | | | | |
| T2 | K.c. | 105(62) | 5(5) | 22507 | 49.1 | 31.25 | 52.5 | 132.55 | 1 |
| | A.c. | 78(20) | 5(3) | 8642 | 36.4 | 31.25 | 20.0 | 87.65 | 2 |
| | A.m. | 25(0) | 4(0) | 10946 | 11.7 | 25.0 | 25.4 | 62.1 | 3 |
| | B.g. | 6(2) | 2(1) | 1036 | 2.8 | 12.5 | 2.4 | 17.7 | 4 |
| | A.i. | 7 | 4 | | | | | | |
| | D.t. | 15 | 2 | | | | | | |
| T3 | K.c. | 580(446) | 14(11) | 33070 | 60.1 | 50.0 | 53.2 | 163.3 | 1 |
| | A.c. | 349(176) | 9(9) | 16613 | 36.1 | 32.0 | 26.7 | 94.8 | 2 |
| | A.m. | 35(0) | 4(0) | 12197 | 3.6 | 14.5 | 19.6 | 37.7 | 3 |
| | B.g. | 2(0) | 1(0) | 339 | 0.2 | 3.5 | 0.3 | 4.2 | 4 |
| | A.i. | 611 | 6 | | | | | | |
| | D.t. | 70 | 7 | | | | | | |
| T4 | A.c. | 297(50) | 8(5) | 60919 | 67.5 | 44.4 | 64.2 | 176.1 | 1 |
| | K.c. | 139(42) | 8(2) | 30199 | 31.6 | 44.4 | 31.8 | 107.8 | 2 |
| | A.m. | 3(0) | 1(0) | 3818 | 0.7 | 5.6 | 4.0 | 10.3 | 3 |
| | B.g. | 1(1) | 1(1) | 0 | 0.2 | 5.6 | 0 | 5.8 | 4 |
| | A.i. | 341 | 4 | | | | | | |

* T1 is at the bird watching station at Chegong Temple, T2 is near the First Watch Tower, T3 is near the Second Watch Tower, T4 is located in 300m west of Shazui River mouth.

** K.c.: *Kandelia candel*; A.m.: *Avicennia marina*; A.c.: *Aegiceras coniculatum*; B.g.: *Bruguiera gumnorrhiza*; A.i.: *Agiceras ilicifolius*; D.t.: *Derris trifoliata*.

% The number indicate seedling counts.

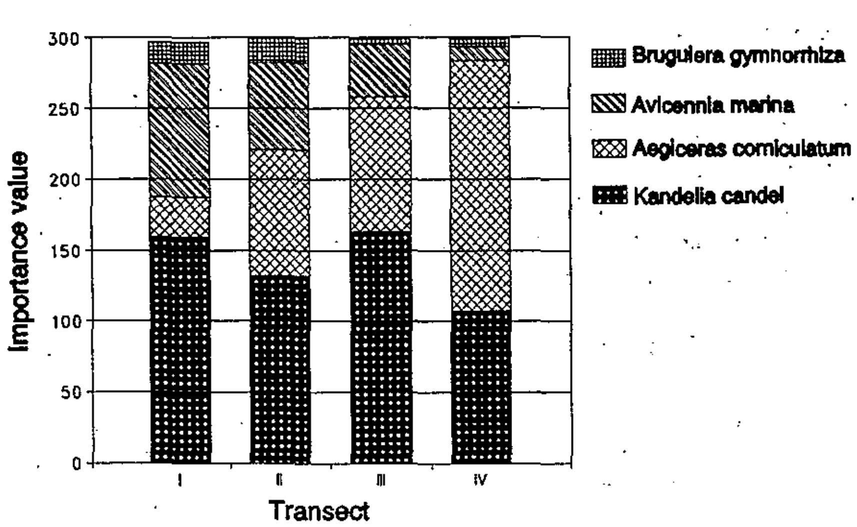


Figure A10.5.5 Importance values at transects I - IV

### A10.5.3.8 Leaf area index(LAI)

In the Futian National Nature Reserve, the LAI of *K. candel* forest was 2.0, *A. marina* forest was 2.1, and *A. corniculatum* forest was 6.9. The former two LAI were comparable with other nearby site, but the latter was somewhat higher.

### A10.5.3.9 Map of the vegetation distribution(MVD)

Figure A10.5.6 shows that the *K. candel* forest and the *A. marina* forest were the main communities in Futian Nature Reserve. and also was the *A. corniculatum* + *K. candel* forest. In addition, there were Some *K. candel* trees and *K. candel* + *A. corniculatum* along the river bank and the seacoast, and a few *A. ilicifolius* along the river bank, seacoast and the *gei wai* bunds.

## A10.5.4 DISCUSSION

Investigation and analysis of transects show that the T3 which is the longest transect (295m) must have been intensively protected. In this transect, there was many communities and species, and a clear zonation pattern of wide zones. T1 and T2 exhibit a clear zonation pattern, in which the density of trees was lower, and the mdbh higher. this shows that the woodland had been protected for a long time. T4 was characterized by early succession state of community and habitat: the distribution of species had clear transitions with higher tree density, low mdbh and fewer species. It shows that the mangrove forests which are distributed from Shenzhen River to Shazui River mouth has been formed recently.

Investigation shows that, there were no *A. marina* seedlings in the *A. marina* forests. This indicates the *A. marina* forests will become *K. candel* forests or *K. candel* + *A. corniculatum* forests in the future. The *A. marina* forest dominated ten years ago (Huang *et al.* 1985), but in this survey, we found that the distribution area of *A. marina* forest was not large, and the age of stand was older. It indicates that *A. marina* is a pioneer tree.

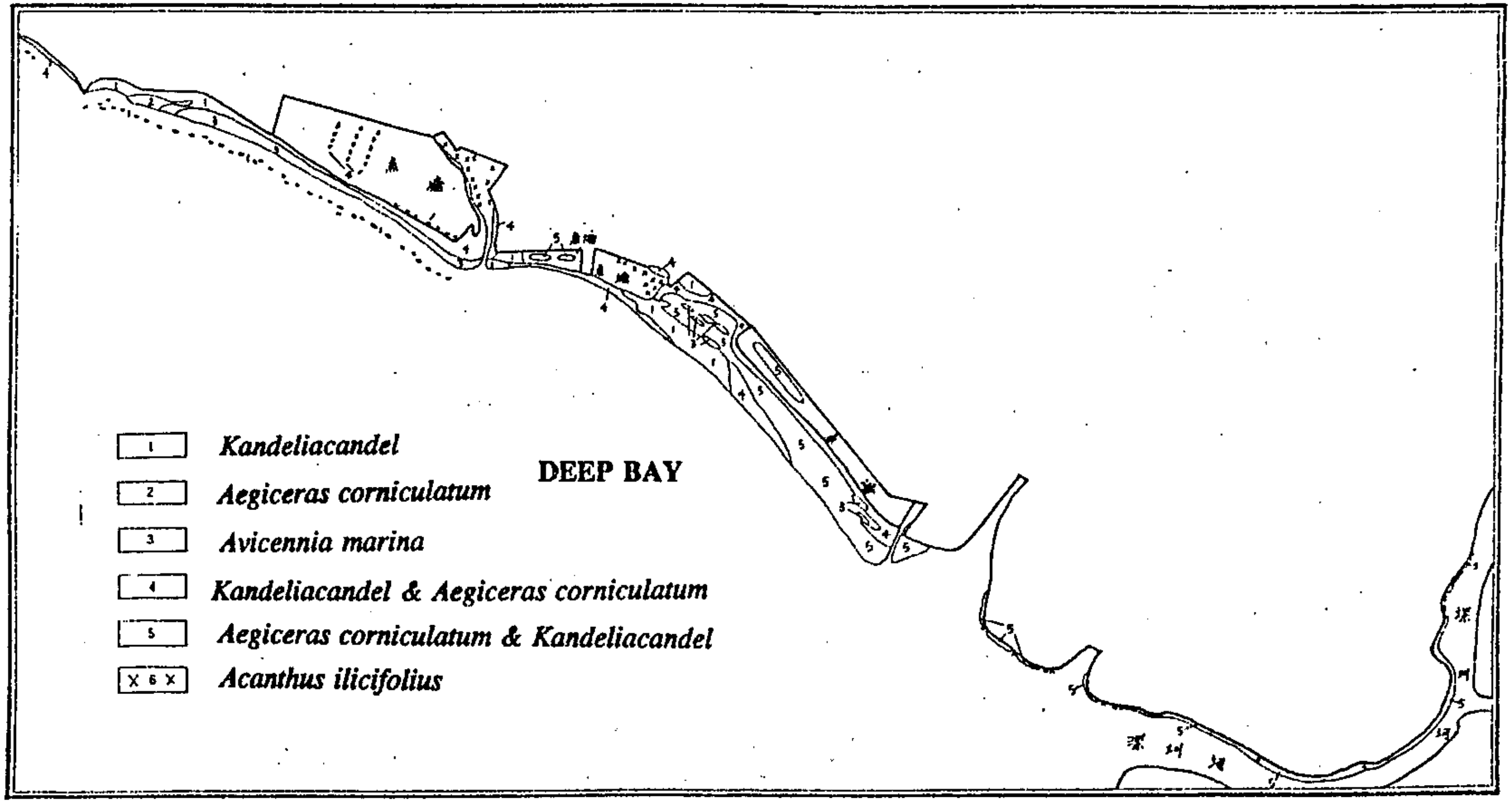


Figure A10.5.6 Mangrove in Futian Nature Reserve

Research on the mangrove habitat (Lin, 1984) shows that the *A. corniculatum* grows on the beach where the topsoil is spongy and deep, and *A. marina* can grow in the sandy soil (beach). Investigation and research of transects indicate that the mangrove forest in Futian Mangrove Nature Reserve has a similar habitat condition as the mangrove forests in other sites in China.

The existing data(Chen *et al.* 1993) shows that the major factor affecting survival and growth of mangroves in Futian National Nature Reserve is the time that the trees are mandated by seawater; the second factor is the depth of mud; the third factor is barnacle damage. The impact of the tide mainly influences the newly planted mangrove seedlings.

Mangrove ecosystem is a buffer system where sediment deposits slowly, and organic matter is decomposed slowly. Mangrove distributed in polluted estuary areas have some anti-pollution capability. This system can change pollutants into insoluble matter by soil depositing and ion-exchange, and solvable nutrition and pollutants in Deep Bay can be reduced by plants and algae absorption. Meanwhile, the microbes in mangrove can purify the sea water by decomposing the organic matters in sewage.

Because the living things in Mangrove area grow rapidly, they are often short of nutrition support in the soil. Analysis of soil sample shows that the TP content was only 0.45mg/kg, and TN was only 0.069 g/kg. The organic pollutants brought by sewage will not produce significant impacts on mangrove, and sometimes can remedy the lack of NP. Since September 1991, Futian National Nature Reserve has conducted an experiment on treating sewage by mangrove; the result are not yet final, but it is often recognized that the domestic sewage has very little influence on mangroves.

As the above preliminary analysis, it can be predicted that the domestic sewage will not seriously influence the mangrove ecosystem, but a prudent policy must be adopted to cope with industrial sewage, and different measures should be use for the treatment of different pollutants.

The mangrove which will be destroyed by the Project should be replanted by taking necessary measures.

## A10.6 SOUTHERN RIVER BANK MANGROVE SURVEY: MAI PO TO LO WU

### A10.6.1 Introduction

The proposed Shenzhen River Training Project will change the profile and course of the Shenzhen river in its lower reaches. The lower reaches of the Shenzhen River are under considerable tidal influence, resulting in an upstream intrusion of mangrove vegetation along the river banks. The aims of this survey were:

- to determine the exact distribution of mangroves on the southern bank of the Shenzhen River from its lower reaches near inner Deep Bay to Lo Wu;
- to determine the species and habitat area lost during the project;
- to provide baseline data which will guide possible replanting/river bank rehabilitation programmes following construction.

### A10.6.2 Methods

The Shenzhen River bank was surveyed, by bicycle and on foot, between the Lo Wu Bridge and the lower reaches of the river where it enters Inner Deep Bay. A rapid survey technique was employed to gain basic data on the distribution and condition of the mangroves in this habitat. For this purpose, 'mangrove vegetation' is defined as containing one or more of the species found commonly or rarely in other mangrove habitats (termed 'mangals') in the region of Southern China (Morton and Morton 1983). Other species, which may include those often found in areas surrounding the mangal or other coastal habitats, are noted but not included in the survey.

The protocol of data collection depended on the structure of each tree found:

#### A10.6.2.1 Individual trees

For mangrove trees of the species *Kandelia candel* and *Bruguiera gymnorrhiza* for which it was possible to identify single trunks, and for the shrubby species *Aegiceras corniculatum* and *Avicennnia marina* for which it was possible to identify single root bases, the location of the tree was noted and checked, where necessary, with compass transits from local landmarks. For the mangrove *Acanthus ilicifolius*, the reed *Phragmites communis*, and the mangrove fern *Acrostichum aureum*, individuals were innumerable or indiscernable. Discrete monospecific stands of these species which covered areas $<2m^2$ were treated as individuals. The height of the tree, or, where several individuals co-occurred, the maximum height of the group of trees, was visually estimated to the nearest metre. The nature of the the river bank at the location of each mangrove was noted into three categories; 'concreted', where concrete slabs, bricks or boulders formed much of the river bank, 'natural', where the river bank was predominantly a soil substrate, and 'mixed', where some concrete was in evidence but did not dominate the bank substrate. Any additional features of the trees or location were also recorded.

#### A10.6.2.2 Stands

Where multiple species stands occurred and it was not possible to discern individuals, the approximate species composition was recorded as a visual estimate of the % of total stand area made up by each species. The location of the stand was noted by the nearest border fence section number, and the maximum height of the stand, maximum width (in the direction river bank to river bed) and length of the stand (along the river course) were estimated. River bank structure was recorded as above.

All drainage channels, streams and sluice gate areas receiving water from the Shenzhen River were similarly surveyed for mangrove species within a 'riparian belt' of 300m from the river banks. (In some cases, for example, the creek flowing out to the river through Tam Kon Chau, mangroves occur further away from the river than this; however, as these are unlikely to be directly affected by engineering works associated with the proposed River Regulation Project, these were not included in the survey). Results were recorded on Maps 2-SE-A and 2-NE-D, scale 1:5000 (Series HP5C, partially revised 1/94, Survey and Mapping Office, Lands Department, Hong Kong Government), with annotations noted separately.

### A10.6.3 Results

Results of the vegetation survey are shown in Figure A10.6.1 (A, B, C from Map 2-SE-A and D, E, F from Map 2-NE-D), with a key (Table A10.6.1) and annotations (Table A10.6.2).

As shown in the figure the southern river bank of the Shenzhen river between Tam Kon Chau and the Lok Ma Chau border crossing is predominantly mangrove-lined. The stands in this part of the river are well established, with trees often reaching over 2m in height. The dominant species are *Aegiceras corniculatum* and *Kandelia candel*, which are both common species in the Deep Bay mangals. Whilst most of the stands appear healthy, there are some suggestions of disturbance, for example by burning (Map C). Further upstream, between Lok Ma Chau and Lo Wu (Maps D, E and F), the mangrove contribution to riparian vegetation assemblages declines markedly, with sparse occurrences of smaller, less vigorous plants, the only significant stand being the large stand of *Aegiceras corniculatum* adjacent to Hoo Hok Wai (HHW; Map E). The upstream limit of true mangrove species was found to be Ta Sha Lok (TSL; Map F), where two individuals of *Aegiceras corniculatum* are located in a small creek between fish ponds. The reed *Phragmites communis* is the dominant species of the marshy areas in between fish ponds in the Hoo Hok Wai and Ta Sha Lok areas, as indicated on Maps E and F.

Table A10.6.1 Key to symbols appearing on Figure A10.6.1

| Symbol | Represents |
|---|---|
| I | *Kandelia candel* |
| △ | *Aegiceras corniculatum* |
| □ | *Acanthus ilicifolius* |
| P | *Phragmites communis* |
| G | Grasses (unknown sp.) |
| ⊗ | *Avicennia marina* |
| A | *Acrostichum aureum* |
| ✡ | *Bruguiera gymnorrhiza* |
| ⬭ | Delimits stand |
| ▨ | Concreted river bank |
| ▬ | Burned area |
| HHW | Hoo Hok Wai |
| TSL | Ta Sha Lok |

In creeks and drainage channels adjacent to the Shenzhen River, mangroves generally occur in sparse stands, with a mixture of other species, including various grasses (Graminae, unidentified species), and the shrubs *Lantana camara* and *Clerodendron inerme*. These species are also found at the top of the river bank in the stands near the Lok Ma Chau Border Crossing (stand numbers 53, 59 and 60).

Of particular note in the mangrove stands along the southern river bank is the occurrence of an individual of *Bruguiera gymnorrhiza* (Map A), a rare species in Hong Kong, and the noticeably few individuals of *Avicennia marina*. This species dominates the mangal at Mai Po (making up over 50% of the mangal area; Anderson, unpublished data). Also of note are the extensive populations of the climber *Derris trifoliata* over many of the mangrove trees along the river.

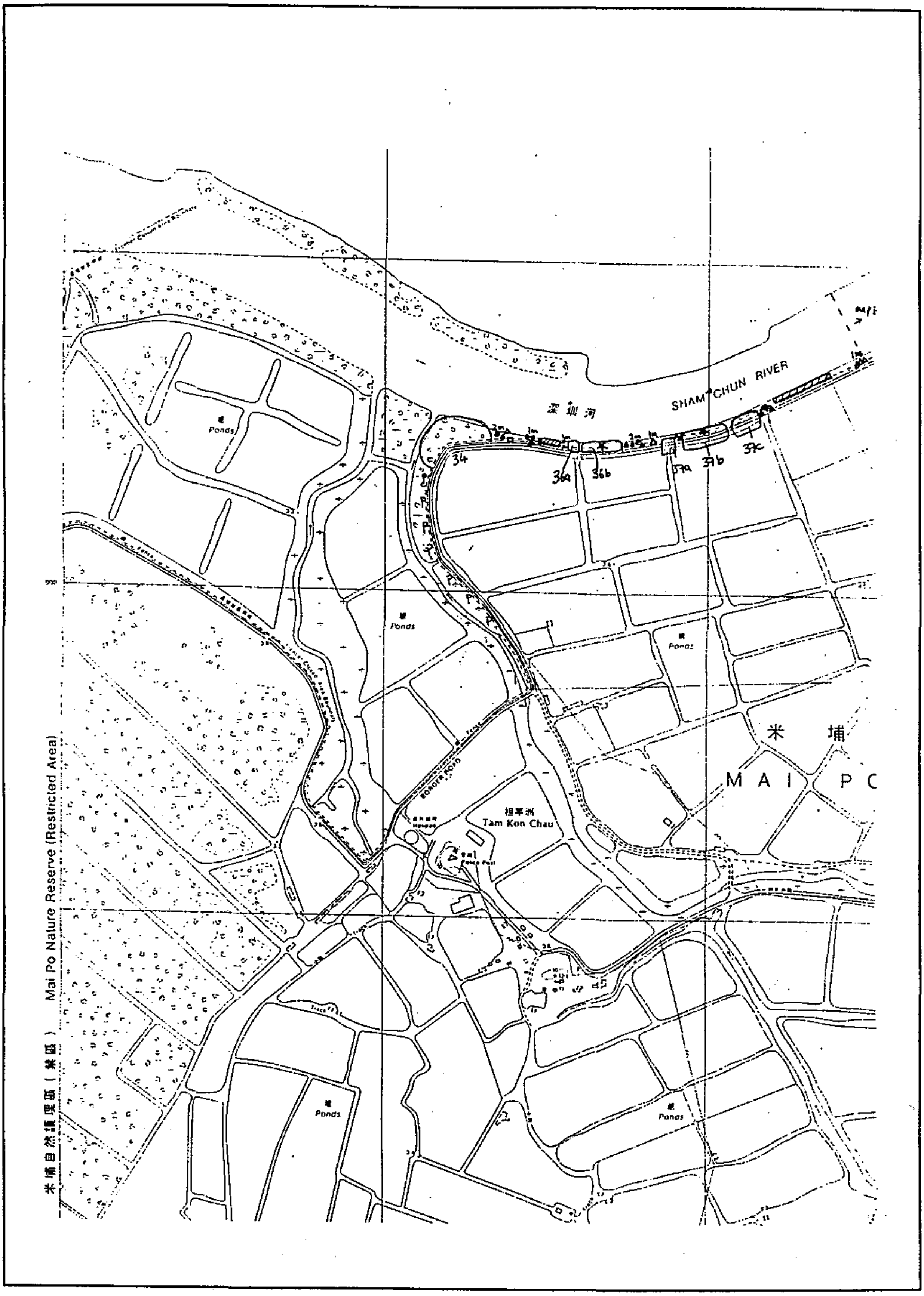


Figure A10.6.1(A) Shenzhen River Mangrove Survey (Map A)

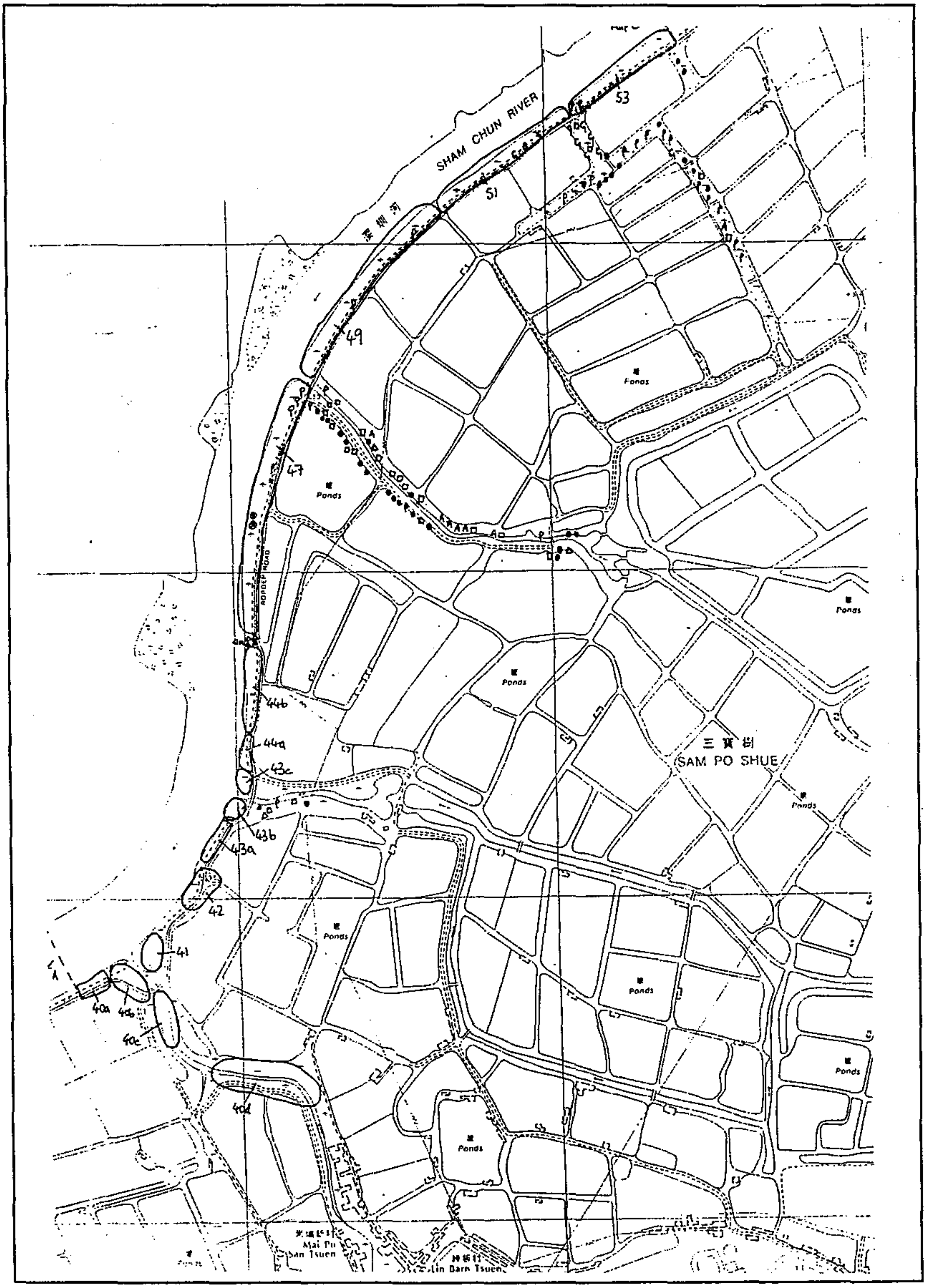


Figure A10.6.1(B) Shenzhen River Mangrove Survey (Map B)

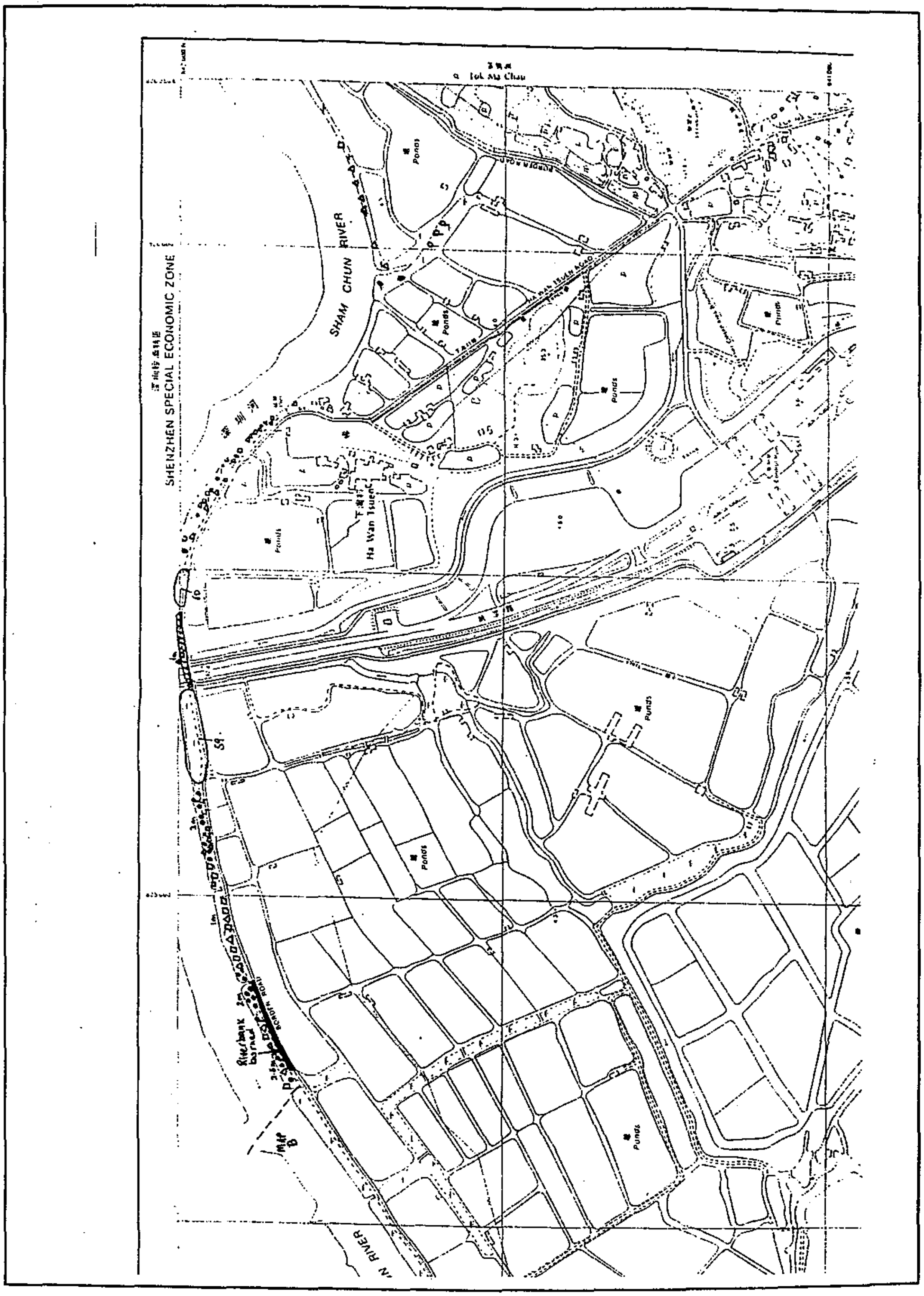


Figure A10.6.1(C) Shenzhen River Mangrove Survey (Map C)

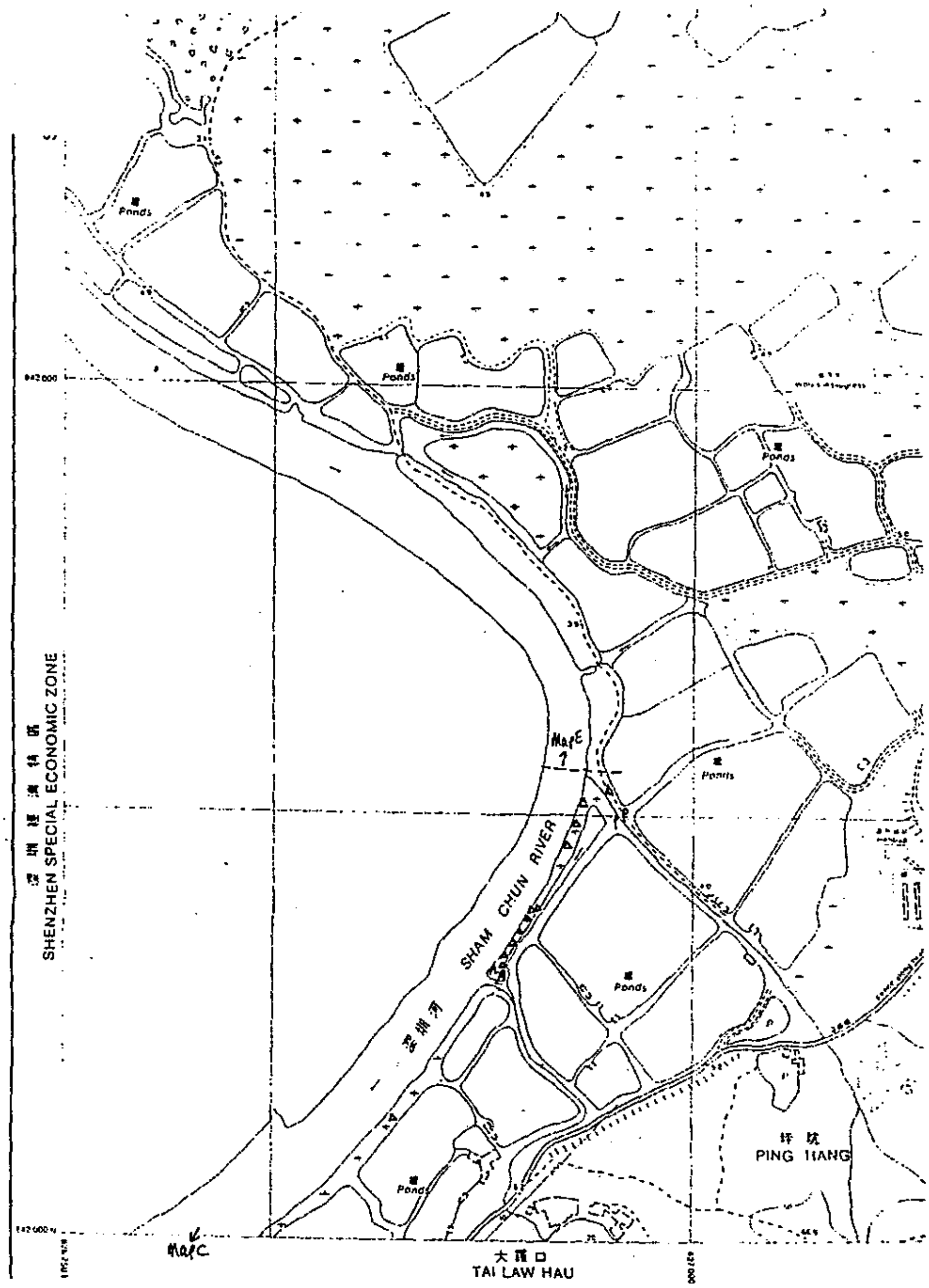


Figure A10.6.1(D) Shenzhen River Mangrove Survey (Map D)

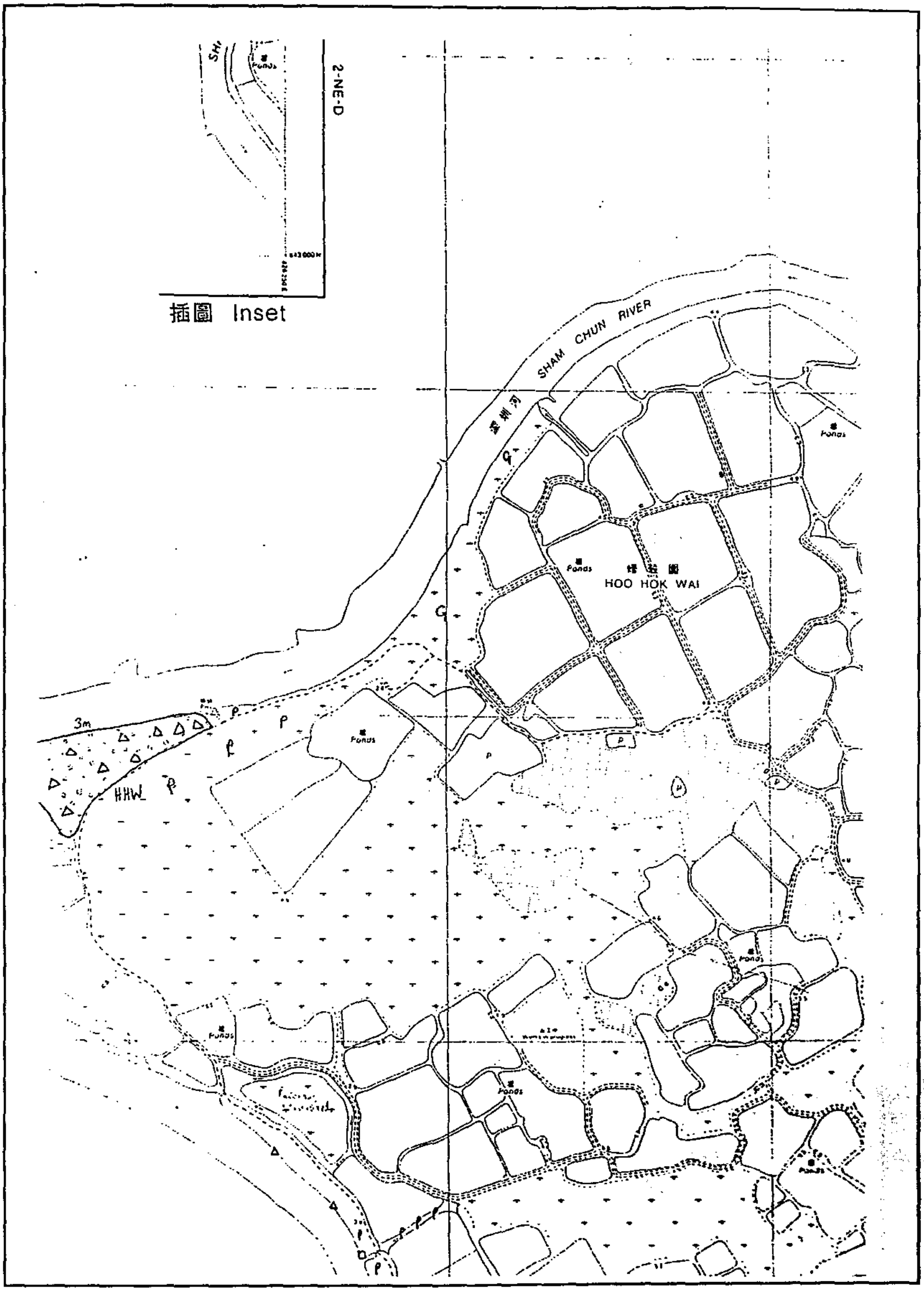


Figure A10.6.1(E) Shenzhen River Mangrove Survey (Map E)

