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A Classification of Tasmanian Estuaries and Assessment of their Conservation Significance using Ecological and Physical Attributes, Population and Land Use

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SUMMARY

Physical attributes of Tasmanian estuaries

A total of 111 estuaries of moderate or large size were recognised around Tasmania and associated Bass Strait islands. The catchments of these estuaries were mapped using GIS, and available data on geomorphology, geology, hydrology and rainfall collated for each estuary and catchment area.

Tasmanian estuaries were classified into nine groups on the basis of physical attributes that included salinity and tidal data collected during a field sampling program. The nine groups primarily reflected the size of estuaries and their tidal, salinity and rainfall characteristics, and the presence of any seaward barrier. Catchments in the west, northwest and south of the state were characterised by high rainfall and high runoff, while catchments in the east and northeast were relatively dry. Estuaries in northern Tasmania possessed much greater tidal ranges than those on the eastern, southern and western coasts and were all open to the sea, whereas many estuaries in eastern Tasmania and the Bass Strait islands were intermittently closed by sand barriers.

Biological attributes of Tasmanian estuaries

Baseline information on the abundance, biomass and estimated production of macrobenthic invertebrate species was collected during a quantitative sampling program at 55 sites in 48 Tasmanian estuaries. These data were generally obtained at three different intertidal levels and two shallow subtidal depths at each site, and included information on a total of 390 taxa and over 100,000 individuals. Data on the distribution of 101 fish species, as obtained during surveys of 75 Tasmanian estuaries using seine nets by Last (1983) with some supplementary sampling, were also incorporated into the study.

Multivariate analyses indicated that the nine estuarine groups identified using physico-chemical attributes were useful for categorising faunal relationships between estuaries, although considerable variation was found between faunas at sites within estuaries, particularly for marine inlet estuaries and drowned river valleys. Variation in faunal composition between sampling dates at the one site was low.

The number of species collected at sites also varied with the estuarine groups identified using physico-chemical attributes, with highest numbers of species occurring in marine inlets and small open estuaries. Relatively few species were collected at sites in microtidal river estuaries, barred low-salinity estuaries or hypersaline lagoons, with extremely low numbers collected in the western Tasmanian Wanderer estuary. North East Inlet (Flinders Island) and seagrass beds at the mouth of the Tamar estuary possessed exceptionally high diversity for both fishes and invertebrates.

The number of macrofaunal species collected at a site was primarily correlated with local salinity and biomass of submerged plant material, particularly seagrass. Species richness also varied with geographic location for both macrofauna and fishes, with highest numbers of species occurring in the Furneaux Group, northeastern Tasmania and southeastern Tasmania. Low numbers of species were collected on the west coast and, to a lesser extent, south coast, central north coast and King Island. These patterns primarily reflected differences in estuary type between regions rather than concentrations of locally endemic species.

Nearly all fish and invertebrate species recorded from Tasmanian estuaries occurred widely within the state and have also been recorded in southeastern Australia. Only 1% of estuarine fish species and <5% of invertebrate species were considered endemic to the state. The general pattern of widespread species' ranges around Tasmania was complicated by the absence of most species from the west coast, a small (<10%) component of species that occurred only in the northeast (particularly Flinders Island), and a few localised species that were restricted to different regions of the state.

The low number of species recorded from estuaries along the western Tasmanian coast reflected extremely low macrofaunal productivity in that region. Estimated secondary productivity of west coast estuaries was generally at least one, and up to three, orders of magnitude lower than equivalent estuaries on other coasts. This low productivity was attributed to unusually low concentrations of dissolved nutrients in rivers and dark tannin-stained waters which greatly restrict algal photosynthesis and primary production.

The estimated productivity and biomass of macrofaunal communities were found to vary little between sites within an estuary compared to variance between estuaries. By contrast, variance in the density of macrofauna was much greater between sites within an estuary than between estuaries, and variance was relatively low at scales of metres and hundreds of metres at similar tidal heights within a site. The environmental factor most highly correlated with animal density was the biomass of plant material, while estimated faunal productivity and biomass were most highly correlated with salinity.

Threats to estuarine biota

Biological resources within most large Tasmanian estuaries are exploited, with unknown consequences for ecosystem structure and function. In addition, nine major indirect threats to Tasmanian estuaries have been recognised: (i) increased siltation resulting from land clearance and urban and rural runoff, (ii) increased nutrient loads resulting from sewage and agricultural use of fertilisers, (iii) urban effluent, (iv) foreshore development and dredging, (v) marine farms, (vi) modification to water flow through dams and weirs, (vii) acidification of rivers and heavy metal pollution from mines, (viii) the spread of introduced pest species, and (ix) long-term climate change. While all of these factors can potentially disrupt ecosystem processes, the magnitude and spatial scale of these threats vary greatly.

The first seven indirect threats affect individual estuaries and can be ameliorated by changing management practices, whereas substantial global warming would affect all estuarine ecosystems within the state through changes to water flow, increased water temperatures and sea level rise. The effects of introduced pests are also increasing and uncontrollable at present. Although only four introduced species – the green crab *Carcinus maenas*, the tanaidacean *Sinelobus stanfordi*, the bivalve *Theora lubrica* and the gastropod *Potamopyrgus antipodarum* – were collected during the present study, the threat posed by these and other species (including the seastars *Asterias amurensis* and *Patiriella regularis*, the molluscs *Musculista senhousia*, *Crassostrea gigas*, *Maoricolpus roseus* and *Corbula gibba*, the polychaete *Sabella spallanzani* and the ricegrass *Spartina anglica*) was considered to be extremely high.

Amongst the more localised threats to estuaries, siltation, or a correlate thereof, was found to have an extremely widespread effect on Tasmanian estuaries. Estuaries with moderate or high human population densities in catchments consistently possessed muddy rather than sandy estuarine beds and shores. Although no change in number of macrofaunal species was associated with high human population densities and associated transformations from sandflats to mudflats, a pronounced shift in the faunal composition was evident in populated estuaries. These faunal changes were readily detectable using two disturbance indices described here, DI_n and DI_p, which are suggested to provide useful indicators of estuarine health.

Assessment of the conservation significance of Tasmanian estuaries

Human population densities within each estuarine catchment and the extent of legislative protection were estimated using GIS, census statistics, dwellings marked on 1:25,000 maps and land tenure data. The catchment areas of all Tasmanian mainland estuaries were also categorised in terms of land and vegetation use using GIS and data derived from satellite images. Satellite data for the Bass Strait islands were not available so estuaries in that region were not similarly examined.

A total of 24 out of the 90 Tasmanian mainland catchments were considered to be pristine, with little human impact within the catchment. These catchments were nearly all distributed in the south and west of the state and on Cape Barren Island. A small number of catchments were severely impacted by urban development and large scale land clearance, and many others were moderately effected by human impacts. The highest levels of land clearance, population and urban development were found in catchments along the south-east, east and north coasts of Tasmania.

The conservation significance of each Tasmanian estuary was assessed using the nine groups of estuaries identified by physical criteria. Within each of the nine groups, estuaries were ranked by level of anthropogenic disturbance using human population density data, and the estuary with least disturbance assigned the highest conservation rank (Class A). Each of these Class A estuaries was therefore the least disturbed estuary of a particular type, and between them they spanned nearly all of the biological and habitat diversity found within estuaries in the state. Where more than one estuary within a group was found to be 'pristine', the estuary with highest conservation status was identified using data on the percentage of catchment area included within national parks and crown reserves, and data on size of estuary.

In addition to the nine representative estuaries found to possess highest conservation value, North East Inlet was also assigned Class A conservation status because it possessed high species diversity and included species not contained in other Class A estuaries. The ten class A estuaries are North East Inlet, Black River estuary, Bryans Lagoon, New River Lagoon, Thirsty Lagoon, Tamar River estuary, Southport Lagoon, Bathurst Harbour, Payne Bay and Wanderer River estuary.

We recommend that plants, animals and habitats within the ten Class A estuaries and associated catchments be protected within an integrated system of Tasmanian estuarine protected areas. We also recommend that catchments and aquatic ecosystems of a further 38 estuaries, which were assigned Class B conservation status on the basis of minimal anthropogenic impacts, be quarantined from future developments, and existing impacts reduced wherever possible.

Recommendations

Specific management recommendations arising from the study are:

- The taking of aquatic flora and fauna other than introduced species (salmonids) by any means be prohibited within National Parks, other than the area of Payne Bay excluded from the proposed Port Davey Marine and Estuarine Protected Area.

- An integrated system of estuarine protected areas be created using legislation to prevent the taking of aquatic flora and fauna by any means from the Black River, Southport Lagoon, Thirsty Lagoon and Wanderer River estuaries.

- The taking of aquatic flora and fauna by any means be prohibited within an area extending offshore for a distance of 500 m from She Oak Point to Low Head in the Tamar estuary.

- The taking of aquatic flora and fauna by any means be prohibited in North East Inlet (Flinders Island) within the area of estuary extending northward for a distance of 1.5 km from the latitude of the junction of Edens Road and North East Inlet Road (Tasmap grid reference ES820995).

- The taking of aquatic flora and fauna other than by rod or handline, or from marine farm leases, be prohibited from the North East Inlet, Sea Elephant River, Foochow Inlet, Middle Inlet, Patriarch River, Sellars Lagoon, Cameron Inlet, Logan Lagoon, Mines River, Dover River, Lee River, Shag Rock River, Modder River, Rices River, Rocky Head River, Mosquito Inlet, Big Lagoon, Sloop Lagoon, Freshwater Lagoon, Great Swanport, Cloudy Bay Lagoon, Catamaran River, D`Entrecasteaux River, Freney River, Lewis River, Mainwaring River, Spero River, Hibbs Lagoon, Henty River, Lagoon River, Pedder River, Nelson Bay River and Arthur River estuaries.
- Non-allocated Crown land or State Forest within the Thirsty Lagoon, Black River, Wanderer River, North East Inlet and Southport Lagoon catchments be upgraded to Crown Reserve, Coastal Reserve or Forest Reserve status.
- Habitat alteration and exploitative activities on private land within the Black River, North East Inlet and Southport Lagoon catchments be minimised wherever possible.
- Habitat alteration and exploitative activities on crown and private land within the Sea Elephant River, Foochow Inlet, Middle Inlet, Patriarch River, Sellars Lagoon, Cameron Inlet, Logan Lagoon, Mines River, Dover River, Lee River, Shag Rock River, Modder River, Rices River, Rocky Head River, Mosquito Inlet River, Big Lagoon, Sloop Lagoon, Cloudy Bay Lagoon, Catamaran River, D`Entrecasteaux River, Freney River, Lewis River, Mainwaring River, Spero River, Hibbs Lagoon, Henty River, Lagoon River, Pedder River, Nelson Bay and Arthur River catchments be minimised wherever possible.
- The establishment and spread of introduced marine pests be minimised wherever possible.
- Isolated areas of the state that presently act as refuges from introduced species, viz. southwestern Tasmania, the Furneaux Group and King Island, be actively managed to prevent the establishment of pests, including the green crab *Carcinus maenas*, the North Pacific sea star *Asterias amurensis*, the Pacific oyster *Crassostrea gigas* and the fan worm *Sabella spallanzani*.

Recommendations for future research are:

- The suitability of Thirsty Lagoon as a Class A estuary be investigated by field inspection and collection of salinity, tidal and biological data. If Thirsty Lagoon dries out in a similar way to Sellars Lagoon and Logan Lagoon or is otherwise unsuitable, then Rocky Head estuary be investigated as a Class A estuary and if suitable substituted for Thirsty Lagoon in recommendations above. If Rocky Head estuary is unsuitable because of small size and limited aquatic habitat, then Cameron Inlet be considered a Class A estuary and substituted for Thirsty Lagoon in recommendations above.

- Boundaries proposed above for an estuarine protected area in North East Inlet be assessed using information on distribution of habitat types and fishing effort, and, if necessary, alternative recommendations made for an area within this estuary.
- Further investigation be made of the estuarine disturbance indices DI_n and DI_p to determine their utility as indicators of environmental health, both within an estuary over time and between different estuaries, and to identify the extent to which these indices are influenced by components of the natural environment.
- Detailed time-series data be collected concurrently with faunal abundance data from a limited number of estuaries to identify aspects of salinity and flow that most affect estuarine biota (e.g. whether maximum, minimum or modal salinity, or length of flood, has greatest affect on distribution and abundance of estuarine fauna).
- Collection of baseline data from as many estuaries as possible for the most important physical variables, including salinity, water flow, turbidity, nutrient concentrations, oxygen concentration, suspended solids, temperature, pH and heavy metal concentrations.

Fig. 1. Map showing estuaries examined around Tasmania. Estuaries assigned Class A conservation significance are shown in bold.

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1. Introduction

1.1 Context

Estuaries provide foci for human development worldwide, with the productivity and fertility of estuaries contributing to the success of human settlements. Rivers and their associated alluvial plains have provided dependable supplies of freshwater and fertile agricultural land, while the productivity of the waters has provided a plentiful source of fish and shellfish. Estuaries offered sheltered ports for the development of sea travel and trade, and rivers made possible access to hinterland areas. Expanding world trade and the development of heavy industries, which rely on transport of raw materials and produce, have promoted the growth of ports and urban and industrial developments around estuaries.

In Australia, estuaries were selected as the principal sites of European settlement (Hodgkin, 1994), with population and urban development continuing to grow along Australia's coastline (Adam *et al*., 1992). In Tasmania, ocean trade has been critical to the economic development of the state, resulting in the major urban centres becoming established around the estuarine ports of Hobart, Launceston, Devonport and Burnie.

Estuaries are highly significant to both commercial and recreational fisheries because they provide important nursery areas and possess extremely high productivity, which results in large populations of invertebrates, fishes and birds in confined areas (Edgar & Shaw, 1995b; Saenger, 1995). Estuaries are also popular sites for tourism and recreational activities, adding to developmental pressures.

Human activities compromise estuarine ecosystems and in many cases have led to large scale alterations of the natural communities in estuaries. Estuaries have been used as conduits for industrial and urban wastes, while reclamation of wetlands, dredging of shipping channels and construction of port facilities have caused large-scale habitat destruction.

Deforestation within estuarine catchments for agriculture, forestry and urban development has increased runoff and peak flow rates, while erosion of exposed soils has increased sediment loads of rivers. Intensive development of estuaries and their catchments since European settlement has also resulted in the deterioration of water quality, increased siltation, reduction and degradation of important habitats such as seagrass, mangrove and saltmarsh, disruption of estuarine ecosystems, and declining fish populations (Dyer, 1973; Adam *et al*., 1992; Saenger, 1995).

The overall problem of estuarine degradation and habitat loss was identified in the Commonwealth State of the Marine Environment Report (SOMER) as amongst the most serious marine environmental issues facing Australia (Saenger, 1995). For Tasmania, SOMER also identified major gaps in our knowledge of estuaries, including habitat distribution, water quality and biotic inventories. These gaps, which include an almost complete lack of physical, chemical and benthic invertebrate data collected from estuaries within the state, prevent the detection and early remediation of problems as they arise. They also limit the ability of planners to interpret and implement the Tasmanian State Coastal Policy and State Water Policy, particularly when assessing the potential impacts of new development applications.

While there is now a strong public awareness of the importance of the conservation of estuaries and their associated wetlands in Australia (Saenger, 1995), human population growth, and urban and industrial development, continue to threaten estuarine ecosystems. Appropriate management of estuarine environments is essential to ensure the protection of natural resources and ecosystems, as well as maintaining the quality of human habitation near estuaries. Estuaries are not independent ecosystems. They are inextricably linked to processes within their catchments and the adjacent marine environment. Management strategies therefore require an understanding of all factors that effect the estuarine environment (Day and Grindley, 1981).

Bucher and Saenger (1989, 1991) recognised the need for a broad overview of the status of Australian estuaries. They produced a national inventory that included habitats, the value of estuarine fisheries, conservation values, water quality, catchment clearance and landuse. Their inventory summarised the current status of knowledge for over 700 Australian estuaries. In Tasmania, 63 estuaries were identified that met the criteria used in the study; however, there was a paucity of information available for the majority of these estuaries. Bucher and Saenger (1989) identified significant areas requiring additional information in Tasmania including: catchment clearance and landuse, water quality, saltmarsh and seagrass distribution, and the value of commercial and recreational estuarine fisheries. Other information recorded in the inventory, such as rainfall and runoff values for estuarine catchments, was extrapolated from minimal data.

In a recent report on the distribution of inshore marine organisms, Edgar *et al.* (1994a) concluded that virtually all estuaries along the east and north coasts of mainland Tasmania are badly degraded by pollution, siltation, nutrification and onshore development. They suggested that estuarine habitats are under greater threat from human impacts than other marine ecosystems in Tasmania, and recommended survey work as a matter of urgency to determine the conservation significance of Tasmanian estuaries and to identify estuarine areas most in need of protection. The study of Edgar *et al.* (1994a) provided the impetus for the present project, which is aimed at describing and classifying the biota and physical attributes of Tasmanian estuaries. It is part of a broader Commonwealth government initiative aimed at identifying representative areas around Australia for inclusion in a comprehensive system of marine and estuarine protected areas (MEPAs) (Zann, 1995). Information on the conservation significance of estuaries provided here should be useful, for example, when development applications affecting estuaries are assessed. Prior to the present study, the impact of a proposed development within a particular estuary could be assessed but no information was available on whether that estuary was already severely degraded, possessed a unique ecosystem, or was the only ecosystem of a particular type that remained undegraded.

1.2 Aims

The aims of the project were to produce an inventory of attributes of Tasmanian estuaries and their catchments, and to use that information to classify and define the conservation values of estuarine environments within the State.

The specific objectives were:

- to define the boundaries of the catchments of Tasmanian estuaries and their associated river systems;
- to derive physical attributes for each catchment and estuary including: catchment area, water surface area, catchment rainfall, catchment runoff, geomorphology, geology and tidal range;
- to use physical and hydrological data to group catchments with similar physical characteristics;
- to obtain quantitative baseline data on fishes, invertebrates and aquatic plants associated with major Tasmanian estuaries;
- to determine the degree of correspondence between physical and biological attributes;
- to obtain data on human population, land tenure, degree of catchment clearance and broad categories of landuse within each catchment; and
- to rank estuaries and associated catchments according to the degree of human impact and their conservation significance.

The process of ranking estuaries and associated catchments in terms of conservation significance was achieved using the procedures summarised in Fig. 1.1. Estuaries within the state were firstly categorised into a limited number of groups on the basis of similarities in geomorphological and hydrological attributes. This step could not be conducted using biological information because data on plants and animals were not available for all estuaries and biological data typically characterised a site rather than encompassed the range of variation within any estuary.

The adequacy of the physical groups was assessed by comparison with invertebrate and fish data sets. Within each of the defined groups, human population and landuse data were then used to assess the level of anthropogenic disturbance to each estuary, and the estuary with least disturbance identified. Where more than one estuary within a group was considered 'pristine', the conservation significance of estuaries was separated using land tenure data. Because estuaries with a high percentage of their catchment included within national parks are least likely to face future threats, these estuaries were ranked higher than estuarine catchments with large areas included in other types of crown reserves. Catchments with crown land available for exploitative purposes (forestry, mining leases, etc.) were in turn ranked lower than catchments with crown reserves and higher than catchments with large areas of private land.

In addition to estuaries assigned high conservation significance because they represent a particular estuary type and have minimal human impacts, estuaries were also assigned high conservation significance if they contained anomalously high species diversity or included endangered species.

A major aim of the process described above was to identify estuarine habitats in a relatively undisturbed state that encompass the range of habitat types and biological diversity around Tasmania. Once these estuaries are identified, an integrated statewide system of estuarine protected areas can be created by government legislation. Such a system of estuarine protected areas is anticipated to provide a number of benefits to the general community, including: (i) maintenance of reservoirs of genetic diversity, (ii) provision of fish propagation areas, (iii) insurance against the possibility of fishery stock collapses, (iv) protection of areas where natural ecosystem processes can be scientifically investigated, (v) provision of recreational sites for divers and naturalists, and (vi) provision of foci for public education about coastal life (Pollard, 1977; Ballantine, 1991; Fairweather & McNeill, 1993; Jones & Kaly, 1995).

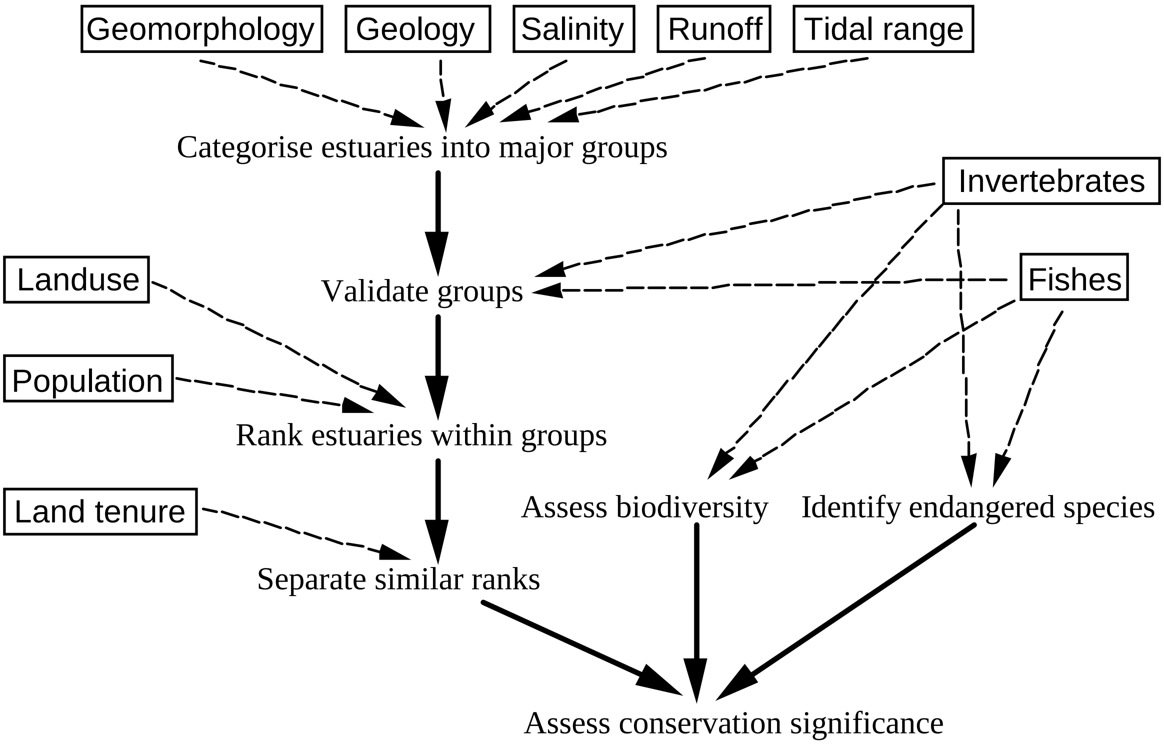

Fig. 1.1 Process used to rank estuaries in terms of conservation significance. Data sets used are enclosed in rectangles.

1.3 Defining an Estuary

Estuaries lie at the interface of marine, freshwater, atmospheric and terrestrial systems. They are dynamic environments, each with uniquely varied and individual characteristics, making generalisations, categorisations and comparisons difficult. Estuaries have been defined by their geographical location, their geomorphology and the physical, chemical and biological processes that occur within them.

The public generally associates the term estuary with the mouth of a river - the location where the river meets the sea. The new shorter Oxford Dictionary, for example, defines an estuary as ‘the tidal mouth of a large river, where the tide meets the stream’ (Brown, 1993). However, this definition neglects important physical features of estuaries. Most authors agree that variability in salinity is an essential feature of all estuaries (Day, 1981). A widely quoted definition is that of Pritchard (1967, as quoted in Dyer, 1973) - "An estuary is a semi-enclosed body of water which has a free connection with the open sea and within which sea water is measurably diluted with fresh water derived from land drainage".

This definition excludes many saline lakes and marine inlets without fresh water inflow. It also excludes tidal reaches of rivers that are beyond the limit of saline incursion. Day (1981) suggest that this may be a useful characteristic as it marks the change from brackish to freshwater and related changes in flora and fauna. McComb & Lukatelich (1986) argue that this could exclude whole rivers where high flow levels prevent any saltwater incursion, while some marine embayments not associated with fluvial drainage show detectable variation in salinity through input of groundwater seepage. For this reason, McComb & Lukatelich's (1986) definition focuses on the importance of fluvial drainage - "that part of a river system in which the level or salinity of water may be affected by that of the sea". However Bayly (1980) also includes other coastal water bodies that have salinity levels "that are outside the range encountered in oceanic waters". This incorporates many hypersaline coastal lakes common in arid zones, such as regions of Australia where evaporation regularly exceeds fresh water inflow. Day (1981) also includes these hypersaline lakes and other temporarily closed or ‘blind’ estuaries in his variation of Pritchard’s definition: "An estuary is a partially enclosed coastal body of water which is either permanently or periodically open to the sea and within which there is a measurable variation of salinity due to the mixture of sea water with fresh water derived from land drainage".

Ketchum (1983) also focuses on variable salinity as the major factor for defining estuarine waters. He attempts to define the inner boundaries of an estuary as the point where there is no net movement of water upstream during a flood tide. Essentially this is the landward extent of saline incursion and the definition excludes the "tidal river" above this point. He notes that the boundary is a dynamic one, varying with river flow levels.

Focussing on salinity as the determinant of estuarine boundaries ignores other physical factors acting within the estuarine environment. Variations in tide and river flows have marked effects on patterns of water circulation and movement of sediments in all areas under tidal influence. Further, defining the seaward boundary of an estuary using salinity causes problems. Large rivers and smaller rivers in flood can discharge plumes of fresh and brackish water for considerable distance offshore. Plumes have been termed offshore estuarine zones (Ketchum, 1983). They have a biota that is distinct from the surrounding marine environment (Kingsford & Suthers, 1994).

There is obviously great difficulty in arriving at a general definition of an estuary that satisfies all researchers and all situations. This is further complicated when administrative or geographical boundaries are imposed on naturally variable systems. However, the important features of estuaries are that they are unique and highly variable environments that represent the major interface between land based processes within the catchment and the marine environment. A useful general definition of an estuary needs to recognise the importance of the interaction between drainage from the land and marine waters, and the unique environments created by the combination of the physical and chemical characteristics of both. At the same time, for practical and administrative purposes, an indication of the geographical limits of an estuary needs to be included.

For the purposes of this study an estuary is defined as:

"*a semi-enclosed or periodically closed coastal body of water in which the aquatic environment is affected by the physical and chemical characteristics of both fluvial drainage and marine systems*".

This definition includes coastal lakes, lagoons and rivers upstream to the limit of tidal influence. It recognises the importance of external inputs from both marine and terrestrial environments and it implies a seaward geographical limit at the opening to the sea. This definition does not include consideration of freshwater plumes and offshore estuarine zones.

1.3.1 Upstream limits of estuaries

A generalised definition of an estuary emphasises the processes occurring within the estuarine environment and recognises the variable and fluctuating nature of these processes. However, for analytical and administrative purposes it is necessary to define precise geographical boundaries for an estuary.

Ketchum (1983) suggests that the upstream limit of an estuary is the point where there is no net movement of water upstream on the flood tide. This may exclude long sections of river affected by changes in tidal levels. It may correspond to the upstream limit of saline incursion. Either of these limits are variable in geographic location and can be difficult to measure. The limit of tidal influence is probably less variable (Adam *et al.*, 1992) but can be difficult to determine by simple observation. Bucher & Sanger (1989) use the point where the sides of the estuary that are represented by separate lines on a 1:100,000 topographic map change to a single line as the point where the river runs into an estuary. This is an easily definable limit with some physical validity as an indication that the topography prevents further upstream incursion of the tide, although very large rivers can have widely-separated banks for considerable distance upstream from the region of salinity and tidal influence. At smaller scales (1:25,000 and lower), it may be valid to use the point where the first contour (5 or 10 m) intersects the river bank.

1.3.2 Downstream limits of estuaries

Seaward limits of estuaries are not precisely defined by salinity distribution because freshwater plumes from large rivers can extend large distances offshore and most coastal waters are diluted by freshwater runoff from land. Ketchum (1983) suggests that the seaward boundary can be geographically defined by a "line between the land masses on each side of the entrance to an estuary". This is usually a convenient definition, and meets the requirement of the general definition that estuaries are semi-enclosed, although it is confusing in situations where several headlands are located at the entrance, each further apart in a downstream direction. In these situations, such as at the mouth of the Derwent River, selection of the entrance headland becomes somewhat arbitrary.

The New South Wales (NSW) Estuary Management Manual (Adam *et al*., 1992) suggests that there is a hydraulic boundary where topography ceases to affect tidal behaviour within an estuary. This boundary may not be evident or distinct in broad-mouthed estuaries of drowned river valleys where there has been little sill or barrier development.

1.3.3 Lateral boundaries of estuaries

Adam *et al*. (1992) define ecological boundaries for estuaries to include all wetlands affected by extremes in tidal or riverine flood events that occur within upstream and downstream boundaries. Other publications do not specifically define lateral estuarine boundaries but generally include in discussion of estuarine ecosystems all associated wetlands, intertidal mud and sand flats, beaches and foreshore environments. The simplest determination of estuarine limits is obtained from the representation of permanent water shown on 1:100,000 or smaller scale maps. Unfortunately these may not include extensive areas of associated wetlands.

1.3.4 Estuarine catchment areas

The definition of physical and geographical boundaries of estuaries is not intended to suggest their isolation from other inputs. Indeed, the dominant factor that makes estuarine environments distinct from the rest of the marine environment is the influence of the volume and quality of freshwater runoff from the land. The catchment is the area of land that drains into the estuary or into stream and river channels that flow into the estuary. The National Oceanic and Atmospheric Administration (NOAA) of the United States Department of Commerce divide estuarine catchment areas (ECAs) into estuarine and fluvial drainage areas (NOAA, 1990).

An Estuarine Drainage Area (EDA) is the land area that drains directly into estuarine waters, while a Fluvial Drainage Area (FDA) drains into rivers or streams upstream of the EDA. NOAA (1990) make the assumption that natural processes and human activities immediately adjacent to an estuary will usually have the greatest effect on estuarine waters. However, where FDAs comprise a large fraction of the catchment, the influence of drainage from the EDA may not be significant (NOAA, 1990).

1.4 Characteristics of Estuaries

1.4.1 Formation of estuaries

Over geological time scales, estuaries are amongst the more ephemeral features of the landscape. Periodic changes in sea level associated with glaciation result in a cycle of erosion of river channels at low sea levels, and flooding of these eroded channels as sea levels rise. Sea level rise is associated with deposition of marine and fluvial sediments in flooded river channels. Sediments may build up to form barriers across the mouths of river channels and shallow embayments, thus creating tidal lakes. Sometimes these lakes are almost totally infilled, leaving a meandering, shifting river channel. Deep narrow river channels are not totally blocked and remain as drowned river valleys, often with relatively shallow sills at the entrance (Hodgkin, 1978; Adam *et al*., 1992; Morrisey, 1995).

The processes of sediment accumulation and stabilisation of sediments by vegetation occur at different rates in all estuarine environments. With the passage of time, natural processes within estuaries are likely to produce low-lying marshland, sealed off from the ocean behind coastal barriers, until falling sea levels again cause rivers to scour old and new channels in their journey to the sea (Carne, 1991; Adam *et al*., 1992).

The last period of extensive glaciation on earth ended between 15,000 and 20,000 years before present (ybp). Sea levels during this glaciation were up to 150 m below present day levels and the coastline extended in places out to the edge of the continental shelf. Some of the deep river channels eroded across this coastal plane remain as submarine trenches that dissect the continental shelf. As the large glacial ice sheets receded with global warming, sea levels rose eustatically at a relatively rapid rate (≈ 1 m per century), until they reached present levels some 5,000 to 7,000 ybp (Davies, 1974; Hodgkin, 1994; Harris, 1995)

Changes in sea level since that time can be largely attributed to isostatic uplifting or sinking of land masses. These tend to be relatively localised events resulting from tectonic movements of shifting continental plates (Yonekura *et al*., 1984) or localised land subsidence (Belperio, 1992).

1.4.2 Water flow in estuaries

Water movement in estuaries is predominantly affected by freshwater inflows from rivers and cyclical movement of seawater into (flood tide) and out off (ebb tide) the estuary. Wind, temperature and salinity gradients also generate secondary currents important in mixing and sediment transport. Freshwater inflows in Tasmania fluctuate between seasons, with higher flows in the winter wet season, and occasional unpredictable flood flows. Tidal flows vary in velocity and direction with the rise and fall of the tide and with the monthly tidal cycle - spring tides with large tidal ranges cause the strongest tidal currents (Dyer, 1973, Adam *et al*., 1992).

The movement of dense saline waters into the seaward end of an estuary is counteracted by freshwater flow into the head of an estuary. This results in a longitudinal density gradient with the highest density to seaward. Gravity forces denser saline water upstream along the bottom of the estuary, causing a downstream flow of less dense freshwater at the surface. This gravitational circulation enhances flood tide currents near the bottom of the estuary and ebb tide currents near the surface (Adam *et al*., 1992).

The amount of net seaward flushing is dependent on seaward flow caused by river discharge, the rate of mixing between freshwater and seawater masses, and the longitudinal dispersion of tidal flows. The greater the river discharge and tidal velocities, the better flushed the estuary.

Tidal flows are complicated by the length and shape of an estuary such that high and low tides can be experienced at the same time in different parts of an estuary, and tidal ranges can be amplified or attenuated. The tidal wave propagates from the ocean to the head of the estuary and back each tidal cycle.

The total volume of water moving into and out of an estuary with each tidal cycle, the tidal prism, is dependent on the dimensions of the estuary and the tidal range. It is also affected by lesser factors such as tidal amplification and attenuation, the lag phase and tidal resonance of the tidal wave moving up the estuary (Ketchum, 1983).

1.4.3 Classification of estuaries

Each estuary possesses a unique and dynamic environment that varies with shape, size, aspect, topography of the estuary and surrounding land, degree of tidal variation and incursion, and by land based processes within the catchment. Catchment factors that effect estuaries include rainfall and runoff, rock and soil type, erosion, vegetation cover and anthropogenic impact.

Attempts to classify estuaries are generally based on geomorphology, the characteristics of salinity distribution and water circulation patterns. These characteristics are largely interdependent as geomorphology, tidal range and river flows are the main determinants of salinity distribution, which in turn affects circulation patterns. Ocean circulation patterns driven by tide and wind currents, as well as river flows, can influence the geomorphology of estuaries and surrounding coastlines. Classifications of estuaries using these characteristics are presented by Ketchum (1983), Dyer (1973), Morrisey (1995) and Adam *et al*. (1992). Geomorphological types of estuaries identified in Australia and discussed here are:

a) *Drowned River Valleys* - estuaries with wide river mouths, rocky headlands and deep channels (e.g. the Derwent and Tamar estuaries);

b) *River estuaries* - estuaries where fast-flowing rivers discharge into the sea with little bar or lagoon development and poor water mixing (e.g. the Don and Pieman estuaries);

c) *Barrier or Bar estuaries* - estuaries with sandbars across their mouths. These are generally associated with depositional coastlines and relatively high fluvial sediment loads. Barrier estuaries are subdivided into permanently-open barrier estuaries (e.g. Prosser River and Ansons Bay) and seasonally-open barrier estuaries (e.g. Wanderer River), which are closed for part of the year when outflow seeps through beach sands;

d) *Saline Coastal Lakes and Lagoons* - flat swampy lagoons with irregular river input and infrequent openings to the sea. Incursion by seawater generally occurs only after extreme runoff events or tides breach the sand barrier, or after artificial breaching (e.g. Big Lagoon and Cameron Inlet);

e) *Coastal Inlets* - enclosed marine embayments with wide mouths that lack large riverine inputs but have detectable reduction in salinity from small creeks after heavy rainfall (e.g. West Inlet).

Many transitional stages occur between these forms. Estuarine morphology is continually changing with ongoing depositional factors counteracted by storm events, tides and riverine flooding.

Salinity distribution within estuaries is determined by the amount of mixing between freshwater from river flows and saline marine water. Mixing occurs by slow diffusion unless turbulence generated by shear stress causes vertical mixing (Adam *et al*., 1992). The rate of mixing is affected by tidal range, river flows, and the shape and depth profile of the estuary, particularly at the mouth of the estuary.

Three stages of estuarine mixing (Figure 2.2) are recognised (Dyer, 1973; Adam *et al*., 1992; Morrisey, 1995). These are:

a) *well mixed* - salinity varies little with depth;

b) *partially mixed* - salinity varies continuously with depth, with no evident interface between the upper and lower layers; and

c) *stratified* - salinity abruptly increases at the depth of the interface between upper fresh water and lower saltwater layers.

The degree of mixing in estuarine waters is greatest when lateral and vertical movement of waters is strongest. This is promoted by fast tidal flows and narrow channels meandering through shallows, bays, shoals and other obstructions that cause redirection of the main current and the generation of eddies. Stratified conditions are caused by low tidal current velocities or high river flows. The underlying ‘salt wedge’ can penetrate many kilometres into the estuary, such as along the Derwent River, where saline water extends ≈30 km upstream as far as New Norfolk (Coughanowr, 1995).

The ratio of river flow (per tidal cycle) to the tidal prism can provide a rough indication of the degree of mixing within estuarine waters. Dyer (1973), citing Simmons (1955), suggests that flow ratios of 1.0 or greater are consistent with highly stratified conditions, a ratio of about 0.25 suggests partial mixing, and a ratio of less than 0.1 indicates well mixed conditions.

Estuaries in Tasmania with low tidal ranges (south-eastern, southern and western coasts) are generally stratified during winter when river flows are high, and partially mixed during lower flow periods over summer. East coast estuaries and lagoons with lower river flows are generally mixed to a greater extent, while estuaries along the Bass Strait coastline, where tidal ranges reach up to 3m, are usually stratified during periods of average river flow. Stratification is generally more pronounced in the mid and upstream sections of estuaries than in the downstream sections.

1.5 The Tasmanian Estuarine Environment

1.5.1 Marine influences

The Tasmanian marine environment is influenced by three main ocean systems:

- the Antarctic circumpolar current transports cold nutrient-rich waters to the southern and western coasts,
- warmer waters from the Great Australian Bight, including the tail of the Leeuwin Current, extend to the northwestern Tasmanian coast and King Island during the cooler months,
- the East Australian Current transports warm waters to Tasmania’s north east coast, particularly in late summer.

Offshore water temperatures vary from a mean of 12°C in late winter, to a mean of 18°C in late summer, with greater fluctuations in sheltered coastal areas and estuaries (Edgar *et al*., 1994a).

Using biological criteria, Edgar *et al*. (1994a; 1997) subdivided Tasmanian coastal waters into two major provinces, the Bassian and Tasmanian, with each further subdivided into four bioregions. These bioregions were based on analysis of distributional data relating to coastal reef fishes, macroinvertebrates and plants. Edgar *et al*. (1994a) also made a limited analysis of patterns in fish and mollusc data from Tasmanian estuaries and beaches, and concluded that the coastal regionalisation probably does not apply to estuaries.

1.5.2 Freshwater influences

Tasmania has a distinctive hydrological region within Australia. It has a cool temperate climate with rugged mountain ranges rising to about 1500 m in the west, south-east, central and north-eastern parts of the island. Heavy rainfall, in excess of 3000 mm per annum, occurs in the western highlands, reducing to 1500 mm per annum in the north-west, south-east and north-eastern highland areas. In the shadow of the mountain ranges, rainfall in central, eastern and south-eastern districts decreases to as low as 500 mm per annum. Potential evaporation in Tasmania is the lowest in Australia. Evaporation is less than 600 mm per annum in the Western Highlands but is generally higher in other inland areas and increases around the coast (Australian Water Resources Council, 1976; Hughes 1987).

Hughes (1987) used available hydrological data from 77 Tasmanian rivers to derive a hydrological classification of Tasmanian rivers. Rivers were divided into four distinct hydrological groups. Rivers in the south-east lowlands and coastal areas were characterised by low runoff levels and greatest variability of flow. Rivers in the west and south have high annual runoff levels with low variation in flow levels. The other two groups of rivers have characteristics intermediate to these. Rivers in the north west having higher, more predictable flows than rivers in the central north and north east of Tasmania.

1.5.3 Biota

Few studies of estuarine biota have been conducted in Tasmania. The only standardised statewide survey of estuarine biota was a survey of fishes in soft bottom habitats around Tasmania conducted by Last (1983). The most important of the regional surveys are: (i) a description of the distribution of zooplankton in the Derwent Estuary by Taw & Ritz (1978, 1979), (ii) a study of mobile macroinvertebrates, fishes and plankton along Bathurst Channel and Bathurst Harbour by Edgar (1991a,b) and Edgar & Cresswell (1991), (iii) a study of macrobenthos along the Derwent estuary by Horwitz & Blake (1992), and (iv) an investigation of macrobenthos in Macquarie Harbour (O’Connor *et al*., 1996).

1.6 Human Impacts and their Management

Human activities can have significant impacts on estuarine environments and their ecosystems. These are best divided into activities that take place within catchments and those that take place within the boundaries of the estuary.

1.6.1 Catchment activities

Land clearance for agriculture, forestry and urban development results in significant increases in catchment runoff, and in sediment and nutrient loads carried by the runoff (Williams, 1980; Campbell & Doeg, 1989; Brodie, 1995). Radiocarbon dating and pollen analysis of sediment layers in a New Zealand estuary have shown a marked increase from 1 to 3 mm/y in sediment accumulation rates since commencement of clearing and European farming practises (Hume & McGlone, 1986). Sediment loads and concentrations of nitrogen (N) and phosphorus (P) from clearfelled forest coups were found to be 10-30 times greater than from uncleared forest in that study. However, topsoil losses can be significantly reduced with carefully planned roading, use of strip harvesting and maintenance of streamside reserves. Despite these measures, losses may still be twice that of uncleared forest (Sopper, 1975). Sediment losses are greatly exacerbated by storm flows (Beasley *et al*., 1986; Campbell & Doeg, 1989).

Cultivation of agricultural land results in a large increase of soil loss through runoff. In a study of a small catchment in NSW, more than 90% of the sediment in a stream draining the catchment came from cultivated vineyard soils that made up only 10% of the catchment. The majority (79%) of the sediment loss occurred in three major runoff events. The remaining sediment was derived from forest and grasslands (Loughran *et al*., 1986).

In Tasmania, the rate of clearance of natural vegetation from 1972 to 1994, as determined from satellite images, has varied between 6,000 ha/y to 15,000 ha/y (average 10,000 ha/y). Some of the losses have resulted from inundation for hydroelectricity production, some from forestry harvesting and forest plantation establishment, and a large proportion (greater than 50%) for agricultural land uses (Kirkpatrick & Dickinson, 1982; Kirkpatrick & Jenkin, 1996).

Human activities within the catchment are the major cause of increased organic matter and nutrient supply to coastal waters, an enrichment that can result in the eutrophication of estuarine ecosystems (Brodie, 1995). Burning, cropping and grazing all result in increased nutrient level in runoff. A number of studies have shown that N and P levels increase according to the proportion of agricultural land within a catchment. Kronvang *et al.* (1995) averaged nutrient losses from 270 catchments in Denmark. The ratios of N and P from agricultural and undisturbed catchments were 14:1 and 4:1 respectively. Gabric & Bell (1993) and Cooper & Thomsen (1988) found that N and P concentrations were an order of magnitude higher in agricultural versus pristine catchments, while Pailles *et al.* (1993) found PO_4 was 3 times higher in suspended sediments from streams draining agricultural catchments. The use of P in agricultural fertilisers in Australia has increased fourfold between 1950 and 1990, while use of N fertilisers has also escalated since the 1960s (Brodie, 1995).

Major urban areas in Australia are often located close to estuaries, and most of the urban sewage effluent is discharged into estuarine coastal waters. Nutrient loadings through sewage, especially phosphorus, may exceed inputs from all other sources. An estimated 10,000 tonnes/y phosphorus and 100,000 tonnes/year nitrogen is discharged through sewage in Australia annually (Brodie, 1995). Sewage discharged each year to the Derwent Estuary is estimated to contain over 100 tonnes phosphorus and 400 tonnes nitrogen, contributing 78% and 69% respectively of total nutrient inputs to the estuary (Coughanowr, 1995).

In urban areas developments, such as roadworks and subdivisions, result in land clearance and exposure of soils to erosion. Large areas of impermeable surfaces, such as roads and roofs, and channelisation of surface drainage, cause high peak storm flows. Runoff from urban areas is characterised by high sediment loads and high nutrient levels (Williams, 1980; Hogg & Norris, 1991). While sewage discharges are the major source of nutrients, stormwater runoff can contribute up to 10% or more of the nutrients from urban catchment (Kingston *et al*., 1990; Brodie, 1995; Coughanowr, 1995).

Runoff from urban areas, agriculture and forestry operations also contain pollutants such as oil, fuels, plastics, heavy metals and toxic organic compounds such as pesticide and herbicide residues. Pesticide levels in urban runoff can be equivalent to residues in agricultural runoff (Kimbrough and Litke, 1994; Lenat & Crawford, 1994).

Mining and associated industries add high levels of sediments to runoff waters. Heavy metal contamination is also common, especially where the exposure of sulphide ores results in oxidisation, producing acids and releasing metals into solution. Mining activities in and around estuaries (e.g. sand mining) can cause locally heavy sediment loads and changes to estuarine circulation patterns (Adam *et al*., 1992).

A large proportion of Tasmanian river systems are dammed for hydroelectricity generation, including a number of diversions between catchments (e.g. Mersey/Forth diversion; see Table 2.1). These impoundments cause substantial changes to the hydrology and sedimentation rates of downstream estuaries (Rosenberg *et al.*, 1995). The majority of dams in Tasmania are flow-through systems, hence seasonal and diurnal flow patterns are modified downstream and flood levels reduced. The few estuaries located downstream of large irrigation dams in Tasmania, such as Pittwater, can have freshwater flows reduced to almost negligible levels outside periods of flood.

High flood levels are often important for the flushing of estuaries. Davies & Kalish (1989, 1994) suggest that changed flow regimes in the southeastern Tasmanian Derwent River have prevented adequate flushing of the upper estuary. Reduced flood flows in conjunction with increased organic loading from paper mill effluent were considered to have caused anoxic conditions to develop in some areas.

Freshwater flows are a major stimulus for estuarine and marine productivity, which in turn can affect fishery production (Schlacher & Wooldridge, 1996a; Whitfield, 1996). Freshwater flows also provide a signal for breeding or migration in many marine and estuarine species (Loneragan *et al*., 1989; Loneragan & Potter, 1990; Adam *et al*., 1992). The presence of dams and weirs can completely disrupt fish communities because they prevent the migration of diadromic fishes, such as eels, lampreys and Australian grayling.

The quality of water released from large dams can be detrimental to downstream organisms. Water from deep levels is often cold and deoxygenated, and can contain toxic compounds such as hydrogen sulphide (Adam *et al*., 1992). A large fish kill on the western Tasmanian Pieman River occurred as a result of the entrapment of air in water passing through turbines in the power station. Expanding air bubbles in the supersaturated water caused embolisms in fish present below the dam (O’Donnell and Livingston, 1992).

Heavy metals produced by mining activity also accumulate in some dam waters, including the Pieman catchment (O’Donnell & Livingston, 1992). One Tasmanian west coast impoundment, Lake Burbury, requires continuous monitoring for heavy metal contamination from old mine workings. The current solution to this problem is to divert polluted waters into the much more heavily-polluted Queen River, which flows into the King River and Macquarie Harbour (O’Donnell & Livingston, 1992).

Low dissolved oxygen concentrations and elevated levels of organic matter were also detected in the lower King River and Macquarie Harbour after operation of the John Butters power station commenced in April 1992, utilising water from Lake Burbury. Water for the operation of this power station is drawn from the deep deoxygenated zone near the lakebed. The deoxygenation problem has largely been resolved by the entrainment of air in the turbine operation; however, monitoring for dangerous levels of hydrogen sulphide and supersaturation of released waters continues to be necessary. Methods to destratify lake waters have been considered as a longer term solution (Sanger, 1993).

In the Gordon River subcatchment of Macquarie Harbour estuary, high summer flows maintained by operation of the power station have reduced the upstream penetration of saline waters. This has disturbed the equilibrium of a number or meromictic lakes in the region that rely on annual replenishment of saline waters during low summer flows (King & Tyler, 1982, 1983).

1.6.2 Activities within estuaries

The sheltered waters and coastlines of estuaries are the site of many human activities. Estuaries are used as ports for shipping and provide an environment for fishing, marine farms, boating and other recreations. Port facilities such as wharves and container terminals often adversely affect estuaries as a result of the destruction of habitat, pollution from oil spills, faunal disturbance, and the introduction of exotic aquatic organisms. Industry located along shorelines also badly degrade estuaries in some situations (Bloom & Ayling, 1977; Windom, 1992).

Dredging and training walls are often necessary in estuaries with port facilities in order to maintain shipping channels. Dredging can result in localised sediment loads that can smother flora and fauna, while training walls, commonly used to stabilise an estuary entrance, result in changes to habitat and alteration of water circulation patterns (Adam *et al*., 1992).

Shellfish farms are becoming more common as a means of producing seafood products. Oyster farming occurs widely in estuaries since the pacific oyster, *Crassostrea gigas*, was introduced to Tasmania in the 1950s (Rees, 1995). Shellfish farms can cause a loss of amenity for other users and a reduction in habitat for particular local species. They also affect ecosystem processes through filtration, which removes suspended particulate material from the water column, and the production of faeces and pseudofaeces, which deposits organic matter on the seabed.

Finfish farming is a rapidly growing enterprise in Tasmanian marine waters. It is associated with intense organic loading as waste products and uneaten food accumulate below cages. At present, the impact of this organic pollution is considered to be localised, and effected sediments are thought to recover once cages are removed (Woodward *et al*., 1992).

Waterfront estates, canal developments and marinas can degrade habitat and change water circulation patterns, resulting in extreme cases in poorly flushed areas that become anoxic. Boating can cause pollution through spills, exhausts, untreated waste, and anti-fouling chemicals. Wash from power boats can cause bank erosion whilst moorings and anchors can damage sensitive habitats (Adam *et al*., 1992).

1.6.3 Eutrophication

The trophic status of aquatic ecosystems is regulated by the supply of nutrients to primary producers (Hatcher, 1994). In depositional environments such as estuaries, the natural trend is for a gradual increase in the productivity and biomass of plants as nutrients are trapped within the system. Nutrient enrichment encourages rapid growth of aquatic plants, often resulting in eutrophication and the rapid depletion of dissolved oxygen (McComb & Lukatelich, 1986; Hillman *et al*., 1990; Adam *et al*., 1992).

Increased levels of nutrients that limit plant growth (particularly N and P) result in an increase in primary production. In the early stages of nutrient enrichment, increased primary production can be beneficial to fisheries with increases in food and habitat. However, further increases in nutrient input can cause eutrophication and serious imbalances to ecosystems (Hodgkin & Hamilton, 1993).

Several stages of eutrophication are recognised (McComb & Lukatelich, 1986; Lavery *et al*., 1991; Brodie, 1995; Cloern, 1996):

a) an initial increase in phytoplankton and macrophyte growth,

b) prolific growth leading to the dominance of a few species of phytoplankton and benthic macroalgae,

c) changes in species composition,

d) massive blooms of nuisance and toxic phytoplankton, and

e) development of anoxic conditions.

The latter stages of eutrophication are often marked by massive fish kills caused by oxygen depletion and toxic algae, and death can occur amongst agricultural stocks as a result of the ingestion of toxic algae.

Phytoplankton blooms are rapid episodic increases in planktonic algal populations. They can occur naturally in many oceans and waterways in response to particular combinations of climatic events, seasonal changes and nutrient availability. Blooms may recur annually (Hallegraeff & Jeffrey, 1993) or spontaneously in response to favourable conditions (Blackburn & Cresswell, 1993).

As nutrient levels increase, the species composition of algal blooms changes. Increases in the proportions of N and P relative to silicon (Si) selectively promotes non-diatom blooms, with dinoflagellates and blue-green algae tending to become more common. Many of these species are unpalatable to zooplankton grazers, disrupting the normal food web. In some situations dinoflagellates produce toxins which cause mortalities at higher trophic levels (Cloern, 1996; Hallegraeff, 1995).

Eutrophication of coastal waters is recognised as a worldwide problem. It is most evident in enclosed and semi-enclosed waters with high nutrient inputs and long water residence times (low flushing). Problems related to rapid eutrophication resulting from anthropogenic nutrient enrichment are documented in numerous estuaries, including the Baltic and Black Seas in Europe, Chesapeake and San Francisco Bays in the USA, and various water bodies around Japan, Hong Kong, Australia and New Zealand (Cloern, 1996).

The Australian coastline is affected by increasing rates of eutrophication in areas subjected to urban and agricultural runoff. In the south-west region of Western Australia, for example, eutrophication of estuaries and coastal embayments, with accompanying nuisance and toxic algal blooms, has been recognised as a major environmental problem since the 1970s. Leaching of nutrients from heavily-fertilised sandy soils in local agricultural districts is primarily implicated (Hodgkin & Hamilton, 1993). In Tasmania, a toxic bloom of *Nodularia spumigena* was documented in Orielton Lagoon as a result of high nutrient inputs and the restriction of tidal flows from the adjacent estuary (Jones *et al*., 1994; Armstrong & Guidici, 1995).

1.6.4 Seagrass decline

Seagrasses often form extensive meadows in shallow coastal waters and estuaries. They are highly productive and provide important habitat and food resources for flora and fauna. Low levels of nutrient enrichment can increase productivity and growth of seagrass beds (Bulthuis *et al*., 1992); however a decline in area and density of seagrass beds generally follows eutrophication in Australia’s low-nutrient coastal environment (Brodie, 1995).

Walker & McComb (1992) summarise losses of seagrass from eleven locations around Australia. The two main causes of seagrasses decline were considered to be nutrient enrichment and smothering by sediment. Nutrient enrichment enhances growth of phytoplankton and algae that grow epiphytically on seagrass stems and leaves. This increased algal growth results in shading of seagrass beds, reducing photosynthesis and seagrass density. Increased levels of suspended sediments and the settlement of fine sediments on leaf blades also reduce light penetration and photosynthesis.

Using aerial photographs and satellite images from the 1990s, Rees (1994) mapped an area of over 22,000 ha of seagrass in coastal waters around Tasmania and the Bass Strait Islands. Although unable to compare all areas, he used archival photographs to document losses of over 5,500 ha since the 1950s. In many areas of decline, surviving seagrasses are covered by epiphytic algae and elevated levels of sediments. Rees argues that most of the losses have occurred in areas affected by nutrient enrichment from sewage, agricultural runoff, coastal shack development and mariculture activity. Losses were most evident in south-eastern Tasmania.

1.6.5 Introduced marine and estuarine species

In contrast to the majority of anthropogenic threats which affect individual estuaries, the spread of introduced pest species represents a different category of threat because it potentially affects all estuaries and estuarine species within the state. The threat of introduced pests is also potentially greater than others because, while most human disturbance can be ameliorated by changing management practices, introduced pests cannot be adequately controlled using current or forseeable technology.

Ecosystems worldwide have been affected by the importation of exotic species to the extent that the dominant organisms in many estuaries are now quite different to those present 200 years ago (Williams *et al*., 1988; Carlton & Geller, 1993). Estuaries, particularly those severely degraded by human activity, act as foci for introductions in the marine environment because they (i) possess high levels of food resources, (ii) high levels of immigrants through coastal shipping, and (iii) low species diversity, an indication that vacant niches and low numbers of competitively-superior species are present. Ecosystem changes caused by introduced taxa are expected to accelerate as the newly established plants and animals extend along the coast and as increased shipping conveys additional species in ballast tanks and hulls into new territory.

In Australian waters, over 100 exotic marine species have been accidentally released during the period of European settlement (Pollard and Hutchings, 1990a,b), transforming the nature of estuarine and coastal ecosystems in many areas. While the situation in Tasmania is not as severe as in California (Carlton, 1989), where lists of macrobenthic species collected in estuaries often contain more than 80% exotic taxa, some estuaries in the state are infested with high densities of foreign species. The dominant benthic invertebrates in the lower Derwent estuary, for example, are largely of foreign origin (seastars *Asterias amurensis* and *Patiriella regularis*, gastropod *Maoricolpus roseus*, chiton *Amaurochiton* *glaucus*, ascidian *Ascidiella aspersa,* crab *Cancer novaezelandiae*), and densities of local species appear to have declined dramatically as these species have become established (Morrice, 1995; Grannum *et al*., 1996).

1.6.6 Long-term climate change

Estuarine ecosystems around Tasmania are likely to change markedly over the next century if predicted increases in air and water temperatures occur as a consequence of increasing global greenhouse gas emissions. Climate change can affect estuarine ecosystems through three mechanisms:

- *increased water temperature*. Because of the position of Tasmania at the southern extremity of Australia, a relatively slight increase in water temperature may result in species extinctions because of the lack of a land mass further south into which species adversely affected by warm water can retreat.

- *modified rainfall patterns.* Increased rainfall in some areas of the state will reduce salinity in local estuaries, while decreased rainfall in other areas will allow saline water to penetrate further up estuaries and promote barrier formation.

- *sea level rises.* Rising sea levels will flood low lying areas within estuarine basins.

1.6.7 Management issues relating to estuaries

Critical to the management of estuaries is the recognition of the impacts of activities within upstream catchment areas. As Adam *et al*. (1992) states, "upstream catchment activities are the single most important factor in determining the present day nutrient balance and water quality of estuaries". In NSW, the Catchment Management Act 1989 formalises the procedures for implementation of catchment management (Adam *et al*., 1992). While the concept of catchment management has not been legislated in Tasmania, it has become a policy of the main land and water management agencies, DELM, DPIF, HEC and the Forestry Commission. Total catchment management (TCM) requires that all issues of resource allocation and environmental effects within a catchment are considered during planning for developments (O’Donnell & Livingston, 1992). The objectives of TCM, as outlined in the NSW Catchment Management Act, are to ensure the sustainable use of natural resources, to rectify degradation of natural resources, and to provide stable and productive soils, high quality water and a protective, productive vegetation cover. Fundamental to the success of TCM is active community involvement in resource management, with the development of increased awareness of the need for conservation of land, water and other natural resources (Adam *et al*., 1992).

The next important step in policy development must be the integration of management of catchments and the coastal and marine zones. This applies to the widespread application of land use planning, pollution control and marine resource management, and also to the distribution of protected areas. Marine and estuarine protected areas (MEPAs) are now recognised as a vital component of any strategy to conserve our marine and estuarine ecosystems by governments at all levels. MEPAs are promoted internationally through the World Conservation Strategy launched in 1981 by IUCN, WWF and UNEP. They are promoted nationally through the National Conservation Strategy of Australia and the intergovernmental Australia New Zealand Environment Conservation Council, and at the state level they receive tripartisan political support in Tasmania. The definition of a MEPA used by the Council of Nature Conservation Ministers (now the Australia New Zealand Environment Conservation Council) and Australian National Parks and Wildlife Service (now Environment Australia) has been based on IUCN objectives:

"*any area of intertidal or subtidal terrain, together with its superjacent waters and associated flora and fauna, which has been reserved by legislation to protect part or all of the enclosed environment for conservational, scientific, educational and or recreational purposes*" (Kriwoken, 1989).

Until 1991, Tasmania was the only Australian state without marine or estuarine protected areas dedicated for the preservation of aquatic ecosystems. Four marine reserves were declared at that time on the eastern and southeastern coasts of Tasmania; however, no estuarine reserves have been declared to protect aquatic communities within the state. Although a total of 15 MEPAs additional to the four marine reserves exist in the state that are mostly marine extensions of terrestrial national parks or conservation areas, these areas have no management plans or regulatory controls relating to marine or estuarine conservation (Kriwoken, 1989; Bosworth, 1995).

A further ten wetland sites around Tasmania are listed under the *Convention on Wetlands of International Importance Especially as Waterfowl Habitat* (Ramsar Convention 1971). Nine of these sites are estuarine or coastal wetlands. However these sites have limited conservation value as the Convention is restricted to wetlands and has no legal support for the prohibition of ecologically damaging activities (Kriwoken & Haward, 1991). Some of these sites are seriously degraded. They are often adjacent to or include private property carrying livestock, some are infested by introduced species, and most are used for uncontrolled recreational activities including hunting. Despite being under the jurisdiction of DELM, and in several cases containing refuges of rare and threatened species, few of these areas are actively managed for conservation purposes (Kriwoken & Haward, 1991; Australian Nature Conservation Agency, 1996).

2. Data Sets, Sampling Methods and Analysis

2.1 Criteria for Selecting Estuaries

Tasmanian estuaries, coastal lagoons and embayments included in this study were those with banks represented by separate lines on 1:100,000 topographic map sheets and connections shown on 1:100,000 topographic map sheets to the sea. They also needed to be of at least moderate size, with either catchment areas exceeding 20 km^2 or areas of open water exceeding 0.2 km^2 (Fig. 2.1, Appendix 1, Appendix Map 1). The latter criterion was used so that the largest coastal lagoons would be included in the study even though lacking extensive catchment areas.

The definition used here was more liberal that of Bucher & Saenger (1989), resulting in the inclusion of nearly double their number of estuaries (111 *cf.* 63). The present study included all estuaries described in Bucher & Saenger's study, with the exception of large partially-enclosed coastal embayments (Robbins Passage, Norfolk Bay, Ralphs Bay, D'Entrecasteaux Channel and Recherche Bay) that have wide marine connections and were considered to be outside the definition of estuary because they were little affected by freshwater flows. Numerous smaller estuaries associated with these embayments have, however, been included in the study.

Four coastal lagoons included in the study possibly fall outside the definition of estuary. Logan Lagoon and Stellars Lagoon on Flinders Island dry completely for periods of up to several years, and were dry when investigated in May 1997. Freney Lagoon and Hibbs Lagoon, located on the southern and western Tasmanian coasts, respectively, possibly lack a significant marine input and, if so, should be classed as coastal lakes. Salinity determinations from these two lagoons in summer are needed to adequately determine their status.

2.2 Geomorphological Classes and Tidal Data

Each estuary was classified by geomorphology using 1:25,000 topographic map sheets and, in most cases, the structure of the entrance observed on field visits. The geomorphological classes were: 1 coastal inlet; 2 drowned river valley; 3 permanently-open barrier estuary; 4 seasonally-closed barrier estuary; 5 river estuary; and 6 coastal lagoon. Characteristics of these six classes were described in Section 1.4.

The presence of seaward barriers in estuaries was assessed during field trips in summer and from aerial photographs. A total of 28 of the 111 estuaries investigated in the study were not visited during field trips. For these estuaries, the presence of any barrier was noted from aerial photographs and 1:25,000 topographic map sheets.