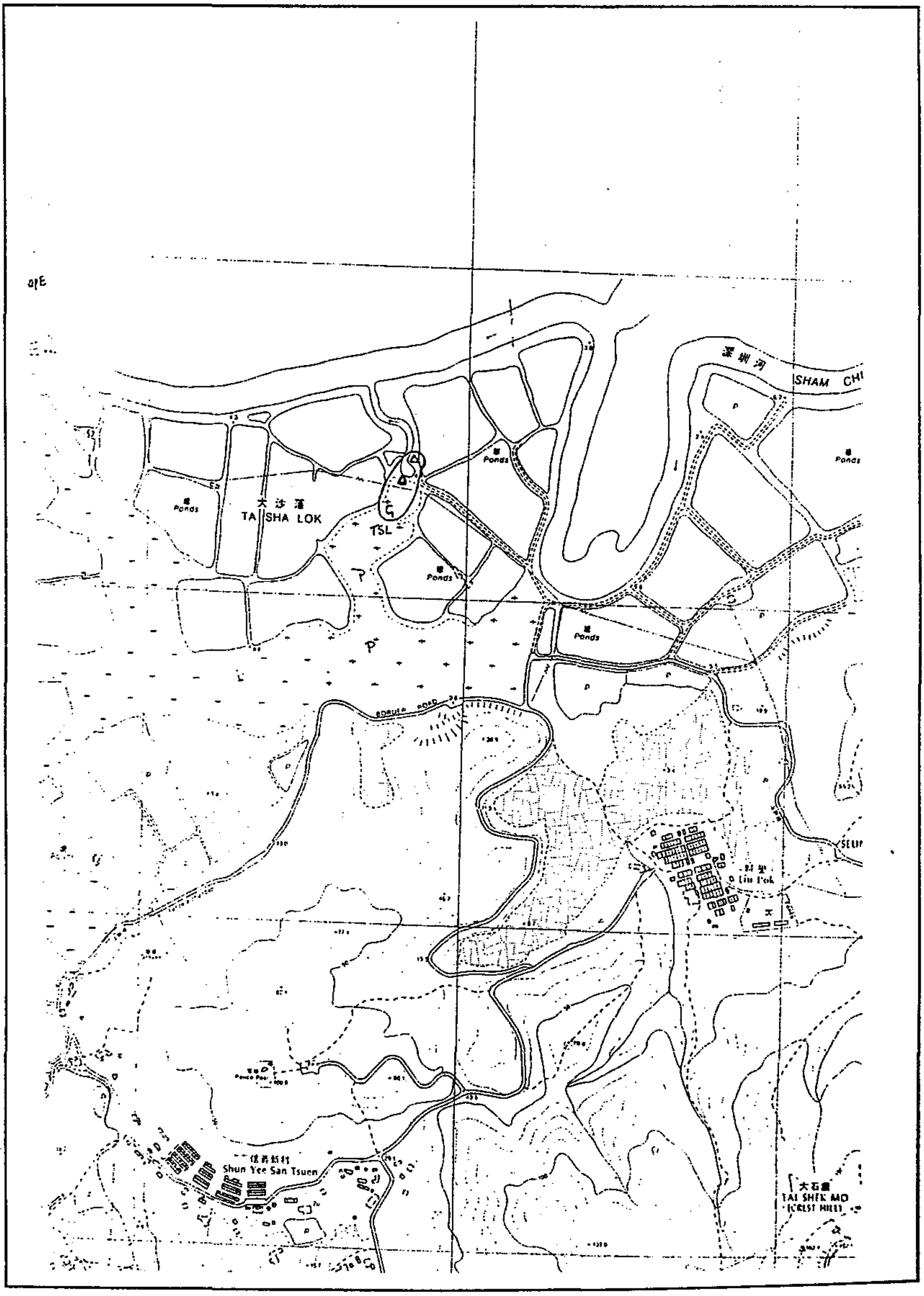


Figure A10.6.1(F) Shenzhen River Mangrove Survey (Map F)

River bank structure, as noted here, is determined by the proximity of the Border Road, such that from Tam Kon Chau to Lok Ma Chau, much of the river bank slope contains concrete, bricks or boulders, with a fringe or ledge of natural substrate which is colonised by mangrove species. At two locations, the bank is composed entirely of artificial substrate and forms a vertical 'wall' which excludes mangrove species (Map A). Where the Border Road departs the river bank, at the Lok Ma Chau Border Crossing, the banks become more natural and are generally more steep-sided and grassy.

Table A10.6.2 Map annotations from mangrove survey from Tam Kon Chau to Lo Wu

| Stand Number | Stand Dimensions (m) | | | Species (% composition by area) | | | | | | | Bank |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Height | Width | Length | Kc | Ac | Ai | Av | Bg | P | Acr | |
| 34 | 3 | 25 | 22 | 90 | 3 | 2 | 0 | 0 | 6 | 0 | C |
| 36a | 2 | 5 | 18 | 50 | 50 | 0 | 0 | 0 | 0 | 0 | C |
| 36b | 3 | 5 | 65 | 40 | 50 | 10 | * | * | 0 | 0 | C |
| 37a | 3 | 5 | 20 | 30 | 70 | 0 | 0 | 0 | 0 | 0 | C |
| 37b | 2 | 3 | 70 | 0 | 100 | 0 | 0 | 0 | 0 | 0 | C |
| 37c | 3 | 8 | 45 | 60 | 40 | 0 | 0 | 0 | 0 | 0 | C |
| 40a | 3 | 8 | 50 | 70 | 20 | 10 | 0 | 0 | 0 | 0 | C |
| 40b | 3 | 5 | 60 | 40 | 60 | 0 | 0 | 0 | * | 0 | N |
| 40c | 4 | 10 | 70 | 20 | 40 | 40 | 0 | 0 | 0 | 0 | N |
| 40d | 2 | 5 | 150 | 10 | 10 | 60 | 0 | 0 | 20 | * | N |
| 41 | 4 | 15 | 35 | 50 | 40 | 10 | 0 | 0 | 0 | 0 | N |
| 42 | 4 | 5 | 45 | 60 | 30 | 10 | 0 | 0 | 0 | 0 | C |
| 43a | <1 | 2 | 73 | 30 | 40 | 30 | 0 | 0 | 0 | * | C |
| 43b | 5 | 10 | 27 | 60 | 30 | 10 | 0 | 0 | 0 | 0 | C |
| 43c | 4 | 10 | 30 | 30 | 40 | 0 | 0 | 0 | 30 | 0 | N |
| 44a | 2 | 8 | 50 | 0 | 0 | 0 | 0 | 0 | 100 | * | C |
| 44b | 6 | 5 | 133 | 70 | 20 | 10 | 0 | 0 | 0 | 0 | C |
| 47 | 7 | 20 | 375 | 60 | 30 | 10 | * | 0 | * | 0 | C |
| 49 | 6 | 5 | 327 | 5 | 85 | 10 | 0 | 0 | * | 0 | M |
| 51 | 4 | 5 | 250 | 30 | 30 | 30 | 0 | 0 | 10 | 0 | M |
| 53 | 2.5 | 4 | 200 | 10 | 40 | 40 | 0 | 0 | 10 | 0 | C |
| 59 | 3 | 3 | 170 | 60 | 30 | 10 | 0 | 0 | 0 | 0 | N |
| 60 | <1 | 1 | 54 | 50 | 50 | 0 | 0 | 0 | 0 | 0 | N |
| HHW | 3 | 120 | 325 | 0 | 100 | 0 | 0 | 0 | 0 | 0 | N |
| TSL | 3 | - | - | 0 | # | 0 | 0 | 0 | 0 | 0 | N |

Stand number = nearest border section number corresponding to mangrove stand, Kc= *Kandelia candel*, Ac = *Aegiceras corniculatum*, Ai = *Acanthus ilicifolius*, Av = *Avicennia marina*, Bg = *Bruguiera gymnorrhiza*, P = *Phragmites communis*, Acr = *Acrostichum aureum*, C = concrete, N = natural, M = mixed, * = species present but represent insignificant proportion of stand area, HHW = Hoo Hok Wai stand, TSL = Ta Sha Lok stand, # = only two individuals present; marked as upstream limit of mangrove intrusion.

## A10.6.4 Discussion

The size and structure of the mangrove stands and the presence of a rare species (*Bruguiera gymnorrhiza*) suggest that between Tam Kon Chau and Lok Ma Chau, the present stands may be remnants of a larger stand which was destroyed during construction of the Border Road. Detailed estimation of mangrove 'health' was not undertaken here, but in crude terms, despite deteriorating water quality and increasing river traffic in the river, the mangroves lining the southern river bank show little sign of degradation. The stands are dominated by species common in the Deep Bay mangals, with the exception of *Avicennia marina*, which is virtually precluded from river bank habitats. It is probably a poor colonist, as propagule production is limited (Anderson and Lee, in press), but, with aerial pneumatophores to facilitate oxygen transport to the roots, may be more sensitive to poor water quality, particularly in terms of sediment load, than *Kandelia candel* or *Aegiceras corniculatum*. Also, there is a marked absence of young seedlings of all species in the river bank stands. A similar pattern (lack of *Avicennia marina* and young seedlings in stands dominated by *Kandelia candel* and *Aegiceras corniculatum*) was documented in the Kam Tin River, Yuen Long, before drainage improvement works (Lee 1992) and was thought to be attributed to water quality parameters exceeding stress limits for establishing seedlings. Additionally, in the Shenzhen River, physical disruption of propagule lodgement may be caused by wash from river traffic, which was not a factor present in the Kam Tin River.

Upstream from the Lok Ma Chau Border Crossing, mangrove species are fewer, perhaps precluded from colonization by poor water quality or steeply sided river banks, as suggested from the stand at Hoo Hok Wai (HHW), which occurs on the inner bend of a meander where deposition of fluvial sediment would be expected. The reed *Phragmites australis*, *Juncus* sp. and *Cyperus* sp. are present in large beds surrounding fish ponds or in abandoned fish ponds, and in areas where the substrate has been disturbed.

The proposed Shenzhen River Regulation Project will result in the destruction of most of the existing mangrove stands surveyed here. The approximate area of mangrove lost may be calculated from the data obtained in this survey, and is given in Table 10.6.3. Consequences of the loss of mangrove from along the river banks include:

- a direct loss of mangrove habitat and the species dependent upon it;
- a loss of a natural corridor for wildlife between Deep Bay and the wetlands and other habitat upstream;
- a loss of probable river bank stability;
- a loss of aesthetic value.

Table A10.6.3 Potential Mangrove Area to be Lost due to Shenzhen River Regulation Project.

| Mangrove | Total area (ha) | Species composition | | |
|---|---|---|---|---|
| | | *Kandelia candel* | *Aegiceras corniculatum* | *Acanthus ilicifolius* |
| Dense stands | 5.71 | 0.81 ha (14%) | 4.55 ha (79%) | 0.27 ha (5) |
| Sparse | 5.11 | na | na | na |

Dense stands = stands where individuals are not discernible; data collected during survey. Sparse = areas where mangroves occur and individuals are discernible; data are map measurements of the area occupied by sparse mangrove vegetation on the river bank and in the drainage channels adjacent to the river. No species composition by area data are available (na=not available).

## A10.6.5 Recommendations

The results of this study indicate that the mangrove assemblages occurring on the current banks of the Shenzhen River are remnants of the larger forest which has been destroyed through fish pond creation and border road construction. The mangroves are subjected to poor water quality and considerable wave action from passing river traffic, which probably limits the survivorship of seedlings along the river bank.

An appropriate, and recommended, measure to compensate for mangrove loss resulting from the project would be to replant mangroves on the banks of the new river channel. A similar programme has been undertaken successfully with 2 year mangrove seedlings in the Yuen Long Creek (Drainage Services Department, 1993). Results of a concurrent study of mangrove seedling survival (Appendix 10.4) indicate that in the short term, seedlings of one species, *Kandelia candel*, apparently survive on the river bank when protected from wake wash of passing river traffic. The following points must be examined when undertaking this option:

1) New River Channel Design: This must include a flat or gently sloping ledge with natural substrate beneath it on the banks. The width and position of the ledge will need to be decided with lateral water flow friction taken into account, as well as the height above PD and tidal inundation frequency.

2) Baffling: When planted, seedlings must be protected from wave action by appropriate means (baffles) until large enough to withstand frequent wake wash.

3) Seedlings: These should be planted out in mixtures of the species reported herein. It is suggested that a mix of 50 *K.candel* to 40 *A.corniculatum* to 10 *A.ilicifolius* would be appropriate.

**References**

Morton, B.S. and Morton, J. 1983. The Seashore Ecology of Hong Kong. Hong Kong University Press.

Lee, S.Y. 1992. Assessment of Effects of Mangrove Removal on Water Quality in Deep Bay. Binnie Consultants Ltd.

Anderson, C. and Lee, S.Y. In press. Defoliation of the mangrove *Avicennia marina* in Hong Kong: cause and consequence. Biotropica.

## A10.7 MANGROVE SURVEY AT MAI PO

### A10.7.1 Introduction

The proposed Shenzhen River Regulation Project will widen the Shenzhen River in its lower reaches, possibly impacting the mangrove and fish pond habitat at the northern end of the Mai Po Marshes Nature Reserve. Impacts are likely to be through direct habitat loss and indirect effects of dredging in the vicinity. By using aerial photographs of the proposed affected region, and ground truthing at several sites, the aim of this survey was :

- to determine the historical development of the mangrove habitat (mangal) affected;
- to determine its present area, structure and biomass;
- to address possible consequences of its removal;
- to provide baseline data against which post-impact assessments and monitoring programmes may be made.

### A10.7.2 Method

#### A10.7.2.1 Photographic survey

The proposed Shenzhen River Regulation project will result in the widening of the river at its mouth in inner Deep Bay, affecting fishpond habitat and mudflat mangal as shown in Figure A10.7.1. To assess the present extent of mangal, and assess development of the mangal with respect to previous impacts (fishpond construction), aerial photographs taken between 1945 and 1993 were obtained. Unfortunately, the region was not regularly or consistently photographed and it was necessary to use photographs taken at varying altitudes, from 2000' to 29200'. The area of mangal in Mangal A was measured from tracings of each photograph, using landmarks of known dimensions (the width of particular gei wais at certain points) for scaling. For early photographs, no distinction was made between 'fringe' mangrove, where small, sparse trees are found with mudflat visible between them, and that with full canopy cover; the limits of the mangal were defined simply as where mangrove plants were clearly visible on the photograph. Mangrove inside fishpond was not measured. These results were compared with data from studies of mangal elsewhere at Mai Po (Anderson, unpublished data) and studies of land use change in the region (Leung, 1986).

Aerial photography has also been successfully used for determination of mangal structure, particularly zonation patterns and canopy species cover (Chapman 1984). Current, low altitude photographs were examined for these purposes, in conjunction with ground truthing results.

#### A10.7.2.2 Ground truthing

Ground truthing was undertaken in April 1994 using a rapid survey technique along three transects in the Mangal A (T1, T2, T3; Figure A10.7.1). A further transect was established in Mangal B (T4; Figure A10.7.1). This supplements two other transects (Y1 and D1) carried out previously in Mangal B by other researchers, the data from which are compared with those obtained herein.

For each transect (T1, T2, T3 and T4), a line was laid out following a compass bearing perpendicular to the landward bund. Every 20m along the transect, a 5m$^2$ quadrant was laid out to the north of the transect line (such that, along the transect, 15m separate quadrants). All emergent flora in the quadrants was examined and the following data recorded *in situ*:

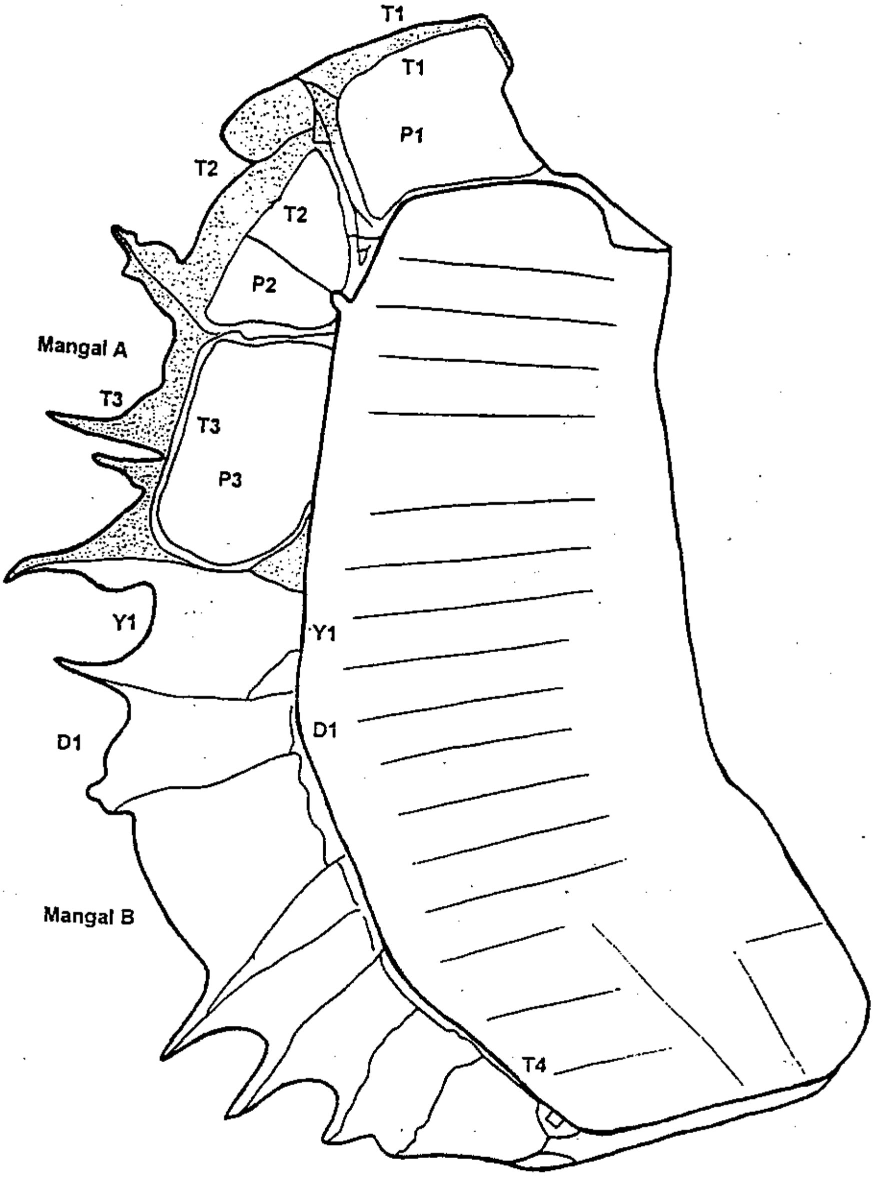


Figure A10.7.1 Sketch map of the Mai Po Marshes Nature Reserve showing location of mangals A and B and transects: T1 = transect 1; T2 = transect 2; T3 = transect 3; T4 = transect 4; Y1 = transect (Young, unpublished data); D1 = transect (Duke and Khan, unpublished data); P 1, 2 and 3 = Ponds 1, 2 and 3

- Species;
- Height (Ht)
- Diameter at Breast Height (Dbh), taken at 1.3m above ground level, for trees where Dbh > 2cm.

Trees which branched below breast height were treated as several stems, and the parameters of each branch recorded. Small (< 1.3m in height) or shrubby plants (e.g. *Acanthus ilicifolius* and *Aegiceras corniculatum*), were noted if abundant, but not measured. Transects continued to the seaward limit of the mangal except in Transects 2 and 4, where mud consistency did not permit further penetration.

These measurements constitute several parameters of forest structure which allow comparisons between stands and between mangals, and form baseline data against which impacts may be measured. These are:

- Species distribution along the transect
- Vertical structure of the forest
- Numerical species composition along the transect (% of total stems measured in quadrant)
- Aboveground biomass: This was determined using a model of tree growth which relates biomass to Ht and Dbh for which species specific allometric equations are available (Anderson 1994; Lee 1992).
- Tree density
- Basal diameter: This is the area covered by a tree stem and is a good measure of stand development (Cintron and Novelli 1984). It is given by the equation:
  Basal area (g) = $(\pi/4).(Dbh^2)$
  Basal diameter (BA) is the summed g values for all trees in the stand.
- Mean stand diameter: This is the diameter of the stem of mean basal area
  mdbh = $sqrt[(BA/n)/(\pi/4)]$
  where mdbh is the mean stand diameter at breast height, BA is basal diameter, and n is tree density.

#### A10.7.2.3 Encroachment rate

To measure the encroachment rate of the mangal onto the mudflat, five reference lines (aligning permanent landmarks in the Mai Po area) were established on an overlay of a series of aerial photographs from Mai Po, as described above. Lines 1, 2 and 3 were in the undisturbed mangal in the south of the reserve. Lines 4 and 5 were in the north of the reserve, near the Shenzhen River. Development of the mangal here has been impeded by construction in the 1970's of fish ponds outside the gei wai's. The width of the mangrove forest, not including the seaward fringe (noted by the presence of mudflat between trees) or mangrove extensions along creek banks on the mudflat, along each line was measured and calibrated against scaling factors for each photograph.

### A10.7.3 Results

#### A10.7.3.1 Photographic Survey.

The present area of Mangal A, and a record of its development since 1945, are shown in Figure A10.7.2. The mangal generally enlarged in this period (12 ha to 36 ha), but suffered some reduction in the years between 1954 and 1960, and again between 1975 and 1984. The reductions are partly attributable to fish pond construction as pond 1 was reclaimed before 1954 and pond 2 was reclaimed before 1973. Other factors may be involved, however, as indicated in Figure A10.7.3, which tracks the areas of Mangals A and B through the last 50 years. Of note is the simultaneous decrease in area covered by both Mangals A and B (which is not under threat from conversion to fishpond) in the 1980's. The cause of this decrease is not apparent in the photographs. Figure A10.7.3 also indicates the overall declining trend in 'swamp and marsh' in the Deep Bay area (Leung 1986).

Aerial photographs also show features of mangal structure, such as zonation pattern and canopy cover. In this case, the photographs showed the development of the mangal with clarity. In 1945 Mangal A appears as a thin fringe of vegetation in which no canopy is visible. In 1954, the mangal area is wider and darker, with some forest canopy apparent, and in subsequent years a full canopy appears. In low altitude photographs, some canopy colour variation is shown, but this does not form a consistent zonation pattern down the shore. Photographs of Mangal B, however, clearly indicate the presence of a zonation pattern, with dark bands at the landward end and homogeneous light bands towards the seaward end. A fringe of dark coloration delimits the pioneering seedlings on the mudflat.

Table A10.7.1 Development of Mangal A through time.

| Year | Mangal A area (ha) |
|---|---|
| 1945 | 11.93 |
| 1954 | 13.18 |
| 1963 | 10.58 |
| 1975 | 26 |
| 1984 | 16.63 |
| 1993 | 36.3 |

### A10.7.3.2 Ground Truthing

Analysis of transect data give some indication of the differences in forest structure which cause differences in appearance of Mangal A and B on aerial photographs. It should be noted that Transects T2 and T4 were stopped before the seaward limit was reached (approximately 20 and 50m before the seaward limit of the main stand, respectively). T3 was stopped some way into a wide fringe of small mangroves on the seaward edge of the mangal, in which approximately 30 Redshank (*Tringa totanus*) were foraging.

*Species distribution and vertical forest structure*

Species distribution and vertical forest structure were recorded for each quadrant as presence and maximum height attained, and are displayed in Figures A10.7.4a, b, c, and d. Transects T1, T2 and T3 do not exhibit a clear zonation pattern, nor a distinct vertical structure, as a mixture of species and heights are recorded throughout. This is in marked contrast to T4, which exhibits a clear high to low shore zonation (monospecific stands of *Kandelia candel* at the high shore being replaced over a small distance by *Avicennia marina*) and a homogeneous vertical structure with a strong canopy formation and little understorey growth. Of interest are the grass (T1; *Eleocharis c.f. ascicularis* ) occurring on the banks of the river (Melville 1994) and the individual of *Bruguiera gymnorrhiza* in T4, which occurred in a small stand with two others and was producing propagules. Zonation patterns exhibited along T4 are similar to those found by Young and Duke and Khan for transects Y1 and D1, respectively (unpublished manuscripts).

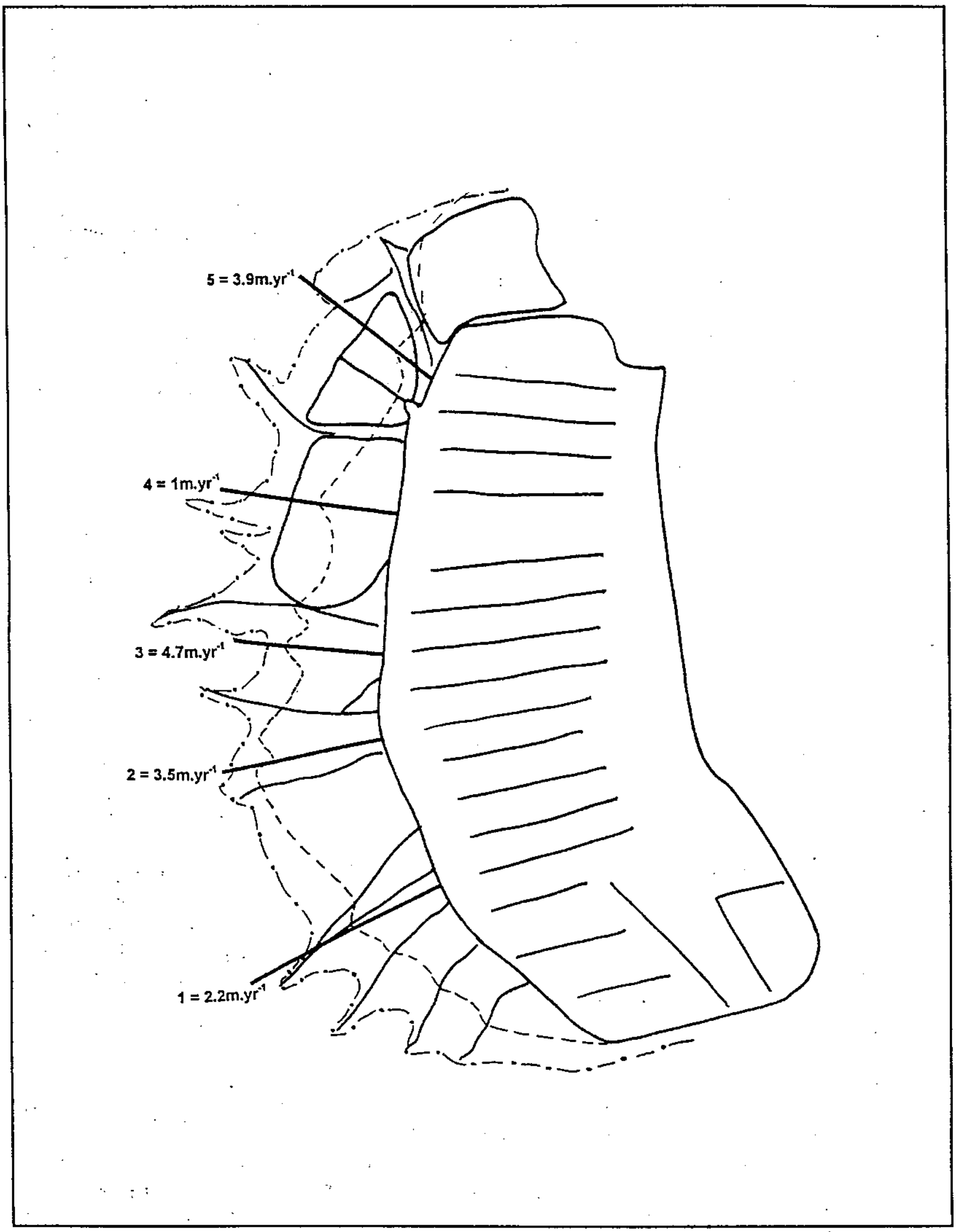


Figure A10.7.2 Sketch map of the Mai Po Marshes Nature Reserve showing its rate of development and encroachment rate. ----- = extent of mangrove in 1945;-•-•-• = current limits of mangal. Reference lines and encroachment rates along each, in $m.yr^{-1}$ are shown

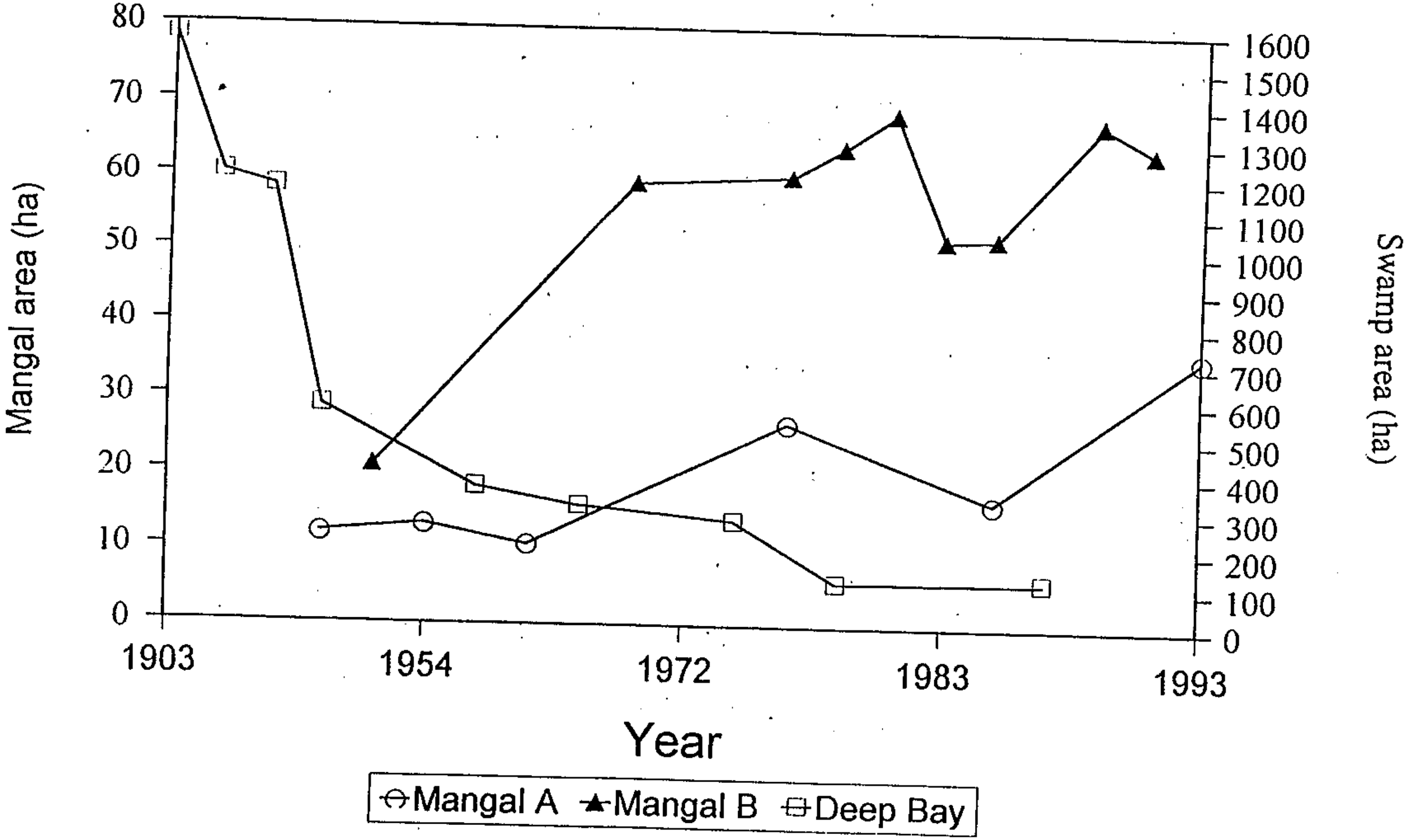


Figure A10.7.3 Changes in area of Mangal A, Mangal B and Marsh in the Deep Bay area between 1903 and 1993

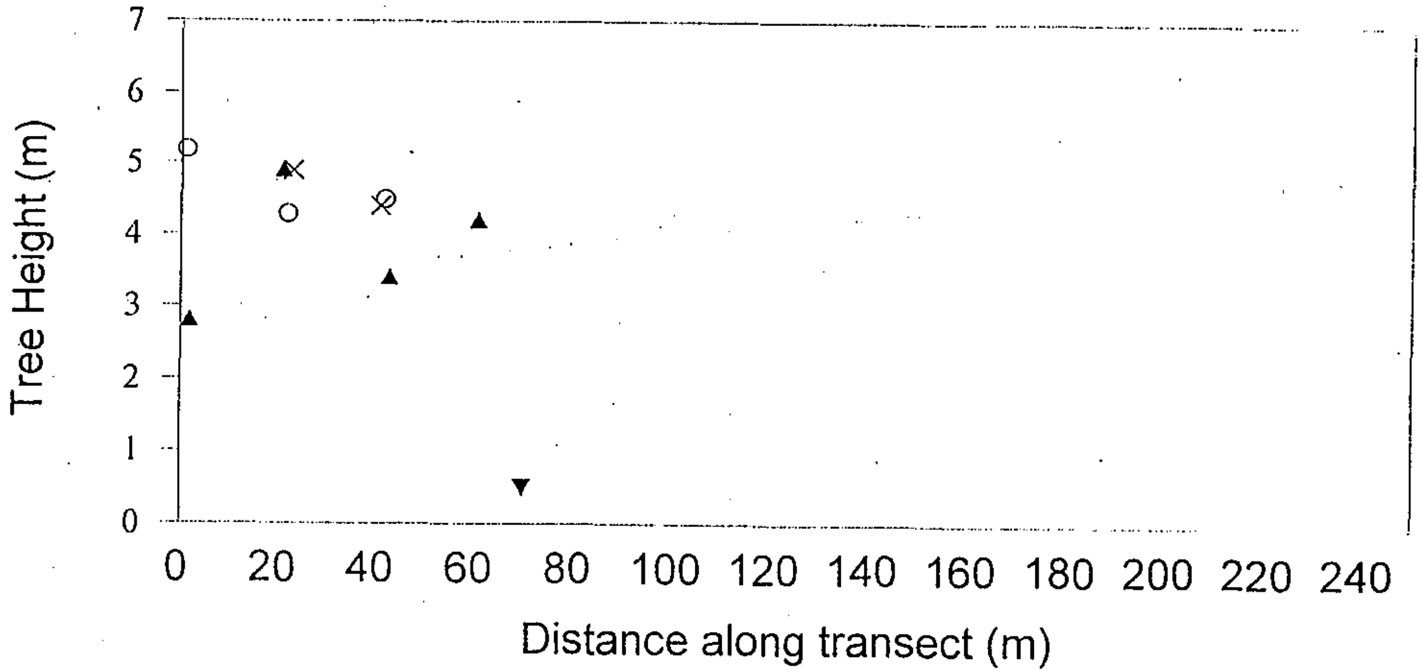


Figure A10.7.4(a) Zonation of species and vertical structure in Transect 1. Species are indicated as presence only, and maximum height is recorded. □ = *Acanthus ilicifolius*; ○ = *Kandelia candel*; × = *Avicennia marina*; ▲ = *Aegiceras corniculatum*; * = *Bruguiera gymnorrhiza*; ▼ = *Eleocharis c.f. ascicularis*

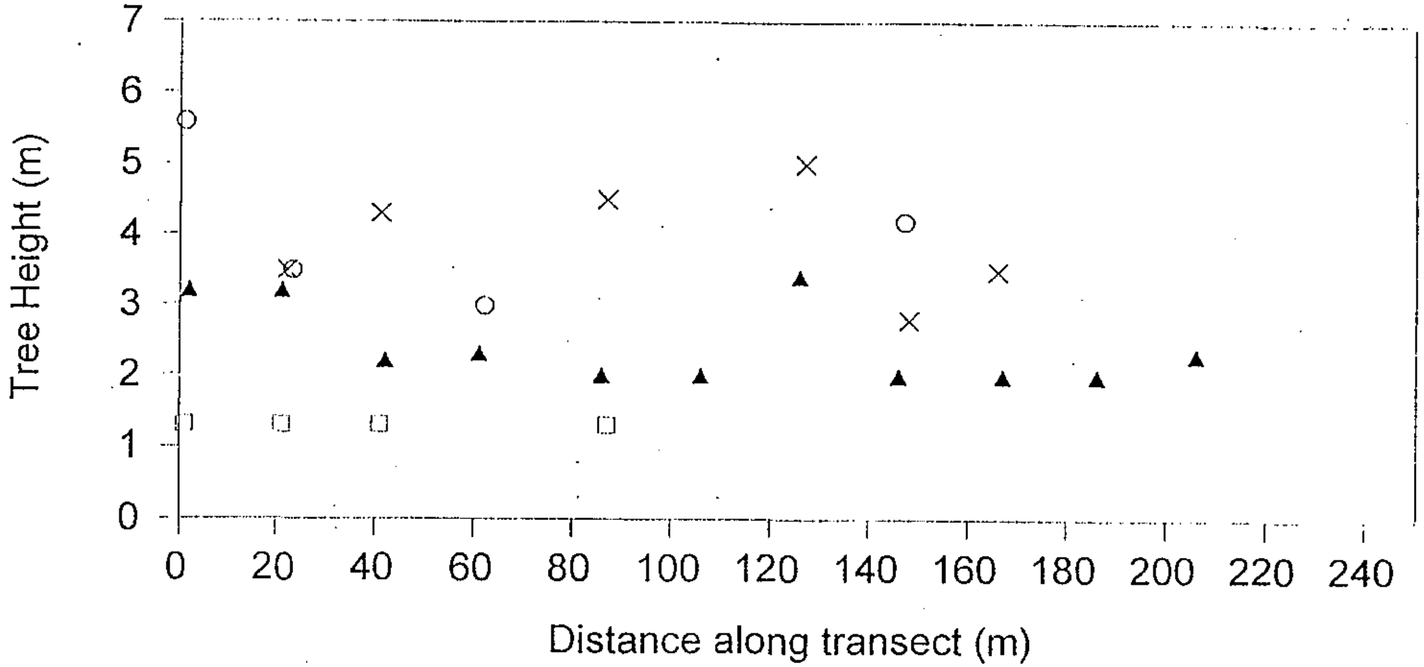


Figure A10.7.4(b) Zonation of species and vertical structure in Transect 1. Species are indicated as presence only, and maximum height is recorded. □ = *Acanthus ilicifolius*; ○ = *Kandelia candel*; × = *Avicennia marina*; ▲ = *Aegiceras corniculatum*; ∗ = *Bruguiera gymnorrhiza*; ▼ = *Eleocharis c.f. ascicularis*

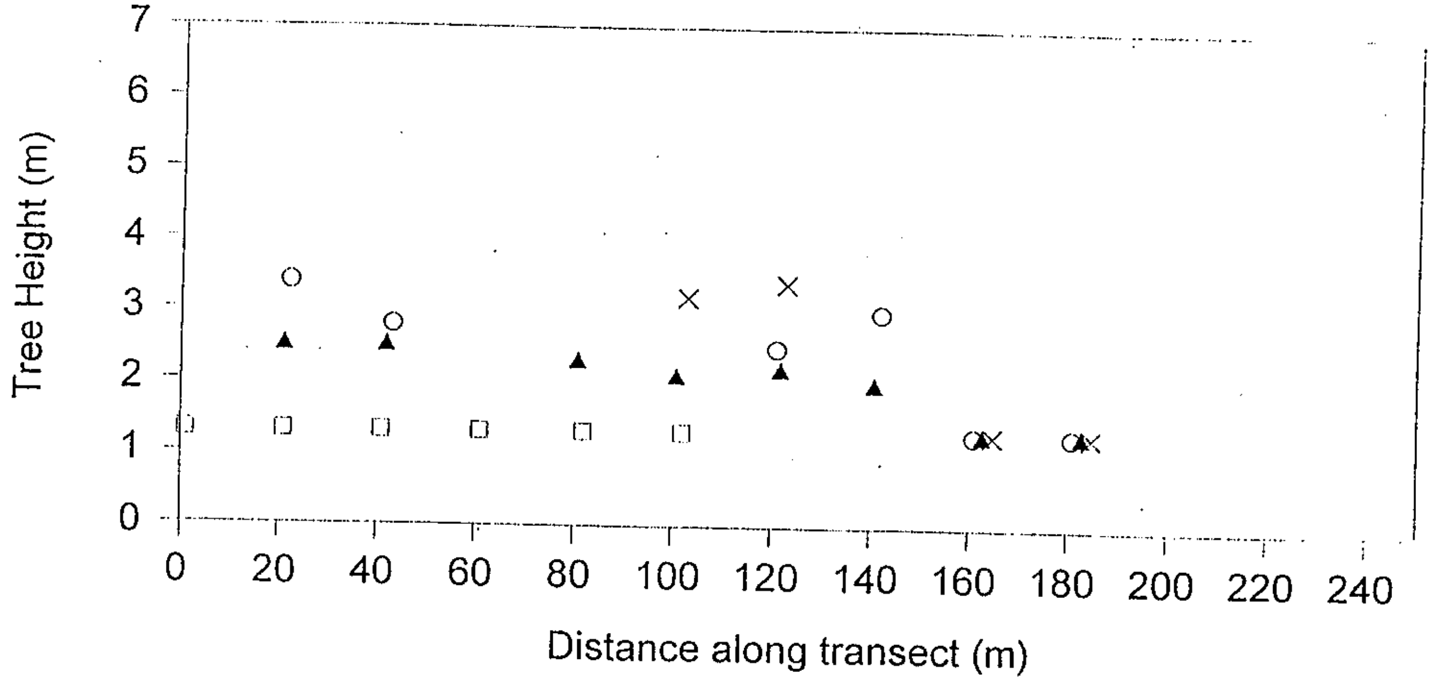


Figure A10.7.4(c) Zonation of species and vertical structure in Transect 1. Species are indicated as presence only, and maximum height is recorded. □ = *Acanthus ilicifolius*; ○ = *Kandelia candel*; × = *Avicennia marina*; ▲ = *Aegiceras corniculatum*; * = *Bruguiera gymnorrhiza*; ▼ = *Eleocharis c.f. ascicularis*

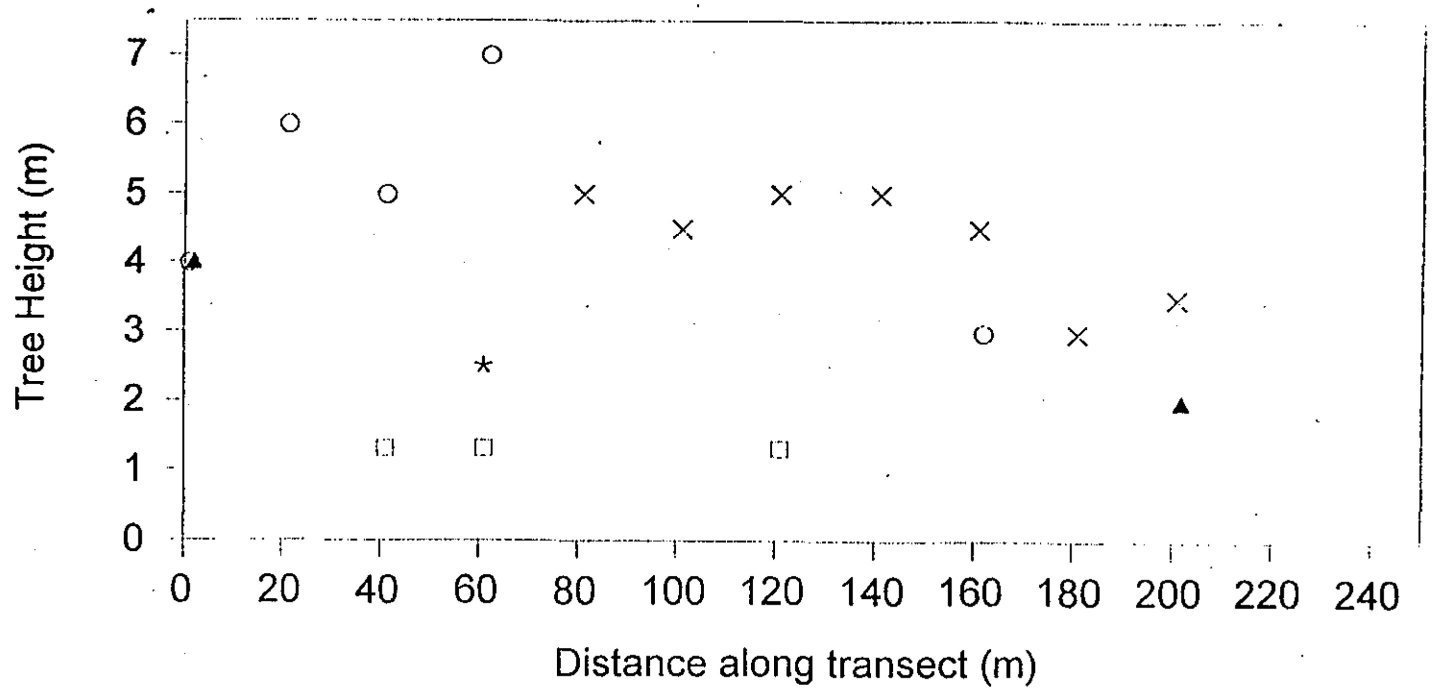


Figure A10.7.4(d) Zonation of species and vertical structure in Transect 1. Species are indicated as presence only, and maximum height is recorded. □ = *Acanthus ilicifolius*; ○ = *Kandelia candel*; × = *Avicennia marina*; ▲ = *Aegiceras corniculatum*; * = *Bruguiera gymnorrhiza*; ▼ = *Eleocharis c.f. ascicularis*

*Numerical species composition*

Shown in Figures A10.7.5a, b, c and d, numerical species composition reinforces the above differences between Mangal A and Mangal B, with strong zonation in dominant species found only in T4. Again, T4 is similar in composition to Y1 and D1 (unpublished manuscripts).

*Tree density*

Tree density (trees.$ha^{-1}$) varies between 800 and 16800 in the sites surveyed (Figure A10.7.6). Variability is high in T1, T2 and T3. Transect T3 intersects the x axis at two points, corresponding to two quadrants which consisted of *Acanthus ilicifolius*. Transect T4 has consistently lower densities in quadrants along its length, except for the initial quadrant at the landward end. This is similar to Young's and Duke and Khan's results of 0 to 7600 stems.$ha^{-1}$ in the main forest (fringe seedlings not included).

*Mean stand diameter*

These are displayed for all transects in Figure A10.7.7. Transect T4 generally has a higher diameter than transects T1,T2 and T3.

*Basal diameter*

As displayed in Figure A10.7.8, basal diameters are highly variable between quadrants. This may, in part, be attributable to changes in species composition along each transect.

*Summary*

Biomass data and a summary of data presented graphically are given in Table A10.7.2.

### A10.7.3.3 Encroachment rates

Results are shown in Table A10.7.3 and give a mean encroachment rate of 3.47m.$yr^{-1}$ for the undisturbed mangal. A similar approach was used by Duke and Khan (unpublished data) using computer scanning of aerial photographs. Their method included fringe forest and finger-like extensions of mangal on the mudflat and gave an overall encroachment rate of 7.6m.$yr^{-1}$.

## A10.7.4 Discussion

The mangal lying on the mudflat at Deep Bay (Mangals A and B), has developed since the 1940's, when the *gei wais* were reclaimed from existing mangrove, effectively pushing the coastline further out into Deep Bay. Leung (1986) notes that the rapid decline in areas of 'swamp and marsh' in the Deep Bay area is caused by reclamation for brackish water paddy and *gei wais*. In fact, the extent of the original mangrove is still visible in aerial photographs taken in the 1940's, despite *gei wai* construction. Photographs in later years suggest that the original mangrove declined rapidly inside the *gei wais*, perhaps under the influence of changed hydrological conditions and felling. Outside the seaward *gei wai* bund, rapid colonisation of the mudflat occurred, forming the present mangal.

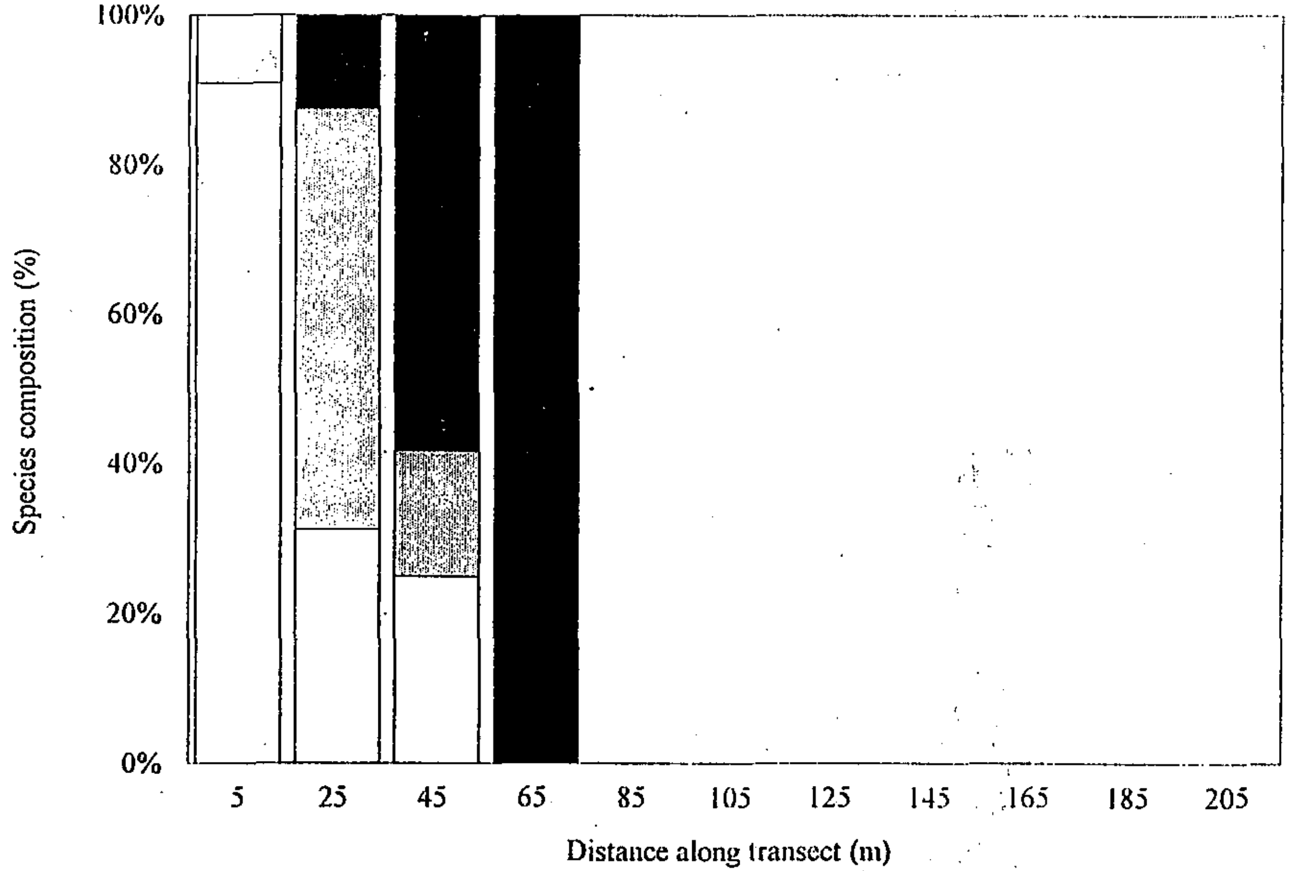


Figure A10.7.5(a) Numerical species composition in Transect 1. □ = *Kandelia candel*; ⁞⁞⁞ = *Aegiceras corniculatum*; ▩ = *Avicennia marina*; ▦ = *Acanthus ilicifolius*

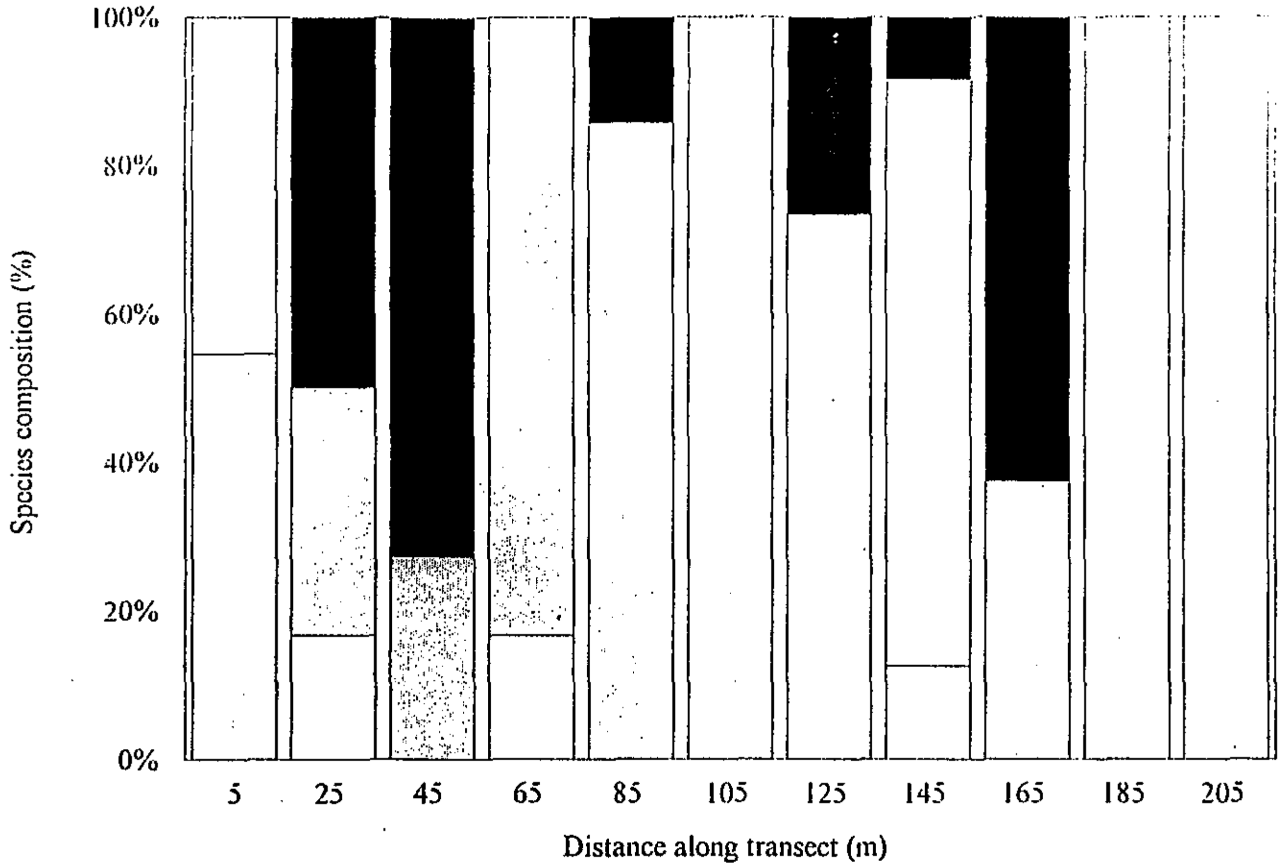


Figure A10.7.5(b) Numerical species composition in Transect 1. □ = *Kandelia candel*; ⁝⁝⁝ = *Aegiceras corniculatum*; ▩ = *Avicennia marina*; ▦ = *Acanthus ilicifolius*

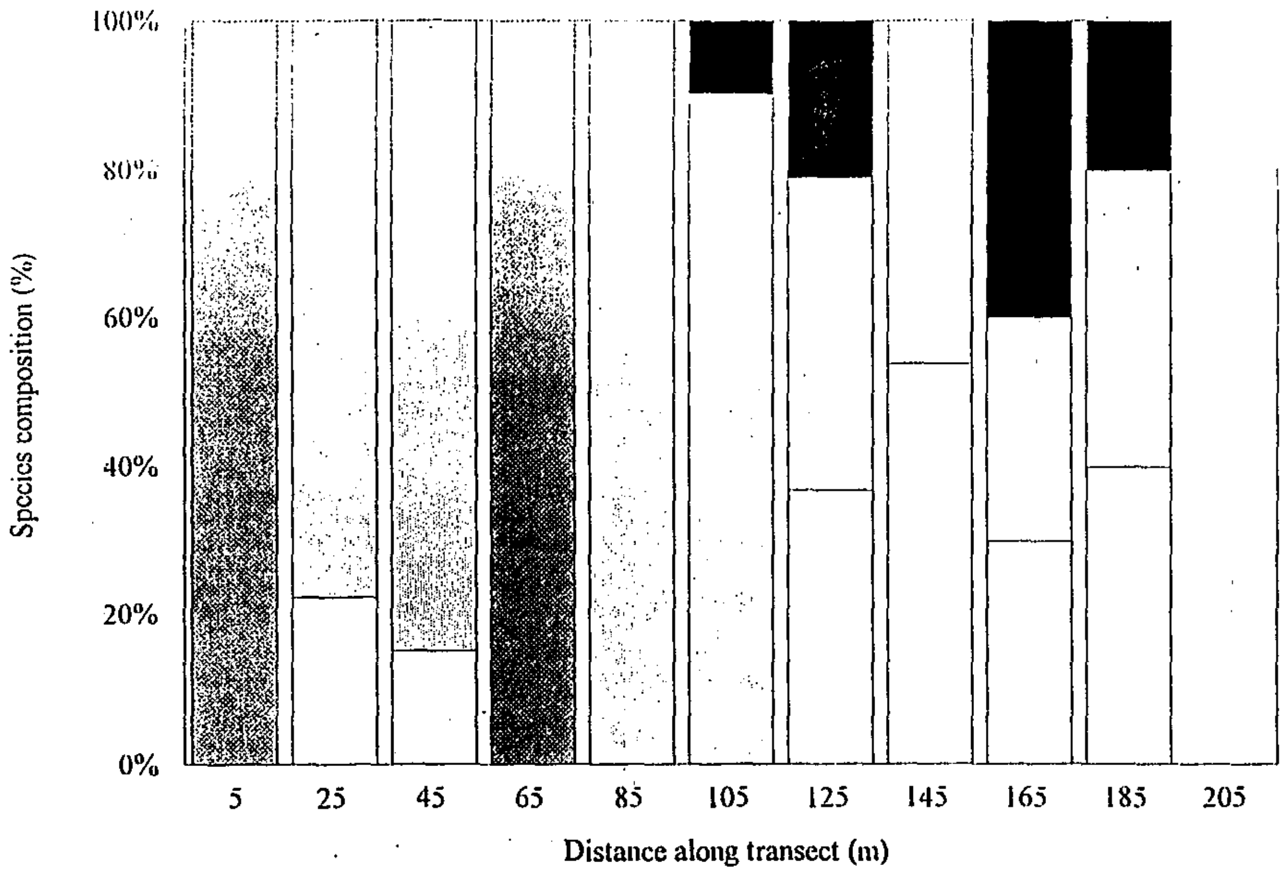


Figure A10.7.5(c) Numerical species composition in Transect 1. □ = *Kandelia candel*; ⁝⁝⁝ = *Aegiceras corniculatum*; ▩ = *Avicennia marina*; ▦ = *Acanthus ilicifolius*.

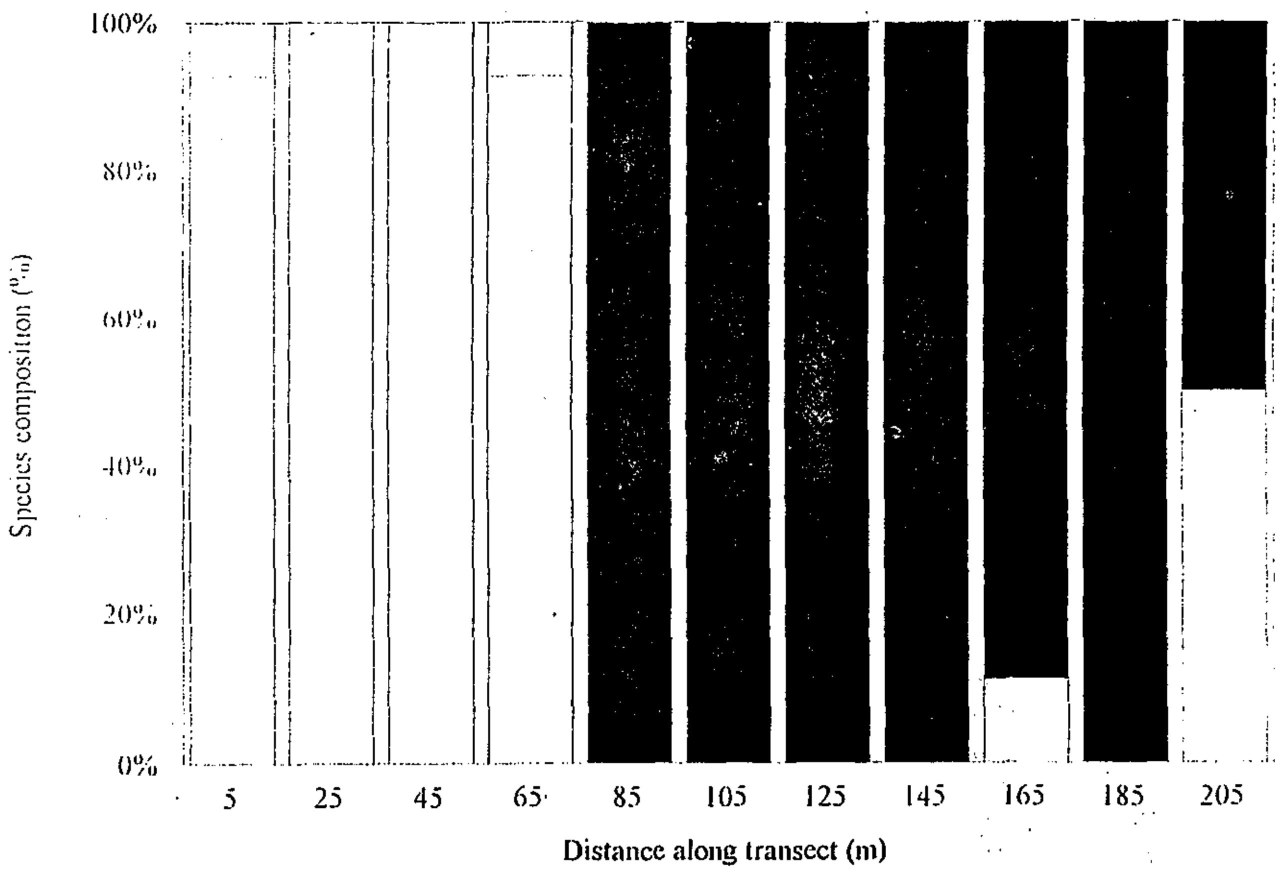


Figure A10.7.5(d) Numerical species composition in Transect 1. □ = *Kandelia candel*; ⁝⁝⁝ = *Aegiceras corniculatum*; ▩ = *Avicennia marina*; ▦ = *Acanthus ilicifolius*