Tidal range was also assessed during field visits by reference to tide charts for the local area (Department of Defence, 1995) and the estimated vertical distance between high and low water marks. The location used for estimates was standardised for comparisons between estuaries at the site in the downstream section of the estuary just upstream from major entrance restrictions to water flow. High water mark was recognised by the layer of deposited debris high on the shore and low water by the furthest extent that water receded during the tidal cycle when field observations were made.

To assess observer error when making these estimates of tidal range, independent estimates from two observers (GE and NB) were compared for 50 estuaries at which both observers were present. The two groups of estimates were in close agreement (r^2=0.95), with the standard deviation of the difference between estimates = 0.12 m.

Estimates of the tidal range of the downstream reaches of estuaries not visited during field trips were made using topographic maps and tide charts. These estimates may therefore include substantial error.

2.3 GIS Procedures

The approach used for physical, land use and human population aspects of the study was to develop a computer based Geographic Information System (GIS) covering Tasmanian catchments and analyse available digital data on rainfall, geology, land tenure, population and landtypes. GIS was the method of choice because of the broad regional nature of the study and the availability of digital data sets, and to enable integration of the data with related projects that also use GIS.

The GIS software used was Arc/Info version 7.0.4 (1996) written by Environmental Systems Research Institute, Inc. (ESRI) and Doric Computer Systems International Ltd. Arc/Info was chosen because of its ability to store and analyse large data-sets. Arc/Info is a powerful GIS toolbox that can work on a number of data types including vector based maps (coverages), raster or cell based maps (grids), tables, tins (triangulated irregular networks) and images (ESRI, 1994).

Coverages in Arc/Info are used to represent points, lines or arcs, enclosed areas or polygons and regions. Once coverages are 'built', Arc/Info uses polygon or arc topology to determine the geographical location of each point or arc, the direction of each arc, which arcs make up a polygon and which side of each arc a polygon is located. Regions can be made up of a number of polygons. Attributes can be linked to points, arcs, polygons or regions. Attributes for each coverage are contained in arc attribute or polygon attribute tables (AATs or PATs respectively). PATs automatically contain the area and perimeter for each polygon as well as internal and user-defined identification numbers. Any number of polygon attributes can be added to the PAT.

Grids in Arc/Info are used to store data about specific locations on the earths surface such as vegetation type, soil type or elevation. They can represent continuous surfaces or discrete groups or classes. Each location is represented as a cell. The cell matrix, or grid, is organised into rows and columns. Cell values are numbers that represent nominal data such as land types or actual or relative measurements such as elevation, rainfall or reflectance values. For grids containing categorical data, Arc/Info creates a value attribute table (VAT) that contains cell values (value) and the number of cells (count) in the grid for each particular value. Additional attributes that can be related to particular cell values can be added to the VAT. Grids containing a wide range of actual measurements or floating point values do not have a VAT.

Arc/Info facilitates the conversion of map data between coverages and grids. Coverages can be produced by vectorisation of grid images. Grids can be produced from coverage polygons using any numeric attribute as the cell value. Some accuracy is lost with each conversion so the number of times that data is converted from one data type to another needs to be minimised.

All analyses of data sets were done using the cell-based analysis tools in the Arc/Info module, GRID. GRID allows transparent processing of grids at different resolutions. It does this by automatically resampling input grids to the coarsest resolution using nearest neighbour resampling. All vector coverages were converted to grids using the Arc command Polygrid. All grids were produced with a cell size of 100 m (1 ha cells), a common origin and the same number of rows and columns. Cell values were derived from a numeric code contained in the coverage attribute table for the relevant attribute (estuary - estcode; river - rivcode; land tenure - tencode; geological type - geocode). Three grids were created from the ABS census district coverage representing population density, dwelling density and density of occupied dwellings. Rainfall data (1000 m by 1000 m cell grid) and landtype data (25 m by 25 m cell grid) were resampled to produce 100 m cell grids.

Several digital map coverages of the state of Tasmania were made available for the study by the Department of Geology, University of Tasmania. These included coverages for coastline, drainage (rivers and lakes) and contours (100 m) that were derived from 1:250,000 map sheets by the Land Information Bureau (LIB), Department of Environment & Land Management (DELM). A digital coverage of the Tasmanian coastline derived from 1:25,000 map sheets by the LIB was provided by the Parks and Wildlife Service (PWS), DELM.

2.4 Catchment Boundaries and Water Diversions

GIS software such as Arc/Info can be used to derive catchment boundaries from digital elevation models (DEMs) where these exist. However the accuracy of boundaries is dependent on the resolution of available DEMs. This was attempted in this study using an available DEM derived from the 1:250,000 contour coverage (100 m contours). The resulting catchment boundaries were nonsensical in areas of shallow topography. This method was therefore rejected in favour of hand drawn catchment boundaries.

Catchment boundaries derived from DEMs are typically assessed by comparison with hand drawn boundaries, with the latter generally found to produce optimal boundaries (Civco, 1995). Future availability of high resolution DEMs for Tasmania may allow more precise catchment boundaries to be determined by digital analysis. This will be useful where catchments need to be determined for large numbers of small subcatchments or multiple pour points within a catchment. For the purposes of this study, digitised hand drawn boundaries provided the most precise determination of catchment boundaries. These boundaries will provide a useful reference for any future determination of catchment boundaries using digital techniques.

2.4.1 Determination of catchment boundaries

Catchment boundaries for estuaries were derived from 1:100,000 topographic map sheets produced by LIB, DELM. The boundary or catchment divide is predicted by assuming that all surface flow occurs in the direction of the land slope, in a direction perpendicular to the contours. The boundary only intersects contour lines when it runs along a ridge (Figure 3.1). Catchment boundaries were traced from the most recent editions of LIB 1:100,000 topographic maps onto polyester drafting film (Rapidraw 0.003”) using a 0.4 mm drafting pen. All reference (or Tic) points used Australian Map Grid (AMG), Zone 55 coordinates.

Traced images were scanned, at a resolution of 300 dots per inch (dpi), on a flat bed scanner at the LIB, DELM. In order to import these images into Arc/Info, the images were inverted (to white lines on a black background) using the image processor package XV (Bradley, 1993). Inverted images were then imported into Arc/Info, then registered and rectified to AMG Zone 55 using the marked Tic points. Rectified grid based images were then vectorised using the Arc command Gridline. The command option settings used were thinning, filter, round, line thickness of 50 map units, minimum dangle length 200 map units and weed tolerance 2 map units. Map units were set in metres.

Vectorised coverages were cleaned to remove intersecting arcs and sliver polygons using a minimum dangle length of 100 m and a fuzzy tolerance of 5 m. Cleaned coverages were edge matched to neighbouring coverages then all individual map sheet coverages were appended to a single coverage of all catchment boundaries.

The catchment coverage was then appended to the 1:25,000 coastline coverage. Estuarine catchment boundaries were joined to the coastline in order to close the polygon for each catchment. Errors in catchment boundaries were identified by overlaying the catchment coverage on the available 1:250,000 drainage and contour coverages.

Corrections were made where boundaries intersected with rivers represented on the drainage coverage. Changes to catchment boundaries were made interactively where corrections of less then 100 m (as determined on the image display) were required. For larger errors and serious anomalies in boundaries, the original map-sheets and line work were referred to. Resulting corrections were manually digitised into the coverage.

Three coverages were created from the original coverage. These covered catchment boundaries for whole catchments (estcatch) which include all land draining into the estuaries, major river catchments with each estuarine catchment (rivcatch) and catchments of major dams built for hydroelectricity production, irrigation projects or water supply (damcatch). Each coverage was made by deleting non-relevant areas from the original coverage. Polygon topography was then built for each coverage and each catchment was attributed with a unique code number and the name of the catchment. Catchment coverages are shown in Appendix Map 1.

Catchment coverages (estcatch, rivcatch, and damcatch) were converted to grids with a cell size of 100 m by 100 m. Cell values were obtained from the value item in the relevant coverage PAT for catchment code (i.e. est-code, riv-code, and dam-code). That is, the value of each cell within a catchment was equal to the code number for that catchment.

2.4.2 Sources of error

The catchment boundaries derived are subject to error resulting from errors in the original map in horizontal position on LIB 1:100,000 topographic map sheets is +/- 25 sheets, errors in defining catchment boundaries and errors in transcription of linework to digital coverage. The stated error m. Errors in determining catchment boundaries are difficult to assess. In areas of steep topography (close contours), errors are likely to be of the same order as the error in the map-sheet. However in areas of shallow topography and indeterminate drainage representation, errors in catchment boundaries are likely to be high (up to 500 m).

Other difficulties in determining catchment boundaries arise with numerous human-made diversions of water flow within and between catchments for hydro-electricity generation and irrigation purposes. The main examples of this are: the diversion of the Great Forester River from the Brid River directly to the sea, the diversion of Great Lake waters from the Derwent Estuary (Ouse River) catchment to the Tamar Estuary (Macquarie River) catchment, diversion of water from the Mersey River into the Forth River, diversion of Lake Pedder from the Huon River catchment to the Gordon River catchment, and diversions between the Nive, Dee and Ouse river catchments (Table 2.1). The latter are difficult to interpret from map-sheets, but are all subcatchments of the Derwent Estuary Catchment. Where diversions could be determined, their catchments have been included in the catchments to which they were diverted. Great Lake and Lake Pedder Catchments are mapped separately in the coverage of river catchment boundaries.

2.4.3 Transcription errors

Small errors are introduced at all stages in transcribing catchment boundaries to digital coverages. A line width of 0.4 mm corresponds to 40 m at 1:100,000 scale. Scanning of this line at 300 dpi gives a line approximately 5 cells wide (cell size is ≈ 8.5 by 8.5 m). It is necessary to have a line several cells wide so that it will be recognised as a line during vectorisation, rather than a series of disconnected points. Errors occur in marking Tic points and in geographical registration of images using these points. Four Tic points were marked on each map sheet, as close to the corners of the map sheets as practical. For 42 map sheets, the average error recorded during rectification was 10.6 m, equivalent to a root mean square error of 0.004 (Maximum error was 26.5 m, RMS 0.01).

Vectorisation produces a line of zero thickness from the grid/cell image. The error at any point in this line will be equivalent to the line thickness of the image, that is +/- 40 m. Summing errors from determining catchment boundaries (+/- 50 m) and transcription (+/- 50 m) gives an approximate error of +/- 100 m. As noted above, this error may be considerably greater in areas of shallow topography. The nominal scale for coverage of catchment boundaries is the same as the source maps, 1:100,000.

2.4.4 Estuary boundaries

A digital coverage of estuaries was created using the LIB 1:25,000 coastline coverage. As discussed previously, in the absence of data on salinity, tidal limits and bathymetry, the definition of estuarine boundaries is necessarily arbitrary.

Upstream boundaries were determined as the point where the separate lines representing estuary banks on 1:100,000 map sheets became single lines. This rule was used in most cases, except where separate lines continued many kilometres inland. In these cases the head of the estuary was taken as either the point of intersection of the last major tributary, the point where 20 m contour lines intersected river banks, or where significant features, such as gorges or rapids, were considered to represent a probable obstruction to tidal incursion. For example: the head of Pieman River estuary was taken as the intersection with the Donaldson River, the head of the Gordon River estuary was taken at the ‘first gorge’, the Arthur River at the intersection with the Frankland River, and the Derwent River at the intersection with the Lachlan River.

Downstream limits were marked as a line between the headlands on either side of the entrance to the estuary. Lateral boundaries used were lines on a topographic map that represented the coastline (Australian height datum).

Where estuaries and coastal lagoons were missing from the LIB coverage, or showed significant variation to those shown on 1:100,000 map sheets, the coverage was edited by digitising estuary boundaries from either 1:100,000 or 1:25,000 topographic map sheets. Downstream boundaries were drawn by adding a straight line joining the points where estuarine catchment boundaries intersected the coastline. Polygon topology was built and each estuary was attributed with the code number and name of the related estuarine catchment.

Estuary catchment areas (ECAs) and estuary water surface area (ESA) were obtained from PATs of vector coverages. The fluvial drainage area (FDA) for each estuary was derived by summing all of the river catchments within the ECA. The estuarine drainage area (EDA) was calculated as the difference between ECA and FDA for each estuary. For coastal lagoons, no river catchments were outlined so that EDA was equal to ECA for these catchments.

2.4.5 Regulation of water flow and diversions in Tasmanian catchments

Much of Tasmania’s surface water resources have been regulated for generation of hydro-electric power. This has also involved extensive water diversions between river basins, complicating calculations for a number of catchments. Table 2.1 lists dams used for power generation, their river catchment and diversions from other catchments, contributing catchment areas and required riparian release volumes (Frost, 1983). Hydro Electric developments have affected catchment areas of eight ECAs (including 39 major river basins) identified in this study. The total catchment area contributing to hydro electric developments was calculated to be 22,548 km^2, approximately 33% of the total land area of Tasmania.

The catalogue of dams in this study is incomplete as significant water storage dams that are used for irrigation and domestic water supply purposes were not all readily identified from 1:100,000 map sheets. Only 22 hydro electric dam catchments and 2 other dam catchments were defined, although this did represent the majority of the catchment areas contributing to hydro electric power.

Table 2.1. Statistics for dams and water diversions for production of hydro-electricity in Tasmania (from Frost, 1983).

Dam	Capacity (MW)	River	Diversions from	Catchment Area (dams, diversions) (km^2)	Riparian Release (m^3/s)
Tarraleah	90	Derwent	Franklin/Wentworth	582 (118)	
Waddamana B	48	Ouse	Great Lake	(Penstock lagoon 5) (Shannon lagoon 22)	
Butlers Gorge	12.2	Derwent	Upper Franklin	582 (9)	
Tungatinah	125	Nive	Ouse/Clarence/Dee	50 (1350)	0
Trevallyn	80	South Esk	Great Lake	8986 (628)	0.42
Lake Echo	32.4	Dee	Little Pine/Ouse	139 (530)	0
Wayatinah	38.25	Derwent	Ouse/Dee	2390 (363)	
Liapootah	83.7	Nive	Ouse/Dee	1449 (363)	
Catagunya	48	Derwent	Ouse/Dee	2993 (363)	
Poatina	300	Shannon	Ouse/Liffey/Brumby Ck.	408 (262)	0.57
Tod’s Corner	1.6	Lake River	Westons Rt.	263	0
Meadow Bank	40	Derwent	Great Lake	6545 (628)	17.0
Repulse	28	Derwent	Dee/Ouse	3106 (363)	0
Rowallan	10.5	Mersey		338	0
Lemonthyme	51	Forth	Mersey	(696)	0.03
Devils Gate	60	Forth	Mersey/Wilmot	723 (829)	0
Wilmot	30.6	Wilmot		133	0.56
Cethana	85	Forth	Mersey/Wilmot	594 (829)	0
Cluny	17	Derwent	Ouse/Dee	3251 (363)	11.33
Paloona	28	Forth	Mersey/Wilmot	759 (829)	0.7
Fisher	43.2	Fisher		75	
Gordon Stage 1	288	Gordon	Lake Pedder/Huon	1280 (734)	2.83
Mackintosh	80	Pieman	Murchison	512 (750)	0
Bastyan	80	Pieman		1397	0
Pieman	224	Pieman		2653	8
Anthony/Henty	82	Anthony	Henty	37.2 (90.6)	0
King	130	King		561	

2.5 Rainfall and Runoff Data

Rainfall data were extracted by PWS from the Bioclimate Prediction System (BIOCLIM) and imported into Arc/Info. The data represents annual rainfall values for one km square grid cells that are derived from 504 Tasmanian rainfall stations with a minimum of 5 years of records. The estimated error in predicted values is less than 10% (Busby, 1986). Rainfall data was stored as a grid with a cell size of 1000 m x 1000 m.

Rainfall estimates for south west Tasmania are based on records from a small number of long term stations situated at low altitude. Nuez *et al.* (1995) suggest that these estimates significantly underestimate rainfall in this region. Their estimates were derived from average annual rainfall values for the region using satellite images. The predicted precipitation data correlated well with variation in alpine flora. Unfortunately these data could not be accessed for this study.

Rainfall statistics were determined for each catchment area using the zonalstatistics function of the Grid module. This function calculates the minimum, maximum, range, median, mean and sum of all cell values of the value grid (Rainfall data) for each cell value in the input (catchment) grid. The sum of values equals the Total Annual Rainfall (TAR) for the catchment. The mean is the average annual rainfall (Rav) across the catchment and also equals the quotient of TAR and catchment area. Minimum (Rmn) and maximum (Rmx) are the lowest and highest cell values for annual rainfall within the catchment. (These values should not be interpreted as minimum and maximum rainfall events, nor as minimum and maximum annual records.) Range (Rrn) and median (Rmd) values give an indication of the variation in annual rainfall levels across a catchment. Appendix 2 lists rainfall statistics by estuarine and river catchments, and the area of each catchment that is dammed.

Figures for mean annual runoff from selected river catchments were derived from annual discharge values published by the Rivers and Water Supply Commission (RWSC), Department of Primary

Industry and Fisheries (RWSC, 1983; Hughes, 1987). These data are shown in Appendix 3, and include the catchment area upstream of the gauge, the mean annual runoff (MAR), presence of upstream regulation of stream flow, and the number of years records have been kept for each gauge. MAR was calculated by dividing mean annual discharge by catchment area.

MAR was estimated for all catchments, including those not gauged, using a regression equation relating MAR and Mean rainfall (Rav) for gauged rivers with catchment areas above the gauge greater than 50% of total catchment area. Variation in MAR corresponded closely with Rav for gauged catchments; the linear regression equation of best fit (MAR = 0.898*Rav -512, n=63) possessed an R^2 value of 0.90. When an outlying value for the Huon River catchment was removed, the R^2 value increased to 0.92. This regression equation (MAR = 0.886*Rav -507) was used to estimate MAR for all catchment areas investigated in the study, with MAR then used to estimate runoff coefficients (= MAR/Rav; Appendix 2). The Huon River provided an anomalous value for runoff, with MAR equal to 99% of annual rainfall for that catchment. This is partly due to underestimation of Rav as a result of the diversion of part the catchment into the Gordon River catchment via Lake Pedder, and stream gauge records having been collected prior to the diversion. Nevertheless, this diversion accounts for only about 10% of incident rainfall.

2.6 Geological Data

Analysis of geological data was based on a 1:500,000 digital geological map coverage provided by the Department of Mineral Resources. This coverage included information on 50 geological classes, an unwieldy number of categories that required aggregation. Following the advice of Dr. Clive Burrett (CODES, University of Tasmania), the 50 geological classes were reclassified into 12 groups that reflected likely effects of geology on water chemistry and sedimentology. The procedure used to reclassify geological classes into 12 groups (alkaline intrusion, basalt, Cambrian acid volcanics, Cambrian ore deposits, carbonaceous, dolerite, dolomite, granitic, limestone, metamorphic, sedimentary and lakes) is described in Table 2.2, with distribution of geological groups within the state shown in Appendix Map 2.

Intrusive alkaline rocks, which are locally most important in the Cygnet area, were included as a separate category because of effects on river pH. Cambrian acid volcanics, such as the Mt Read formation, were considered important because of acid mine drainage effects, while Cambrian ore deposits have high loadings of heavy metals (particularly lead, copper and zinc). In Tasmania, carbonaceous formations possess high levels of sulphur, dolomite formations high levels of magnesium, and limestone formations high levels of calcium. Sedimentary rocks have a variable effect on the river environment, depending on parent rock types.

Table 2.2. Geological groups recognised in this study, and description of component rock types.

Group	*Geocode*	*Geol_type*	*Age*	*Symbol*	*Description*
Alkaline Intrusion	15	Ka	Cretaceous	5	Appinite
Alkaline Intrusion	16	Ks	Cretaceous	12	Syenite
Basalt	18	Lb	Precambrian	43	Basalt lavas
Basalt	46	Tb	Tertiary	91	Basalt and related rock types
Basalt	50	Tv	Tertiary	91	Basalt and related igneous rock types
Cambrian Acid Volcanics	1	Ca	Cambrian	787	Acid with intermediate volcanic and associated rocks dominant
Cambrian ore Deposits	2	Cb	Cambrian	928	Basic-intermediate volcanic and associated rocks dominant
Cambrian ore Deposits	3	Cc	Cambrian	707	Coarser grained basic rocks
Cambrian ore Deposits	5	Cm	Cambrian	980	Probably Cambrian unfossiliferous usually greywacke turbidite sequences
Cambrian ore Deposits	6	Co	Cambrian	771	Probably Cambrian unfossiliferous orthoquartzite sequence
Cambrian ore Deposits	7	Cs	Cambrian	10	"Serpentinite, peridotite and associated rocks"
Cambrian ore Deposits	8	Ct	Cambrian	870	Middle-Upper Cambrian fossiliferous usually greywacke turbidite sequences
Cambrian ore Deposits	9	Cu	Cambrian	742	Undifferentiated

Carbonaceous	32	Pfa	Permian	852	Freshwater sequence with some coal measures
Carbonaceous	33	Pfb	Permian	724	Freshwater sequences with some coal measures
Carbonaceous	36	Ptc	Triassic	824	Carbonaceous sequences
Dolerite	14	Jd	Jurassic	123	Dolerite and related rocktypes
Dolerite	19	Ld	Precambrian	2	Dolerite
Dolomite	21	Ll	Precambrian	36	Dolomite
Granitic	4	Cg	Cambrian	6	Granitic rocks
Granitic	10	Dga	L.Carboniferous (?), Devonian	157	Biotite-hypersthene-adamellite porphyry
Granitic	11	Dgg	L.Carboniferous (?), Devonian	172	Dominantly granodiorite
Granitic	12	Dgl	L.Carboniferous (?), Devonian	157	Dominantly adamellite-granite
Granitic	20	Lg	Precambrian	6	Granite
LAKE	17	LAKE		0	
Limestone	29	Ol	Ordovician	234	Limestone sequence with siltstone in som areas
Limestone	41	Qpl	Pleistocene	723	Limestone
Limestone	43	SDl	Devonian	402	"Limestone, siltstone"
Limestone	48	Tm	Tertiary	347	Marine limestone
Metamorphic	22	Lm	Precambrian	739	Metamorphic rocks of dominantly metaquartzite and pelitic sequences
Metamorphic	23	Lms	Precambrian	14	Amphibolite
Sedimentary	13	Dm	Upper-Middle Devonian	284	Terrestrial cavern fillings
Sedimentary	24	Ls	Precambrian	736	Orthoquartzite - mudstone sequences
Sedimentary	25	Lt	Precambrian	39	Quartzwacke turbidite successions
Sedimentary	26	Lu	Precambrian	32	Undifferentiated comparatively unmetamorphosed sequences
Sedimentary	27	Mm	L.Devonian, Cambrian (?)	454	Mudstone sequences dominant
Sedimentary	28	Mt	L.Devonian, Cambrian (?)	417	Micaceous quartzwacke turbidite sequenc dominant
Sedimentary	30	Os	Ordovician	127	"Siliceous conglomerate, shallow-water, quartzose sandstone and siltstone"
Sedimentary	31	PTu	Triassic,Permian, U.Carboniferous	475	Undifferentiated
Sedimentary	34	Pga	Permian, U.Carboniferous	442	"Lower glacio-marine sequence of pebbly mudstone, pebbly sandstone, minor limes'
Sedimentary	35	Pgb	Permian	788	"Upper glacio-marine sequence of pebbly mudstone, pebbly sandstone and limeston

Table 2.2. (cont.). Geological groups recognised in this study, and description of component rock types.

Group	*Geocode*	*Geol_type*	*Age*	*Symbol*	*Description*
Sedimentary	37	Ptf	Triassic	728	"Fluvio-lacustrine sequences of sandstone, siltstone and mudstone"
Sedimentary	38	Pu	Permian, U.Carboniferous	539	Undifferentiated
Sedimentary	39	Qh	Holocene	710	"Alluvium, sand, gravel, talus"
Sedimentary	40	Qp	Pleistocene	718	"Till, fluvioglacial, periglacial and associated deposits"
Sedimentary	42	Qu	Holocene	715	Undifferentiated
Sedimentary	44	SDs	"L.Devonian, Silurian"	399	"Quartzite, sandstone, siltstone, shale"
Sedimentary	45	SDu	"L.Devonian, Silurian"	396	Undifferentiated
Sedimentary	47	Tf	Tertiary	316	Non-marine sequence
Sedimentary	49	Tu	Tertiary	97	Undifferentiated

2.7 Population Statistics

Population, dwelling and occupancy statistics for Tasmania were taken from Australian Bureau of Statistics (ABS) census data, 1991 (Cdata91; ABS, 1993). A digital map of the census districts used for Census 1991 was translated from the MapInfo version of Cdata91 (owned by the Department of Geography and Environmental Studies), to an Arc/Info vector coverage. The translation was done with the help of Landfile Consultancy Pty. Ltd. using version 2.70c of AIMI (Arc/Info MapInfo) translation software. The AIMI translation was imported into Arc/Info and projected using AMG Zone 55 coordinates (the original file in MapInfo used geographic coordinates, latitude and longitude).

A number of problems became evident when transferring vector coverages between MapInfo and Arc/Info. MapInfo represents areas with complete polygons so that adjacent polygons do not share arcs at their adjoining edges. In Arc/Info, the polygon topology allows arcs to be shared by adjacent polygons. When translating from MapInfo to Arc/Info, this results in double arcs where two polygons meet. The resulting areas contain multiple intersection points which are illegal or invalid in Arc/Info polygon coverages. Intersections are removed by using ‘clean’. The fuzzy tolerance must be set at a level that prevents formation of sliver polygons without removing smaller map areas.

A major problem with versions of AIMI prior to 2.70c is that polygon attributes become randomised. Version 2.70c has largely eliminated this problem although twenty ‘island’ polygons lost their attributed census district and were labelled with the attributes of the surrounding polygon.

The imported coverage of census districts was cleaned and polygon topology built. Island polygons were attributed with the correct census codes obtained by using MapInfo to refer to the original coverage. Each polygon was also attributed with values for population density (population/ha - popdens), dwelling density (dwellings/ha - dweldens) and occupation density (occupied dwellings/ha - occdens). These values were determined by dividing census values for each census district by the total area for each district as derived from the Arc/Info coverage.

Tasmania has been divided into 953 census districts. ABS attempts to create districts with an equivalent number of dwellings and population. The average population and number of dwellings for Tasmanian census districts are 475 and 165 respectively. There is a wide variation in the size of census districts between densely populated urban areas and sparsely populated rural and remote areas. The area of census districts ranges from 3.125 ha to 497,205.5 ha with a median of 101 ha and a mean of 7,195 ha.

Three grids were created from the ABS census district coverage representing population density, dwelling density and density of occupied dwellings. Cell values for each census district were obtained from the polygon attributes popdens, dweldens and occdens respectively. Due to the limited available disc space at the time these grids were created, they were created with a cell size of 100 m by 100 m (1 ha). This resolution was considered adequate to accurately represent population values for each census district as the minimum census district area was greater than 3 ha.

As can be seen in the map of census districts overlaid on estuary catchments (Appendix Map 3), ABS collection district boundaries do not often match up well with catchment boundaries. This brings into question the validity of the results obtained by this method. However, closer observation shows that areas of high density population (represented by large numbers of small collection districts) are concentrated around estuaries, and therefore contained within catchment boundaries, often within estuarine drainage areas and within 1 km of the estuary. Estimates of population and number of dwellings are valid where small census collection districts, with high population/dwelling densities, lie wholly within a catchment area. Erroneous results are obtained where large, low density census collection districts overlap large proportions of adjacent catchments. These errors are most significant in statistics derived for remote, unpopulated or sparsely populated catchments.

In catchments where total population numbers were calculated using census data to be less than 100 or where such errors were evident or suspected, more accurate population numbers were estimated using data on the number of dwellings per catchment mapped on 1:25,000 scale topographic map sheets (where available). The number of dwellings shown within a catchment was recorded and combined with number of occupants per dwelling for that census district to provide an estimate of total population. While occupancy rates are likely to be substantially lower in remote areas than urban centres, and are subject to seasonal fluctuations in most areas, errors should not exceed a factor of two using the topographic map method whereas order of magnitude errors accrue using interpolated census data for catchments with populations less than 10. In a few catchment areas, population density for the estuarine drainage area (EDA) and freshwater catchment area (FCA) were calculated using different methods. In these cases, the estuarine catchment area (ECA) was recalculated as the total of EDA and FCA values.

2.8 Land Tenure Data

Land tenure information was obtained from 1:500,000 digital land tenure coverage provided by the Forestry Commission. The 25 land tenure classes used in this database were aggregated and reclassified to indicate four basic levels of protection: national park, crown reserved, crown exploited and private (Appendix Map 5). The reclassification groups for each of the land tenure classes are described in Table 2.3.

Table 2.3. Relationship between land tenure groups used in this study and land tenure classes applied by management agencies.

Group	*encode*	*Ten#*	*Label*	*Symbol*	*Agency*
National Park	NAP	14	National Park	111	DELM
Crown reserved	ABO	1	Aboriginal Site	23	DELM
Crown reserved	COM	2	Commonwealth land	138	Commonwealth
Crown reserved	COR	3	Coastal Reserve	24	DELM
Crown reserved	CRR	4	Crown Reserve	48	DELM
Crown reserved	CRW	5	Crown Water	0	DELM
Crown reserved	FOR	6	Forest Reserve	139	Forestry
Crown reserved	GAM	7	Game Reserve	47	DELM
Crown reserved	HIS	9	Historic Site	71	DELM
Crown reserved	HNP	10	National Park - Hydro	7	DELM
Crown reserved	LAK	11	Lakeside Reserve	72	DELM
Crown reserved	MUR	12	Municipal Reserve	114	DELM
Crown reserved	NAT	15	Nature Reserve	95	DELM
Crown reserved	OLD	16	Other Crown Reserve	119	DELM
Crown reserved	PAS	17	Protected Archaeological Site	31	DELM
Crown reserved	PRO	19	Protected Area	112	DELM
Crown reserved	RIV	20	River Reserve	120	DELM
Crown reserved	SRA	22	State Recreation Area	144	DELM
Crown reserved	STR	24	State Reserve	143	DELM
Crown exploited	HEC	8	Hydro-electric Commission land	94	HEC
Crown exploited	NAC	13	Non-allocated Crown land	133	DELM
Crown exploited	SFH	21	State Forest - Hydro	115	Forestry
Crown exploited	STF	23	State Forest	131	Forestry
Private	PRI	18	Private property	130	Private
	ZZZ	25	No data	0	

2.9 Satellite Derived Landtype Data

Satellite imagery was used to categorise different landtypes within estuarine catchment areas. The main benefit of satellite imagery is the provision of a regional overview, allowing spatial analysis on a scale not feasible with other methods (Johnston & Barson, 1993; Evans, 1995; Ritman, 1995).

Digital raster images showing major landtypes across mainland Tasmania were provided under licence by the State of Environment Report (SER) unit of DELM through Mr. Ross Lincolne at the Central Scientific Laboratories (CSL). Images for the Bass Strait islands were not available. The images were derived from composite Landsat TM images selected from available images for early summer of 1988 and 1994. Landtype classification was based on digital analysis of spectral data from Landsat TM bands 1, 2, 3, 4 and 5 using ERDAS Imagine software. Land was initially classified into 13 main landtype groups (Appendix Map 4) and then aggregated into six major landtype categories for analysis in this study (woody, herbaceous, bare, water, cleared, urban; Table 2.4). The initial landtype 'cleared forest' was identified by analysing temporal changes from or to woody vegetation classes over the 6 years separating image sets.

Table 2.4. Relationship between original landtype groups and reclassified landtype categories.

Code	*Landtype Group*	*Landtype Category*
1	Rainforest	Woody
2	Forest	Woody
3	Woodlands	Woody
4	Scrub	Herbaceous
5	Alpine scrub	Herbaceous
6	Heath or buttongrass	Herbaceous
7	Alpine heath	Herbaceous
8	Bare land or rock	Bare
9	Alpine bare land or rock	Bare
10	Water	Water
11	Agriculture	Cleared
12	Cleared forest	Cleared
13	Urban	Urban

The landtype data was supplied as an ERDAS Imagine image with a resolution of 25 m (i.e. minimum pixel or cell size is 25 m by 25 m). Arc/Info supports the conversion of ERDAS images to grids. The landtype data was imported into Arc/Info and stored as a grid with a cell size of 25 m x 25 m. For analysis, the grid was resampled to 100 m by 100 m.

2.9.1 Limitations of satellite-derived landtype classification

In a broad sense, the classification of landtypes across Tasmania from satellite data provides a reasonably accurate representation of the major vegetation classes. The accuracy of the data has not been assessed by ground-based mapping (this would be prohibitively expensive on this scale). However, truthing using aerial photographs of representative areas and comparison with existing vegetation maps is an accepted method of verifying digital classifications of satellite data (Ritman, 1995).

In this study, the landtypes used have been equated with landuse. Agricultural, urban and cleared forest landtypes are associated with those anthropogenic activities, while other landtypes are considered to be natural features. Classification of agricultural land did not differentiate natural grasslands or wetlands. No attempt was made to distinguish between different agricultural operations, such as pasture production, cropping, horticulture or grazing. Significant areas of scrub, heathlands and open woodlands are likely to be used for grazing. The level of impact of grazing on these vegetation types is dependent on the intensity of grazing pressure and can be severe in some areas.

Different uses of cleared forest also were not differentiated. Cleared forest may represent areas of natural or plantation wood harvesting, or land clearance for development of agricultural or urban land. The differentiation of heath and buttongrass was complex and these vegetation classes were amalgamated into one landtype category. For the purpose of this study this is not significant. The bareground category includes rock, sand and bare earth. Roads and areas of land cleared for urban development, or ploughed paddocks could be included in this category. However, the majority of these areas are likely to be classified in their relevant categories by post processing procedures. Some small areas of highly reflective sand dunes and claypans have been classified as urban land. This has resulted in some small errors (<0.2 km^2) in the subsequent analysis, most evident as areas of urban or cleared land in otherwise pristine catchments such as Saltwater and Freshwater Lagoons in the Freycinet National Park. To correct for this error, all catchments with 'cleared' or 'urban' values <0.2 km^2 were rescaled to 0 and associated values for 'urban' landtype category added to 'bare' landtype category. Overall the data was considered to provide a reasonable representation of landtypes and land clearance for anthropogenic purposes on the regional scale used in this study.

2.9.2 Calculating a Naturalness Index

The degree of naturalness of estuaries was estimated using the basic assumption that woody and herbaceous vegetation, water and bareground landtypes represent natural landtypes while cleared and urban landtypes have been effected by human impact. For each catchment, the proportion of each landtype was multiplied by an environmental impact factor (EIF) of 1 for natural landtypes, 5 for cleared landtypes and 20 for urban landtypes. Natural landtypes were considered to have a neutral impact. Cleared forest landtypes were given an EIF = 5, a conservative estimate of the likely increase in nutrient and sediment loads contained in runoff from these landtypes. Numerous studies indicate that nutrient levels from agricultural land and cleared forest are from 2 to 30 times higher than from the same area of natural vegetation while the volume of sediment can be considerably greater from cultivated land (Williams, 1980; Loughran *et al*., 1986; Cooper & Thomsen, 1988; Campbell & Doeg, 1989; Gabric & Bell, 1993; Brodie, 1995; Kronvang *et al*., 1995). Urban land was given an EIF = 20, again a conservative estimate of the increase in nutrient and sediment loads from urban sewage, industry effluent and runoff from urban developments compared with natural landtypes. Coughanowr (1995) reported that sewage discharges contributed around 70% of nutrient input into the Derwent Estuary. Urban land makes up less than 1% of this catchment (Appendix 8) which translates to over 200 times higher nutrient load per unit of area from urban sources than all other sources.

Naturalness index values can be viewed in terms of anthropogenic impact using the classification shown in Table 2.5. Class 1 contains only natural landtypes and represents catchments that are largely untouched by human activities. Class 2 includes catchments that have less than 10% agricultural or cleared land, class 3 has less than 25% agricultural or cleared land, class 4 has less than 50% cleared land, class 5 has the equivalent of up to 75% cleared land.

Table 2.5. Groupings by Naturalness Index.

Class	*NI*	*Naturalness*
1	1.00	Pristine
2	1.01-1.50	Natural
3	1.50-2.00	Low impact
4	2.00-3.00	Moderate impact
5	3.00-4.00	High impact
6	>4.00	Severe impact

2.10 Hydrological Data

A search of published and unpublished information on salinity, temperature, nutrient levels and turbidity in Tasmanian estuaries provided little relevant data. The limited information that was available largely related to the larger estuaries (Cresswell *et al*., 1989; Edgar & Cresswell, 1991; Davies & Kalish, 1989, 1994) and to a monitoring program conducted between 1961 and 1981 in the vicinity of aquaculture farms (Thomson *et al*., 1982). Two field trips were therefore undertaken around the Tasmanian mainland in summer (4-8 February 1997) and winter (26-30 August 1996) seasons in order to collect hydrological data from accessible estuaries. Sampling was timed to coincide as close as possible with low tide, although this was not always possible because constraints associated with travel precluded sampling within an hour of low tide in some estuaries.

Salinity and temperature profiles were obtained from the water surface to the estuary bed at 1 m intervals at sampling stations. For many estuaries, additional salinity profiles were collected during periods of high flow in order to assess environmental extremes. Salinity and temperature measurements were also collected opportunistically during the macroinvertebrate sampling program. Overall, hydrological measurements were collected from a total of 646 stations at 466 sites in 74 estuaries. Oxygen profiles were recorded at 47 sites in 24 estuaries.

Because of intermittent faults, three instruments were used to measure salinity and temperature during the study: a Yeokal Model 602 Mk II, WTW LF196 and Hamon Salinometer. Calibration of these instruments revealed errors of less than 0.5°C and 1‰. Turbidity was recorded as depth of disappearance of a 150 mm diameter Secchi Disc, while oxygen was measured using a Yeokal Model 603 O_2 meter.

Hydrological data was primarily collected during the two main field trips so that sites could be ranked in terms of salinity regimes. While we recognise that estuarine salinity, particularly surface waters, can fluctuate rapidly over tidal and other short term cycles, analysis of the salinity regimes of Tasmanian estuaries using limited data was undertaken because of the importance of salinity when categorising estuaries. The assumption was made that estuaries could be ranked in terms of upstream penetration of saline water by comparing measurements recorded in different estuaries over a short time period at the same stage of the tidal cycle (low tide), providing that little rainfall occurred between measurements in different estuaries. The validity of this assumption decreases with distance between estuaries because of the patchiness of rainfall across the state

Because all open estuaries range in salinity from 0‰ at upstream sites to ≈33‰ at the entrance, information on the salinity of estuaries could only be used for comparisons between estuaries by standardising geographical location within estuary. Tasmanian estuaries were therefore subdivided into three regions of equal length (upstream, mid and downstream) for salinity and other comparisons.

All Tasmanian estuaries for which data were available for surface water in the upstream section in winter were ranked in order of increasing salinity, and these rankings then standardised by dividing by the number of estuaries analysed. Similar rankings were made for mid and lower sections in winter and for upstream, mid and downstream sections in summer. Mean salinity rankings for each estuary were then calculated for both summer and winter using average rankings for the three sections.

In order to express salinity rankings in meaningful terms and to account for nonlinearities (i.e. considerable variation in rankings between estuaries at the high end of the scale reflect relatively minor differences in salinity around 33‰, whereas similar variation at the middle of the scale may reflect a range of 10-20‰), rankings were converted to a salinity scale using empirically derived polynomial regression equations. These regressions were calculated from direct measurement of surface salinity in the mid sections of estuaries (S) versus salinity rankings (R): $S = -4.995 + 1.8410.R - 0.09155.R^2 + 0.0002526.R^3 - 0.00002933.R^4 + 0.0000001182.R^5$ ($r^2 = 0.931$) for summer data, and $S = -2.142 + 0.859.R - 0.0630.R^2 + 0.001864.R^3 - 0.0000205.R^4 + 0.0000000767.R^5$ ($r^2 = 0.925$) for winter data. The converted salinity rankings can therefore be viewed as standardised estimates of the salinity of surface water in the middle section of the estuary.

Approximately one third of all Tasmanian estuaries could not be allocated salinity rankings in this way because they lacked any salinity data. Estimates of the salinity of surface waters in the mid section of these estuaries were made by assigning them the salinity value of the estuary with closest geomorphological similarity, as assessed in multivariate analyses (see below). Such estimates may possess substantial error if the estuary has been poorly characterised using physical data. To assess this error, estimates of salinity were made using geomorphological criteria for a random subsample of 10 estuaries with measured salinity values. The standard deviation of difference between measured and estimated salinity values was found to be 4.6 ‰ for these 10 estuaries.

2.11 Macroinvertebrate and Plant Data

As with hydrological data, very little quantitative information was available prior to the study on invertebrates or aquatic plants present in Tasmanian estuaries. Useful information was only available from studies of the distribution of macrobenthos along the Derwent (Horwitz & Blake, 1992), Bathurst Harbour (Edgar, 1991a) and Macquarie Harbour (O'Connor *et al.*, 1996; Talman *et al.*, 1996) estuaries. Accordingly, a major component of this project involved sampling macroinvertebrates and associated plants in estuaries around the state. Quantitative samples were needed so that data could also be used as a baseline for determining effects on biota when estuarine protected areas are declared, and also for identifying other environmental changes in the future (eg. those associated with new shellfish farms or the introduction of the green crab *Carcinus maenas*). The specific aims of the macroinvertebrate sampling program were to:

- Collect quantitative baseline data for macroinvertebrate densities in Tasmanian estuaries
- Determine whether estuarine macrobenthic assemblages vary systematically between different regions
- Determine patterns of variation in macroinvertebrate assemblages within estuaries and between depths
- Determine the extent of variation in macroinvertebrate assemblages over time
- Identify estuaries with high macroinvertebrate species richness
- Identify estuaries with unusual macroinvertebrate assemblages
- Identify macroinvertebrate species with highly restricted distributions

2.11.1 Sites examined

A nested sampling protocol was used to provide the optimal compromise between effort and power for statistical comparisons over the range of spatial scales relevant to the study. Sites within an estuary were sampled with three transect lines located perpendicular to the shoreline, spaced approximately 100m apart, and with two replicate core samples taken at each of 5 levels down each transect. The five levels investigated were (i) high water mark (as indicated by the flotsam line), (ii) midway between high and low water mark, (iii) low water mark (as indicated by the level to which water receded at low tide on the day of sampling), (iv) 0.3 m depth below low water mark, and (v) 0.7 m depth below low water mark. Records were taken of the distance along the transect line at which each pair of samples was collected in order to allow resampling on future occasions and to allow the gradient of the shoreline to be calculated (when combined with estimates of tidal elevation).

A total of 30 cores were collected at most sites sampled (3 transects x 5 levels x 2 replicates); however, some estuaries possessed negligible tidal influence or drained completely at low tide, in which case the mid-tide or subtidal levels could not be sampled, respectively. Four or three levels were consequently sampled at these sites, and 24 or 18 samples collected, respectively. Four other deviations from general sampling protocols occurred: (i) in the Lisdillon estuary, where only two transects ≈050 m apart could be placed in the restricted area available for sampling, (ii) at Cornelian Bay, where the efficacy of sampling using a 2 mm rather than 1 mm mesh was tested on the first sampling occasion and some samples were sorted using only the 2 mm sieve on that date, (iii) the Leven estuary, where samples could not be collected on all transects at the lowest tidal level, and (iv) Macquarie Heads, where sampling was obstructed by bushes at the highest tidal level on one transect.

Sites were generally located in different estuaries in order to maximise information on statewide biogeographical patterns; however, five estuaries (Derwent, Huon, Tamar, Macquarie Harbour and Cloudy Lagoon) were sampled at more than one site in order to assess spatial variation within an estuary. Sampling was thus conducted at five different spatial scales: replicate (≈1 m scale), tidal depth (≈10 m scale), transect (≈100 m scale), within estuary (≈10 km scale) and between estuaries (≈100 km scale). Depth varied systematically and so was a fixed factor while the four other spatial variables were considered random factors.

In order to allow an assessment of the extent of temporal variation within sites, sampling was repeated between six and ten months after initial sampling at four sites (Leven River, Paper Beach, Cornelian Bay and Cradoc). Overall, sampling was conducted at two temporal scales - a scale of hours during which individual sites were sampled and a scale of months during which different sites were sampled or the one site was repeatedly sampled.

On the second sampling occasion at the four sites repeatedly investigated, cores were relocated within ≈5 m of the initial sampling location by replacing transect lines (100 m measuring tape) from high water mark perpendicular to the shore and collecting samples at the same distance down the transect line as previously. The error associated with the relocation process increased offshore due to errors in duplicating the angle of the transect line. All sites examined during the benthic study are shown in Fig. 2.1 and sampling dates listed in Table 2.6.

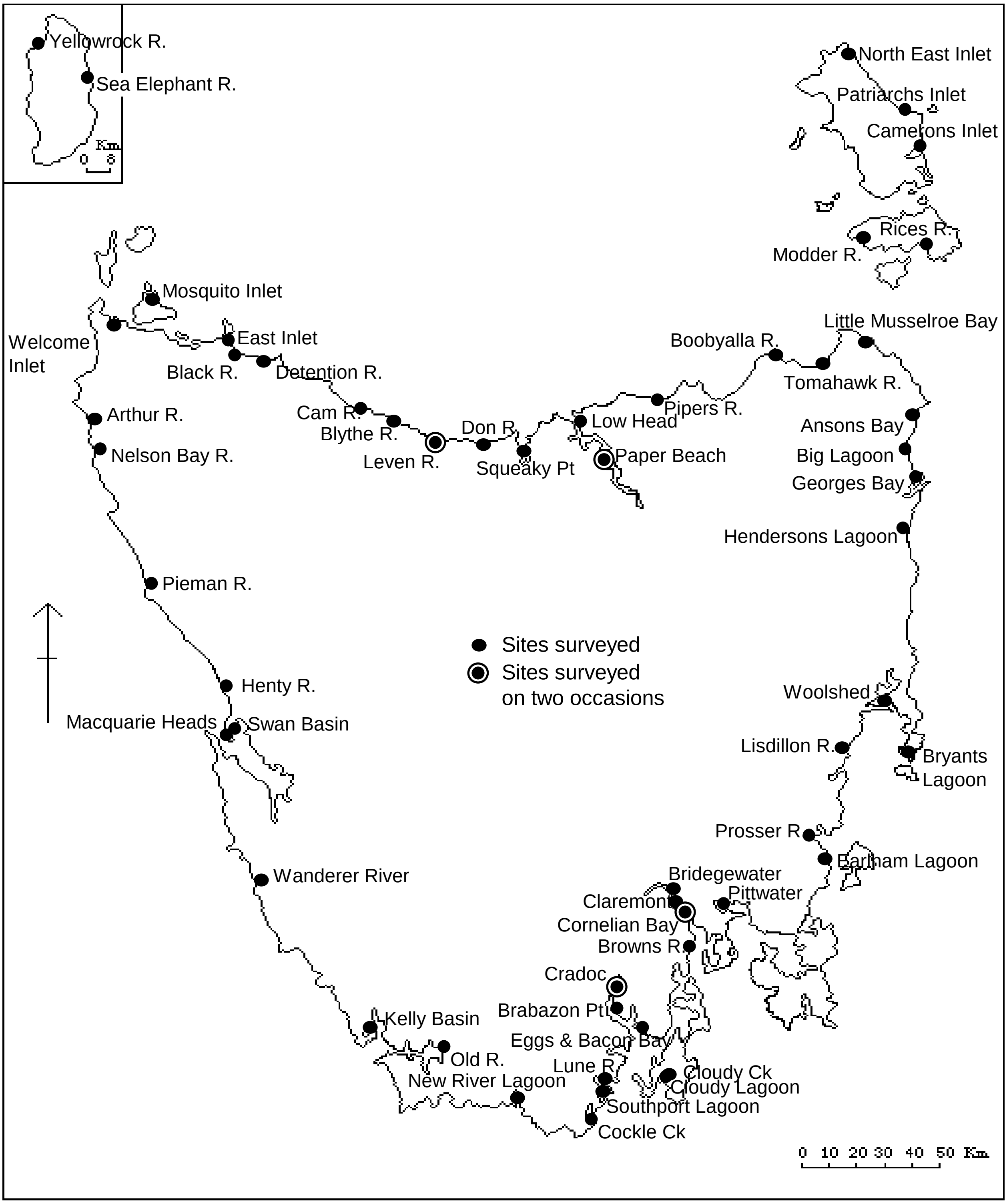

Fig. 2.1. Sites at which benthic macrofauna was sampled.

Table 2.6. Sites examined during benthic sampling program and surface salinity measured on sampling date.

Estuary	*Site*	*Date*	*Salinity*	*Latitude (S)*	*Longitude (E)*
Sea Elephant	Sea Elephant River	24-Feb-97	31.7	39°49.427'	144°06.656'
Yellow Rock	Yellow Rock R. mouth	23-Feb-97	4.6	39°42.076'	143°53.177'
North East Inlet	North East R. mouth	8-May-97	34.5	39°44.660'	147°57.000'
Patriarch Inlet	Patriarch Inlet	9-May-97	34.2	39°57.000'	148°10.800'
Cameron Inlet	Cameron Inlet	9-May-97	52.7	40°04.740'	148°15.720'
Modder	Modder River mouth	12-May-97	18.7	40°25.680'	148°02.000'
Rices	Rices River mouth	6-May-97	15.4	40°25.595'	148°18.410'
Welcome Inlet	Welcome Inlet	21-Feb-97	34.8	40°43.162'	144°46.299'
Mosquito Inlet	Mosquito Inlet	22-Feb-97	34.9	40°37.703'	144°56.656'
East Inlet	East Inlet	15-Jan-97	35.0	40°47.514'	145°16.141'
Black/Dip	Black River	14-Jan-97	22.0	40°50.659'	145°18.276'
Detention	Detention	13-Jan-97	22.0	40°52.892'	145°26.443'
Cam	Cam River	26-Sep-96	0.3	41°02.514'	145°50.328'
Blythe	Blythe River	16-Jan-97	14.0	41°04.686'	145°59.353'
Leven	Ulverstone	25-Sep-96	6.6	41°09.380'	146°09.570'
Leven	Ulverstone	17-May-97	12.1	41°09.380'	146°09.570'
Don	Don River	24-Sep-96	0.5	41°10.681'	146°19.104'
Port Sorell	Squeaky Pt	17-Jan-97	35.7	41°11.422'	146°34.311'
Tamar	Low Head	16-Dec-96	35.0	41°04.514'	146°48.399'
Tamar	Paper Beach	17-Dec-96	28.0	41°15.243'	146°58.579'
Tamar	Paper Beach	17-Jun-97	10.1	41°15.243'	146°58.579'
Pipers	Pipers River mouth	20-Nov-96	22.0	41°01.108'	147°09.795'
Tomahawk	Tomahawk R. mouth	22-Nov-96	11.0	40°52.259'	147°45.142'
Boobyalla	Ringarooma R. mouth	19-Nov-96	0.1	40°53.000'	147°53.184'
Little Musselroe Bay	Little Musselroe Bay	14-Nov-96	35.0	40°46.097'	148°01.874'
Ansons Bay	Ansons Bay	12-Nov-96	32.7	41°02.352'	148°15.674'
Big Lagoon	Big Lagoon	13-Nov-96	14.4	41°11.097'	148°16.094'
Georges Bay	Georges Bay	11-Nov-96	32.3	41°18.384'	148°15.975'
Hendersons Lagoon	Hendersons Lagoon	13-Nov-96	36.0	41°29.227'	148°15.388'
Bryans Lagoon	Bryans Lagoon	13-May-97	23.3	42°15.827'	148°17.366'
Great Swanport	Woolshed	23-Dec-96	20.0	42°05.130'	148°10.224'
Lisdillon	Lisdillon	17-Sep-96	19.1	42°17.378'	147°60.306'
Prosser	Orford	16-Sep-96	31.3	42°33.357'	147°52.387'
Earlham Lagoon	Earlham Lagoon	20-Aug-96	32.8	42°39.265'	147°56.334'
Pittwater	Pittwater	23-Oct-96	32.4	42°47.081'	147°30.602'
Derwent	Bridgewater	21-Oct-96	4.9	42°44.757'	147°14.051'
Derwent	Claremont	21-Oct-96	16.8	42°47.524'	147°15.477'
Derwent	Cornelian Bay	24-Apr-96	14.4	42°51.178'	147°19.124'
Derwent	Cornelian Bay	13-Feb-97	22.8	42°51.178'	147°19.124'
Browns	Browns River mouth	2-Jul-96	25.6	42°58.730'	147°19.630'
Huon	Brabazon Pt	6-Nov-96	25.6	43°11.541'	146°59.459'
Huon	Cradoc	5-Nov-96	4.3	43°07.135'	147°00.697'
Huon	Cradoc	16-May-97	7.4	43°07.135'	147°00.697'
Huon	Eggs and Bacon Bay	31-Oct-96	29.4	43°14.784'	147°05.800'
Lune	Southport	9-Jan-97	28.3	43°26.568'	146°56.278'
Southport Lagoon	Southport Lagoon	19-Jun-97	33.9	43°28.351'	146°57.936'
Cloudy Bay	Cloudy Creek	24-May-97	33.4	43°25.276'	147°13.846'
Cloudy Bay	Oyster lease	18-May-97	33.4	43°26.097'	147°12.533'
Cockle Creek	Cockle Creek	7-Jan-97	33.0	43°35.092'	146°53.460'
New River Lagoon	New River Lagoon	18-Feb-97	6.9	43°31.751'	146°34.336'
Bathurst Harbour	Old River mouth	19-Feb-97	25.0	43°19.822'	146°13.102'
Payne Bay	Kelly Basin	19-Feb-97	31.8	43°16.438'	145°52.296'
Wanderer	Wanderer R. mouth	20-Feb-97	0.8	42°43.508'	145°23.778'
Macquarie Harbour	Macquarie Heads	30-Sep-96	5.0	42°13.389'	145°14.867'
Macquarie Harbour	Swan Basin	23-Jun-97	4.7	41°12.384'	145°16.207'
Henty	Henty River mouth	25-Jun-97	0	42°02.362'	145°14.618'
Pieman	Pieman River mouth	24-Jun-97	0	41°39.735'	144°55.711'
Nelson Bay	Nelson Bay	14-Jan-97	8.3	41°08.416'	144°40.671°'
Arthur	Arthur River mouth	13-Jan-97	13.0	41°03.070'	144°39.812'

2.11.2 Sampling methods

Each sample was collected using a 150 mm core pushed into the sediment to a depth of 10 cm. Cores were sieved in the field using a 1mm mesh sieve, and animal, plant material and sediment retained on the sieve then placed into vials and diluted with 5% formalin. In the laboratory, samples were washed through a stacked series of sieves (1, 1.4, 2, 2.8, and 4 mm) using the methods described by Edgar (1990a). The sizes of bivalves (shell width), gastropods (shell height) and crabs (carapace width) greater than 4 mm sieve size were measured with vernier callipers. The salinity of surface water at each site was measured at the time of benthic sampling.

Plant material was identified to species whenever possible and dried at 60° for at least two days for dry weight determination. Nine categories of plant material were recognised: *Zostera muelleri, Heterozostera tasmanica*, *Posidonia australis, Ruppia* spp., *Lepilaena* spp., *Ulva* sp., *Enteromorpha* spp., *Gracilaria* sp. and unidentifiable plant material.

2.11.3 Sediment analysis

Sediments were collected at the majority of sites investigated (39 sites) by pushing a 30 mm diameter core to a depth of 50 mm and then retrieving the contents of the core. This process was repeated several times between 0.3 and 0.7 m depth near the end of each transect line, and sediments from each site amalgamated. In the laboratory, the sediment particle size-distribution was determined by wet sieving samples through a nested series of sieves (0.63, 0.125, 0.25, 0.5, 1, 2 and 4 mm mesh size), and then sediments retained by different sieves were weighed after drying at 50°C for at least two days. Water passing through sieves, and therefore associated with particles <0.063 mm, was decanted over a period of several days and excess water removed, and then the silt/clay fraction of sediments was determined by drying in the oven.

2.11.4 Taxonomic uncertainty

To maintain taxonomic consistency, all invertebrates collected during the study were sorted by two people only (GJE and NSB) and classified into species groups by one (GJE). Invertebrates were identified to species by GJE (most crustaceans, molluscs and minor groups) and Dr R. Wilson (polychaetes), Dr G.C.B. Poore (isopods), T. O'Hara (echinoderms), Ms E. Turner (some molluscs), Dr W. Ponder (hydrobiid gastropods), C. Shepherd (talitrid amphipods), Dr G. Fenton (mysids), Dr J. Jarman (trichopterans) and Dr C. Erseus (oligochaetes). Nomenclature for undescribed talitrid amphipods follows the labelling system used by Dr. A. Richardson (pers. comm.). Some undescribed polychaete species possess a Museum of Victoria (MOV) species number (Dr R. Wilson, pers. comm.). Oligochaetes were still being identified at the time of report preparation, with names obtainable from GJE.

Three common pairs of sibling species (*Nassarius pauperata* and *N. burchardii*, *Tatea rufilabrus* and *T. huonensis*, *Limnoporeia yarrague* and *L. kingi*) could not always be confidently separated in samples because of overlap in morphological features, so distributional and abundance data associated with these taxa should be treated with an element of doubt. The gastropods *Nassarius pauperata* and *N. burchardii* were distinguished on the basis of nodulation on ribs (Marine Research Group of Victoria, 1984), and *Tatea rufilabrus* and *T. huonensis* on the ratio of shell length to shell width (Ponder *et al*., 1991). *Limnoporeia yarrague* and *L. kingi* were distinguished on the basis of the presence of a seta on the inner rami of uropod 3, as suggested by Barnard and Drummond (1978), although a high level of overlap in other diagnostic features makes the separation of these species doubtful.

2.11.5 Estimation of faunal biomass and productivity

The faunal biomass of benthic invertebrates between 1 mm and 2.8 mm sieve size was estimated for each sample by assuming that the ash-free dry weight (AFDW) of individuals was equal to the mean AFDW of animals in the same sieve size-class, as calculated from the regression equations listed in Table II of Edgar (1990a). Crustaceans, bivalves and gastropods retained on the largest (4 mm) sieve were assigned ash-free dry weights using their length measurements and regression equations relating log length (i.e. carapace length of crustaceans, length of gastropods and width of bivalves) to log weight. The regression equations used were directly calculated in this study for 16 common species on the basis of data on measured length of 116 animals and the difference in weight between drying at 60°C for 2 days and ashing at 550°C for 2 hours. The biomass of crustaceans, bivalves and gastropod species lacking direct regression estimates was estimated using the length-weight regression of the species with most similar body proportions. The biomass of polychaetes was calculated using data on the mean AFDW of animals greater than 4 mm sieve size. Direct measurements of mean AFDW were made for the six most abundant polychaete species and the holothurian *Leptosynapta dolabrifera*. Other taxa were assigned the mean biomass of the species closest in body dimensions.

Estimates of the daily productivity of benthic invertebrates were calculated using mean weight estimates for each animal and the equation $P = 0.0049*B^{0.80}T^{0.89}$ which relates daily macrobenthic productivity P (µg/d) to ash-free dry weight B (µg)and water temperature T (°C) (Edgar, 1990a). No correction was added for water temperature, which was standardised at 20°C, because productivity estimates were used to indicate relative effects (between different sites, times, levels, etc.) rather than to provide an absolute measurement of productivity on the date of sampling (Edgar, 1993). As such, productivity provides an index of community processes that is not greatly biased by either small or large animals (Edgar & Shaw, 1995a,b), and is also approximately proportional to total community respiration and consumption.

2.12 Fish Data

In contrast to other biological data sets, considerable information on the distribution of estuarine fishes around Tasmania has been collected previously as a result of the Ph.D study conducted of Dr Peter Last, CSIRO (Last, 1983). These data were generously made available for the present project. During his study, fishes were seine-netted between 1977 and 1979 at 231 sites in 71 estuaries around Tasmania, including the Bass Strait islands. Densities of fishes at each site were recorded in a semiquantitative form using $\log_3$ abundance classes (ie. class 1 indicates 1 individual, class 2 indicates 2-3 individuals, class 3 indicates 4-9 individuals, class 4 indicates 10-27 individuals, etc.).

Limited additional information on fishes was collected during the present project using a 1 mm mesh seine net (15 m long, 3 m drop) used within 11 estuaries, including four not examined in Last's study (Welcome Inlet, Mosquito Inlet, Bryans Lagoon, New River Lagoon). Fishes were collected using four to six replicate tows at each site, with the number of fish collected for each species recorded and later converted to $\log_3$ abundance classes to correspond with the Last data set. Estuaries from which fish data were collected are listed in Table 2.7.

Table 2.7. Number of sites within Tasmanian estuaries at which fishes were collected by Last (1983) and during the present study. Single asterisks indicate estuaries not examined by Last and double asterisks indicate sites examined in both projects.

Estuary	*Sites*	*Estuary*	*Sites*
Sea Elephant**	4	Georges Bay	10
Yarra	1	Scamander	2
Ettrick	1	Henderson's Lagoon	3
Yellow Rock**	4	Templestowe	4
North East Inlet	4	Douglas	2
Patriarch**	3	Denison	1
Cameron Inlet**	3	Bryans Lagoon*	1
Pats	2	Great Swanport**	13
Welcome*	1	Meredith	1
Mosquito Inlet*	1	Buxton	3
Duck Bay	6	Lisdillon	2
West Inlet	2	Little Swanport	4
East Inlet	2	Spring	1
Black/Dip	1	Prosser	2
Crayfish	1	Earlham Lagoon	2

Detention	2	Blackman Bay	3
Inglis	2	Carlton	5
Cam	1	Pittwater	6
Emu	1	Pipeclay Lagoon	2
Blythe	2	Derwent	13
Leven	3	Browns	1
Forth	3	Port Cygnet	2
Don	1	Huon	5
Mersey	3	Esperance	5
Port Sorell	5	Lune	1
Tamar	11	Southport Lagoon	1
Curries	1	Cloudy Bay**	3
Piper	2	Catamaran	1
Little Forester	1	D'Entrecasteaux	1
Brid	3	Cockle Ck.	2
Tomahawk	1	New River Lagoon*	1
Boobyalla Inlet	2	Bathurst Harbour**	7
Little Musselroe	2	Payne Bay	9
Great Musselroe	2	Macquarie Harbour	13
Ansons Bay	10	Pieman	4
Big Lagoon	2	Nelson Bay	2
Sloop Lagoon	1	Arthur	4
Grants Lagoon	1		

2.13 Statistical Analyses

2.13.1 Variance estimates

The value of collecting macroinvertebrate samples at different spatial (replicate, tidal height, transect, within estuary and between estuary) and temporal (hour and month) scales was assessed by partitioning the variance of samples using ANOVA. Because the sampling design was incomplete (*ie.* not all estuaries contained more than one site, not all sites were sampled on more than one occasion, not all levels were sampled at each site, etc.), the contribution of each scale to total variance was assessed using three different ANOVA designs.

The variance of different spatial and temporal components of the ANOVAs were estimated from the various models of expected mean squares (Tables 2.8-2.10). Density, biomass and productivity data were highly skewed and possessed heterogeneous variances (as assessed using Cochran's test and inspection of box plots), so were log transformed to homogenise variances. Log transformation of data is contrary to the recommendations of Underwood (1981) and Morrisey *et al* (1992a) who suggest that variance estimates based on ANOVA should be calculated using untransformed data. However, if the distribution of a parameter is highly skewed then calculation of its variance is meaningless.

The initial ANOVA design investigated variance at five different spatial scales – estuary, site within estuary, transect, tidal height and replicate. Duplicate or triplicate localities were sampled within only the Derwent, Tamar, Huon, Cloudy Lagoon, Macquarie Harbour estuaries, so the analysis was confined to these five estuaries. The third localities sampled within the Derwent and Huon estuaries were removed by random selection to maintain a balanced design. Two tidal heights (high and low tide levels) were also removed because of incomplete data. The analysis thus involved five estuaries, two localities nested within estuary, three transects nested within locality and two replicate samples, with tidal height (three levels) as a fixed factor orthogonal to the random factors (Table 2.8).

Table 2.8. Expected mean squares for four-factor ANOVA using five estuaries, two localities nested within each estuary, three transects nested within each locality, three tidal heights and two replicates.

Source	*df*	*Expected mean squares*
Estuary (E)	4	$\sigma^2e+6\sigma^2T(L(E))+18\sigma^2L(E)+36\sigma^2E$
Locality (L(E))	5	$\sigma^2e+6\sigma^2T(L(E))+18\sigma^2L(E)$
Transect (T(L(E)))	20	$\sigma^2e+6\sigma^2T(L(E))$
Height (H)	2	$\sigma^2e+2\sigma^2T(L(E)).H+6\sigma^2L(E).H+12\sigma^2E.H+60\sigma^2H$
E*H	8	$\sigma^2e+2\sigma^2T(L(E)).H+6\sigma^2L(E).H+12\sigma^2E.H$

L(E)*H	10	$\sigma^2_e+2\sigma^2_{T(L(E)).H}+6\sigma^2_{L(E).H}$
T(L(E))*H	40	$\sigma^2_e+2\sigma^2_{T(L(E)).H}$
Residual (*e*)	90	σ^2_e

Because the previous analysis may have been influenced by characteristics of the five particular estuaries examined, a three-factor ANOVA was run using a much greater number of sites and the three tidal heights. A total of 25 randomly-selected sites from different estuaries was included in this analysis (Table 2.9), the maximum that the statistical program used (SYSTAT) could handle, and the tidal heights mid tide, -0.3 and -0.7 m. Note that site in this analysis includes both the estuary and locality components of the previous analysis.

Table 2.9. Expected mean squares for three-factor ANOVA using 25 sites, three transects nested within each site, three tidal heights and two replicates.

Source	*df*	*Expected mean squares*
Site (S)	24	$\sigma^2_e+6\sigma^2_{T(S)}+18\sigma^2_S$
Transect (T(S))	50	$\sigma^2_e+6\sigma^2_{T(S)}$
Height (H)	2	$\sigma^2_e+2\sigma^2_{T(S).H}+6\sigma^2_{S.H}+150\sigma^2_H$
S*H	48	$\sigma^2_e+2\sigma^2_{T(S).H}+6\sigma^2_{S.H}$
T(S)*H	100	$\sigma^2_e+2\sigma^2_{T(S).H}$
Residual (*e*)	225	σ^2_e

Temporal effects were investigated using a four-way ANOVA with site, transect nested within site and month nested within transect as random factors and tidal level as a fixed factor crossed with the others (Table 2.10). The three sites sampled twice during the study using 1 mm mesh sieves were analysed using this design (Paper Beach, Cradoc, Leven), with two tidal levels (mid tide and -0.3 m) included. High, low and -0.7 tidal levels were not sampled at all three sites so data from these levels could not be readily used.

Table 2.10. Expected mean squares for four-factor ANOVA using three sites, three transects nested within each site, two sampling periods nested within each transect, two tidal heights and two replicates.

Source	*df*	*Expected mean squares*
Site (S)	2	$\sigma^2_e+4\sigma^2_{M(S)}+8\sigma^2_{T(S)}+24\sigma^2_S$
Transect (T(S))	6	$\sigma^2_e+4\sigma^2_{M(S)}+8\sigma^2_{T(S)}$
Month (M(T(S)))	9	$\sigma^2_e+4\sigma^2_{M(S)}$
Height (H)	1	$\sigma^2_e+2\sigma^2_{M(S).H}+4\sigma^2_{T(S).H}+12\sigma^2_{S.H}+36\sigma^2_H$
S * H	2	$\sigma^2_e+2\sigma^2_{M(S).H}+4\sigma^2_{T(S).H}+12\sigma^2_{S.H}$
T(S)* H	6	$\sigma^2_e+2\sigma^2_{M(S).H}+4\sigma^2_{T(S).H}$
M(T(S))* H	9	$\sigma^2_e+2\sigma^2_{M(S).H}$
Residual (*e*)	36	σ^2_e

ANOVAs have been used in this study solely to partition variance and to identify at which scale variance was greatest. In contrast to most other ecological studies that use ANOVAs, no attempt has been made to assign significance values to the various sources of variation identified using ANOVA. We consider that all natural communities fluctuate in time and place, albeit that some fluctuations will be extremely small, so the null hypothesis that no differences exist between sites, times or site/time interactions will only be true in artificial or trivial situations. The detection of significant differences between groups of field data using ANOVA indicates that the level of replication and power of the

ANOVA is adequate to detect differences, but provides negligible biological information. The important information is provided by estimates (with confidence intervals) of the magnitude and direction of differences between groups.

2.13.2 Associations between physical and biological variables

Relationships between physical and biological variables were investigated using correlation and regression procedures. Because of a lack of prior knowledge about whether relationships were linear or curvilinear, associations between parameters were initially flagged using Spearman rank correlation coefficients (r_S). Correlations between parameters that exceeded 0.30 were investigated using boxplots to identify whether the relationship was linear and residuals homogeneous, or whether transformation was required. After transformation of variables where appropriate, stepwise regression was carried out in order to produce an overall model that used physical variables to explain variation in the biological variables. Physical variables were included in the model if their addition contributed more than 5% to total variance explained. The physical variables examined using this procedure were: total plant biomass, *Zostera* biomass, shore gradient, tidal range, salinity, estuarine area, latitude, longitude, percent silt/clay content of sediments, human population density in adjacent catchment and drainage area, percent cleared land in adjacent catchment and drainage area. The silt/clay fraction of sediments was examined in preference to other sediment particle parameters because previous studies have shown it to be the most highly correlated with biological parameters (Edgar & Shaw, 1995b).

2.13.3 Multivariate analyses

Estuaries were initially classed into groups with similar physical characteristics on the basis of nine available variables considered to have large influences on estuarine structure. Five of these variables were geomorphological (catchment area size, estuarine drainage area size, area of open water, estuarine perimeter length, presence of seaward barrier), two were hydrological (standardised salinity of surface water midway along estuary in summer and winter), while single tidal (estimated tidal range inside entrance of estuary) and runoff (estimated annual riverine input) variables were also included. Many of these variables were intercorrelated with each other. Underlying patterns were identified using cluster analysis and multidimensional scaling (MDS), as run by SYSTAT (Wilkinson, 1989) and PRIMER (Carr, 1996) programs.

For all multivariate analyses involving geomorphology and runoff, variables were log-transformed and data standardised by dividing by the maximum value for each variable. Data matrices were analysed using agglomerative and divisive clustering methods. In the agglomerative clustering process, data were first converted to a symmetric matrix of similarity between pairs of sites using Euclidean distance. The similarity matrix was clustered using ranked data and group-averaging, as suggested by Clarke (1993). Divisive clustering utilised the original data matrix (site versus transformed physical variable) and used the K-means procedure to maximise the between groups variation relative to within groups variation for a predefined number of groups (Hartigan, 1975).

Similarity matrices calculated using Euclidean distance were also analysed using MDS to present the best graphical depiction in two and three dimensions of physical similarities between sites. The usefulness of the MDS display of relationships between sites is indicated by the stress statistic, which if <0.1 indicates that the depiction of relationships is good, and if >0.2 that the depiction is poor (Clarke, 1993).

In contrast to the physical data set, which possessed variables that were best analysed using a similarity matrix based on Euclidean distance (Clarke, 1993), the majority of cells in the invertebrate and fish data sets possessed 0 values. Accordingly, the similarity matrices for these data sets were calculated using the Bray-Curtis similarity coefficient after double root transformation, as recommended by Faith *et al* (1987) and Clarke (1993). The similarity matrices were then analysed using MDS in the same way as for the physical data set.

An additional three analyses were undertaken utilising Bray-Curtis similarity matrices and the PRIMER statistical program. An analysis of similarities (ANOSIM) was conducted to determine whether the fauna of predefined groups of sites differed significantly from each other (Clarke, 1993). SIMPER analysis was used with the raw data matrix after double square root transformation to identify species that typified predefined groups and contributed substantially to the average similarity within the group (Clarke, 1993). The BIOENV procedure was used to determine which combination of physical variables correlated best with patterns in the biotic similarity matrix (Clarke & Ainsworth, 1993).

3. Results

3.1 Physical Attributes of Estuaries

3.1.1 Geomorphology and tidal range

A total of 111 estuaries, lagoons and embayments of moderate or large size that are subject to fluvial drainage were identified around Tasmania. Data on the size of estuarine catchment area, estuarine drainage area, surface area of water, distance around estuarine perimeter, geomorphological type, existence of any seaward barrier and estimated tidal range in the mid section of each estuary are presented in Appendix 1. An unexpected finding was that the Wanderer estuary, which possesses a large catchment and lies in a region of high rainfall on the west coast, was occasionally closed by a bar. This bar was present during the field trip on 20 February 1997 and, on the basis of aerial photographs in November 1989, appeared to seasonally block the estuary distances in excess of 500 m.
Table 3.1 summarises data on water surface area, catchment size and estimated tidal range for the different geomorphological classes of estuary in Tasmania. River estuaries were the most common estuary type within the state, while only six large drowned river valleys were present. Average water surface area and catchment area of estuaries generally increased from lagoons to barrier estuaries and again to coastal inlets and drowned river valleys. Tidal range was extremely low in barrier estuaries and lagoons, and high in coastal inlets and river estuaries.

Table 3.1. Summary of relationships between geomorphological type and water surface area, catchment area and estimated tidal range in downstream section of estuary.

		Water surface area (km^2)			*Catchment area* (km^2)			*Tidal range* (m)		
Estuary type	*No.*	*min.*	*max.*	*mean*	*min.*	*max.*	*mean*	*min.*	*max.*	*mean*
Coastal Inlet	17	0.533	46.4	11.4	14.4	922	209	0.4	2.3	1.3
Drowned River Valley	6	44.17	291.7	105.0	924.8	13137	6503	0.3	2.3	0.8
Open Barrier	24	0.025	40.7	4.3	16.8	1031	275	0.1	2.2	0.8
Seasonal Barrier	20	0.013	1.6	0.3	15.5	353	99	0.1	0.4	0.2
River Estuary	31	0.017	4.8	0.6	42.2	3866	509	0.2	2.2	1.1
Lagoon	13	0.223	13.5	3.1	5.8	192	42	0.0	0.2	0.0

Geomorphological types of estuaries were not evenly distributed around the Tasmanian coastline (Table 3.2). Over half of all coastal lagoons were located along the east Tasmanian coast, with many of the remaining lagoons in the Furneaux Group. River estuaries were prevalent along the north, west and south coasts of Tasmania but were largely replaced by barrier estuaries elsewhere. Coastal inlets were concentrated in the northwest and southeast of the state.

Table 3.2. Number of estuaries of different geomorphological type in eight regions of the state. The Furneaux region includes Flinders Island and Cape Barren Island, the northwest region extends from Port Sorell to Welcome Inlet, the eastern north region from the Tamar to Little Musselroe Bay, the east region from Great Musselroe Bay to Earlham Lagoon, the southeast region from Blackman Bay to Cockle Creek, the south region from South Cape Rivulet to Payne Bay, and the west region from the Mulcahy River to the Arthur River.

Region	King I.	Furneaux	Northwest	E. North	East	Southeast	South	West
Coastal Inlet	0	2	7	0	1	7	0	0
Drowned River Valley	0	0	0	1	0	2	2	1

Open Barrier	0	6	3	1	7	6	1	0
Seasonal Barrier	3	5	0	0	8	0	0	4
River Estuary	1	0	8	6	1	3	3	9
Coastal Lagoon	1	3	0	0	7	0	1	1
Total	5	16	18	8	24	18	7	15

3.1.2 Rainfall and runoff

Substantial variation in rainfall occurred around the Tasmanian coastline (Table 3.3). Very high rainfall values were evident for the west coast and some northwest catchments, while a rainshadow effect caused low rainfall values in east coast catchments. Average rainfall was more than twice as high along the south and west coasts as in the Furneaux Group and along the northeast and east coasts. The percentage of rainfall that occurred as runoff showed corresponding changes, with the average runoff coefficient in the Furneaux Group one third of that estimated for the west coast.

Table 3.3. Mean average runoff (Rav), total annual runoff (TAR) and runoff coefficient (ROC) for estuarine catchments in different geographical regions. Regions as described in Table 3.2.

Region	*Rav* (mm)	*TAR* (GL)	*ROC* (%)
King Island	972	108	0.36
Furneaux Group	761	51	0.22
Northwest	1219	533	0.46
Eastern north	852	1709	0.28
East	864	167	0.28
Southeast	1086	968	0.38
South	1843	777	0.60
West	2091	2338	0.64
Tasmania	1174	780	0.39

The total annual runoff into estuaries was affected by both average rainfall and size of catchment. Mean total annual runoff was extremely low in the Furneaux Group, King Island and east coast - regions with relatively low rainfall, numerous small estuaries and lagoons, and lacking large drowned river valleys. Rainfall and runoff statistics for each estuary catchment are listed in more detail in Appendix 2.

3.1.3 Salinity

Mean salinities measured near the water surface and below the halocline, and depth of halocline, are listed for the three defined sections (upstream, mid, downstream) of each estuary in Appendix 4. Surface salinities in the mid section of estuaries, as standardised using the procedures described in Section 2.10, were highest in coastal inlets and lowest in river estuaries in both summer and winter (Table 3.4). Most estuaries experienced a range in salinity of ≈10‰ between average summer and winter conditions; however, conditions were generally less variable in drowned river valleys and more variable in river estuaries, open barrier estuaries and lagoons. Water column stratification was much more prevalent in winter than summer, in the upstream rather than downstream section, and in river estuaries and open barrier estuaries rather than coastal inlets (Appendix 4).

Table 3.4. Summary of relationships between geomorphological type of estuary and standardised salinity for surface waters midway along estuary in summer and winter.

	Summer salinity (‰)	*Winter salinity* (‰)

Estuary type	*No.*	*min.*	*max.*	*mean*	*min.*	*max.*	*mean*
Coastal Inlet	17	16.0	39.3	33.9	1.71	34.5	25.4
Drowned River Valley	6	13.2	33.3	21.1	4.12	29.6	14.2
Open Barrier	24	10.7	36.4	28.9	1.16	32.9	14.7
Seasonal Barrier	20	1.9	39.3	19.2	2.2	33.5	10.3
River Estuary	31	0	36.2	18.6	0	19.8	3.51
Lagoon	13	0	39.3	23.0	0	34.5	10.8

The average salinity of surface waters varied systematically around the state (Table 3.5). Lowest salinity values were found on the west coast, a region with exceptionally high rainfall, and King Island, a region with the majority of estuaries barred to the sea. By contrast, salinities were generally high in the Furneaux Group, a region of low rainfall, and the southeast coast, a region with numerous coastal inlets.

Table 3.5. Average surface salinity in the central section of estuaries in different regions as standardised using procedures described in Section 2.10. Regions as described in Table 3.2.

Region	*Summer* (‰)	*Winter* (‰)
King Island	18.6	5.1
Furneaux Group	27.7	17.3
Northwest	23.9	9.6
Eastern north	22.2	9.9
East	24.7	15.6
Southeast	28.5	18.4
South	21.9	10.4
West	15.3	4.5

3.1.4 Geology

The total area covered by different geological classes in each estuary catchment is listed in Appendix 5. The most prevalent geological classes within Tasmania were sedimentary (48% of total area), dolerite (20%) and metamorphic (12%). Alkaline intrusions, which have the potential to cause substantial elevation in riverine pH, were rare, only occurring in the Port Cygnet catchment (2.4% of total area) and Huon catchment (0.2%). Cambrian acid volcanics were also relatively uncommon; however, they covered relatively large proportions of the Lewis (45% of area), Mainwaring (17%), Henty (15%), Wanderer (11%) and Pieman (8%) catchments, and may have caused acidified conditions in these areas. These river systems may also carry large heavy metal loads because acid volcanics were also often associated with Cambrian ore deposits.

Sedimentary rocks were the predominant rock type in all regions of the state other than the east coast, where dolerite was more common, and the south coast, where metamorphic rocks predominated (Table 3.6). Basaltic rocks were prevalent in the northwestern region of Tasmania, dolerite covered large areas (≈40%) of catchment in the northeast, east and southeast of the state, and granitic intrusions were common in the Furneaux Group and along the east coast.

Table 3.6. Mean proportion (%) of major geological classes (alkaline intrusion, basalt, Cambrian acid volcanics, Cambrian ore deposits, carbonaceous, dolerite, dolomite, granite, lake, limestone, metamorphic and sedimentary) in catchments of estuaries in different Tasmanian regions. Regions as described in Table 3.2.

Region	Alkaline	Basalt	CaAcid	CaOre	Carbon.	Dolerite	Dolomite	Granite	Lake	Lime.	Met.	Sed.
King Island	0	0.1	0	0.2	0	0	0	3.6	0	0.1	25.7	70.2
Furneaux Grou	0	0.5	0	0	0	0	0	27.8	0.8	7.1	0	63.9
Northwest	0	21.6	1.6	10.7	0.9	6.8	1.4	2.2	0.5	1.8	6.4	47.2
Eastern north	0	3.7	0.0	0.4	0.9	32.0	0	8.9	1.8	0.0	0.0	53.1
East	0	0.7	0	0	1.6	46.0	0	17.3	0	0	0	36.1

Southeast	0.1	4.3	0	0.1	1.0	42.8	0.7	0	2.0	1.1	0.6	48.3
South	0	0	0	0.1	0	0.4	0	0.0	0.0	0.6	59.2	39.6
West	0	2.7	4.0	8.2	0.2	1.0	1.7	1.7	5.0	2.2	30.0	43.5
Tasmania	<0.1	5.0	1.4	3.9	0.6	20.0	0.8	5.2	2.3	1.2	12.4	47.8

3.1.5 A classification of Tasmanian estuaries based on physical attributes

Agglomerative cluster analysis of the 111 Tasmanian estuaries using nine physical variables (catchment area size, estuarine drainage area size, area of open water, estuarine perimeter length, presence of seaward barrier, standardised salinity of surface water midway along estuary in summer and winter, estimated tidal range midway along estuary and total annual runoff) revealed that estuaries in the state could be classed into a number of major groups (Fig. 3.1). For the purposes of the present project, estuaries were separated into ten groups at an Euclidean distance level of 4.5. This level was considered most appropriate because subdivision into nine groups would not separate drowned river valley estuaries (Bathurst Harbour, Derwent, Huon, Macquarie Harbour) from shallow river estuaries (New River Lagoon, Henty, Pieman, Arthur), whereas subdivision into eleven groups would split marine inlets with many features in common (e.g. East Inlet, West Inlet, Little Musselroe Bay, North East Inlet, Cloudy Lagoon). Three of the ten major groups consisted of a single estuary only (Tamar, Wanderer and Crayfish).

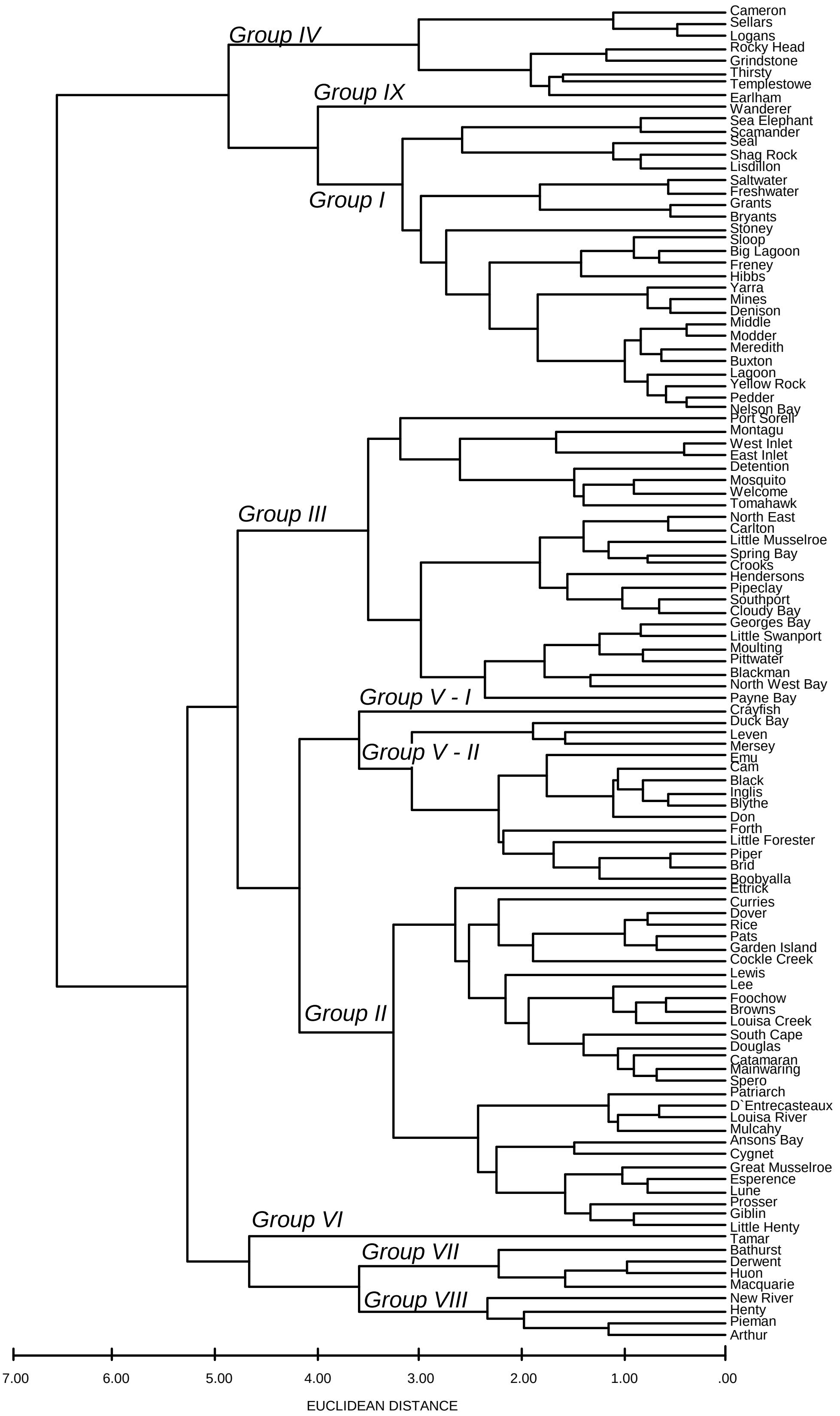

Fig. 3.1. Results of cluster analysis for 111 estuaries using information on nine physical variables (catchment area size, estuarine drainage area size, area of open water, estuarine perimeter length, presence of seaward barrier, standardised salinity of surface water midway along estuary in summer and winter, estimated tidal range midway along estuary and total annual runoff).

K-means divisive clustering of the data set was used to determine whether the ten groups defined by agglomerative procedures were robust. The only major difference identified by K-means clustering was that the Crayfish estuary was not classed as a separate entity but was included in the group containing other northern river estuaries (Group V).

The physical attributes of the nine groups defined by the two procedures are shown in Table 3.7, and each Tasmanian estuary is listed with its class in Appendix 1 and Tables 3.47-3.53. The estuarine groups derived by cluster analysis differed in several respects from geomorphological classes (Table 3.8) because of the effects of tidal range, salinity and runoff. Lagoons and seasonal barrier estuaries were placed in two major groups (Groups I and IV, plus the Wanderer estuary, Group IX) that were subdivided on the basis of salinity (ie. whether hypersaline or hyposaline) rather than extent of barrier closure. Four drowned river valleys were placed in a class (Group VI), while the Tamar drowned river valley formed its own group (Group VI) and Payne Bay was placed with coastal inlets (Group III). Open barrier estuaries and river estuaries were generally subdivided on the basis of salinity and tide rather than geomorphology (Groups II, V and VIII; Table 3.7).

Table 3.7. Mean values for different physical variables (estuarine catchment area, estuarine drainage area, estuarine area, perimeter length, tidal range, closure by entrance bar, total annual runoff, winter salinity, summer salinity) for estuaries categorised into different estuary groups.

Group	*ECA* (km^2)	*EDA* (km^2)	*EA* (km^2)	*Perimeter* (km)	*Tide* (m)	*Bar*	*TAR* (gl)	*Sal Win* (‰)	*Sal Sum* (‰)	*Number*
I	67	5.6	0.3	5.5	0.1	+	68.9	8.3	16.9	25
II	143	11.4	1.2	9.0	0.5	-	191.9	6.9	25.4	29
III	285	36.7	11.3	32.1	1.1	-	308.8	28.7	33.7	24
IV	63	27.7	4.9	15.3	0.1	+	49.5	32.6	43.2	8
V	580	18.1	2.4	18.5	2.0	-	673.4	2.1	18.1	15
VI	11589	558.3	97.9	252.7	2.3	-	10938.1	8.0	24.3	1
VII	6625	403.6	122.0	176.7	0.6	-	8634.9	8.0	19.5	4
VIII	1791	53.1	4.1	25.2	0.4	-	3649.7	2.1	4.1	4
IX	354	70.4	1.0	19.5	0.1	+	850.3	0.0	0.8	1

Table 3.8. Number of geomorphological classes of estuary within each estuary group.

Estuary group	Geomorphological class						
	Coastal Inlet	Drowned River Valley	Open Barrier	River Estuary	Seasonal Barrier	Lagoon	Total
I	0	0	0	0	16	9	25
II	1	0	14	14	0	0	29
III	14	1	8	1	0	0	24
IV	0	0	0	0	3	5	8
V	1	0	2	12	0	0	15
VI	0	1	0	0	0	0	1
VII	0	4	0	0	0	0	4
VIII	0	0	1	3	0	0	4
IX	0	0	0	0	1	0	1
Total	16	6	25	30	20	14	111

Multidimensional scaling (MDS) of the nine-variable physical data set indicated that physical relationships between estuaries could be accurately displayed on three dimensional graphs (stress = 0.060), but that the corresponding two dimensional display was less clear (stress = 0.133). Groups identified in the cluster analysis remained coherent when overlaid on the MDS axes (Fig. 3.2).

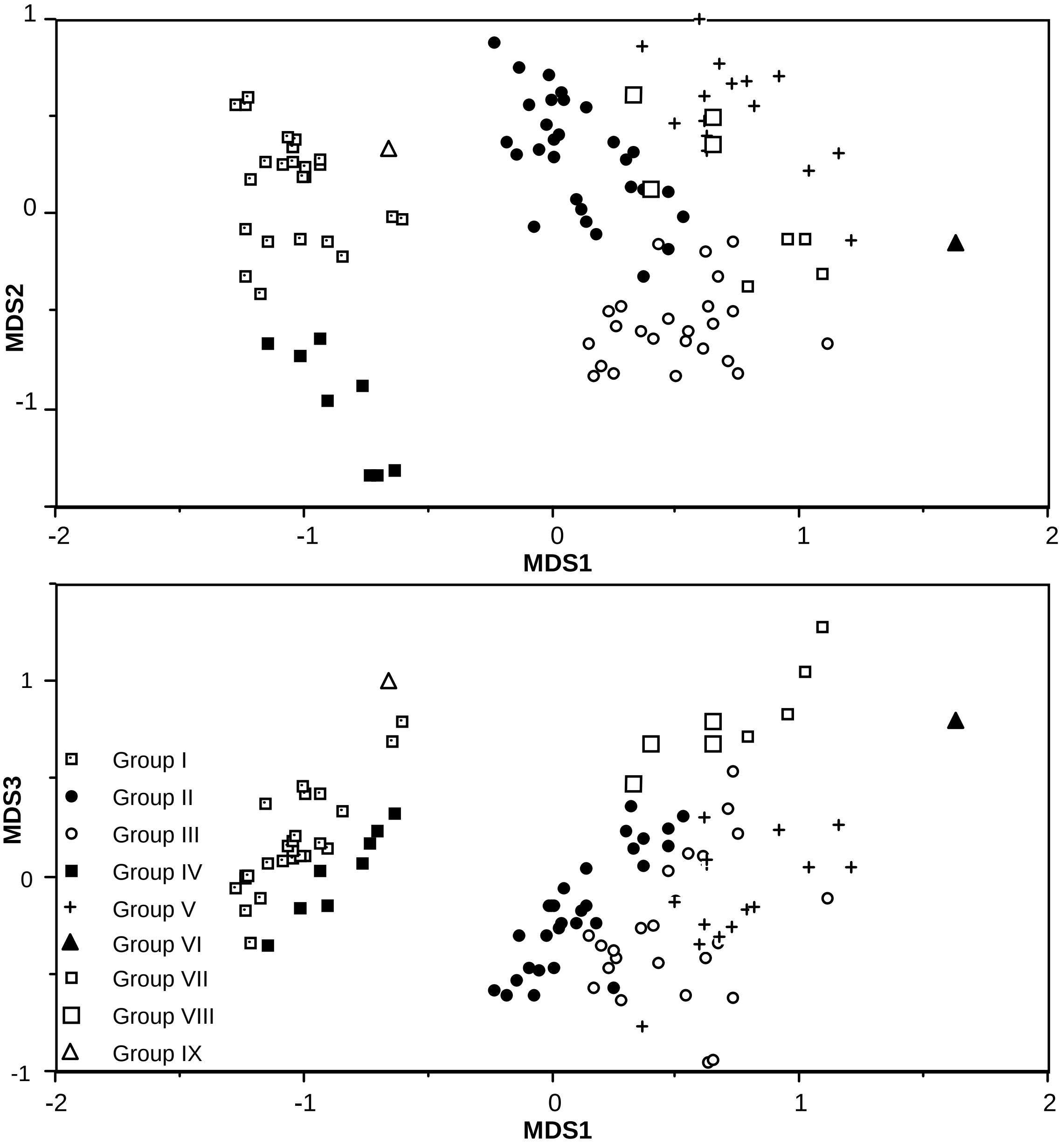

Fig. 3.2. Results of MDS analysis using nine physical variables (estuarine catchment area, estuarine drainage area, estuarine area, perimeter length, tidal range, closure by entrance bar, total annual runoff, winter salinity, summer salinity), with overlay of groups identified using cluster analysis.

Overlays of physical data onto the MDS axes (Fig. 3.3) revealed systematic influences contributing to the separation of sites. Geographic size variables increased with MDS axes 1 and 3. Salinity generally decreased with axes 1 and 2, while tidal range generally increased with axis 1 and decreased with axis 3. Estuaries with downstream barriers grouped together on the basis of differences in axis 1 into two distinct clusters, a subdivision forced on the data set because of the categorical nature of these data.

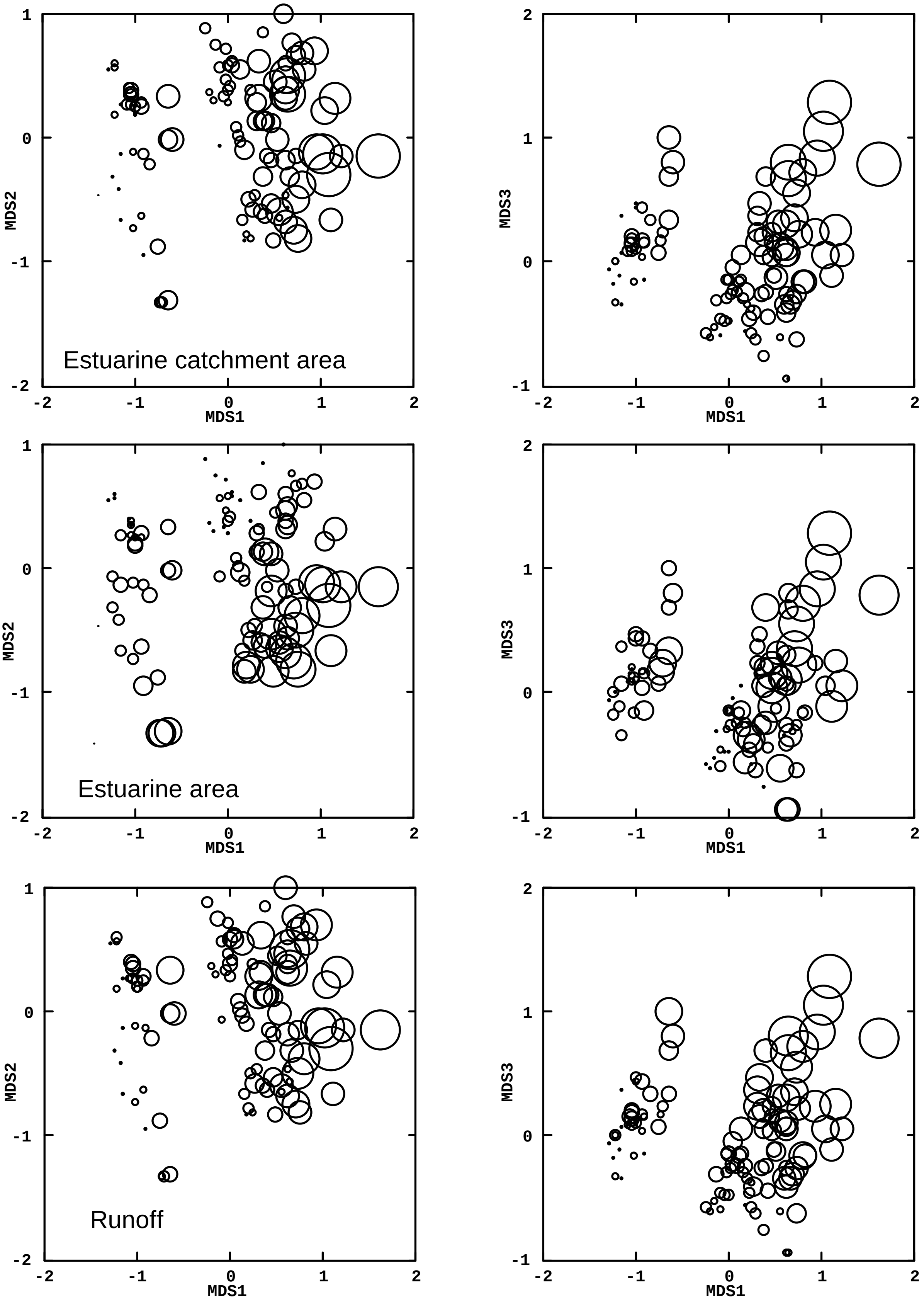

Fig. 3.3a. Bubble plot overlays of estuarine catchment area, estuarine area and total annual runoff on results of MDS analysis using data on nine physical variables. Increasing symbol size indicates increase in magnitude of variable.

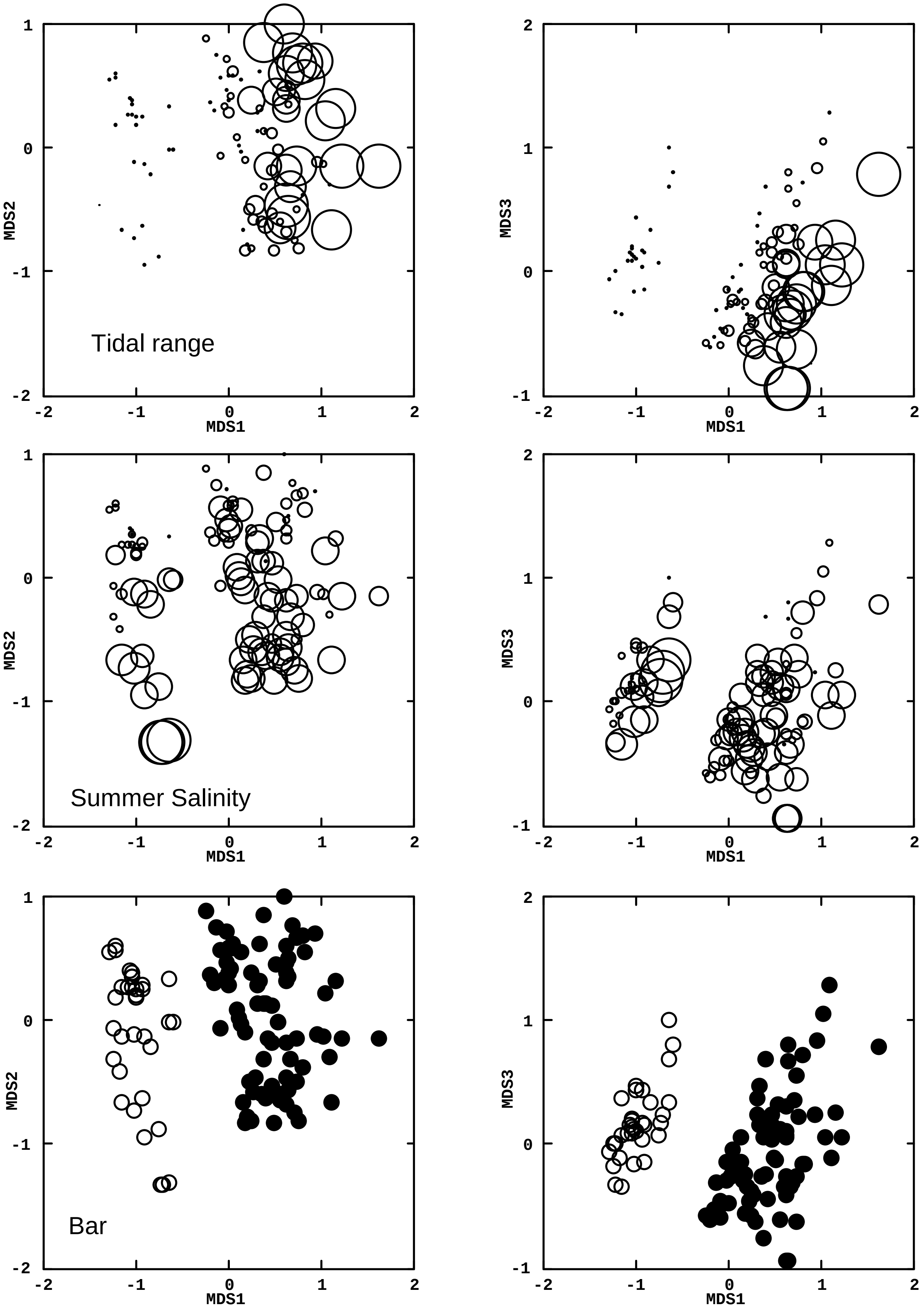

Fig. 3.3b. Bubble plot overlays of estimated tidal range and estimated surface salinity in middle reaches of estuary on results of MDS analysis using data on nine physical variables. Increasing symbol size indicates increase in magnitude of variable. Barrier presence and absence is also shown.

3.2 Macroinvertebrates and Plants

3.2.1 Floral composition

Aquatic plants were collected in benthic cores at 30 of the 55 sites investigated. The seagrass *Zostera muelleri* (20 sites) and *Ruppia* spp. (7 sites) were the only widespread plants, with other taxa present at one or two sites only (Table 3.9).

Table 3.9. Mean density (g DW/m^2) of different plant taxa (*Zostera muelleri, Heterozostera tasmanica, Posidonia australis, Ruppia* sp., *Lepilaena* spp., *Enteromorpha* spp., *Gracilaria* sp., *Ulva* sp. and unidentified plants) collected in benthic cores at various sites. Density estimates were calculated using the cross-sectional area of 150 mm diameter cores, and represent the mean of cores from mid-intertidal to subtidal shore heights. Terrestrial plant material collected at high water mark has not been included.

Site	Zostera	Heterozostera	Posidonia	Ruppia	Lepilaena	Enteromorpha	Gracilaria	Ulva	Other
Yellow Rock	0	0	0	0	73.4	0	0	0	0
North East	8.4	4.2	0	0	0	0	0	0	0
Rices	17.3	0	0	0	0	0	0	0	0
Welcome Inlet	19.4	0	0	0	0	0	0	0	0
East Inlet	4.5	0	0	0	0	0	0	0	0
Blythe	0	0	0	0	0	17.3	0	0	0
Low Head	7.1	0	2.4	0	0	0	0	0	0
Little Musselroe	6.8	0	0	0	0	0	0	0	0
Ansons Bay	16.9	0	0	0	0	0	0	0	0
Big Lagoon	0	0	0	23.7	0	0	0	0	0
Georges Bay	0.6	0	0	0	0	0	0	0	0
Bryans Lagoon	0	0	0	14.5	0	0	11.1	7.3	0
Woolshed	30.3	0	0	0	0	0	0	0	0
Lisdillon	31.8	0	0	0	0	0	0	0	0
Orford	13.3	0	0	0	0	0	0	0	0
Earlham Lagoon	3.9	0	0	0	0	0	0	0	0
Cornelian Bay	14.2	0	0	0	0	0	0	0	0
Claremont	6.8	0	0	0	0	86.5	0	0	0
Bridgewater	0	0	0	140.7	0	0	0	0	0
Cradoc	0.7	0	0	0	0	0	0	0	1.1
Eggs & Bacon	15.3	0	0	0	0	0	0	0	0
Southport	11.9	0	0	0	0	0	0	0	0
Cloudy Creek	0.2	0	0	0	0	0	0	0	0
Cloudy Bay	8.7	0	0	0	0	0	0	0	0
New River Lagoon	0	0	0	5.6	0	0	0	0	0
Kelly Basin	1.1	0	0	0	0	0	0	0	0
Wanderer	0	0	0	0.7	0	0	0	0	0
Swan Basin	0	0	0	0	0	0	0	0	3.8
Pieman	0	0	0	0.8	0	0	0	0	0
Arthur	0	0	0	25.7	0	0	0	0	0

The distribution of *Zostera muelleri* and *Ruppia* spp. varied with tidal height and salinity (Fig. 3.4). *Zostera* commonly occurred at sites with salinity greater than 20‰ and was recorded from midtidal regions to 0.7 m depth, but was most prevalent subtidally. *Ruppia* possessed a complementary distribution, generally occurring at sites with salinity less than 15‰. The densest beds of *Ruppia* were found at 0.7 m depth. Two other seagrasses, *Heterozostera tasmanica* (North East) and *Posidonia australis* (Tamar), were only collected at 0.7 m depth at single marine locations.

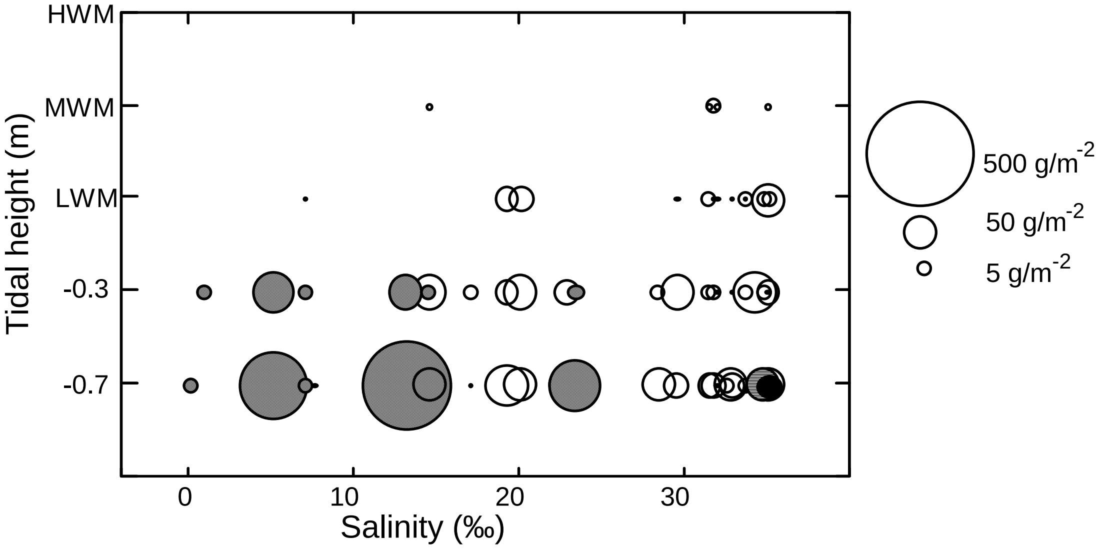

Fig. 3.4. Mean density of the plants *Zostera muelleri* (open circles), *Ruppia* spp. (shaded circles), *Heterozostera tasmanica* (lined circle) and *Posidonia australis* (filled circle) at different tidal heights and salinities.

3.2.2 Patterns of invertebrate species richness

A total of 390 invertebrate taxa were recorded from 55 sites in 49 estuaries during the benthic sampling program (Appendix 9). Crustaceans (153 species) comprised the taxonomic group with the greatest number of species, followed by polychaetes (102 species), gastropods (51 species) and bivalves (43 species). Nine species of fish were also collected in benthic cores but have not been included in analyses.

North East Inlet and the Low Head (Tamar) sites possessed substantially higher species richness than other sites (Table 3.10), with 120 species collected at the North East Inlet site and 116 at Low Head compared to 71 at the next richest site (Welcome Inlet). At the other extreme were sites on the Henty and Wanderer estuaries on the west coast, each with only two species.

Table 3.10. Total number of species collected at different sites (Spp.). Number of species restricted to each site (Spp. #) and number of species in each of the major taxonomic groups Crustacea, Gastropoda, Bivalvia and Polychaeta are also shown.

Estuary	*Site*	*Date*	*Spp.*	*Spp.#*	*Crust.*	*Gast.*	*Biv.*	*Poly.*	*Other*
Sea Elephant	Sea Elephant River	24-Feb-97	24	0	8	4	4	3	5
Yellow Rock	Yellow Rock R. mouth	23-Feb-97	17	3	9	1	0	0	7
North East Inlet	North East R. mouth	8-May-97	120	30	40	16	13	40	11
Patriarch Inlet	Patriarch Inlet	9-May-97	35	1	8	5	9	8	5
Cameron Inlet	Cameron Inlet	9-May-97	8	0	2	2	0	2	2
Modder	Modder River mouth	12-May-97	19	0	8	4	1	1	5
Rices	Rices River mouth	6-May-97	54	2	26	10	5	8	5
Welcome Inlet	Welcome Inlet	21-Feb-97	71	12	25	14	10	14	8
Mosquito Inlet	Mosquito Inlet	22-Feb-97	40	2	14	4	9	11	2
East Inlet	East Inlet	15-Jan-97	66	6	26	7	10	18	5
Black/Dip	Black River	14-Jan-97	33	0	14	3	7	7	2
Detention	Detention	13-Jan-97	24	1	10	2	6	5	1
Cam	Cam River	26-Sep-96	18	1	9	0	2	2	5
Blythe	Blythe River	16-Jan-97	40	3	17	5	4	10	4
Leven	Ulverstone	25-Sep-96	31	6	6	3	8	10	4
Leven	Ulverstone	17-May-97	38	6	12	3	9	11	3
Don	Don River	24-Sep-96	23	0	8	3	2	8	2
Port Sorell	Squeaky Pt	17-Jan-97	56	9	25	5	8	14	4
Tamar	Low Head	16-Dec-96	116	37	49	11	12	40	4
Tamar	Paper Beach	17-Dec-96	32	3	10	5	6	9	2
Tamar	Paper Beach	17-Jun-97	25	3	4	5	5	7	4
Pipers	Pipers River mouth	20-Nov-96	29	1	10	2	4	10	3
Tomahawk	Tomahawk R. mouth	22-Nov-96	26	0	5	2	9	6	4
Boobyalla	Ringarooma R. mouth	19-Nov-96	26	0	14	4	1	4	3
Little Musselroe Bay	Little Musselroe Bay	14-Nov-96	49	3	14	6	7	15	7
Ansons Bay	Ansons Bay	12-Nov-96	41	0	9	7	11	10	4
Big Lagoon	Big Lagoon	13-Nov-96	21	0	8	3	2	5	3
Georges Bay	Georges Bay	11-Nov-96	46	9	12	3	11	14	6
Hendersons Lagoon	Hendersons Lagoon	13-Nov-96	34	2	12	2	5	10	5
Bryans Lagoon	Bryans Lagoon	13-May-97	18	0	4	2	1	6	5
Great Swanport	Woolshed	23-Dec-96	36	0	16	8	3	6	3
Lisdillon	Lisdillon	17-Sep-96	36	0	14	7	2	9	4
Prosser	Orford	16-Sep-96	42	1	17	9	4	9	3
Earlham Lagoon	Earlham Lagoon	20-Aug-96	35	0	11	7	6	7	4
Pittwater	Pittwater	23-Oct-96	35	0	10	8	10	6	1
Derwent	Cornelian Bay	24-Apr-96	28	0	9	3	3	10	3
Derwent	Cornelian Bay	13-Feb-97	35	0	10	5	7	9	4
Derwent	Bridgewater	21-Oct-96	25	2	9	4	2	4	6
Derwent	Claremont	21-Oct-96	27	2	10	5	4	4	4
Browns	Browns River mouth	2-Jul-96	22	1	11	2	4	3	2
Huon	Eggs and Bacon Bay	6-Nov-96	51	2	19	4	9	14	5
Huon	Brabazon Pt	5-Nov-96	28	1	8	2	5	11	2
Huon	Cradoc	31-Oct-96	23	1	7	7	2	3	4
Huon	Cradoc	16-May-97	24	0	8	6	1	4	5
Lune	Southport	9-Jan-97	37	3	11	7	6	11	2
Southport Lagoon	Southport Lagoon	19-Jun-97	51	5	13	7	11	13	7
Cloudy Bay	Oyster lease	18-May-97	64	2	19	8	9	14	1
Cloudy Bay	Cloudy Creek	24-May-97	51	3	18	11	9	21	5
Cockle Creek	Cockle Creek	7-Jan-97	32	1	12	5	7	6	2
New River Lagoon	New River Lagoon	18-Feb-97	17	0	5	3	1	4	4
Bathurst Harbour	Old River mouth	19-Feb-97	20	1	7	3	1	5	4
Payne Bay	Kelly Basin	19-Feb-97	49	2	11	8	9	15	6
Wanderer	Wanderer R. mouth	20-Feb-97	2	0	2	0	0	0	0
Macquarie Harbour	Macquarie Heads	30-Sep-96	17	0	7	0	2	4	4
Macquarie Harbour	Swan Basin	23-Jun-97	19	0	8	2	1	2	6
Henty	Henty River mouth	25-Jun-97	2	0	1	0	0	0	1
Pieman	Pieman River mouth	24-Jun-97	12	0	6	1	0	1	4
Nelson Bay	Nelson Bay	14-Jan-97	15	1	8	3	0	1	3
Arthur	Arthur River mouth	13-Jan-97	17	1	11	3	0	1	2

The total number of species collected at different sites varied consistently between the nine estuary groups identified by multivariate analysis of physical variables (Table 3.11). The number of species ranged from an average of 51 species in marine bays and 74 species in the Tamar to only 2 species in the Wanderer estuary and an average of 12 species in the large open river estuaries. Group I barred low-salinity estuaries possessed only moderate species richness (≈21) even though the densities of animals were higher than in other estuary groups (Table 3.11).

The number of species in different taxonomic groups occurred in nearly the same proportions in estuaries of different types (Table 3.11), except that the proportion of bivalves to gastropods increased from low salinity estuaries to estuaries with marine conditions. Crustaceans comprised the richest taxonomic group in nearly all estuaries, followed by polychaetes, bivalves and gastropods.

Table 3.11. Mean number of species collected from sites in different estuary groups. Standard deviation of total number of species and number of sites for each group are also shown.

Group	*Estuary*	*Crustacea*	*Gastropod*	*Bivalvia*	*Polychaeta*	*Other*	*Total*	*SD*	*Sites*
I	Barred low-salinity estuary	8.4	3.4	1.4	3.6	4.6	21.4	7.0	7
II	Small open estuary	13.4	6.4	6.6	7.9	3.3	37.6	9.8	7
III	Marine inlet	16.9	6.9	8.7	13.9	4.8	51.1	22.9	16
IV	Hypersaline lagoon	6.5	4.5	3.0	4.5	3.0	21.5	19.1	2
V	Mesotidal river estuary	11.1	2.9	4.0	7.3	3.3	28.6	7.1	7
VI	Tamar	29.5	8.0	9.0	24.5	3.0	74.0	59.4	2
VII	Microtidal drowned river valley	9.4	3.6	3.7	6.2	4.3	27.2	10.4	9
VIII	Large open microtidal river	5.8	1.8	0.3	1.5	2.8	12.0	7.1	4
IX	Wanderer	2.0	0.0	0.0	0.0	0.0	2.0	-	1

3.2.3 Macrofaunal abundance, biomass and productivity

A total of 109,776 individuals were recorded from the 55 sites investigated. Gastropods (43,060 individuals) and crustaceans (27,190) were the groups with highest abundance, while bivalves (21,716) and polychaetes (13,363) were also common. The number of animals collected at each site and the mean estimated biomass and productivity of animals from 0 m to 0.7 m depth are shown in Table 3.12. Biomass and productivity data for shallow depths near low water mark have been amalgamated in this table because they were relatively homogeneous, while the fauna near high water mark differed greatly in faunal composition and patchiness. Amalgamation of data from the higher tidal region therefore complicated rather than clarified patterns. Moreover, data from the high tide region have not been reported from other studies for comparative purposes, whereas considerable information is available on faunal communities near low tide.

Table 3.12. Total number of animals collected at all levels and mean estimated biomass and productivity of macrofauna across the three lowest tidal levels at different sites. The number of cores collected at each site and ratio of annual production to biomass are also shown.

Estuary	*Site*	*Date*	*Cores*	*Number*	*Biomass* ($g.m^{-2}$)	*Productivity* ($\mu g.m^{-2}.d^{-1}$)	*P/B*
Sea Elephant	Sea Elephant River	24-Feb-97	30	4871	84.6	457.7	2.0
Yellow Rock	Yellow Rock R. mouth	23-Feb-97	30	4186	2.2	52.7	8.6
North East Inlet	North East R. mouth	8-May-97	30	1580	58.7	385.8	2.4

Patriarch Inlet	Patriarch Inlet	9-May-97	30	904	11.6	74.7	2.3
Cameron Inlet	Cameron Inlet	9-May-97	24	1109	5.0	69.2	5.1
Modder	Modder River mouth	12-May-97	24	1814	2.0	34.1	6.3
Rices	Rices River mouth	6-May-97	24	2116	21.5	198.4	3.4
Welcome Inlet	Welcome Inlet	21-Feb-97	30	4673	73.5	430.8	2.1
Mosquito Inlet	Mosquito Inlet	22-Feb-97	24	1082	587.0	2500.3	1.6
East Inlet	East Inlet	15-Jan-97	30	2416	13.7	134.9	3.6
Black/Dip	Black River	14-Jan-97	30	934	18.2	131.1	2.6
Detention	Detention	13-Jan-97	30	438	3.9	36.0	3.4
Cam	Cam River	26-Sep-96	30	1925	3.3	45.1	5.0
Blythe	Blythe River	16-Jan-97	30	1026	7.0	63.6	3.3
Leven	Ulverstone	25-Sep-96	28	693	95.4	431.6	1.7
Leven	Ulverstone	17-May-97	26	767	94.2	461.5	1.8
Don	Don River	24-Sep-96	24	447	12.9	91.8	2.6
Port Sorell	Squeaky Pt	17-Jan-97	30	478	271.3	1158.3	1.6
Tamar	Low Head	16-Dec-96	30	1205	18.9	136.8	2.6
Tamar	Paper Beach	17-Dec-96	30	756	27.7	201.1	2.6
Tamar	Paper Beach	17-Jun-97	24	752	55.4	447.1	2.9
Pipers	Pipers River mouth	20-Nov-96	30	362	4.1	37.5	3.4
Tomahawk	Tomahawk R. mouth	22-Nov-96	30	229	18.3	101.8	2.0
Boobyalla	Ringarooma R. mouth	19-Nov-96	30	2147	5.1	66.0	4.8
Little Musselroe Bay	Little Musselroe Bay	14-Nov-96	30	4516	48.9	374.5	2.8
Ansons Bay	Ansons Bay	12-Nov-96	18	847	55.8	338.3	2.2
Big Lagoon	Big Lagoon	13-Nov-96	18	5783	12.6	228.7	6.6
Georges Bay	Georges Bay	11-Nov-96	30	763	25.3	156.4	2.3
Hendersons Lagoon	Hendersons Lagoon	13-Nov-96	18	713	18.0	129.6	2.6
Bryans Lagoon	Bryans Lagoon	13-May-97	24	6547	10.0	154.4	5.6
Great Swanport	Woolshed	23-Dec-96	30	4406	13.8	174.8	4.6
Lisdillon	Lisdillon	17-Sep-96	20	3883	100.6	580.0	2.1
Prosser	Orford	16-Sep-96	30	1978	42.8	298.7	2.5
Earlham Lagoon	Earlham Lagoon	20-Aug-96	30	1508	48.6	272.1	2.0
Pittwater	Pittwater	23-Oct-96	30	1064	56.8	316.7	2.0
Derwent	Cornelian Bay	24-Apr-96	30	676	18.2	152.2	3.1
Derwent	Cornelian Bay	13-Feb-97	30	1937	38.8	353.0	3.3
Derwent	Bridgewater	21-Oct-96	18	8309	16.0	249.6	5.7
Derwent	Claremont	21-Oct-96	18	2023	23.6	197.7	3.1
Browns	Browns River mouth	2-Jul-96	30	286	7.9	57.4	2.6
Huon	Eggs and Bacon Bay	6-Nov-96	30	1148	28.1	242.5	3.2
Huon	Brabazon Pt	5-Nov-96	18	88	15.2	78.5	1.9
Huon	Cradoc	31-Oct-96	18	1934	8.4	89.7	3.9
Huon	Cradoc	16-May-97	18	2252	3.3	63.4	7.0
Lune	Southport	9-Jan-97	30	937	17.5	115.5	2.4
Southport Lagoon	Southport Lagoon	19-Jun-97	30	4775	118.6	630.5	1.9
Cloudy Bay	Oyster lease	18-May-97	30	2486	18.9	132.2	2.6
Cloudy Bay	Cloudy Creek	24-May-97	30	1507	101.0	461.7	1.7
Cockle Creek	Cockle Creek	7-Jan-97	30	1266	98.5	424.6	1.6
New River Lagoon	New River Lagoon	18-Feb-97	24	1054	1.9	30.4	5.8
Bathurst Harbour	Old River mouth	19-Feb-97	24	1542	1.8	34.2	7.0
Payne Bay	Kelly Basin	19-Feb-97	30	3125	108.1	445.7	1.5
Wanderer	Wanderer R. mouth	20-Feb-97	24	3	0.001	0.037	14.1
Macquarie Harbour	Macquarie Heads	30-Sep-96	28	866	5.9	48.0	3.0
Macquarie Harbour	Swan Basin	23-Jun-97	30	680	1.7	24.4	5.2
Henty	Henty River mouth	25-Jun-97	30	294	0.55	9.8	6.5
Pieman	Pieman River mouth	24-Jun-97	30	593	0.58	12.1	7.7
Nelson Bay	Nelson Bay	14-Jan-97	30	1565	1.3	27.5	7.9
Arthur	Arthur River mouth	13-Jan-97	30	1551	1.8	36.1	7.3

The total number of animals collected at different sites varied from 8,309 at Bridgewater (Derwent) to only 3 animals amongst 24 cores at the Wanderer estuary (Table 3.12). Low salinity estuaries and the upper reaches of drowned river valleys generally possessed extremely high densities of animals, due largely to a predominance of small grazing gastropods (Table 3.13). By contrast, sites in open estuaries with fluctuating environmental regimes usually possessed low animal densities. Variation between sites within the nine estuary groups identified by multivariate analysis of physical variables was considerably greater in Type VII drowned river valleys than within other estuary groups. Sites within drowned river valleys typically possessed high densities of animals in the upstream reaches, low densities in the middle reaches and moderate densities in the downstream zone.

Table 3.13. Mean density (/m^2) of animals over all tidal levels at sites in different estuary groups. Maximum and minimum densities and number of sites in each group are also shown.

Group	Estuary description	Sites	Crustacea	Gastropod	Bivalvia	Polychaeta	Other	Total	Max	Min
I	Barred low-salinity estuary	7	2045	4718	1943	711	422	9837	18168	2952
II	Small open estuary	7	929	794	367	374	77	2540	4989	539
III	Marine inlet	16	377	1746	1263	552	187	4124	9007	432
IV	Hypersaline lagoon	2	328	573	377	1402	50	2730	2845	2615
V	Mesotidal river estuary	7	1238	172	348	231	35	2024	4050	683
VI	Tamar	2	391	77	526	768	66	1827	2258	1426
VII	Drowned river valley	9	1647	2602	543	408	226	5425	26119	277
VIII	Large open microtidal river	4	875	546	67	245	38	1771	2926	555
IX	Wanderer	1	7	0	0	0	0	7	7	7

Patterns of faunal abundance between sites differed from patterns identified for estimated macrofaunal biomass and productivity. The two sites with highest densities of animals, Bridgewater and Bryans Lagoon, possessed macrofaunal assemblages with moderate rather than high biomass and productivity (Table 3.12).

Both estimated biomass and productivity varied enormously between sites. The Mosquito Inlet site, where high densities of bivalves were present, was found to possess macrofaunal biomass over five orders of magnitude and productivity over four orders of magnitude higher than at the Wanderer site, where only three small amphipods were collected. Biomass at the Wanderer site was in fact two orders of magnitude lower than at the second lowest site, the Henty estuary.

The ratio of production to biomass, when calculated on an annual basis to allow comparison with other studies, varied with total biomass of sites through a tenfold range. Sites with low biomass estimates were typically dominated by small-sized animals with rapid turnover rates and high P/B ratios, while sites with high macrofaunal biomass were dominated by relatively slow-growing bivalves.

Estimated macrofaunal biomass showed little systematic variation between estuaries of different physical type, other than that biomass was extremely low in the Wanderer estuary, low in Type VIII large open microtidal river estuaries and relatively high in Type III marine inlets (Table 3.14). Bivalves were by far the most important contributors to total biomass in the three estuary groups most strongly influenced by seawater - groups II, III and VI.