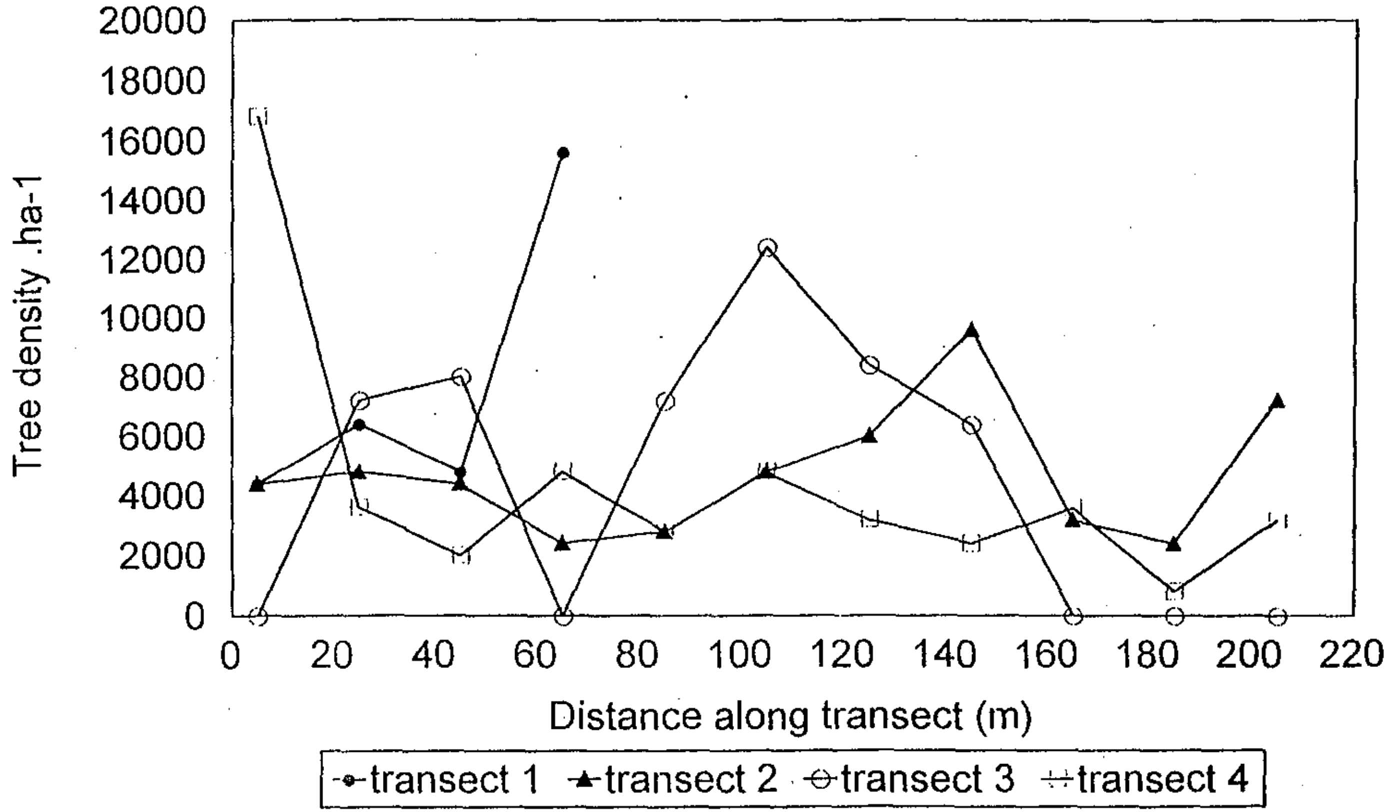


Figure A10.7.6 Tree density (stems.$ha^{-1}$) in all transects

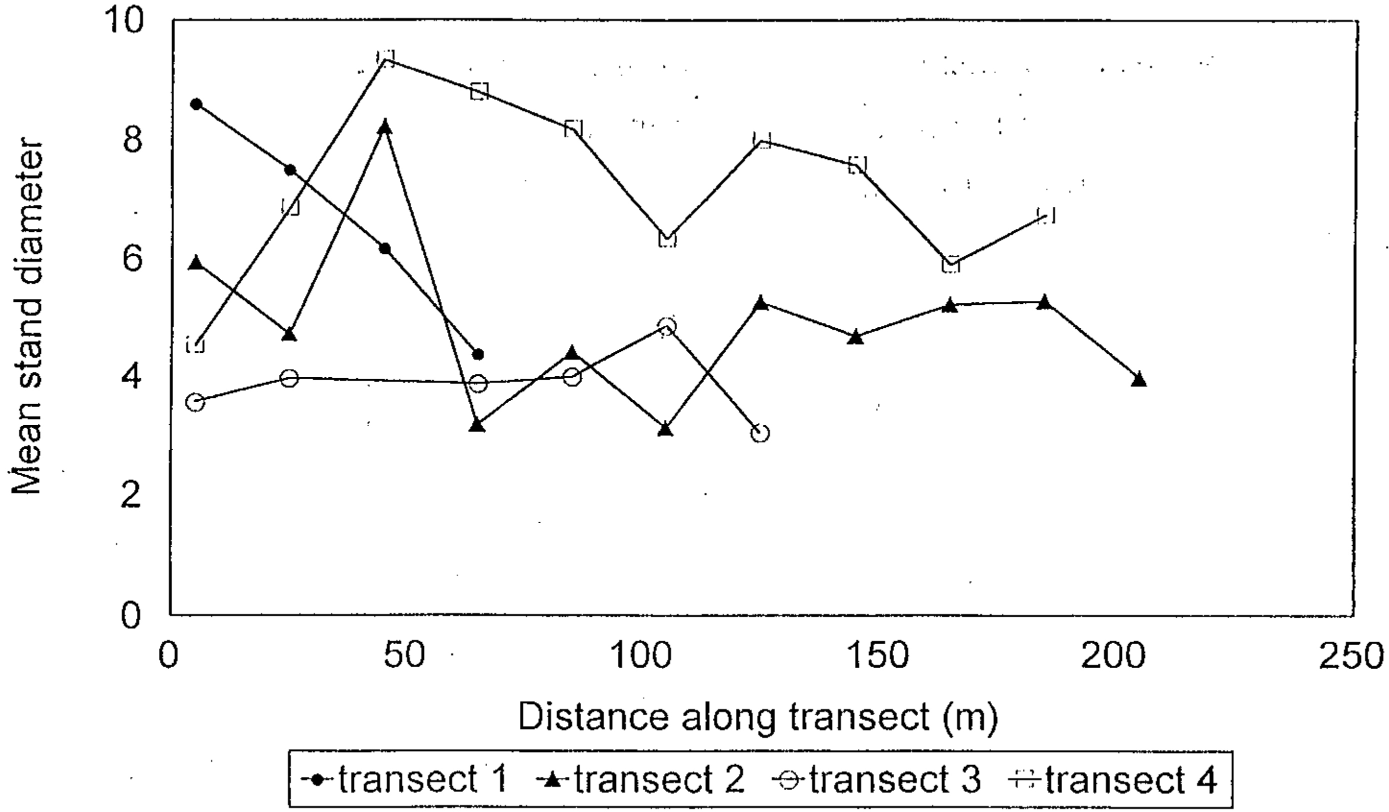


Figure A10.7.7 Mean Stand Diameter ($cm^2$.quadrant$^{-1}$) in all transects

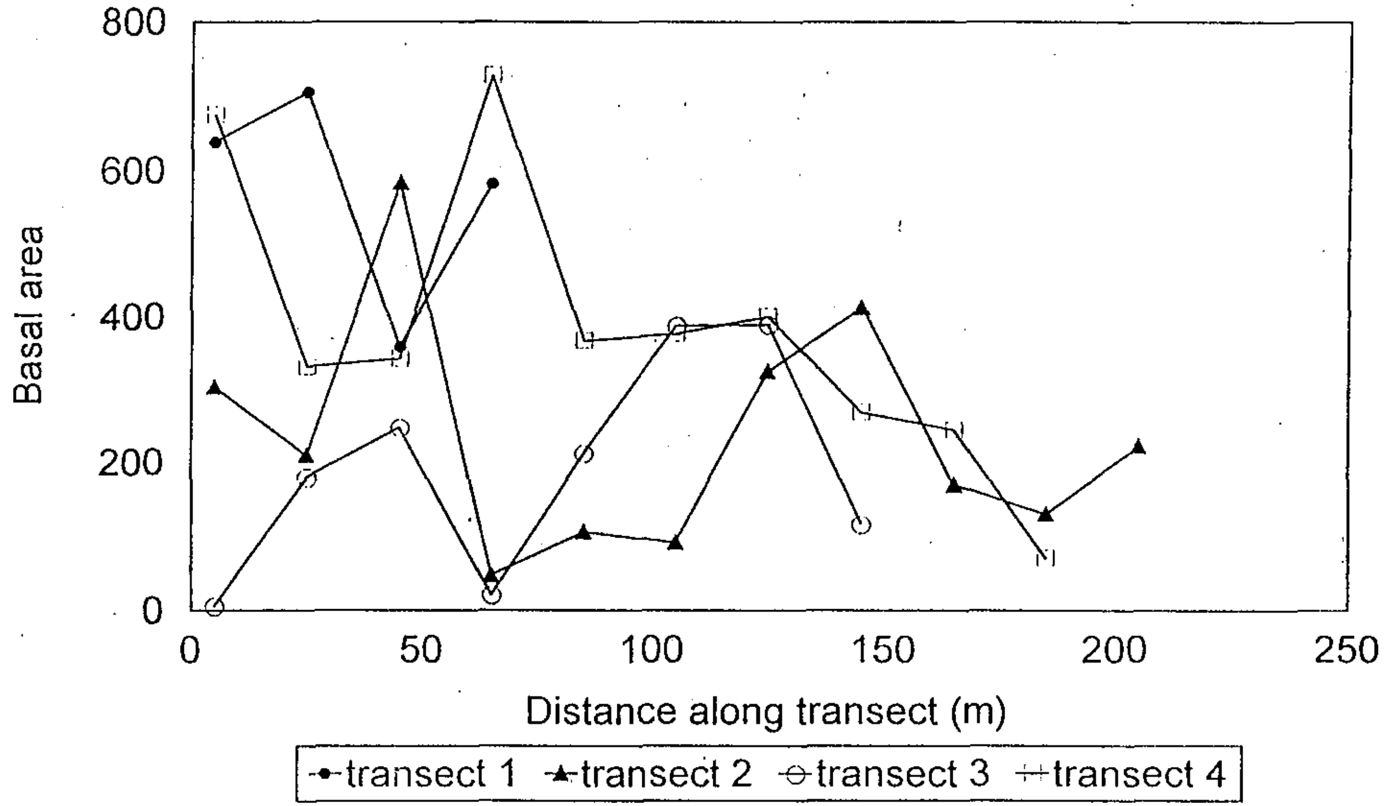


Figure A10.7.8 Basal area ($cm^2.quadrant^{-1}$) in all transects

Table A10.7.2(a) Results of the transect carried out at one site in Mangal A (T1)

| TRANSECT 1 | | % Species Composition | | | Biomass (kg.ha$^{-1}$) x100 | | | Stand Structure | |
|---|---|---|---|---|---|---|---|---|---|
| m along transect | tree density | Kc | Ac | Am | Kc | Ac | Am | BA | mdbh |
| 5 | 4400 | 90 | 10 | 0 | 728 | 136 | 0 | 639 | 8.6 |
| 25 | 6400 | 31 | 56 | 13 | 312 | 20 | 264 | 706 | 7.5 |
| 45 | 4800 | 25 | 17 | 58 | 64 | 436 | 512 | 358 | 6.2 |
| 65 | 15600 | 0 | 0 | 100 | 0 | 109 | 0 | 582 | 4.4 |
| 85 | | | | | | | | | |
| 105 | | | | | | | | | |
| 125 | | | | | | | | | |
| 145 | | | | | | | | | |
| 165 | | | | | | | | | |
| 185 | | | | | | | | | |
| 205 | | | | | | | | | |

Table A10.7.2(b) Results of the transect carried out at one site in Mangal A (T2)

| TRANSECT 2 | | % Species Composition | | | Biomass (kg.ha$^{-1}$) x100 | | | Stand Structure | |
|---|---|---|---|---|---|---|---|---|---|
| m along transect | tree density | Kc | Ac | Am | Kc | Ac | Am | BA | mdbh |
| 5 | 4400 | 55 | 45 | 0 | 252 | 48 | 0 | 303 | 5.9 |
| 25 | 4800 | 17 | 33 | 50 | 16 | 20 | 0 | 209 | 4.7 |
| 45 | 4400 | 0 | 27 | 73 | 0 | 12 | 1104 | 583 | 8.2 |
| 65 | 2400 | 17 | 83 | 0 | 8 | 20 | 0 | 48 | 3.2 |
| 85 | 2800 | 0 | 86 | 14 | 0 | 20 | 216 | 106 | 4.4 |
| 105 | 4800 | 0 | 100 | 0 | 0 | 40 | 0 | 92 | 3.1 |
| 125 | 6000 | 0 | 73 | 27 | 0 | 68 | 420 | 324 | 5.2 |
| 145 | 9600 | 13 | 79 | 8 | 52 | 68 | 132 | 412 | 4.6 |
| 165 | 3200 | 0 | 38 | 62 | 0 | 12 | 216 | 170 | 5.2 |
| 185 | 2400 | 0 | 100 | 0 | 0 | 20 | 0 | 130 | 5.3 |
| 205 | 7200 | 0 | 100 | 0 | 0 | 64 | 0 | 222 | 3.9 |

Tree density = stems.ha$^{-1}$; % species composition = numerical composition based on abundances in quadrats; Kc = *Kandelia candel*; Ac = *Aegiceras corniculatum*; Am = *Avicennia marina*; biomass is calculated from standard allometric equations (Anderson unpublished data; Lee 1992) and is represented as kg dry mass.quadrant$^{-1}$; BA = basal area, in cm$^2$.quadrat$^{-1}$; mdbh = mean stand diameter at breast height, in cm

Table A10.7.2(c) Results of the transect carried out at one site in Mangal A (T3)

| TRANSECT 3 | | % Species Composition | | | Biomass (kg.ha$^{-1}$) x100 | | | Stand Structure | |
|---|---|---|---|---|---|---|---|---|---|
| m along transect | tree density | Kc | Ac | Am | Kc | Ac | Am | BA | mdbh |
| 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 25 | 7200 | 22 | 78 | 0 | 20 | 72 | 0 | 179 | 3.6 |
| 45 | 8000 | 15 | 85 | 0 | 0 | 44 | 96 | 247 | 3.9 |
| 65 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 85 | 7200 | 0 | 100 | 0 | 0 | 92 | 0 | 212 | 3.9 |
| 105 | 12400 | 0 | 90 | 10 | 0 | 140 | 64 | 387 | 4 |
| 125 | 8400 | 43 | 38 | 19 | 84 | 36 | 128 | 389 | 4.8 |
| 145 | 6400 | 44 | 38 | 18 | 32 | 20 | 0 | 117 | 3 |
| 165 | | | | | | | | | |
| 185 | | | | | | | | | |
| 205 | | | | | | | | | |

Table A10.7.2(d) Results of the transect carried out at one site in Mangal B (T4)

| TRANSECT 4 | | % Species Composition | | | Biomass (kg.ha$^{-1}$) x100 | | | Stand Structure | |
|---|---|---|---|---|---|---|---|---|---|
| m along transect | tree density | Kc | Ac | Am | Kc | Ac | Am | BA | mdbh |
| 5 | 16800 | 93 | 7 | 0 | 408 | 32 | 0 | 674 | 4.5 |
| 25 | 3600 | 100 | 0 | 0 | 316 | 0 | 0 | 331 | 6.8 |
| 45 | 2000 | 100 | 0 | 0 | 308 | 0 | 0 | 341 | 9.3 |
| 65 | 4800 | 100 | 0 | 0 | 1220 | 0 | 0 | 727 | 8.8 |
| 85 | 2800 | 0 | 0 | 100 | 0 | 0 | 752 | 367 | 8.2 |
| 105 | 4800 | 0 | 0 | 100 | 0 | 0 | 652 | 376 | 6.3 |
| 125 | 3200 | 0 | 0 | 100 | 0 | 0 | 772 | 399 | 8 |
| 145 | 2400 | 0 | 0 | 100 | 0 | 0 | 592 | 269 | 7.6 |
| 165 | 3600 | 11 | 0 | 89 | 12 | 0 | 460 | 244 | 5.9 |
| 185 | 800 | 0 | 0 | 100 | 0 | 0 | 28 | 70 | 6.7 |
| 205 | 3200 | 0 | 50 | 50 | 0 | 12 | 128 | 153 | 5.2 |

Tree density = stems.ha$^{-1}$; % species composition = numerical composition based on abundances in quadrats; Kc = *Kandelia candel*; Ac = *Aegiceras corniculatum*; Am = *Avicennia marina*; biomass is calculated from standard allometric equations (Anderson unpublished data; Lee 1992) and is represented as kg dry mass.quadrant$^{-1}$; BA = basal area, in cm$^2$.quadrat$^{-1}$; mdbh = mean stand diameter at breast height, in cm

Aerial photographs give useful information monitoring the development of the mangal. Area measurements of Mangal A (this study) and Mangal B (Anderson, unpublished data) track the colonisation of the mudflat, with the most reliable area estimates from low altitude photographs (5000' or lower). No information is available on the error involved in using high altitude photographs, and in either series, no account is taken of scale distortions across the photograph, beyond the rejection of oblique shots. The method nevertheless does detect changes in mangal area through time, albeit those of a notable proportion. Minor changes are unlikely to be detected. The mangal accretes sediment by slowing water flow in the mangal, causing sediment to settle out of tidal water. Using data from electronically-scanned photographs and measured profiles of the mangal, Duke and Khan (unpublished data) estimate that the mangal is accreting at a rate of 1.1cm.yr$^{-1}$. From this figure, and the data obtained here, the mangal may be assumed to encroach at a rate of 3.15m.cm$^{-1}$ of accreted sediment. This data may be used for predicting the effects of increased sedimentation rates on the mangal.

Table A10.7.3 Encroachment rates of the Mai Po mangal onto the mudflat. Values are the widths of the mangal (m) along 5 reference lines in Mangal B and Mangal A which was partially removed in the 1970's to accommodate fish pond construction, as shown in Figure A10.7.2.

| | Reference Line No. (Mangal) | | | | |
|---|---|---|---|---|---|
| Year | 1 (A) | 2 (A) | 3 (A) | 4 (B) | 5 (B) |
| 1945 | 315.3 | 349 | 146.4 | 123.9 | 101.3 |
| 1949 | 383.3 | 367.5 | 183.8 | | |
| 1954 | 212 | 235 | 212 | 212 | 181.5 |
| 1960 | 368.3 | 368.3 | 306.9 | 282.4 | 233.3 |
| 1969 | 370.8 | 384.6 | 315.9 | 260.9 | 274.7 |
| 1972 | 392 | 392 | 280 | 266 | 252 |
| 1975 | 406.3 | 415.8 | 256.8 | 330.7 | 66.2 |
| 1984 | 449.2 | 473.7 | 343 | 122.5 | 81.6 |
| 1987 | 471.1 | 491.3 | 370.7 | 137.9 | |
| 1990 | 422 | 517 | | | |
| 1991 | | | | 156.4 | |
| 1993 | | | | 172 | 291.6 |
| Mean m.yr$^{-1}$ | 2.2 | 3.5 | 4.7 | 1 | 3.9 |

Aerial photographs also yield useful data on the structure of the mangrove forest. Whereas in Mangal B a distinct zonation pattern is seen, none exists in Mangal A, which has a heterogeneous texture in the photographs. Many factors are thought to influence mangrove forest zonation patterns (e.g. physiology, topography, propagule structure, competition, seedling predation; Smith 1992), however the history of development impact in Mangal A (in the form of fishpond construction) show that Mangal A is approximately 18-23 years younger than Mangal B. The difference in age between the two stands is reflected in other parameters of forest structure, as shown above. Although not tested statistically, cursory comparisons of T4 (and Y1 and D1) and T2, T3 and T4, indicate that the older stand has generally lower tree density, higher mean stand diameter and higher basal area.

This information provides baseline data for future reference, but may also be used in impact assessment of Shenzhen River Regulation Project. Following mangrove removal at the present mouth of the River into Deep Bay, and construction of bunds and new River banks, mangrove colonisation of the mudflat adjacent to the River is likely, particularly at the upstream end of this section of works, and providing hydrography, water quality and sediment characteristics are not altered as a result of the works. The extent to which mangrove colonisation may occur may not be predicted at this time as local deposition of sediment is unquantified yet. Mangal recolonization may result in significant reductions in the area of mudflat at the River mouth. This is an area where significant numbers of waders have been seen (Leader, pers. comm. and during this study as described above). Habitat loss (mudflat) caused by the inadvertent creation of more of another habitat (mangal) by the Project is an issue that must be addressed.

Sedimentation models for this project predict that inputs of Shenzhen River-borne sediment will decrease as a result of the project, although during construction, sedimentation may reach approximately $4cm.yr^{-1}$, or 4 times the current estimated rate. From the data shown here, it is apparent that an increase in mangrove encroachment of the mudflat would be expected during the construction phase of this project. It is essential that the balance between mudflat and mangrove forest at Mai Po be maintained and mitigation measures, e.g., sedimentation traps, active management of the fringe mangroves, be carried out as part of the mitigation measures of this project. Deposition at this rate may influence the productivity of the mangrove forest, but is unlikely to cause mangrove death unless sediment is released as pulses in the short term during construction. The sediment size distribution of particles released during construction is currently unknown. Once this information becomes available, an assessment of its effects on mangroves must be made as fine marl deposited on mangrove roots is documented as causing mangrove death (Lugo and Snedaker 1974).

Loss of all or part of Mangal A is unlikely to affect water quality as mangrove derived organic matter from Mai Po is estimated to be <1% of the organic material in the Bay (Anderson, unpublished). Even with the implementation of water quality control ordinances restricting discharge of livestock waste and main trunk sewer systems, organic waste load reductions (from the Hong Kong side) are unlikely to be so great that mangrove material assumes an increased importance in the system. The water quality models predict little change in inputs to Deep Bay.

Fauna associated with Mangal A will be lost with that part of the habitat removed. Benthic fauna in Mangal A is more abundant than other sites (McChesney 1994), which may be a response to high organic loads in Mangal A.

Mangrove area removal is often mitigated by replanting programmes. In this case, history suggests that the mangrove will recolonise fairly rapidly, although it may take several decades before it attains the structure of a mature mangal. Replanting in another area as a compensation measure will probably remove mudflat area in addition to that to be colonised, and for this reason must be examined carefully. An optimal solution may be to design an appropriate river profile in this section of the River, in which mangrove replanting can occur (thus conserving habitat and compensating for organic matter loss) without sacrificing mudflat habitat.

Long term post impact monitoring programmes in Mangal A, using low altitude aerial photography and permanent transect with marked trees, would be advised, to monitor changes in mangal structure and extent, and to detect those changes caused by the River Regulation Project which may not be predicted.

### A10.7.5 Recommendations

The results of this study indicate that the main body of the mangrove forest at Mai Po has developed since the 1940's and has now attained the structure of a mature forest. In the north of the reserve, the forest was disturbed by illegal fish pond construction in the 1970's and although mangroves recolonized the area rapidly, the forest has not yet matured. Estimates of encroachment rates of the mangroves on the mudflat are given, which indicate that increased sedimentation during the construction phase of the project will cause increased mangrove expansion. From these findings, the following recommendations are made with respect to the Shenzhen River Regulation Project.

Sediment release during construction must be kept to a minimum by the use of sediment traps and any other possible means of reducing inputs of sediment to Deep Bay.

1. Actual sedimentation rates and mangrove encroachment onto the mudflat at Mai Po must be monitored during construction and operation of the project and mangrove encroachment actively curtailed if current mean rates are exceeded.

2. Replanting to mitigate for mangrove loss is not recommended in Mai Po.

3. Prior to starting construction of the project, data on the sediment particle size distribution must be gained, and assessed in terms of its potential for coating mangrove pneumatophores and stems and, therefore, causing mangrove loss or reduced production. Effects on mangrove fauna must be determined concurrently.

It should be noted that in 1988 it was recommended that a monitoring programme should be established to investigate 'siltation rates in the coastal mangroves' and 'changes in the area extent of mangroves... and mudflats' (Anon, 1988). Unvortunately these recommendations were not implemented - had they been, there would have been a considerable body of dta relevant to the present study, which would have enabled a more detailed interpretation.

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## A10.8 PRELIMINARY DETERMINATION OF DEEP BAY FOOD WEBS BASED ON STABLE ISOTOPE ANALYSIS

### A10.8.1 Introduction

The Terms of Reference (section A.1.ii). for the proposed Shenzhen River Regulation Project require that food web relationships be determined. The proposed project will improve water quality in the river such that organic loads, which are mostly derived from domestic and agricultural effluents, will be slightly reduced.The organic matter in the water column, whether derived from effluents, phytoplankton, benthic algal detritus or mangrove detritus, supports various benthic, epibenthic and pelagic fauna in Deep Bay, which form the food sources of resident and migratory waterbirds. Any impact of the proposed project on the production end of the food web will probably be reflected in higher trophic levels. Given the critical importance of Deep Bay to these birds and to other wildlife (Appendices 10.9 and 10.12) potential impacts of the project must be identified. To do this, however, an understanding of the resource utilization by species, i.e., the food web relationships of the system, must be gained. This is the aim of this study.

The food resources of benthic and pelagic organisms may be determined by gut content analysis, but there are several problems with this. The material in an animal's gut reflects that which it has ingested but not necessarily that which it digests and absorbs, e.g., microbial "stripping" by detritivores (Lopez and Levinton 1987). Some material, e.g., soft animal tissue, is rapidly broken down in the gut and although such food may form a significant fraction of the animals' diet, it is not seen in representative quantities in the gut. Gut contents only show a 'snapshot' of the animal's diet and may not indicate diet changes. Finally, many aquatic and marine detritivores, in particular, ingest fragmented material in water or sediments, the origin of which may be unknown (but see the work of Cammilleri 1991). For detritivores, the origin of their food source is often indeterminate.

The use of stable isotopes to track the diets of animals is now common, based on the finding that the stable isotope ratios of common elements in autotrophs, e.g., carbon and nitrogen, are both unique and mostly conserved through the food chain although some fractionation occurs through enzymatic discrimination (Boultton 1991). Carbon isotope ratios ($^{12}C/^{13}C$) are often used, but as the resolution of the method is improved with more isotopes, nitrogen isotope ratios ($^{14}N/^{15}N$) are generally used in tandem.

Material to be tested is either combusted to $CO_2$ (for carbon stable isotopes) or chemically converted to $N_2$ (for nitrogen stable isotopes) and the gases are introduced into a mass spectrometer. The peaks obtained are compared with those produced by a standard; Pee Dee Belemnite (PDB) for carbon and atmospheric $N_2$ for nitrogen. The isotope ratio of the sample is given as a comparison with these standards, in parts per thousand and is calculated by:

$$\delta X_{std} = (R_{sample} / R_{std} - 1) \times 1000$$

where $\delta X_{std}$ is the isotope ratio in $\delta$ units relative to the standard and $R_{sample}$ and $R_{std}$ are absolute isotope ratios of the sample and standard, respectively (Ehrleringer and Rundel 1989). PDB is a carbon source of marine origin, so $\delta X_{std}$ for, say, marine dissolved inorganic carbon, is often 0‰. The nitrogen content of, for example, leguminous plants with symbiotic nitrogen-fixing bacteria in root nodules approaches that of atmospheric nitrogen, so $\delta X_{std}$ in these, too, is close to 0‰ (Fry and Sherr 1989; Boultton 1991). Analytical variability associated with stable isotope analysis is low, at 0.1 to 0.3‰ (Gearing 1991).

The stable isotope ratios of autotrophs are unique because of enzymatic isotope discriminations during photosynthesis. The C3, C4 and CAM photosynthesis pathways have unique fractionation properties (ranges found are: C3, -23 to -32‰; C4, -9 to -16‰; CAM, -11 to -33‰; Ehrleringer and Rundel 1989). Phytoplankton carbon metabolism is also through the C3 cycle, but isotope ratios range between -18 and -30‰ (Boultton 1991). Some variation does occur in carbon isotope ratios, possibly owing to salinity and water use efficiency, soil water potential and dissolved $CO_2$ composition (Guy *et al.* 1980; Lin *et al.* 1991; Rau *et al.* 1991; Lin and Sternberg 1992). Owing to different metabolic pathways required for their construction, plant components may differ in their stable isotope composition, e.g., leaves are generally more $\delta^{13}C$ depleted than woody tissue (Gearing 1991).

Studies have shown that the stable isotope ratios of faunal tissue reflect those of its food, with some enrichment of heavy isotopes with each trophic step (Fry and Arnold 1982; Tieszen *et al.* 1983). For carbon isotopes, the enrichment is by 1-2‰ and for nitrogen isotopes it is by 3-5‰ (DeNiro and Epstein 1978; Monteiro *et al.* 1991; Sholto-Douglas *et al.* 1991; but see Macko 1982, who did not detect enrichment in amphipods). Stable isotope analysis gives a time-integrated (over the turnover period of the tissue) picture of the animals' diet (Rau *et al.* 1983). This is a distinct advantage over the 'snapshot' given by gut content analysis. Problems do exist, however. Like plants, different tissues have different stable isotope ratios, e.g., lipids are low in $\delta^{13}C$ compared with muscle (Wada *et al.* 1991). If two or more possible food sources are present which have similar isotope ratios, it may not be possible to distinguish between them. The use of multiple isotopes, e.g., C, N and S, and concurrent studies of the morphology, behaviour, natural history and gut contents are advocated to overcome these problems (Fry and Sherr 1989; Gearing 1991). A preliminary stable isotope analysis at Mai Po was successful in tracking the food of two species (Anderson, unpublished data) and has been used in species and system level studies of coral reefs (Thomas *et al.* 1993), a lake (Yoshioka *et al.* 1994), estuaries (Wada and Cahoun. 1993), Antarctic and Benguela current pelagic food chains (Monteiro *et al.* 1991; Sholto-Douglas *et al.* 1991; Rau 1993), salt marshes (Haines 1977 check date - see References) and mangroves (Rodelli *et al.* 1984; Fleming *et al.* 1990). It has also been used to determine the origin of riverine and estuarine sediments and organic matter (Victoria *et al.* 1992; Mulholland and Olson 1992).

The aim of this study was to answer the following questions:

- What is the dominant food source of the fauna of the Deep Bay mangal and mudflat?
- Of what origin is the particulate and dissolved organic matter in the tidal waters of Deep Bay?
- What, therefore, are the probable impacts of the project?

### A10.8.2 Methods

The following material was collected from the mangal or mudflat at Mai Po, during 1994.

#### A10.8.2.1 Autotrophs

Senescent leaves of the mangroves *Kandelia candel* and *Avicennia marina* were collected from 4 litter traps placed at two sites under the canopy in the mangal and left for one week. Leaf material was dried at 80°C then crushed to a fine powder in an acid-washed mortar and pestle. The benthic algae *Enteromorpha crinata* was collected from dense mats formed on the mudflat adjacent to the mangal. Collected samples were rinsed in freshwater through a 0.5mm mesh sieve and all sediment and animals removed. Samples were dried at 80°C then crushed as above. Benthic diatoms (unknown species) were collected from samples of surface mud from the mudflat. This was spread to a depth of 3cm in plastic drying trays. Glass beads were placed on a piece of plastic mesh in the surface of the mud and the trays placed under bright natural or artificial light. Diatoms migrate up towards the light in the film of water covering the beads and are collected in this manner. After at least 12 hours the beads were removed and washed in deionised, distilled water. The rinsings were centrifuged at 2500rpm for 5 minutes to remove contaminating sediment and the supernatant filtered under vacuum through pre-ashed glass fibre filter paper. This was dried as above and crushed in an acid-washed mortar and pestle.

#### A10.8.2.2 Heterotrophs

The following animals were collected from the mangal, mudflat or tidal waters. Each was collected only once; however, for each species, at least 5 individuals were collected (except those marked * which were difficult to trap, in which case sufficient tissue to give the minimum testable, i.e., 0.4g, was collected).

The mangrove crab *Chiromanthes bidens*
The mudflat crab *Macrophthalamus* sp.*
The filter-feeding polychaete
The omnivorous polychaete *Dendronereis* sp.
The bivalve *Sinonovacular constricta*
The mudskipper *Periophthalamus cantonensis**
The shrimp *Metapenaeus ensis*

All animals except the polychaetes were killed by freezing, rinsed of contaminating sediments and dissected to remove the gut and major bones if necessary. The polychaetes were retained pending sorting in distilled water in the refrigerator, which also caused them to expel remaining food particles from the gut. The guts of those that had not purged were dissected out. All samples were dried and crushed as above.

#### A10.8.2.3 Other organic matter

Dissolved organic matter (DOM) and particulate organic matter (POM) from ebb and flood tides was collected in January, March, June and September 1994. Three x 4.5l acid washed collection vessels were filled with subsurface water 30 minutes before HW and another 3 filled 30 minutes after HW. Water was refrigerated in the laboratory pending processing, which occurred within 12 hours of collection. Water was filtered through pre-ashed, pre-weighed glass fibre filter paper in acid-washed vacuum filtration equipment. Filter papers were dried and crushed as above.

Approximately 2l of water from each sample were filtered under a slight vacuum (<5psi) to prevent dissolution of gases and the filtrate collected. This was stored in acid-washed bottles that were completely filled, then frozen for subsequent retrieval of dissolved organic compounds.

For conversion and collection of carbon compounds, the same method of automatic flow-through techniques, which is the UV-persulphate oxidation method (Bauer *et al.* 1991) has been used. Organic matter in 5 - 10ml of water was oxidized by persulphate in the presence of UV light, to $CO_2$. Silver nitrate (0.5ml) was added for samples with salinity greater than 10‰ as chloride ions slow the oxidation procedures. $CO_2$ was released from solution by heating and collected by adsorption on to soda lime pellets. These were sealed in glass tubes to prevent contamination with atmospheric $CO_2$. Blanks, using distilled water, were also undertaken.

For conversion and collection of nitrogenous compounds, the Kjeldahl procedure was followed, which, in the presence of strong acid and a catalyst, changes organic nitrogen into ammonia. This is then released by neutralizing with strong alkali and collected by warming to 40°C and absorbing the gas released on to acid-spotted glass fibre filter paper (Shearer and Kohl 1993). Again, blanks were undertaken using distilled water.

All material was sent to the University of Utah's Stable Isotope Research Facility for Environmental Research. Carbon and nitrogen stable isotope values for three replicates of each material were measured.

It was not possible to carry out analyses of all sources of organic matter in Deep Bay and the experiment omits data from phytoplankton, domestic and agricultural effluents and terrestrial run-off. Published values for these are referred to for comparison with the results obtained.

## A10.8.3 Results

Data obtained are shown in Table A10.8.1. Samples were successfully analysed for most materials, and the data show that three replicates were apparently sufficient as the variability in most samples is low. The notable exception is $\delta^{15}N$ data for POM. As the samples were crushed to an apparently homogeneous, powdered state, and similar variability is not exhibited in the $\delta^{13}C$ values, the reason for the high variability in most of these samples is unknown. Further replication would be required to reduce these standard deviations.

For $\delta^{13}C$ determination of DOM, insufficient was collected for three replicates, therefore, one was collected from each sample. Some breakage of glass tubing occurred *en route* to Utah, which may have led to contamination of the samples by atmospheric $CO_2$. The blank samples, however, which also broke, did not contain sufficient $CO_2$ for analysis so it was assumed that contamination did not occur (C. Cook, pers. comm.). Little nitrogenous material was extracted from DOM for analysis and these data are also derived from single samples. A blank sample was analysed using distilled water. It was found to have a considerably different isotopic signature from the tidal water DOM, indicating the presence of some contaminating nitrogen (perhaps atmospheric) during the extraction procedure. Without further replication, it is not possible to determine the significance of contamination in the samples, and all data is presented as is Table 10.8.1.

POM in tidal waters did not vary much in $\delta^{13}C$ contents throughout the tides and months sampled (Figure A10.8.1). To test for significant differences between ebb and flood tides and between months, an ANOVA was carried out on log-transformed data. No differences were found (ANOVA; $p > 0.05$) and transformation did not affect the outcome. Assuming the values obtained for DOM are representative of the means of larger samples, it may be concluded that DOM is more variable between tides and months than POM. DOM is also more enriched in the heavy carbon isotope. POM $\delta^{15}N$ values were variable, as described above (Figure A10.8.2) and, when analysed (ANOVA on log-transformed data), did not show significant differences between samples (ANOVA; $p > 0.05$). Transformation did, however, affect the outcome. This is probably a result of insufficient replication such that variation in some samples remains high and data is non-normal (tests for homogeneity of variance or normality were not carried out). Further replication may have revealed differences between flood and ebb tides or between monthly samples. DOM nitrogen signatures are depleted in the heavy N isotopes, as shown in Figure A10.8.3. It is possible that this data is biased towards the heavy isotope as enrichment observed in blank samples is not taken into account, Some fractionation may occur during extraction (C.Cook, pers. comm.), but its extent and significance is not known.

Table A10.8.1 Results of the stable isotope analysis of key autotrophs, heterotrophs and water-borne organic matter in Deep Bay.

| Species | mean $\delta^{13}C$ | s.d. (n=3) | mean $\delta^{15}N$ | s.d. (n=3) |
|---|---|---|---|---|
| 1. Autotrophs | | | | |
| *Kandelia candel* | -27.59 | 0.11 | 6.2 | 0.58 |
| *Avicennia marina* | -27.57 | 0.09 | 10.46 | 1.08 |
| *Enteromorpha crinata* | -21.19 | 0.05 | 4.07 | 0.48 |
| Benthic diatoms | -24.79 | 0.265 | 5.93 | 1.61 |
| 2. Heterotrophs | | | | |
| *Chiromanthes bidens* | -23.82 | 0.17 | 10.56 | 0.52 |
| *Macrophthalamus* sp. | -15.78 | 0.08 | 9.86 | 0.4 |
| Sabellidae polychaete | -22.03 | 0.03 | 2.96 | 0.24 |
| *Dendronereis* sp. | -19.51 | 0.25 | 6.2 | 0 |
| *Sinonovacular constricta* | -16.69 | 0.41 | 3.73 | 0.09 |
| *Periophthalamus cantonensis* | -20.32 | 0.18 | 9.3 | nd |
| *Metapenaeus ensis* | -18.98 | 0.016 | 19.16 | 0.49 |
| 3. Organic matter | | | | |
| POM -flood tide - Jan | -24.67 | 1.24 | 1.35 | 1.15 |
| POM - ebb tide - Jan | -25.33 | 0.59 | 1 | 0 |
| POM -flood tide - Mar | -25.32 | 0.63 | 2.5 | 1.25 |
| POM - ebb tide - Mar | -24.99 | 0.91 | 2.47 | 0.59 |
| POM -flood tide - Jun | -25.07 | 0.4 | 4.46 | 0.32 |
| POM - ebb tide - Jun | -25.05 | 0.35 | 3.2 | 0.8 |
| POM -flood tide - Sep | -25.62 | 0.15 | 0.38 | 1.04 |
| POM - ebb tide - Sep | -25.61 | 0.28 | 1.43 | 1.11 |
| DOM -flood tide - Jan | -18.6 | nd | -11 | nd |
| DOM - ebb tide - Jan | -16.9 | nd | -7.5 | nd |
| DOM -flood tide - Mar | -20.7 | nd | -13.5 | nd |
| DOM - ebb tide - Mar | -22 | nd | -1.9 | nd |
| DOM -flood tide - Jun | -22.4 | nd | -4.6 | nd |
| DOM - ebb tide - Jun | -23.7 | nd | -11.7 | nd |
| DOM -flood tide - Sep | -18.8 | nd | -12.2 | nd |
| DOM - ebb tide - Sep | -18.8 | nd | -9.1 | nd |

nd =not determined as only one sample was obtained.

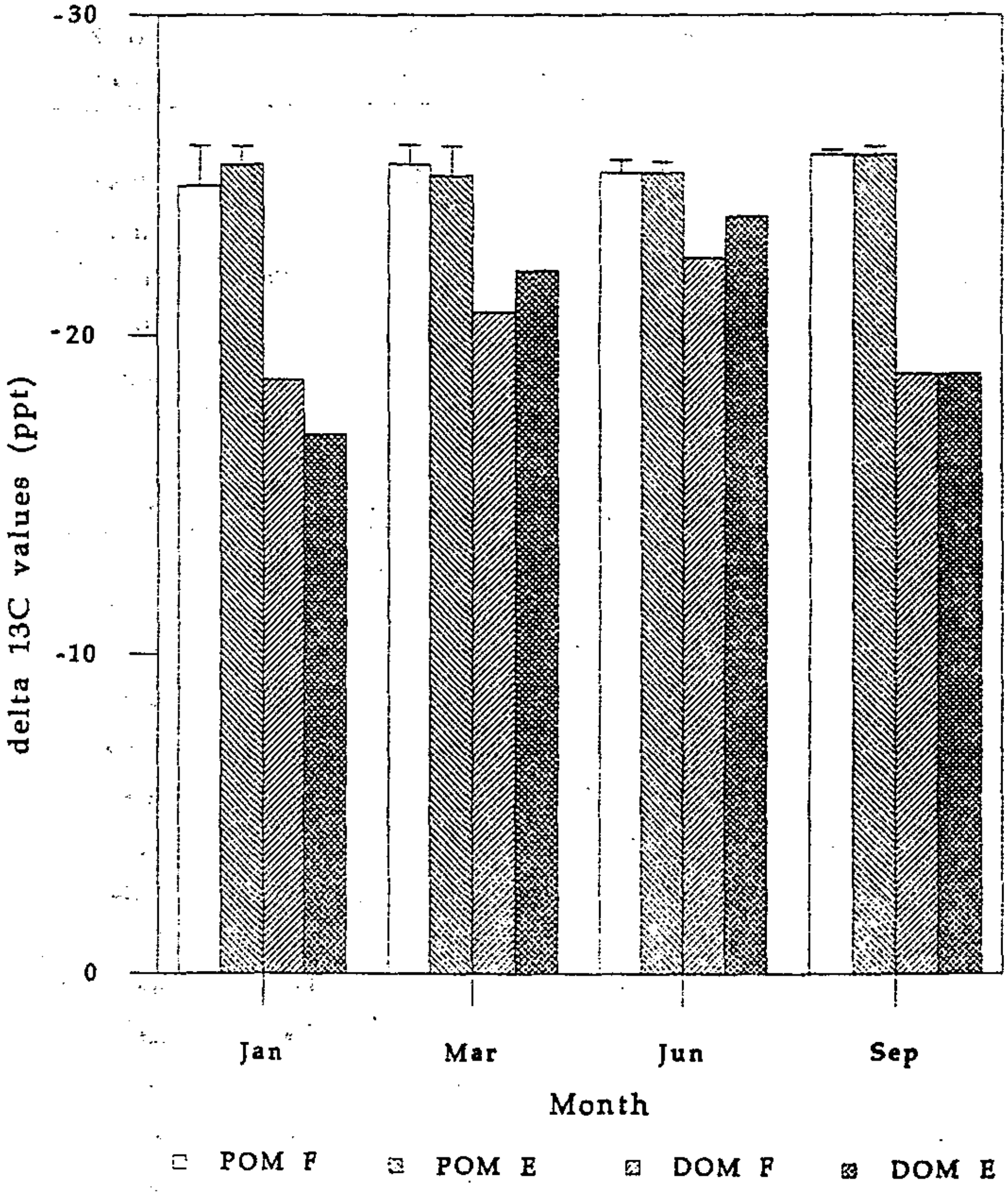


Figure A10.8.1 Data $\delta^{13}C$ values for POM (+SD) and DOM from ebb (E) and flood (F) tides at Mai Po in January, March, June and September 1994

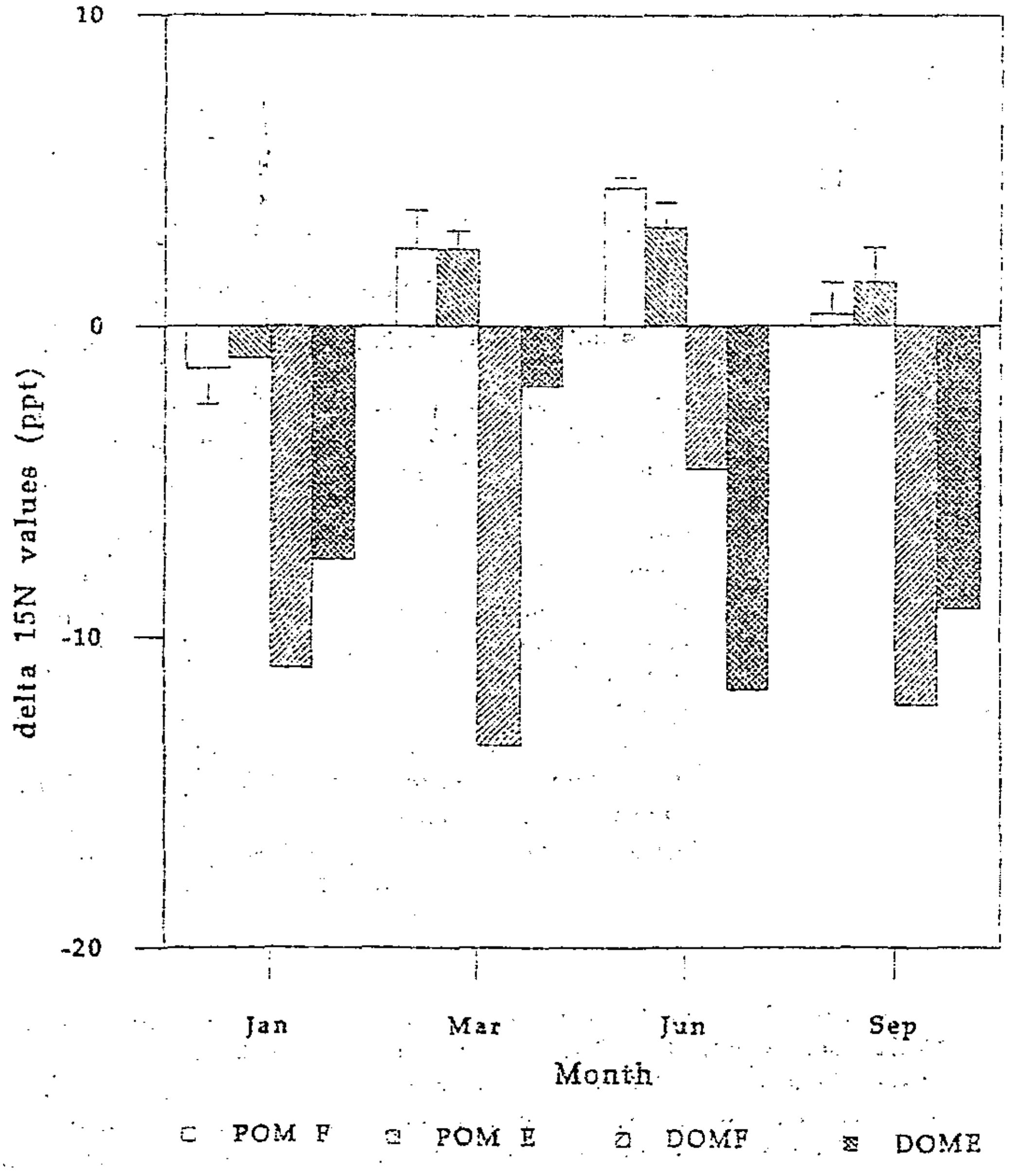


Figure A10.8.2 $\delta^{15}N$ values (+SD) from POM and DOM in flood(F) and ebb(E) tides at Mai Po in January, March, June and September, 1994

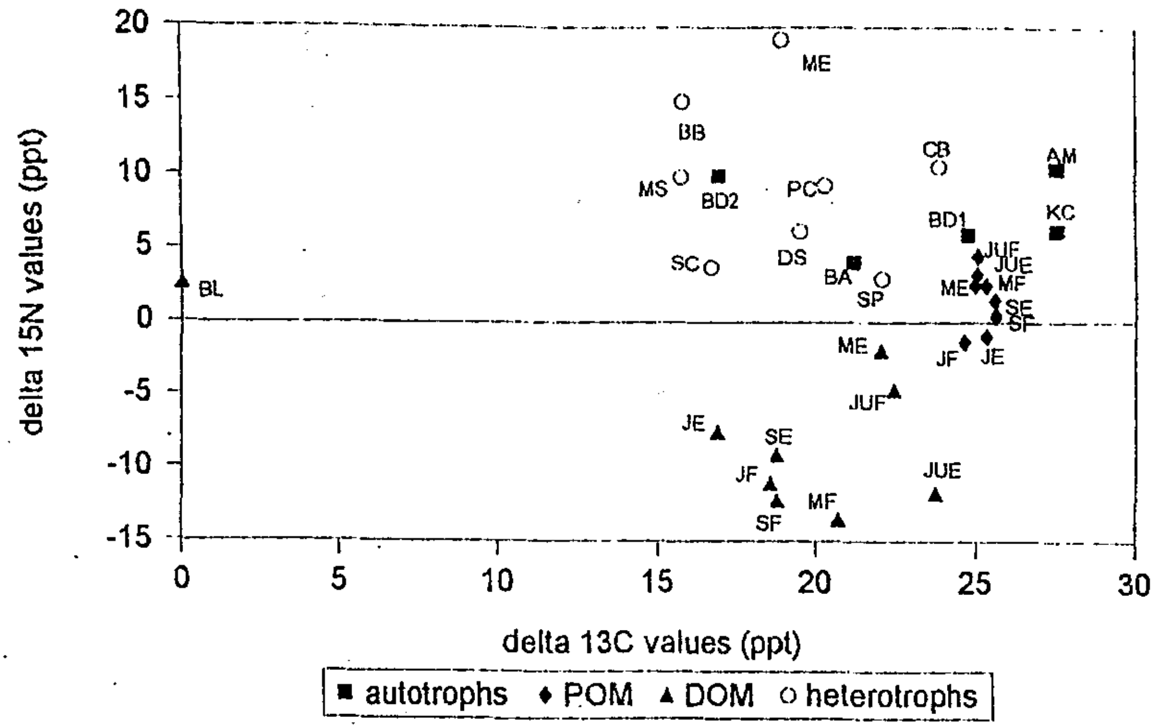


Figure A10.8.3 Results of stable isotope analysis for $\delta^{13}C$ (plotted as positive values for graphical clarity) and $\delta^{15}N$ isotopes in some autotrophs, heterotrophs and organic sources in Deep Bay. Mean values in ‰ are plotted. Values for DOM are given for $\delta^{13}C$ only.

Autotrophs: AM = *Avicennia marina*; KC = *Kandelia candel*; BA = benthic alga (*Enteromorpha crinata*); BD1 = benthic diatoms recorded here although contamination may have occurred; BD2 = approximate value for benthic diatoms obtained from the literature (Haines 1977; Rodelii *et al.* 1984; Wada 1993).

Heterotrophs: CB = *Chiromanthes bidens*; SP = Sabellidae polychaetes; DS = *Dendronereis* sp.; SC = *Sinonovacular constricta*; PC = *Periophthalmus cantonensis*; BB = *Boleophthalmus boddaerti* (data from Anderson, unpublished); ME = *Metapenaeus ensis*; MS = *Macrophthalamus* sp.; POM: J = January; M = March; JU = JUNE; S = September; F = Flood tide; E = Ebb tide.

Few data on $\delta^{15}N$ values of natural materials are available in the literature for comparison with for the values obtained here. The $\delta^{13}C$ values of several species were, however, similar to those obtained by Rodelli *et al.* (1984) in a Malaysian mangal. The comparable values are shown in Table A10.8.2. Only one type of material was considerably different from published values. Benthic diatoms in this study had $\delta^{13}C$ values of -24.79, considerably more negative than the mean values of -17.8 to -16.2 reported from the Malaysian study and others (Haines 1976; Rodelli *et al.* 1984). Mean values for each type of material examined are shown in Figure A10.8.3.

Table A10.8.2 $\delta^{13}C$ values obtained for various species in a Malaysian mangrove system by Rodelli *et al.* (1984), which are comparable to those obtained here.

| Species | $\delta^{13}C$ value obtained (‰) |
|---|---|
| Mangrove leaves, various species | -24.5 to -28.5 |
| Benthic algae | -18.6 to -22.5 |
| Mangrove crab *Sesarma* spp. | -27.2 |
| Polychaete *Nereis* sp. | -18.9 |
| Mudskipper *Periophthalamus* sp. | -22.9 |
| Prawn *Metapenaeus* sp. | -18.4 to -22.3 |

## A10.8.4 Discussion

The carbon and nitrogen stable isotopes ratios of key autotrophs, heterotrophs and organic matter types were determined successfully and the data may be used to answer the questions noted in the introduction.

1. *Of what origin is the particulate and dissolved organic matter in the tidal waters of Deep Bay?*

Mean POM content of tidal waters was $4.2 \pm 0.63 mg.l^{-1}$. POM in Deep Bay may be derived from phytoplankton, mangrove-derived material, river-borne terrestrial material and organic effluents. Marine-derived organic material may also be present but probably in small quantities as Deep Bay and environs are predominantly estuarine. DOM may be of the same sources, being solutes and exudates from the lining or decomposing material. Assuming that the range of values recorded for $\delta^{15}N$ of POM is representative of the range that would be found given increased replication, Figure A10.8.3 shows that POM in tidal waters is of relatively constant isotopic signature, and therefore, relatively constant composition throughout the year. Phytoplankton $\delta^{13}C$ is reported to range between -20 and -22‰ and $\delta^{15}N$ ranges between 8.2 and 11.7‰ in marine systems although estuarine species may be more negative (Fry and Sherr 1989; Sholto Douglas *et al.* 1991). River-borne terrestrial material probably has similar $\delta^{13}C$ and $\delta^{15}N$ values to those of terrestrial plants (-25 to -30‰ and around 0‰, respectively; Wada *et al.* 1993). Organic effluent from domestic and agricultural sewage is enriched in $\delta^{15}N$; 10-14‰ has been reported by Wada *et al.* 1993. Petersen and Fry (1987) note that terrestrial plants have $\delta^{15}N$ values which range between -8 and 3‰. With enrichment occurring via the diets of humans and agricultural animals, when the material enters the water column as sewage its values would be expected to lie between 6 and 13‰.

Mangrove-derived material is unlikely to constitute a large proportion of POM. No differences were detected between samples from ebb and flood tides which were collected adjacent to the Mai Po mangrove forest, suggesting that either outwetling of mangrove-derived material did not occur or it occured in sufficiently small quantities to be masked by the volume of organic material already present in the water column.

Evidence from another study (Anderson, unpublished data) suggests that mangrove-derived organic matter from Mai Po accounts for $< 1\%$ of organic inputs into the Bay. This is clearly supported by these results.

Both the $\delta^{15}N$ and $\delta^{13}C$ values of POM suggest that phytoplankton is not a significant contributor to the POM pool in Deep Bay. It is interesting to note, however, that although not found to be significantly different from other samples, $\delta^{15}N$ values of POM from the January sample, which was taken at night, when phytoplankton biomass is at its lowest, were negative. Whether this is a seasonal, rather that diurnal trend is unknown; corresponding changes in $\delta^{13}C$ were not observed. A study of plankton dynamics in Deep Bay is necessary which, as yet, has not been carried out. Estimates of their productivity lie in the range of 4 to 40tC/year not cited (ERM 1986), which indicates the degree of uncertainty over their role. EPD (1987) notes that chlorophyll a values are low in the Bay, despite high nutrient contents, as high turbidity inhibits algal production.

The results suggest that allochthonous inputs (river-borne terrestrial material and organic effluents) form most of the POM in Deep Bay. $\delta^{13}C$ values are similar to what would be expected from terrestrial sources. $\delta^{15}N$ values are low but $> 0$, suggesting a mixture of enriched and less-enriched material. EPD (1987) notes that good mixing occurs in Deep Bay. These data are, therefore likely to be representative of the POM throughout the water column. A study of the Nanakita river estuary in Japan revealed a cline in the influence of terrestrial material in the POM pool along the river, with marine sources becoming more dominant towards its mouth (Wada *et al.* 1993). Whether the same would be found within Deep Bay, given its good mixing properties, is unknown. A method is available for estimating the proportions of two sources in one sample (the two-end member model; Shearer and Kohl 1993). Elucidation of isotope ratios of all possible sources of organic matter in Deep Bay, taking into account possible seasonal changes, was beyond the scope of this study.

The $\delta^{13}C$ values for DOM are more variable than POM and generally lower, indicating enrichment in the heavier isotope. The values do, however, indicate a terrestrial origin for the dissolved material. With the current high organic pollution and faecal bacterial loads in Deep Bay, it is likely that the DOM measured here is a product of decomposition processes of POM. Changes in isotopic composition of materials as they undergo saprophytic decay have not been examined in depth. Some authors have noted, however, a slight increase in $\delta^{13}C$ values between decomposing material and its living form (Haines 1977,Wada *et al.* 1993). This suggests that decay product which are incorporated into saprophyte tissue or lost as solutes may be enriched in the heavy isotope. These products themselves form the basis of a food chain which begins with the absorption of dissolved substances into the metabolism of various microbes (the so-called 'microbial loop'). Isotopic changes through this pathway have not been examined and are probably complex.

It can be concluded therefore, that while the stable isotope signatures of organic matter in tidal waters do not indicate one dominant source, there is evidence to suggest that river-borne organic material and organic effluents from domestic and industrial sewage are the main sources of organic matter in Deep Bay. Autochtonous inputs from mangroves and phytoplankton are apparently low.

2. *What is the dominant food source of the mangal and mudflat fauna of Deep Bay ?*

The aim of this study was to elucidate the food web relationships of fauna in Deep Bay which are considered to be key species in that they form the food of the resident and migratory birds which utilize Mai Po. Stable isotopes have been used in such studies in the past (Petersen and Fry 1987) but, as pointed out by Gearing (1990), these studies are most useful when combined with other ecological data on the species in question. Where possible this approach is used here to determine the food web relationships of the species selected for study.

The autotrophs in Deep Bay which were examined here had values similar to those reported elsewhere, as shown in Table A10.8.2. The exception to this was the values obtained for benthic diatoms, which were considerably different from published values. $\delta^{13}C$ values for benthic diatoms are reported to lie between -16.2 and -17.9‰ (although some were cultured for measurement; Rodelli *et al.* 1984), while Wada *et al.* (1993) report $\delta^{15}N$ values of 14.6 for benthic algae. The proximity of the values obtained here to those obtained for POM suggest that some contamination of organic matter may have occurred, despite the efforts to the contrary. (The values are, interestingly, not in keeping with data obtained elsewhere from Mai Po (Anderson, unpublished data) for the mudskipper *Boleophthalamus boddaerti*, which, from a detailed study of its ecology, is known to consume diatoms (Yan, pers. comm). Collection of diatoms has been noted as being problematic, requiring culture in some cases ( Rodelli *et al.* 1984). Repetition of this investigation using an improved method of collection would be desirable given these concerns.

The species selected have a variety of feeding habits; they include filter feeders, deposit feeders, detritivores and predators. As described above, the trophic level at which a species feeds does, through enrichment, determine the distance between its isotopic signature and that of the autotroph(s)/organic matter which form the basis of its food chain. In the analysis of food web patterns presented here, it should be noted that the species selected for study were sampled once. By virtue of having a high population turnover, a generalistic diet and /or different dietary requirements at different stages in the life cycle, some species may show different isotopic signatures with age or season. As these issues were not addressed here, in this respect, this study must be considered preliminary.

The mangrove crab, *Chiromanthes bidens*, is known to feed on decaying mangrove leaves (Lee 1989, Kwok, pers. comm.) although it does also deposit feed and scavenge. Its isotope values are close to that found for senescent *Avicennia marina* mangrove leaves. Enrichment in $\delta^{13}C$ has occurred by approximately 3‰ but little has occurred in $\delta^{15}N$. Clearly the mangrove litter forms the major part of the diet of this species although the differences with expected enrichment rates support the observation of occasional diversions in the diet. The values obtained are similar to those obtained in another study (Anderson, unpublished).

The Sabellidae polychaetes, which occur at high densities, are embedded in the mud and filter feed at HW through retractable ciliated radioles, are apparently consume POM in the water column, as shown in Figure A10.8.3. *Dendronereis* sp., which is a burrowing polychaete equipped with two teeth in the proboscis, has an isotopic signature which is somewhat removed from the autotrophs, but is not so enriched in either isotope to be obviously predatory. It is, in fact, thought to be omnivorous, scavenging in the mud and predating upon other benthic invertebrates. The enrichments it exhibits (i.e. 5‰ in $\delta^{13}C$ and 1~2‰ in $\delta^{15}N$) suggest a mixed diet, but also that much of its food supply is dependent on POM and possibly benthic algae. This worm occurs in extraordinarily high densities in the mud and is thought to be a common prey item for several species of waterbird (see Appendices 10.9 and 10.12).

The mudskipper *Periophthalamus cantonensis* shows considerable enrichment in both carbon and nitrogen isotopes. This would be expected from a predatory species, which it is thought to be (Chan 1990). Once more, POM and possibly benthic algae apparently form the basis of the food chain for this species.

The bivalve *Sinonovacular constricta* shows considerable enrichment in $\delta^{13}C$ from the sources of organic matter examined. It is a filter feeding species that burrows to depths > 10cm. Its source of nutrition is not apparent; its values lie outside those that would be expected from trophic interactions with the material examined here. It is possible that it takes in bacteria or other microbes, or strips them from POM in the water column, but as this aspect of the food web was not investigated herein and, in fact, has received little attention elsewhere, its role in the food web remains unclear.

The mudflat crab *Macrophthalamus* sp. is a deposit feeder and has an isotopic signature greatly removed from those of the autotrophs and organic matter examined here. It is similar, however, to the expected true value of benthic diatoms (Figure A10.8.3) and it is, therefore, probably extracting these from the mud for nutrition, as does the second mudskipper, *Boleophthalamus boddaerti*.

Finally, the shrimp *Metapenaeus ensis*. These are farmed in the Mai Po gei wai's for economic gain and are commonly associated with mangroves. The sample for this collection were small-sized individuals collected from a tidal channel in the mangrove forest at Mai Po. The tissue shows a signature which is highly enriched in $\delta^{13}C$ and $\delta^{15}N$, which, as in the case of *Sinonovacular constricta*, is outside the range expected from trophic interactions with food chains originating from the organic matter recorded here. Possible food sources include phytoplankton, zooplankton, or a mixture of both, since published values indicate that phytoplankton may have large $\delta^{15}N$ values. Such diets for mangrove-associated shrimp have been reported elsewhere, as have diets based upon organic aggregates of microbes. POM and diatoms. Still others have recorded mixed diets, with the majority consisting of meio or micro-fauna (Robertson *et al.* 1992). Further work is clearly required before the diet of this species may be elucidated. The ecology of the shrimp assemblage of the gei wai has been studied by Leung (1991) and a comparison between diets of those inside and outside the gei wais would be helpful in determining the requirements of this species and the impacts of this, or future developments in and around Deep Bay.

3. *What are the probable impacts of the Shenzhen River Regulation Project on the food webs in Deep Bay?*

The results of the food web analysis presented here indicate that, as might have been predicted from quantitative data on the organic inputs to Deep Bay, the system is driven largely by the river-borne material of terrestrial origin and organic effluent. Autochthonous inputs are apparently low, although some (mangrove detritus and benthic diatoms) support specific fauna. It is interesting to note that the species found here to be reliant on POM in tidal waters, which consists of river-borne material and effluent, are the ones noted in Appendix 10.9 to occur in some parts of the mudflat at high densities. This supports the conclusion that the structure of the benthic faunal assemblage is influenced by the pollution inputs such that tolerant species are favoured.

Results of the hydrology and water quality models for the Shenzhen River Project state that the project will result in slightly improved water quality from the Shenzhen River. Had the Project resulted in significantly improved water quality in terms of organic inputs, this study indicates that several species which depend on these inputs would have been affected. Such a scenario would have had knock-on effects on the carrying capacity of the mudflat for water birds. Increases in organic inputs into Deep Bay, on the other hand, would be expected to enhance the dominance of those species dependent on it providing other parameters, e.g. DO, remain favourable, to the detriment of less-tolerant species. As described in Appendix 10.9, however, the risk of eutrophic collapse under these condition is considerable.

The magnitude of changes predicted to arise from the project is small and unlikely to affect the food web as described here. As described above, this study must be treated as a preliminary one; it was not possible to sample all sources and consumers of organic matter in the system (leading to incomplete conclusions for two species). As development proceeds around Deep

Bay, however, further work may elucidate more links in the food web and add to that gained here.

To conclude, this study has used stable isotope analysis of carbon and nitrogen to track organic matter flow and utilisation from and to a selection of species in Deep Bay. In most cases this was possible, and the results show that, of the 7 heterotrophs examined, three relied upon POM and river-borne organics, one consumed mangrove detritus and one fed upon diatoms. The diets of two species require further elucidation. As only slight changes in water quality and conditions are predicted as a result of this project, little change in food web structure is expected.

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## A10.9 ECOLOGY OF BENTHIC INVERTEBRATES IN THE MAI PO MUDFLATS, INNER DEEP BAY

### A10.9.1 Introduction

Inner Deep Bay is unique in the Pearl River Estuary in that it is a spur-shaped bay in the otherwise funnel-shaped estuary, highly protected from wind and wave energy. Its role as a potential nursery for the region's fisheries has only begun to be investigated (e.g. D. Vance, pers. comm.). The role of its intertidal mudflats for tens of thousands of migratory waterfowl annually is better understood. These migrants depend on the food resources to fuel their movements between breeding grounds as far north as Siberia, and wintering areas as far south as New Zealand. Sixteen species of waterbirds are abundant enough in Deep Bay to consider the site internationally important according to the criteria of the Ramsar Convention, to which both the People's Republic of China and the United Kingdom are signatories. Numbers of birds increase and new species arrive every year. Bird watchers from around the world visit Deep Bay to see these migrants, and there is potential to increase ecotourism dollar earnings.

Urbanisation, industrialisation, and agriculture surrounding Deep Bay threaten all of the Bay's ecological roles, primarily through threats of habitat loss and water pollution.

This technical appendix sets out the evidence, largely from data collected during the Shenzhen River EIA, that suggests the intertidal mudflats may be close to their carrying capacity with respect to waterbirds. Opportunities for additional birds to utilise the food resources seem limited. Section A9.3.1 reports the results of mudflat and mangrove monitoring. The clams, worms, snails, and crabs that the birds harvest are distributed across the mudflats such that key food animals are more abundant, or their body size is larger, away from the Shenzhen River mouth. The Shenzhen River is the primary source of pollution entering Deep Bay. Pollution threatens food resources via increasing pollution loads reaching the mudflats, causing eutrophication earlier in the year, when waterbirds are particularly stressed to fuel up for their journeys.

Section A9.3.2 presents the results of predator exclusion manipulations. These data suggest that birds are able to harvest most of the food that the mudflat provides. Habitat loss threatens food resources via erosion of the flats, deposition of thick blankets of sediment, progradation of the mangrove forest, or changes in the sediment grain sizes deposited across the mudflats.

### A10.9.2 Purpose

The investigation of the ecology of invertebrates on the Mai Po mudflats, Inner Deep Bay had two purposes: first, to describe existing conditions, providing baseline data against which to determine environmental changes resulting from the project; and second, to predict ecological implications owing to the construction and operation of the project.

The study comprised three tasks: first, monitoring the distribution, abundance, and biomass of invertebrate benthic infauna in the mangroves and mudflat at Mai Po; second, predicting carrying capacity of the mudflat through predator exclusion manipulations; and third, measuring the abundance, distribution, and biomass of crabs on the mudflat.

### A10.9.3 Methods

#### A10.9.3.1 Mangrove and mudflat benthos monitoring

The abundance and biomass of benthic fauna on the mudflat and in the mangrove was monitored four times, in January, March, May, and August, 1994. Table A10.9.1 outlines the monitoring methods.

Table A10.9.1 Methods for Mudflat and Mangrove Benthic Monitoring

| Task | Methods | Notes |
|---|---|---|
| Sampling location and frequency | A two mudflat and three mangrove transects established<br>B stations fixed along each transect<br>C sampled in January, March, May, and August | A see Figure A10.9.1 for locations<br>B samples from within about 20 $m^2$ at each station, except January samples at ET1 which are within 200 metres of subsequent samples, and August samples at RBO and RB3, which are within 500m of their previous locations<br>C stations CH1 and ET3 only sampled in January |
| Replicate core sampling | 5 cores at each station except 4 cores at RBO, RB3, 450, CH1, ET3 in January | All cores 10cm diameter, 20cm deep on mudflat, 15cm deep in mangrove |
| Preservation | A mudflat samples<br>1 killed in 5% pH-neutralized (hexamine) formalin<br>2 preserved in 70% ethanol<br>B mangrove samples<br>1 killed in 5% pH-neutralized formalin<br>2 rose bengal stain added to help see worms<br>3 preserved in 70% ethanol | AFDM not affected by this method (McChesney unpublished; Leuven *et al.* 1985.) |
| Sieving | A 1mm mesh in January<br>B 900 micron mesh used subsequently | Finer mesh selected to recover Capitellid polychaetes and oligochaetes |
| Sorting to morphospecies | Beneath 6X binocular microscope | |
| Biomass determination | A dry weight determined for each morphospecies large enough to weigh, smaller species lumped in order to obtain a mass large enough<br>B AFDM determined by Peking University<br>C benthos with calcareous skeletal components digested overnight in 10% HCl prior to determining biomass | |
| Determining average size | Slope of linear regression between biomass and abundance | Standard error of Y estimate available to estimate uncertainty |
| Productivity | Methods in Crisp (1971) | Data from 1992-93 (McChesney unpublished) |

Small cores, 7cm in diameter and 100mm deep, were collected at the same time as benthos samples to determine particle size distribution and total organic carbon. Sediment cores were dried in the oven at 80 degrees Celsius, then transported to Peking University for particle size distribution and total organic carbon determination.

### A10.9.3.2 Predator exclusion manipulation: carrying capacity of the mudflat

The mudflats of Deep Bay feed as many as 50,000 birds at any time (Hong Kong Bird Watching Society midwinter waterfowl counts). To escape predators, the benthic prey burrows into the mud, camouflages itself, or depends on swift avoidance behaviour. Only a fraction of the entire standing stock of benthos is available to birds at any instant (e.g. Evans 1979; Piersma 1987).

Cages were erected to prevent birds from foraging on patches of mud but to allow other predators (e.g. fish at high tide, crabs) to forage. Bamboo sticks about 50cm long were inserted deeply into the mud to resist tidal currents, so that only 20cm of the sticks were above the surface. Sticks were placed 1m apart, and two strings were tied between each stick. One string was 15cm above the mud, the other 4cm above the mud. Cages were square and 5m on a side. The original design included two strings across the top of the cage from corner to corner, but after the first month when these diagonal strings stretched in the wind and water and laid ineffectively on the surface, they were eliminated from subsequent cages. Table A10.9.2 outlines the methods used in the predator exclusion manipulations.

Previous work with predator exclusion cages in Deep Bay (McChesney 1993a) was insufficiently powerful to detect the effect of predation, so treatment replication was increased for this study.

### A10.9.3.3 Crab program

Collecting samples with a corer is ineffective at catching the larger swift and mobile crabs living on the mudflat. Some migratory birds, including Eurasian Curlew (*Numenius arquata*), Whimbrel (*N. phaeopus*), Terek Sandpiper (*Xenus cinereus*), and the endangered Saunders' Gull (*Larus saundersi*), eat crabs. Attempts were made to determine the distribution, abundance, and biomass of mudflat crabs. Table A10.9.3 outlines the methods used in the crab program.

## A10.9.4 Results

### A10.9.4.1 Benthic infauna monitoring

Table A10.9.4 lists the morphospecies codes used in the Figures, and level of taxonomic identification, for benthos recovered during Mai Po mudflat investigations.