Table 3.14. Mean estimated biomass (g.m-^{2}) of animals collected from 0-0.7 subtidal depth levels at sites in different estuary groups. Biomass at sites with maximum and minimum levels, and number of sites in each group, are also shown.

Group	Estuary description	Sites	Crustacea	Gastropod	Bivalvia	Polychaeta	Other	Total	Max	Min
I	Barred low-salinity estuary	7	1.8	13.7	13.4	1.3	0.2	30.5	100.6	1.3
II	Small open estuary	7	4.5	6.6	23.1	2.2	0.0	36.5	98.5	7.9
III	Marine inlet	16	2.8	5.1	83.6	3.9	0.7	96.0	587.0	3.9
IV	Hypersaline lagoon	2	2.1	12.7	8.4	3.5	0.1	26.8	48.6	5.0
V	Mesotidal river estuary	7	4.3	0.4	23.8	1.4	0.0	30.0	95.4	3.3
VI	Tamar	2	1.4	1.5	28.5	2.5	0.1	34.0	55.4	18.9
VII	Drowned river valley	9	2.6	4.1	5.5	2.1	0.3	14.6	38.8	1.7
VIII	Large open microtidal river	4	0.7	0.2	0.0	0.3	0.0	1.2	1.9	0.5

IX	Wanderer	1	0.001	0	0	0	0	0.001	0.001	0.001

Estimated productivity also varied greatly within estuaries of a particular physico-chemical group, with relatively little systematic variation between different groups (Table 3.15). Bivalve productivity and total productivity tended to be highest in marine inlets, although one marine inlet (Detention) had a total productivity substantially lower than that found in most other estuaries (12 µg.m^{-2}.d^{-1}). Crustacean productivity showed little systematic change between all estuary groups other than group IX (the Wanderer estuary), while the productivity of polychaetes was highest in the two saline estuary types (hypersaline lagoons and marine inlets).

Table 3.15. Mean estimated productivity (µg.m^{-2}.d^{-1}) of animals collected from 0-0.7 depth levels at sites in different estuary groups. Productivity at sites with maximum and minimum levels, and number of sites in each group, are also shown.

Group	*Estuary description*	*Sites*	*Crustacea*	*Gastropod*	*Bivalvia*	*Polychaeta*	*Other*	*Total*	*Max*	*Min*
I	Barred low-salinity estuary	7	24.3	91.9	82.0	17.4	3.7	219.3	580.0	27.5
II	Small open estuary	7	31.9	65.8	94.0	23.1	0.5	215.4	424.6	57.4
III	Marine inlet	16	20.3	49.8	359.1	38.4	5.6	473.1	2500.3	36.0
IV	Hypersaline lagoon	2	13.2	71.7	39.0	45.7	1.0	170.7	272.1	69.2
V	Mesotidal river estuary	7	35.3	4.6	109.8	15.8	0.6	166.0	461.5	37.5
VI	Tamar	2	12.9	14.2	203.2	30.5	0.9	261.7	447.1	136.8
VII	Drowned river valley	9	27.7	53.0	33.3	22.1	3.2	139.4	353.0	24.4
VIII	Large open microtidal river	4	12.1	4.5	0.6	4.6	0.3	22.1	36.1	9.8
IX	Wanderer	1	0.037	0	0	0	0	0.037	0.037	0.037

3.2.4 Effects of tidal emersion

Total number of species was strongly affected by tidal emersion. The number of species collected increased consistently over a threefold range in a downshore direction (Table 3.16), reaching a maximum of 309 species at the deepest level (0.7 m below low water mark).

The density of macrofauna also increased in a downshore direction to 0.3 m depth but then decreased in deeper water. The density of animals collected at high water mark was only ≈20% of densities in shallow waters. Estimated biomass and productivity showed an even greater increase from high to low water mark, both increasing over an order of magnitude through this range. These two variables then declined from low water mark to 0.7 m depth. The overall decline in macrofaunal productivity from low water mark to 0.7 m depth was, however, not as strongly marked as for biomass, with biomass declining by 42% over this range and productivity declining by 31%.

Table 3.16. The overall mean density (m^{-2}), estimated biomass (g.m^{-2}), estimated productivity (µg.m^{-2}.d^{-1}) and annual P:B ratio of invertebrates collected at different tidal levels.

Level	*Species*	*Density*	*Biomass*	*Productivity*	*Annual P:B*
HWM	86	1017	2.0	20.5	3.67
MW	140	2955	16.5	125.4	2.77
LWM	190	4057	52.0	274.4	1.93
-0.3m	249	5565	39.7	236.5	2.17
-0.7m	309	5097	30.3	189.8	2.29

Similar patterns were evident when the different levels at each site were ranked from the level with highest species richness to the level with lowest species richness. At only three sites was species richness maximal at the high water level, compared to 27 sites at which species richness was maximal at the 0.7 m depth level (Table 3.17). Although mean biomass and estimated productivity were both highest at low water mark, these two variables were higher at subtidal levels than at low water mark at the majority of sites. Extremely high faunal biomass present near low water mark at a few sites was apparently overriding general patterns of increasing biomass and productivity with depth. The hypothesis that the counts shown in Table 3.17 arose from a homogeneous distribution across all levels was assessed using a $\chi 2$ test and rejected for all variables ($p<0.01$).

Table 3.17. The number of sites at which each of four variables (number of species, density, estimated biomass and estimated productivity) was ranked highest between the five levels investigated (*e.g.*, number of species was found to be highest at high water mark at 3 sites). At several sites a similar maximum number of species was recorded at more than one level, hence the column total for species exceeds the number of sites (55).

Level	*Species*	*Density*	*Biomass*	*Productivity*
HWM	3	2	2	2
MW	6	8	6	7
LWM	10	17	13	15
-0.3m	16	15	20	17
-0.7m	27	13	18	18

Species richness and the other three major variables investigated all showed significant differences in ranks between tidal levels, as assessed using Kruskal-Wallis test ($p<0.001$) for the 36 sites where data were collected at all five tidal levels. Tests of differences between adjacent tidal levels using Wilcoxon signed ranks test indicated that the number of species differed between HWM and MW ($p<0.001$), MW and LWM ($p<0.001$), and LWM and -0.3 m ($0.001<p<0.01$) but not between -0.3 m and -0.7 m ($0.05<p<0.1$). The density of animals varied between HWM, MW and LWM ($0.001<p<0.01$) but not between LWM and -0.3 m or between -0.3 and -0.7 m ($p>0.05$). Estimated biomass and productivity also both differed between HWM and MW ($p<0.01$) and between MW and LWM ($0.01<p<0.05$) but not for the two deeper comparisons ($p>0.05$).

High correlations were detected using data from the 55 sites in species richness, faunal density, biomass and productivity of samples collected at adjacent tidal levels other than for the correlation between high water mark and mean water samples (Table 3.18). Thus, sites with high species richness (or high density, biomass or productivity) at low water mark also generally possessed high values at subtidal and midtidal levels. By contrast, numerous sites were sampled with high values at mid to low tidal levels and low values at high water mark, and vice versa.

Table 3.18. Spearman rank correlation coefficients relating total number of species recorded at different sites between two adjacent tidal levels. Analogous results for mean faunal density, estimated biomass and estimated productivity at the 55 sites are also shown.

	HWM/MW	*MW/LWM*	*LWM/0.3m*	*0.3m/0.7m*
Species	0.44	0.73	0.83	0.77
Density	0.17	0.58	0.53	0.78
Biomass	0.20	0.77	0.74	0.71
Productivity	0.15	0.72	0.73	0.72

3.2.5 Effects of salinity and other physical factors

Invertebrate species richness at different sites showed a close correspondence with the salinity of estuaries at the time of sampling (Fig. 3.5). The linear regression relating these variables was highly significant ($S=14.7+0.93*C$, $n=59$, $r^2=0.31$, $p<0.001$, where S is number of species and C is salinity), and became even more significant when three outlying points were excluded ($S=14.7+0.93*C$, $n=56$, $r^2=0.56$, $p<0.001$).

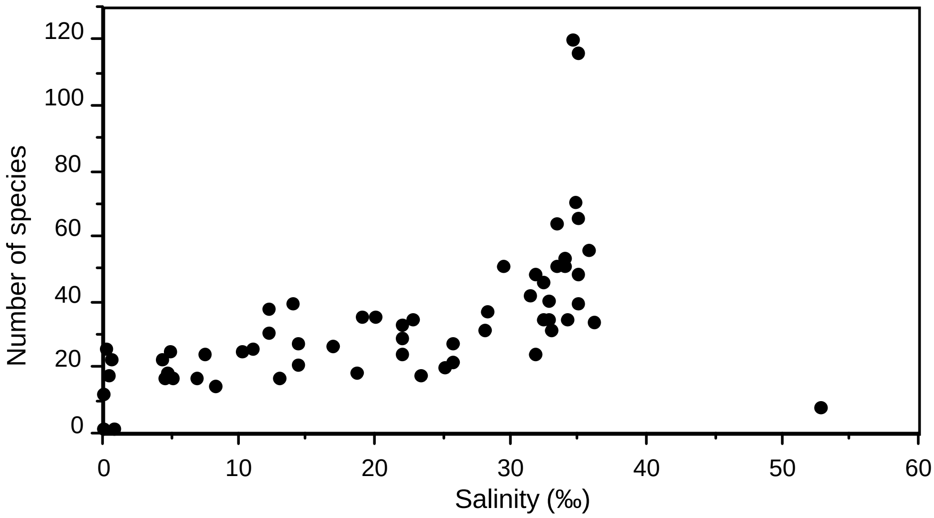

Fig. 3.5. Relationship between total number of species collected at each site and salinity.

A mean of 15 species was collected at freshwater-influenced sites whereas marine embayments generally contained around 50 species. The number of species at mesohaline sites remained approximately constant (˜25) within the salinity range of 5‰ to 25‰. Two sites, Low Head and North East Inlet, possessed anomalously high species richness. These sites were both fully marine and were the only sites where the seagrasses *Posidonia australis* and *Heterozostera tasmanica*, respectively, were encountered. By contrast, the single hypersaline lagoon investigated (Cameron Inlet) yielded only 8 species.

Much of the reason for the extremely high species richness at North East Inlet and Low Head was that both sites included a large component of species not collected elsewhere. These species were probably marine in origin rather than estuarine. A plot of number of species restricted to each site versus salinity (Fig. 3.6) indicates that most sites with large numbers of species restricted to that site were marine influenced. The Tasmanian estuarine fauna therefore appeared to be widely distributed with marine species patchily intruding into estuaries at particular sites.

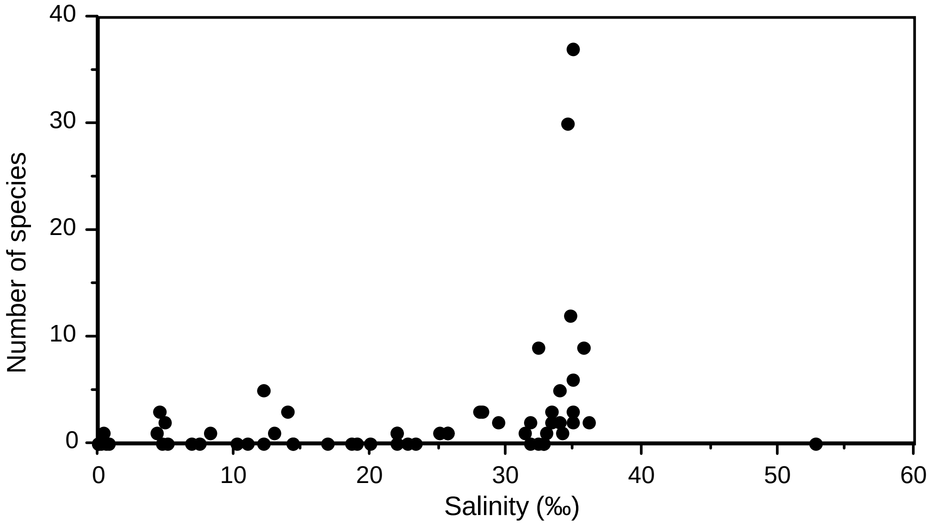

Fig. 3.6. Relationship between number of species collected solely at each site and salinity.

Given the large changes in faunal variables between samples collected at different tidal heights, particularly between high water mark and mean water, the effects of physical factors on macrofaunal assemblages have been independently assessed for each tidal height. Eleven physical factors were incorporated in this analysis, eight that varied between sites (salinity, estuarine area, tidal range, latitude, longitude, silt/clay content of sediments, mean human population density of estuarine catchment area and estuarine drainage area, mean percent cleared land in estuarine catchment area and estuarine drainage area) and an additional three that also varied between tidal heights (mean plant biomass, mean *Zostera* biomass, shore gradient). Spearman rank correlation coefficients (r_S) relating these physical factors to the faunal variables are listed for each tidal level in Table 3.19. The number of species in these analyses refers to the total number of species collected at the one tidal height within a site, rather than total number of species at a site as in previous analyses.

Faunal assemblages near high water mark were not highly correlated with any of the physical factors investigated in this study, so probably respond interactively to a variety of factors, or are primarily affected by factors not quantified here. The only moderately high r_S-values were those relating number of species to percent cleared land, faunal density to human population density, and faunal biomass and productivity to the silt/clay fraction of subtidal sediments. Given the number of tests made, most of these values probably represent Type I statistical errors.

Two physical factors, *Zostera* biomass and salinity, were consistently associated with variation in faunal variables between sites at tidal levels from mean water to 0.7 m depth (Table 3.19). These two factors possessed a moderately highly correlation with each other at the three lowest tidal levels (r_S = 0.16, 0.34, 0.29, 0.31 at MW, LWM, 0.3 m, 0.7 m, respectively), so possibly interacted in their effects on the fauna. Total plant biomass, a variable that includes *Zostera* biomass, was also consistently correlated with faunal variables; however, in all cases other than faunal density at subtidal depths, plant biomass was less highly correlated than *Zostera* biomass, so plants other than *Zostera* contributed little to the correlation.

Table 3.19. Spearman rank correlation coefficients relating four faunal variables (number of species, density, estimated biomass and estimated productivity) to eleven physical factors (total plant biomass, *Zostera* biomass, shore gradient, tidal range, salinity, estuarine area, latitude, longitude, percent silt/clay content of sediments, human population density, percent cleared land) at each of five tidal levels. Correlation coefficients <0.25 are not shown to emphasise more important results.

Variable	*Plant*	*Zostera*	*Gradient*	*Tide*	*Salinity*	*Est. Are*	*Lat.*	*Long.*	*Silt/clay*	*Pop.*	*Cleared*
					gh water						
Species number	.	.	.	.	.	.	.	.	.	.	0.31
Density	.	.	.	.	.	.	.	.	.	.	.
Biomass	.	.	.	.	.	-0.3	.	.	0.31	.	.
Productivity	.	.	.	.	.	-0.29	.	.	0.31	.	.
					an wate						
Species number	0.26	0.26	0.26	.	0.31	.	.	.	.	-0.29	.
Density	0.27	0.27	0.27	.	.	.	.	.	.	-0.33	.
Biomass	.	.	.	0.37	0.32	.	0.27	.	.	.	0.29
Productivity	.	.	.	0.33	0.32	.	0.28	.	.	.	0.26
					w water						
Species number	0.49	0.59	0.34	.	0.54	.	.	.	.	.	.
Density	0.56	0.53	.	.	0.27	.	.	.	.	.	.
Biomass	.	0.35	0.38	0.51	0.43	.	.	.	.	.	0.27
Productivity	.	0.39	0.37	0.47	0.43	.	.	.	.	.	0.29
					3m dept						
Species number	0.44	0.54	.	.	0.53	.	.	0.3	.	.	.
Density	0.53	0.42	.	-0.28	.	.	.	0.27	.	-0.25	.
Biomass	.	0.47	0.27	0.31	0.56	.	.	.	.	.	.
Productivity	0.29	0.5	.	.	0.51	.	.	.	.	.	.
					7m dept						
Species number	0.47	0.59	0.45	.	0.59	0.31	.	0.4	.	.	.
Density	0.71	0.4	.	.	.	.	.	.	.	.	.
Biomass	0.32	0.59	0.27	.	0.62	.	.	0.3	.	.	.
Productivity	0.48	0.61	0.29	.	0.55	.	.	0.36	.	.	.

Several other physical variables occasionally produced high correlations with particular faunal variables at particular depths. The shore gradient was highly correlated (r_S = 0.45) with number of species at 0.7 m depth, tidal range was highly correlated with estimated biomass (r_S = 0.51) and production (r_S = 0.47) at LWM, and longitude was highly correlated with species richness at 0.7 m depth (r_S = 0.40).

Examination of box plots for relationships involving faunal density, faunal productivity, faunal biomass, *Zostera* biomass, plant biomass and estuary area revealed curvilinear relationships and heterogeneous variances in many cases. These distortions from linearity and homoscedasticity were corrected by log transformation for regression analysis.

Results of stepwise regression analysis relating biological to physical variables indicated consistent responses between variables at LWM, 0.3 m and 0.7 m depth (Table 3.20). Number of species was almost equally affected by the salinity of sites and the biomass of plant material (particularly *Zostera*), with these variables together explaining about half of all variance. The density of animals in samples was primarily affected by the biomass of plant material, which explained between 21% and 41% of total variance. Faunal biomass and productivity were primarily affected by salinity (˜25% of total variance), with a variety of other factors (tide, plant biomass, land clearance and shore gradient) explaining lesser amounts of the total variance.

Table 3.20. Stepwise regression equations relating the faunal variables total number of species, log density (/m^2), log estimated biomass (g.m^{-2}) and log estimated productivity (mg.m^{-2}.d^{-1}) to the physical factors log total plant biomass (plant; g.m^{-2}), log *Zostera* biomass (zostera; g.m^{-2}), shore gradient (gradient), tidal range (tide; m), salinity (‰), log estuarine area (ea; m^2), latitude, longitude, silt/clay content of sediments (silt; %), human population density (/km^2), cleared land (clear; %) at each of five tidal levels. Physical variables were only included in the equation if they explained >5% of total variance. Total variance for the regression equation and number of sites examined are also listed. Variance explained when each variable is added to the regression is shown in parenthesis after variable name.

Variate	*Regression equation*	r^2	*n*
	High water mark		
Species number	7.04+0.37*silt (26)	0.258	35
Density	none		
Biomass	2.60+0.11*silt(15)	0.146	35
Productivity	-0.03+0.13*silt(18)-0.187*ea(6)	0.240	35
	Mean water		
Species number	12.90+0.30*sal(11)	0.107	56
Density	3.75+0.02*grad(7)+0.42*silt(12)	0.192	42
Biomass	3.00+1.01*tide(10)+0.020*grad(9)	0.189	56
Productivity	-0.09+1.31*tide(12)+0.024*grad(10)	0.217	56
	Low water mark		
Species number	15.09+9.21*zost(49)+0.34*sal(8)	0.571	52
Density	5.17+0.58*plant(25)	0.254	52
Biomass	2.92+0.05*sal(18)+1.09*tide(22)+0.010*grad(7)	0.464	52
Productivity	0.09+0.06*sal(18)+1.39*tide(23)+0.013*grad(8)	0.490	52
	0.3 m depth		
Species number	12.70+0.64*sal(24)+4.67*plant(20)	0.437	58
Density	5.29+0.37*plant(21)	0.213	58
Biomass	4.45+0.06*sal(26)	0.258	51
Productivity	1.06+0.10*sal(30)+0.03*clear(9)	0.389	58
	0.7 m depth		
Species number	6.34+0.89*sal(26)+5.44*plant(23)	0.485	55
Density	4.58+0.43*plant(41)+0.005*grad(6)+0.025*silt(9)	0.557	39
Biomass	4.06+0.05*sal(28)+0.31*plant(24)	0.518	54
Productivity	1.84+0.06*sal(34)+0.42*zost(16)	0.498	54

Relationships between biological and physical variables at high water mark and mean water were relatively weak and patterns differed between tidal levels. The only important relationship identified at these tidal heights was between the number of species and the silt/clay fraction of sediments at high water mark (r^2 = 0.26). Species richness at high water mark was considerably higher at sites with muddy sediments than at sandy beach sites.

3.2.6 Scale of variation in species richness, abundance, biomass and productivity data

Results of the four-factor ANOVAs involving estuary, locality within estuary, transect and tidal height are shown in Table 3.21, with variance components calculated using the model of expected mean squares described in Table 2.8. In contrast to most studies where negative variances are equated with zero (see Snedecor & Cochran, 1967), negative variances are included in the table because they have value in indicating the scale of errors. Errors associated with estimates of variance increase with spatial scale because of the dependence of calculations on results for lower scales (Underwood & Petraitis, 1991). Estimates of variance associated with locality and estuary therefore should be treated with greatest caution.

The number of species collected in samples possessed variances that were approximately evenly distributed between all spatial scales in the five estuaries examined. Variance in density of animals was similar at replicate, transect and tidal height scales, but was almost three times as high at the locality scale and was much lower at the estuary scale. Biomass and productivity varied primarily at the estuary and replicate scales, with relatively low variance at the transect height and locality scales. These results imply that, at least for the five estuaries investigated, the biomass and production of macrofauna in estuaries were largely a function of characteristics of the estuary, while abundance and species richness were largely affected by local site characteristics and position in estuary.

Table 3.21. Results of four-factor ANOVAs (estuary, site nested within estuary, transect nested within site, tidal height) explaining number of species, number of individuals (ln (x+1) transformed), estimated biomass (ln (x+0.01) transformed) and estimated productivity (ln (x+0.1) transformed) of benthic samples. Sum of squares, mean squares and estimated variance are shown for each variable.

Source	*df*	*Species*			*Density*			*Biomass*			*Production*		
		SS	*MS*	σ^2	*SS*	*MS*	σ^2	*SS*	*MS*	σ^2	*SS*	*MS*	σ^2
Estuary	4	996.9	249.2	3.73	100.1	25.0	0.16	129.0	32.3	0.82	119.5	29.9	0.77
Locality	5	575.0	115.0	4.6	97.0	19.4	0.96	13.7	2.7	0.04	10.1	2.0	0.02
Transect	20	644.0	32.2	4.57	43.2	2.2	0.31	39.3	2.0	0.18	32.0	1.6	0.18
Height	2	879.7	439.9	5.76	38.3	19.1	0.26	41.8	20.9	0.24	36.7	18.3	0.22
E*H	8	756.2	94.5	4.25	28.8	3.6	-0.06	50.9	6.4	0.19	41.0	5.1	0.12
L*H	10	435.7	43.6	5.39	42.7	4.3	0.49	41.2	4.1	0.47	37.3	3.7	0.48
T*H	40	450.3	11.3	3.25	52.2	1.3	0.51	52.9	1.3	0.23	34.8	0.9	0.16
Error	90	427.5	4.8	4.75	25.6	0.3	0.28	78.4	0.9	0.87	49.1	0.5	0.55

The three factor ANOVA involving site, transect and height differed from the previous analysis primarily in showing that variation in species richness was much greater between sites over the larger range of sites used in this analysis (Table 3.22). Variance was again much greater at the scale of site and estuary than at the scale of replicate for density data but not for biomass or production data, indicating considerable patchiness between biomass but not density of samples at the scale of ≈1 metre.

Table 3.22. Results of three-factor ANOVAs (site, transect nested within site, tidal height) explaining number of species, number of individuals (ln (x+1) transformed), estimated biomass (ln (x+0.01) transformed) and estimated productivity (ln (x+0.1) transformed) of benthic samples. Sum of squares, mean squares and estimated variance are shown for each parameter.

Source	*df*	*Species*			*Density*			*Biomass*			*Production*		
		SS	*MS*	σ^2	*SS*	*MS*	σ^2	*SS*	*MS*	σ^2	*SS*	*MS*	σ^2
Site (S)	24	3883	161.8	8.12	398.6	16.6	0.81	407.7	17.0	0.82	315.8	13.2	0.63
Transect (T)	50	781	15.6	2.07	105.1	2.1	0.30	110.1	2.2	0.23	94.2	1.9	0.23
Height (H)	2	2219	1109.4	7.09	136.6	68.3	0.43	119.6	59.8	0.37	107.8	53.9	0.34
S*H	48	2210	46.0	7.14	173.1	3.6	0.55	219.2	4.6	0.62	164.4	3.4	0.49
T*H	100	846	8.5	2.63	121.7	1.2	0.47	109.7	1.1	0.14	89.7	0.9	0.19
Error	225	722	3.2	3.21	62.9	0.3	0.28	184.8	0.8	0.82	114.7	0.5	0.51

Estimates of variance components in the four-factor ANOVA involving sites, transects nested within sites, month nested within site and tidal height are shown in Table 3.23. These estimates may include considerable error because of the complicated mixture of fixed and random factors incorporated in the model. The presence of errors was evident in that 7 of the 32 variance estimates were negative, a contrast with the two previously described models which generated only one negative value amongst 56 variance estimates.

Between month variance was negligible for animal density at sites sampled on two occasions (Table 3.23). Between month variance was also extremely low for species richness, but moderately high for estimated biomass and estimated production data. Most of the variation in animal density was attributable to site, with variance between tidal heights also important. Species richness primarily varied with tidal height, while biomass and productivity of samples showed greatest variance at the replicate, tidal height and site scales.

Table 3.23. Results of four-factor ANOVAs (site, transect nested within site, month nested within transect, tidal height) explaining number of species, number of individuals (ln (x+1) transformed), estimated biomass (ln (x+0.01) transformed) and estimated productivity (ln (x+0.1) transformed) of benthic samples. Sum of squares, mean squares and estimated variance are shown for each parameter.

Source	*df*	*Species*			*Density*			*Biomass*			*Productivity*		
		SS	*MS*	σ^2	*SS*	*MS*	σ^2	*SS*	*MS*	σ^2	*SS*	*MS*	σ^2
Site (S)	2	75.3	37.6	1.15	43.3	21.6	0.83	51.8	25.9	1.05	20.8	10.4	0.40
Transect (T)	6	60.3	10.0	0.75	10.8	1.8	0.16	4.3	0.7	-0.39	4.6	0.8	-0.22
Month (M)	9	36.1	4.0	0.26	4.3	0.5	0.05	34.5	3.8	0.84	23.1	2.6	0.55
Height (H)	1	351.1	351.1	9.33	18.7	18.7	0.49	49.4	49.4	0.98	37.7	37.7	0.78
S*H	2	30.6	15.3	1.16	1.8	0.9	-0.02	28.3	14.1	0.88	19.5	9.7	0.58
T*H	6	8.4	1.4	-1.06	6.8	1.1	0.18	21.1	3.5	0.32	16.4	2.7	0.28
M*H	9	50.6	5.6	1.32	3.8	0.4	0.06	20.2	2.2	0.89	14.4	1.6	0.62
ERROR	36	107.5	3.0	2.99	10.4	0.3	0.29	17.0	0.5	0.47	12.9	0.4	0.36

Estimates of the variance of the major spatial and temporal components affecting the species richness, abundance, biomass and productivity of benthic samples are summarised in Table 3.24. Error associated with these estimates decreases with increasing degrees of freedom, hence the three factor ANOVA involving 25 sites provides substantially better estimates of overall variance than other models.

Table 3.24. Ratios of variance estimates to residual estimates for main treatment effects in the three ANOVA models described in Tables 1, 2 and 3: ELTH - estuary, locality nested within estuary, transect nested within locality, tidal height; STH - site, transect nested within site, tidal height; STMH - site, transect nested within site, month nested within site, tidal height. #The fixed factor ‘height’ differs between STMH and the other two analyses because the 0.7 m depth level was not included in the STMH analysis.

Source	*ANOVA*	*df*	*Ratio*			
			Species	*Density*	*Biomass*	*Productivity*
Estuary	ELTH	4	0.79	0.57	0.94	1.40
Site (E+L)	STMH	2	0.38	2.85	2.22	1.12
Site (E+L)	STH	24	2.53	2.89	1.00	1.24

Locality	ELTH	5	0.97	3.43	0.05	0.05
Transect	STMH	6	0.25	0.57	-0.83	-0.62
Transect	ELTH	20	0.96	1.11	0.21	0.33
Transect	STH	50	0.64	1.07	0.28	0.45
Height[#]	STMH	1	3.12	1.70	2.07	2.17
Height	ELTH	2	1.21	0.93	0.28	0.40
Height	STH	2	2.21	1.54	0.45	0.67
Error	STMH	36	1.00	1.00	1.00	1.00
Error	ELTH	90	1.00	1.00	1.00	1.00
Error	STH	225	1.00	1.00	1.00	1.00
Month	STMH	9	0.09	0.16	1.77	1.54

Temporal variance, which includes variation from hourly to seasonal scales, was extremely low compared to spatial variance for species richness and faunal density. The major source of variation in species richness was tidal height followed by site (including both within and between estuaries components). Variance between transects was lower than variance between samples in all three models tested, and variance between months of sampling was very low.

Variance in mean density was primarily evident at the site and location scales. Variance between transects set ˜100 m distance apart was similar to variance between individual replicates placed ˜1 m apart, and also to mean variance up the transect between tidal heights ˜10 m apart.

Variance in log biomass and log productivity were relatively high between replicates in comparison to variance between transects, while variance between localities within the three estuaries examined was low. Variance between estuaries was relatively high.

3.2.7 Distribution of common taxa by tidal height and salinity

The Tasmanian estuarine fauna is dominated by gastropod, bivalve, amphipod, polychaete and isopod species (Table 3.25; Appendix 9). The most abundant invertebrate species collected was an amphipod, *Paracorophium* cf *excavatum,* and the most widespread species was a bivalve *Arthritica semen*. The other five of the seven commonest species were all gastropods.

Table 3.25. The total abundance of common invertebrate species (>200 specimens collected) at different tidal levels, and the number of sites at which they were recorded.

Code	*Species*	*Taxon*	*HWM*	*MW*	*LWM*	*-0.3m*	*-0.7m*	*Total*	*Sites*
CA11	*Paracorophium cf excavatum*	Amphipod	112	613	2870	5600	3428	12623	40
MG06	*Ascorhis victoriae*	Gastropod	5	1238	1841	3413	5587	12084	25
MP03	*Arthritica semen*	Bivalve	337	2545	2693	3716	2171	11462	45
MG08	*Hydrococcus brazieri*	Gastropod	39	2350	3707	2128	799	9023	16
MG01	*Tatea huonensis*	Gastropod	2	1577	32	1526	2996	6133	10
MG21	*Tatea rufilabrus*	Gastropod	2	696	221	2330	2221	5470	15
MG05	*Eubittium lawleyanum*	Gastropod	4	765	2140	1764	16	4689	12
CI01	*Actaecia bipleura*	Isopod	3100	213	30	4	7	3354	36
MP09	*Mysella donaciformis*	Bivalve	3	128	659	771	1257	2818	24
WP33	*Boccardiella* sp.	Polychaete	2	210	410	974	420	2016	24
WP05	*Simplisetia aequisetis*	Polychaete	21	330	278	750	265	1644	14
MP19	*Cyamiomacra mactroides*	Bivalve	1	57	437	742	360	1597	8
AI13	Chironomid spp.	Insect	29	128	156	524	720	1557	32
MP08	*Xenostrobus inconstans*	Bivalve	0	102	28	611	651	1392	16
CA12	*Gammaropsis* sp.1	Amphipod	6	150	362	335	534	1387	30
MG14	*Potamopyrgus antipodarum*	Gastropod	2	712	136	142	350	1342	10
MP29	*Paphies cuneata*	Bivalve	0	655	497	109	78	1339	11
WP04	*Perinereis vallata*	Polychaete	43	421	394	194	208	1260	18
WP36	*Magelona* sp.	Polychaete	13	33	312	598	295	1251	22
CA09	*?Exoediceroides* sp.	Amphipod	5	168	365	519	126	1183	4
WP53	*Capitella* sp.2	Polychaete	14	74	317	547	207	1159	14
WP41	*Nephtys australiensis*	Polychaete	12	118	265	362	315	1072	37
CA01	*Paracalliope australis*	Amphipod	21	109	234	271	387	1022	17
MG03	*Salinator fragilis*	Gastropod	99	570	169	70	34	942	33
MP31	?*Mysella* sp.	Bivalve	1	199	222	331	8	761	17
MG02	*Nassarius pauperatus*	Gastropod	0	62	269	253	163	747	31
CA61	*Melita* sp.	Amphipod	3	17	61	194	433	708	17
MG18	*Nassarius burchardi*	Gastropod	0	5	36	234	371	646	14
WP21	*Leitoscoloplos normalis*	Polychaete	7	106	158	196	137	604	38
WP17	*Euzonus* sp.	Polychaete	41	426	79	37	2	585	18
MG19	*Zeacumantus diemenensis*	Gastropod	0	71	257	199	56	583	13
MG25	*Diala suturalis*	Gastropod	10	23	8	358	130	529	6
CB03	*Mictyris platycheles*	Crab	12	308	146	35	6	507	22
WP54	*Heteromastus* sp. MOV 858	Polychaete	18	9	82	79	311	499	27
CA03	*Paracalliope vicinus*	Amphipod	43	44	22	217	154	480	9
CA06	*Exoediceroides ?maculosus*	Amphipod	14	163	158	121	20	476	16
MP01	*Notospisula trigonella*	Bivalve	3	6	186	34	219	448	8
CA10	*Corophium* sp.	Amphipod	0	0	3	299	110	412	6
CI21	*Exosphaeroma* sp.	Isopod	3	141	178	74	14	410	19
CA41	*Urohaustorius halei*	Amphipod	0	110	28	51	200	389	11
CI11	*Pseudolana concinna*	Isopod	6	37	37	206	82	368	13
MP20	*Wallucina assimilis*	Bivalve	3	47	100	91	82	323	8
MP05	*Tellina deltoidalis*	Bivalve	0	4	104	135	72	315	28
MP10	*Katelysia scalarina*	Bivalve	0	35	134	92	11	272	23
CB05	*Amarinus lacustris*	Crab	0	7	27	109	121	264	16
MP12	*Anapella cycladea*	Bivalve	2	250	2	2	0	256	10
WP15	*Syllides* sp.	Polychaete	2	12	44	125	52	235	3
CA13	*Gammaropsis* sp.2	Amphipod	1	3	6	135	88	233	5
CA02	*Exoediceroides latrans*	Amphipod	1	11	213	8	0	233	8
CB02	*Paragrapsus gaimardii*	Crab	10	19	73	65	64	231	27
MG12	*Pseudoliotia micans*	Gastropod	0	0	3	63	144	210	6
WP19	*Leitoscoloplos latibranchus*	Polychaete	0	2	60	76	72	210	2
WP98	*Olganereis edmonsi*	Polychaete	0	26	90	64	24	204	10

Table 3.26. The mean abundance of common invertebrate species (>200 specimens collected) at sites grouped by salinity regime.

Code	*Species*	*Taxon*	*Habitat*	*Salinity (‰)*					
				<5	*5-15*	*15-25*	*25-33*	*33-37*	*>37*
CA11	*Paracorophium cf excavatum*	Amphipod	Estuarine	427	260	304	133	18	59
MG06	*Ascorhis victoriae*	Gastropod	Estuarine	292	106	485	193	27	0
MP03	*Arthritica semen*	Bivalve	Estuarine	172	85	523	183	79	0
MG08	*Hydrococcus brazieri*	Gastropod	Marine	0	0	7	173	515	11
MG01	*Tatea huonensis*	Gastropod	Estuarine	416	49	100	0	1	0
MG21	*Tatea rufilabrus*	Gastropod	Estuarine	43	307	159	1	1	0
MG05	*Eubittium lawleyanum*	Gastropod	Marine	0	0	0	37	323	0
CI01	*Actaecia bipleura*	Isopod	Estuarine	43	50	89	93	15	41
MP09	*Mysella donaciformis*	Bivalve	Marine	0	26	2	29	164	0
WP33	*Boccardiella* sp.	Polychaete	Estuarine	38	45	65	33	1	0
WP05	*Simplisetia aequisetis*	Polychaete	Estuarine	10	2	41	41	13	399
MP19	*Cyamiomacra mactroides*	Bivalve	Marine	0	0	0	16	107	0
AI13	Chironomid spp.	Insect	Estuarine	74	12	22	17	12	17
MP08	*Xenostrobus inconstans*	Bivalve	Estuarine	2	114	5	3	2	0
CA12	*Gammaropsis* sp.1	Amphipod	Estuarine	80	6	29	9	4	0
MG14	*Potamopyrgus antipodarum*	Gastropod	Fresh	81	40	1	0	0	0
MP29	*Paphies cuneata*	Bivalve	Marine	0	3	28	0	79	0
WP04	*Perinereis vallata*	Polychaete	Marine	0	0	48	21	39	0
WP36	*Magelona* sp.	Polychaete	Estuarine	0	38	8	55	3	0
CA09	*?Exoediceroides* sp.	Amphipod	Fresh	43	64	0	0	0	0
WP53	*Capitella* sp.2	Polychaete	Marine	0	0	30	3	21	558
WP41	*Nephtys australiensis*	Polychaete	Estuarine	6	14	25	26	20	0
CA01	*Paracalliope australis*	Amphipod	Estuarine	3	4	92	2	0	0
MG03	*Salinator fragilis*	Gastropod	Marine	0	3	43	9	26	23
MP31	?*Mysella* sp.	Bivalve	Marine	0	1	0	4	53	0
MG02	*Nassarius pauperatus*	Gastropod	Marine	0	3	21	13	25	0
CA61	*Melita* sp.	Amphipod	Estuarine	19	10	29	7	0	0
MG18	*Nassarius burchardi*	Gastropod	Estuarine	0	13	37	10	1	0
WP21	*Leitoscoloplos normalis*	Polychaete	Estuarine	4	6	14	13	14	0
WP17	*Euzonus* sp.	Polychaete	Marine	0	0	3	9	34	0
MG19	*Zeacumantus diemenensis*	Gastropod	Marine	0	0	0	4	41	0
MG25	*Diala suturalis*	Gastropod	Marine	0	0	0	1	39	0
CB03	*Mictyris platycheles*	Crab	Marine	0	0	12	7	23	0
WP54	*Heteromastus* sp. MOV 858	Polychaete	Estuarine	1	10	2	18	10	0
CA03	*Paracalliope vicinus*	Amphipod	Fresh	30	13	0	0	0	0
CA06	*Exoediceroides ?maculosus*	Amphipod	Estuarine	9	18	3	10	1	0
MP01	*Notospisula trigonella*	Bivalve	Estuarine	0	20	0	18	0	0
CA10	*Corophium* sp.	Amphipod	Marine	0	0	0	31	1	0
CI21	*Exosphaeroma* sp.	Isopod	Marine	0	0	8	3	22	0
CA41	*Urohaustorius halei*	Amphipod	Marine	0	0	5	9	17	0
CI11	*Pseudolana concinna*	Isopod	Estuarine	20	1	6	5	2	0
MP20	*Wallucina assimilis*	Bivalve	Marine	0	0	0	3	22	0
MP05	*Tellina deltoidalis*	Bivalve	Estuarine	1	13	3	9	1	0
MP10	*Katelysia scalarina*	Bivalve	Marine	0	5	1	3	14	0
CB05	*Amarinus lacustris*	Crab	Estuarine	3	7	10	4	1	0
MP12	*Anapella cycladea*	Bivalve	Estuarine	0	12	0	1	9	0
WP15	*Syllides* sp.	Polychaete	Marine	0	0	0	0	18	0
CA13	*Gammaropsis* sp.2	Amphipod	Marine	0	0	0	4	14	0
CA02	*Exoediceroides latrans*	Amphipod	Fresh	2	20	0	0	0	0
CB02	*Paragrapsus gaimardii*	Crab	Estuarine	1	4	6	3	5	0
MG12	*Pseudoliotia micans*	Gastropod	Estuarine	0	0	7	10	0	0
WP19	*Leitoscoloplos latibranchus*	Polychaete	Marine	0	0	0	0	16	0
WP98	*Olganereis edmonsi*	Polychaete	Marine	0	0	0	0	15	0

The majority of the 53 most common species were collected in highest numbers subtidally at 0.3 m (20 species) or 0.7 m (14 species) depth. Relatively few common species were most abundant at the mid tide level and only one, *Actaecia bipleura*, was predominantly an inhabitant of the high intertidal (Table 3.25). *Actaecia bipleura* was by far the most important species near the high intertidal mark, comprising 56% of all animals collected at that level.

The mean abundance of common species at sampling sites have been grouped by salinity in Table 3.26. Salinity data used were obtained at low tide at the water surface on the day of benthic sampling. Species were categorised on the basis of these distribution patterns into (i) freshwater species, which predominantly occur at low salinity sites and were not found at marine locations, (ii) estuarine species, which occur widely through a range of salinities and generally peak at sites with intermediate salinity regimes, and (iii) marine species, which predominantly occur at marine locations and are not found in low salinity habitats.

A slightly lower number of common species were categorised as marine rather than estuarine (23 *cf.* 26), while only four species predominantly occurred in the freshwater sections of estuaries. Relatively few marine species were, however, included amongst the extremely abundant species; only four of the 16 most abundant species were marine. The only lagoon with extreme hypersaline conditions sampled (Cameron Inlet) possessed a mixture of species categorised as estuarine and marine.

3.2.8 Geographic patterns

The number of species collected at different sites around the Tasmanian coast was partly dependent on geographical region (Fig. 3.7a). Extremely low species richness was found at sites on the west coast from Kelly Basin to the Arthur River and on King Island. Individual sites along the northern Tasmanian coast and eastern Bass Strait islands possessed variable species richness, ranging from low values in riverine estuaries to extremely high values at Low Head and North East Inlet. A greater total pool of species appeared to be present along the northern coast and Flinders Island, with numerous species restricted to a single site (Fig. 3.7b).

These patterns were most evident in a plot that smooths differences in individual sites by adding species not collected at the site but occurring within five sites in both directions along the coast, and therefore with an overlapping range (Fig. 3.8). The region with greatest number of species is seen in this analysis to extend between the two exceptionally rich sites at Low Head and North East Inlet. The pool of species gradually declines down the east coast to the Huon region, where numbers rise in a local pocket of high species richness that peaks at Cloudy Lagoon. A consistently low number of species is present on the west coast and King Island.

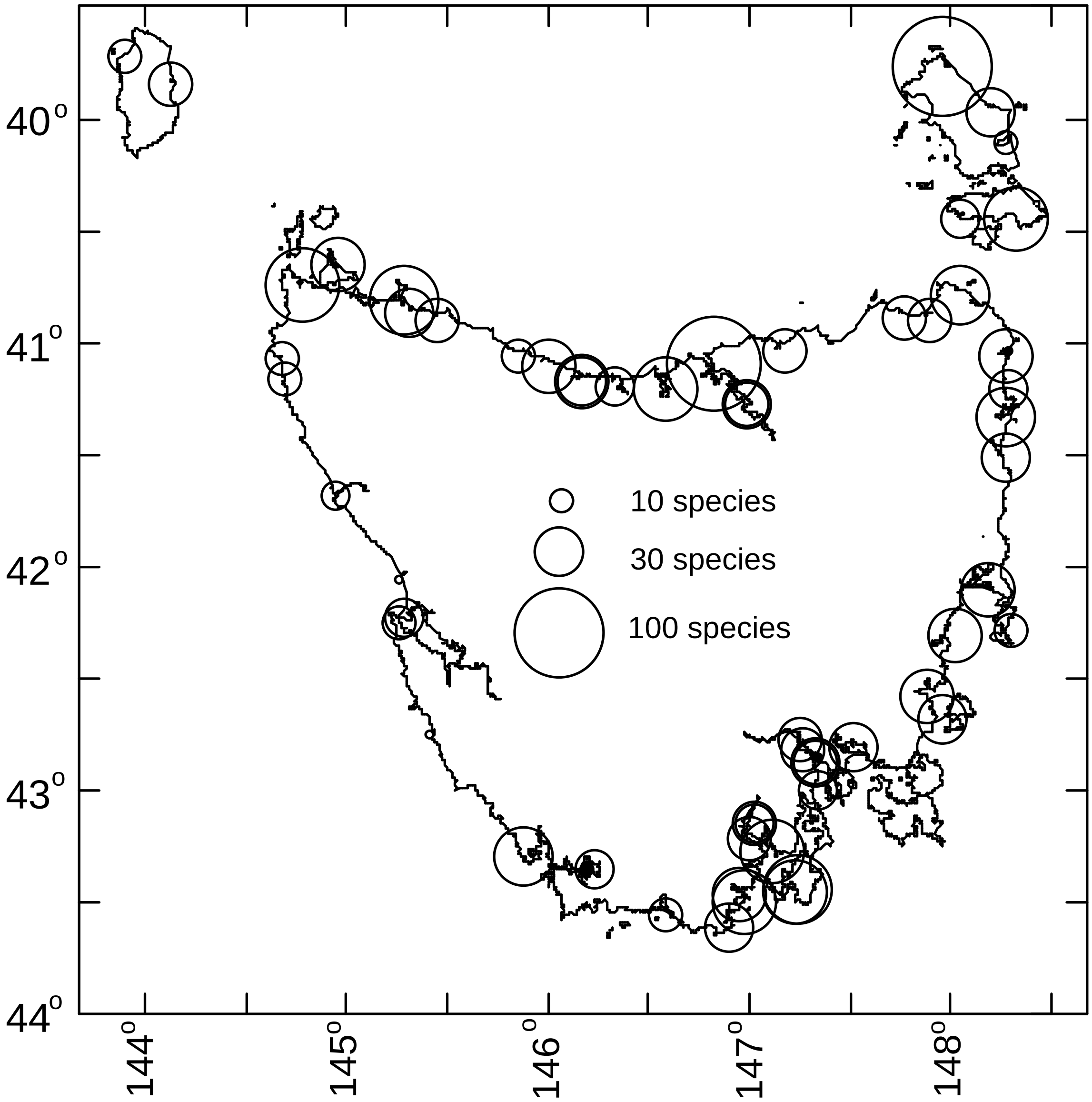

Fig. 3.7a. Total number of macrofaunal species collected at different sites.

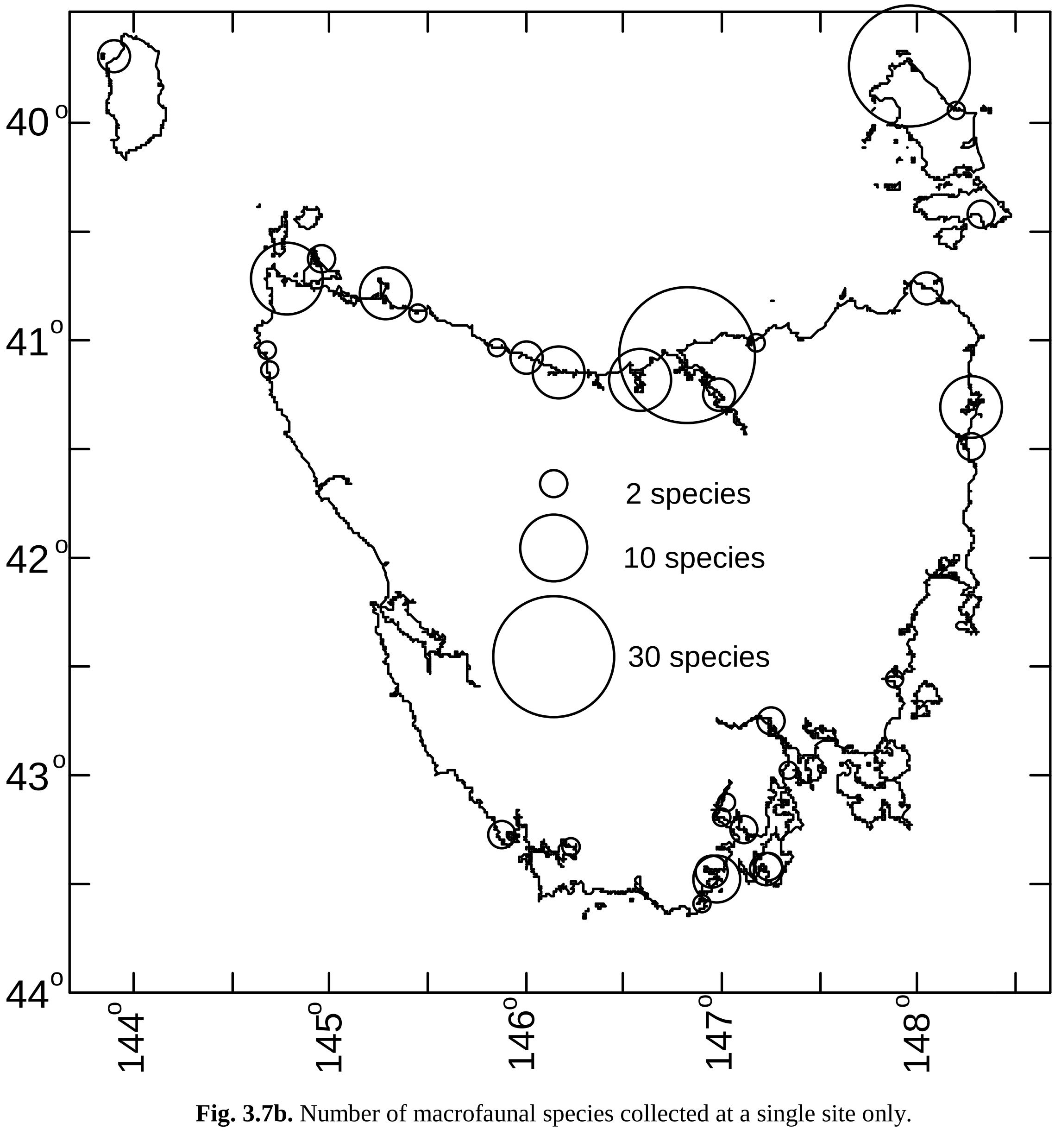

Fig. 3.7b. Number of macrofaunal species collected at a single site only.

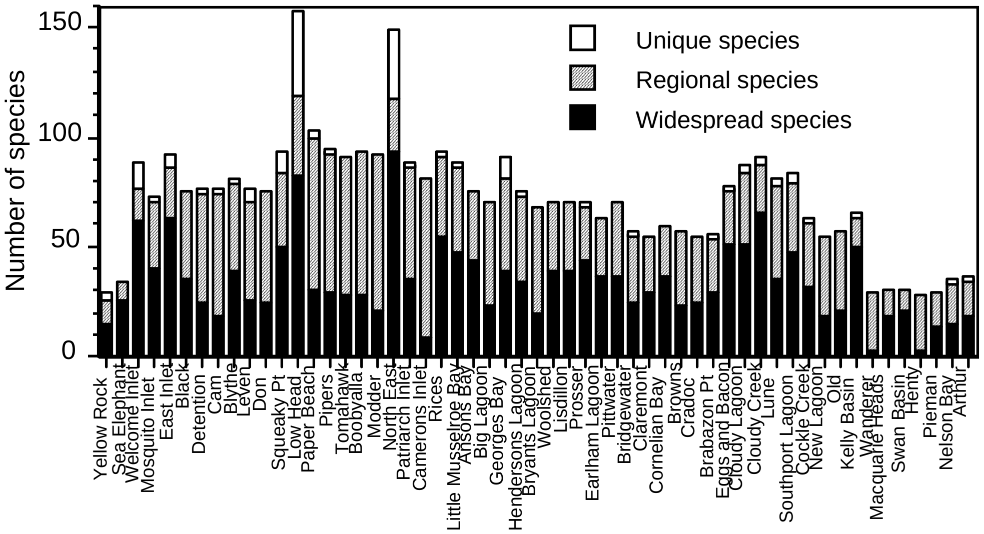

Fig. 3.8. Number of species collected solely at each sample site (unique species), number of species collected that occurred at more than one site (widespread species), and number of species interpolated to occur in the same region because they were present within the five nearest sites in both directions along the coast (regional species). Sites are arranged in geographic order around the coast with King Island inserted between Arthur River and Welcome Inlet and the Furneaux Group of islands inserted between Boobyalla estuary and Little Musselroe Bay.

Similar results were obtained when data on species present at sites in different regions were aggregated. In Table 3.27, data have been pooled from 5 or 6 sites in close proximity, and the total number of species for that regional grouping of sites presented. King Island sites and the Wanderer River were not included in this analysis because of a lack of other sites in their near vicinity.

Table 3.27. Number of estuarine species present in different regions around Tasmania. Species categories are (i) Total species - total number of macrofaunal species collected within the region, (ii) Restricted species - species collected only in that region, (iii) Widespread species - species collected at more than one site, (iv) Regional species - species collected at more than one site and restricted to that region (1), species collected at more than one site and restricted to that region and adjoining region on either side (3), and species collected at more than one site and restricted to that region and group of two adjoining regions on either side (5). The ten regions used here are the west coast (Arthur River to Macquarie Harbour), south coast (Kelly Basin to Lune River), Huon (Cloudy Bay and Huon estuary sites), Derwent (Browns River, Pittwater and Derwent estuary sites), east coast (Earlham Lagoon to Bryans Lagoon), northeast coast (Hendersons Lagoon to Little Musselroe Bay), Furneaux (Flinders Island and Cape Barren Island), eastern north coast (Boobyalla to Tamar estuary), central north coast (Squeaky Point to Cam River) and northwest coast (Detention River to Welcome Inlet).

Category	*West*	*South*	*Huon*	*Derwent*	*East*	*N/East*	*Furneaux*	*E/North*	*C/North*	*N/West*
Total species	41	113	129	88	76	118	159	176	119	142
Restricted species	5	10	12	3	1	14	34	42	21	25
Widespread species	36	103	117	85	75	104	125	134	98	117
Regional species (1)	3	1	1	0	0	0	1	1	2	3
Regional species (3)	11	12	11	4	3	4	19	20	14	9
Regional species (5)	29	25	20	22	20	25	30	53	47	34

Highest species richness was found in this analysis to occur along the north coast and in the Furneaux regions, due largely to the numerous species that occurred only at the North East Inlet and Low Head sites. The pool of species present along the west coast was several times lower than in the north, with relatively few species also collected in the Derwent and east coast regions.

Nearly all species were either collected at a single site (40% of total) or were widely distributed throughout Tasmania. The number of species found at two or more sites within a single region but not in other regions was very low (12 species), with only two such species occurring abundantly. These two species were *?Exoediceroides sp.*, a oedicerotid amphipod that was extremely common (1183 specimens) at four west coast sites (Pieman, Nelson Bay, Henty and Arthur estuaries), and the crab *Heloecius cordiformis* (51 specimens), which was collected at four sites on the north coast from the Blythe estuary to Squeaky Point. *Heloecius cordiformis* has previously been recorded as far down the Tasmanian east coast as the D'Entrecasteaux Channel (Griffin, 1969).

When data from three adjacent regions were aggregated, approximately 25 species were found to be restricted to the northeastern corner of Tasmania and the Furneaux Group, with another group of ≈15 species restricted to the southeastern corner (regional species (3) in Table 3.27). However, the majority of species restricted to three regions were rare (<10 individuals collected), and so were probably widely distributed but not collected elsewhere because of limitations in the sampling program.

A total of 21 estuarine species occurred in sufficiently high numbers to be considered to have restricted ranges in Tasmania (Table 3.28), using the criteria of ten or more individuals collected, presence at more than two sites, presence restricted to four or less adjacent regions, and absence of a gap of two adjacent regions when range extends across four regions. Half of these species occurred only in marine sectors of estuaries and were confined to the Bass Strait coast of Tasmania (Table 3.28), with the remainder possessing ranges centred almost evenly along the eastern, southeastern and western coasts. Most species considered to possess restricted ranges in Tasmania, particularly those in northern regions, have been recorded in southeastern Australia. Only four species listed in Table 3.28 are presently considered to be endemic to Tasmania (?*Exoediceroides* sp., *Paracorophium* sp., Talitrid TA59 and Talitrid TA281), with all possessing western to southeastern Tasmanian distributions.

A total of 20 invertebrate species collected during the study were considered to have extremely localised distributions, in that they were found at only one site and occurred in numbers greater than 10 at that site (Table 3.29). The majority of these species were collected at high salinity locations and were probably vagrant marine species. The three truly estuarine species included (i) the introduced tanaidacean *Sinelobus stanfordi*, which was collected at Cradoc (Huon estuary), (ii) a high intertidal amphipod (Talitrid TA283) which was collected at Nelson Bay and has also been recorded elsewhere on the western Tasmanian coast (A.M.M. Richardson, pers. comm.), and (iii) a sphaeromatid isopod (*Cymodetta gambosa*), which occurs commonly in southeastern Australia but was found only at Bridgewater during the present study.

Table 3.28. Species with restricted ranges, showing distribution, total number of animals collected and number of sites at which collected. Presence of species in a region is indicated by x. Regions are as follows: west coast (W), south coast (S), Huon (H), Derwent (D), east coast (E), northeast coast (NE), Furneaux (F), east north coast (EN), central north coast (CN) and northwest coast (NW).

Species	*W*	*S*	*H*	*D*	*E*	*NE*	*F*	*EN*	*CN*	*NW*	*Number*	*Sites*
Heloecius cordiformis	0	0	0	0	0	0	0	0	x	0	51	4
Paraonid sp.	0	0	0	0	0	0	0	x	x	x	31	3
Sphageris phycodes	0	0	0	0	0	0	0	x	x	x	17	4
Scoloplos novaehollandiae	0	0	0	0	0	0	x	x	0	x	20	4
Paphies cuneata	0	0	0	0	0	0	x	x	x	x	1339	11
Mysid sp.2	0	0	0	0	0	0	x	x	x	x	10	8
Parawaldeckia stebbingi	0	0	0	0	0	0	x	x	0	x	12	3
Birubius maldus	0	0	0	0	0	0	x	x	0	x	21	3
Amaena trilobata	0	0	0	0	0	0	x	0	x	x	39	3
Natatolana woodjonesi	0	0	0	0	0	0	x	0	x	x	32	4
Platynympha longicaudata	0	0	0	0	0	0	x	x	0	0	10	3
Eupolymnia koorangia	0	0	0	0	0	x	x	x	0	0	117	4
Syllides sp.	0	0	0	0	0	x	x	0	0	0	235	3
Orthoprionospio cirriformia	0	0	0	x	x	x	0	0	0	0	146	4
Batillaria australis	0	0	0	x	x	0	0	0	0	0	43	4
Talitrid TA59	0	0	x	x	x	0	0	0	0	0	189	8
Paracorophium sp.	0	x	x	x	x	0	0	0	0	0	111	6
Tatea huonensis	0	x	x	x	0	0	0	0	0	0	6133	10
Talitrid TA281	x	x	0	0	0	0	0	0	0	0	144	3
Oecetis sp.	x	x	0	0	0	0	0	0	0	0	15	3
?*Exoediceroides* sp.	x	0	0	0	0	0	0	0	0	0	1182	4

Table 3.29. Abundance of species with more than 10 individuals collected at a single site only, and salinity of site recorded at time of sampling.

Species	*Site*	*Abundance*	*Salinity (‰)*
Sinelobus stanfordi	Cradoc	49	4.3
Cymodetta gambosa	Bridgewater	25	4.9
Talitrid TA283	Nelson Bay	32	8.3
Capitella sp.1	Cloudy Creek	36	33.4
Cantharidella hisseyana	Southport Lagoon	31	33.9
Birubius panamunus	Southport Lagoon	14	33.9
Neanthes cricognatha	North East Inlet	74	34.5
Diastylid sp.	North East Inlet	16	34.5
Birubius thalmus	North East Inlet	15	34.5
Tellina margaritina	North East Inlet	15	34.5
Edwardsia sp.2	North East Inlet	12	34.5
Maldanid sp.2	North East Inlet	12	34.5
Spirorbid sp.1	Low Head	199	35.0
Parawaldeckia dilkera	Low Head	52	35.0
Aonides oxycephala	Low Head	38	35.0
Zeuxo sp.2	Low Head	16	35.0
Zeuxo sp.1	Low Head	14	35.0
Birubius ?jirandus	Low Head	12	35.0
Maldane sp.	Squeaky Point	14	35.7
Maldanid sp.3	Henderson Lagoon	26	36.0

The abundance of animals at different sites was primarily affected by site characteristics, and showed no consistent geographic patterns (Fig. 3.9). Estimated faunal biomass and productivity also showed considerable local variation between adjacent sites; however, levels were extremely low at all west coast and south coast sites other than Kelly Basin. The seven sites with the lowest estimated biomass and productivity were all located on the west and south coasts.

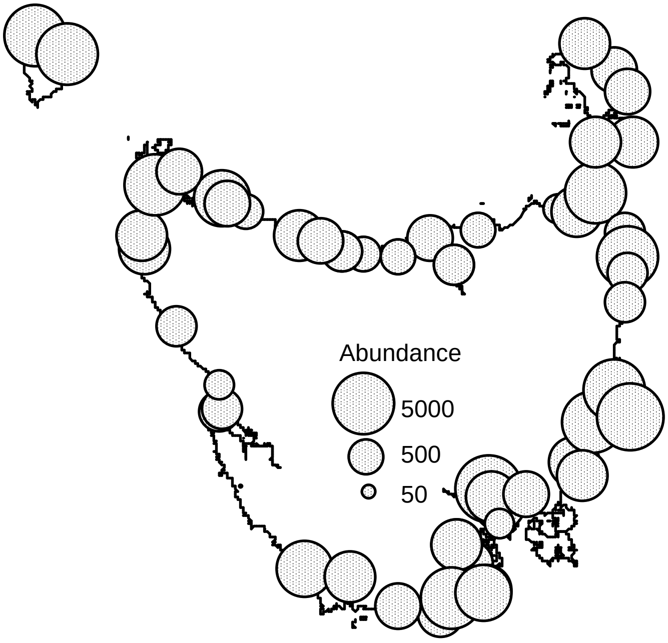

Fig. 3.9a. Total number of animals collected at different sites.

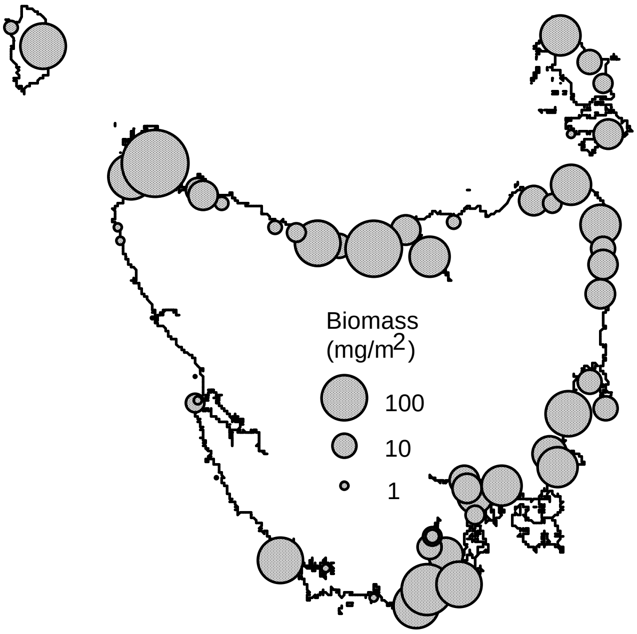

Fig. 3.9b. Mean estimated biomass at different sites of faunas collected between low water mark and 0.7 m depth.