Table A10.9.2 Predator Exclusion Manipulation Methods

| Task | Methods | Notes |
|---|---|---|
| Location and frequency | 2 sites (upper and lower exclusion area) each with 8 cages; in January, March, May, and September | See Figure A10.9.1 |
| Measuring predation | Watching birds forage outside cages<br>checking for footprints, droppings, foraging marks within cages | See section 10-9.3.2.c for information on confounding effects |
| Sampling | 24 cores (In February) or 15 cores (subsequent months) taken to characterize benthos prior to each manipulation; after two weeks, benthos in each cage estimated with three replicate cores, and compared with 12 control cores outside cages | BACI-type design (e.g. Bernstein and Zalinski 1983, Stewart-Oaten *et al.* 1986 ) |
| Sieving | 1 900 micron sieve<br>2 sieving machine used to process samples | Machine destroys small annelids (codes w *caps*, and *olig*) but leaves molluscs and Nereidae polychaetes intact |
| Preservation | 1 benthos killed in 5% pH-neutralized (hexamin) formalin<br>2 preserved in 70% ethanol | |
| Sorting | 1 February samples sorted to morphospecies<br>2 subsequent samples sorted to morphospecies for bivalves and Nereidae polychaetes only | 1 effect of cages on abundance confined to larger bivalves and perhaps Nereidae (see section 10.9.3.2) |
| Statistical analyses | T-test and oneway ANOVA by SPSS PC+ | Homogeneity of variance checked graphically, square-root transformed according to Freeman and Tukey (1950) in Zar (1984) |
| Measuring confounding effects | Determine crab burrow density inside and outside cages | |

Table A10.9.3 Methods for Crab Program

| Task | Methods | Notes |
|---|---|---|
| 1 Determine abundance & distribution | A erected 12 1x3 meter quadrats adjacent to each birdwatching hide | See location map, Figure A10.9.1 |
| | B measured burrow abundance and diameter in April and November | Determined abundance in size classes greater and less than 2cm |
| | C counted crabs in quads every 15 minutes in October | |
| | D visually estimated carapace width against fixed measuring sticks in October | |
| 2 Collect crabs | A grabbed by hand in April and September | |
| | B killed in freezer | |
| | C preserved in 70% ethanol | |
| 3 Sorting | A morphospecies distinguished | |
| | B sex determined for each individual | |
| 4 Size measured | A carapace width at widest point | |
| | B dactylus length measured | |
| | C propodus length measured | |
| 5 Determine biomass | A carapace digested overnight in 10% HCl to remove carbonate | |
| | B dry mass determined after 48 hours at 80 degrees Celcius | |
| | C sent to Peking University for AFDM determination | |
| 6 Productivity | Determined as per Crisp (1971) | Standing crops determined twice 4.5 months apart. In order to report productivity on an annualized basis, first standing crop (April) is also used at the end of a year to calculate productivity. |

Table A10.9.4 List of morphospecies codes, and the taxonomical determination achieved in this study

| Code | Phylum | Class | Subclass | Order | (Super)Family | Genus | Species |
|---|---|---|---|---|---|---|---|
| *abre* | *Mollusca* | *Gastropoda* | *Prosobranchia* | *Mesogastropoda* | *Assimineidae* | *Assiminea* | *brevicula* |
| *acon* | *Annelida* | *Polychaeta* | *Errantia* | | *Pilargiidae* | *Ancistroyllis* | *constricta* |
| *anem* | *Echinodermata* | *Holothuroidea* | *Apoda* | | | | |
| *asp* | *Mollusca* | *Gastropoda* | *Prosobranchia* | *Mesogastropoda* | *Assimineidae* | *Assiminea* | *sp.* |
| *asp1* | *Mollusca* | *Gastropoda* | *Prosobranchia* | *Mesogastropoda* | *Assimineidae* | *Assiminea* | *sp.1* |
| *asp2* | *Mollusca* | *Gastropoda* | *Prosobranchia* | *Mesogastropoda* | *Assimineidae* | *Assiminea* | *sp.2* |
| *asp3* | *Mollusca* | *Gastropoda* | *Prosobranchia* | *Mesogastropoda* | *Assimineidae* | *Assiminea* | *sp.3* |
| *asp4* | *Mollusca* | *Gastropoda* | *ProsobrPanchia* | *Mesogastropoda* | *Assimineidae* | *Assiminea* | *sp.4* |
| *bivl* | *Mollusca* | *Bivalvia* | *Lamellibranchia* | *Heterodonta* | | | |
| *blon* | *Mollusca* | *Gastropoda* | *Opisthobranchia* | *Cephalaspidea* | | | |
| *brog* | *Annelida* | *Oligochaeta* | | | | | |
| *cap?* | *Annelida* | *Polychaeta* | *Sedentaria* | | *Capitellidae* | | |
| *ccap* | *Annelida* | *Polychaeta* | *Sedentaria* | | *Capitellidae* | *Capitella* | *capitata* |
| *ceph* | *Mollusca* | *Gastropoda* | *Opisthobranchia* | *Cephalaspidea* | | | |
| *clen* | *Mollusca* | *Gastropoda* | *Prosobranchia* | *Mesogastropoda* | *Hydrobiidae* | | |
| *dost* | *Mollusca* | *Gastropoda* | *Prosobranchia* | | | *Dostia* | *sp.* |
| *dpin* | *Annelida* | *Polychaeta* | *Errantia* | | *Nereidae* | *Dendronereis* | *pinnaticirrus* |
| *glau* | *Mollusca* | *Bivalvia* | *Lamellibranchia* | *Heterodonta* | *(Galeommatacea)* | | |
| *euni* | *Annelida* | *Polychaeta* | *Errantia* | | *Eunicidae* | | |
| *goby* | *Vertebrata* | | *Teleostei* | | | | |
| *gly1* | *Annelida* | *Polychaeta* | *Errantia* | | *(Glyceracea)* | | |
| *hsim* | *Annelida* | *Polychaeta* | *Sedentaria* | | *Maldanidae* | *Heteromastus* | *similis* |
| *ibom* | *Mollusca* | *Gastropoda* | *Prosobranchia* | *Mesogastropoda* | *Iravidiidae* | *Iravadia* | *bombayana* |
| *iljv* | *Arthropoda* | *Crustacea* | *Malacostraca* | *Decapoda* | *Ocypodidae* | *Ilyoplax* | *sp.* |
| *ils2* | *Arthropoda* | *Crustacea* | *Malacostraca* | *Decapoda* | *Ocypodidae* | *Ilyoplax* | *sp.2* |
| *inin* | *Arthropoda* | *Crustacea* | *Malacostraca* | *Decapoda* | *Ocypodidae* | *Ilyoplax* | *ningpoensis* |
| *ins1* | *Arthropoda* | *Insecta* | | | | | |
| *ins2* | *Arthropoda* | *Insecta* | | | | | |
| *iorn* | *Mollusca* | *Gastropoda* | *Prosobranchia* | *Mesogastropoda* | *Iravidiidae* | *Iravadia* | *ornata* |
| *irs2* | *Mollusca* | *Gastropoda* | *Prosobranchia* | *Mesogastropoda* | *Iravidiidae* | *Iravadia* | *sp.2* |
| *itan* | *Arthropoda* | *Crustacea* | *Malacostraca* | *Decapoda* | *Ocypodidae* | *Ilyoplax* | *tanshuiensis* |
| *laem* | *Mollusca* | *Gastropoda* | *Prosobranchia* | *Mesogastropoda* | | *Laemodonta* | *sp.* |
| *laon* | *Annelida* | *Polychaeta* | *Sedentaria* | | *Sabellidae* | *Laonome* | *sp.* |
| *lgog* | *Annelida* | *Polychaeta* | | | | | |
| *lin1* | *Mollusca* | *Gastropoda* | *Prosobranchia* | *Mesogastropoda* | *Pyramidellidae* | *Linopygra* | *sp.1* |
| *lin2* | *Mollusca* | *Gastropoda* | *Prosobranchia* | *Mesogastropoda* | *Pyramidellidae* | *Linopygra* | *sp.2* |
| *mac* | *Mollusca* | *Bivalvia* | *Lamellibranchia* | *Heterodonta* | | *Macoma* | *sp.* |
| *mald* | *Annelida* | *Polychaeta* | *Sedentaria* | | *Maldanidae* | | |
| *mcro* | *Arthropoda* | *Crustacea* | *Malacostraca* | *Decapoda* | *Ocypodidae* | *Macrophthalamus* | *sp.* |
| *mncp* | *Annelida* | *Polychaeta* | | | *Capitellidae* | | |

Table A10.9.4 List of morphospecies codes, and the taxonomical determination achieved in this study (cont'd)

| Code | Phylum | Class | Subclass | Order | (Super)Family | Genus | Species |
|---|---|---|---|---|---|---|---|
| *msan* | *Annelida* | *Polychaeta* | | | *Eunicidae* | *Marphysa* | *sanguinea* |
| *msen* | *Mollusca* | *Bivalvia* | *Lamellibranchia* | *Anisomyaria* | | *Musculista* | *senhausia* |
| *nam1* | *Annelida* | *Polychaeta* | *Errantia* | | *Nereidae* | | |
| *nam2* | *Annelida* | *Polychaeta* | *Errantia* | | *Nereidae* | | |
| *nema* | *"nematoda"* | | | | | | |
| *neme* | *Nemertean* | | | | | | |
| *ngla* | *Annelida* | *Polychaeta* | *Errantia* | | *Nereidae* | *Neanthes* | *glandicincta* |
| *nmn2* | *Annelida* | *Polychaeta* | *Errantia* | | *Nereidae* | | |
| *npol* | *Annelida* | *Polychaeta* | *Errantia* | | *Syllidae* | *Nephtys* | *polybranchiata* |
| *odos* | *Mollusca* | *Gastropoda* | *Prosobranchia* | *Mesogastropoda* | *Pyramidellidae* | *Odostomia* | *sp.* |
| *olig* | *Annelida* | *Oligochaeta* | | | | | |
| *owen* | *Annelida* | *Polychaeta* | *Sedentaria* | | *Oweniidae* | | |
| *pcir* | *Annelida* | *Polychaeta* | *Sedentaria* | | *Spionidae* | *Prionospio* | *cirrifera* |
| *phyl* | *Annelida* | *Polychaeta* | *Errantia* | | *Phyllodocidae* | | |
| *plan* | *Platyhelminthes* | | | | | | |
| *plep* | *Annelida* | *Polychaeta* | *Sedentaria* | | *Sabellidae* | *Potamilla* | *leptochaeta* |
| *ply1* | *Annelida* | *Polychaeta* | *Errantia* | | *Polynoidae* | | |
| *ply2* | *Annelida* | *Polychaeta* | *Errantia* | | *Polynoidae* | | |
| *plyd* | *Annelida* | *Polychaeta* | *Sedentaria* | | *Spionidae* | *Polydora* | *sp.* |
| *pmai* | *Mollusca* | *Bivalvia* | *Lamellibranchia* | *Heterodonta* | *(Galeommatacea)* | *Pseudopythina* | *maipoensis* |
| *poto* | *Mollusca* | *Bivalvia* | *Lamellibranchia* | *Heterodonta* | | *Potomocorbula* | *sp.* |
| *pull* | *Annelida* | *Polychaeta* | *Sedentaria* | | *Capitellidae* | | |
| *pyr2* | *Mollusca* | *Gastropoda* | *Prosobranchia* | *Mesogastropoda* | *Pyramidellidae* | | |
| *sab?* | *Annelida* | *Polychaeta* | *Sedentaria* | | *Sabellidae* | | |
| *scon* | *Mollusca* | *Bivalvia* | *Lamellibranchia* | *Heterodonta* | *(Solenacea)* | *Sinonovacula* | *constricta* |
| *serm* | *Mollusca* | *Gastropoda* | *Prosobranchia* | *Mesogastropoda* | | *Sermyla* | *tornatella* |
| *sesr* | *Arthropoda* | *Decapoda* | *Malacostraca* | *Decapoda* | *Grapsidae* | | |
| *sfra* | *Mollusca* | *Gastropoda* | *Prosobranchia* | *Mesogastropoda* | *Amphibolidae* | *Salinator* | *fragilis* |
| *spi1* | *Arthropoda* | *Arachnida* | | *Araneae* | | | |
| *spi2* | *Arthropoda* | *Arachnida* | | *Araneae* | | | |
| *spio* | *Annelida* | *Polychaeta* | *Sedentaria* | | *Spionidae* | | |
| *ste1* | *Mollusca* | *Gastropoda* | *Prosobranchia* | *Mesogastropoda* | *Stenothyridae* | *Stenothyra* | *sp.1* |
| *ste2* | *Mollusca* | *Gastropoda* | *Prosobranchia* | *Mesogastropoda* | *Stenothyridae* | *Stenothyra* | *sp.2* |
| *ste3* | *Mollusca* | *Gastropoda* | *Prosobranchia* | *Mesogastropoda* | *Stenothyridae* | *Stenothyra* | *sp.3* |
| *tcfi* | *Mollusca* | *Bivalvia* | *Lamellibranchia* | *Heterodonta* | | *Theora* | *cf. iridescens* |
| *thar* | *Annelida* | *Polychaeta* | *Sedentaria* | | *Cirratulidae* | | |
| *tlat* | *Mollusca* | *Bivalvia* | *Lamellibranchia* | *Heterodonta* | | *Theora* | *lata* |
| *uca* | *Arthropoda* | *Crustacea* | *Malacostraca* | *Decapoda* | *Ocypodidae* | *Uca* | *sp.* |

For biomass determination, the following codes indicate the lumping of morphospecies required to obtain a large enough sample to measure. These codes are also used on the abundance and biomass graphs.
X = exoskeletal-bearing animals, which could include abre, asp, asp1, asp2, asp3, asp4, bivl, blon, clen, dost, glau, iorn, irs2, laem, lin1, lin2, odos, poto, pyr2, sfra, ste1, ste2, ste3
w = undifferentiated annelids which could include acon, brog, euni, gly1, hsim, laon, lgog, mald, nema, neme, nmn2, nam1, nam2, npol, olig, owen, pcir, phyl, plan, ply1, ply2, plyd, sab?, spio
bivs = bivalves, which could include mac, scon, tcfi, tlat
nam = Namalycastis polychaetes, which could include nam1, nam2, nmn2
caps = Capitellid polychaetes which could include ccap, cap?, mncp, pull
crab = crabs, which could include iljv, ils2, inin, itan, mcro, sesr, uca
insx = insects, which could include ins1, ins2
The other codes for biomass determinations are: anem, mald, nmn2, nam2, nam1, ibom, dpin, ngla, plep, ceph, serm, pmai

*Precision of Replication*

The arbitrary choice of five replicate samples at each sampling station was based on practical logistic considerations. The goal was to maximize replication given the number of samples that could be processed, divided among the sites determined necessary for establishing baseline conditions.

Previous work on the mudflat (McChesney 1993b) provided data for a pilot program to establish precision of abundance estimates. Using t-statistics (Green 1978), the precision of abundance estimates based on 4 replicate samples was 21-49% of the mean. The five replicates feasible in this EIA improved slightly the precision of the abundance estimate.

*Monitoring frequency: arbitrary seasons*

Four monitoring collections were arbitrarily scheduled to characterize different seasons. Sampling in January is assigned to Winter; in March, to Spring; in May to Summer; and in August to Autumn.

As Morrisey *et al.* (1992) point out, characterizing variation as seasonal when only taking a single sample in each season is as seriously under-replicated as comparing two mudflats with only a single sample from each.

Previous regular sampling on the mudflat between January 1992 and July 1993 (McChesney unpublished) has been analysed with a model II nested ANOVA (Sokol and Rohlf 1981) to investigate the variation attributable to seasons and the variation attributable to sampling months within seasons. When seasons are arbitrarily defined as winter (January-March), spring (April-June), summer (July-September), and autumn (October-December), there is no significant variation in total abundance owing to seasons (about 2% of the variation is attributable to these arbitrary seasons, $0.1 > p > 0.05$). Significant variation in abundance is attributable to variation between months (about 10% of the total variation is attributable to variation between months within seasons, $p < 0.01$). Variation is mostly between replicate samples from different parts of the mudflat within months (about 88% of the total variation) (McChesney unpublished). These data have not been checked nor transformed for homogeneity of variance, an assumption required by ANOVA.

*Monitoring locations: arbitrary transects*

Two transects were arbitrarily established across the mudflat, and three transects were arbitrarily located through the mangrove (Figure A10.9.1). This design allowed a nested ANOVA to test whether the apparent variation in abundance between transects (Figure A10.9.2) was statistically significant (Morrisey *et al.* 1992).

For the total abundance of benthos on the mudflat in March, there was highly significant variation between the two transects as well as between sites along each transect ($p < 0.001$ in both cases). By far most of the variation was between transects (94.5%) and only 3.5% of the variation was attributable to variation between sites along the transects. The remaining variation (about 2%) was attributable variation between samples. These data also have not been checked nor transformed for homogeneity of variance, an assumption required by ANOVA.

*Mudflat faunal abundance*

Figure A10.9.2 illustrates the abundance of invertebrates across the mudflat in the four monitoring months (January, March, May, and August). Abundance of invertebrates from February is also shown: these samples were collected to illustrate the homogeneity of the control area before and after manipulation.

Within each month, the bars are arranged from left to right in the same order as the stations cross the mudflat towards the Shenzhen River mouth: RBO to the west and ET1 to the east (see Figure A10.9.1). Each stacked bar consists of species groups keyed to patterns as shown, and the patterns occur in each bar in the order from bottom to top as shown in the key.

January samples were sieved through a coarser mesh than all the other samples, hence the total abundance figures for January are low. However, the larger polychaetes (code *dpin* and *ngla*) were large enough to be recovered in the coarser screen, and their abundance can be reliably compared with the other months.

Some important distributions are apparent. Figure A10.9.2 illustrates that channel levee samples (CH1 and ET3), only collected in January, were very different in species composition and total abundance compared with the other stations sampled in January. Second, Figure A10.9.3 shows the mean abundance of larger bivalves (codes *scon, tcfi, tlat*, and *mac*) at the sampling sites. Larger bivalves were more abundant in spring and were restricted in distribution to the RB transect when present.

Patchiness

The patchiness of invertebrate abundance on the mudflat was on the scale of kilometres (variability between transects) and hundreds of metres (variability between stations along transects; see section A9.3.1.c). The scale of patchiness at closer intervals was not investigated, but other ecological work (e.g. Morrisey *et al.* 1992a) showed patchiness at a range of scales. Figure A10.9.2 illustrates that the channel levees are very different from the surrounding mudflat. Bunds between mudskipper territories were visibly different (pers. obs.).

The mudflat was visibly textured with polygonally shaped mudskipper territories about 30cm across in most months. The centres of these territories were low and the perimeter was formed by a low bund of mud. Snails were visibly more abundant on the bunds than in the centres (pers. obs.), and centres of territories were always sampled to eliminate this bias. Due to this method, snail abundance was probably underestimated.

Mudflat faunal abundance changes in space

Referring to Figure A10.9.2, in any month, of the two large Nereidae polychaetes *dpin* and *ngla*, only *dpin* was abundant across both transects. If *ngla* occurred at all on the ET transect, its abundance was half or less compared with its abundance on the RB transect in that month. The organic pollution indicator species capitellid polychaetes (denoted *"caps"*) were most abundant on the ET transect. Abundant *caps* were present in the January channel levee samples as well.

Like capitellids, Nereidae polychaetes *ngla* and *dpin* were more abundant on the ET transect. There was an inverse relationship between the average number of *caps* and the average number of Nereidae polychaetes on the ET transect. Total abundance was greater along the ET transect.

The number of different species ("species richness," Figure A10.9.4) tended to be higher on the RB transect than the ET transect.

Mudflat faunal abundance changes in time

Mudflat invertebrate abundance collapsed after summer. In August, there was only a fraction of the abundance present in May. This seasonal event was also documented in previous mudflat sampling (McChesney 1993b).

The collapse was heralded by the relative increase in the proportion of tiny invertebrates (Figure A10.9.2, codes *pmai, x, caps*, and *olig*) as larger animals (*dpin*) decreased along the ET transect between March and May.

Compared with previous work, no individuals of the gastropod "*ceph*" were present during this EIA study. *Ceph* and *serm*, both gastropods, were present at different times of the year: *ceph* from winter to summer, and *serm* from late summer until mid-winter.

The numerically most abundant animal on the mudflat was the tiny bivalve, *Pseudopythina maipoensis* (code *pmai*), described only from Deep Bay (Morton and Scott 1989). Together with all the other bivalves, *pmai* was a victim of the summertime die off (see Figures A10.9.2 and A10.9.3). In August, oligochaete annelids (code *olig*) became the most abundant invertebrate.

In August, more than 90% of the invertebrates along the ET transect were surface dwelling gastropods (*serm*) or tiny annelids (*w, olig*, or *caps*). Small juveniles of the sedentary polychaete *plep* made up most of the remainder of the August invertebrate abundance along the ET transect.

***Mangrove faunal abundance***

As with mudflat samples, the total abundance figures for January were low because samples for that month only were sieved through a coarser screen. Overall abundance figures were much lower in the mangrove than on the mudflat. There were virtually no species in common between the mangrove and the mudflat (compare Figures A10.9.2 and A10.9.5).

Mangrove faunal abundance changes in space

The stacked bar charts in Figure A10.9.5 consist of the groups of species codes shown in the key. In each month, the bars are arranged from left to right in the same sequence as the stations are placed in the mangrove from west to east (see Figure A10.9.1).

In each month, faunal abundance was lowest at the NA and NK stations, and increased towards the Shenzhen river mouth. Number of species (species richness) tended to increase in the same direction.

Mangrove faunal abundance changes in time

The peaks of abundance and species richness changed with time. In January, sites closest to the river mouth (TA-TK) had the greatest abundance, although species richness was higher in the sites to the west (LA-LK). In all subsequent months, peaks in abundance and species richness shifted away from the rivermouth sites to the LA-LK site.

In January, Capitellid polychaetes were evenly distributed with low abundance throughout the mangrove, but became strongly zoned in the warmer months. The peak in Capitellid abundance in March near the river mouth (site TK) shifted downstream in May to site LK.

*Mudflat faunal biomass*

Figure A10.9.6 displays the composition of total biomass at the six monitoring sites across the mudflat during the four months of monitoring. The stacked bars in each month are arranged from left to right in the figure in the same sequence stations are located across the mudflat (see Figure A10.9.1). The species codes comprising the total biomass are identified in the key, and occur in each stacked bar in the order shown from bottom to top in the key.

In the first part of the year (January-March-May) more than 45% of the biomass was composed of Nereidae polychaetes (code *dpin* and *ngla*). The Mai Po mudflats are notable for the huge percentage of biomass in polychaetes, when compared to other intertidal mudflats across the world (Piersma *et al.* 1993).

Mudflat faunal biomass changes in space

Total biomass tended to be higher on the ET transect compared to the RB transect. Importantly, Figure A10.9.7 shows that the average sizes of polychaetes were smaller along the ET transect.

The biomass present on intertidal channel levees in January 1994 (stations CH1 and ET3) was less than 25% of the biomass on the surrounding mudflat (Figure A10.9.6). The species composition of tidal channel levee sites was also very different, lacking Nereidae polychaetes and containing *Ilyoplax* spp. crabs.

Capitellid polychaetes (code *caps*) were only abundant enough to show up on the biomass plot along the ET transect adjacent to the Shenzhen river mouth. No Capitellids are shown for March on the biomass figure owing to a laboratory mistake where the Capitellids were lumped together with the other small annelids (code *w*). Capitellids were present in March: Figure A10.9.2 illustrates that up to 50% of the combined number of *w+caps* in March were Capitellids.

Mudflat faunal biomass changes in time

The decline in biomass between May and August is thought to have resulted from the annual defaunation during the hot, wet summer. The low biomass measured in August reflected the small body size of the Nereidae polychaetes being recruited at this time.

Biomass in May was approximately 50% of the March biomass, and the decline corresponded with the decline of about half the biomass and abundance of *dpin* Nereidae polychaetes. Gulls and waders eat red polychaetes (see Appendix A10.12, McChesney unpublished) and at least part of the decline in biomass between March and May was attributable to consumption of Nereidae by migrant birds.

The channel levee sites CH1 and ET3 were sampled only once during this EIA, but previous work (McChesney unpublished) illustrated that, in general throughout the year, a single channel levee site near CH1 was poor in Nereidae polychaetes, rich in *Ilyoplax* crabs, and contained lower biomass than most of the other mudflat sites.

Recruitment of *Sermyla tornatella* gastropods (code *serm*) in summer accounted for their relative richness as the highest proportion of biomass along the ET transect in August. Recruitment of the Nereidae polychaete *ngla* between March and May was illustrated by the increase in abundance with the decrease in biomass of *ngla*.

*Mangrove faunal biomass*

Mangrove biomass was generally dominated by the gastropod *Iravadia (Fairbakia) bombayana* (code *ibom*), and it is always the dominant component of biomass along the central LK-LA transect. As for March mudflat samples, Capitellid polychaetes were lumped with other small annelids (code *w*) by mistake in March, so do not show up in the mangrove biomass bars for March (Figure A10.9.8).

Mangrove faunal biomass changes in space

A peak in total biomass (Figure A10.9.8) was located away from the sampling site closest to the river mouth (TA), and usually occurred along the LK-LA transect.

Mangrove faunal biomass changes in time

The biomass peak was close to the river mouth in January, but shifted downstream in March and May. In August there was no peak in biomass, owing to eutrophic collapse of the benthos during summer (Figure A10.9.8).

Although total mangrove faunal biomass seemed to fall off from March through May to August, as with mudflat biomass, each month having about half of the previous biomass, the details of the defaunation were different. Namalycastid polychaetes (code *nam*) seemed to be recruiting in May, when a high abundance of small individuals were present. These polychaetes seem to make up a high proportion of the mangrove biomass in August. The parapodia of Namalycastid polychaetes are notably long and paddle-like and would make these organisms excellent swimmers. The exceptionally polluted conditions in August evidenced by stinking black mud all the way to the surface (pers. obs.) would not greatly affect these swimmers.

***Benthic Infaunal Productivity***

Using the methods of Crisp (1971) the annual productivity of benthic infauna was estimated from data from previous work on the Mai Po mudflat (McChesney unpublished). That annual productivity estimate was 45.3 g AFDM/m$^2$. This figure does not include productivity owing to crabs, which is estimated in a following section.

This amount of productivity compares with a range of annual productivity for intertidal benthic communities worldwide between 6.00 g AFDM/m$^2$ and 74.93 g AFDM/m$^2$ (Kaletja and Hockey 1991).

### A10.9.4.2 Predator exclusion manipulations

The worms, clams, snails, and crabs comprised food for the migrant and resident waterbird population of Deep Bay. Watching birds forage can provide an accurate assessment of what prey birds harvest (e.g. Kaletja 1992). An empirical method was chosen to ascertain the effect of bird predation on the benthic community by excluding birds from foraging on patches of mud, comparing the invertebrate assemblage inside and outside the cages, and inferring the difference was owing to predation by birds (Hall *et al.* 1990; Rafaelli and Milne 1987; Quammen 1981; Kent and Day 1983; Reise 1978; Wilson 1991; review by Baird *et al.* 1985.)

***Effect of predation on benthos***

Previous predator exclusion attempts (McChesney unpublished) were useful in suggesting that the abundance of benthos was different inside and outside cages. Exclusion manipulations for this EIA were conducted in February, April, June and September, 1994.

Effect in February

All morphospecies were counted in February exclusion samples. For the lower mudflat, the combined abundance of the two larger bivalves present (codes *scon* and *tcfi*) is plotted in Figure A10.9.9. Six of eight cages contained the bivalves but only two of 12 control samples contained these bivalves. This difference just failed to be statistically significant ($p=0.071$, t-test). The abundance of no other morphospecies present in February at either exclusion location, showed any significant difference between the cages and control.

*Macoma* sp. were present in February but were not included in the analysis because their body sizes observed beneath the microscope while sorting, and their measured biomass, were similar to the tiny bivalve *Pseudopythina maipoensis* (code *pmai*) in February. No effect of predation was detectable on *pmai*, and birds are unlikely to select another species of bivalve as tiny as *pmai*.

Effect in April

*Macoma* sp. (code *mac*) were included in the April analysis because they had nearly doubled in biomass since February. The other bivalves present in February (codes *scon* and *tcfi*) were included in the April analysis as well. Figure A10.9.10 displays that, on the lower mudflat, larger bivalves were present in 7 of 8 cages, while only 2 of 12 control cores contained these bivalves. This difference was statistically significant ($p= 0.048$, t-test).

The upper mudflat typically hosted fewer bivalves than the lower mudflat, or was devoid of bivalves, at all times of year (Figure A10.9.3). However, on the upper mudflat, two of eight cages contained bivalves while none of the 12 control cores contained any (Figure A10.9.11).

Effect in June

In June the abundance of the larger bivalves (comprised of only *Macoma* sp. in June) was more even between cages and control on the lower mudflat: all eight cages contained them, and half of the control cores (6 of 12) also contained larger bivalves (Figure A10.9.12). On the upper mudflat, bivalve density remained low with two of eight cages and one of twelve control cores containing bivalves (Figure A10.9.13).

The absence of bird predators in June (Appendix A10.12) is an explanation for the more even distribution of bivalves between cages and control: there was less effect of excluding predators because the predators were absent. In response, prey species survived outside as well as inside cages.

Effect in September

There were no bivalves whatsoever, large or tiny, in any of the September exclusion samples. The abundance of other morphospecies sorted from September samples did not show any effect due to the cages.

*Predation by birds around cages*

Observations from hides confirmed [illegible] and in general avoided foraging with [illegible] preyed on benthos in the vicinity of the [illegible] evidence of bird predation: footprint [illegible] The mudflat inside cages was [illegible] that birds were not entirely exclude [illegible] or bill marks. While some evidence [illegible] of bird foraging within. The cages w [illegible] cages, only a few cages showed any [illegible] of foraging by bird predators, so an [illegible] be effective in at least reducing the [illegible] the true effect of predation. [illegible] predation on infauna is likely to underestimate [illegible]

Consistent with the observations of [illegible] behaviour reported in this study (Appendix A10.12), foraging around the cages [illegible] intense as the tidal strandline passed the [illegible] on a rising or falling tide. There wa [illegible] about an hour to ninety minutes [illegible] water being shallow enough for dab [illegible] to forage (present in autumn and winter [illegible]) the passage of flocks of waders co [illegible] along the moving tidal strand. In addition, wintering flocks of small waders (Ke [illegible] *Charadrius alexandrinus* and Dunlin (*Calidris alpina*) roosted and foraged lightly i [illegible] of the upper exclusion area through the low tide exposure in autumn and win [illegible]

*Minimising confounding effects*

As Morrisey *et al.* (1992a) pointed [illegible] differences between treatments and controls cannot automatically be attributed to the tre [illegible] It must be shown that the control is [illegible] before and after the treatment. This [illegible] principle behind BACI designs (before after control-impact) (see Bernstein and Za [illegible] and Stewart-Oaten *et al.* 1986). Samples were taken before the cages were erected [illegible] A10.9.2 shows the comparison of control samples with pre-treatment samples [illegible] exclusion manipulation. As [illegible] (1992) insisted, this design still do [illegible] demonstrate that different abundances [illegible] treatments and control are not simpl [illegible] natural variation in time or place [illegible] nothing to do with the cages. To dem [illegible] that natural variation in time does not [illegible] any difference between treatment and [illegible] sampling must to be replicated in time [illegible] and after the impact. This characterise [illegible] scale natural variability against which to test whether the difference between trea [illegible] control is greater than the variation [illegible] expected from natural variation.

Insufficient personnel were available [illegible] the desired scope of sampling and [illegible] the rigors of temporal replication. We ass [illegible] the short time interval (two weeks) between control-area samples taken prior to ex [illegible] predators made comparisons accurate with the control-area samples at the conclusion [illegible] manipulation.

### A10.9.4.3 Crab survey

Two crab collections on the mudflat found [illegible] crab species: *Macrophthalamus* sp. [illegible] and Grapsidae sp. 1 (code *gra1*). The ca [illegible] width of all Grapsidae crabs collected [illegible] was less than 21 mm, while the carapace width [illegible] *Macrophthalamus* was greater than [illegible] Figures A10.9.17 and A10.9.18). Pre [illegible] *Macrophthalamus* crabs were [illegible] burrows less than 20mm in diameter, s [illegible] measured burrows in greater and less [illegible] size classes provides a first approximati [illegible] of the proportion of these two crab species in the mudflat. However, the carapace of a [illegible] *phthalamus* crab is wider than [illegible] 20mm-wide crabs could scoot sidew [illegible] shown burrows less than 20mm in [illegible] Nevertheless, the data were collected in [illegible] size classes and provide a first [illegible]

Burrow density was assumed to be related to crab density, but mudskippers used burrows too, and no attempt was made to determine which were crab burrows and which were mudskipper burrows. Indeed, during the course of observations, crabs and mudskippers were seen using the same burrow.

Crab density on the surface varied throughout the day, possibly in response to temperature. Other studies on fiddler crabs *Uca* sp. showed that crab density varied with tidal cycle, and that different sexes used the sediment at different times (Cararello and Cameron 1987). Crabs were most abundant just after the tide dropped past the observation site in mid-afternoon, and declined until dark, on the day of the observation.

Figure A10.9.14 illustrates the relationship between burrows measured in quadrats and the sum of all crabs seen within the same quadrat. The equation for the best-fit line through these data suggests that one of every three burrows was attributable to crabs. Some of the burrows belonged to mudskippers, and some underground galleries may have had more than one entrance.

Figures A10.9.15 and A10.9.16 illustrate the relationship between biomass of *Macrophthalamus* sp. and measured propodus and dactylus length.

### *Standing Crop*

From these observations a rough estimate of the standing crop biomass of crabs on the mudflat can be calculated. Assuming that burrows greater than 20mm diameter host *Macrophthalamus* and those less than 20mm host Grapsidae sp. 1, measured burrow densities can be converted to crab densities.

Table A10.9.5 lists burrow densities of the two size classes by location on the mudflat in March and September. Mean burrow density and 1 standard deviation from the 12 quadrats is tabulated. Crab density was estimated from the mean burrow density using the equation of the best-fit line, $y=0.3209x$ (Figure A10.9.14).

The regressions for carapace width and dry weight biomass (Figures A10.9.17 and A10.9.18) were used to estimate the biomass for the average crab for each species.

Table 5 shows variation in crab density between different locations on the mudflat. To estimate standing crop, the mean crab density between the TBT location and the LMC location (extremes in the variation in March) was used.

The standing crop of *Macrophthalamus* in March/April was 1.243 g (dry mass)/$m^2$, and in September is 0.614 g (dry mass)/$m^2$. The standing crop of Grapsidae in April was 0.09 g (dry mass)/$m^2$, and in September was 0.181 g (dry mass)/$m^2$.

### *Crab productivity*

The two estimates of standing crop can be used to estimate the productivity of crabs on the mudflat. Crab productivity was estimated at 7.019 g (dry mass)/$m^2$ in the interval between crab collections, about 4.5 months. If crabs have an annual cycle and it is assumed that the measurements of their population during this EIA sufficiently estimate inter-annual variability, crab productivity can be estimated for a year. In that case, crab productivity was estimated at 2.176 g (dry mass)/$m^2$/yr.

Table A10.9.5 Estimation of standing crop of crabs in March/April and August/September 1994.

| a | b | c | d | e | f | g | h | i |
|---|---|---|---|---|---|---|---|---|
| season | date | size class | location | burrow density ($m^{-2}$) | standard deviation | crab density ($m^{-2}$) | average biomass (g) | standing crop (g $m^{-2}$) |
| March/ April | 7 March | >2cm (mcro) | TBT hide | 2.92 | 1.51 | 0.94 | 2.357 (18 Apr) | 1.237 |
| | | <2cm (gral) | | 3.83 | 1.90 | 1.23 | 0.755 (18 Apr) | 0.676 |
| | | >2cm (mcro) | Floating Hide | 0.67 | 0.65 | 0.22 | | |
| | | <2cm (gral) | | 3.67 | 3.3 | 1.18 | | |
| | 11 March | >2cm (mcro) | LMC hide | 0.33 | 0.49 | 0.11 | | |
| | | <2cm (gral) | | 1.75 | 1.36 | 0.56 | | |
| August/ September | 13 Sept | >2cm (mcro) | TBT hide | 1.08 | 1.08 | 0.35 | 1.533 (1 Sep) | 0.682 |
| | | <2cm (gral) | | 60.8 | 2.19 | 1.95 | 0.182 (1 Sep) | 0.199 |
| | 25 Aug | >2cm (mcro) | LMC hide | 1.67 | 2.15 | 0.54 | | |
| | | <2cm (gral) | | 0.75 | 1.22 | 0.24 | | |

Crab density (column g) was estimated from the mean measured burrow density given in column e, using the best-fit line equation from figure 14. Average biomass (column h) is calculated using the regressions from figures 17 and 18, or by inspection of the graph for Grapsidae in April, owing to few data points. Standing crop (column i) was determined from the mean crab density between the TBT and LMC hides in the season, multiplied by the average biomass for that species.

### A10.9.4.4 Total benthic productivity of the mudflat

Using the relationship between dry mass and AFDM as determined for annelids collected in February 1994, the dry weight-based productivity estimate for crabs became 0.26g AFDM/$m^2$/year. Combined with the benthic productivity estimate from previous work reported above (45.3 g AFDM/$m^2$/yr), total mudflat productivity was estimated at 45.6 g AFDM/$m^2$/yr.

Crab productivity accounted for less than 10% of annual productivity.