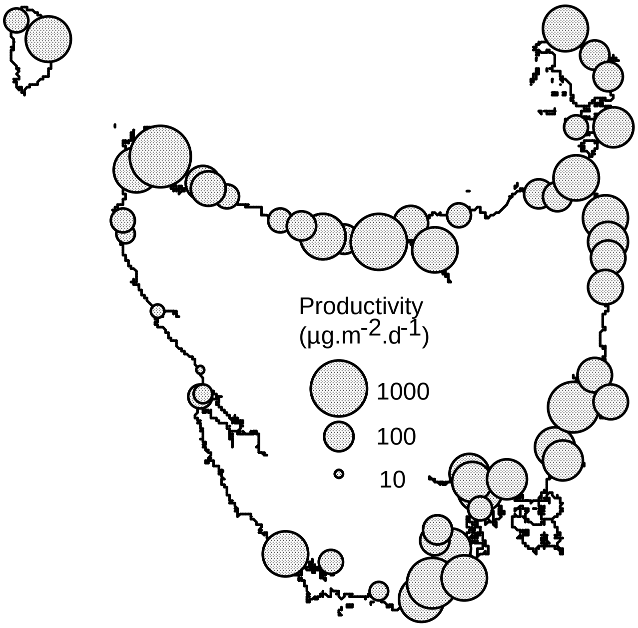

Fig. 3.9c. Mean estimated productivity at different sites of faunas collected between low water mark and 0.7 m depth.

3.2.9 Introduced species

Few introduced species were collected from intertidal or shallow subtidal habitats during the sampling program. The only introduced species identified were the green crab *Carcinus maenas,* the hydrobiid gastropod *Potamopyrgus antipodarum,* the tanaidacean *Sinelobus stanfordi* and the bivalve *Theora lubrica,* while amphipods in the genus *Corophium* that have not yet been fully identified were probably also introduced.

Potamopyrgus antipodarum was collected widely in the freshwater headwaters of estuaries around the state. The green crab was collected in northern areas from Mosquito Inlet in northwest Tasmania to Lisdillon on the central east coast, and at Cameron Inlet on Flinders Island. These records include crabs collected by seine net as well as core. All animals collected at Cameron Inlet appeared moribund at the time of sampling, presumably because of extreme hypersalinity (53‰). The bodies of large numbers of recently-dead crabs were present in shallow water at the time of the visit. *Theora lubrica* was collected only in Georges Bay, but is known to have a wider distribution that includes the Derwent and Tamar estuaries (Furlani, 1996).

3.2.10 Community analyses

Data relating site and total number of each species were analysed using multidimensional scaling (MDS) to provide a graphical display of faunal relationships between sites. In this analysis, the faunal similarity between each pair of sites was calculated using the Bray Curtis similarity coefficient, abundance data were double square root transformed, and rarer species (< 50 individuals collected from all sites) were removed. The stress statistic associated with results was 0.17 for a two-dimensional plot of results and 0.12 for a three- dimensional display. The two dimensional display was thus considered barely adequate while the three-dimensional display, shown in Fig. 3.10, was considered good.

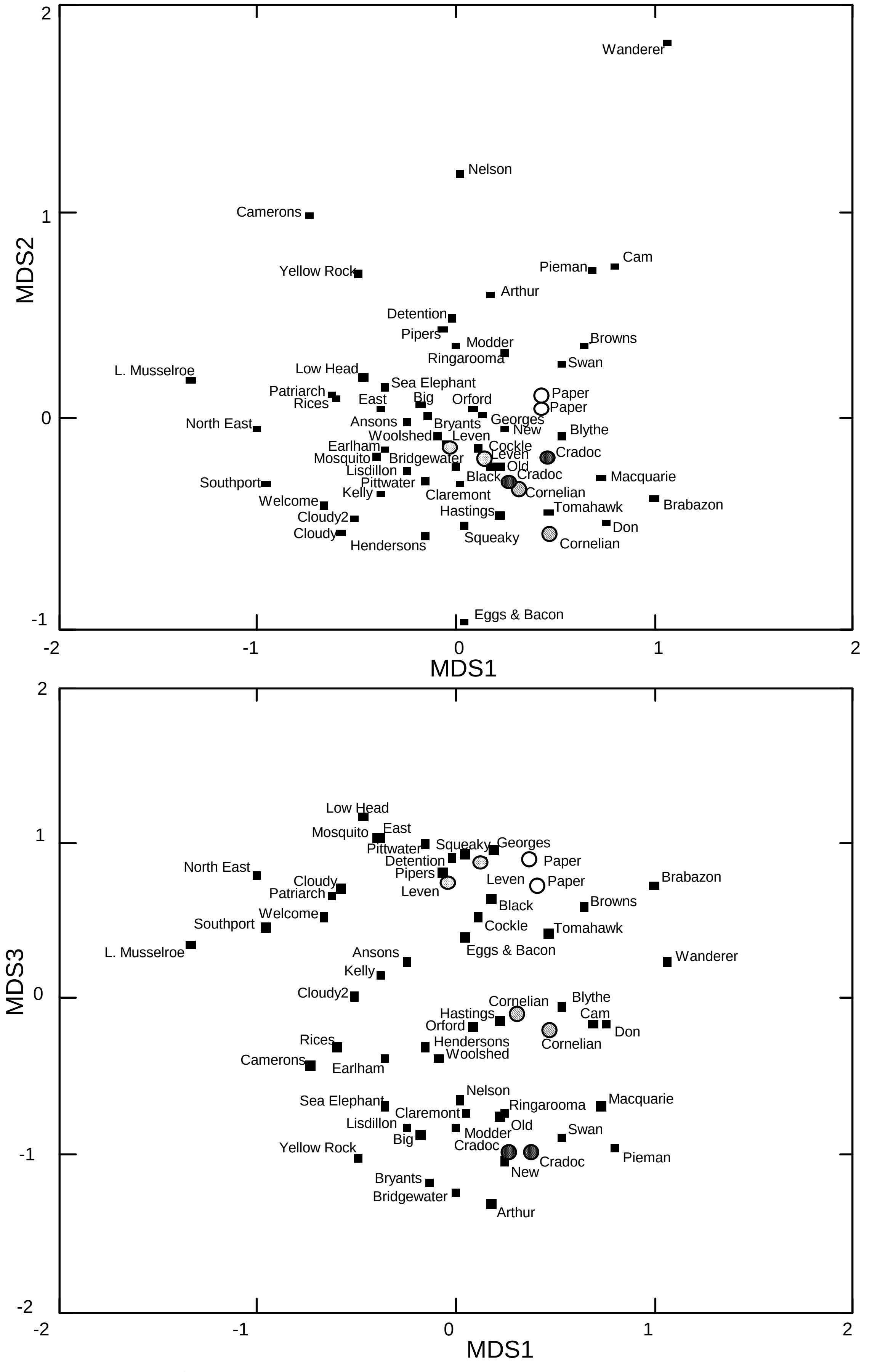

Fig. 3.10. Results of three-dimensional MDS analysis using benthic invertebrate data. The stress-statistic associated with these plots in 0.12.

The west coast Henty site was found to be an extreme outlier in the initial MDS analysis as it possessed very little faunal similarity to any other site. The Henty site was consequently removed from the MDS, with results after the analysis had been rerun shown in Fig. 3.10. Sites did not separate into distinct clusters, as would be expected if coherent assemblages occurred around the state, but generally formed a cloud of points with a high degree of overlap between faunal assemblages. A high level of faunal consistency was found for sites sampled on two occasions. These grouped closely together and in almost all cases showed a higher level of Bray-Curtis similarity with each other than with other sites. Several of the physical variables examined showed clear trends when overlayed on MDS results, with salinity corresponding most obviously with the distribution of different faunal types (Fig. 3.11). The plot of MDS axis 1 included virtually no overlap between faunas associated with high and low salinity environments, while MDS axis 3 showed a slight positive trend and axis 2 showed no clear trend. The only highly hypersaline lagoon sampled (Cameron Inlet) grouped with marine assemblages on axis 1.

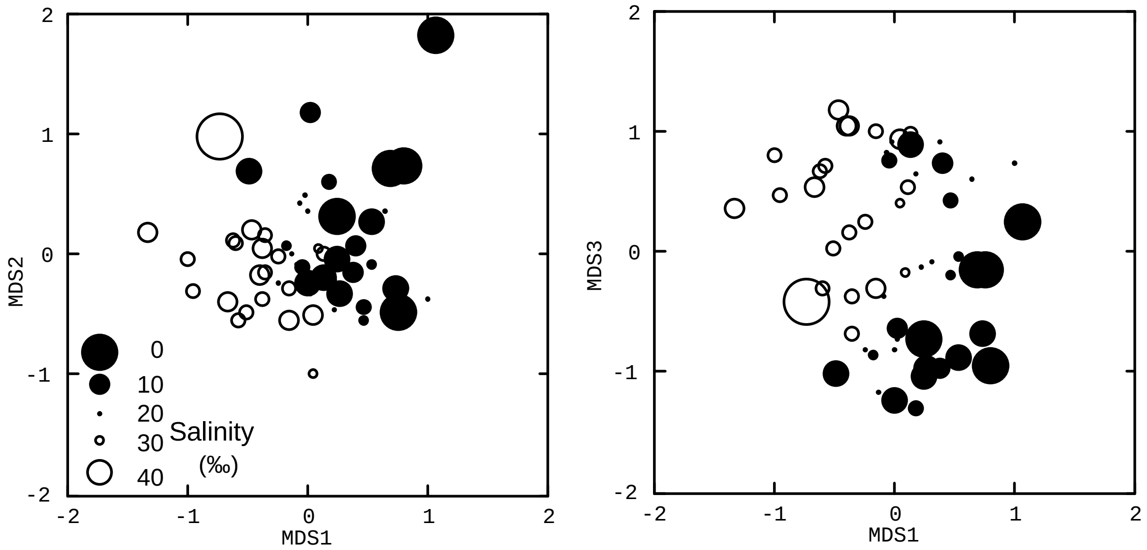

Fig. 3.11. Bubble plot overlay of salinity at time of benthic sampling on MDS results. Sites with high salinities are shown with large open circles while low salinity values are shown by large filled circles.

The relationship between macrofaunal assemblages and total annual runoff was complementary to that found for salinity, presumably because sites in estuaries with high runoff were affected by considerable freshwater outflow. Total annual runoff showed a strong positive association with MDS axis 1 and no clear association with axes 2 or 3 (Fig. 3.12).

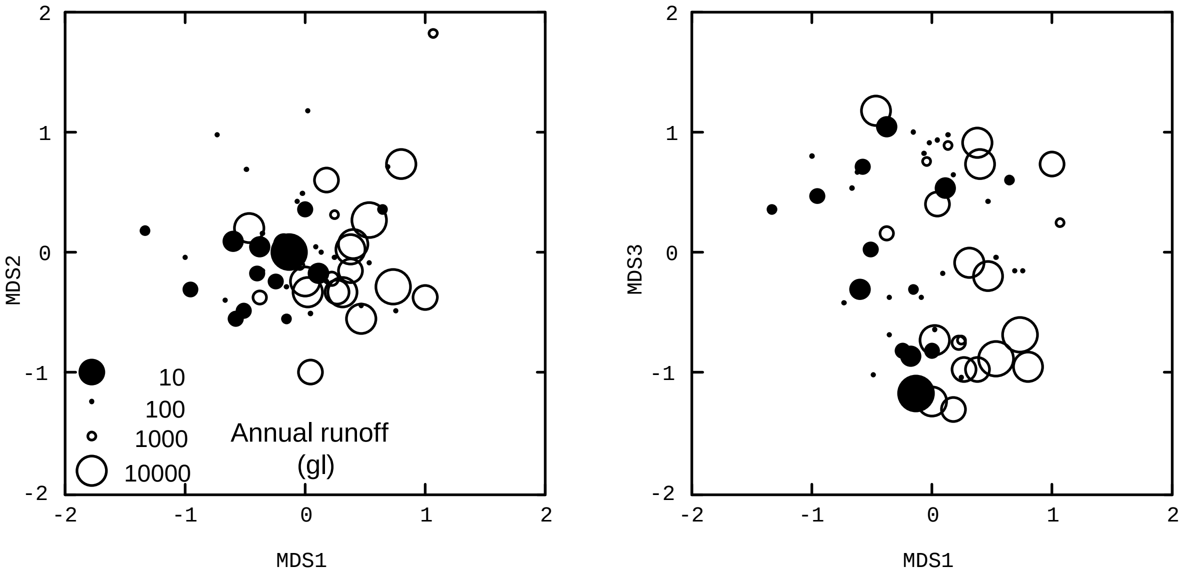

Fig. 3.12. Bubble plot overlay of total annual runoff on MDS results for benthic invertebrate data. Sites with high runoff are shown with large open circles while low runoff values are shown by large filled circles.

Tidal range was also closely associated with the faunal composition of benthic samples. Sites with high tidal ranges possessed macrofaunal assemblages which were strongly positively associated with MDS axis 3 (Fig. 3.13) and slightly positively associated with MDS axis 1. Tidal range had no obvious association with MDS axis 2.

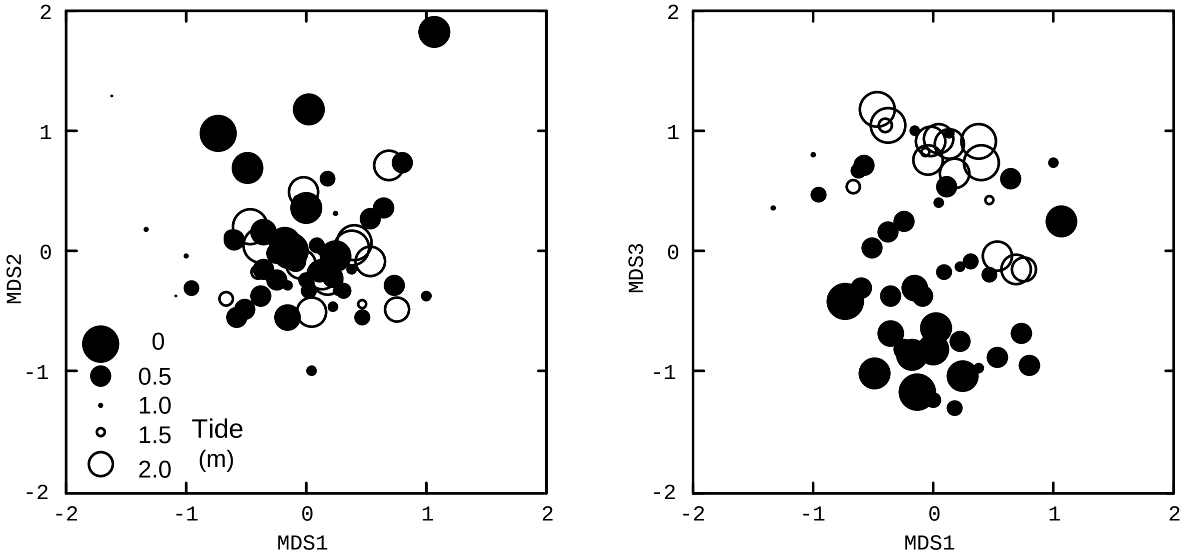

Fig. 3.13. Bubble plot overlay of estimated tidal range on MDS results for benthic invertebrate data. Sites with high tidal range are shown with large open circles while microtidal sites are shown by large filled circles.

Sediment particle size was not strongly associated with the distribution of biota (Fig. 3.14). Sites composed of fine muds often possessed similar faunas to sites with relatively coarse sand sediments.

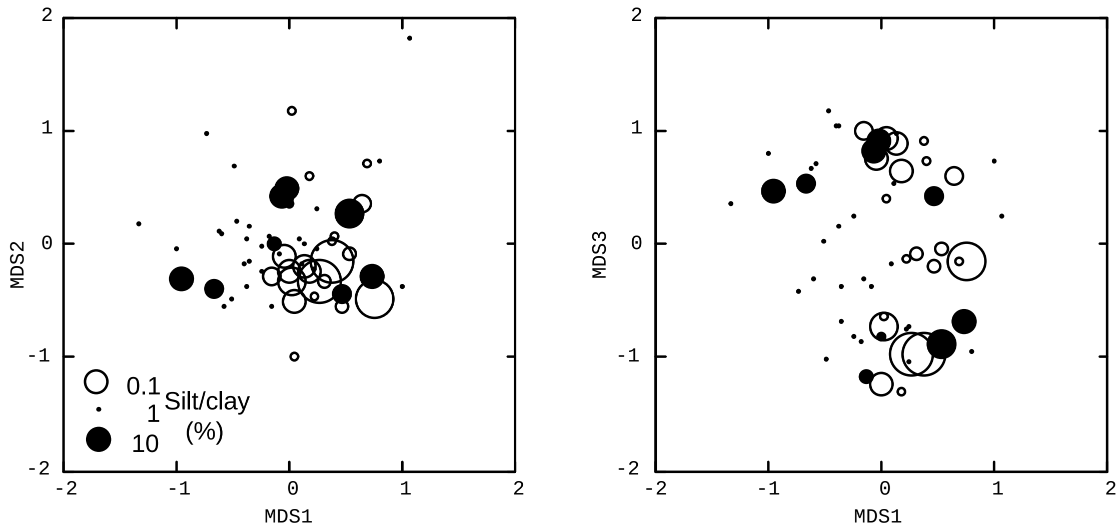

Fig. 3.14. Bubble plot overlay of silt/clay content on MDS results for benthic invertebrate data. Sites with fine muds are shown with large open circles while sandy sites are indicated by filled circles.

Sites in several of the barred estuaries possessed faunas that lay well outside the bounds of assemblages associated with open estuaries (Fig. 3.15). The Wanderer estuary, with its extremely low abundance and species richness, was the most atypical. Other barred estuaries grouped together on the plot of MDS axes 1 and 3, indicating substantial similarities in their faunas.

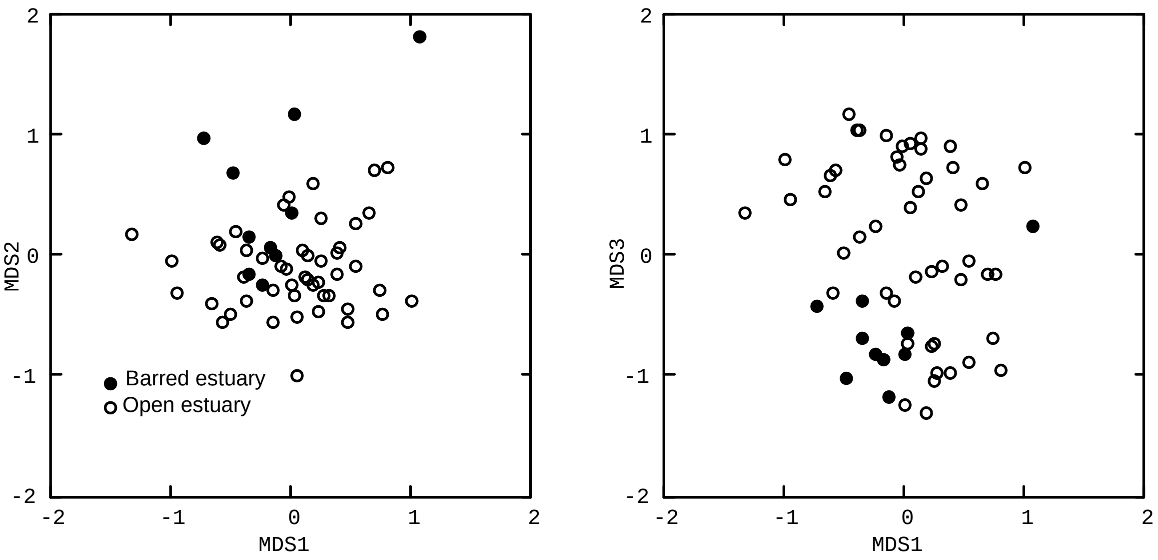

Fig. 3.15. Results of MDS analysis for benthic invertebrate data, showing sites sampled in barred estuaries.

Faunal assemblages showed clear trends with latitude (Fig. 3.16). The separation of northern sites from southern sites was clearly defined on MDS axis 1 and, to a lesser extent, on axis 2.

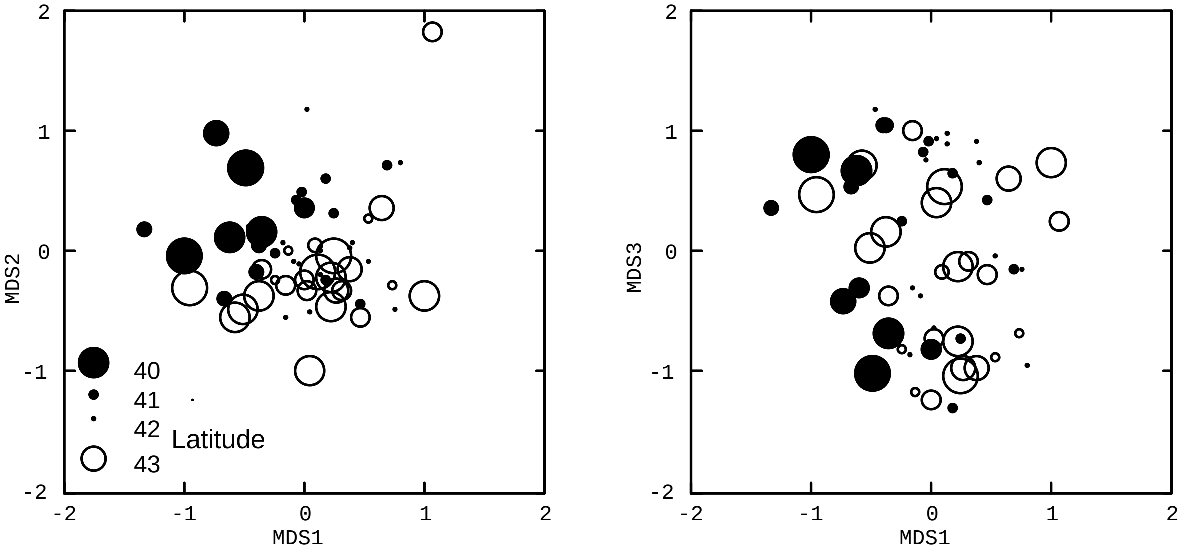

Fig. 3.16. Bubble plot overlay of latitude on MDS results for benthic invertebrate data. Sites at high latitude are shown with large open circles while northern sites are shown by large filled circles.

The biota collected at different estuarine sites was not influenced to any detectable extent by the predominant rock type in the estuarine catchment area (Fig. 3.17). Sites in sandstone regions encompassed the range of biological assemblages collected during the study, while doleritic and granitic areas also included a wide diversity of assemblage types. Analysis of Similarities (ANOSIM) using the five main rock types shown in Fig. 3.17 revealed no significant differences between faunas in areas with different rock types (global r = -0.169, p>0.10).

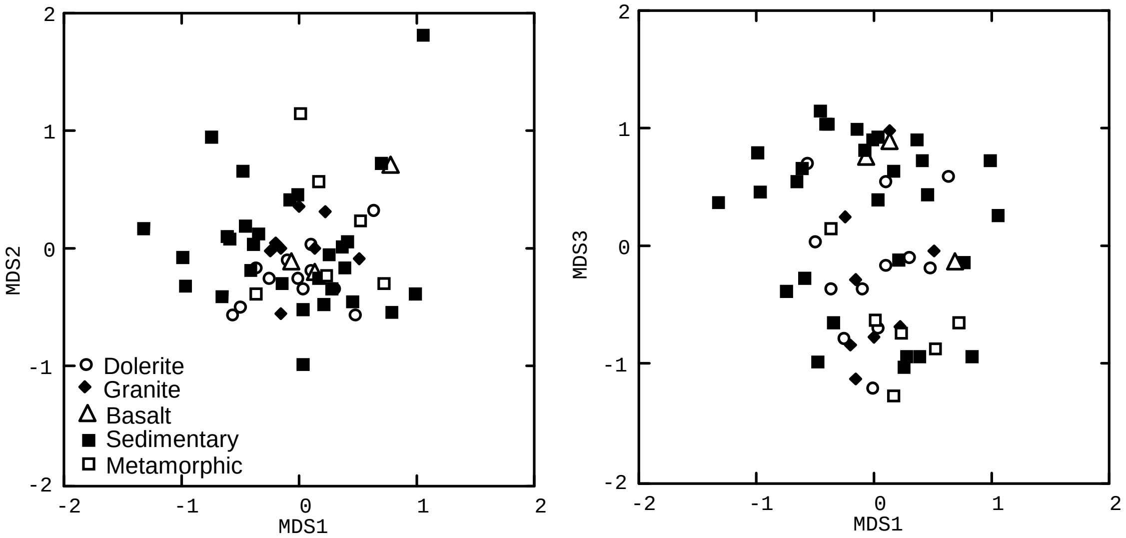

Fig. 3.17. Results of MDS analysis for benthic invertebrate data, showing sites sampled in estuaries with different predominant rock types in catchment areas.

Anthropogenic impacts on macrofaunal assemblages appeared less clearly defined than the impacts of natural physical variables such as salinity and tidal range. The naturalness index NI, as described in Section 2.9, showed no clear association with MDS axes 1, 2 or 3 (Fig. 3.18). Nevertheless, faunas sampled in estuaries with high human population densities grouped consistently in the upper right section of the plot of axes 1 and 3 (Fig. 3.19).

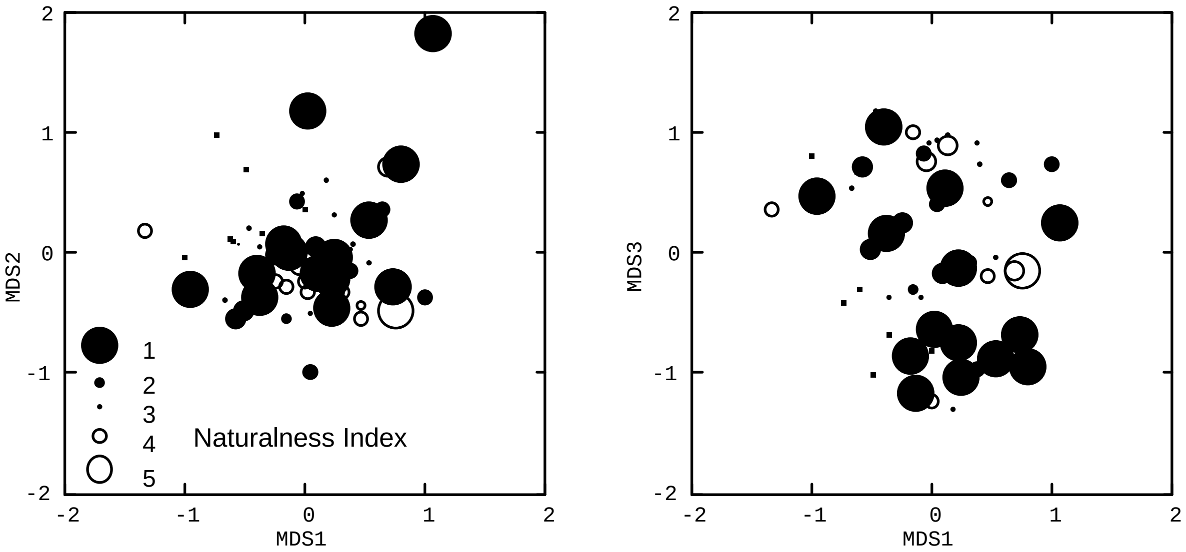

Fig. 3.18. Bubble plot overlay of the naturalness index NI on MDS results for benthic invertebrate data. Sites with high NI values are shown with large open circles while low NI values are shown by large filled circles.

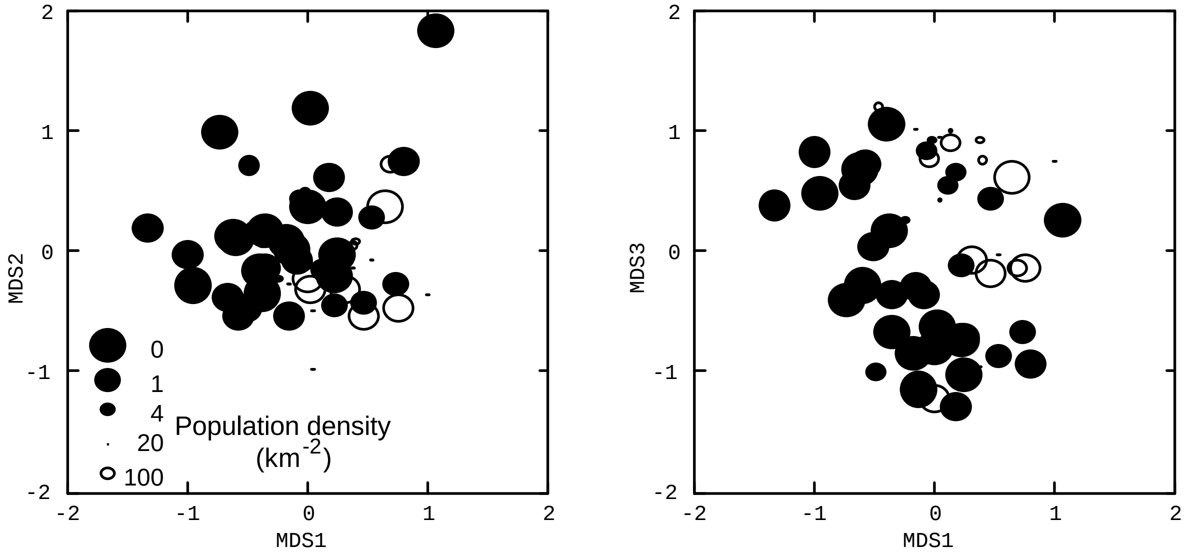

Fig. 3.19. Bubble plot overlay of population density in catchment on MDS results for benthic invertebrate data. Sites with high population densities are shown with large open circles.

In summary, the overlays of physical variables on results of MDS analysis indicate that macrofaunal assemblages were affected by several physical factors. MDS axis 1 was strongly affected by salinity, runoff and latitude of sites, axis 2 was strongly affected by barrier presence, and axis 3 was strongly affected by tidal range. In most cases the patterns displayed by the physical variables were dissimilar to each other, indicating that a complex combination of physical variables was responsible.

Analysis of the macrofaunal data set using BIOENV, a procedure which maximises correlations between biological and physical data sets (Clarke & Ainsworth, 1993), indicated that salinity of site and tidal range together provided the maximum correlation with the faunal similarity matrix ($r_s = 0.34$). Other physical variables examined (i.e., annual runoff, latitude, silt/clay content of sediments, presence of barrier, naturalness index and population density) did not contribute significant additional information towards explaining the distribution of faunal assemblages.

Although salinity of site and tidal range provided the best explanation of the invertebrate data set, this analysis included environmental data collected at site as well as estuary scales. When data relating to summer salinity of surface water in the mid section of the estuary was substituted for salinity of sampling site, the correlation between the faunal data matrix and salinity declined from 0.28 to 0.23. The correlation of site plus tidal range also declined ($r_s = 0.30$), and then was less than the correlation between barrier presence and the invertebrate data matrix ($r_s = 0.32$). At estuary scales, the primary factor affecting macrofauna in estuaries appeared to be presence of a seaward barrier.

The nine estuary groupings identified using physical data have been overlayed on the MDS results in Fig. 3.20. Some groups (particularly the Group I barred low-salinity estuaries) showed a high degree of faunal cohesion, whereas other groups (e.g. Group III marine inlets) were relatively diffuse, indicating that they contained a range of different assemblage types. Overall faunal differences between estuary groups were highly significant (global r = 0.395, $p<0.001$), as assessed using Analysis of Similarities (ANOSIM) (Clarke, 1993).

By comparison, results of ANOSIM using groups categorised solely on geomorphological criteria (viz., drowned river valleys, marine inlets, river estuaries, lagoons, permanently-open barrier estuaries and seasonally-closed barrier estuaries) provided substantially less explanation of the biotic data (global r = 0.290, $p<0.001$). Paired comparison tests indicated that marine inlets and open barrier estuaries both possessed distinctive faunal assemblages that differed significantly in all comparisons, but that none of the four other geomorphological classes differed significantly from each other in fauna. The separation of the marine inlet estuaries and open barrier estuaries reflected higher salinity regimes in these systems.

Three of the groups identified using multivariate physical data, Groups IV, VI and IX, were only sampled at one or two sites, so quantitative assessment of the similarities of these groups with others was not possible. These groups were, however, all outliers in the MDS analysis (Fig. 3.18), so each was considered to comprise a distinctive grouping.

Results of ANOSIMs for paired comparisons between the other six groups are shown in Table 3.30. Groups II and III were broadly overlapping and not found to be significantly different ($p=0.334$) using ANOSIM, with non-significantly different faunas also identified for Groups II and V ($p = 0.167$). The diffuse separation of sites for Groups II, III and V indicated that each group was heterogeneous (see Fig. 3.20) and consisted of a range of different assemblage types. Amalgamation of these three groups into one therefore could not be justified.

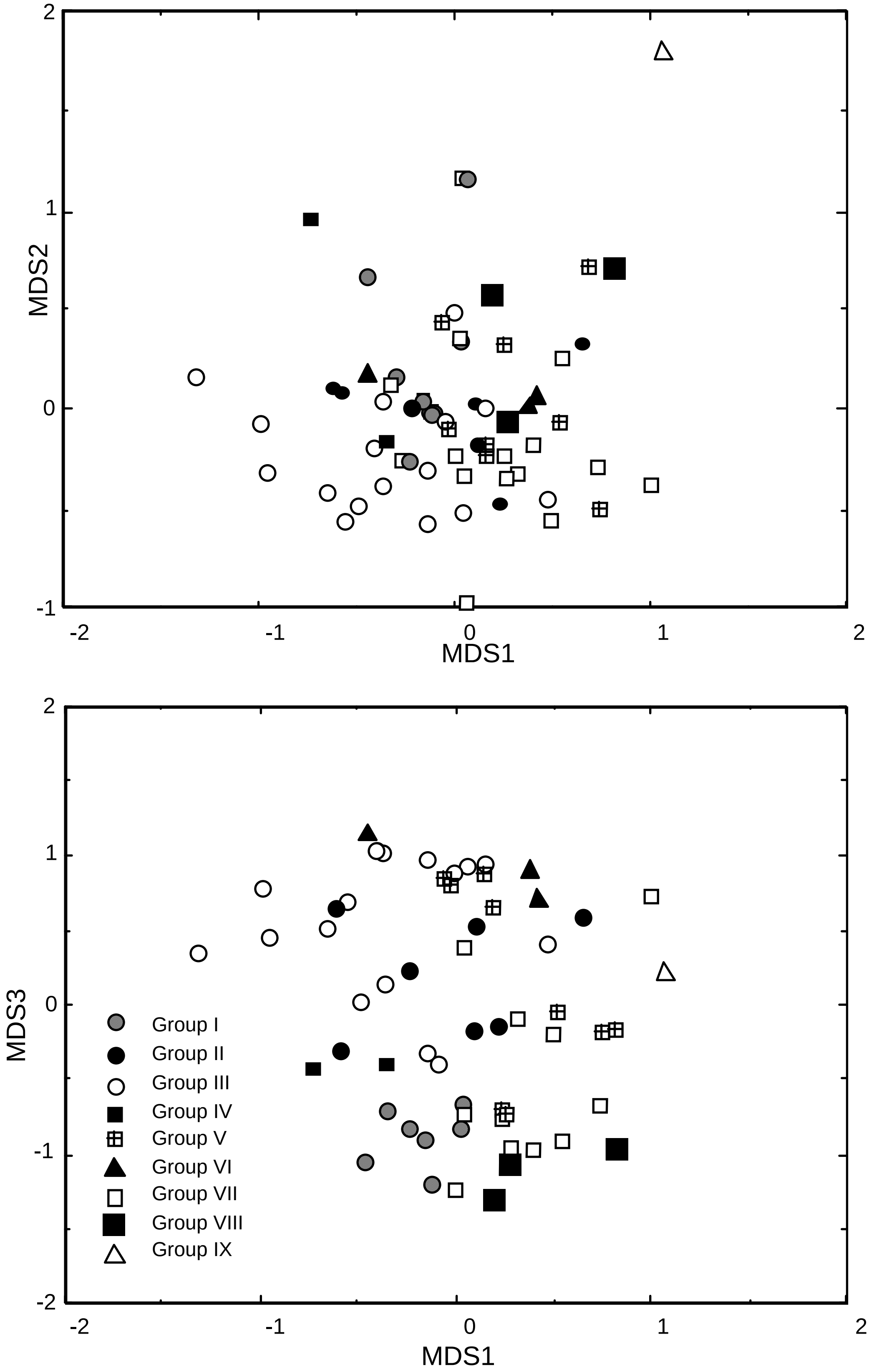

Fig. 3.20. Physical estuarine groups overlayed on results of MDS analysis for benthic invertebrate data.

Table 3.30. Results of ANOSIMs comparing faunal similarities between paired estuarine groups. Analysis 1 used estuarine groups identified from multivariate analysis of physical data, while these groups were slightly modified using the categorisation system described in Table 3.31 for analysis 2.

Group 1	Group 2	*Analysis 1*		*Analysis 2*	
		r-statistic	*p*	*r-statistic*	*p*
I	II	0.555	0.001	0.565	0.000
I	III	0.727	0.000	0.858	0.000
I	V	0.597	0.001	0.554	0.001
I	VII	0.191	0.026	0.191	0.027
I	VIII	0.487	0.015	0.487	0.015
II	III	0.028	0.334	0.186	0.014
II	V	0.102	0.167	0.170	0.048
II	VII	0.262	0.016	0.362	0.001
II	VIII	0.772	0.003	0.845	0.000
III	V	0.254	0.013	0.474	0.001
III	VII	0.537	0.000	0.664	0.000
III	VIII	0.886	0.000	0.935	0.001
V	VII	0.283	0.018	0.269	0.019
V	VIII	0.582	0.003	0.548	0.006
VII	VIII	0.306	0.062	0.306	0.062

Inspection of physical data associated with sites in Groups II, III and IV indicated that the physical multivariate classification reflected a complex combination of environmental factors, with estuary size, salinity and tidal range the predominant factors. Given that salinity and tidal range were found to exert the greatest biological influences amongst the variables examined, estuaries were reclassified with emphasis placed on these variables rather than estuary size. Estuaries with seasonally depressed salinity regimes that were originally placed in Group III were reclassified into Group II (i.e. Great Swanport, Pittwater, Port Sorell, Payne Bay and Tomahawk), and the high tidal range estuary at Detention River was reclassified from Group III to Group V.

ANOSIM results indicated that the revised estuarine groups were much more biologically meaningful than the groups originally deduced by multivariate analysis of physical data, with substantially more of the variation between sites explained by the groupings (global r = 0.486). All six major groups differed significantly from each other in terms of the invertebrate data set ($p<0.05$; Table 3.30), with the exception of Groups VII and VIII ($p=0.062$). Group VIII included data from four low diversity river estuaries only, while Group VIII included data from a range of sites in drowned river valleys. Because of the likelihood that one Type I error will occur amongst the 15 ANOSIM tests undertaken, the paucity of data from river estuaries, and the considerable faunal difference between Group VII and Group VIII estuaries (as indicated by the r-statistic of 0.306), these two groups were considered distinctly different.

Changes to the multivariate groupings of estuaries necessitated a reclassification of all estuaries in the state, including those not investigated biologically. The key used in the reclassification process is described in Table 3.31. This key maintains most original groupings (97 of 111), and primarily reclassifies site III estuaries with depressed winter salinities or large tidal ranges. Salinity, tide and bar data collected in future from estuaries not previously visited may indicate additional reclassification of estuaries is required using this key.

Table 3.31. Process used to categorise Tasmanian estuaries.

1	closed on occasion by seaward barrier	
1.1	summer salinity >35‰ and winter salinity >25‰ in central region	Group IV
1.2	summer salinity <35‰ or winter salinity <25‰ in central region	
1.2.1	Total annual runoff <2,000 gl	Group I
1.2.2	Total annual runoff >2,000 gl	Group IX
2	permanently open	
2.1	Tidal range near mouth <1 m or summer salinity >30‰ in central region	
2.2.1	Estuarine area >50 km^2	Group VII
2.2.2	Estuarine area <50 km^2	
2.2.2.1	Summer salinity <12‰ in central region or total annual runoff <1000 gl	Group VIII
2.2.2.2	Summer salinity >12‰ in central region and total annual runoff >1000 gl	
2.2.2.2.1	Winter salinity <27‰ in central region	Group II
2.2.2.2.2	Winter salinity >27‰ in central region	Group III
2.2	Tidal range near mouth >1 m and summer salinity <30‰ in central region	
2.2.1	Estuarine catchment area <2,000 km^2	Group V
2.2.2	Estuarine catchment area >2,000 km^2	Group VI

Species that occurred consistently at sites within each of the groups of estuaries categorised in Table 3.31 were identified using the SIMPER procedure (Clarke, 1993), and are listed in Table 3.32. Estuary groups IV, VI and IX could not be analysed using this procedure because they contained insufficient sites. A number of species, particularly the polychaete *Nephtys australiensis* and amphipod *Paracorophium cf excavatum*, were widespread in a range of habitats and occurred consistently in several different estuary groups.

Group I and Group VIII estuaries typically included species classed on the basis of their salinity affinity as freshwater or estuarine (Table 3.32), while Group III estuaries included a predominance of marine species. Other estuary types were characterised by species with a wide range of salinity tolerances.

Table 3.32. Average abundance ($\bar{x}$) of important species in each estuary group, their contribution to the average similarity ($\bar{S_i}$) within the group, the standard deviation of the average similarity for different groups (SD($\bar{S_i}$)), and the cumulative percentage of total similarity ($\%\bar{S_i}$).

	$\bar{x}$	$\bar{S_i}$	SD($\bar{S_i}$)	$\bar{S_i}$/SD($\bar{S_i}$)	$\%\bar{S_i}$
Group I (barred low salinity estuaries)					
Ascorhis victoriae	1434.4	7.7	3.8	2.0	16.1
Paracorophium cf excavatum	392.7	6.6	2.5	2.6	13.7
Arthritica semen	577.0	4.1	4.5	0.9	8.5
Chironomid spp.	114.1	3.7	1.5	2.4	7.8
Actaecia bipleura	144.1	3.2	3.7	0.9	6.7
Melita sp.	55.9	2.7	2.1	1.3	5.7
Amarinus lacustris	22.6	2.4	1.8	1.4	5.1
Boccardiella sp.	118.0	2.4	2.8	0.9	5.0
Tatea rufilabrus	497.9	2.2	2.5	0.9	4.6
Paracalliope australis	87.9	2.2	1.7	1.3	4.6
Group II (open estuaries)					
Arthritica semen	257.9	4.1	1.4	2.9	11.1
Nephtys australiensis	27.3	2.7	2.0	1.3	7.2
Actaecia bipleura	90.5	2.1	1.9	1.1	5.7
Nassarius pauperatus	11.1	2.0	1.4	1.4	5.5
Leitoscoloplos normalis	22.2	1.9	1.8	1.0	5.2
Tellina deltoidalis	8.0	1.7	1.2	1.4	4.5
Salinator fragilis	10.5	1.6	1.2	1.4	4.3
Group III (marine inlets)					
Hydrococcus brazieri	641.2	2.7	2.9	0.9	7.0
Euzonus sp.	30.8	2.2	1.3	1.7	5.9
Mysella donaciformis	180.2	2.2	2.0	1.1	5.7
Exosphaeroma sp.	26.0	1.8	1.0	1.7	4.7
Nassarius pauperatus	31.7	1.7	1.5	1.1	4.4
?Mysella sp.	67.6	1.6	1.0	1.6	4.1
Nephtys australiensis	25.3	1.5	1.7	0.9	3.8
Heteromastus sp. MOV 858	18.1	1.3	1.5	0.9	3.3
Salinator fragilis	33.0	1.2	1.4	0.9	3.2
Katelysia scalarina	13.6	1.2	1.0	1.2	3.1
Group V (mesotidal river estuaries)					
Arthritica semen	90.0	3.9	1.2	3.1	11.3
Nephtys australiensis	16.4	2.5	2.7	0.9	7.1
Leitoscoloplos normalis	5.4	1.8	2.1	0.9	5.2
Magelona sp.	17.6	1.8	2.1	0.9	5.2
Heteromastus sp. MOV 858	11.6	1.5	1.6	0.9	4.5
Group VII (microtidal drowned river valleys)					
Paracorophium cf excavatum	403.4	5.6	3.2	1.8	15.8
Arthritica semen	227.8	4.7	3.1	1.5	13.3
Leitoscoloplos normalis	15.6	2.0	1.9	1.1	5.6
Nephtys australiensis	23.2	1.8	1.8	1.0	5.0
Group VIII (microtidal river estuaries)					
?Exoediceroides sp.	134.8	8.1	10.5	0.8	25.1
Paracorophium cf excavatum	196.0	5.5	6.1	0.9	17.0
Potamopyrgus antipodarum	121.8	4.8	5.3	0.9	14.8
Chironomid spp.	6.0	2.4	2.7	0.9	7.5

3.2.11 Anthropogenic effects on biota

Relationships between macrofauna and human disturbance

Relationships between abundances of species and anthropogenic disturbance were assessed by calculating Spearman rank correlation coefficients between total animal abundance at each site and three disturbance variables - human population density, percent cleared land and the naturalness index NI. The three disturbance variables were calculated for each site as the mean of estuarine catchment area and estuarine drainage area values (Appendix 9).

Population density was generally more highly correlated with species abundance than percent cleared land or NI and therefore appears to be the better variable for discriminating human impacts (Table 3.33). Population density produced a maximum correlation coefficient of 0.51 for *Tellina deltoidalis* and a minimum value of -0.45 for *Limnoporeia kingi*, compared to maximum and minimum values of 0.38 and -0.32 using NI, and 0.37 and -0.29 using percent cleared land, for different species.

The seven widespread species most highly correlated with human population density were infaunal species typically associated with mudflats (Table 3.33). Many additional species that were also highly correlated with population density but not shown in Table 3.33 because they occurred at less than 12 sites, and so have a high chance of being spuriously correlated, were also mudflat dwelling species (e.g. *Notospisula trigonella* - r_S = 0.40, *Heloecius cordiformis* - r_S = 0.28, *Helograpsus haswellianus* - r_S = 0.24; Table 3.35).

By contrast, the six widespread species showing greatest negative correlations with population density were epifaunal species, including three that generally associate with sandflats in similar salinity and tidal height conditions to the mudflat species (*Eubittium lawleyanum, Hydrococcus brazieri* and *Exosphaeroma* sp.). Nearly all additional species with strong negative correlations with population density that were not included in Table 3.33 because of restricted distribution were also sandflat inhabitants (e.g. *Wallucina assimilis* - r_S = -0.32, *Diala suturalis* - r_S = -0.25, *Haminoea maugensis* - r_S = -0.24; see Table 3.35).

Spearman rank correlation coefficients (r_S) relating animal density to human population density for all species were used to calculate an index of anthropogenic disturbance (DI) for each site by summing the proportional abundance of each species multiplied by r_S:

$$DI = \Sigma r_S * n_i / N$$

where n_i is the abundance of species i and N is total abundance of all species at the site. The site with the highest DI, and therefore the one most dominated by species typical of disturbed (i.e. heavily populated) conditions, was Paper Beach (Tamar estuary) while Rices River was found to be the least disturbed. DI values rescaled in the range from 0 to 10 (where 0 indicates the site examined during the study with lowest DI and 10 the site with highest DI) for all sites are listed in Appendix 9.

Table 3.33. Spearman rank correlation coefficients (r_S) relating abundance at different sites of widespread species (ie. those present at 12 or more sites) with population density (Pop), % cleared land (Clear) and the naturalness index (NI). Infaunal or epifaunal habit of species is also shown. Significance values have not been assigned to correlation coefficients because of uncertainty caused by the large number of species investigated increasing the probability of Type I error, and the generally small number of sites at which each species was recorded increasing the probability of Type II error.

Code	*Species*	*Habit*	*Group*	*Pop* r_S	*Clear* r_S	*NI* r_S
MP05	*Tellina deltoidalis*	Infaunal	Bivalve	0.51	0.37	0.38
WP36	*Magelona* sp.	Infaunal	Polychaete	0.39	0.30	0.26
WP11	*Lumbrineris* sp.1	Infaunal	Polychaete	0.39	0.35	0.29
CB01	*Macrophthalmus latifrons*	Infaunal	Crab	0.36	0.24	0.33
WP41	*Nephtys australiensis*	Infaunal	Polychaete	0.32	0.15	0.13
CD5	*Callianassa arenosa*	Infaunal	Shrimp	0.30	0.17	0.08
MG18	*Nassarius burchardi*	Epifaunal	Gastropod	0.26	0.15	0.07
WP02	*Neanthes vaalii*	Infaunal	Polychaete	0.24	0.26	0.23
CB02	*Paragrapsus gaimardii*	Epifaunal	Crab	0.22	0.19	0.28
CA12	*Gammaropsis* sp.1	Epifaunal	Amphipod	0.21	0.01	0.24
CI01	*Actaecia bipleura*	Epifaunal	Isopod	0.19	0.27	0.26
WP46	*Phyllodoce* sp.	Epifaunal	Polychaete	0.19	0.35	0.03
CA31	*Limnoporeia yarrague*	Epifaunal	Amphipod	0.18	0.22	0.01
WP03	*Australonereis ehlersi*	Infaunal	Polychaete	0.13	0.02	-0.07
CU1	*Dimorphostylis colefaxi*	?Epifaunal	Cumacean	0.09	-0.04	0.21
WP54	*Heteromastus* sp. MOV 858	Infaunal	Polychaete	0.08	0.11	-0.02
CB03	*Mictyris platycheles*	Infaunal	Crab	0.07	0.14	0.06
CA06	*Exoediceroides ?maculosus*	Infaunal	Amphipod	0.07	0	0.07
MG02	*Nassarius pauperatus*	Epifaunal	Gastropod	0.07	-0.08	0.03
MP09	*Mysella donaciformis*	Infaunal	Bivalve	0.07	0.10	0.29
CA11	*Paracorophium cf excavatum*	Infaunal	Amphipod	0.06	0.20	-0.04
CD2	*Macrobrachium* sp.	Epifaunal	Shrimp	0.06	-0.09	-0.06
CI11	*Pseudolana concinna*	Epifaunal	Isopod	-0.01	-0.17	0.13
MP08	*Xenostrobus inconstans*	Epifaunal	Bivalve	-0.04	0.02	0.03
CA01	*Paracalliope australis*	Epifaunal	Amphipod	-0.05	0.17	-0.02
WN1	*Nemertean* sp.1	Infaunal	Nemertean	-0.06	-0.05	0.09
CA61	*Melita* sp.	Epifaunal	Amphipod	-0.07	0.20	0.03
MP03	*Arthritica semen*	?Infaunal	Bivalve	-0.11	0.01	-0.13
WP17	*Euzonus sp.*	Infaunal	Polychaete	-0.11	0.05	0.01
MP10	*Katelysia scalarina*	Infaunal	Bivalve	-0.11	0.03	0.12
WP53	*Capitella* sp.2	Infaunal	Polychaete	-0.12	0	0.22
MG21	*Tatea rufilabrus*	Epifaunal	Gastropod	-0.12	0.02	-0.24
WP21	*Leitoscoloplos normalis*	Infaunal	Polychaete	-0.12	-0.15	-0.21
WP33	*Boccardiella* sp.	Infaunal	Polychaete	-0.13	0.09	-0.09
MG03	*Salinator fragilis*	Epifaunal	Gastropod	-0.14	-0.12	-0.02
WP05	*Simplisetia aequisetis*	Infaunal	Polychaete	-0.15	-0.25	0.04
WP04	*Perinereis vallata*	Infaunal	Polychaete	-0.19	0.04	0.08
AI13	Chironomid spp.	Epifaunal	Insect	-0.20	0.01	-0.19
MG19	*Zeacumantus diemenensis*	Epifaunal	Gastropod	-0.21	0.09	0
MP31	*?Mysella* sp.	?Infaunal	Bivalve	-0.24	-0.10	-0.14
MG06	*Ascorhis victoriae*	Epifaunal	Gastropod	-0.27	-0.23	-0.22
CI21	*Exosphaeroma* sp.	Epifaunal	Isopod	-0.28	-0.22	0.05
MG08	*Hydrococcus brazieri*	Epifaunal	Gastropod	-0.28	0	-0.01
CB05	*Amarinus lacustris*	Epifaunal	Crab	-0.35	-0.21	-0.32
MG05	*Eubittium lawleyanum*	Epifaunal	Gastropod	-0.38	-0.29	-0.03
CA33	*Limnoporeia kingi*	Epifaunal	Amphipod	-0.45	-0.17	-0.20

DI appears to be useful as an environmental indicator of anthropogenic disturbance of sites. It retains a high correlation with population density ($r_S = 0.74$) and, to a lesser extent, with percent cleared land ($r_S = 0.55$), but was not strongly correlated with the major physical variable salinity ($r_S = -0.31$). In addition, bubble plots overlaying DI values on MDS results showed very good separation of sites (Fig. 3.21), particularly for the plot of MDS axis 1 versus axis 3. DI therefore has a high degree of faunal consistency and discriminates well between sites.

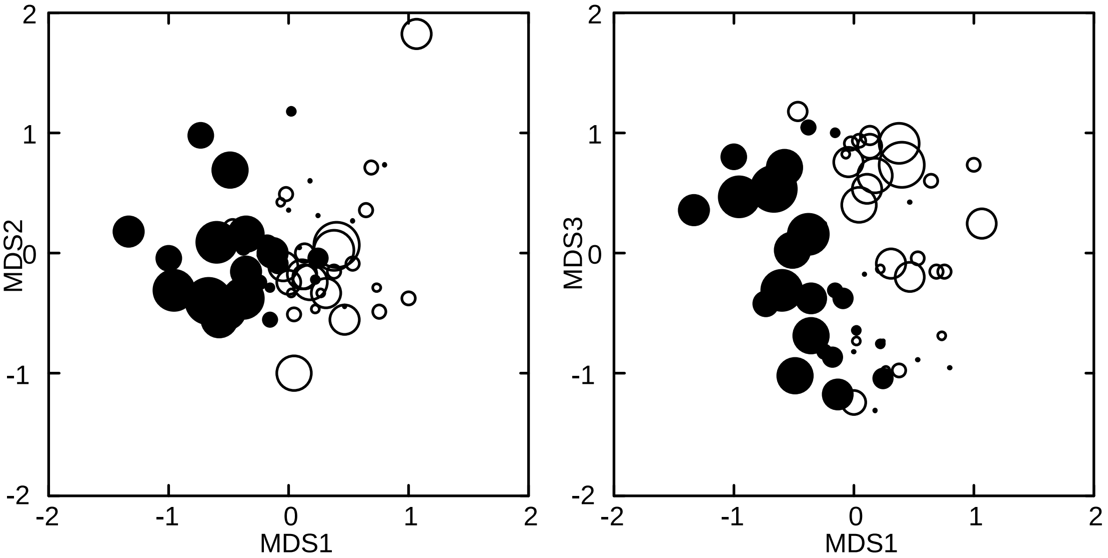

Fig. 3.21. Bubble plot overlay of site DI values on MDS results. Sites with high DI values are shown with large open circles while low DI values are shown by large filled circles.

Stabilised disturbance indices

Iteration procedures analogous to those used for the SIGNAL-97 biotic index of Chessman *et al* (1997) were applied to the initial DI values by recalculating r_S values using DI rather than human population density as the correlate of total animal abundance at each site. The revised DI values were then used as initial DI values to recalculate r_S for each species again, and the procedure repeated until DI values stabilised. Chessman *et al.* (1997) suggest that this procedure adjusts the biotic index (ie. SIGNAL-97 or DI) for internal conditions.

After 12 iterations, DI reached equilibria. Bubble plots overlaying the stabilised DI values on MDS results showed complete separation of sites on the basis of stabilised DI, and thus a very high level of faunal consistency (Fig. 3.22). Unfortunately, the stabilised DI values showed a relatively poor correlation with the initial correlate used at the start of the iteration procedure (human population density; $r_S = 0.16$) but a good correlation with salinity ($r_S = 0.57$), so are much more indicative of salinity at sites than anthropogenic disturbance.

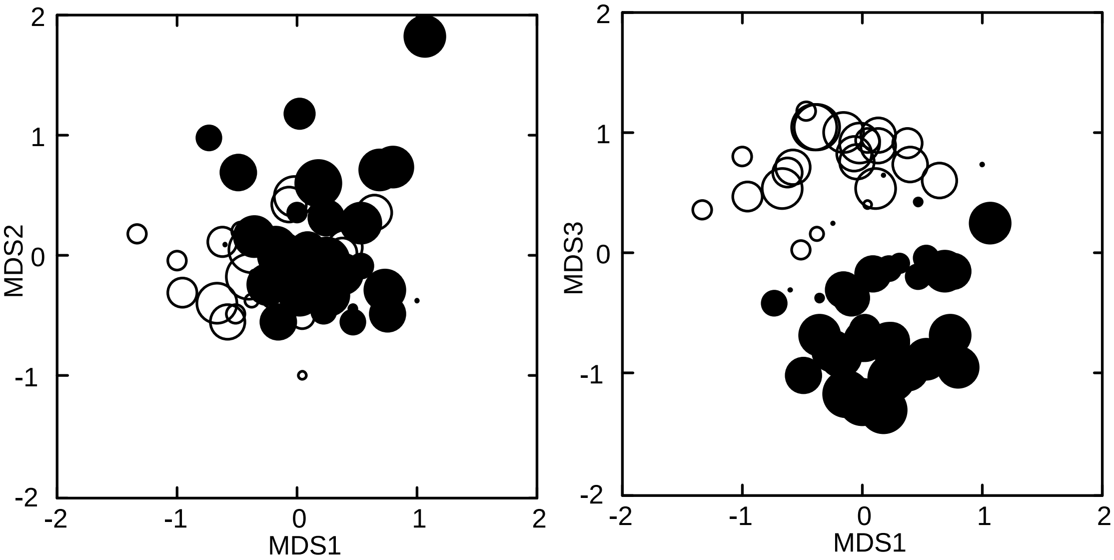

Fig. 3.22. Bubble plot overlay of stabilised DI values on MDS results. Sites with high DI values are shown with large open circles while low DI values are shown by large filled circles.

Disturbance indices based on family data

The DI values calculated above utilised individual species information, so DI cannot be calculated for site data outside the Tasmanian/southeastern Australian region. In order to assess whether a more generally useful DI could be calculated as an environmental indicator, r_S values relating human population density in catchments with animal abundance at sites were also calculated for macrofaunal families. For these calculations, abundance data for all species within a family were amalgamated at each site. The results of this analysis for families collected at more than five sites are shown in Table 3.34. The family r_S values largely reflect the influence of the dominant species in each family, with the Tellinidae (which includes the most influential species *Tellina deltoidalis*) showing the highest correlation (0.46).

DI values calculated using family data (Fig. 3.23) show similarly good discrimination between sites as DI values calculated using species data (Fig. 3.21); however, this discrimination was accompanied by a reduced correlation with human population density (r_S = 0.57). Inspection of species r_S values indicated that many families possessed species with opposite responses to human population density. For example, the two species collected belonging to the family Glyceridae possessed r_S values of 0.25 and -0.25 (Table 3.35), which combined to produce an overall family coefficient of -0.03, with the loss of useful information.

Table 3.34. Spearman rank correlation coefficients (r_S) relating human population density in catchments with total abundance of animals in families collected at >5 sites.

Family	r_S	*Family*	r_S	*Family*	r_S
Actiniidae	0.08	Eusiridae	0.07	Diastylidae	0.00
Edwardsiidae	0.01	Paracalliopidae	0.12	Batillaridae	-0.35
Opheliidae	-0.13	Hyalidae	-0.19	Dialidae	-0.25

Phyllodocidae	0.19	Isaeidae	0.18	Hydrobiidae	-0.11
Capitellidae	-0.04	Melitidae	-0.08	Amphibolidae	-0.02
Nephtyidae	0.33	Oedicerotidae	0.00	Littorinidae	-0.22
Glyceridae	-0.03	Phoxocephalidae	-0.18	Nassaridae	0.23
Lumbrineridae	0.39	Aoridae	0.05	Retusidae	-0.13
Maldanidae	-0.13	Talitridae	0.17	Trochidae	-0.15
Nereidae	-0.07	Urohaustoridae	0.01	Vitrinellidae	0.07
Orbinidae	-0.11	Grapsidae	0.23	Assiminidae	-0.28
Spionidae	-0.09	Hymenosomatidae	-0.31	Laternulidae	0.10
Magelonidae	0.39	Ocypodidae	0.37	Mactridae	0.40
Cirratulidae	-0.17	Portunidae	0.02	Montacutidae	0.01
Syllidae	-0.24	Callianassidae	0.25	Erycinidae	-0.11
Terrebellidae	-0.10	Palaemonidae	0.15	Mytilidae	-0.03
Synaptidae	-0.15	Cirolanidae	0.02	Psammobiidae	-0.07
Curculionidae	0.08	Actaeciidae	0.16	Tellinidae	0.46
Chironomidae	-0.20	Idoteidae	-0.08	Lucinidae	-0.30
Ampithoidae	-0.13	Sphaeromatidae	-0.18	Veneridae	-0.04
Corophiidae	0.09	Mysidae	-0.12	Mesodesmatidae	0.13
Dexaminidae	-0.03	Tanaidae	0.08	Cyamiidae	-0.22

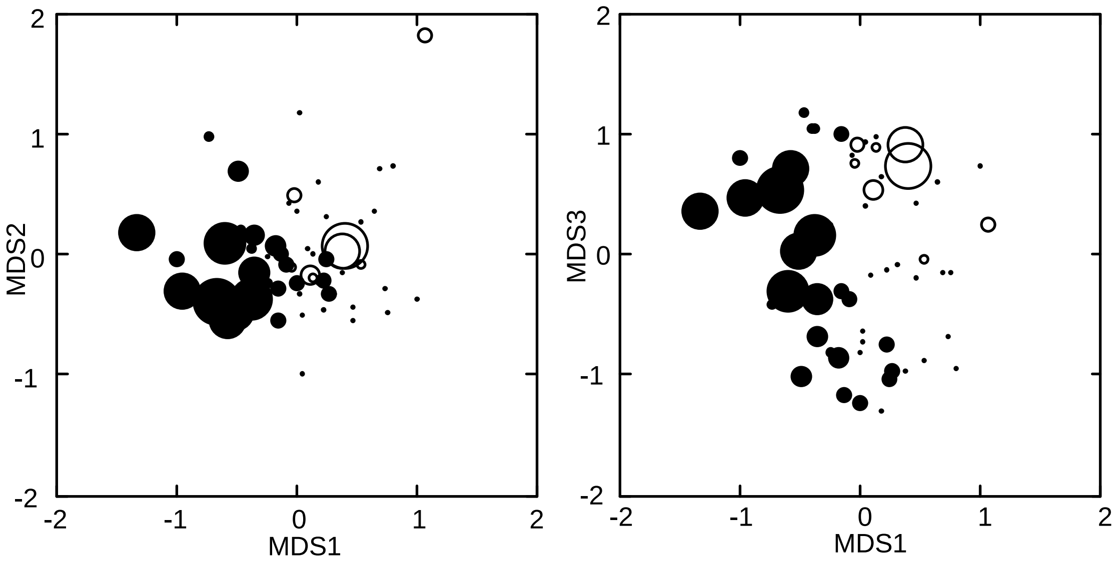

Fig. 3.23. Bubble plot overlay of DI values calculated using aggregated family data on MDS results. Sites with high DI values are shown with large open circles while low DI values are shown by large filled circles.

Disturbance indices based on reduced species data

In order to determine whether a limited number of influential species were dominating calculations of DI, DI was recalculated using data from the 15 species most highly positively and negatively correlated with human population density, as listed in Table 3.35.

Table 3.35. Spearman rank correlation coefficients (r_S) relating human population density in catchments with total abundance of animals for species showing strong correlations.

Species	r_S	*Species*	r_S
Tellina deltoidalis	0.51	*Limnoporeia kingi*	-0.45
Notospisula trigonella	0.40	*Eubittium lawleyanum*	-0.38
Magelona sp.	0.39	*Amarinus lacustris*	-0.35
Lumbrineris sp.1	0.39	*Wallucina assimilis*	-0.32
Macrophthalmus latifrons	0.36	*Scolecolepides sp.*	-0.31

Nephtys australiensis	0.32	*Hydrococcus brazieri*	-0.28
Callianassa arenosa	0.30	*Exosphaeroma sp.*	-0.28
Barantolla lepte	0.30	*Olganereis edmonsi*	-0.27
Heloecius cordiformis	0.28	*Ascorhis victoriae*	-0.27
Corophium sp.	0.27	Glycerid sp.1	-0.25
Nassarius burchardi	0.26	*Diala suturalis*	-0.25
Placamen placida	0.25	*Solemya sp.*	-0.24
Glycerid sp.2	0.25	*?Mysella sp.*	-0.24
Helograpsus haswellianus	0.24	*Haminoea maugensis*	-0.24
Neanthes vaalii	0.24	*Cyamiomacra mactroides*	-0.22

DI values for sites calculated using the reduced species data set possessed a similar correlation with human population density as the full data set (r_S = 0.73 *cf.* 0.74). The bubble plots of DI overlaying MDS results (Fig. 3.24) were also similar to plots obtained using all species (Fig. 3.21).

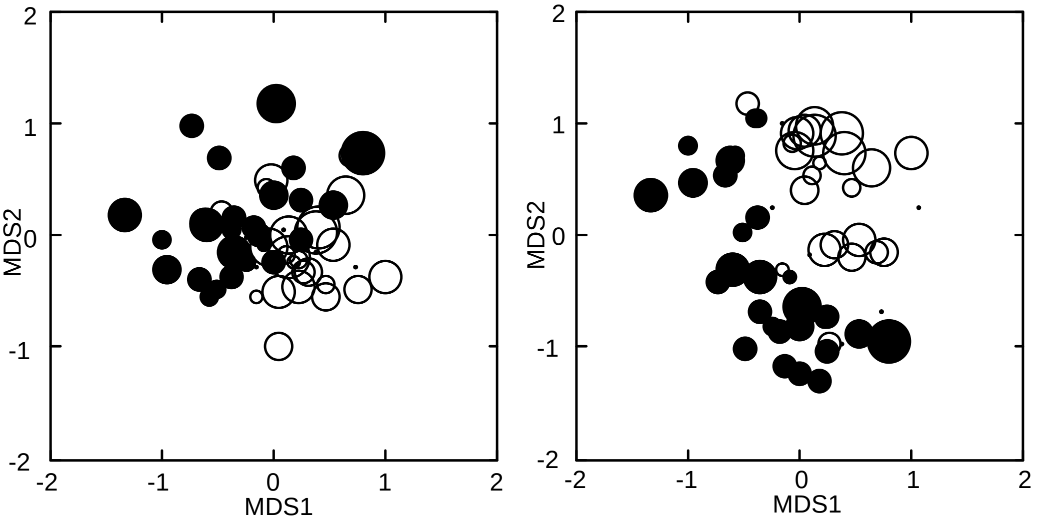

Fig. 3.24. Bubble plot overlay of DI values calculated using 30 species on MDS results. Sites with high DI values are shown with large open circles while low DI values are shown by large filled circles.

Disturbance indices based on biomass and productivity data

DI was also calculated using data on the total biomass (DI_b) and estimated productivity (DI_p) of all species at each site rather than total numbers (DI_n). The bubble plot overlays on MDS results (Figs 3.25, 3.26) indicated that sites separated less strongly on the basis of DI_b than on DI_p or DI_n. Relatively few sites possessed high DI_p values - most were either low, indicating a predominance of species associated with undisturbed conditions, or moderate.

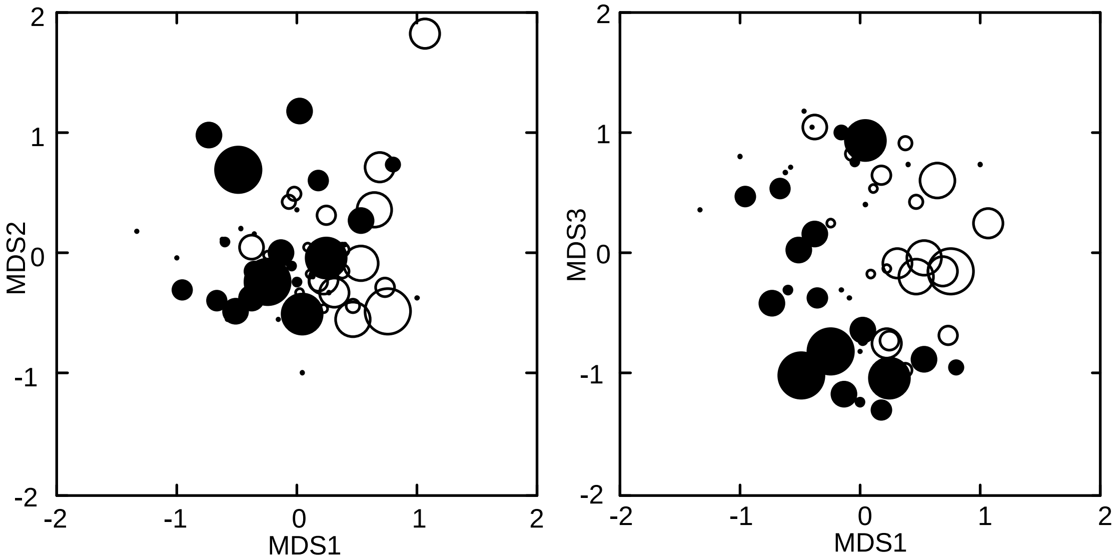

Fig. 3.25. Bubble plot overlay of DI values calculated using biomass data on MDS results. Sites with high DI_b values are shown with large open circles while low DI_b values are shown by large filled circles.

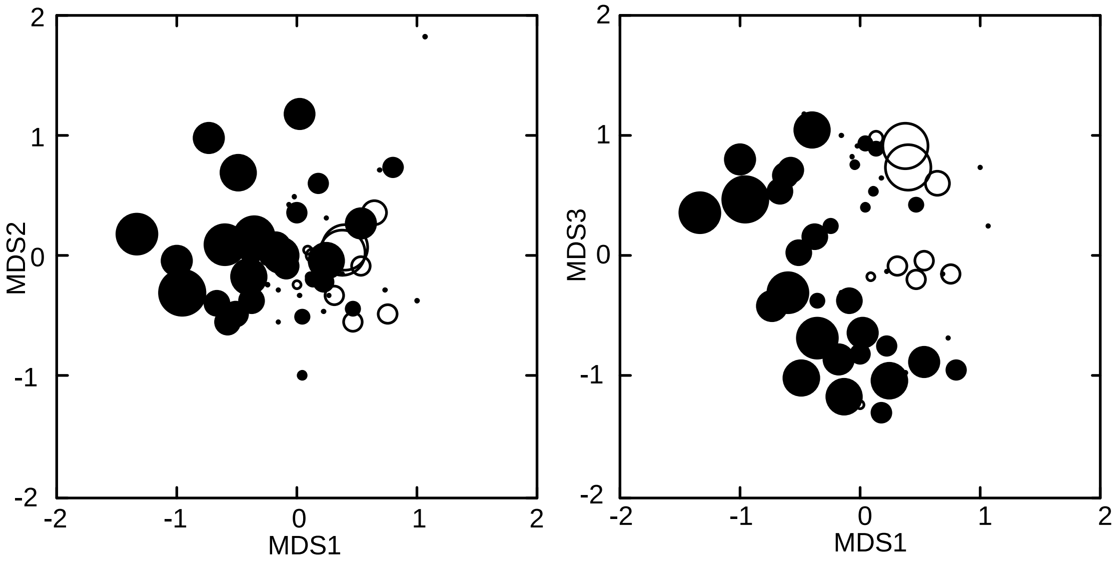

Fig. 3.26. Bubble plot overlay of DI values calculated using estimated productivity data on MDS results. Sites with high DI_p values are shown with large open circles while low DI_p values are shown by large filled circles.

DI_p was the best performing of all indices examined in terms of retaining its correlation with human population density (r_s=0.78, Table 3.36), while the correlation of DI_b was relatively poor (r_s=0.40). DI_p also maintained a better correlation with other disturbance variables (NI and percent cleared land) than DI_n, and was less influenced by the major physical variables salinity, tidal range and total annual runoff (Table 3.36). DI_p maintained a high correlation with the silt/clay fraction of sediments, tidal range and TAR, as was expected given the high correlation of population density itself with these variables. DI_n, DI_b and DI_p were all moderately negatively correlated ($-0.49 < r_s < -0.28$) with the density of animals at sites but were not greatly affected by the total biomass, total estimated productivity or total number of species.

Table 3.36. Spearman rank correlation coefficients relating disturbance indices calculated using abundance (DI_n), biomass (DI_b) and productivity (DI_p) data, human population density and physical and biological variables. In addition to the full data set, DI_n was calculated for families and with a reduced 30 species data set, and was stabilised by the iteration procedure of Chessman *et al* (1997). DI_n was also calculated using percent cleared land rather than human population density as the initial correlate.

Variable	DI_n	DI_b	DI_p	DI_n *Family*	DI_n *Reduced*	DI_n *Stabilised*	DI_n *% Cleared*	*Population*
Population density	0.74	0.40	0.78	0.57	0.73	-0.16	0.41	1.00
NI	0.38	0.26	0.47	0.26	0.41	-0.26	0.38	0.72
% Cleared land	0.37	0.28	0.46	0.27	0.43	-0.30	0.44	0.67
Salinity	-0.30	-0.13	-0.26	-0.39	-0.11	-0.58	0.31	-0.21
Tidal range	0.50	0.38	0.47	0.41	0.59	-0.50	0.61	0.57
Latitude	-0.18	-0.02	-0.24	-0.05	-0.20	-0.16	0.17	-0.16
TAR	0.52	0.12	0.47	0.36	0.35	0.24	0.10	0.49
% Silt/clay	0.59	0.29	0.60	0.32	0.45	-0.10	0.18	0.65
Species	-0.10	-0.15	-0.02	-0.25	0.13	-0.63	0.36	0.11
Faunal density	-0.49	-0.28	-0.38	-0.66	-0.55	0.29	-0.53	-0.26
Faunal biomass	-0.04	-0.09	-0.05	-0.18	0.12	-0.59	0.40	0.14
Faunal productivity	-0.08	-0.15	-0.11	-0.26	0.04	-0.47	0.28	0.12

Pearson correlation coefficients (r) relating log population density to DI_n, DI_b and DI_p at different sites were similar to the rank correlation coefficients shown in Table 3.36 ($r = 0.70$, 0.42 and 0.74, respectively), indicating that relationships were linear rather than curvilinear.

DI values rescaled between a maximum value of 10 and minimum value of 0 for data from all sites are listed for the sites sampled on two occasions in Table 3.37. DI_n and DI_p both showed extremely little change over time, with DI_p the marginally more stable. By contrast, DI_b fluctuated considerably between sampling occasions, depending partly on the occasional collection of very large individuals. The average standard deviation of DI at sites between times was 0.84 for DI_b, compared to 0.25 and 0.24 for DI_n and DI_p, respectively. The corresponding standard deviations for DI_n using the family and reduced species data sets were intermediate in magnitude: 0.41 and 0.48, respectively.

Table 3.37. DI_n, DI_b and DI_p values rescaled between the range 0 and 10 for four sites sampled on two occasions (t_1 and t_2). DI_n values for family data set and reduced data set with 30 species are also shown.

Site	Di_n		Di_b		DI_p		*Family* DI_n		*Reduced* DI_n	
	t_1	t_2	t_1	t_2	t_1	t_2	t_1	t_2	t_1	t_2
Cornelian Bay (Derwent)	7.0	7.2	9.1	8.6	7.2	7.4	5.6	5.3	8.4	8.3
Cradoc (Huon)	5.7	5.8	5.8	7.0	4.7	5.3	3.4	4.2	7.8	5.8
Paper Beach (Tamar)	9.1	10.0	7.1	5.7	10.0	9.9	8.9	10.0	9.9	10.0
Leven	7.1	7.4	5.6	3.9	3.4	3.8	6.6	6.5	9.9	9.4

3.3 Fishes

3.3.1 Patterns of species richness

Fish data analysed in the present study consisted largely of the Last (1983) data set, which contained information on the $\log_3$ abundance of fishes at sites in 71 estuaries around Tasmania. To this data set was added quantitative seine haul information collected during the present study from 11 estuaries, including four estuaries not sampled in the Last study. The fish data set therefore differed substantially from the benthic invertebrate data set by covering more estuaries and many more sites, but with less detail relating to each site and with data in a semiquantitative form.

A total of 101 fish species was recorded during sampling in estuaries. The number of species collected varied greatly between estuaries, depending largely on sampling effort within the estuary. The total number of species collected per estuary (S) showed a close relationship with the number (N) of samples collected in the estuary at different sites or on different days ($S = 4.82 + 1.51*N$; $r^2 = 0.65$, n=75, $p<0.001$, Fig. 3.27). The Huon estuary possessed an anomalously high number of species given the small sampling effort, while Macquarie Harbour possessed a disproportionately low number of species. The Tamar and North East estuaries possessed highest numbers overall (41 and 40, respectively).

For species collected from estuaries dominated by marine or intermediate polyhaline conditions, the relationship between number of species per estuary and sample size was linear and showed little indication of nearing an asymptote (Fig. 3.27). Nevertheless, such an asymptote is to be expected if sampling continues given the limited pool of species associated with Tasmanian estuaries.

When data for only the 12 low salinity estuaries (surface salinity generally <10‰ in their central region) were examined (Fig. 3.27), the number of species collected appeared to reach an asymptote at ˜25 species. A levelling off in this relationship was indicated by the log regression equation having a substantially higher r^2-value (0.84, n=12) than the linear regression equation ($r^2 = 0.62$), in contrast to the curves for marine ($r^2 = 0.77$ for log and 0.84 for linear equation, n=14) and intermediate polyhaline estuaries ($r^2 = 0.64$ *cf.* 0.68, n=21). However, the asymptote in the freshwater estuary relationship was largely caused by the low number of species in the Macquarie Harbour estuary, an estuary intensively sampled at 15 sites on 27 site.days. Further sampling is required to indicate whether patterns in Macquarie Harbour are unique or are typical of other low salinity estuaries at high levels of sampling.

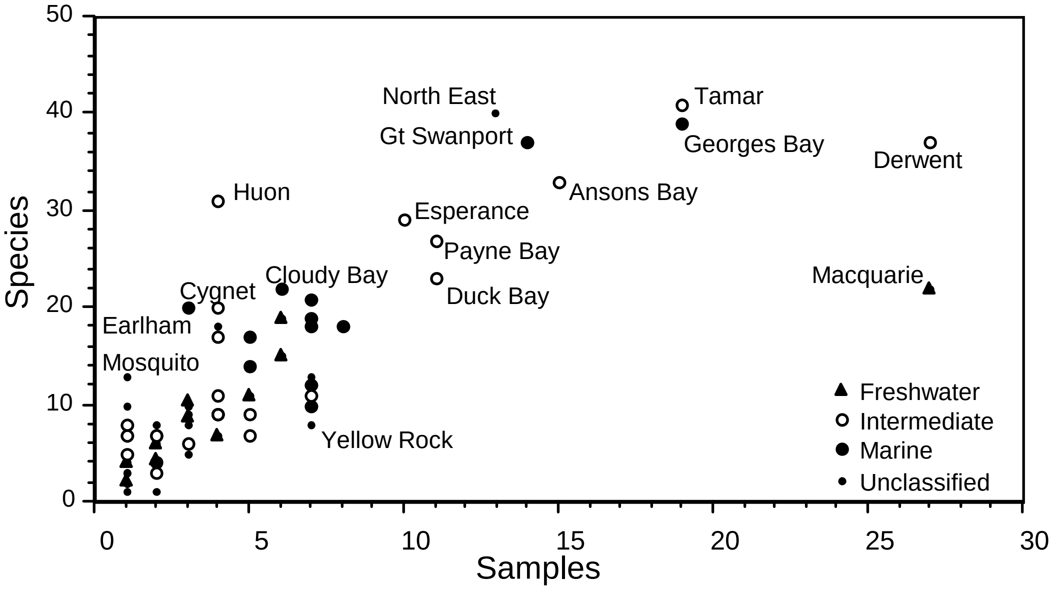

Fig. 3.27. Number of species collected per estuary versus number of site.day samples (where a site sampled on two occasions and two sites sampled within the estuary are both considered two samples). Estuaries with large sample sizes or showing anomalously high or low values are labelled. Estuaries are classed on the basis of salinity records in the central region of the estuary as freshwater-dominated (salinity generally =10‰), intermediate (salinity generally between 10‰ and 30‰) or marine (salinity=30‰).

Limits to the pool of species associated with freshwater-dominated estuaries are most clearly seen in rarefaction curves which plot the accumulated number of species collected from a random sample of estuaries (Fig. 3.28). A total of approximately 30 species were collected in a random sample of 10 freshwater-dominated estuaries, compared to a total of ≈60 species and ≈55 species in the same number of polyhaline intermediate and marine estuaries, respectively.

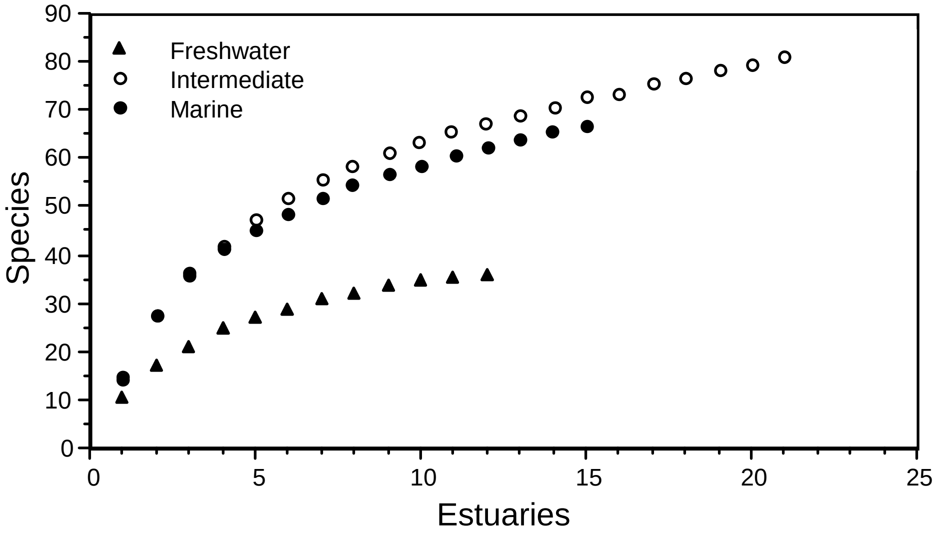

Fig. 3.28. Rarefaction curve showing cumulative total number of species as data from estuaries selected in random order are pooled. Estuaries are classed on the basis of salinity records in the central region of the estuary as freshwater-dominated (salinity generally =10‰), intermediate (salinity generally between 10‰ and 30‰) or marine (salinity=30‰).

In order to determine whether distance along an estuary affects fish species richness, all estuaries were subdivided into three sectors of equal length, and sampled sites were categorised into upper (freshwater), mid or lower (marine) sectors. The mean number of fish species collected per site was

3.39 in the upper sector, 5.96 in the mid sector and 5.27 in the lower sector. Wilcoxon sign ranks test indicated that the difference in species richness between mid and lower sectors was not significant but between the upper and mid sector was highly significant (z-statistic = 2.67, p=0.008, n=11).

The relationship between mean number of species collected per site and mean summer surface salinity for that sector of the estuary, as recorded during hydrological and benthic invertebrate surveys, is shown in Fig 3.29. Note that these plots do not include all fish data because salinity information was not available for many of the sectors within estuaries. The relationship between species richness and summer salinity is significant (r^2 = 0.13, n= 80, p<0.001), and becomes more so when outlying data from the mid and lower sectors of hypersaline Cameron Inlet are removed (r^2 = 0.18, n= 78).

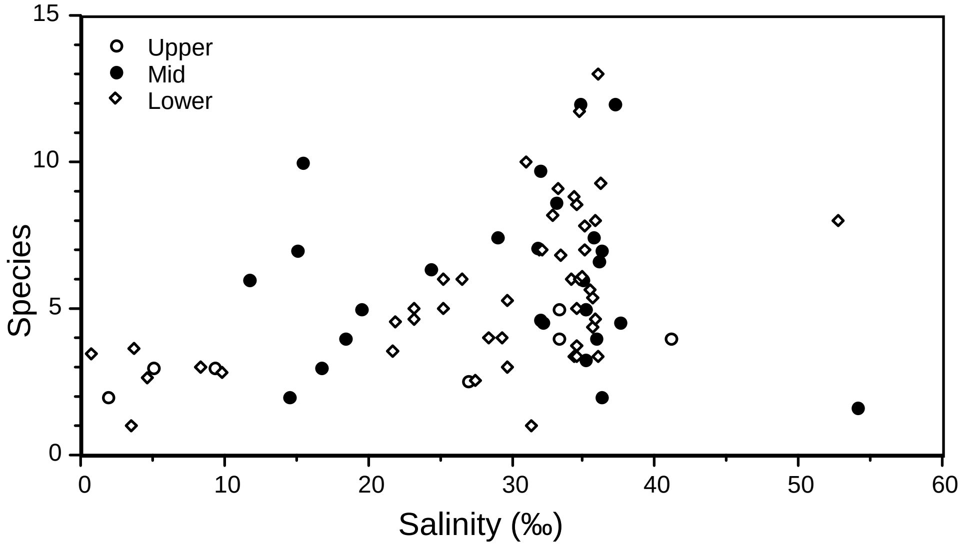

Fig.3.29. Mean number of species collected in each sampled sector of an estuary versus salinity for that sector.

Neither the slopes nor the intercepts of the regression equations relating species number to salinity were significantly different for the three different sectors, as assessed using Analysis of Covariance (slopes: df=2/74, F=2.64, p<0.05; intercepts: df=2/76, F=1.88, p<0.05). The differences in species richness of sites in different sectors of an estuary therefore seems fully attributable to the effects of salinity.

Given the huge influence of sampling intensity on number of fish collected, the effect of area of estuary on fish species richness was investigated using data standardised for the effects of sampling. This was done by calculating residuals from the general relationship between number of species and number of samples ($S = 4.82 + 1.51*N$), and regressing these residuals against log area of estuary. The resultant relationship, shown in Fig. 3.30, was marginally significant (r^2=0.06, n=75, p=0.04).

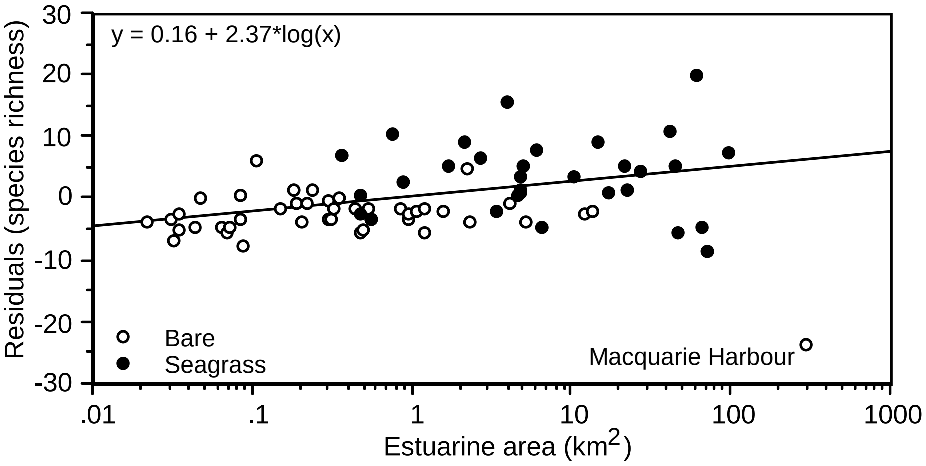

Fig. 3.30. Log estuarine area versus residuals from species richness/sample size relationship (S = 4.82 + 1.51∗N; see Fig. 3.27). Estuaries which included seagrass sites are distinguished from those with bare habitats only.

The relationship between species richness residuals and estuarine area was complicated by an extreme outlier, Macquarie Harbour, the estuary possessing the largest area. When Macquarie Harbour was excluded from the analysis, the significance greatly increased (r^2=0.18, n=74, p<0.001).

Data shown in Fig. 3.30 show increasing scatter with estuarine area; however, results changed little when scatter was reduced using a square root [-√(-x) when x<0] transformation (r^2=0.11 when Macquarie Harbour included, r^2=0.19 when excluded). The corresponding plot of residuals versus summer salinity was also significant (r^2=0.14, n=38, p=0.02) when data from Cameron Inlet were removed.

Although total number of species within estuaries varied significantly with estuarine area, this relationship was confounded by the presence of seagrass in some estuaries but not others, and by variation in salinity. When species richness residuals were plotted separately against estuarine area for estuaries that included sites with seagrass (*Zostera*) habitat and estuaries with bare sites only (see Fig. 3.30), no significant effects were detected for either regression (r^2=0.00, n=30, for estuaries with seagrass; r^2=0.04, n=44, for estuaries lacking seagrass, Macquarie Harbour excluded).

Estuaries where some seagrass habitat was sampled possessed many more species than estuaries with bare habitat only (mean = 7.5 in bare estuaries *cf.* 20.1 in estuaries with seagrass); however, they were also disproportionately large in area, possessed relatively high salinities and were sampled more intensively. Comparisons of total fish numbers in estuaries therefore have little value because they are badly confounded. Nevertheless, the mean number of species per site in estuaries lacking seagrass was also significantly lower than in estuaries with seagrass (mean = 3.36 *cf.* 5.06, respectively; t-test, n=75, p=0.002).

When residuals of the species richness/sampling effort regression were compared between estuaries with and without seagrass, highly significant differences were detected (mean = -2.64 for estuaries with bare habitat; mean = 3.90 for estuaries with seagrass; t-test, p<0.001, n=75). Thus, after the effects of variable sampling intensity were removed, an average of 6.54 more species were collected in estuaries where seagrass habitat was sampled than in estuaries with bare habitat only. These results are still, however, confounded by the effects of salinity.

3.3.2 Geographic patterns

Patterns of fish species richness in estuaries around the state corresponded closely with patterns of macrofaunal species richness. Despite great differences in scale of sites sampled, year of sampling and method of sampling, the mean number of macrofaunal invertebrate species collected at sites within different estuaries was very highly correlated with the mean number of fish species collected (r = 0.61, n = 45, p<0.001; Fig. 3.31).

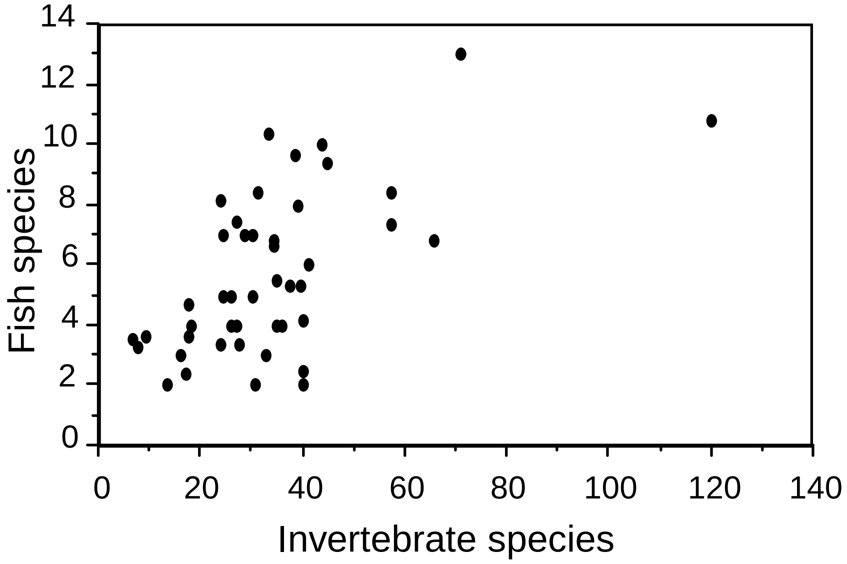

Fig. 3.31. Relationship between mean number of fish (F) and macrofaunal invertebrate (M) species collected at sites in different estuaries ($F = 2.79 + 0.086 * M$; $r^2 = 0.37$).

The mean $\log_3$ abundances of all fish species collected during estuarine sampling within each of 12 regions around Tasmania are shown in Table 3.38. The regions are the same as used for benthic invertebrate data, except that intensive sampling in the northeast region made it desirable to split that region into two to maintain comparable sample sizes in different regions. The regions are: northwest (Welcome Inlet to Detention River), central north (Inglis River to Port Sorell), eastern north (Tamar River to Ringarooma River), upper north east (Little Musselroe Bay to Grants Lagoon), lower north east (Georges Bay to Douglas River), east (Bryans Lagoon to Blackman Bay), Derwent (Carlton River to Browns River), Huon (Port Cygnet to Esperance and Cloudy Bay), south (Lune River to Port Davey) and west (Macquarie Harbour to Arthur River). A full list of species collected in each estuary with mean $\log_3$ abundance is provided in Appendix 10.

Fishes collected during estuarine sampling generally possessed widespread geographic distributions. Only one species taken has not been recorded off the Australian mainland - the spotted handfish *Brachionichthys hirsutus*, an endangered species presently known only from the Derwent estuary and D'Entrecasteaux Channel. This species, like approximately half the species shown in Table 3.38, is only found in the downstream marine section of the estuary and is better categorised as a sheltered marine rather than estuarine species. Nine of the 101 species collected are primarily associated with freshwater habitats, and 41 species are primarily associated with estuaries. None of the fish species collected, with the exception of the rare vagrant *Girella tricuspidata*, can be categorised as marine species that are dependent on estuaries for nursery habitat.

A total of 32 species were collected within a single estuary only. Nearly all of these species most commonly occur in marine or freshwater habitats around Tasmania and are present as vagrants in estuaries. The species collected within a single estuary that have not been commonly recorded in marine habitats in Tasmania were all Australian mainland vagrants. These were: *Upeneus tragula* (North East Inlet), *Dicotylichthys myersi* (North East Inlet), *Kaupus costatus* (North East Inlet), *Pugnaso curtirostris* (Tamar estuary), *Siphonognathus radiatus* (Tamar estuary), *Philypnodon grandiceps* (Mersey estuary), *Cristiceps argyropleura* (Sea Elephant estuary) and *Vanacampus poecililaemus* (Georges Bay estuary). *Upeneus tragula* and *D. myersi* are commonly found in marine embayments in New South Wales, *P. grandiceps* occurs in rivers from Queensland to South Australia, while the remaining five species generally associate with seagrass beds along the southern Australian coast.

The number of fishes collected in the various estuaries showed little regional consistency around the Tasmanian coastline due to huge differences in sampling effort between estuaries. Intensely studied estuaries show as black spikes in Fig. 3.32. Nevertheless, when regional patterns are smoothed by assuming a species range overlaps an estuary if that species occurs within six sampled estuaries in both directions along the coast, then changes in species richness around the coast are evident (Fig. 3.32). The region of highest diversity extends from Flinders Island and northeastern Tasmania to the Huon region, with a slight depression along the central east coast. The eastern north and northwest coasts also have a relatively large pool of species, whereas relatively few species are present on the west coast and central north coast.

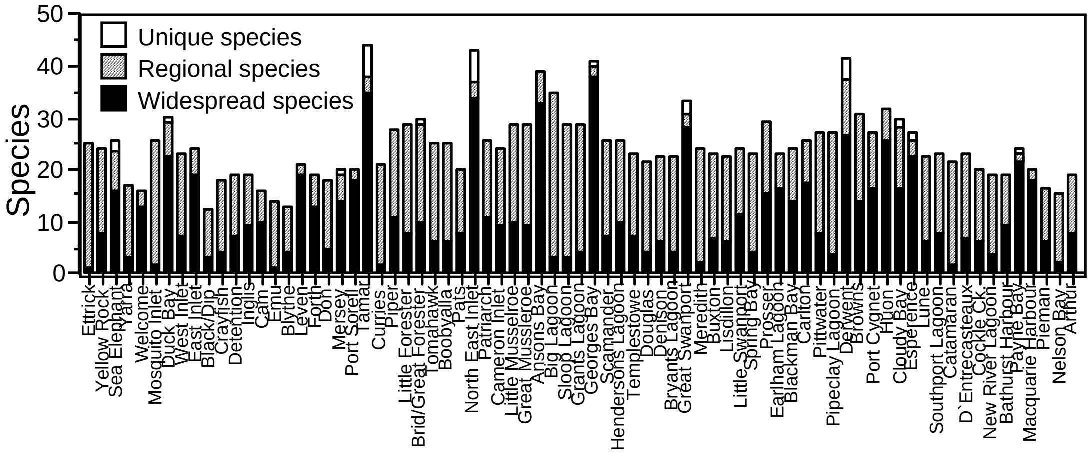

Fig. 3.32. Number of species collected solely at each sample site (unique species), number of species collected that occurred at more than one site (widespread species), and number of species interpolated to occur in the same region because they were present within the six nearest sites in both directions along the coast (regional species). Sites are arranged in geographic order around the coast with King Island inserted between Arthur River and Welcome Inlet and the Furneaux Group inserted between Boobyalla estuary and Little Musselroe Bay.

Table 3.38. Mean $\log_3$ abundance of fish species sampled at sites in different regions. Regions are King Island, northwest, central north, eastern north, Flinders Island, upper north east, lower north east, east, Derwent, Huon, south and west. *Species primarily associated with estuaries. **Species primarily associated with freshwater habitats.

Species	King	NW	CN	EN	linders	UNE	LNE	E	erwent	Huon	S	W
Acanthaluteres spilomelanurus	0.18	0.82	0	0.19	0.21	0.16	0.23	0.34	0.10	0.93	0.26	0.01
Acanthaluteres vittiger	0	0.13	0	0.06	0.07	0	0	0.06	0	0.13	0	0
*Acanthopagrus butcheri**	0	0	0	0	0	0.01	0.63	0.04	0.30	0	0	0
Alabes dorsalis	0	0	0	0	0	0	0	0	0	0.29	0	0
*Aldrichetta forsteri**	3.25	1.98	3.50	5.85	3.21	1.56	2.73	1.87	1.84	0.35	0.52	1.39
Ammotretis liturata	0	0	0	0	0	0	0.07	0	0.01	0.06	0.02	0.27
*Ammotretis rostratus**	0.93	0.97	0.70	0.53	0.37	0.42	1.57	2.34	0.46	0.76	0.63	0.58
*Anguilla australis***	0	0	0.02	0	0.57	0.09	0	0.03	0.06	0	0.04	0
*Anguilla reinhardtii***	0	0	0	0	0	0	0	0.01	0	0	0	0
Apogon conspersus	0	0	0	0	0	0	0.01	0	0	0	0.03	0
Aracana aurita	0	0	0	0	0	0	0	0	0	0.16	0	0
*Arenigobius bifrenatus**	0	0.01	0	0	0	0.03	0.08	0	0	0.06	0	0
*Arenigobius frenatus**	0	0	0	0.01	0	0	0	0	0	0	0	0
Arnoglossus bassensis	0	0	0.01	0	0	0	0	0	0	0	0	0.01
Arripis spp.	0.96	0.21	0.64	0.82	0.48	0.10	2.05	0.96	0.88	0.41	0.49	0.04
*Atherinasoma microstoma**	1.82	0.30	1.15	1.54	4.87	4.83	2.49	2.54	2.15	0.38	1.48	0.30
Atherinason hepsetoides	0	0	0	0.03	0	0	0	0	0.02	0	0	0
Atypichthys strigatus	0	0	0	0	0	0.01	0	0	0	0.13	0	0
Bovichtus angustifrons	0	0	0	0.06	0	0	0.01	0	0	0	0	0
Brachaluteres jacksonianus	0	0	0	0	0.08	0	0.01	0.01	0	0.03	0	0
Brachionichthys hirsutus	0	0	0	0	0	0	0	0	0.01	0	0	0
Chelidonichthys kumu	0	0	0	0	0.01	0	0	0	0	0	0	0
*Contusus brevicaudus**	0	0.09	0.10	0.30	0.07	0	0	0	0	0	0	0
*Contusus richei**	0	0.02	0.19	0.02	0.31	0	0	0.14	0	0.05	0	0
Crapatalus munroi	0	0	0.01	0	0.01	0	0.01	0	0	0	0.13	0
*Cristiceps argyropleura**	0.07	0	0	0	0	0	0	0	0	0	0	0
*Cristiceps australis**	0.21	0	0	0.03	0	0	0.08	0.14	0.05	0.39	0.03	0
Dicotylichtys myersi	0	0	0	0	0.08	0	0	0	0	0	0	0
Diodon nichthemerus	0	0.02	0	0	0.01	0	0.02	0	0.01	0	0	0
Engraulis australis	0	0.02	0.04	0.02	0	0.02	0.07	0.01	0.08	0	0	0
Enoplosus armatus	0	0	0	0.01	0	0	0	0	0	0	0	0
*Favonigobius lateralis**	0	0.19	0.11	0.38	0.31	0.06	0.30	0.03	0	0	0	0
*Favonigobius tamarensis**	0.39	0.09	0.88	0.10	0.54	0.14	0.60	0.35	0.53	0.55	0.92	0.01
*Galaxias maculatus***	1.46	1.10	1.76	0	0	0.03	0.08	0.32	0.25	0.70	0.44	1.81
*Galaxias truttaceus***	0	0	0.20	0	0	0	0	0	0.01	0.06	0.20	2.07
Genypterus tigerinus	0	0	0	0	0.06	0	0	0	0	0	0	0
*Girella tricuspidata**	0	0.02	0	0	0.07	0.02	0.09	0	0	0	0	0
*Gymnapistes marmoratus**	0	0.14	0	0.11	0.55	0.03	0.08	0.34	0.44	0.48	0.34	0
*Haletta semifasciata**	0	0.18	0	0.02	0	0	0	0.06	0	0.04	0	0
Heteroclinus forsteri	0.11	0	0	0	0	0	0	0	0	0	0	0
Heteroclinus heptaeolus	0.07	0	0	0	0	0	0	0	0	0	0	0
*Heteroclinus perspicillatus**	0.11	0	0	0.09	0.04	0.04	0.11	0.13	0.02	0.53	0.13	0
Hippocampus abdominalis	0	0	0	0	0	0	0	0	0.01	0.10	0.02	0.01
*Hippocampus breviceps**	0	0	0	0	0	0	0	0	0	0.05	0	0
Hyporhamphus melanochir	0	0	0	0	0.06	0	0.03	0.05	0.09	0	0	0
Kathetostoma laeve	0	0	0	0	0	0	0	0	0	0	0.01	0
*Kaupus costatus**	0	0	0	0	0.03	0	0	0	0	0	0	0
*Kestratherina brevirostris**	0	0.07	0	0.09	0	0.02	0	0	0.01	0.25	0.02	0
*Kestratherina esox**	0	0	0	0.02	0	0	0	0.24	0.04	0.03	0.25	0
Latridopsis forsteri	0	0	0	0	0	0	0	0.01	0	0	0	0

Table 3.38 (cont.). Mean log3 abundance of fish species sampled at sites in different regions. Regions are King Island, northwest, central north, eastern north, Flinders Island, upper north east, lower north east, east, Derwent, Huon, south and west. Undescribed gobies follow the nomenclature of Last et al. (1983). *Species primarily associated with estuaries. **Species primarily associated with freshwater habitats.

Species	*King*	*NW*	*CN*	*EN*	*linders*	*UNE*	*LNE*	*E*	*erwent*	*Huon*	*S*	*W*
*Leptatherina presbyteroides**	0.04	1.08	0.67	1.83	1.06	2.38	0.20	2.66	2.04	2.88	2.37	0.60
Lesueurina platycephala	0.07	0	0	0	0	0	0	0.25	0.01	0	0.02	0.04
*Lovettia sealii***	0	0.01	0.36	0.03	0	0	0	0	0.02	0	0.35	0.14
Meuschenia freycineti	0	0.36	0	0.02	0.07	0.13	0.12	0.14	0.05	0.13	0	0
*Mitotichthys semistriatus**	0	0.13	0	0	0	0	0	0	0	0.41	0	0
Mugil cephalus	0	0	0	0	0.33	0	0	0	0	0	0	0
Myliobatis australis	0	0	0	0	0	0	0	0	0.01	0	0	0
*Myxus elongatus**	0	0	0	0	0.10	0.03	0.05	0.03	0	0	0	0
*Nannoperca australis***	0	0	0	0.03	0	0	0	0	0	0	0	0
Nemadactylus macropterus	0	0	0	0	0	0	0	0.02	0.02	0	0	0
Neoodax balteatus	0	0.16	0	0.05	0	0.01	0	0.30	0.05	0.63	0.13	0
Neosebastes scorpaenoides	0	0.01	0	0	0	0	0	0	0	0	0	0
Nesogobius hindsbyi	0	0.01	0	0.01	0	0	0.03	0	0.28	1.06	1.30	0.01
Nesogobius pulchellus	0	0	0	0	0	0	0.03	0	0	0.06	0	0
Nesogobius sp.2	0.39	2.11	0.19	0.35	0.94	2.02	1.20	0.99	2.33	2.61	1.63	0.06
Nesogobius sp.3*	0	0	0	0.01	0	0	0	0	0	0	0	0
Nesogobius sp.5*	0	0	0	0.01	0	0.03	0.06	0.02	0.07	0.40	0.05	0.01
Nesogobius sp.7	0	0	0	0	0	0	0	0	0	0.05	0	0
Notolabrus tetricus	0.04	0.02	0	0.14	0	0.01	0	0.02	0	0	0	0
*Oncorhynchus mykiss***	0	0	0.02	0	0	0	0	0	0.05	0	0	0
Ophiclinus gracilis	0	0	0	0	0	0	0	0	0	0.04	0	0
*Philypnodon grandiceps***	0	0	0.04	0	0	0	0	0	0	0	0	0
Platycephalus bassensis	0	0.39	0.07	0.07	0.11	0	0.04	0.03	0.06	0.30	0.14	0.01
Platycephalus castelnaui	0	0	0	0.04	0.01	0	0	0	0	0	0	0
Platycephalus laevigatus	0	0.25	0	0	0.03	0	0	0	0	0	0	0
Pomatomus saltatrix	0	0	0	0	0.17	0	0.02	0	0	0	0	0
*Prototroctes maraena***	0.38	0	0	0	0	0	0	0	0	0	0	0.79
*Pseudaphritis urvillii**	0.29	0.02	0.02	0.07	0.44	0.20	0.22	0.11	0.73	1.43	1.64	0.33
Pseudocaranx dentex	0	0	0.02	0.03	0.08	0.16	0.35	0.03	0	0.09	0	0
*Pseudogobius olorum**	0	0.15	0.07	0	0.88	0.65	0.07	0.35	0.49	0	0.38	0
Pseudophycis barbatus	0.07	0.02	0	0	0	0	0	0.01	0.01	0	0	0
*Pugnaso curtirostris**	0	0	0	0.01	0	0	0	0	0	0	0	0
*Retropinna tasmanica**	0.25	0.15	0.46	0.04	0	0	0	0	0.40	0.25	1.69	1.00
Rhombosolea tapirina	0	2.56	1.70	0.79	1.10	0.79	1.08	2.02	2.34	1.21	1.34	0.94
Sillago flindersi	0	0	0	0	0	0	0	0.01	0	0	0	0
Siphamia cephalotes	0	0	0	0.01	0	0	0	0	0	0	0	0
Siphonognathus radiatus	0	0	0	0.01	0	0	0	0	0	0	0	0
Spratelloides robustus	0	0	0	0.05	0.08	0	0	0	0	0	0	0
*Stigmatopora argus**	0	0	0	0.02	0.24	0.10	0.08	0.11	0	0.53	0.12	0
*Stigmatopora nigra**	0	0.59	0	0.03	0.08	0.18	0.58	0.78	0.11	0.33	0.13	0.05
Taratretis derwentensis	0	0	0	0	0	0	0	0	0.01	0	0	0
*Tasmanogobius lasti**	0.71	0.11	0.19	0	0.31	0	0.03	0.09	0.58	0.40	1.50	0.04
*Tasmanogobius lordi**	0	0.18	0.62	0.02	0	0	0	0.01	0.01	0.63	0	0.19
*Tetractenos glaber**	0	0.14	0.43	1.16	0.43	0.20	0.07	0.16	0.10	0.66	0.09	0
Trachurus declivis	0	0	0	0	0.01	0	0	0	0	0	0	0
Upeneus tragula	0	0	0	0	0.01	0	0	0	0	0	0	0
*Urocampus carinirostris**	0	0	0	0	0	0.07	0.06	0.02	0	0	0	0
Urolophus cruciatus	0	0	0	0	0	0	0	0	0.01	0	0	0
Urolophus paucimaculatus	0	0	0	0	0	0	0	0	0.01	0	0	0
*Vanacampus phillipi**	0	0.38	0	0.02	0.15	0.02	0.07	0.01	0.05	0.21	0	0
*Vanacampus poecililaemus**	0	0	0	0	0	0	0.01	0	0	0	0	0

A total of 17 species were considered to show restricted ranges in Tasmania on the basis of the present study. These fishes, which are listed in Table 3.39, were collected from more than one estuary and did not extend outside five adjacent regions around the Tasmanian coast. The majority of these species are better categorised as marine vagrants rather than estuarine species, with only the toadfish *Contusus brevicaudus*, sand mullet *Myxus elongatus*, bream *Acanthopagrus butcheri* and the pipefish *Urocampus carinirostris* and *Mitotichthys semistriatus* primarily associated with estuarine habitat, and the grayling *Prototroctes maraena* primarily associated with freshwater.

Table 3.39. Number of estuaries in which fish species with restricted ranges in Tasmania were collected. Species collected in a single estuary are not individually listed in the table but are grouped in 'total species (+ singletons)'. Regions are as described in Table 3.2.

Species	*King*	*NW*	*CN*	*EN*	*urneau*	*UNE*	*LNE*	*E*	*erwent*	*Huon*	*S*	*W*
Platycephalus laevigatus	0	1	0	0	1	0	0	0	0	0	0	0
Contusus brevicaudus	0	1	1	2	1	0	0	0	0	0	0	0
Spratelloides robustus	0	0	0	1	1	0	0	0	0	0	0	0
Platycephalus castelnaui	0	0	0	2	1	0	0	0	0	0	0	0
Bovichtus angustifrons	0	0	0	2	0	0	1	0	0	0	0	0
Mugil cephalus	0	0	0	0	2	0	0	0	0	0	0	0
Pomatomus saltatrix	0	0	0	0	1	0	1	0	0	0	0	0
Myxus elongatus	0	0	0	0	1	1	1	1	0	0	0	0
Hyporhamphus melanochir	0	0	0	0	1	0	1	2	1	0	0	0
Acanthopagrus butcheri	0	0	0	0	0	1	3	1	1	0	0	0
Urocampus carinirostris	0	0	0	0	0	1	1	1	0	0	0	0
Nesogobius pulchellus	0	0	0	0	0	0	1	0	0	1	0	0
Nemadactylus macropterus	0	0	0	0	0	0	0	1	1	0	0	0
Aracana aurita	0	0	0	0	0	0	0	0	0	2	0	0
Hippocampus abdominalis	0	0	0	0	0	0	0	0	1	2	1	1
Prototroctes maraena	1	0	0	0	0	0	0	0	0	0	0	2
Arnoglossus bassensis	0	0	1	0	0	0	0	0	0	0	0	1
Total species	1	2	2	4	8	3	7	5	4	3	1	3
Total species (+ singletons)	4	3	3	11	14	3	8	8	9	7	2	3
Estuaries sampled	4	8	9	7	4	6	6	10	5	4	8	4
Site.days sampled	17	29	37	36	23	26	42	39	47	24	25	40

The highest concentration of species with restricted ranges occurred in the Furneaux region, with a total of eight species distributed in two or more estuaries plus six species collected in a single estuary only (North East Inlet). The high number of regional species around Flinders Island was evident despite relatively little sampling effort in the region. Field work was restricted to four estuaries sampled on a total of only 23 site.days.

Moderately-high concentrations of species with restricted ranges occurred around the northeastern and southeastern coasts of Tasmania, from the Tamar estuary to Esperance. Few restricted species were collected on the south, west or northwest coasts or King Island.

3.3.3 Multivariate analyses

Fish data obtained from the 39 estuaries sampled most frequently (>5 site.times) have been analysed using multidimensional scaling, and results presented in Fig. 3.33. A three-dimensional plot has been used because of the high stress value associated with the associated two dimensional plot (stress = 0.21 *cf.* 0.14 for 3-d plot). The mean $\log_3$ abundance ranks for fish species recorded in each estuary were used in this analysis.

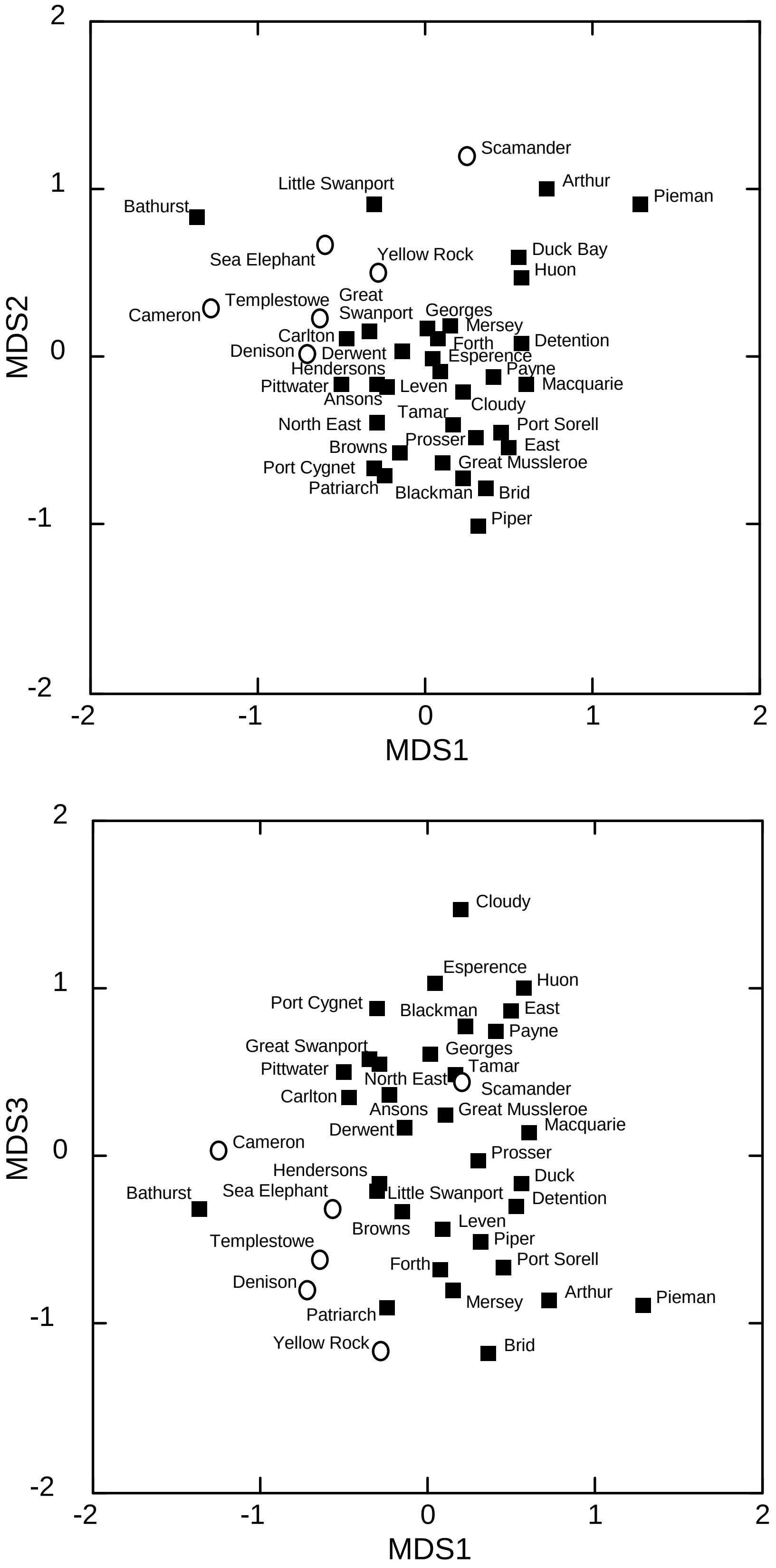

Fig. 3.33. Results of three-dimensional MDS analysis using fish data. The stress-statistic associated with these plots in 0.14. Sites in estuaries that are sometimes closed by bar are shown by open circle, sites in permanently-open estuaries are shown by filled squares.

The major environmental factor associated with differences in fish assemblages between estuaries was the presence of a seaward barrier (see Fig. 3.33). The BIOENV procedure indicated that this variable alone had the greatest correlation with the Bray-Curtis similarity matrix relating fish faunas in estuaries (r = 0.344). Other variables used in this procedure were latitude, summer surface salinity in central region, tidal range, log total annual runoff, presence of seagrass within estuary, log human population density and the naturalness index. SIMPER analysis indicated that the fish species particularly associated with open estuaries were free-swimming species (*Arripis* spp., *Leptatherina presbyteroides, Galaxias maculatus* and *Pseudocaranx dentex*) and seagrass-associated species (*Gymnapistes marmoratus, Stigmatopora nigra* and *Neoodax balteatus*), while soft-sediment demersal species (*Pseudaphritis urvillii, Favonigobius tamarensis, Tetractenos glaber* and *Pseudogobius olorum*) were disproportionately represented in closed estuaries.

A bubble plot overlay of summer surface salinity in the central region of each estuary indicated that this factor was associated with differences in estuary assemblage type on MDS axes 1 and 3 (Fig. 3.34); however, this variable presumably interacted with barrier presence. Tidal range inside the entrance of estuaries had no clear effect on fish assemblages present within the estuary (Fig. 3.35).

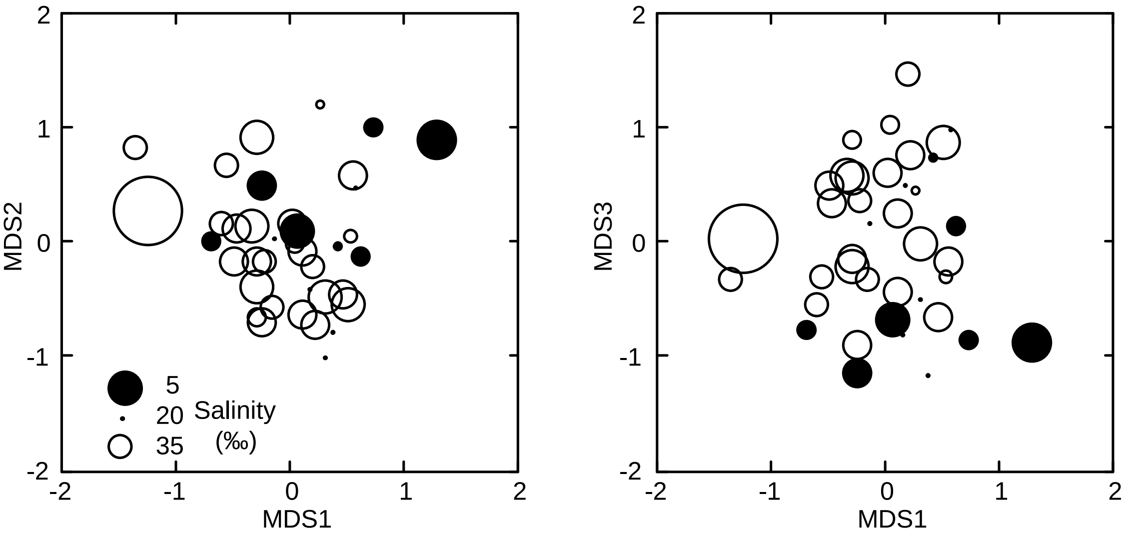

Fig. 3.34. Bubble plot overlay of salinity at time of benthic sampling on MDS results. Sites with high salinities are shown with large open circles while low salinity values are shown by large filled circles.

The one additional environmental variable that showed a strong correlation with the fish similarity matrix, and also interacted with estuary barring, was the presence of seagrass within the estuary (Fig. 3.36). This factor separated on MDS axis 3. Estuaries with seagrass present clearly included a large component of species that were absent from estuaries lacking seagrass.

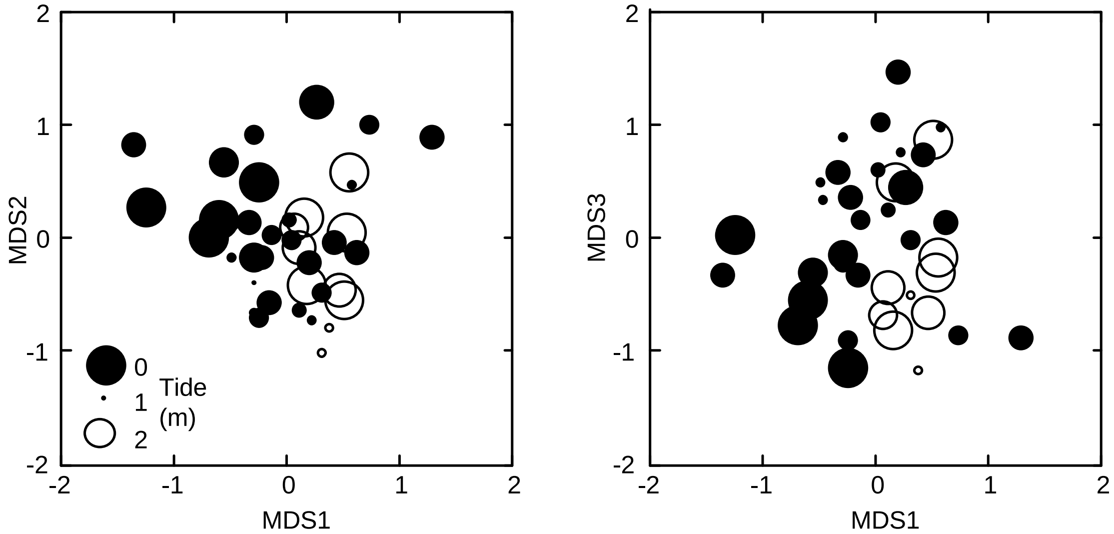

Fig. 3.35. Bubble plot overlay of salinity at time of benthic sampling on MDS results. Sites with high salinities are shown with large open circles while low salinity values are shown by large filled circles.

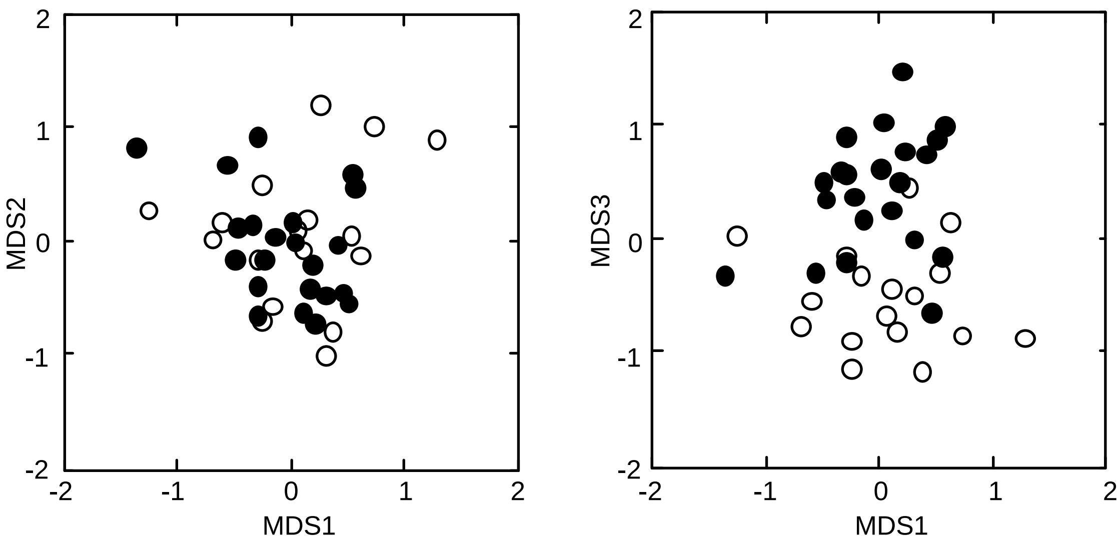

Fig. 3.36. Bubble plot overlay of presence of seagrass beds within the estuary on MDS results. Estuaries with seagrass beds present are shown by open circles, estuaries lacking beds are shown by filled circle.

Most of the estuarine groups produced by multivariate classification of environmental data included distinctive fish assemblages (global r = 0.347); however, Group II and Group III estuaries were completely overlapping, and several other estuary groups were not found to be significantly different in paired comparisons (Analysis 1 in Table 3.40).

Table 3.40. Results of ANOSIMs comparing similarities between paired estuarine groups using fish data and estuarine groups with more than four sites sampled. Analysis 1 used estuarine groups identified from multivariate analysis of physical data, while these groups were slightly modified using the categorisation system described in Table 3.31 for analysis 2.