### A10.9.5 Discussion

#### A10.9.5.1 Carrying capacity

Two methods evaluating the carrying capacity of the Deep Bay mudflats are, one, the predator exclusion manipulations, and two, the balance between productivity and predator consumption (Appendix A10.12). Both methods suggest that the mudflat is close to carrying capacity. Any loss of mudflat habitat due to erosion, deposition of thick blankets of sediment, encroachment by prograding mangrove forest, or change in sediment grain size is likely to reduce the amount of prey and hence decrease the number of waterbirds that Deep Bay can feed. Section A9.3.1 demonstrates that the invertebrate abundance and biomass in the mangrove is a fraction of that in the mudflat (compare Figure A10.9.2 with Figure A10.9.5, and Figure A10.9.6 with Figure A10.9.8); hence the available food resources are likely to diminish as mangrove progrades across the mudflat. The section also demonstrates that coarser sediments deposited at channel levee sites host a fraction of the mudflat benthic abundance and biomass (Figures A10.9.2 and A10.9.6). Again, the available food resources are likely to be reduced if sediment grain size coarsens across the mudflat.

Assessing the effect of bird predation on the mudflat benthos using caging experiments is confounded by various factors. Benthos is mobile and can crawl out of the cages to be consumed, reducing the difference between cages and controls. Predacious crabs can take refuge in the cages to escape their predators, and their increased density lowers the abundance of invertebrates within the cages, masking the effect of bird predation outside the cages.

Even so, watching any individual bird forage on the mudflat confirms that birds are consuming invertebrates. The fact that this harvest is detectable with statistical significance in April but not in February is a problem of statistical power.

Previous exclusion work (McChesney 1993a), using caging methods similar to those employed in this study, was insufficiently powerful to have a good chance of detecting the difference in invertebrate abundance outside and inside cages. This is probably primarily due to the fact that, at any instant, only a small fraction of the standing crop of biomass is harvestable by predators. That is, only a fraction is shallow enough to be snared by a bird's probing bill, or visible enough to be snatched by an observant predator. Presumably, there would be a large effect of predation if it could be assessed on only the harvestable proportion of total prey. The methods of predator exclusion manipulations sample the entire standing crop. The remainder of the standing crop which is not harvestable by birds will show no effect of predation by birds, and this becomes the "noise" through which the effect of predation is masked.

One way to increase statistical power is to increase the number of treatment replicates. The maximum number of samples that could possibly be sieved was determined, and eight treatment replicates (cages), each at two sites on the mudflat, maximized the chances of detecting the effect of predation.

The fact that 6 or 7 of 8 cages contained bivalves, while only 2 of 12 control cores contained bivalves in both February and April, when predators were present, is considered to be a biologically meaningful indication of the intensity of predation by birds on invertebrate benthos. The fact that the difference is statistically significant in April supports the biological conclusion. This interpretation is supported by the fact that the effect of caging in June was less on bivalve abundance when numbers of waterbirds predators were low.

Predator exclusion work reported in this study suggests that birds are harvesting most of the bivalve molluscs when both birds and molluscs are present. The complicating problem that at any instant only a fraction of the total standing stock of prey is harvestable by birds prevents an accurate assessment of the proportion of the standing stock harvested by birds.

The balance between annual prey consumption (Appendix A10.12) and annual benthic production also indicates that the mudflat is close to carrying capacity. Birds only intensely forage on moving tides when prey is presumably most active and foraging is most efficient. Yet birds still harvest most of the bivalves (see Figures A10.9.9 - A10.9.13). The fact that only few waders forage with little intensity on the mudflats during low tide (Appendix A10.12) does not indicate there is unused capacity.

#### A10.9.5.2 Eutrophication

There is a strong pollution gradient reflected in differences in benthos from the Shenzhen River across the Deep Bay mudflats. There is no benthic macrofauna whatsoever in Shenzhen River bottom sediments, and the river bubbles $H_2S$ gas in summertime (McChesney in press). Pearson and Rosenberg (1978) review the literature describing changes in benthos across pollution gradients. Figure A10.9.19 reproduces their abundance-biomass-species richness distributions in relation to a source of organic pollution in time or space. The Deep Bay mudflats display the typical sequence of characteristics away from a severely polluted source.

Specifically, at any time, the proportion of Capitellid polychaetes in mangrove or mudflat abundance or biomass increases towards the river mouth (recall this is not visible on the biomass plots for the month of March because Capitellids were lumped with other small annelids). On the mudflat, the increase of Capitellids corresponds to a decrease in Nereidae polychaetes, specifically *Neanthes glandicincta* (code *ngla*). *N. gladicincta* adults are present in higher abundances along the more diluted RB transect. In life it is a red worm like the other Nereid *Dendronereis pinniticirrus* (code *dpin*), but upon preservation, *ngla* loses its red colour while *dpin* stays red. This may be due to the amount of, or specific character of haemoglobin in the two worm species, such that *dpin*, containing more abundant or more efficient haemoglobin, is able to survive in the more polluted, hypoxic to anoxic conditions closer to the river mouth.

Across the mudflat, the average body size of individuals in the two species of Nereidae polychaetes decreased towards the river mouth (Figure A10.9.7). The proportion of small bodied species (codes *w, olig, x*) comprising the abundance increases towards the river mouth.

As temperature increases from winter through summer, the solubility of oxygen in water decreases, and the effect of eutrophication is clear between May and August: defaunation of the mudflat occurs. The defaunation is more likely owing to anoxia (e.g. Santos and Simon, 1980) than it is to osmotic problems with freshwater from summer rains. The black anoxic layer is just below a thin (about 2-3 mm, pers. obs.) brown aerated surface film in August, while in January perhaps 7-8 cm of oxidized brown mud overlies the black anoxic sediment (pers. obs.). In August, along the ET transect adjacent to the river mouth, between 50-90% of the benthos is surface-dwelling gastropod *Sermyla tornatella* (code *serm*) and the remainder is small-bodied annelid species (code *w*), Capitellids (code *caps*), or small juvenile larvae of larger polychaetes that do not burrow yet (codes *plep, ngla, dpin*).

Increasing organic pollution reaching the mudflats of Deep Bay will have the effect of increasing eutrophication: reducing average body size of prey species of benthos, eliminating some important species (larger bivalves), and shifting the benthic assemblage towards abundant, small-sized, opportunistic species such as Capitellid polychaetes. These shifts in benthos owing to eutrophication are likely to impact the bird population by reducing the amount of food available, since prey will be too small in size for most bird species to feed on.

As a stated objective of the Shenzhen River Project is to improve water quality in the river by flushing pollutants into Deep Bay, that objective is inconsistent with protection of the Deep Bay ecosystem. Mitigation ought to require sewage treatment for effluent entering the Shenzhen river. Because the volume of organic pollution is so large now, it is very unlikely that incrementally improved water quality will reduce the productivity of the mudflat in the short run, while decreasing water quality appears likely to push the mudflats over the edge towards eutrophic collapse earlier in the season, when benthos provides an essential food supply for migrating birds (see Appendix A10.12).

### A10.9.5.3 Sediment particle size

Benthic communities are sensitive to the particle size of the sediments they live in (see Green *et al.* 1992, for example). Previous work on the Mai Po mudflats (McChesney unpublished) determined that more than 96% of the mudflat sediment is finer than 125 microns. Crossing the mudflat are intertidal channels flowing between the river and the mangrove. These intertidal channels are flanked by levees, consisting of firmer sediment. The levees dry out faster than the adjacent mudflat because they are slightly higher. The confinement of tidal flow in these channels increases the velocity of water in the channels, which is capable of carrying coarser sediments. These coarser sediments are deposited onto the levees when the channel floods on the rising tide and velocity suddenly decreases. The results of sediment particle size distribution of the channel levees has yet to be reported by Peking University from samples submitted to them in February 1994, but channel levee sediments must be coarser than the adjacent mudflat sediments.

Benthic sampling included two channel levee sites in January (CH1 and ET3). The channel levee site adjacent to CH1 was sampled eight times between January 1992 and July 1993 during previous work (McChesney unpublished). Figures A10.9.2 and A10.9.6 demonstrate that channel levee sites contained much less biomass and many fewer individuals comprising different species than the adjacent mudflat.

On rising tides, some waders are noticeably concentrated along these intertidal channels. Duck rafts forage above these locations when the mudflat is covered with water (Appendix A10.17).

It can be predicted that any coarsening of sediment deposited on the Deep Bay mudflat as a result of either construction dredging or increased velocity of water from Shenzhen River will cause a shift in the benthic fauna towards the channel levee assemblage. This will tend to lower biomass, abundance, and species richness on the mudflat and may be detrimental to birds depending on mudflat food.

Mudflat sediments adjacent to Futien Reserve are noticeably coarser than sediments on the Hong Kong side. The report on benthos and sediment particle size from Xiamen University will provide further predictability for the effect of sediment particle size on benthic composition and biomass.

### A10.9.5.4 Boat speeds

Although increased navigability is not a stated objective of the river regulation project, the increased channel size will be exploited by shipping traffic in the river. Boat wakes are extremely high energy waves, capable of eroding soft sediments (Wolanski pers. comm). As concrete lining of the channel through Inner Deep Bay is impractical, it will be necessary for the Shenzhen authorities to ensure that shipping traffic obeys speed limits which cause no waves. Already severe gullying can be seen in the mangroves along the north side of the river.

### A10.9.5.5 Recommendations

1 Apparently variation in benthic abundance and biomass is owing to seasonal fluctuations, for example recruitment and hypoxia. Neither this study nor previous work has demonstrated the variation due to seasonality. Benthic monitoring will require sufficient resources to include temporal replication as well as spatial replication, in order to account for variability owing to seasonal changes and variability owing to sampling intervals within seasons. Without confidence that observed variation is either seasonal or owing to project impacts, acceptability cannot be evaluated.

2 Spatial variation (patchiness) of benthos needs to be determined in order to explain observed variation in samples collected from different sites. Without knowledge of the expected spatial variation in occurrence and abundance of invertebrates, it is impossible to detect the effect of ecological changes owing to construction and operation of the project.

3 Intertidal channel levee sites are important foraging sites for some birds. The species utilizing channels need to be determined. If sedimentation is likely to change the mudflat benthic community, knowledge of the distribution and abundance of the resulting fauna is required to determine acceptability. Studying the channel levees provides a natural laboratory opportunity for studying the effects of coarser sediments.

4 Determining the impact of foraging birds on the intertidal channel levees requires sufficient resources for temporal replication of before-after-control-impact designs, i.e. "beyond BACI" design (Underwood 1992).

5 The annual defaunation of the mudflat during summer appears to be the most important factor structuring the mudflat invertebrate community which feeds migratory birds. We do not know whether anoxia associated with eutrophication or osmotic stress associated with rain water from summer monsoons is the factor. Bench-top experiments are needed to elucidate the cause.

6 Organic pollution entering Deep Bay promotes eutrophication, which is a threat to the ecology of the Bay. In addition to organic pollution, contamination by heavy metals and especially organo-chloride complexes needs to be quantified. Sub-lethal effects, such as biomagnification, need to be quantified.

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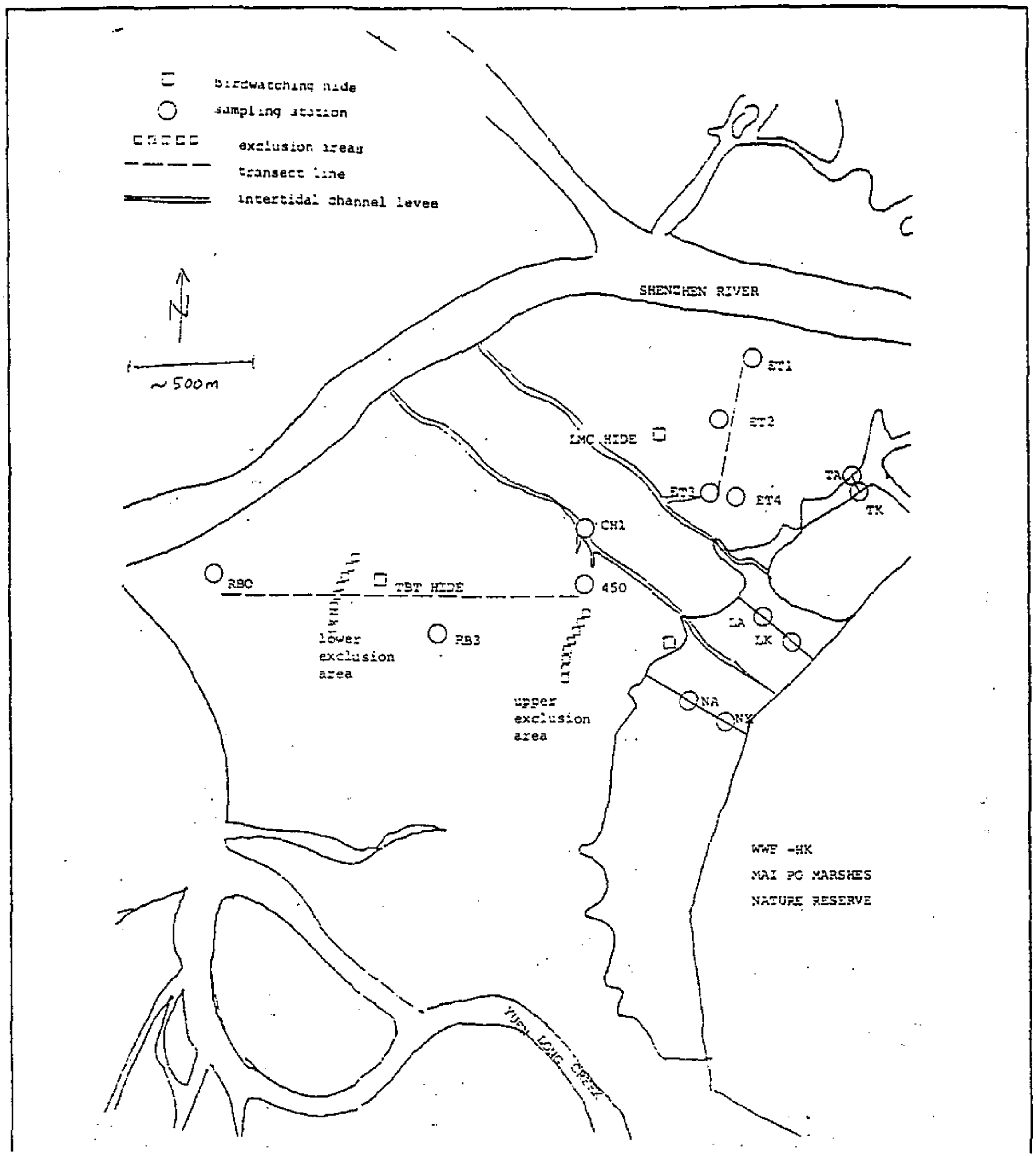
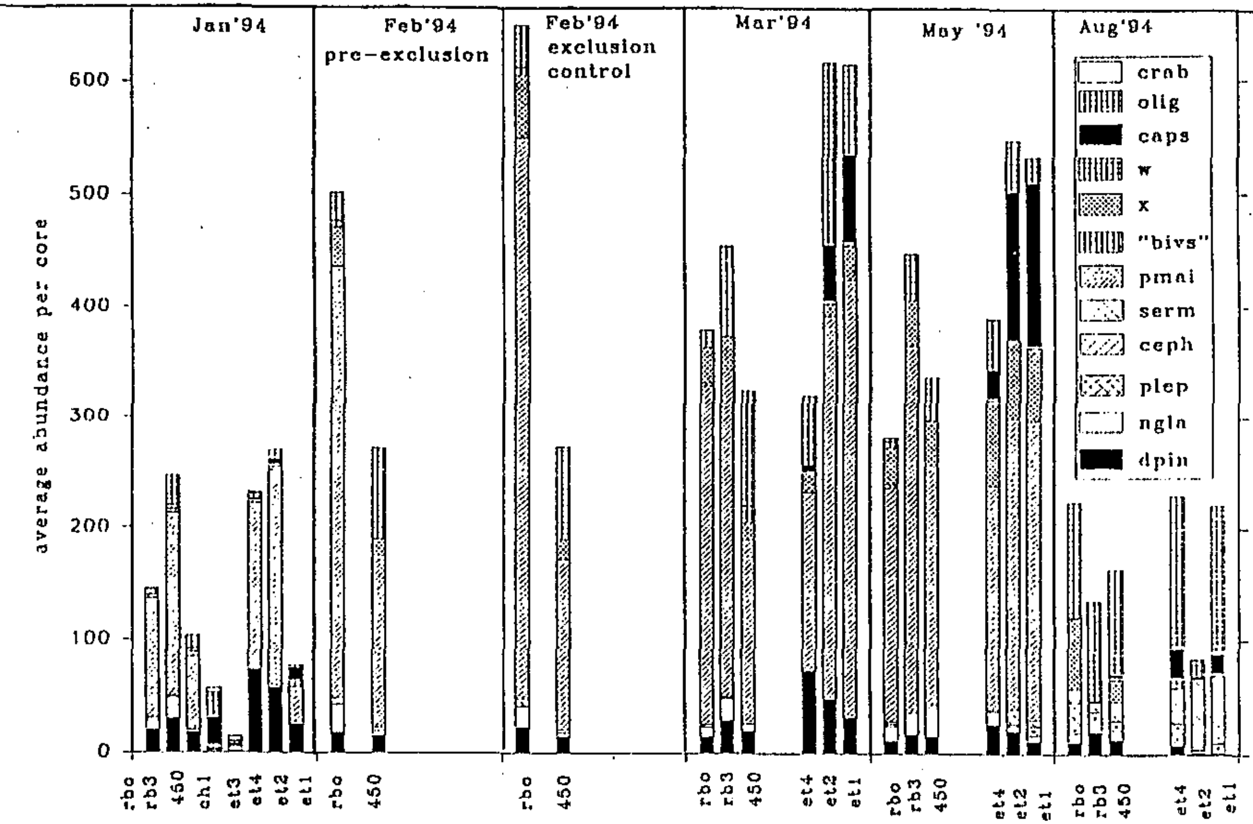
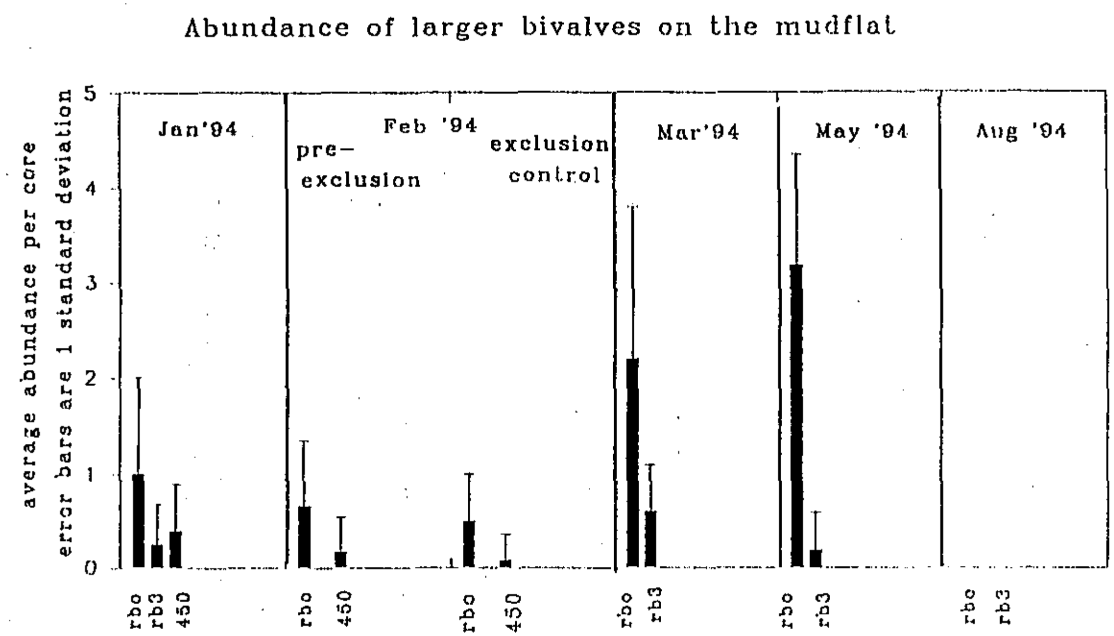



Figure A10.9.1 Two mudflat transects (RB and ET) with three stations along each plus two channel levee sites; three mangrove transects (N,L, and T) with two stations along each; three birdwatching hides at TBT, LMC, and Floating Hide; and two predator exclusion areas (upper and lower) are shown in relation to the Worldwide Fund for Nature Hong Kong Mai Po Marshes Nature Reserve.



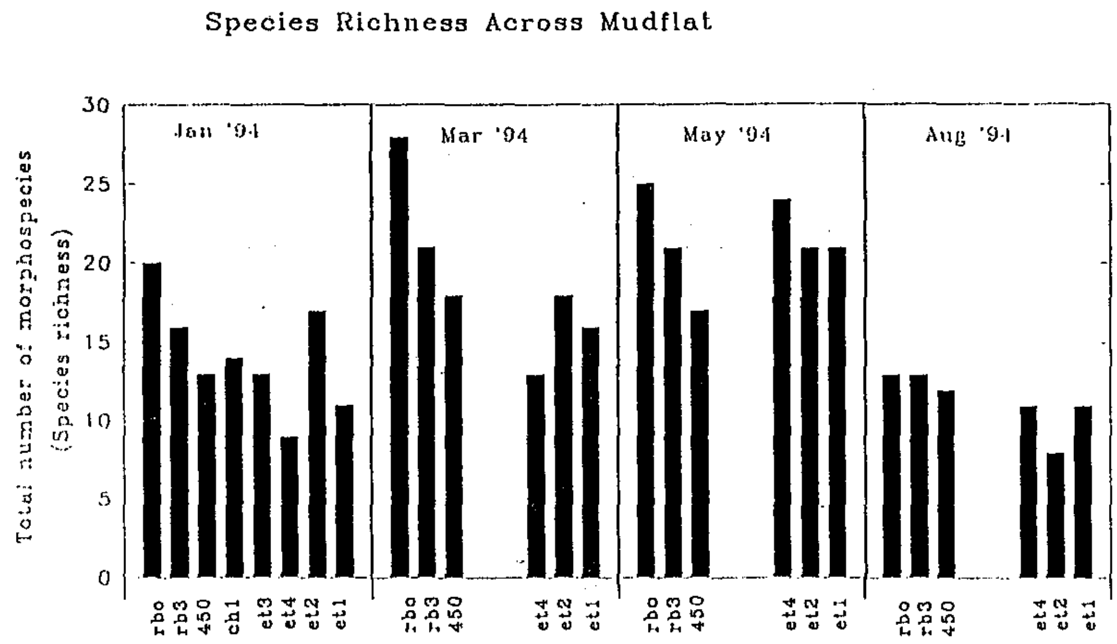

Bars are arranged by month; bars within each month are arranged in the same order as stations cross the mudflat (see Figure 1). Bars are composed of species codes shown in the key, and codes are stacked into each bar in the same order they appear in the key, from bottom to top. Hence, the black pattern for "caps" can be differentiated from the same pattern for "dpin", because "dpin" is at the bottom of the bar when they are present. Codes are explained in Table 4.

Figure A10.9.2 Average Abundance of Invertebrates per Core on the Mudflat



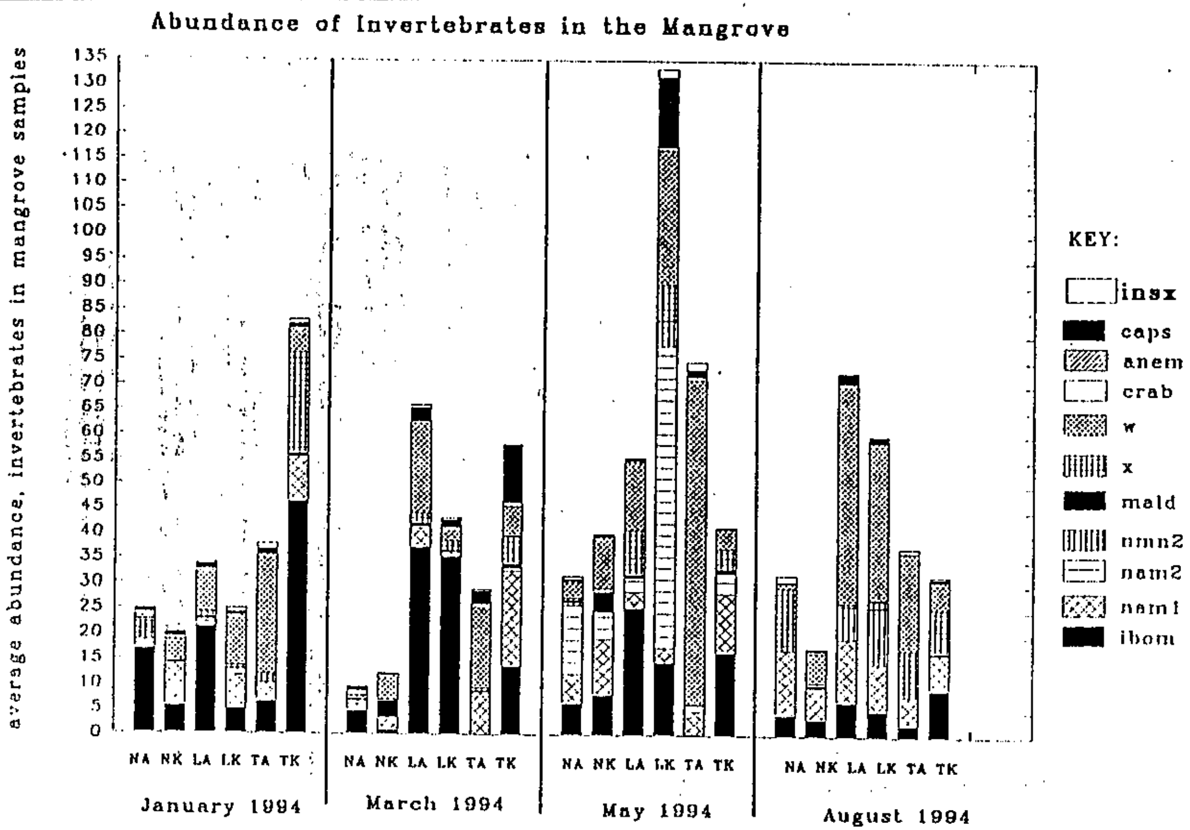

Error bars indicate 1 standard deviation of the mean. Species include codes *scon*, *mac*, *tcfi*, and *tlat*. Bars are arranged by month; bars within each month are arranged in the same order as stations cross the mudflat from west to east (see Figure 1). Stations are indicated only if bivlaves were present at that station in the month.

Figure A10.9.3 Abundance of Larger Bivalues on the Mudflat



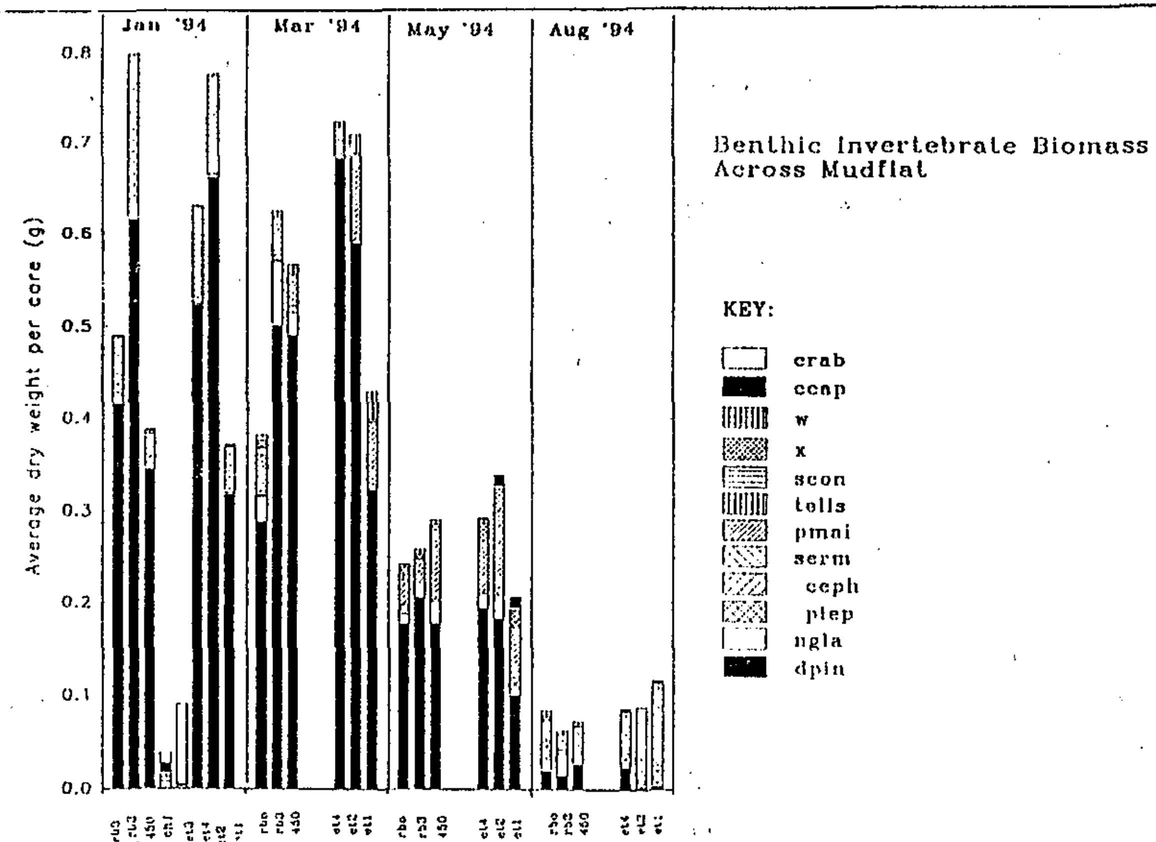

Bar height indicates the total number of morphospecies collected from all replicates at the stations in the month. Bars are grouped into months; bars within each month are arranged in the same order as stations cross the mudflat from west to east (see Figure 1).

Figure A10.9.4 Species Richness Across Mudflat



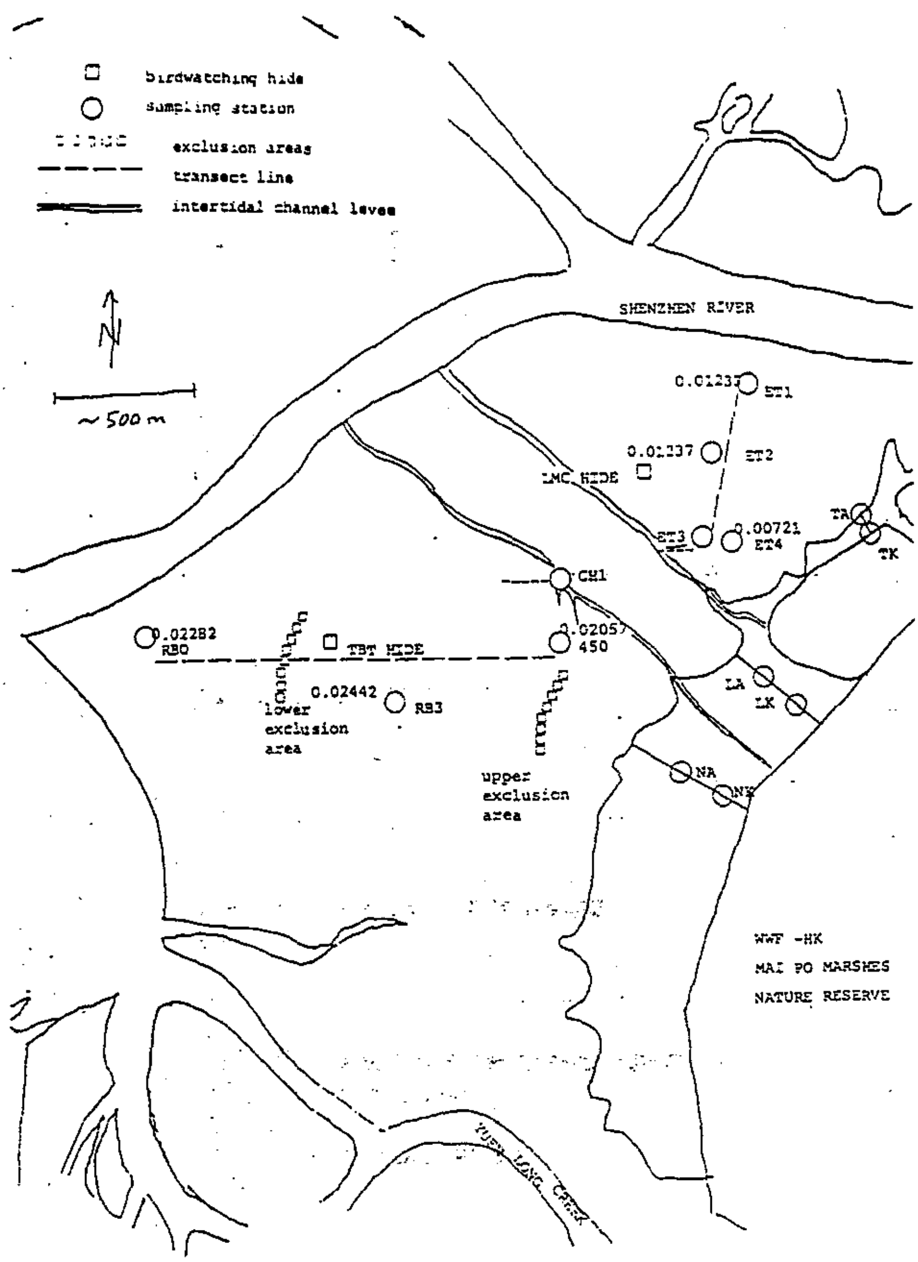

Bars are arranged by month; bars within each month are arranged in the same order as stations in the mangrove, trom west to east, approaching the river mouth (see Figure 1). Bars are composed of species groups indicated in the key. Codes are stacked in each bar in the same order as they are shown in the key, from bottom to top. Hence, the black pattern for "caps" can be differentiated from "ibom", because "ibom" is at the bottom of the bars. Codes are explained in Table 4.

Figure A10.9.5 Abundance of Invertebrates in the Mangrove



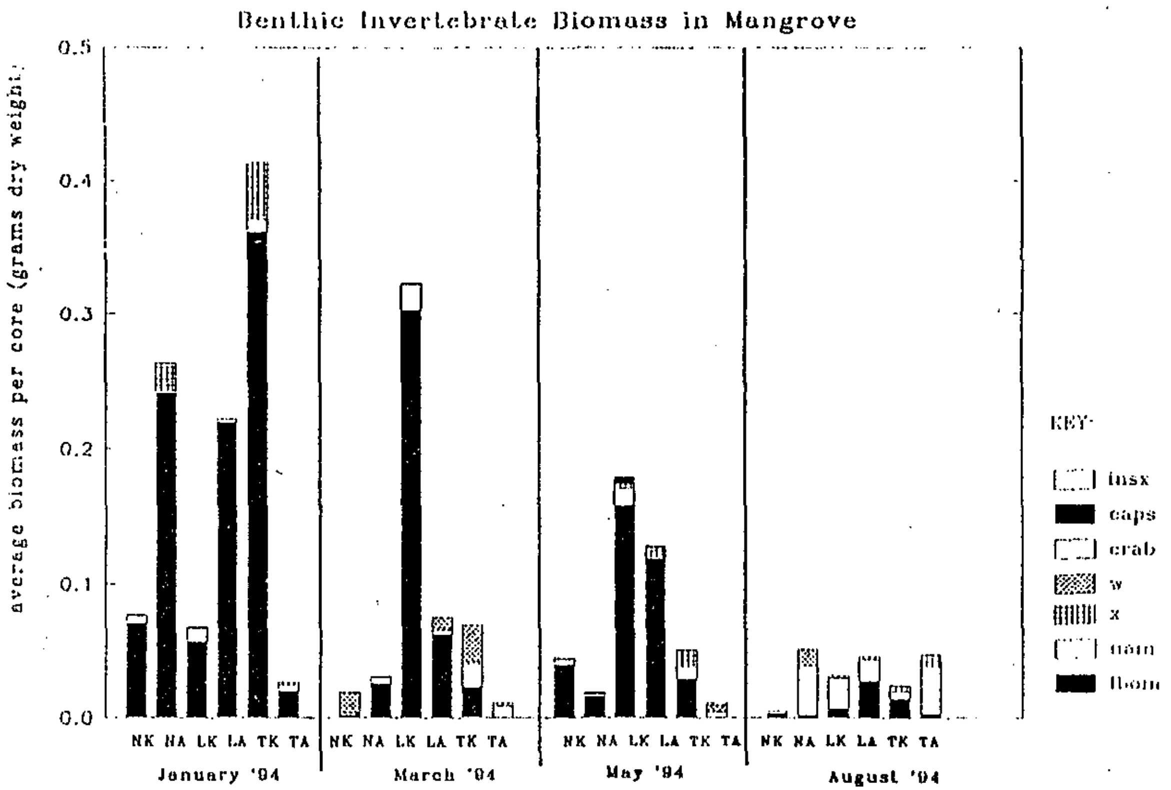

Bars are arranged by month; bars within each month are arranged in the same order stations cross the mudflat from west to east (see Figure 1). Bars are composed of species groups shown in the key, and codes are stacked in each bar in the same order they appear in the key, from bottom to top. Hence, the black pattern for "ccap" can be differentiated from "dpin", because "dpin" is at the bottom of the bars when they are present. Codes are explained in Table 4.

Figure A10.9.6 Benthic Invertebrate Biomass Across Mudflat



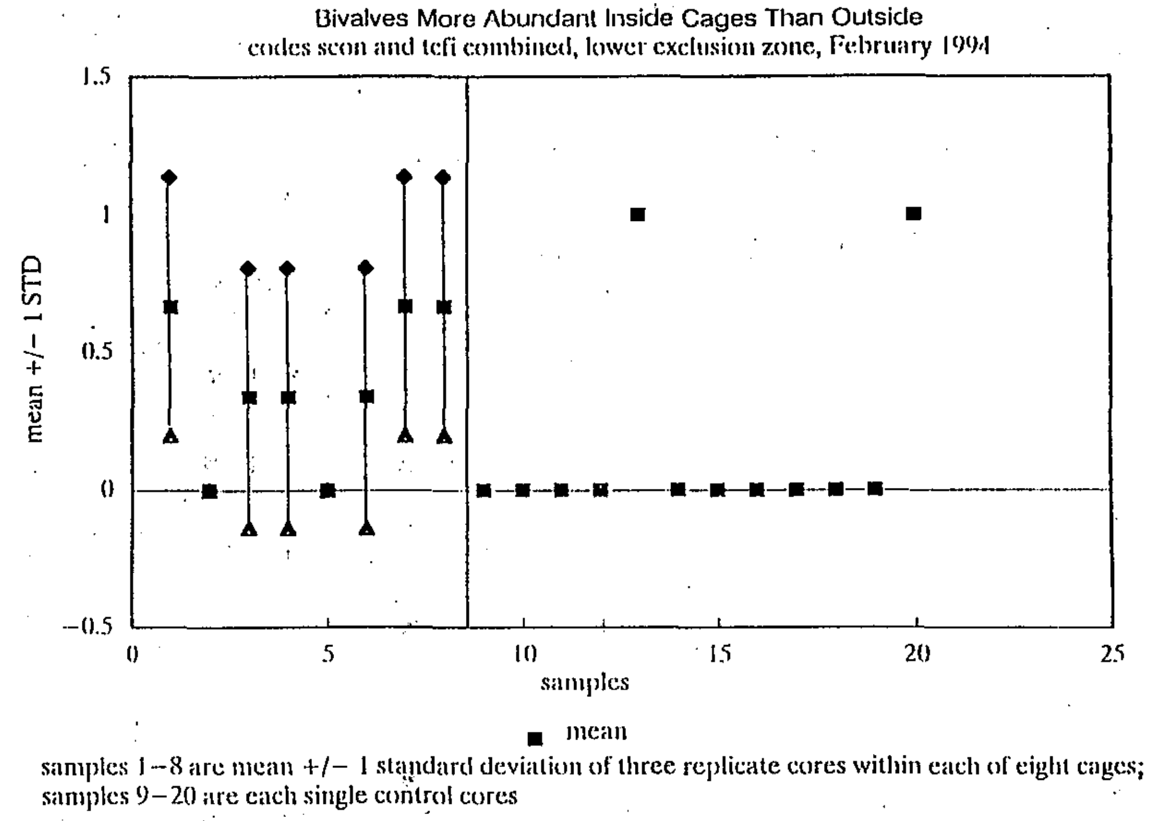

Average size is determined from the linear regression between biomass (dry mass) and abundance for replicate samples at each station.

Figure A10.9.7 Average Size of Nereidae Polychaetes Across Mudflat, January 1994



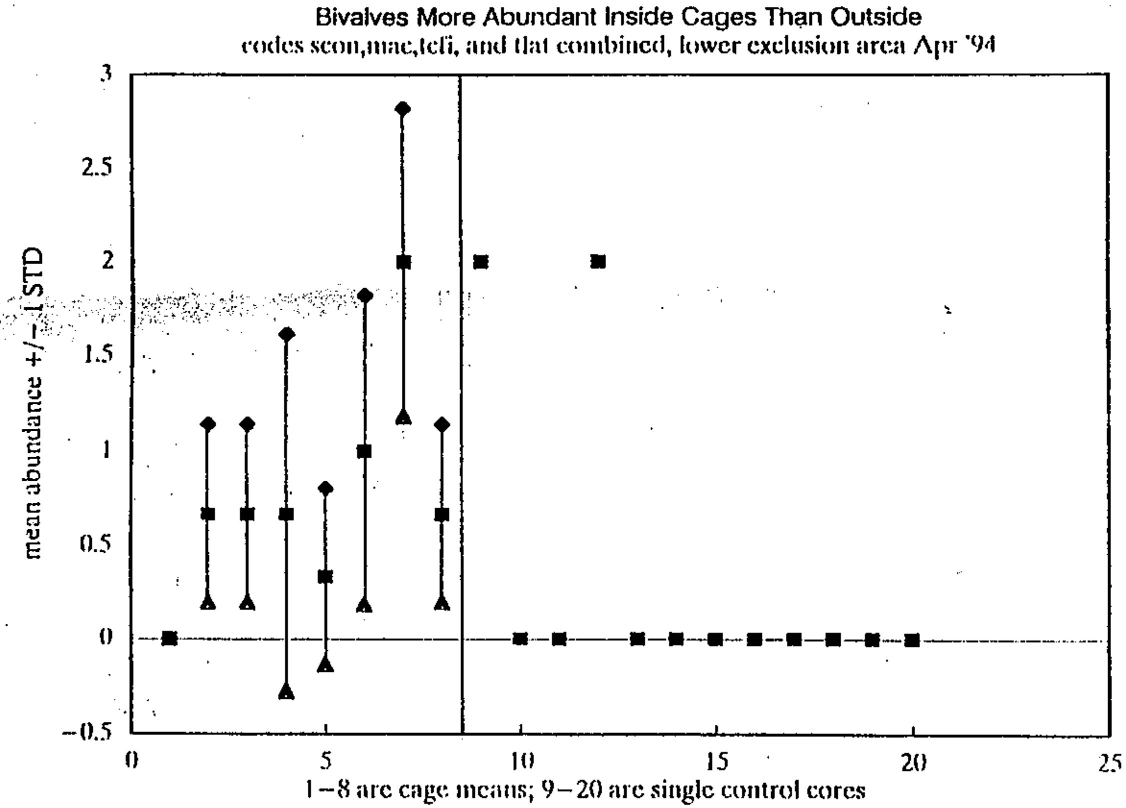

Bars are arranged by month; bars within each month are arranged in the same order stations in the mangrove from west to east, approaching the River mouth (see Figure 1). Bars are composed of species groups shown in the key, and codes are stacked in each bar in the same order they appear in the key, from bottom to top. Hence, the black pattern for "caps" can be differentiated from "ibom", because "ibom" is at the bottom of the bars. Codes are explained in Table 4.

Figure A10.9.8 Benthic Invertebrate Biomass in Mangrove



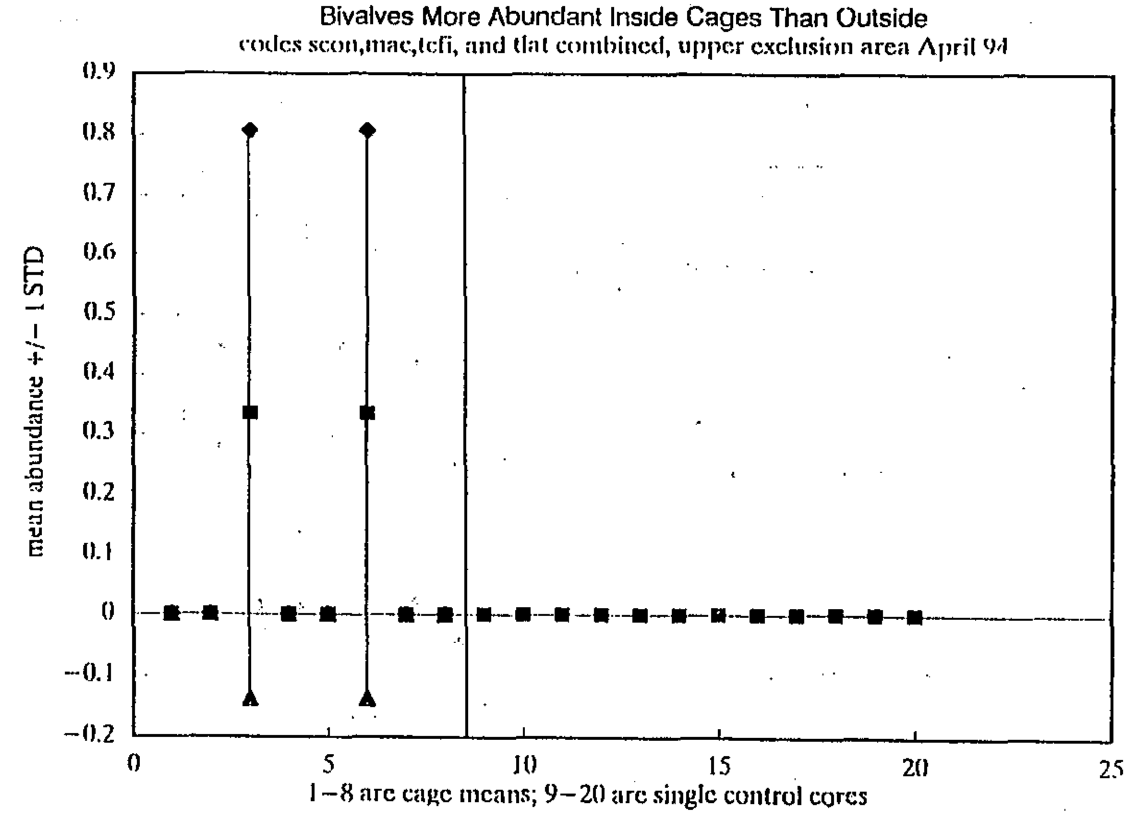

Lower exclusion area. Mean abundance and 1 standard deviation is shown for each of eight treatment cages within which three replicate cores are used to estimate abundance. These are compared with the abundance in 12 single control cores.

Figure A10.9.9 Large Bivalves More Abundant Inside Cages Than Outside Cages, February 1994



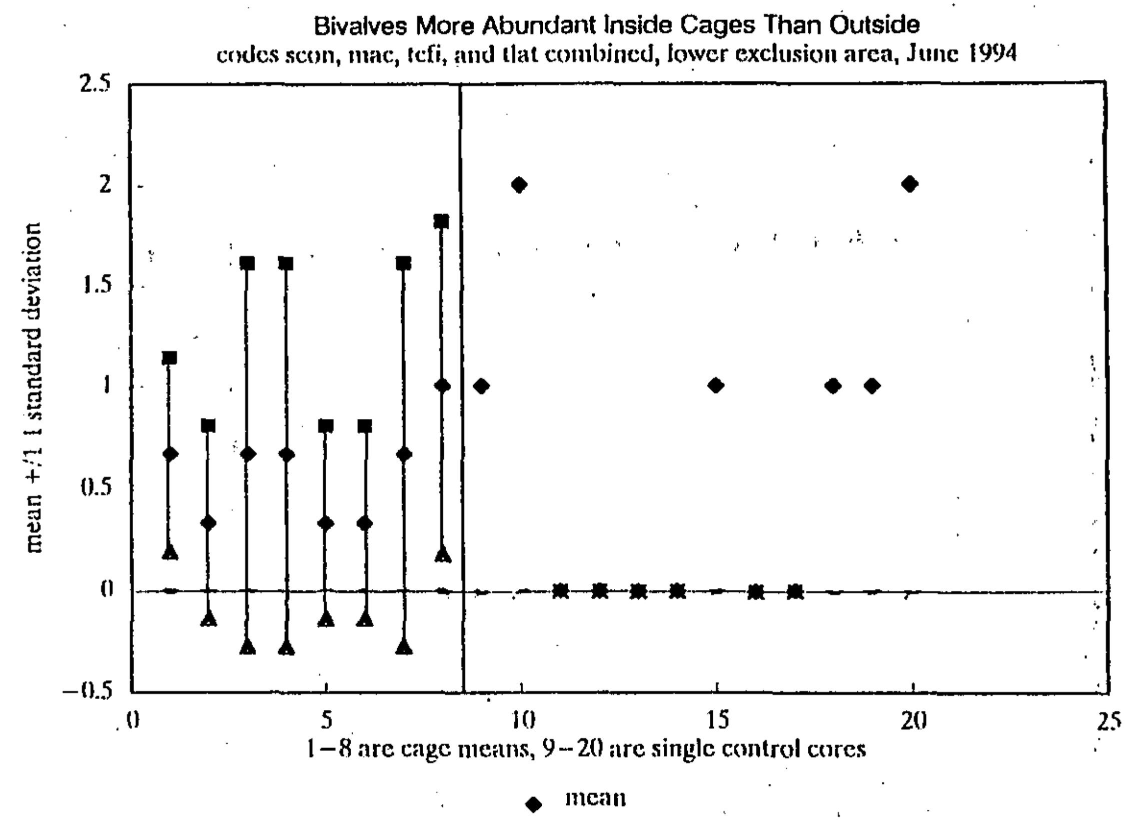

Lower exclusion area. Mean abundance and 1 standard deviation is shown for each of eight treatment cages within which three replicate cores are used to estimate abundance. These are compared with the abundance in 12 single control cores.

Figure A10.9.10 Large Bivalves More Abundant Inside Cages Than Outside Cages, April 1994



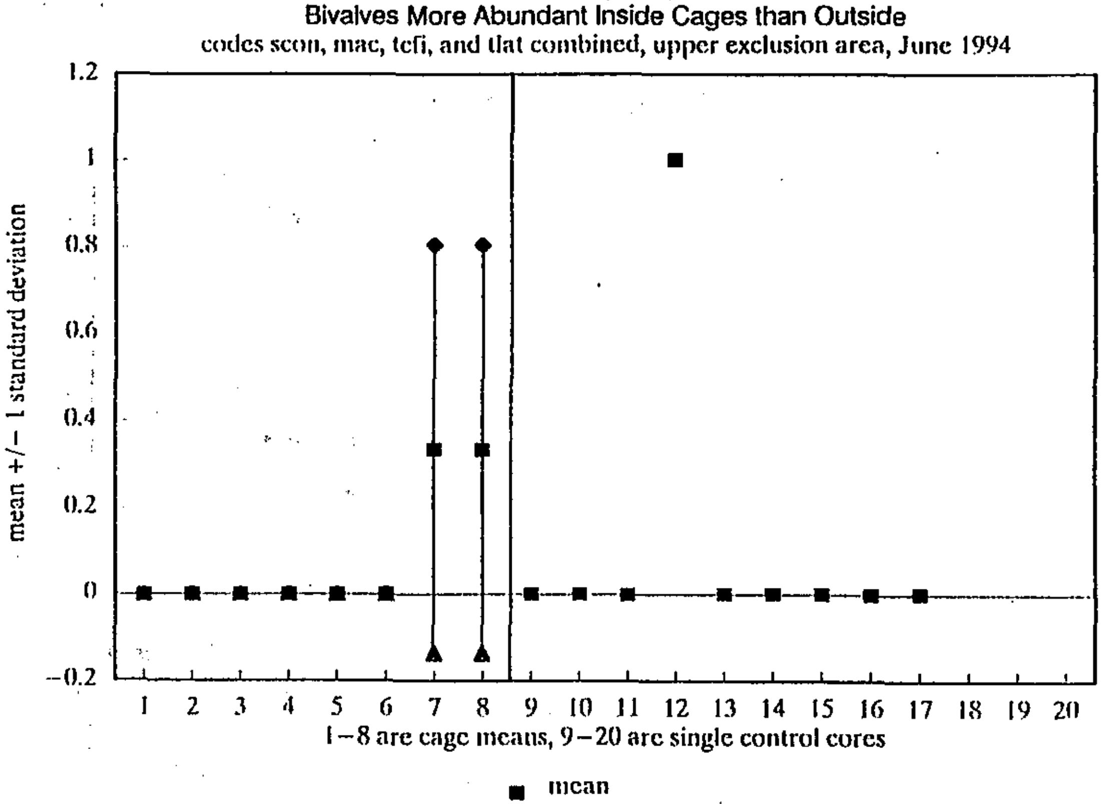

Upper exclusion area. Mean abundance and 1 standard deviation is shown for each of eight treatment cages within which three replicate cores are used to estimate abundance. These are compared with the abundance in 12 single control cores.

Figure A10.9.11 Large Bivalves More Abundant Inside Cages Than Outside Cages, April 1994



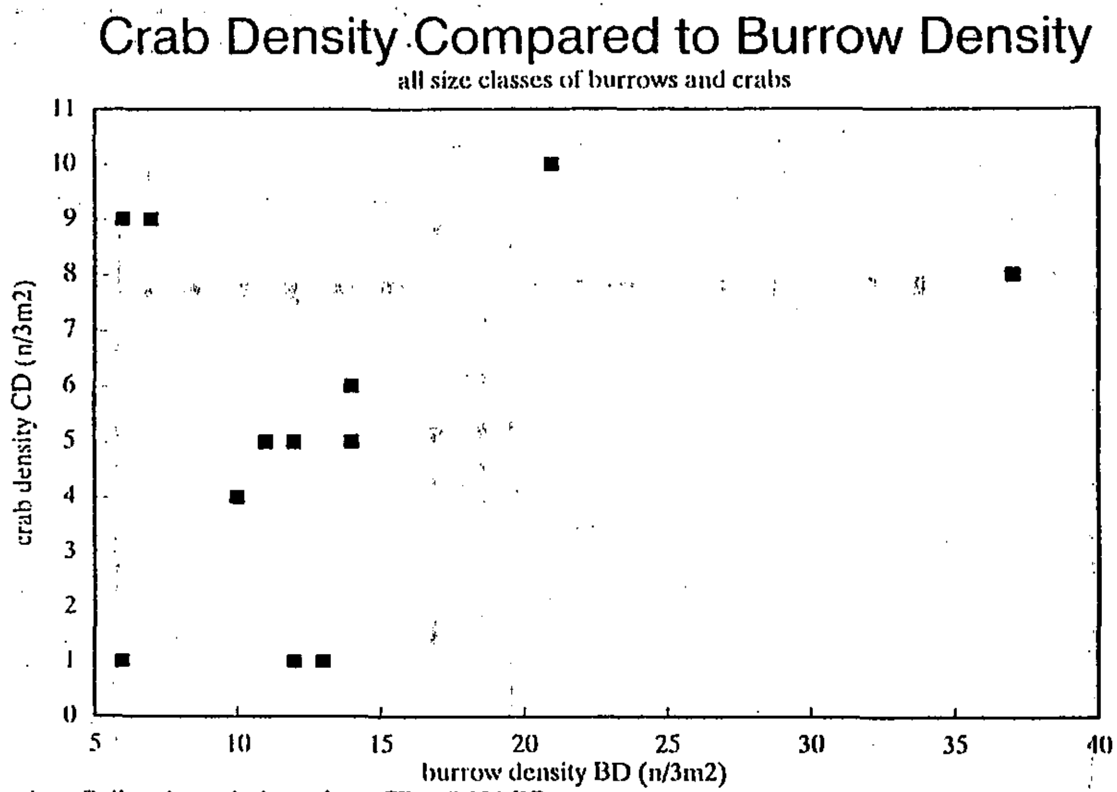

Lower exclusion area. Mean abundance and 1 standard deviation is shown for each of eight treatment cages within which three replicate cores are used to estimate abundance. These are compared with the abundance in 12 single control cores.

Figure A10.9.12 Large Bivalves More Abundant Inside Cages Than Outside Cages, June 1994




Upper exclusion area. Mean abundance and 1 standard deviation is shown for each of eight treatment cages within which three replicate cores are used to estimate abundance. These are compared with the abundance in 12 single control cores.

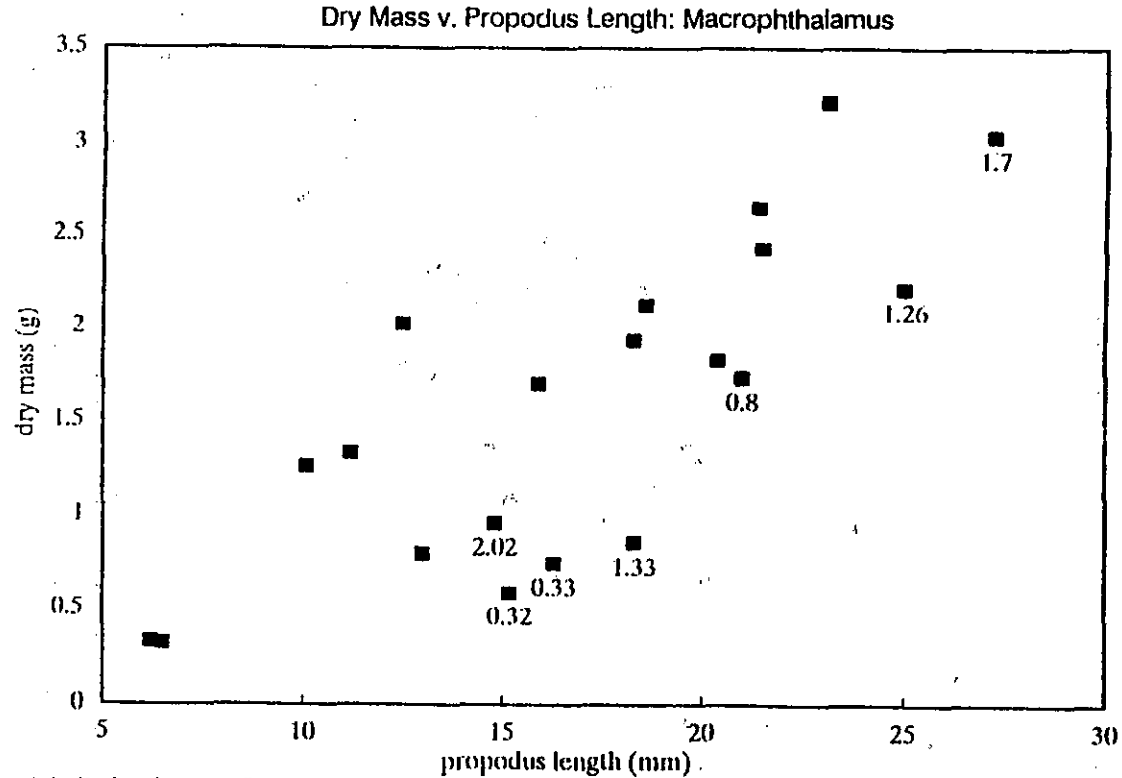
Figure A10.9.13 Large Bivalves More Abundant Inside Cages Than Outside Cages, June 1994




best fit line through these data: CD= 0.321 BD

**Observations from quadrats adjacent to TBT hide, October 1994. Best-fit line calculated to predict crab density from burrow abundance.**

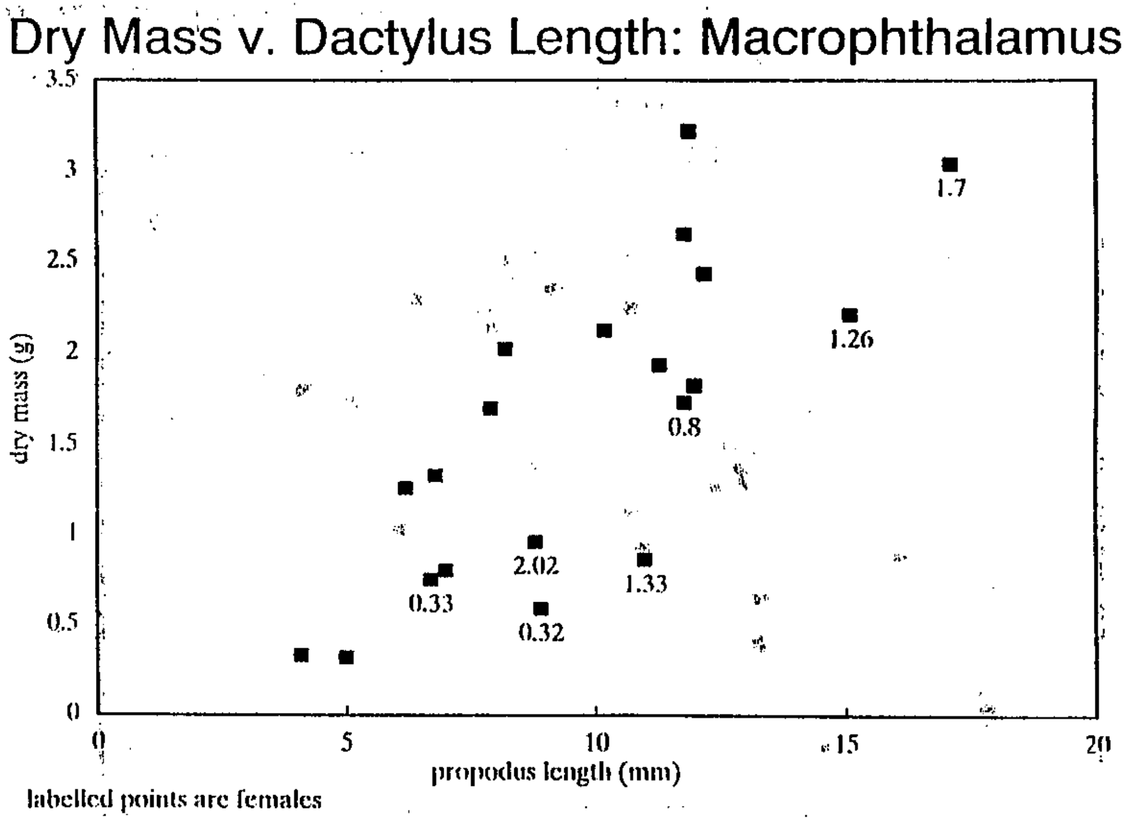
Figure A10.9.14 Crab Density Compared to Burrow Density




labelled points are females

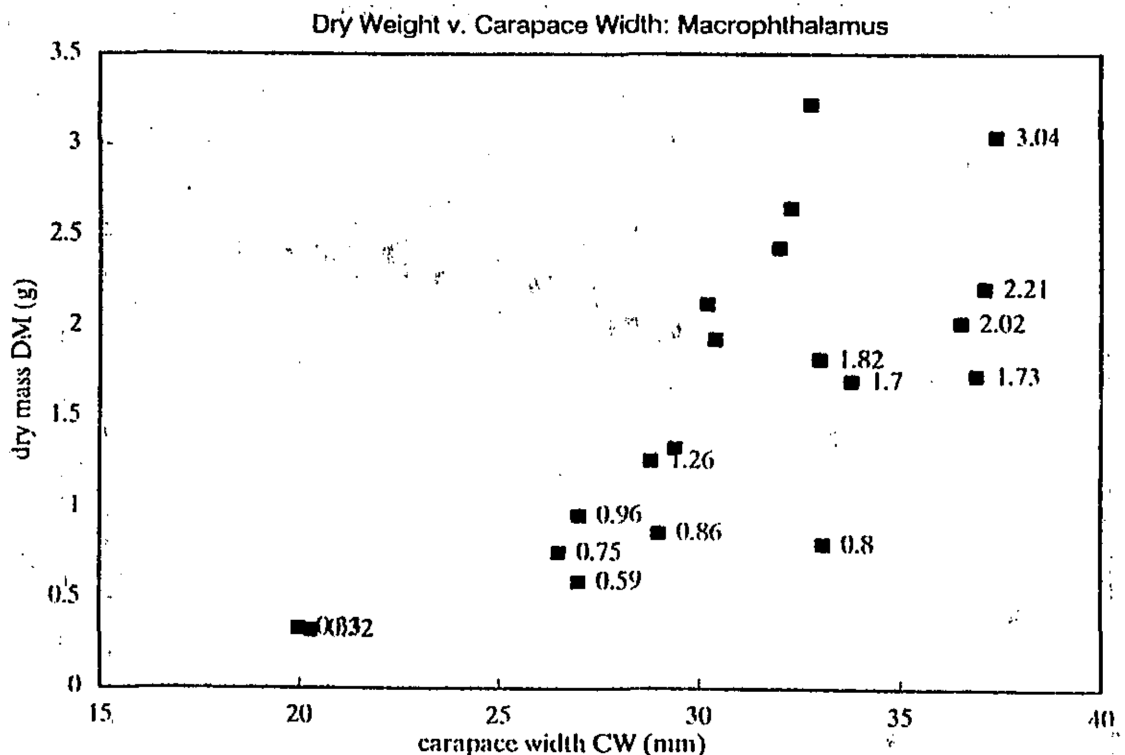
Data combined from both collections, April and September, 1994.

Figure A10.9.15 Dry Mass versus Propodus Length: *Macrophthalamus*




Data combined from both collections, April and September, 1994.

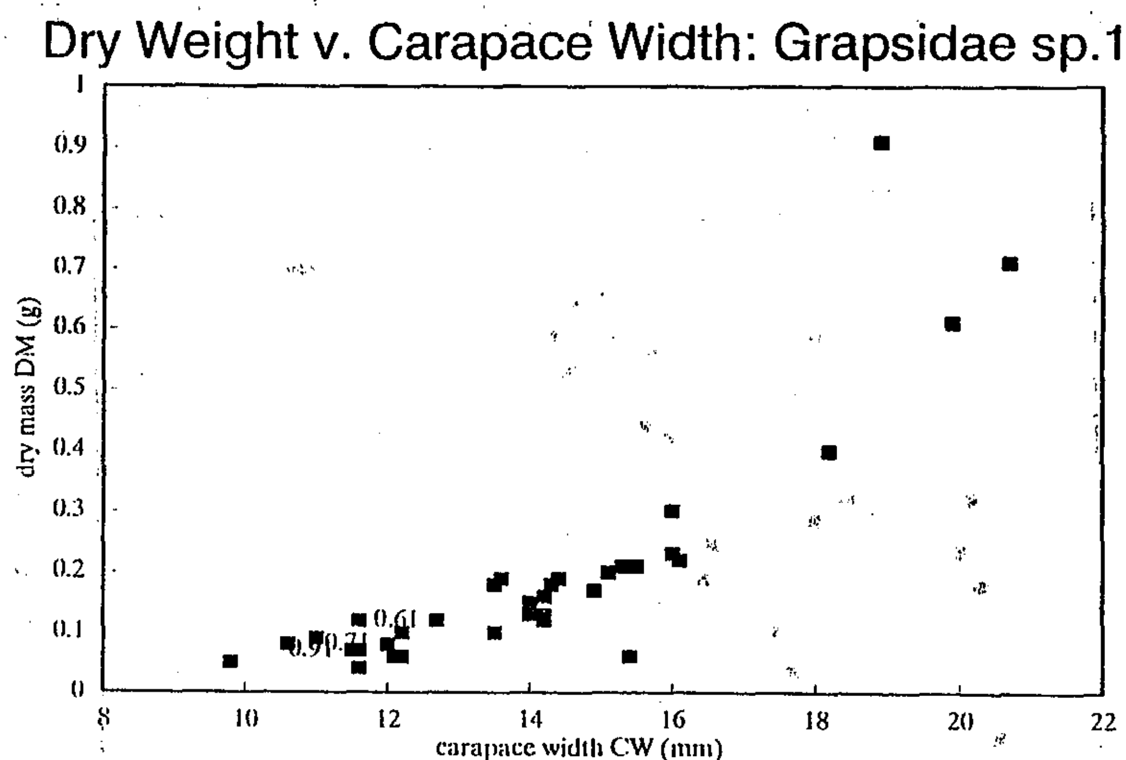
Figure A10.9.16 Dry Mass versus Dactylus Length: *Macrophthalamus*




unlabelled points from 18 Apr 94. Linear regression DM= 0.074 CW; R2= 0.269
labelled points from 1 Sep 94. Linear regression DM= 0.046 CW: R2= 0.464

Note individual body sizes are heavier for a given carapace width in April than in September. Linear regressions calculated to approximately determine biomass over these limited widths. The regression is more likely a cubed power function.

Figure A10.9.17 Dry Mass versus Carapace Width: *Macrophthalamus*




labelled points from 18 Apr 94. Linear regresson DM= −0.12 CW; r2= 0.492
unlabelled points from 1 Sept 94. Linear regression DM= 0.011 CW; r2= .376

Note that carapace widths hardly overlap widths for *Macrophthalamus*. Linear regressions calculated to approximately determine biomass over these limited widths. The regression is more likely a cubed power function.

Figure A10.9.18 Dry Mass versus Carapace Width: *Grapsidae* sp. 1