Group 1	Group 2	*Analysis 1*		*Analysis 2*	
		r-statistic	*p*	*r-statistic*	*p*
I	II	0.533	0.006	0.397	0.001
I	III	0.535	0.002	0.663	0.001
I	V	0.472	0.005	0.388	0.016
I	VII	0.323	0.086	0.362	0.032
II	III	- 0.028	0.570	0.036	0.317
II	V	0.329	0.015	0.179	0.065
II	VII	0.176	0.142	0.140	0.196
III	V	0.400	0.002	0.757	0.001
III	VII	0.217	0.116	0.349	0.027
V	VII	0.444	0.005	0.481	0.008

In contrast to the invertebrate data set, changes to the classification system to better reflect tidal range and salinity within estuaries only slightly improved the explanation of fish data (global r = 0.354). Group II and Group III estuaries remained non-significantly different, as were Group II and VII estuaries and Group II and V estuaries (Analysis 2 in Table 3.40). Group II estuaries thus included a heterogeneous assemblage of fishes that overlapped with a range of other estuary groups.

3.4 Factors affecting Conservation Significance of Estuaries

3.4.1 Human population density

The 1991 census of Tasmanian population (Australian Bureau of Statistics, 1993) recorded a total population of 452,851. Population statistics were collected from 953 collection districts (CDs), with an average population of 475 (mode 426). The census counted 156,686 dwellings of which 138,929 (around 88%) were occupied on census night (Table 3.41).

Table 3.41. Summary of Census Data for Tasmanian census districts in 1991.

	Total	*Mean*	*Mode*
No. of districts	953	-	-
Population	452,851	475	426
Dwellings	156,686	164	133
Occupied dwellings	138,929	146	140
Proportion occupied (%)	88.7	-	-

GIS analysis of population and dwelling densities gave estimates of population and dwellings for each catchment area (Appendix 6). These results are summarised for estuarine catchment areas (ECAs), freshwater drainage areas (FDAs) and estuarine drainage areas (EDAs) in Table 3.42. Errors in these estimates result from mismatching of catchment boundaries and CD boundaries (as discussed in section 2.7), loss of resolution in transforming data from a vector coverage to a grid, and using a 1 ha grid cell size for analysis. The total population for Tasmania derived by GIS analysis is 454,998. This overestimates the population by around 0.5%.

Table 3.42. Total Population and Dwellings in Tasmanian Catchments.

Area	*Population*		*Dwellings*		*Occupied*	
	Number	*%*	*Number*	*%*	*Number*	*%*
ECA	381017	83.7	129135	81.7	137435	83.9
FDA	161104	35.4	58341	36.9	56785	34.7
EDA	219913	48.3	70794	44.8	80650	49.2
Outside	73981	16.3	28832	18.3	26391	16.1
Tasmania	454998	100.0	157967	100.0	163826	100.0

Nearly half of Tasmania's population lives in areas that drain directly into estuaries (EDAs), with 84% living within estuarine catchment areas (Table 3.41). Thirty-five percent live in inland river catchments, while around 16% live outside ECAs. The area outside catchments mostly consists of land in the coastal zone that drains directly to the ocean or to small streams that run into the ocean and are not identified as estuaries in this study. Adding the population outside of catchments to the population in estuarine drainage areas gives an estimation of the population inhabiting the coastal zone of Tasmania. By this calculation, approximately two thirds (67%) of the population lives in the coastal zone.

On a regional basis, the population of Tasmania is largely concentrated in catchments along the southeast, northwest and northeast coasts (Table 3.43). The latter region has a very high total population largely because Launceston has been included in that region. By contrast, catchments along the south coast and in the Furneaux Group possess very few inhabitants and negligible population densities.

Table 3.43. Mean estimated number of inhabitants and population density of estuarine catchment areas and estuarine drainage areas in different regions of Tasmania. Regions as defined in Table 3.2.

Region	*ECA*	*EDA*

	Population	*Density*	*Population*	*Density*
King Island	112	1.70	2	5.01
Furneaux Group	7	0.06	1	0.27
Northwest	3112	6.53	1620	91.03
Eastern north	14845	4.03	4960	22.19
East	232	1.29	117	11.92
Southeast	10339	14.01	8221	59.65
South	2	0.00	2	0.01
West	873	0.63	42	0.11
Tasmania	3425	4.07	1985	28.89

Catchments in all regions other than the west coast possess much lower population densities in freshwater drainage areas than in estuarine drainage areas, indicating that population centres are located on estuaries in most catchments. The west coast of Tasmania is anomalous because only one town, Strahan, occurs on the coast, whereas several mining towns of moderate size occur inland in this region.

3.4.2 Land tenure

Approximately one third of land in Tasmania is privately owned, one third is contained in National Parks and reserves, and one third is crown land available for forestry and other exploitative purposes (Table 3.44). The extent of private land in different regions of Tasmania varies from negligible levels along the south and west coasts to 84% of the total on King Island. About half the land in catchments in the other five regions is owned privately.

Only a small proportion of land is contained in crown reserves and National Parks in catchments in the King Island, Furneaux Group, northwest, northeast and east regions. By contrast, nearly all land in catchments along the south coast and much of the land in catchments on the west coast is contained in the Southwest National Park. The area of different land tenure types in each estuary catchment is listed in Appendix 7.

Table 3.44. Mean proportion (%) of major land tenure classes in catchments of estuaries in different Tasmanian regions. Regions as described in Table 3.2.

Region	*National Park*	*Crown Reserve*	*Crown Exploited*	*Private*
King Island	0	8.3	8.2	83.5
Furneaux Group	0	9.2	47.9	42.9
Northwest	9.7	4.7	34.8	50.8
Eastern north	1.1	4.2	31.1	63.5
East	4.1	8.4	38.6	49.0
Southeast	17.9	5.8	27.9	48.4
South	98.7	0	1.3	0
West	52.7	3.4	41.5	2.4
Tasmania	24.9	5.5	33.3	36.3

3.4.3 Landtype and degree of naturalness

On the basis of satellite images, the surface area of Tasmanian mainland catchments has been categorised into six land type classes (Appendix 8). Approximately half of the surface of Tasmania is covered by woody vegetation, with half of the remainder covered by natural heaths and shrubs (Table 3.45). Cleared areas are most prevalent in catchments in the northeast of the state, particularly the Tamar, and in the northwest, southeast and east. Little clearance has occurred in catchments on the west coast, and negligible clearance has occurred in the south. Only a very small proportion of the total area of the state is occupied by urban development, with the largest proportion occurring around Hobart in the southeast.

Table 3.45. Mean proportion (%) of major landtype classes in estuary catchments in different Tasmanian regions. Regions as described in Table 3.2.

Region	Woody	Herbaceo	Bare	Water	Cleared	Urban	Unclassified
Northwest	59.73	11.29	2.04	0.71	25.61	0.21	0.41
Eastern north	52.10	9.58	1.83	1.71	34.41	0.35	0.02
East	66.75	10.91	2.33	0.25	19.53	0.19	0.02
Southeast	52.94	21.62	1.51	2.18	20.93	0.45	0.37
South	42.62	55.93	1.13	0.26	0.06	0.00	0.00
West	55.55	35.87	2.25	4.99	1.03	0.01	0.29
Tasmania	54.99	23.01	1.93	2.62	17.00	0.22	0.23

The extent to which mainland Tasmanian catchments and estuarine drainage areas are affected by anthropogenic change has been assessed using a naturalness index (NI). This index increases from a base of 1 in pristine areas lacking cleared land or urban areas, and is weighted by a factor of 5 for cleared areas and a factor of 20 for urban areas (see section 2.9; Table 3.46).

Table 3.46. Number of estuarine catchment areas and estuarine drainage areas around the Tasmanian mainland placed in different naturalness index classes.

Class	*NI*	*Naturalness*	*ECA*	*EDA*
1	1.00	Pristine	24	28
2	1.01-1.5	Natural	20	7
3	1.5-2.0	Low impact	17	9
4	2.0-3.0	Moderate impact	21	20
5	3.0-4.0	High impact	7	17
6	>4.0	Severe impact	1	9

The majority of estuarine catchments around the Tasmanian mainland were little affected by anthropogenic impacts (NI<2.0). Twenty-four ECAs (29% of total), most of which were located in the Tasmanian Wilderness World Heritage Area, were identified as pristine.

Eight ECAs were rated severely or highly impacted (Pipeclay Lagoon, Little Musselroe, Don, West Inlet, Grindstone, East Inlet, Pittwater and Duck Bay). In addition, many of the catchment areas classed as moderately impacted also have severely or highly impacted estuarine drainage areas. The severely impacted EDAs were the Emu, Don, Mersey, Forth, Cam, Leven, Pipeclay Lagoon, Spring Bay and Pittwater.

Values of the naturalness index are shown for all Tasmanian mainland estuaries in Tables 3.47-3.53. These tables also incorporate summary information on the population density and land tenure usage of each estuary, and presence of marine farm leases, with estuaries listed within the physical classes of estuary derived by multivariate analysis. Estuaries included in each of these tables are listed in order of anthropogenic disturbance, following the mean ranking of NI and population densities of both estuarine catchment areas and estuarine drainage areas.

Eight Group I estuaries (low salinity estuaries that are intermittently barred) lack population within catchments and possess a naturalness index of 1.00 (Table 3.47), so can be considered pristine. These estuaries are located in the Furneaux Group, Freycinet National Park, and on the west and south coasts. Estuaries in Group I that are moderately or highly impacted by human activity are located on the east coast and King Island.

Table 3.47. Naturalness attributes of Group I estuaries (barred, low-salinity estuaries). Presence of a marine farm lease within or at entrance to estuary is indicated by M.

egion	*Estuary*	*Naturalness Index*		*Population (km^{-2})*		*ECA Land tenure (%)*			*EDA Land tenure (%)*			*Farm*
		ECA	*EDA*	*ECA*	*EDA*	*NP*	*Res*	*Crown*	*NP*	*Res*	*Crown*	
E	Bryans Lagoon	1.00	1.00	0.00	0.00	100.0	100.0	100.0	100.0	100.0	100.0	
W	Lagoon	1.00	1.00	0.00	0.00	0.0	100.0	100.0	0.0	100.0	100.0	
F	Mines			0.00	0.00	0.0	59.1	85.5	0.0	0.0	0.0	
F	Middle Inlet			0.00	0.00	0.0	0.0	12.3	0.0	0.0	100.0	

F	Shag Rock			0.00	0.00	0.0	0.0	100.0	0.0	0.0	100.0
F	Modder			0.00	0.00	0.0	0.0	100.0	0.0	0.0	100.0
S	Freney	1.00	1.00	0.00	0.00	28.6	28.6	100.0	28.6	28.6	100.0
W	Hibbs Lagoon	1.00	1.00	0.00	0.00	0.0	0.0	100.0	0.0	0.0	100.0
F	Logan Lagoon			0.14	0.00	0.0	0.0	43.7	0.0	0.0	43.7
E	Freshwater Lagoon	1.00	1.00	0.11	0.05	28.6	28.6	100.0	28.6	28.6	100.0
E	Big Lagoon	1.00	1.00	0.14	0.14	0.0	42.5	98.6	0.0	42.5	98.6
W	Nelson Bay	1.05	1.00	0.00	0.00	0.0	73.1	100.0	0.0	86.0	100.0

Table 3.47 (cont.). Naturalness attributes of Group I estuaries (barred, low-salinity estuaries).

egion	*Estuary*	*Naturalness Index*		*Population (km^{-2})*		*ECA Land tenure (%)*			*EDA Land tenure (%)*			*Farm*
		ECA	*EDA*	*ECA*	*EDA*	*NP*	*Res*	*Crown*	*NP*	*Res*	*Crown*	
W	Pedder	1.02	2.05	0.00	0.00	0.0	80.8	100.0	0.0	98.7	100.0	
E	Sloop Lagoon	1.00	1.00	0.40	0.40	0.0	15.1	100.0	0.0	15.1	100.0	
E	Saltwater Lagoon	1.44	1.44	0.00	0.00	9.3	9.3	47.9	9.3	9.3	47.9	
K	Sea Elephant			0.46	0.00	0.0	15.1	26.5	0.0	26.4	72.7	M
K	Seal			1.40	0.00	0.0	1.0	18.1	0.0	5.8	15.5	
E	Yellow Rock			0.67	1.73	0.0	1.9	2.0	0.0	0.0	10.9	
E	Grants Lagoon	1.00	1.00	7.25	7.25	0.0	23.9	65.3	0.0	23.9	65.3	
E	Buxton	1.34	3.18	0.22	7.89	0.0	18.3	73.8	0.0	0.0	0.0	
E	Scamander	1.19	1.92	1.79	19.06	0.0	5.9	94.4	0.0	17.7	42.8	
E	Templestowe	1.90	1.90	1.25	1.25	59.4	59.4	62.5	59.4	59.4	62.5	
E	Stoney	2.35	3.06	0.73	0.00	0.0	0.0	0.0	0.0	0.0	0.0	
E	Meredith	1.52	3.63	0.31	11.25	0.0	2.0	47.2	0.0	0.0	0.0	
E	Denison	1.14	2.38	0.93	77.78	85.5	85.5	85.5	0.0	0.0	0.0	
E	Lisdillon	1.56	3.86	0.50	6.82	0.0	1.3	45.1	0.0	0.0	0.0	M
K	Yarra			5.04	23.33	0.0	0.0	0.0	0.0	0.0	0.0	

Group II estuaries (open estuaries) comprise the largest group and best protected estuaries in Tasmania (Table 3.48). This category includes 5 undisturbed estuaries that are fully contained within National Parks and another 10 that are pristine and lack human residents. The Pittwater and Leven estuaries have EDAs that are classed as severely impacted by anthropogenic activity, and the Browns River, North West River and Leven estuaries have extremely high population densities.

Only one of the marine Group III estuaries remains in pristine condition - Southport Lagoon (Table 3.49). An additional three estuaries (Mosquito Inlet, North East Inlet and Cloudy Bay) are listed as relatively natural; however, the extent of land clearing in North East Inlet on Flinders Island has not been quantified and this estuary possibly has a NI>1.5. All of the other Group III estuaries have high population densities or drainage areas that are at least moderately impacted, with Pipeclay Lagoon and Spring Bay classed as having severely impacted drainage areas.

The majority of Group IV hypersaline lagoons in Tasmania possess catchments with negligible population densities (Table 3.50). Rocky Head and Thirsty Lagoon are located on Cape Barren Island and probably have pristine catchments, whereas the other lagoons and inlets lacking NI data are all located on Flinders Island and have catchments used partly for grazing. Sellars Lagoon and Logan Lagoon were both dry in February 1997.

Group V estuaries (river estuaries with large tidal ranges) are nearly all highly degraded by human activity (Table 3.51), and include the most impacted estuarine drainage areas in Tasmania (Emu, Don, Cam, Forth and Mersey Rivers). The Crayfish estuary remains in a relatively natural condition, although affected by a number of dwellings near the mouth.

Table 3.48. Naturalness attributes of Group II estuaries (open estuaries). Presence of a marine farm lease within or at entrance to estuary is indicated by M.

Region	*Estuary*	*Naturalness Index*		*Population* (km^{-2})		*ECA Land tenure* (%)			*EDA Land tenure* (%)			*Farm*
		ECA	*EDA*	*ECA*	*EDA*	*NP*	*Res*	*Crown*	*NP*	*Res*	*Crown*	
S	Payne Bay	1.00	1.00	0.00	0.00	100.0	100.0	100.0	100.0	100.0	100.0	
S	Louisa River	1.00	1.00	0.00	0.00	100.0	100.0	100.0	100.0	100.0	100.0	
S	Louisa Creek	1.00	1.00	0.00	0.00	100.0	100.0	100.0	100.0	100.0	100.0	
W	Giblin	1.00	1.00	0.00	0.00	100.0	100.0	100.0	100.0	100.0	100.0	
W	Mulcahy	1.00	1.00	0.00	0.00	100.0	100.0	100.0	100.0	100.0	100.0	
S	South Cape Rt	1.00	1.00	0.00	0.00	99.4	99.4	100.0	100.0	100.0	100.0	
SE	Catamaran	1.00	1.00	0.00	0.00	67.6	68.1	100.0	0.0	16.2	100.0	
W	Lewis	1.00	1.00	0.00	0.00	34.4	34.4	100.0	0.0	0.0	100.0	
W	Spero	1.00	1.00	0.00	0.00	34.9	34.9	100.0	0.0	0.0	100.0	
W	Mainwaring	1.00	1.00	0.00	0.00	0.0	0.0	100.0	0.0	0.0	100.0	
F	Foochow Inlet			0.00	0.00	0.0	16.3	35.9	0.0	0.0	92.5	
F	Dover			0.00	0.00	0.0	0.0	100.0	0.0	0.0	100.0	
F	Lee			0.00	0.00	0.0	0.0	100.0	0.0	0.0	100.0	
F	Rice			0.00	0.00	0.0	0.0	100.0	0.0	0.0	100.0	
SE	D`Entrecasteaux	1.00	1.00	0.00	0.00	61.7	61.9	98.2	0.0	2.8	78.1	M
F	Patriarch			0.12	0.00	0.0	0.2	19.5	0.0	0.0	82.9	
SE	Cockle Creek	1.00	1.00	0.89	2.57	69.8	70.3	100.0	53.2	54.8	100.0	
SE	Lune	1.01	1.03	0.71	1.19	44.7	48.1	94.7	0.1	14.0	71.1	M
K	Ettrick			0.91	0.00	0.0	0.7	1.1	0.0	0.0	0.0	
W	Little Henty	1.03	1.01	3.42	0.00	0.0	0.4	99.4	0.0	1.9	99.4	
F	Pats			0.43	4.10	0.0	0.6	53.1	0.0	32.8	32.8	
SE	Esperance	1.05	1.40	1.30	5.51	12.0	12.7	94.6	0.0	1.5	67.8	M
E	Ansons Bay	1.33	1.59	0.58	5.07	0.3	8.4	74.1	3.9	13.1	65.8	
E	Douglas	1.16	3.83	0.26	2.54	91.1	91.1	92.2	0.0	0.0	0.0	
SE	Garden Island	1.14	1.49	1.93	10.06	0.0	0.0	44.0	0.0	0.0	0.0	
E	Great Swanport	1.68	2.22	0.35	0.51	5.4	9.7	54.7	0.7	6.3	17.8	M
E	Great Musselroe	2.25	2.49	0.33	0.58	5.7	7.8	46.5	18.2	28.9	28.9	
E	Little Swanport	2.38	2.74	0.60	2.05	0.0	13.2	21.6	0.0	0.0	3.3	M
EN	Tomahawk	2.47	3.67	0.17	1.08	0.0	1.9	51.3	0.0	39.5	39.5	
E	Prosser	1.91	1.50	1.35	19.31	0.0	11.9	29.3	0.0	19.3	27.7	
SE	Port Cygnet	1.94	2.26	14.71	19.22	0.0	3.1	9.6	0.0	0.0	2.6	M
NW	Port Sorell	2.46	2.32	4.87	18.86	2.2	6.1	37.0	17.5	20.9	36.7	M
NW	Duck Bay	3.03	3.02	9.14	25.36	0.0	2.5	24.4	0.0	0.3	24.0	M
NW	Leven	2.03	4.40	11.40	131.75	0.0	1.3	42.1	0.0	5.7	9.7	
SE	North West Bay	1.97	2.79	39.33	126.32	0.0	11.5	24.8	0.0	11.6	14.9	
SE	Pittwater	3.07	4.09	8.90	44.05	0.0	3.5	10.5	0.0	13.1	13.1	M
SE	Browns	2.03	1.70	103.58	454.93	0.0	6.4	6.4	0.0	0.0	0.0	

Table 3.49. Naturalness attributes of Group III estuaries (marine inlets and bays). Presence of a marine farm lease within or at entrance to estuary is indicated by M.

egion	*Estuary*	*Naturalness Index*		*Population* (km^{-2})		*ECA Land tenure* (%)			*EDA Land tenure* (%)			*Farm*
		ECA	*EDA*	*ECA*	*EDA*	*NP*	*Res*	*Crown*	*NP*	*Res*	*Crown*	
SE	Southport Lagoon	1.00	1.00	0.00	0.00	0.1	0.1	81.3	0.0	0.0	73.7	
NW	Mosquito Inlet	1.06	1.06	0.00	0.00	0.0	0.0	0.0	0.0	0.0	0.0	
F	North East Inlet			0.03	0.21	0.0	58.6	74.8	0.0	39.6	41.2	
SE	Cloudy Bay	1.28	1.54	0.45	0.18	0.0	14.0	49.8	0.0	6.7	22.8	M
NW	Welcome	1.65	2.11	0.38	0.75	0.0	4.0	24.5	0.0	0.0	0.0	
E	Hendersons Lagoon	2.02	2.02	1.33	0.75	0.0	8.2	37.4	0.0	8.2	37.4	
EN	Little Musselroe	3.81	3.99	0.31	0.47	0.0	1.0	1.0	0.0	9.9	9.9	
E	Georges Bay	1.64	2.15	3.18	32.31	0.0	8.1	68.9	0.0	39.6	50.6	M
SE	Blackman Bay	1.99	2.65	3.49	4.97	0.0	4.8	36.9	0.0	0.0	2.5	M
SE	Crooks	1.53	1.98	9.34	23.13	0.0	0.0	60.0	0.0	0.0	0.0	
SE	Carlton	2.10	2.80	4.10	13.49	0.0	0.1	11.3	0.0	0.0	0.0	
NW	West Inlet	3.52	2.43	3.34	7.92	0.0	0.0	0.0	0.0	0.0	0.0	
NW	East Inlet	3.30	2.63	9.83	5.40	0.0	0.0	0.0	0.0	0.0	0.0	
E	Spring Bay	2.01	4.20	8.31	90.27	0.0	50.3	55.0	0.0	0.3	0.3	
SE	Pipeclay Lagoon	4.28	4.28	43.85	43.85	0.0	0.0	0.0	0.0	0.0	0.0	M

Table 3.50. Naturalness attributes of Group IV estuaries (hypersaline lagoons).

egion	*Estuary*	*Naturalness Index*		*Population* (km^{-2})		*ECA Land tenure* (%)			*EDA Land tenure* (%)			*Farm*
		ECA	*EDA*	*ECA*	*EDA*	*NP*	*Res*	*Crown*	*NP*	*Res*	*Crown*	
F	Thirsty Lagoon			0.00	0.00	0.0	0.7	100.0	0.0	0.7	100.0	
F	Rocky Head			0.00	0.00	0.0	0.0	100.0	0.0	0.0	100.0	
F	Sellars Lagoon			0.00	0.00	0.0	0.0	97.0	0.0	0.0	97.0	
F	Cameron Inlet			0.23	0.00	0.0	0.3	43.1	0.0	0.0	81.3	
E	Earlham Lagoon	1.60	2.65	0.16	0.68	0.0	2.1	54.0	0.0	0.0	6.1	
E	Grindstone	3.49	3.81	0.97	0.00	0.0	0.0	1.6	0.0	0.0	0.0	

Table 3.51. Naturalness attributes of Group V estuaries (large mesotidal river estuaries). Presence of a marine farm lease within or at entrance to estuary is indicated by M.

egion	*Estuary*	*Naturalness Index*		*Population* (km^{-2})		*ECA Land tenure* (%)			*EDA Land tenure* (%)			*Farm*
		ECA	*EDA*	*ECA*	*EDA*	*NP*	*Res*	*Crown*	*NP*	*Res*	*Crown*	
NW	Black/Dip	1.53	3.12	1.75	1.81	0.0	8.4	73.4	0.0	5.8	7.5	
NW	Crayfish	1.11	1.00	0.47	25.64	0.0	0.2	80.4	0.0	23.7	23.7	
NW	Detention	1.79	2.87	1.23	6.49	5.0	5.1	57.8	0.9	2.2	3.5	
EN	Boobyalla Inlet	2.01	3.29	1.63	0.69	0.0	3.8	65.6	0.0	25.8	29.0	
EN	Piper	2.57	1.74	3.56	2.85	0.0	1.7	30.6	0.0	0.3	4.9	
NW	Montagu	2.84	3.46	1.23	3.46	0.0	2.1	53.1	0.0	0.0	0.0	M
EN	Little Forester	2.14	3.98	2.36	7.79	0.0	0.2	44.0	0.0	14.3	17.5	
EN	Curries	1.80	3.18	3.27	65.87	0.0	26.9	68.2	0.0	25.1	43.1	
NW	Forth	1.57	4.50	2.46	69.87	32.4	33.2	72.4	0.0	3.6	3.6	
NW	Blythe	2.07	2.99	3.95	47.52	0.0	1.6	50.5	0.0	14.8	34.1	
EN	Brid/Great Forester	2.31	3.59	11.45	28.71	0.0	3.2	49.0	0.0	0.0	19.8	
NW	Mersey	1.91	5.62	11.47	285.41	19.0	30.3	65.1	0.0	0.0	0.0	
NW	Emu	2.10	7.05	6.61	217.09	0.0	1.4	19.5	0.0	6.8	6.8	
NW	Inglis	2.37	3.33	12.68	375.83	0.0	5.4	36.4	0.0	1.9	1.9	
NW	Cam	2.46	4.41	11.75	136.95	0.0	1.8	10.6	0.0	1.3	1.3	
NW	Don	3.66	5.84	25.01	278.49	0.0	3.2	5.6	0.0	0.0	0.0	

Amongst the Group VI and VII drowned river valleys, only Bathurst Harbour remains in a pristine condition (Table 3.52). At the other extreme, the largest Tasmanian cities are located on the Tamar (Launceston) and Derwent (Hobart) estuaries. The Macquarie Harbour estuary has a high NI and low population density indicating natural conditions, but is badly degraded as a result of acid mine drainage from Queenstown and the King River subcatchment.

Table 3.52. Naturalness attributes of Group VI (Tamar - mesotidal drowned river valley) and Group VII (microtidal drowned river valley) estuaries. Presence of a marine farm lease within or at entrance to estuary is indicated by M.

egion	*Estuary*	*Naturalness Index*		*Population* (km^{-2})		*ECA Land tenure* (%)			*EDA Land tenure* (%)			*Farm*
		ECA	*EDA*	*ECA*	*EDA*	*NP*	*Res*	*Crown*	*NP*	*Res*	*Crown*	
EN	Tamar	2.50	2.81	9.52	70.02	1.5	5.9	32.5	0.0	4.8	10.0	M
S	Bathurst Harbour	1.00	1.00	0.01	0.06	98.3	98.3	100.0	99.0	99.0	100.0	
W	Macquarie Harbour	1.01	1.01	4.81	1.07	77.6	78.5	99.9	24.2	37.5	98.7	M
SE	Huon	1.24	1.85	3.63	12.21	46.4	48.5	77.0	0.0	1.1	20.1	M
SE	Derwent	2.09	3.89	16.00	312.01	10.9	18.6	46.8	0.0	14.7	17.8	

The Group VIII and IX estuaries remain little affected by human activity and have low population densities (Table 3.53). The New River Lagoon and Wanderer estuaries remain pristine.

Table 3.53. Naturalness attributes of Group VIII (large open microtidal river) and Group IX (Wanderer - barred river) estuaries.

Region	*Estuary*	*Naturalness Index*		*Population* (km^{-2})		*ECA Land tenure* (%)			*EDA Land tenure* (%)			*Farm*
		ECA	*EDA*	*ECA*	*EDA*	*NP*	*Res*	*Crown*	*NP*	*Res*	*Crown*	
S	New River Lagoon	1.00	1.00	0.00	0.00	100.0	100.0	100.0	100.0	100.0	100.0	
W	Henty	1.02	1.12	0.14	0.00	0.0	1.3	98.7	0.0	0.0	77.6	
W	Pieman	1.09	1.00	0.76	0.30	18.9	21.5	97.5	0.0	72.4	100.0	
W	Arthur	1.16	2.22	0.31	0.32	0.0	12.1	84.0	0.0	18.6	48.3	
W	Wanderer	1.00	1.00	0.00	0.00	10.4	10.4	100.0	0.1	0.1	100.0	

4. Discussion

4.1 Biogeographic Patterns

The Tasmanian estuarine fauna consisted largely of species that were widely distributed within the state and also occurred in southeastern Australia. Many of the taxa found to be dominant in studies of Victorian and New South Wales estuaries were also collected in the present study (e.g., see Poore & Kudenov, 1978; Rainer, 1981; Poore, 1982; Jones *et al*., 1986; Jones, 1987). Nine of the twelve invertebrates that Poore (1982) named as widespread estuarine macroinvertebrate species in south-eastern Australia were collected, including the common invertebrates *Spisula trigonella*, *Tellina deltoidalis, Australonereis ehlersi, Nephtys australiensis* and *Callianassa arenosa*. The three species cited by Poore (1982) but not collected during our study were the polychaete *Ceratonereis erythaeensis* and the isopods *Colanthura peroni* and *Syncassidina aesturia*.

Only one of the 101 fish species collected during the study was endemic to Tasmania - the spotted handfish *Brachionichthys hirsutus*, an endangered species restricted to the lower Derwent estuary and nearby marine embayments. All of the described invertebrates listed amongst the 56 common species in Table 3.25 have been recorded on the Australian mainland. However, two of the undescribed species listed in Table 3.25, *?Exoediceroides* sp. and *Euzonus* sp., appear restricted to the state on current information. The amphipod *?Exoediceroides* sp. was collected only along the faunally-depauperate Tasmanian west coast, and was the dominant species in estuaries within that region. The ophelinid polychaete *Euzonus* sp. occurred commonly in mid intertidal sands at several marine-influenced sites.

A large number of undescribed invertebrate species were collected at only a single site during the study. The majority of these single-site species were probably collected at the one site because of limited sampling effort rather than because their ranges were narrowly restricted. Fishes were the sole faunal group with good distributional data available, and only the spotted handfish amongst the single-site fish species possessed a range that extended less than 500 km.

Marine conditions prevailed at most sites where single-site invertebrate species were collected, hence the majority of these animals were probably marine species that sporadically enter the lower reaches of estuaries. Only three invertebrate species were collected abundantly at single polyhaline estuarine sites.

The wide ranges of estuarine species agree well with the spans of marine species, yet contrast markedly with the generally narrow ranges of freshwater and terrestrial species (see Hockey & Branch, 1994). Approximately 3% of coastal marine fish species are restricted to Tasmania, a similar proportion to that recorded for estuarine species, whereas ≈50% of the freshwater fish fauna is endemic to the state (Last *et al*., 1983). Comparable disparities between patterns of endemism for estuarine and freshwater species appear to be the general rule elsewhere in the world (Whitfield, 1994a). The most likely hypotheses explaining the wide ranges of estuarine species are that: (i) estuarine species possess good dispersal mechanisms because they need to move between estuarine systems that disappear over periods of a few thousand years, and (ii) estuarine species evolve slowly due to a need to remain flexible in their response to fluctuating external environments (Whitfield, 1994a).

Species found in estuaries can be categorised into six groups on the basis of adaptations to particular salinity levels (Day, 1981):

- stenohaline marine species - organisms adapted to a narrow salinity range that are found at the saline mouth of an estuary;
- euryhaline marine species - organisms adapted to a wide range of salinity and which extend from the sea to areas of moderate salinity (≈25‰);
- true estuarine species - organisms restricted to estuarine waters
- euryhaline freshwater species - organisms restricted to low salinity waters associated with river flows;
- migratory species - organisms that pass into or through estuaries from either marine or freshwater environments, often for the purpose of spawning;

- terrestrial species - organisms found in the upper tidal levels that are distributed independently of salinity.

The stenohaline marine species category included approximately half of all species collected in the present study. Despite this high diversity, these species contributed only a small proportion of total faunal densities because they typically occurred in low abundance at a single site only. These invertebrate and fish species can be considered marine vagrants that occur around the coast and only irregularly enter the entrance of estuaries.

Euryhaline marine and estuarine species were the predominant animals at all sites investigated. The distinction of Day (1981) between animals restricted to estuaries and those that also occurred in sheltered marine embayments provided a useful subdivision in the present study. The euryhaline marine component consisted largely of sandflat species (including the invertebrates *Eubittium lawleyanum, Cyamiomactra mactroides, Zeacumanthus diemenensis* and *Wallucina assimilis,* and the fish *Nesogobius* sp. 2), seagrass-associated fishes (e.g., *Acanthaluteres spilomelanurus, Stigmatopora nigra, Urocampus carinirostris* and *Vanacampus phillipi*) and pelagic fishes (e.g., *Arripis* spp., *Aldrichetta forsteri, Engraulis australis* and *Pseudocaranx dentex*). The estuarine component included many of the most abundant and ubiquitous invertebrates (e.g., *Paracorophium excavatum, Ascorhis victoriae* and *Arthritica semen*) and fishes (e.g., *Atherinasoma microstoma, Leptatherina presbyteroides* and *Favonigobius tamarensis*).

The most notable feature of the freshwater component within Tasmanian estuaries was its scarcity. None of the common invertebrate species (listed in Table 3.26) were restricted to sites with observed salinities <5‰, and only three amphipod species (?*Exoediceroides* sp., *Exoediceroides latrans* and *Paracalliope vicinus*) were restricted to sites <15‰. Groups that are typically found in freshwater habitats, such as aquatic insects and planarians, were almost completely absent. The only common insects were chironomid midges and coleopteran and fly larvae, with the latter two taxa primarily associated with debris and vegetation in the high intertidal region. Many of the chironomids belonged to the genus *Pontomyia*, a genus absent from freshwater habitats but common in sheltered marine habitats around southern Australia (e.g., see Edgar, 1997). None of the fish species collected also occur commonly in freshwater habitats, other than the migratory species.

Migratory species were also rarely collected in Tasmanian estuaries; none of the invertebrates and only one of the common (*Galaxias maculatus*) and four of the rarer fish species could be assigned to this category (whitebait *Lovettia sealii,* rainbow trout *Oncorhynchus mykiss*, and the eels *Anguilla australis* and *A. reinhardtii*).

Invertebrate species with terrestrial affinities were collected at high tidal levels at nearly all sites. These species, including the extremely abundant isopod *Actaecia bipleura*, were little affected by the salinity of estuaries.

Geographic patterns of species richness for fishes and benthic invertebrates corresponded very closely with each other (Fig. 3.31, Fig. 3.8 *cf* Fig. 3.32), even though sampling for these two groups was primarily conducted in different decades, at different sites and by different investigators. The scale of sampling also differed greatly for fishes and invertebrates, with a single site sampled in most estuaries for macrofauna and several sites sampled less intensively for fishes.

Species richness was highest on a regional basis at Flinders Island, around the northeastern corner of Tasmania from the Tamar to Georges Bay, in southeastern Tasmania near the Huon, and in northwestern Tasmania from Welcome Inlet to East Inlet. Species richness was very low on the west coast and moderately low on the east coast, south coast, King Island and central north coast.

Patterns of variation in species richness around the state depended largely on variation in the number of stenohaline marine species, which in turn primarily reflected the number of marine inlets within a region rather than local patterns of endemism. The only general gradients in species richness observed were a slight decline from North East Inlet on Flinders Island to the north eastern Tasmanian coast, and from the northern and eastern coasts to the south and west. The latitudinal trend was most apparent for fishes because of the good distributional data available for that group. It involved only a small component (<10%) of fish species (*Upeneus tragula*, *Dicotylichtys myersi*, *Kaupus costatus, Platycephalus laevigatus*, *Platycephalus castelnaui*, *Mugil cephalus*, *Myxus elongatus* and *Pomatomus saltatrix*), none of which were abundant at any site.

The latitudinal decline in fish species richness was weak compared to that documented for marine species (see Edgar *et al*., 1994) and for estuarine species on other continents (e.g., Whitfield, 1994b), perhaps because of a general lack of marine species using estuaries for spawning or as nursery areas. Whereas Whitfield (1994b) considered that marine species dependent on estuaries for spawning or nurseries comprised a major component of the fish assemblage in South African estuaries, this category was only represented by one relatively rare species (*Girella tricuspidata*) in Tasmania.

Further sampling is required to determine whether the extremely high invertebrate species richness in North East Inlet and the Tamar estuary includes many species unique to those sites within Tasmania, or whether they primarily contain marine species that are distributed more widely around the Tasmanian coast. The latter is probably true for the Tamar estuary, the only site where the marine seagrass *Posidonia australis* was sampled, whereas conditions in North East Inlet appeared similar to those at several other estuarine sites.

The large number of species collected from southeastern Tasmanian estuaries, particularly those in the Huon region, is best attributed to the majority of sampled estuaries in that area possessing broad marine sandflats. Although most sites sampled in southeastern Tasmania possessed numerous species, very few invertebrates and only one fish species (*Brachionichthys hirsutus*) appeared restricted to that area. The western and southern Tasmanian coasts from Cockle Creek in the southeast to Welcome Inlet in the northwest include only one major estuary with marine sandflats, Payne Bay. While this estuary contains moderately high numbers of fish (Appendix 10; Edgar, 1991b) and invertebrate species (Table 3.10), the total pool of species along these coasts was very low (Fig. 3.8).

Extremely low species richness within the west coast Macquarie Harbour estuary has been recognised previously, and ascribed to high concentrations of toxic heavy metals released from the almost azoic King River subcatchment (O'Connor *et al.*, 1996). Low diversity in west coast estuaries was, however, a general rather than localised pattern, with numbers of invertebrate and fish species associated with river estuaries in the region also anomalously low compared to river estuaries on the north and east coasts.

The west coast depression in species richness was reflected to an even greater extent in data on invertebrate biomass and secondary productivity. These variables were estimated to be one to three orders of magnitude lower in west coast estuaries than in comparable estuaries elsewhere around the state, and are very low compared to other estuaries studied worldwide. Most intertidal and shallow subtidal estuarine habitats possess mean biomass values within the range from 10-50 g AFDW.m^{-2} (Kalejta & Hockey, 1991; Heck *et al.*, 1995).

The low faunal species richness along the southern and western Tasmanian coasts is best ascribed to two factors: (i) high rates of riverine runoff, which generally prevent the incursion of the diverse marine fauna into estuaries, and (ii) very low rates of secondary production within estuaries. When production is low and few animals are collected in samples, the number of species collected also tends to be low. High heavy metal concentrations also presumably affected species richness in localised areas.

The low abundance and production of fauna in western and southern Tasmanian estuaries probably resulted from very low primary productivity and a paucity of available food. Waters flowing into estuaries along these coasts possess extremely low levels of nutrients due to the prevalence in catchments of metamorphosed Precambrian rocks with almost no leachable minerals (Buckney & Tyler, 1973), and a lack of human fertiliser or sewage inputs (Edgar & Cresswell, 1991).

Moreover, benthic primary production within estuaries is likely to be extremely low as a consequence of poor light penetration to the estuary bed. Riverine water throughout southern and western Tasmania contains high levels of tannins and other humic leachates that darkly stain the water and rapidly absorb light (Edgar & Cresswell, 1991). Abrupt declines in macroinvertebrate production associated with the influx of tannin-stained riverine surface water has been previously described for the Bathurst Harbour estuary in southwestern Tasmania (Edgar, 1991a). Macrobenthic production in Bathurst Harbour was found to decline by an order of magnitude at upstream sites during winter when negligible light penetrated to the seabed, and by a similar amount from upstream sites to marine sites.

4.2 Relationships between Physical and Biotic Variables

4.2.1 Variance in sample estimates at different spatial and temporal scales

Temporal variance was extremely low compared to spatial variance for species richness and density; however, relatively high values were associated with biomass and productivity using the four-way ANOVA model. These high values appear to be inflated as a consequence of the limited three site data set examined. Little temporal change occurred at two sites but a doubling in faunal biomass and productivity occurred over time at the Paper Beach site. Inspection of data associated with this site indicated a dense patch of bivalves was sampled at the low tidal level on one occasion only, greatly affecting the ANOVA analysis. A relatively low level of variance attributable to month is indicated within the larger 25 site data set because the residual error term, which incorporated month as well as small spatial scale variance, is comparatively low. The study would have been seriously confounded by the fourteen month time period over which samples were collected if temporal variance was large.

The lack of substantial change over time in faunal variables at individual sites is contrary to conclusions of Morrisey*et al.* (1992), who suggest that considerable variation in soft-sediment benthos occurs at temporal scales from days to months. However, Morrisey *et al.* appear to have overemphasised short-term temporal effects in their analysis because they did not consider Type I errors; they in fact detected only 2 significant differences involving day and week temporal factors as a consequence of 48 tests, when the likely number of Type I errors in such a situation was 2.4. The number of significant results involving month and season was substantially higher, at 9 of 48 tests, albeit with several taxa examined showing non-significant results at all temporal levels.

Given that the majority of invertebrate species investigated in Tasmanian estuaries grew to sizes in excess of 2 mm and had lifespans extending from several months to several years (see Robertson, 1979), a lack of substantial change between sampling dates was not surprising. Major short-term changes in community variables would only be expected following large mortality or recruitment events, or if the fauna migrated along estuaries or across the shore. Such changes affecting density were not evident for any of the common species studied here, although seasonal and short-term movement of invertebrates in estuaries have been reported elsewhere (Schlacher & Wooldridge, 1996b; Hewitt *et al*., 1997). Seasonal investigation of macrofauna in one Tasmanian estuary, Bathurst Harbour, revealed a lack of migration along the estuary or between depths in different seasons, with species maintaining a high fidelity to site throughout the year (Edgar, 1991a). Cross-shore migrations cued to the tidal cycle were factored out of the present study by standardising sampling at low tide.

The magnitude of short-term and seasonal changes in total animal density varies greatly between reported studies. Although studies generally reveal pronounced changes in faunal assemblages over seasonal scales, much of this change is caused by population fluctuations of one or two species (e.g., Edgar, 1990b; Service & Feller, 1992; Baron *et al.*, 1993), and, in some cases, by mismatch between the spatial and temporal scales of sampling (Livingston, 1987; Thrush *et al*., 1994). Total production and biomass are rarely found to double through the year (see, e.g., Beukema, 1974; Hibbert, 1976; Edgar, 1990b; Kalejta & Hockey, 1991), other than in situations where habitat transformation occurs, such as when the biomass of seagrass fluctuates (Edgar *et al*,, 1994b). In the only detailed seasonal study of macrobenthic invertebrates in a Tasmanian estuary, fluctuations in total animal density and biomass in the Bathurst Harbour estuary were associated with spatial and seasonal changes in the light regime, probably through the effect of light on primary production (Edgar, 1991a).

Pronounced recruitment and mortality events are most likely to be detected in investigations of macrofauna where 0.5 mm mesh sieves are used or in studies of meiobenthos, because small invertebrates can undergo huge cyclic oscillations in population numbers over periods of weeks (Imada & Kikuchi, 1984; Edgar, 1990b). Biomass and productivity data should generally be less sensitive than abundance to temporal fluctuations because those variables are primarily sensitive to changes in numbers of animals of large body size and relatively long life-spans.

The variance components associated with the five spatial scales investigated differed considerably between the four faunal variables investigated (Table 3.24). Species richness varied most with tidal height, and possessed similar variance at replicate, transect, site and estuary scales.

Variance at the replicate scale was low for faunal density, high for faunal biomass and moderate for faunal productivity. By contrast, variance at the transect scale was higher for density than for biomass or productivity. Faunal biomass and productivity therefore appear to be relatively patchy at the replicate scale, presumably because the distribution of large bivalves, which greatly affect total biomass data, is more clumped at the scale of metres than the distribution of smaller animals such as amphipods, which primarily influence total density. Knowledge of these scales of variation is useful when deciding on sampling protocols. Investigations aimed at calculating mean faunal biomass of sites would benefit from increased replicate number, whereas studies of faunal density would benefit from an increased number of transects.

At large spatial scales, variance associated with faunal density was relatively high at the between sites within estuary scale, whereas faunal biomass and productivity showed highest levels of variance between estuaries (Table 3.24). These three variables therefore responded to different elements of the physical environment. Faunal density was probably affected by such factors as seagrass biomass and sediment particle size, which are specific to the site environment. Faunal biomass and productivity, on the other hand, were most affected by general characteristics of the estuary. The most important of these factors were probably those affecting primary productivity, such as nutrient levels, light penetration, turbidity and flux of allochthonous organic matter.

4.2.2 Environmental influences on biota

Results of BIOENV analyses revealed that the presence of a bar at the estuary mouth provided the best correlation with the composition of both fish and invertebrate assemblages at the estuary scale. The presence of a bar at the entrance to estuaries presumably affected the biota in two ways. Bars restrict the movement of species into and out of the estuary (Whitfield and Kok, 1992), and also, through changes to water flow and stratification, affect the salinity, tidal range, oxygen concentrations and other physical aspects of the environment. These physical factors, particularly oxygen concentrations (Dauer & Ranasinghe, 1992; Stanley & Nixon, 1992; Diaz & Rosenberg, 1995), in turn influence faunal population dynamics.

Faunal changes and declines in species richness in barred estuaries were probably closely associated with the period of estuary closure. Macrofaunal assemblages associated with four of the ten estuaries barred to the sea at the time of sampling had diverged considerably from assemblages found in open estuaries (Fig. 3.10 and 3.15), while the other six barred estuaries possessed a relatively homogeneous invertebrate fauna that was consistent with the fauna at Bridgewater and Claremont in the upper Derwent estuary. Fish assemblages associated with all barred estuaries investigated were distinct from fish assemblages in open estuaries. The extreme hypersaline conditions in Cameron Inlet were associated with an extremely low number of invertebrate and fish species, with numerous moribund individuals observed in the shallows during the summer macrofaunal sampling trip.

Overlays of physical data on results of multidimensional scaling of biological data indicated that the species composition of macrofaunal assemblages at estuarine sites varied with the salinity, runoff, tidal range, presence of bars and latitude of sites (Figs 3.13 - 3.18). Species composition was not, however, influenced to a major extent by the predominant rock type in the catchment area, the reason that geology was excluded from the physical categorisation of Tasmanian estuaries.

Variation between samples in abundance and species richness of macrofauna was primarily related to tidal emersion, salinity, and, to a lesser extent, plant biomass (Table 3.20). A variety of other physical factors were also associated with patterns of variation, particularly tidal range, silt/clay content of sediments and shore gradient; however, none had a consistent influence.

Samples collected at a site showed a relatively high level of faunal coherence between the three lowest tidal levels (LWM, 0.3 and 0.7 m depth). A minor faunal disjunction was generally present between mean water and low water mark, and a major disjunction between high water mark and mean water. These patterns were reflected in mean number of species, abundance and biomass down the shore (Table 3.16), with significantly lower values for these variables at the highest tidal level. The distinctiveness of the fauna at the highest tidal level is indicated by the dominance of the isopod *Actaecia bipleura*, which accounted for 56% of total abundance at high water mark but only 1% of abundance at the mid tidal level.

Relationships between biological and physical variables were relatively poor at the two highest tidal levels. Regression equations relating biological and physical variables typically explained ≈50% of total sample variance at low water mark and the shallow subtidal levels, but only ≈20% of sample variance at high and mean water levels (Table 3.20). Animals living in the high intertidal were presumably responding to aspects of the environment not assessed in the present study. At high intertidal levels, terrestrial factors such as humidity, rainfall, air temperature and biomass of plant litter probably affected patterns of faunal distribution at least as much as hydrological factors.

The only factor additional to tidal emersion that greatly affected the total density of animals in samples was the mean biomass of plant material (Table 3.20). Small abundant species probably responded to the increased surface area available in dense macrophyte habitats because of a need for space (see Hall & Bell, 1988; Hacker & Steneck, 1990; Edgar & Robertson, 1992), or perhaps because they were utilising food resources such as diatom/bacterial mats associated with the plant surface (Kitting, 1984; Kitting *et al*., 1984; Orth & van Montfrans, 1984; Jernakoff *et al*., 1996). Nevertheless, a lack of correlation between the biomass of plant material and total faunal production indicates that macrophytes were not supplying a major additional food resource.

The biomass of plant material was associated with variation in macrofaunal species richness between sites, with macrophyte beds possessing substantially more diverse faunas than unvegetated habitats. Similar results have been found in nearly all comparative studies of seagrass and unvegetated habitats (e.g., Lewis, 1984; Harrison, 1987; Edgar, 1990c; Edgar *et al*., 1994b; Heck *et al*., 1995).

The number of macrofaunal species within a tidal level was also highly correlated with salinity. Low salinity sites possessed an average of 35 fewer species than marine sites. The relatively low number of macrofaunal species collected in the upper reaches of Tasmanian estuaries was consistent with the results of other studies worldwide that show low diversity in brackish estuaries (e.g., McKlusky *et al*., 1994; Heip & Herman, 1995).

Although pertaining to European estuaries, the studies of Remane (1934) and Khlebovich (1968), which show a depression in species numbers at salinities of 5-8‰, remain commonly cited as providing an indication of global patterns (Remane & Schlieper, 1971; Hodgkin, 1994). Remane (1934) considered that the low number of species at 5‰ was due to a disjunction between freshwater and brackish-water faunas, with freshwater species not able to tolerate saline water at his level and estuarine species not osmotically capable of surviving extended periods in freshwater. Khlebovich (1968) found pronounced changes in ionic ratios in the 5-8‰ salinity range.

Patterns of macrofaunal species richness along salinity gradients observed in the present study (Fig. 3.29) nevertheless differed from the patterns observed by Remane (1934) because species richness continued to decline below 5‰. Freshwater species were not collected in Tasmanian estuaries in any numbers, even at sites with minimal input of saline water and despite the presence of a diverse fauna in Tasmanian rivers. Analogous declines have been documented in studies on other continents (e.g., Montagna & Kalke, 1992; Ysebaert *et al*., 1993; Schlacher & Wooldridge, 1996b), so a continuous decline in species richness up estuaries is possibly the general rather than exceptional pattern. Day (1981) suggests that these difference in species richness patterns relate to whether estuaries are tidally flushed or not. Our results support his contention that elevated species richness only occurs at salinities less than 5‰ in large well-mixed estuaries lacking tidal influences in their upper reaches.

Salinity also influenced the species richness of fishes in estuaries; however, effects were not as clearly defined in the lower reaches as for macrofauna, and interpretation of salinity effects was complicated by confounding from other factors that could not be easily separated (*viz*. bar presence, estuarine area, presence of seagrass). The number of fishes collected varied greatly with sampling effort, which in turn was affected by size of estuary, number of habitats sampled within the estuary, and whether seagrass beds were present. Large estuaries and estuaries with seagrass beds were generally sampled at more sites than small estuaries.

Patterns of fish diversity were further complicated by the lack of quantitative data on salinity and other local factors at the time of sampling, and consequent errors introduced when salinity estimates were made. Overall, species richness of fishes was found to significantly vary with salinity, the presence of seagrass and estuarine area. The first two of these factors have also been found to be correlated with fish species richness in other studies (e.g. Lonergan & Potter, 1990; Humphries *et al*., 1992), albeit with little change in species richness at moderate to high salinity sites (Whitfield *et al*., 1981; Gray *et al*., 1996). Whether any of these factors were causally linked to changes in species richness, or whether they were indirectly associated through correlation with other factors, has not been determined.

The regression equations relating macrofaunal and physical variables at low tidal levels possessed similar levels of precision (≈50%) to that found in a broad-scale study of southern Australian macrobenthos, where macrofaunal productivity was related to seagrass biomass and the silt/clay content of sediments (Edgar & Shaw, 1995b; $r^2 = 0.50$). The level of precision in these regression equations can be considered good given the inaccuracies associated with measurement of the physical variables and the large number of potentially influential variables not considered. Amongst the many factors known to affect the distribution of species and their productivity, but which were not included here, were nutrient concentrations (nitrate, phosphate, silicate, micronutrient), turbidity, dissolved oxygen levels, water flow rates, flux of suspended material, temperature, pH, depth of aerobic layer in sediment and heavy metal concentration (see Kennish, 1990).

A further problem associated with relating environmental to biological variables is a lack of knowledge about how physical factors affect the biota, and whether upper or lower extremes, or mean values, most need to be measured. Salinity, for example, varies rapidly over time because of fluctuations in river runoff and tidal flows. Mean salinity values, or *ad hoc* collections such as those incorporated in the present regression models, may have much less relevance to the biota than daily or seasonal extremes, or the irregular catastrophic flood.

Behavioural as well as physiological factors will also modify the influence of physical factors on different taxa. During unfavourable conditions, mobile organisms can migrate vertically and horizontally through sediment and water, whereas sessile animals are restricted to the one location. The effects of physical factors are further complicated to an unknown extent by biological interactions, and can vary with the presence of particular species. Hodgkin & Rippingale (1971), for example, suggest that the copepod *Gladioferens imparipes* is normally confined to low-salinity waters in the Swan Estuary (WA) because of the presence of predators. Although *G. imparipes* tolerated salinities ranging from <1‰ to 60‰ in laboratory tests, predatory copepods rapidly attacked larvae in downstream areas, and so prevented *G. imparipes* from becoming more widely established.

4.2.3 Biological indicators of human disturbance

The two anthropogenic disturbance indices proposed in this study, DI_n and DI_p, appear to be sensitive biological indicators of human impacts within Tasmanian estuaries, so warrant further investigation. Both indices were highly correlated with human population density within catchment area, discriminated well between sites, and showed negligible change between different seasons.

The index based on faunal abundance, DI_n, has one major advantage over the index based on faunal productivity, DI_p, in that it is simple to measure and comprehend. The advantages of DI_p over DI_n are that the former is more biologically meaningful and not heavily biased by either large- or small-sized species. The productivity of a species is directly proportional to total food consumption, total respiration and total reproductive output of that species, and so provides an reliable index of its trophic importance (Edgar, 1990a, 1993). By contrast, indices which relate the abundance of a species to others have much less biological meaning because they can be influenced by one or two species of small size that contribute relatively little to the functioning of the community. Small species tend to be far more abundant in samples than large species.

An additional advantage of DI_p over DI_n was that it showed a higher correlation with percent cleared land, and so probably responded to a wider range of human impacts (Table 3.36). DI_p was also less strongly correlated with natural environmental variables (salinity, tidal range, total annual runoff) and the total animal density of samples (r_s = -0.38 and -0.49).

The extent to which DI_n and DI_p are affected by natural physical factors and total sample size needs to be clarified as a matter of priority in future studies. This is best done by manipulation of the level of anthropogenic impact independently of changes in physical factors. Such studies should also examine whether the biological indicators are affected by a large or narrow range of anthropogenic impacts (e.g. siltation, nutrification, reduced oxygen concentrations, heavy metal concentrations).

While DI_n and DI_p are likely to prove useful for assessing the 'health' of estuaries in Tasmania and perhaps southeastern Australia, these two indices have restricted geographic applicability because they are based on Spearman rank correlation coefficients for individual species. Reducing the species data set to the family level, as is generally done with freshwater taxa (Chessman *et al*., 1997), was not found to be useful because species within a family often responded in different directions to anthropogenic disturbance (e.g. *Australonereis ehlersi* and *Perinereis vallata*). Moreover, the number of species within families was low, hence disturbance indices calculated for families were heavily biased by individual species. For example, the family Tellinidae showed a very high correlation with human population density solely on the basis of the response of the species *Tellina deltoidalis*. In regions lacking *T. deltoidalis,* the general response of tellinid species may be quite different. No evidence was found to support the suggestion that our r_s values for families would be similar to r_s values for the same families in other geographic areas.

The iteration procedure used by Chessman *et al*. (1997) to modify and stabilise disturbance indices for freshwater habitats could not be usefully applied to estuarine ecosystems. While Chessman *et al*. (1997) correctly assert that the iteration procedure adjusts biotic indices for internal conditions, the well-defined faunal groups produced by the iteration procedure were much more highly correlated with salinity, the primary factor affecting animal distribution, than with human disturbance. When salinity rather than human population density was used as the initial correlate, the same stabilised DI values resulted. Estuarine faunas were affected by salinity to a much greater extent than anthropogenic activities (i.e., land clearance or population density), forcing groups based on salinity to emerge during the iteration procedure. By contrast, anthropogenic disturbance in the freshwater streams investigated by Chessman *et al.* possibly had a greater impact on invertebrate faunas than natural environmental factors.

4.2.4 Anthropogenic impacts on biota in Tasmanian estuaries

Macrofaunal species living in the upper and middle reaches of Tasmanian estuaries are adapted to a physical environment that undergoes rapid and extreme fluctuations in salinity, temperature, water flow and turbidity. Most estuarine species also appear to be resilient to the effects of human disturbance. None of the community variables examined (species richness, faunal density, faunal biomass, faunal productivity) was found to be highly correlated with human population density, percent cleared land or the naturalness index NI in our study.

Nevertheless, variation between estuaries in the disturbance indices DI_n and DI_p revealed clear differences between faunal assemblages in estuaries with different levels of human population density. Increasing population density was associated with increasing silt/clay content of sediments, habitat changes from sandflats to mudflats in downstream regions, and with a shift from epifaunal to infaunal species.

Such changes were unlikely to have been detected using methods other than disturbance indices. Species richness provided a poor indication of human disturbance in Tasmanian estuaries, largely because mudflats and sandflats contained faunas of similar species richness but different species composition. The Abundance/Biomass Comparison method for detecting human impacts (Warwick, 1986; Warwick *et al*., 1987) was also unlikely to prove useful because many of the infaunal species associated with high population densities possessed large body size and biomass (e.g. *Tellina deltoidalis*). Moreover, multivariate methods that incorporate environmental variables into a predictive model, and then assess the difference between observed and predicted assemblages (e.g. Moss *et al.,* 1987) are also unsuitable because characteristics of the habitat type are themselves affected by human impacts. Such models will always predict a mudflat fauna for sites with muddy sediments when sediment characteristics are incorporated into the model.

The close associations between human population density, silt/clay fraction of sediments and faunal composition may be due to direct dependence between these factors, or to indirect associations arising from shared relationships with other factors. Given the large number of studies that identify direct causal relationships between human activities in catchments and increased sediment loads (e.g. Williams, 1980; Campbell & Doeg, 1989), the most likely hypothesis relating these factors is that anthropogenic activity in catchments and around estuary margins causes large inputs of fine suspended sediments that are transported to the lower reaches of estuaries and deposited there. These fine deposits coat the estuarine bed and eventually convert sandflats into mudflats, which attract infaunal species (such as *Tellina deltoidalis* and *Magelona* sp.) and displace epifauna (such as *Eubittium lawleyanum* and *Zeacumantus diemenensis*).

An alternative hypothesis is that human settlement, with resulting high population densities, preferentially occurs in estuaries with muddy rather than sandy sediments, perhaps because of richer soils for agriculture in the hinterland. While this hypothesis cannot be rejected outright, it is less likely than the previous hypothesis given the interspersion of estuaries with high and low human population densities studied around the state, and the extremely consistent relationships between human population density, silt-clay content of sediments and DI_n. Only one of the fifteen sites with population density >5 km^2 in its estuarine drainage area possessed sediments with silt-clay content <3%, whereas none of the fifteen sites with population density <1.5 km^2 possessed a silt-clay content of sediments >3%. Moreover, anecdotal information consistently indicates that as human populations increase within catchments the foreshores of associated estuaries change from sandflat to mudflat. For example, Cornelian Bay in the lower Derwent possessed a sandy beach until ca. 1940, but the shore has since degraded and now includes large quantities of silt and clay (SDAC, 1996).

The task of confidently identifying biological changes in estuaries caused by human activities is virtually impossible without prior information (see Green, 1979), particularly if the change is one of habitat alteration. However, this task is relatively easy when predisturbance data have been collected. For this reason, a major objective of the present study was to compile a quantitative data base describing biota in estuaries, so that future changes, including amelioration as well as acceleration, can be recognised. The recent Tasmanian state of the Environment Report flagged the paucity of baseline information on marine and estuarine communities as a problem that needed remedying as a matter of urgency (SDAC, 1996).

Difficulties in identifying biological consequences of human activities are not confined to the effects of increased siltation within estuaries. The effects of changes to the hydrological regime that follow upstream developments are also extremely difficult to quantify without data collected prior to development. Although little information exists on the effects of dams on estuarine ecosystems in Australia, overseas experience suggests that dams and water diversions can cause the decline of some coastal fisheries, and ecosystems may change substantially as a consequence of reduced freshwater flows (Adam *et al*., 1992; Schlacher & Wooldridge, 1996a). These effects are largely mediated by changes to oxygen and nutrient levels, turbidity, estuarine flushing rates, water temperatures, heavy metal and H_2S loadings, breeding stimuli such as flood flows, and by restriction on movement of diadromic species (Kennish, 1992).

The majority of anthropogenic threats, including land clearance (Brodie, 1995), dam construction (Rosenberg *et al*., 1995), siltation (Newcombe & Jensen, 1996), eutrophication (McComb & Lukatelich, 1986; Lavery et al., 1991; Cloern, 1996), foreshore development (Whitfield, 1986), dredging (van Dolah *et al*., 1984), mining (Adam *et al*., 1992) and marine farming (Ritz *et al.*, 1989; DeFur & Rader, 1995; Grant *et al*., 1995; Tsutsumi, 1995), affect individual estuaries and can be controlled by changing management practices. The spread of introduced pest species, on the other hand, affects all estuaries within Tasmania and, although the threat can be reduced, it cannot be halted by active management. The dominant organisms in many estuaries worldwide are now quite different to those present 200 years ago because of the scale of introductions into estuaries (Williams et al., 1988; Carlton, 1989; Carlton & Geller, 1993).

Despite the potential scale of the threat of introduced species and the numerous invertebrates that have invaded the larger Derwent, Tamar and Huon estuaries (Grannum *et al.*, 1996; Furlani, 1996), few introduced species were sampled in small Tasmanian estuaries. The only introduced species commonly collected were the widespread gastropod *Potamopyrgus antipodarum* and the green crab *Carcinus maenas*, which was recorded around the northern and eastern Tasmanian coasts from Mosquito Inlet to Lisdillon, and at Cameron Inlet on Flinders Island. This crab has caused rapid declines in mollusc populations in other countries (Ropes, 1968; Grosholz & Ruiz, 1995), and also poses a major threat to local estuaries because of active carnivorous feeding habits and extremely high densities. Green crabs have greatly expanded their range in Tasmania over the past two decades, and been linked with declines in bivalve densities in east coast estuaries (G. Ruiz & S. Lewis, pers. comm.).

4.3 The Conservation Significance of Tasmanian Estuaries

The primary aim of this study was to identify estuaries and associated catchments in Tasmania with highest conservation significance. Once these estuaries have been identified, they can be more adequately protected using statutory and legislative procedures and policing. In order to minimise inconvenience to public users, protocols used to identify estuaries of highest conservation significance were chosen so that the number of estuaries given the highest ranking, and number of users affected, were kept as low as possible, while still encompassing the range of biological and geomorphological diversity found in estuaries within the state.

As outlined in the Introduction and Fig. 1.1, the method used to assess the conservation significance of Tasmanian estuaries was to firstly classify estuaries into groups with similar physical, geomorphological and hydrological attributes, to validate or amend these groups using biological attributes, and to then rank estuaries within each group in terms of current anthropogenic impacts. The estuary in each group with the least human disturbance and greatest proportion of catchment area under statutory protection was considered to possess highest conservation significance. Estuaries could also be assigned a high level of conservation significance if they possessed exceptional species diversity or included species with restricted distributions. Using these criteria, estuaries were assigned to one of five classes:

Class A. *Critical conservation significance* (10 estuaries) - Estuary and associated catchment area show minimal effects of human activity and are identified as key components within an integrated system of representative reserves around Tasmania. Also includes sites with exceptional fish and invertebrate biodiversity. Plants, animals and habitats within Class A estuaries and associated catchments should be fully protected as a matter of highest priority.

Class B. *High conservation significance* (38 estuaries) - Estuary and associated catchment area remain relatively pristine or contain an unusual range of species. Class B estuaries and associated catchments should be quarantined from future developments, and existing human impacts reduced wherever possible. Aquatic biota should be protected other than from anglers using hook and line or exploitation within existing marine farm lease boundaries.

Class C. *Moderate conservation significance* (34 estuaries) - Estuary and associated catchment area are affected by human habitation and land clearance, but have not been badly degraded. Class C estuaries should be made available for a variety of recreational and commercial purposes.

Class D. *Low conservation significance - moderately degraded* (21 estuaries) - Estuary and associated catchment have been moderately degraded by human impacts. Class D estuaries should be made available for a variety of recreational and commercial purposes. Remediation processes should be assisted where practical.

Class E. *Low conservation significance - severely degraded* (8 estuaries) - Estuary and associated catchment have been severely degraded by human impacts. Class E estuaries should be made available for a variety of recreational and commercial purposes, except where threats to public health exist. Remediation processes should be assisted where practical.

The ten estuaries with highest conservation significance (Class A) are listed in Table 4.1. Four of these estuaries are located in the South West Tasmania World Heritage Area, while the other six estuaries are distributed around the remainder of the Tasmanian coast and the Furneaux Group. Although an estuarine protected area on King Island is desirable, no Class A estuaries are located on King Island because of the poor development of estuaries in that region, high level of land clearance within catchments, and lack of known endemic species.

Included as Class A estuaries were the estuaries with lowest population densities in catchments for each of the physical groups identified by multivariate analysis, with the exception of Group V estuaries where the Black River estuary rather than Boobyalla estuary was assigned highest conservation significance. Emphasis was placed on population density as an indicator of anthropogenic disturbance because changes in population density were associated with siltation and much more pronounced changes in estuarine communities than land clearance. Moreover, protection of these estuaries from exploitation should affect relatively few local residents. Identifying the Group II estuary with highest conservation value required an additional criterion because five estuaries in this group were fully contained within National Parks and possessed no resident human population. Payne Bay estuary was selected from amongst these estuaries because it had the largest catchment area, and so should be most highly buffered against future impacts.

The Black estuary was preferred over the Boobyalla estuary as representative of Group V estuaries because the population densities in catchments of these two estuaries were similar, the proportion of agricultural land in Black River catchment was lower, and the Black estuary was not affected by mine drainage. Also, nearly half of the Tasmanian coastline, extending from the Tamar to Port Davey, would lack a Class A estuary if the Black was assigned a lower conservation class. The other possible Class A estuary in Group V, the Crayfish estuary, possessed a less degraded catchment than the Black or Boobyalla, but was affected by a number of dwellings near the mouth and included only a small estuarine area.

Table 4.1. Tasmanian estuaries with critical conservation significance (Class A), as listed by geographical region.

Bass Strait Islands	*North coast*	*East coast*	*South + west coasts*
North East Inlet	Black	Bryans Lagoon	New River Lagoon
Thirsty Lagoon	Tamar	Southport Lagoon	Bathurst Harbour
			Payne Bay
			Wanderer

In addition to the nine estuaries selected to represent particular types of estuary, North East Inlet was also assigned Class A status due to its exceptional species richness and the presence of numerous invertebrate and fish species not recorded elsewhere. North East Inlet provided habitat for a quantum level more invertebrate and fish species than other estuaries sampled in the state apart from the Tamar. The Tamar estuary was a problematic inclusion as a Class A estuary. This estuary deserved highest conservation significance because: (i) it is the only estuary of its type (mesotidal drowned river valley) in Tasmania, (ii) it possesses extremely high plant, invertebrate and fish diversity, and (iii) it possesses a large component of species not recorded elsewhere. However, the estuary is also badly degraded as a result of human activities, particularly as a consequence of the large urban population in its drainage area and land clearance in its catchment. Extremely high loads of silt continue to be deposited in the estuary, leading to active dredging to maintain shipping channels and rising mudflats along the shoreline. The estuary is also severely impacted by introduced species, including ricegrass *Spartina anglica*, East Asian bag mussel *Musculista senhousia* and pacific oysters *Crassostrea gigas*.

One of the Class A estuaries listed in Table 4.1, Thirsty Lagoon, was not visited during the study, so requires a field survey to confirm that it has been placed in the appropriate estuarine group. In particular, bar formation needs to be assessed and salinity and tidal range data collected. Fishes and invertebrates should also be sampled in this estuary. If Thirsty Lagoon is found to dry out in the same way as Sellars Lagoon and Logan Lagoon, another estuary should be assigned Class A status from amongst the Group IV estuaries.

Estuaries accorded Class B conservation status because they remain in a relatively pristine condition are listed in Table 4.2. The specific criteria used to identify Class B estuaries were human population densities <0.5 km^{-2} in catchment and drainage areas, and agricultural and cleared land covering <10% of catchment area. Great Swanport lay marginally outside these criteria because the population density in its estuarine drainage area was estimated to be 0.51 km^{-2}; however, this estuary was placed in the Class B category because of high fish diversity (Fig. 3.32) and the estuaries' importance as waterfowl habitat. This estuary is listed as a Ramsar site. The Boobyalla estuary also lay outside the population density criteria but was elevated to Class B status because of the absence of any other large river estuary (Group V) with low population density, the paucity of undisturbed estuaries on the north coast, and its listing as a Ramsar site.

Mosquito Inlet ranks highest in terms of conservation value amongst the Class B estuaries, and could arguably have been included with the Class A estuaries because it is the sole remaining estuary on the north coast with low human population density (<0.5 km^{-2}). This inlet also contains numerous invertebrate species (Table 3.10) due to prevailing high salinity conditions, and was the site of the highest invertebrate biomass recorded during sampling (Table 3.12). Cloudy Lagoon, Sea Elephant, Boobyalla Inlet and Great Swanport also possess high conservation significance compared to other Class B estuaries, which were either small in size and so provide limited habitat for plants and animals, or located around the faunally-depauperate south and west coasts of Tasmania.

Tasmanian estuaries of moderate conservation significance (Class C) were primarily identified by low human population densities (<10 km^{-2}) in estuarine catchment and drainage areas (Table 4.3). The Huon and Derwent estuaries, which both possess high population densities, were also included as Class C estuaries because of high species richness and the presence of species not found elsewhere. The Huon estuary possesses high fish and invertebrate diversity (Figs. 3.30 and 3.9), while the Derwent estuary possesses an extremely high level of endemism, perhaps the highest of all estuaries in Australia. The spotted handfish *Brachionichthys hirsutus*, a species listed under the Commonwealth Endangered Species Act, the bare-backed three fin *Forsterygion gymnotum* and the seastar *Marginaster littoralis* are all restricted to the lower Derwent estuary and associated embayments. On endemic species grounds the Derwent should therefore be categorised as a Class A estuary; however, this is negated by human impact criteria, which indicate that the estuary should be assigned Class E conservation status.

Table 4.2. Tasmanian estuaries with high conservation significance (Class B), as listed by geographical region.

Bass Strait Islands	*North coast*	*East coast*	*South + west coasts*
Sea Elephant	Mosquito Inlet	Big Lagoon	South Cape Rivulet
Foochow Inlet	Boobyalla Inlet	Sloop Lagoon	Louisa River
Middle Inlet		Freshwater Lagoon	Louisa Creek
Patriarch		Great Swanport	Freney
Sellars Lagoon		Cloudy Bay	Mulcahy
Cameron Inlet		Catamaran	Giblin
Logan Lagoon		D`Entrecasteaux	Lewis
Mines			Mainwaring
Dover			Spero
Lee			Hibbs Lagoon
Shag Rock			Henty
Modder			Lagoon
Rices			Pedder
Rocky Head			Nelson Bay
			Arthur

Table 4.3. Tasmanian estuaries with moderate conservation significance (Class C), as listed by geographical region.

Bass Strait Islands	*North coast*	*East coast*	*South + west coasts*
Ettrick	Welcome	Little Musselroe	Little Henty
Seal	Montagu	Great Musselroe	Pieman
Yellow Rock	West Inlet	Ansons Bay	
Pats	East Inlet	Grants Lagoon	
	Detention	Hendersons Lagoon	
	Piper	Templestowe	
	Little Forester	Douglas	
	Tomahawk	Saltwater Lagoon	
		Stoney	
		Buxton	

		Lisdillon	
		Little Swanport	
		Grindstone	
		Earlham Lagoon	
		Blackman Bay	
		Derwent	
		Huon	
		Esperance	
		Lune	
		Cockle Creek	

Degraded estuaries in Tasmania, as recognised by high human population densities in catchments, were almost exclusively located along the northern and eastern Tasmanian coasts (Tables 4.4 and 4.5). The only Class D estuary outside the northern and eastern regions was Yarra Creek on King Island, which possessed an estimated density of 23 people per km^2 in its estuarine drainage area.
Degraded estuaries in Tasmania were divided into moderately-degraded Class D estuaries (Table 4.4), with population densities between 10 and 100 km^{-2}, and severely-degraded Class E estuaries (Table 4.5), which had population densities in catchments exceeding 100 km^{-2}. Macquarie Harbour, an estuary with a population density of only 4.8 km^{-2} in its catchment area, was included with the Class D rather than Class C estuaries because of extremely high levels of heavy metal pollution arising from mining operations in the King River catchment.

Table 4.4. Degraded Tasmanian estuaries of low conservation significance (Class D), as listed by geographical region.

Bass Strait Islands	*North coast*	*East coast*	*South + west coasts*
Yarra	Duck Bay	Georges Bay	Macquarie Harbour
	Crayfish	Scamander	
	Blythe	Denison	
	Forth	Meredith	
	Port Sorell	Spring Bay	
	Curries	Prosser	
	Brid/Great Forester	Carlton	
		Pittwater	
		Pipeclay Lagoon	
		Garden Island	
		Port Cygnet	
		Crooks	

Table 4.5. Severely degraded Tasmanian estuaries of low conservation significance (Class E), as listed by geographical region.

Bass Strait Islands	*North coast*	*East coast*	*South + west coasts*
	Inglis	Browns	
	Cam	North West Bay	
	Emu		
	Leven		
	Don		
	Mersey		

4.4 Management Options and Recommendations

Other than restrictions on particular methods of capture (such as gillnetting prohibitions), aquatic organisms are not protected within any estuary in Tasmania. This situation contrasts greatly with the terrestrial environment, where plants and animals are fully protected in the 25% of the land area covered by National Parks. Although protecting habitats, legislation that protects organisms within

National Parks specifically excludes fish and other aquatic species, an anomaly that needs to be rectified. By enacting legislation that extends protection to estuarine species in National Parks, the basic framework of a system of representative estuarine protected areas would be created within the state. Four of the ten Class A estuaries would become true estuarine protected areas (Bryans Lagoon, New River Lagoon, Bathurst Harbour, Payne Bay) with no negative impact on the public except for fishers utilising resources in Payne Bay (Port Davey) within the South West National Park. Negligible exploitation of biotic and abiotic estuarine resources currently occurs in National Parks other than Payne Bay, and no dwellings are located on the shores of estuaries within National Parks.

While the fishing prohibition in National Parks would affect rock lobster and abalone fishers operating in Port Davey, this impact can be minimised by zoning and permitting exploitation of fishery stocks in particular areas. The process of identifying the boundaries of closed and open fisheries zones in Payne Bay is currently underway as part of negotiations between stakeholders over a proposed Port Davey marine and estuarine protected area (MEPA). The creation of a system of estuarine protected areas in the state should not affect these negotiations, other than to affirm the importance of including Kelly Basin within the MEPA. Kelly Basin contains the only shallow sandflats, the most degraded estuarine habitat-type around Tasmania, within Payne Bay.

In order for the proposed system of estuarine protected areas to comprehensively protect all major elements of the Tasmanian biota, the taking of flora and fauna should be prohibited in all Class A reserves, except where such restrictions would substantially disadvantage members of the public. Prohibitions on the taking of flora and fauna in the Thirsty Lagoon and Wanderer estuaries should not affect any members of the public due to the isolation of these estuaries. Because other areas are available for fishing nearby, prohibitions on the taking of estuarine life in the Black River and Southport Lagoon estuaries also should not substantially disenfranchise the public, with the possible exception of the users of dwellings (approximately five in total) adjacent to the Black River estuary. The number of local residents affected by a Black River MEPA, the only recommended MEPA that covers a complete estuary on the northern Tasmanian coast, would be less than for any other possible estuarine protected area in that region other than Boobyalla Inlet or Welcome Inlet.

Given the extent of urban development in the Tamar estuary and the amount of human activity within its middle and upper reaches, declaration of the whole of this estuary as a MEPA would be impractical and unwarranted. The component of the Tamar estuary that requires protection within the MEPA system is the seagrass habitat near the mouth, a habitat that possesses extremely high biodiversity, including numerous species not protected elsewhere in the MEPA system. Accordingly, we recommend that the taking of aquatic fauna be prohibited in a MEPA at the mouth of the Tamar which covers an area of at least 1 km^2 and includes *Heterozostera*, *Posidonia* and *Amphibolis* seagrass beds. A MEPA has already been proposed for this area by the Tasmanian Fishing Industry Council and Tasmanian Amateur Fishermans Association; however, their proposed area, which extends from Low Head to Dotterel Point, lacks seagrass habitat. We therefore recommended that the area proposed for protection be extended southward to encompass seagrass beds in Lagoon Bay, the site sampled during the present study. This MEPA would then extend 500 m offshore for a distance of ≈3 km along the coast from Low Head to She Oak Point, and would include unusual deepwater habitats off Barrel Rock.

North East Inlet, the Class A estuary with highest species diversity recorded during surveys, lies within the Wingaroo Nature Reserve and so contains habitats that are protected by legislation but have no specific restrictions on the taking of aquatic organisms. On the basis of conservation criteria alone, North East Inlet should be closed to fishing and a MEPA declared to accommodate its exceptional biodiversity and numerous fish and invertebrate species not protected elsewhere within the State. However, this estuary is of major recreational importance to the Flinders Island community, hence a compromise is required between recreational and conservational interests. Accordingly, we recommend that the taking of all aquatic life be prohibited within a MEPA located near the mouth of the estuary that includes *Heterozostera* beds and has an area of approximately 1 km^2. Fishing using rod or handline should be permitted within the 3 km^2 of the estuary outside the MEPA, but the taking of plants or invertebrates by any means or fish using net or spear should be prohibited. These recommendations provide what we consider to be an appropriate balance between conflicting demands; they fully protect much of the high diversity seagrass habitat while allowing fishing to continue through most of the estuary. They also protect the estuary from future exploitation of seaweed and invertebrate resources.

Relatively few members of the public should be inconvenienced by the North East Inlet proposal; members of the public primarily affected are lessees of shacks located immediately adjacent to the proposed MEPA (≈5 in total), who will need to move their fishing activities further along the estuary, and recreational fishers who spear flounder or take prawns. The use of gillnets in North East Inlet is prohibited under current regulations.

It can be argued that prohibitions on fishing and taking aquatic life in Class A estuaries are unnecessary given that little fishing or exploitation of biological resources presently occurs in most of these estuaries. However, the level of exploitation of estuarine resources is rapidly rising as a consequence of several factors: (i) increased leisure time allowing more recreational fishing, (ii) improving technology allowing increased catch efficiency and greater access to estuaries, and (iii) new resources such as cockles and seaweeds being utilised. Restrictions on fishing within the conservationally-significant estuaries should therefore be applied now while few members of the public are inconvenienced, and before more estuaries become obviously degraded. Tasmania is fortunate compared to other southern Australian states in that it presently retains a number of estuaries in an almost pristine state.

An additional benefit of prohibiting fishing in some estuaries is that the impact of fishing on ecosystem processes can then be assessed. Removal of top predators such as bream, or filter feeders such as cockles, possibly has major consequences that flow through ecosystems, but which presently go unnoticed because all estuaries on the eastern and northern Tasmanian coasts are similarly affected. These effects will, however, be detectable when some estuaries are closed to fishing.

Benefits in the educational and fishery management areas will also occur as a direct result of closing some estuaries to fishing and creating a system of estuarine protected areas. The public will receive a clear message that the conservation value of estuaries is similar to that of terrestrial and marine habitats - a message that needs reinforcement to counter a common perception that estuaries, particularly those with mudflats, are foul-smelling wastelands inhabited by biting insects. Protection to conservationally-important estuaries will also fulfil a fishery management function in protecting the habitat of juveniles of commercially and recreationally important species such as flathead, bream, gummy shark and flounder.

Given the benefits that accrue when the taking of aquatic organisms is restricted in estuaries of high conservation value, we recommend that regulations prohibiting the taking of aquatic fauna by any means other than fish by rod or handline also apply to Class B estuaries. Such restrictions would primarily be applied as a precautionary measure to prevent increasing exploitation of shellfish and seaweeds, and should not unduly affect the public. Most Class B estuaries are located in relatively remote areas, and virtually all exploitation of Class B estuaries at present is by rod and line. Anglers in some areas should directly benefit from these restrictions, such as fishers for bream in Great Swanport estuary, who can expect more reliable catches when habitat and ecosystem processes are better protected.

Estuarine ecosystems can never be fully protected using regulations that apply only in the estuary itself, because processes acting in the catchment area also threaten these habitats. In particular, clearance of land that releases silt, agricultural practices that allow fertiliser and pesticide to run off into creeks and rivers, and mining activities that cause acidification of rivers and heavy metal pollution, continue to cause severe degradation to many Tasmanian estuaries. In order to protect estuaries of high conservation value from these processes, deleterious activities in the catchments of Class A and B estuaries should be prevented as much as possible. We therefore recommend that unallocated crown land in Class A catchments be upgraded to Crown Reserve or Forestry Reserve status to prevent deterioration in water quality. Also, planning approval for activities on private land in catchments of estuaries of high conservation significance should only been given after downstream effects on estuaries are fully considered.

In summary, specific management recommendations arising from the study are:

- The taking of aquatic flora and fauna other than introduced species (salmonids) by any means be prohibited within National Parks, other than the area of Payne Bay excluded from the proposed Port Davey Marine and Estuarine Protected Area.

- An integrated system of estuarine protected areas be created using legislation to prevent the taking of aquatic flora and fauna by any means from the Black, Southport Lagoon, Thirsty Lagoon and Wanderer estuaries.

- The taking of aquatic flora and fauna by any means be prohibited within an area extending offshore for a distance of 500 m from She Oak Point to Low Head in the Tamar estuary.

- The taking of aquatic flora and fauna by any means be prohibited in North East Inlet (Flinders Island) within the area of estuary extending northward for a distance of 1.5 km from the latitude of the junction of Edens Road and North East Inlet Road (Tasmap grid reference ES820995).

- The taking of aquatic flora and fauna other than by rod or handline, or from marine farm leases, be prohibited from the North East Inlet, Sea Elephant, Foochow Inlet, Middle Inlet, Patriarch, Sellars Lagoon, Cameron Inlet, Logan Lagoon, Mines, Dover, Lee, Shag Rock, Modder, Rices, Rocky Head, Mosquito Inlet, Big Lagoon, Sloop Lagoon, Freshwater Lagoon, Great Swanport, Cloudy Bay Lagoon, Catamaran, D`Entrecasteaux, Freney, Lewis, Mainwaring, Spero, Hibbs Lagoon, Henty, Lagoon, Pedder, Nelson Bay and Arthur estuaries.
- Non-allocated Crown land or State Forest within the Thirsty Lagoon, Black, Wanderer, North East Inlet and Southport Lagoon catchments be upgraded to Crown Reserve, Coastal Reserve or Forest Reserve status.
- Habitat alteration and exploitative activities on private land within the Black/Dip, North East Inlet and Southport Lagoon catchments be minimised wherever possible.
- Habitat alteration and exploitative activities on crown and private land within the Sea Elephant, Foochow Inlet, Middle Inlet, Patriarch, Sellars Lagoon, Cameron Inlet, Logan Lagoon, Mines, Dover, Lee, Shag Rock, Modder, Rices, Rocky Head, Mosquito Inlet, Big Lagoon, Sloop Lagoon, Cloudy Bay, Catamaran, D`Entrecasteaux, Freney, Lewis, Mainwaring, Spero, Hibbs Lagoon, Henty, Lagoon, Pedder, Nelson Bay and Arthur catchments be minimised wherever possible.

The management recommendations described above are designed to isolate representative estuarine ecosystems from anthropogenic threats. However, the threats of global warming and introduced marine pests remain, with both potentially able to cause substantial loss of biodiversity within the state. It is therefore recommended that:

- The establishment and spread of introduced marine pests be minimised whenever possible.
- Isolated areas of the state that presently act as refuges from introduced species (viz. southwestern Tasmania, Flinders Island and King Island) be actively managed to prevent the establishment of pests, including the green crab *Carcinus maenas*, the North Pacific sea star *Asterias amurensis*, the Pacific oyster *Crassostrea gigas*, the fan worm *Sabella spallanzani*. and rice grass *Spartina anglica*.

Recommendations for future research aimed at conserving Tasmanian estuarine ecosystems are:

- The suitability of Thirsty Lagoon as a Class A estuary be investigated by field inspection and collection of salinity, tidal and biological data. If Thirsty Lagoon dries out in a similar way to Sellars Lagoon and Logan Lagoon or is otherwise unsuitable, then Rocky Head estuary be investigated as a Class A estuary and if suitable substituted for Thirsty Lagoon in recommendations above. If Rocky Head estuary is unsuitable because of small size and limited aquatic habitat, then Cameron Inlet be considered a Class A estuary and substituted for Thirsty Lagoon in recommendations above.
- Boundaries proposed above for an estuarine protected area in North East Inlet be assessed using information on distribution of habitat types and fishing effort, and, if necessary, alternative recommendations for an area within this estuary made.
- Further investigation be made of the estuarine disturbance indices DI_n and DI_p to determine their utility as indicators of environmental health, both within an estuary over time and between different estuaries, and to identify whether they are biased by natural environmental factors.
- Detailed time-series data be collected concurrently with faunal abundance data from a limited number of estuaries to identify aspects of salinity and flow that most affect estuarine biota (e.g., whether maximum, minimum or modal salinity, or length of flood, has greatest affect on distribution and abundance of estuarine fauna).
- Collection of baseline data from as many estuaries as possible for the most important physical variables, including salinity, water flow, turbidity, nutrient concentrations, oxygen concentration, suspended solids, temperature, pH and heavy metal concentrations.

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List of Abbreviations and Acronyms

AAT	arc attribute table
ABS	Australian Bureau of Statistics (Commonwealth Government)
AIMI	Arc/Info MapInfo translation software
AMG	Australian Map Grid
ANOSIM	Analysis of similarities
ANOVA	Analysis of variance
BIOENV	Biological/environmental analysis
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CSL	Central Science Laboratory (University of Tasmania)
DELM	Department of Environment and Land Management (Tasmanian Government)
DEM	digital elevation model
DPIF	Department of Primary Industry and Fisheries (Tasmanian Government)
ECA	estuary catchment area
EDA	estuary drainage area
EIF	environmental impact factor
ESRI	Environmental Systems Research Institute, Inc., USA
FDA	fluvial drainage area
GIS	geographic information system
HEC	Hydro-Electric Corporation (Commission), Tasmania
HWM	High water mark
Landsat TM	Landsat Thematic Mapper
LIB	Land Information Bureau, DELM (Tasmanian Government)
LWM	Low water mark
MDS	Multidimensional scaling
MEPA	marine and estuarine protected area
MW	Mean water
NOAA	National Oceanic and Atmospheric Association, USA
PAT	polygon attribute table
PWS	Parks and Wildlife and Service, DELM (Tasmanian Government)
RWSC	Rivers and Water Supply Commission, DPIF (Tasmanian Government)
SER	State of the Environment Report (Tasmanian Government)
SIMPER	Similarity percentages analysis
SOMER	State of the Marine Environment Report (Commonwealth Government)
TCM	total catchment management
VAT	value attribute table
ybp	years before present

Appendices

APPENDIX 1. Estuarine catchment area (ECA), estuarine drainage area (EDA), estuarine area, perimeter length, estimated tidal range, presence of bar and physical group derived using multivariate analysis for 111 Tasmanian estuaries investigated. Regions shown are King Island (K), Furneaux Group (F), northwest (NW), eastern north (EN), east (E), southeast (SE), south (S) and west (W).

Regior	Estuary	ECA (km)	EDA (km)	Area (km)	Perimeter (km)	Tide (m)	Bar	Physical Group
K	Sea Elephant	294.8	14.3	0.9	17.9	0.3	Yes	I
K	Yarra	38.1	0.4	0.0	0.9	0.1	Yes	I
K	Ettrick	45.5	0.1	0.0	0.8	0.5	No	II
K	Seal	77.6	6.6	0.7	7.5	0.1	Yes	I
K	Yellow Rock	119.2	1.4	0.1	2.8	0.1	Yes	I
F	North East Inlet	125.2	21.7	4.0	23.0	0.9	No	III
F	Foochow Inlet	67.3	2.8	0.2	3.3	0.5	No	II
F	Middle Inlet	61.2	1.5	0.1	2.7	0.2	Yes	I
F	Patriarch	177.9	4.4	0.4	7.0	0.6	No	II
F	Sellars Lagoon	44.1	44.1	11.8	33.7	0	Yes	IV
F	Cameron Inlet	192.8	43.4	13.5	21.0	0	Yes	IV
F	Logans Lagoon	69.8	69.8	9.7	32.3	0	Yes	IV
F	Pats	69.6	1.2	0.0	2.3	0.6	No	II
F	Mines	21.2	0.2	0.0	1.6	0.1	Yes	I
F	Dover	32.2	2.2	0.0	1.3	0.4	No	II
F	Lee	61.5	0.4	0.1	2.9	0.4	No	II
F	Shag Rock	39.4	3.7	0.2	2.7	0.1	Yes	I
F	Modder	45.2	2.1	0.1	2.5	0.1	Yes	I
F	Rices	29.8	1.7	0.1	2.8	0.4	No	II
F	Rocky Head	15.5	1.1	0.2	3.2	0.1	Yes	IV
F	Thirsty Lagoon	14.4	14.4	2.1	10.7	0.4	Yes	IV
NW	Welcome	304.3	12.1	2.7	10.8	1.7	No	III
NW	Montagu	327.4	10.1	0.6	8.3	1.7	No	III
NW	Mosquito Inlet	28.6	28.6	6.6	14.6	1.7	No	III
NW	Duck Bay	549.3	78.1	22.3	66.1	2.3	No	V
NW	West Inlet	22.6	3.4	4.1	11.2	2.3	No	III
NW	East Inlet	21.3	4.6	4.8	14.2	2.3	No	III
NW	Black/Dip	345.1	9.9	0.6	11.0	2.2	No	V
NW	Crayfish	44.3	0.4	0.0	2.1	2.2	No	V
NW	Detention	151.9	5.6	0.5	12.0	2.2	No	III
NW	Inglis	505.0	6.0	0.3	6.6	2.2	No	V
NW	Cam	249.2	9.3	0.1	4.0	2.2	No	V
NW	Emu	243.2	1.2	0.1	3.8	2.2	No	V
NW	Blythe	277.1	4.6	0.2	7.1	2.2	No	V
NW	Leven	697.9	47.8	2.3	29.7	2.1	No	V
NW	Forth	1124.6	14.8	1.0	24.0	2	No	V
NW	Don	135.6	5.8	0.4	8.2	2	No	V
NW	Mersey	1753.3	44.0	4.8	49.3	2.2	No	V
NW	Port Sorell	643.1	80.0	17.2	89.8	2.1	No	III
EN	Tamar	11588.8	558.3	97.9	252.7	2.3	No	VI
EN	Curries	83.9	1.7	0.0	3.0	1.5	No	II
EN	Piper	464.6	14.2	1.2	18.0	1.5	No	V
EN	Little Forester	347.2	4.2	0.2	8.4	1.5	No	V
EN	Brid/Great Forester	776.5	15.0	0.9	18.7	1.5	No	V
EN	Tomahawk	144.5	5.5	0.3	9.6	1.5	No	III
EN	Boobyalla Inlet	1187.0	16.0	1.1	21.1	1.2	No	V
EN	Little Musselroe	79.5	6.4	0.5	5.5	1.2	No	III
E	Great Musselroe	431.7	71.3	3.4	32.2	0.7	No	II
E	Ansons Bay	259.0	21.9	4.9	23.2	0.5	No	II
E	Big Lagoon	17.2	17.2	0.5	5.5	0.2	Yes	I
E	Sloop Lagoon	10.8	10.8	0.3	4.0	0	Yes	I
E	Grants Lagoon	6.8	6.8	0.5	6.6	0	Yes	I
E	Georges Bay	556.7	34.2	21.1	53.8	0.7	No	III
E	Scamander	340.8	13.8	1.6	36.8	0.2	Yes	I

APPENDIX 1 (cont.). Estuarine catchment area (ECA), estuarine drainage area (EDA), estuarine area, perimeter length, estimated tidal range, presence of bar and physical group.

Region	*Estuary*	*ECA (km)*	*EDA (km)*	*Area (km)*	*Perimeter (km)*	*Tide (m)*	*Bar*	*Physical Group*
E	Hendersons Lagoon	50.4	50.4	1.0	12.1	0.3	No	III
E	Templestowe	25.2	25.2	0.6	5.8	0.1	Yes	IV
E	Douglas	73.5	3.2	0.1	3.6	0.5	No	II
E	Denison	26.8	0.3	0.0	1.8	0.1	Yes	I
E	Saltwater Lagoon	8.6	8.6	0.2	2.7	0	Yes	I
E	Freshwater Lagoon	11.8	11.8	0.3	4.2	0	Yes	I
E	Bryans Lagoon	5.8	5.8	0.3	5.1	0	Yes	I
E	Great Swanport	1031.2	140.8	40.7	110.1	0.5	No	III
E	Meredith	98.3	1.6	0.1	5.6	0.4	Yes	I
E	Stoney	26.7	0.4	0.0	1.2	0.4	Yes	I
E	Buxton	60.7	1.1	0.2	3.7	0.4	Yes	I
E	Lisdillon	51.2	3.3	0.2	5.4	0.4	Yes	I
E	Little Swanport	733.7	55.9	4.8	48.1	0.6	No	III
E	Grindstone	30.6	6.9	0.2	4.7	0.1	Yes	IV
E	Spring Bay	96.9	6.8	0.5	9.3	0.8	No	III
E	Prosser	701.1	14.3	0.4	6.4	0.6	No	II
E	Earlham Lagoon	109.7	17.1	0.8	11.0	0.4	Yes	IV
SE	Blackman Bay	102.2	60.7	26.7	46.3	0.8	No	III
SE	Carlton	164.7	23.3	1.7	16.2	0.8	No	III
SE	Pittwater	922.9	109.4	46.4	105.0	0.8	No	III
SE	Pipeclay Lagoon	16.5	16.5	5.3	14.7	0.7	No	III
SE	Derwent	9254.8	422.7	70.7	160.6	0.6	No	VII
SE	Browns	59.5	1.4	0.1	4.8	0.4	No	II
SE	North West Bay	176.7	35.0	19.4	35.4	0.7	No	III
SE	Garden Island	42.2	2.2	0.1	2.9	0.8	No	II
SE	Port Cygnet	140.8	36.4	14.6	35.6	0.8	No	II
SE	Huon	3041.9	310.8	60.0	150.8	0.8	No	VII
SE	Crooks	139.5	7.0	1.2	8.0	0.7	No	III
SE	Esperance	257.6	21.6	2.2	18.0	0.6	No	II
SE	Lune	172.6	30.2	4.6	27.7	0.8	No	II
SE	Southport Lagoon	27.2	13.8	10.5	21.0	0.6	No	III
SE	Cloudy Bay	42.7	18.1	6.1	14.4	0.4	No	III
SE	Catamaran	68.6	2.0	0.1	2.7	0.7	No	II
SE	D`Entrecasteaux	78.6	5.2	0.2	5.4	0.5	No	II
SE	Cockle Ck.	16.8	5.8	0.2	4.6	0.5	No	II
S	South Cape Rt.	53.1	4.9	0.0	1.3	0.3	No	II
S	New River Lagoon	298.2	75.3	12.0	32.8	0.1	No	VIII
S	Louisa R.	83.3	4.0	0.3	10.3	0.4	No	II
S	Louisa Ck.	56.6	2.5	0.2	7.6	0.2	No	II
S	Freney	19.7	19.7	0.7	3.9	0	Yes	I
S	Bathurst Harbour	1067.6	213.1	65.8	153.4	0.4	No	VII
S	Payne Bay	924.8	130.7	44.2	76.1	0.5	No	III
W	Mulcahy	58.0	3.2	2.0	7.8	0.4	No	II
W	Giblin	323.5	13.8	0.4	13.7	0.4	No	II
W	Lewis	213.1	18.8	0.1	2.1	0.4	No	II
W	Mainwaring	51.1	2.9	0.1	4.3	0.4	No	II
W	Wanderer	353.6	70.4	1.0	19.5	0.1	Yes	IX
W	Spero	116.0	3.0	0.1	5.2	0.4	No	II
W	Hibbs Lagoon	52.2	4.8	0.6	4.5	0	Yes	I
W	Macquarie Harbour	13137.4	668.0	291.7	242.1	0.4	No	VII
W	Henty	502.5	13.4	0.8	13.8	0.4	No	VIII
W	Little Henty	329.5	48.4	0.9	17.1	0.2	No	II
W	Pieman	3866.9	28.2	2.3	24.2	0.5	No	VIII
W	Lagoon	86.5	0.7	0.1	2.8	0.1	Yes	I
W	Pedder	82.5	1.5	0.0	2.7	0.1	Yes	I
W	Nelson Bay	70.7	2.6	0.0	3.4	0.1	Yes	I
W	Arthur	2495.2	95.5	1.2	29.9	0.6	No	VIII
	Outside Catchments	7145.8						

APPENDIX 2. Minimum (R_{man}), maximum (R_{Max}) and mean (R_{av}) rainfall in GIS cells within catchments, total annual rainfall (TAR), mean annual runoff (MAR) and runoff coefficient (ROC) for estuarine catchment areas and estuarine drainage areas.

Estuary	*Estuarine catchment area*						*Estuarine drainage area*					
	Rmn (mm)	*Rmx (mm)*	*Rav (mm)*	*TAR (gl)*	*MAR (mm)*	*ROC*	*Rmn (mm)*	*Rmx (mm)*	*Rav (mm)*	*TAR (gl)*	*MAR (mm)*	*ROC*
Sea Elephant	801	1087	907	267.4	297	0.33	856	931	883	12.6	275	0.31
Yarra	952	1089	1001	38.2	380	0.38	952	955	955	0.4	339	0.35
Ettrick	976	1105	1021	46.4	397	0.39	976	990	981	0.1	362	0.37
Seal	981	1124	1021	79.2	397	0.39	986	1083	1017	6.7	394	0.39
Yellow Rock	863	975	912	108.7	301	0.33	877	916	900	1.2	291	0.32
North East Inlet	700	954	745	93.3	153	0.21	700	833	731	15.8	141	0.19
Foochow Inlet	724	832	740	49.8	149	0.20	724	730	728	2.0	138	0.19
Middle Inlet	729	896	746	45.7	154	0.21	729	733	731	1.1	141	0.19
Patriarch	728	1190	777	138.3	182	0.23	728	877	743	3.3	152	0.20
Sellars Lagoon	729	871	744	32.8	152	0.20	729	871	744	32.8	152	0.20
Cameron Inlet	730	1210	790	152.4	193	0.24	730	759	739	32.1	148	0.20
Logans Lagoon	725	827	742	51.7	150	0.20	725	827	742	51.7	150	0.20
Pats	729	1210	812	56.5	212	0.26	729	765	738	0.9	147	0.20
Mines	705	910	740	15.7	149	0.20	707	720	714	0.1	125	0.18
Dover	718	1002	754	24.2	161	0.21	718	768	728	1.6	138	0.19
Lee	703	1148	779	47.9	183	0.24	703	710	708	0.3	120	0.17
Shag Rock	720	1239	755	29.7	162	0.21	720	746	724	2.6	134	0.19
Modder	657	1494	785	35.5	188	0.24	657	925	726	1.5	137	0.19
Rices	707	1239	759	22.6	165	0.22	707	749	730	1.2	140	0.19
Rocky Head	673	1059	743	11.5	151	0.20	673	696	683	0.7	98	0.14
Thirsty Lagoon	721	1099	767	11.0	172	0.22	721	1099	767	11.0	172	0.22
Welcome	1037	1384	1138	346.2	501	0.44	1037	1187	1084	13.1	453	0.42
Montagu	1049	1478	1156	378.5	517	0.45	1049	1110	1079	10.9	449	0.42
Mosquito Inlet	962	1066	1011	28.9	389	0.38	962	1066	1011	28.9	389	0.38
Duck Bay	1030	1617	1202	660.4	558	0.46	1030	1195	1107	86.5	474	0.43
West Inlet	990	1147	1041	23.5	415	0.40	990	1033	1012	3.5	390	0.39
East Inlet	981	1197	1071	22.8	442	0.41	981	1146	1035	4.7	410	0.40
Black	1045	1749	1267	437.2	616	0.49	1045	1197	1105	10.9	472	0.43
Crayfish	1116	1420	1195	52.9	551	0.46	1116	1130	1117	0.4	483	0.43
Detention	1075	1773	1243	188.9	595	0.48	1075	1177	1136	6.3	499	0.44
Inglis	1073	1911	1351	682.3	690	0.51	1073	1131	1094	6.6	462	0.42
Cam	1070	1910	1350	336.4	689	0.51	1070	1232	1168	10.9	528	0.45
Emu	1116	2400	1384	336.5	719	0.52	1116	1167	1149	1.3	511	0.44
Blythe	1060	2126	1345	372.7	685	0.51	1060	1153	1111	5.1	477	0.43
Leven	995	2687	1383	965.0	718	0.52	995	1279	1089	52.1	458	0.42
Forth	958	2872	1531	1721.5	849	0.55	958	1065	1030	15.2	405	0.39
Don	928	1362	1063	144.0	434	0.41	928	1014	977	5.7	359	0.37
Mersey	911	2709	1320	2315.1	663	0.50	930	1113	995	43.8	375	0.38
Port Sorell	772	1211	897	576.7	287	0.32	772	931	829	66.3	227	0.27
Tamar	524	2126	944	10938.1	329	0.35	687	1187	874	487.8	267	0.31
Curries	726	1122	814	68.3	214	0.26	726	939	744	1.2	152	0.20
Piper	744	1545	896	416.2	287	0.32	744	826	786	11.2	190	0.24
Little Forester	758	1578	891	309.3	282	0.32	759	803	783	3.3	187	0.24
Brid/Great Forester	732	1635	874	662.5	268	0.3	747	816	781	12.1	185	0.24
Tomahawk	569	1423	725	104.8	135	0.19	569	611	594	3.3	19	0.03
Boobyalla Inlet	651	1832	936	1110.8	322	0.34	651	800	684	10.9	99	0.14
Little Musselroe	658	895	733	58.2	142	0.19	658	768	696	4.4	109	0.16
Great Musselroe	711	1819	919	396.7	307	0.33	711	873	778	55.5	183	0.23
Ansons Bay	834	1727	997	258.1	376	0.38	834	991	914	20.0	303	0.33
Big Lagoon	957	1287	1106	19.1	473	0.43	957	1287	1106	19.1	473	0.43
Sloop Lagoon	908	1287	1025	11.1	401	0.39	908	1287	1025	11.1	401	0.39
Grants Lagoon	870	1312	1031	7.0	407	0.39	870	1312	1031	7.0	407	0.39
Georges Bay	748	1832	1097	610.6	465	0.42	748	1128	865	29.6	259	0.30
Scamander	736	1659	969	330.1	351	0.36	736	938	787	10.9	190	0.24
Hendersons Lagoon	741	1444	1091	55.0	460	0.42	741	1444	1091	55.0	460	0.42

APPENDIX 2 (cont.). Minimum (R_{man}), maximum (R_{Max}) and mean (R_{av}) rainfall amongst GIS cells, total annual rainfall (TAR), mean annual runoff (MAR) and runoff coefficient (ROC) for catchments.

Estuary	*Estuarine catchment area*						*Estuarine drainage area*					
	Rmn (mm)	*Rmx (mm)*	*Rav (mm)*	*TAR (gl)*	*MAR (mm)*	*ROC*	*Rmn (mm)*	*Rmx (mm)*	*Rav (mm)*	*TAR (gl)*	*MAR (mm)*	*ROC*
Templestowe	744	1235	1106	27.9	473	0.43	744	1235	1106	27.9	473	0.43
Douglas	739	1326	992	72.9	372	0.37	739	1017	815	2.6	215	0.26
Denison	779	1155	988	26.5	368	0.37	964	1074	985	0.3	365	0.37
Saltwater Lagoon	651	737	686	5.9	101	0.15	651	737	686	5.9	101	0.15
Freshwater Lagoon	686	848	749	8.9	157	0.21	686	848	749	8.9	157	0.21
Bryans Lagoon	675	736	695	4.1	109	0.16	675	736	695	4.1	109	0.16
Great Swanport	595	1291	759	782.8	166	0.22	597	765	651	91.6	70	0.11
Meredith	620	978	722	70.9	132	0.18	629	679	653	1.0	72	0.11
Stoney	642	804	682	18.2	97	0.14	656	663	656	0.2	74	0.11
Buxton	638	976	746	45.2	154	0.21	638	669	659	0.8	76	0.12
Lisdillon	621	975	698	35.8	112	0.16	621	675	634	2.1	54	0.09
Little Swanport	598	914	709	519.9	121	0.17	605	821	677	37.8	93	0.14
Grindstone	648	839	703	21.5	116	0.17	648	733	670	4.6	86	0.13
Spring Bay	641	910	744	72.1	152	0.20	641	836	664	4.5	81	0.12
Prosser	564	963	728	510.2	138	0.19	650	836	727	10.4	137	0.19
Earlham Lagoon	663	992	797	87.4	199	0.25	691	836	755	12.9	162	0.21
Blackman Bay	699	992	824	84.2	223	0.27	699	927	791	48.0	194	0.25
Carlton	617	899	712	117.2	124	0.17	617	739	659	15.3	77	0.12
Pittwater	539	975	631	582.3	52	0.08	541	706	615	67.3	38	0.06
Pipeclay Lagoon	615	720	650	10.7	69	0.11	615	720	650	10.7	69	0.11
Derwent	512	2710	1148	10624.1	510	0.44	536	1456	783	331.0	187	0.24
Browns	740	1444	868	51.7	262	0.30	740	846	769	1.1	174	0.23
North West Bay	707	1531	1081	191.0	451	0.42	707	1272	867	30.4	261	0.30
Garden Island	861	1341	949	40.0	333	0.35	867	909	883	2.0	276	0.31
Port Cygnet	846	1531	981	138.2	363	0.37	859	1195	947	34.5	332	0.35
Huon	778	2328	1490	4531.9	813	0.55	778	1531	886	275.4	278	0.31
Crooks	923	1825	1136	158.5	500	0.44	923	1186	968	6.7	351	0.36
Esperance	979	1932	1294	333.2	639	0.49	979	1328	1126	24.3	490	0.44
Lune	1069	1930	1502	259.1	823	0.55	1069	1616	1208	36.4	563	0.47
Southport Lagoon	1063	1499	1215	33.1	570	0.47	1063	1238	1154	15.9	515	0.45
Cloudy Bay	888	1158	934	39.9	321	0.34	888	1017	920	16.7	308	0.34
Catamaran	1191	2112	1489	102.2	812	0.55	1191	1538	1212	2.4	567	0.47
D`Entrecasteaux	1154	2019	1399	110.0	733	0.52	1154	1311	1202	6.2	558	0.46
Cockle Ck.	1172	1332	1246	21.0	597	0.48	1172	1311	1245	7.3	596	0.48
South Cape Rt.	1217	2034	1498	79.5	820	0.55	1301	1585	1484	7.3	808	0.54
New River Lagoon	1259	2085	1549	461.9	866	0.56	1259	2065	1453	109.4	781	0.54
Louisa R.	1421	2121	1588	132.3	900	0.57	1462	1614	1557	6.2	873	0.56
Louisa Ck.	1514	2094	1680	95.1	982	0.58	1514	1680	1612	4.0	921	0.57
Freney	1803	1993	1908	37.5	1184	0.62	1803	1993	1908	37.5	1184	0.62
Bathurst Harbour	1595	2559	2153	2298.8	1401	0.65	1925	2457	2166	461.5	1412	0.65
Payne Bay	2124	2830	2523	2333.2	1728	0.69	2310	2727	2432	317.8	1648	0.68
Mulcahy	2360	2696	2421	140.4	1638	0.68	2360	2470	2381	7.5	1603	0.67
Giblin	2350	2848	2509	811.6	1716	0.68	2350	2430	2369	32.7	1592	0.67
Lewis	2228	2831	2385	508.4	1606	0.67	2228	2336	2272	42.6	1506	0.66
Mainwaring	2169	2501	2262	115.5	1497	0.66	2169	2191	2178	6.3	1423	0.65
Wanderer	2053	2844	2405	850.3	1623	0.68	2053	2549	2291	161.2	1523	0.66
Spero	1963	2641	2161	250.6	1408	0.65	1963	1998	1983	6.0	1250	0.63
Hibbs Lagoon	1886	2325	1997	104.2	1262	0.63	1886	1988	1904	9.2	1180	0.62
Macquarie Harbour	1524	3457	2447	17084.8	1661	0.68	1648	3019	2126	1177.0	1377	0.65
Henty	1402	3509	1938	973.9	1210	0.62	1402	1469	1423	19.0	754	0.53
Little Henty	1434	3215	2077	684.3	1333	0.64	1434	3063	1657	80.1	961	0.58
Pieman	1353	3438	2215	8565.8	1456	0.66	1353	2000	1743	49.2	1038	0.60
Lagoon	1428	2603	1729	149.6	1025	0.59	1428	1432	1428	0.9	759	0.53
Pedder	1426	2008	1540	127.1	857	0.56	1427	1432	1428	2.2	759	0.53
Nelson Bay	1278	1904	1439	101.7	768	0.53	1278	1304	1285	3.3	631	0.49
Arthur	1187	2622	1842	4597.2	1125	0.61	1187	1390	1285	122.7	631	0.49
Outside Catchments	445	2676	1132	8086.2	496	0.44						

APPENDIX 3. Regulation and runoff attributes of catchments gauged by Rivers and Water Supply Commission.

Estuary	*Catchment*	*GIS Data*			*RWSC Data*				*Reference*
		Catchment Area (km^2)	*Dam Area* (km^2)	*Rav* (mm)	*Catchment Area* (km^2)	*MAR* (mm)	*Upstream Regulation* (mm)	*Records* (yrs)	
Ettrick		45	0	1059	45	225	nil	5	RWS 83
Pats		68	0	866	21	225	nil	14	RWS 83
Montagu		317	0	1238	323	415	nil	18	Hughes 87
Duck Bay		392	0	1289	339	588	nil	17	RWS 83
Black	Black/Dip	335	0	1436	324	738	nil	14	Hughes 87
Inglis	Flowerdale	173	0	1524	152	806	nil	17	Hughes 87
Inglis	Inglis	326	0	1460	172	765	nil	16	Hughes 87
Cam		238	0	1541	221	684	nil	15	Hughes 87
Emu		242	0	1624	93	1172	yes	28	Hughes 87
Blythe		271	0	1592	285	838	nil	6	RWS 83
Leven	Leven	560	0	1815	500	1053	nil	20	Hughes 87
Leven	Gawler	87	0	1273	86	513	yes	18	Hughes 87
Forth	Forth	1107	936	2055	311	1480	nil*	17	Hughes 87
Don		129	0	1155	128	562	nil	16	Hughes 87
Mersey		1706	713	1654	1618	658	yes HEC	21	Hughes 87
Port Sorell	Franklin Rt.	132	0	974	132	245	nil	8	RWS 83
Port Sorell	Rubicon	262	0	980	259	326	nil	3	RWS 83
Tamar	Andersons	49	0	1059	50	423	nil	19	Hughes 87
Tamar	Supply	135	0	1034	134	373	nil	19	RWS 83
Tamar	North Esk	1065	0	1158	373	466	nil	60	Hughes 87
Tamar	South Esk	9543	9524	893	8997	200	yes HEC	82	Hughes 87
Tamar	Meander	1334	1334	1128	1269	492			Hughes 87
Tamar	Liffey	234	234	1129	224		yes	3	RWS 83
Tamar	Nile	323	323	984	226		nil	1	RWS 83
Tamar	Break`O`Day	230	230	958	111	800	nil		
Tamar	Macquarie	1557	1558	646	365	202	yes	4	RWS 83
Tamar	Lake	813	813	914	421	446	yes	26	Hughes 87
Tamar	Elizabeth	399	399	718	70	331	yes	7	RWS 83
Curries R.		82	0	855	17	296	nil	4	RWS 83
Pipers R.		375	0	973	298	347	nil	11	Hughes 87
Brid	Brid	149	0	1108	140	386	nil	18	RWS 83
Brid	G. Forester	517	0	1010	193	465	nil	13	RWS 83
Tomahawk		139	0	863	115	265	nil	15	Hughes 87
Boobyalla	Ringarooma	912	0	1278	482	644	nil	6	Hughes 87
Boobyalla	Boobyalla	250	0	1003	116		yes		
G. Musselroe		368	0	1066	352	286	nil	14	RWS 83
Ansons Bay		237	0	1088	228	209	nil	14	RWS 83
Georges Bay		522	0	1336	405	525	nil	8	Hughes 87
Apsley		231	0	824	155	402	nil	15	Hughes 87
G. Swanport		659	0	794	448	343	nil	19	Hughes 87
Meredith		96	0	797	86	239	nil	13	Hughes 87
L. Swanport		605	0	698	597	121	nil	22	Hughes 87
Prosser		686	687	727	684	167	yes	19	Hughes 87
Carlton		141	0	761	141	143	nil	14	Hughes 87
Pittwater	Coal	541	246	623	303	75	yes	23	Hughes 87
Pittwater	Orielton	50	0	603	48	53	nil	11	Hughes 87
Pittwater	Iron Ck.	94	0	698	95	139	nil	21	Hughes 87

APPENDIX 3 (cont.). Regulation and runoff attributes of catchments gauged by Rivers and Water Supply Commission.

Estuary	*Catchment*	*GIS Data*			*RWSC Data*				*Reference*
		Catchment Area (km^2)	*Dam Area* (km^2)	*Rav* (mm)	*Catchment Area* (km^2)	*MAR* (mm)	*Upstream Regulation* (mm)	*Records* (yrs)	
Derwent	Nive	1089	1089	1542	186	1058	nil	19	Hughes 87
Derwent	Derwent	7367	6145	1243	7060	486	yes HEC	24	Hughes 87
Derwent	Clyde	1117	1118	661	1012	79	yes HEC	20	Hughes 87
Derwent	Jordan	1244	0	598	742	36	nil	23	Hughes 87
Derwent	Florentine	443	443	1680	436	883			Hughes 87
Derwent	Tyenna	336	0	1346	205	865	nil	18	Hughes 87
North West	North West	96	0	1032	88	238	yes	18	Hughes 87
North West	Snug	23	0	1309	17	286	nil	19	Hughes 87
Huon	Huon	2266	0	1641	1829	1588	yes HEC	35	Hughes 87
Huon	Mountain	187	0	1021	40	690	nil	15	Hughes 87
Esperance		173	0	1540	175	705	nil	18	Hughes 87
Payne Bay	Davey	724	0	2538	686	1933	nil	19	Hughes 87
Macquarie H.	Franklin	1656	0	2769	1590	1872	nil	22	Hughes 87
Macquarie H.	Gordon	5183	2013	2519	458	1550			Hughes 87
Macquarie H.		811	557	2866	449	2339	nil	55	Hughes 87
Henty		375	0	2555	116	?	nil	18	Hughes 87
Pieman	Whyte	387	0	2189	325	1480	nil	23	Hughes 87
Pieman	Pieman	3830	2661	2384	2541	1566	yes HEC	28	Hughes 87
Arthur	Arthur	1829	0	1822	1535	1179	nil	28	Hughes 87
Arthur	Hellyer	327	0	1984	102	1343	nil	26	Hughes 87

APPENDIX 4a. Mean salinity recorded during summer field trips at the water surface and below the thermocline in upstream, mid and downstream sections of estuaries. Also shown are the number of stations investigated in each estuary, the depth of the thermocline or whether fully mixed (M), and salinity rank at surface in mid section. Salinity ranks are shown in bold when calculated using regression equations and are in plain text when no data were available and they were derived from the most similar estuary (see section 2.10). [1]Data from Thomson *et al.* (1982), [2]Edgar & Cresswell (1991) and [3]Cresswell *et al.* (1989).

Estuary	*Stations*	*Upstream*			*Mid*			*Downstream*			*Rank*
		Therm. (m)	*Surface (‰)*	*Bottom (‰)*	*Therm. (m)*	*Surface (‰)*	*Bottom (‰)*	*Therm. (m)*	*Surface (‰)*	*Bottom (‰)*	
Sea Elephant	1				M	31.7					**28.4**
Yarra											11.0
Ettrick											11.0
Seal											36.5
Yellow Rock	1								4.6		**5.9**
North East Inlet	1							M	34.5		**36.5**
Foochow Inlet											30.6
Middle Inlet											12.1
Patriarch	1							M	34.2		**34.8**
Sellars Lagoon											37.4
Cameron Inlet[1]	1		54.0						52.7		**37.4**
Logans Lagoon											34.8
Pats											14.8
Mines											11.0
Dover											17.6
Lee											30.6
Shag Rock											36.5
Modder	1							M	18.7		**11.5**
Rices	1					15.4			34.0		**22.0**
Rocky Head											39.3
Thirsty Lagoon											35.8
Welcome	1							M	36.1		**35.2**
Montagu											25.1
Mosquito Inlet	1							M	34.9		**35.8**
Duck Bay[1]		M	28.3		M	34		M	34.5		**35.9**
West Inlet	1				M	37.5					**39.3**
East Inlet	2				M	36.3			33.4		**36.4**
Black	1							M	29.8		**20.5**
Crayfish	1							0.25	29.3	35.0	**19.5**
Detention	1				M	29.0					**25.1**
Inglis	2				1	15.4	29.6	M	31.1		**16.7**
Cam	1							M	23.3		**13.3**
Emu	1							0.5	3.5	28.8	**3.32**
Blythe	1							M	27.4		**16.9**
Leven	2							M	35.6		**34.9**
Forth	2	M	0.0					2.0	3.8	18.0	**3.0**
Don	2				0.5	15.0	28.3	M	34.4		**22.6**
Mersey	2	2	0.6	22.1				M	34.4		**20.3**
Port Sorell	3	M	35.2		M	35.6		M	35.8		**35.1**
Tamar	5	M	1.0		M	24.3		M	34.4		**21.1**
Curries											17.6
Piper	1							M	28.4		**18.6**
Little Forester	2	0.5	9.3	30.3	M	27.3					**25.5**
Brid/Great Forester	2				0.5	18.3	33.2	M	26.6		**16.0**
Tomahawk	3	M	30		M	36		M	36		**35.8**
Boobyalla Inlet	2				M	11.7		M	9.2		**8.2**
Little Musselroe	2				M	36.0		M	35.9		**34.6**
Great Musselroe	2				M	35.2			35.5		**35.8**
Ansons Bay	5	0.5	4.8	24.8	M	32.0		M	33.3		**26.8**
Big Lagoon	2				M	14.4		0.5	16.5	24.2	**9.7**
Sloop Lagoon	1							M	11.3		**9.8**
Grants Lagoon	2								27.6		**17.7**
Georges Bay	4	M	33.2		M	34.8			35.2		**36.4**

APPENDIX 4a (cont.). Mean salinity in different sections of estuaries as recorded during summer field trips.

Estuary	*Stations*	*Upstream*			*Mid*			*Downstream*			*Rank*
		Therm. (m)	*Surface (‰)*	*Bottom (‰)*	*Therm. (m)*	*Surface (‰)*	*Bottom (‰)*	*Therm. (m)*	*Surface (‰)*	*Bottom (‰)*	
Scamander	3	0.5	1.0	27.8	M	26.2		M	34.5		**23.5**
Hendersons Lagoon	3	M	41.0		M	36.0			36.2		**34.8**
Templestowe	1				M	32.1					**32.7**
Douglas	1							0.5	6.3	21.0	**6.9**
Denison	1							1.0	17.0	24.9	**11.0**
Saltwater Lagoon											13.9
Freshwater Lagoon											13.9
Bryans Lagoon	1								23.3		**13.9**
Great Swanport	1	M	22.9		M	36.2		M	36.3		**35.6**
Meredith	1							M	21.7		**12.1**
Stoney	1							M	32.3		**27.6**
Buxton											12.1
Lisdillon	2	M	62.8					M	31.4		**36.5**
Little Swanport	3				M	36.3		M	35.6		**34.7**
Grindstone	2								43.0		**39.3**
Spring Bay	2	M	33.9								**35.8**
Prosser	1							M	34.8		**36.2**
Earlham Lagoon	1				M	37.2					**37.0**
Blackman Bay[1]	3	M	37.5			34.6		M	34.7		**36.2**
Carlton	2	M	33.2					M	35.2		**35.9**
Pittwater	2				M	35.2		M	34.5		**36.5**
Pipeclay Lagoon						35.8					**35.8**
Derwent	7	4.0	3.2	11.4	3.0	16.3	32.8	M	29.8		**17.3**
Browns	2				M	32.9		M	32.1		**30.6**
North West Bay	2				M	26.7		M	33.4		**26.8**
Garden Island	2	M	1.5					M	31.0		**17.6**
Port Cygnet	1							M	33.3		**29.5**
Huon	7	2.0	1.8	13.9	2.0	19.5	27.2		33.7		**22.1**
Crooks											35.8
Esperance	2	0.5	9.5	31.5				M	32.9		**29.3**
Lune	3	0.3	6.4	27.8	M	30.2		M	31.9		**25.8**
Southport Lagoon											34.8
Cloudy Bay[1]						33.0					**34.8**
Catamaran	1				0.3	16.7	28.9				**14.8**
D`Entrecasteaux											34.8
Cockle Ck.	1								25.2		**14.6**
South Cape Rt.											14.8
New River Lagoon	2				M	6.7		M	25.2		**10.7**
Louisa R.											34.8
Louisa Ck.											30.6
Freney											9.7
Bathurst Harbour[2]		M	27.0		M	32.0		M	34.0		**33.3**
Payne Bay[2]		2.0	0.7	20.1	2.0	15.3	30.0	M	34.9		**19.5**
Mulcahy											34.8
Giblin											36.2
Lewis											36.2
Mainwaring											14.8
Wanderer	3				2.0	0.8	16.6	1.0	2.5	18.1	**1.9**
Spero											14.8
Hibbs Lagoon											9.7
Macquarie Harbour[3]		5.0	5.0	16.0	8.0	10.0	31.5	5.0	21.9	30.5	**13.2**
Henty	1								0.0		**0**
Little Henty											29.3
Pieman	7	13.0	0.5		9.0	0.7	6.8	7.0	0.7	8.5	**1.5**
Lagoon											12.1
Pedder											7.8
Nelson Bay	1							1.0	8.3	25.3	**7.8**
Arthur	1							3.0	9.8	26.9	**9.2**

APPENDIX 4b. Mean salinity recorded during winter field trips at the water surface and below the thermocline in upstream, mid and downstream sections of estuaries. Also shown are the number of stations investigated in each estuary, the depth of the thermocline or whether fully mixed (M), and salinity rank at surface in mid section. Salinity ranks are shown in bold when calculated using regression equations and are in plain text when no data were available and they were derived from the most morphologically similar estuary (see section 2.10). [1]Data from Thomson *et al.* (1982), [2]Edgar & Cresswell (1991) and [3]Cresswell *et al.* (1989).

Estuary	*Stations*	*Upstream*			*Mid*			*Downstream*			*Rank*
		Therm. (m)	*Surface (‰)*	*Bottom (‰)*	*Therm. (m)*	*Surface (‰)*	*Bottom (‰)*	*Therm. (m)*	*Surface (‰)*	*Bottom (‰)*	
Sea Elephant											2.2
Yarra											2.2
Ettrick											2.2
Seal											10.0
Yellow Rock											8.8
North East Inlet											31.0
Foochow Inlet											1.8
Middle Inlet											8.8
Patriarch[1]						18.0					**12.1**
Sellars Lagoon											34.5
Cameron Inlet[1]			36.0								**34.5**
Logans Lagoon											32.7
Pats											12.4
Mines											2.2
Dover											12.4
Lee											1.8
Shag Rock											10.0
Modder											8.8
Rices											12.4
Rocky Head											27.5
Thirsty Lagoon											34.5
Welcome											32.4
Montagu											19.6
Mosquito Inlet											30.7
Duck Bay[1]		?	10.5	21.8		11.0			23.8		**19.5**
West Inlet	1				M	29.0					**29.3**
East Inlet	2				M	31.2		M	33.2		**30.7**
Black	1							2.0	0.7	31.0	**1.2**
Crayfish	1							0.5	2.5	33.1	**1.8**
Detention	1				M	24.3					**19.6**
Inglis	14	3.0	0.3	8.7	3.0	1.3	23.1	1.5	11.2	27.1	**1.8**
Cam	7				3.0	1.5	26.9				**1.9**
Emu	3							M	0.6		**0.4**
Blythe	7				3.0	1.2	30.4				**1.7**
Leven	20	M	0.2		3.0	3.2	30.7	1.0	12.0	31.6	**1.7**
Forth	4							M	0.3		**0**
Don	6				3.0	0.9	31.5	0.5	0.7	27.6	**1.4**
Mersey	14	3.0	0.4	28.6	2.0	3.1	31.4	1.0	15.1	28.0	**2.2**
Port Sorell	9	2.0	2.6	19.1	M	27.9		M	30.6		**24.0**
Tamar	14	M	0.4		M	8.0		M	26.7		**7.7**
Curries											12.4
Piper	6	2.0	0.8	22.0	1.0	3.6	30.1	0.5	2.2	33.6	**3.2**
Little Forester	3				2.0	1.4	29.5				**1.9**
Brid/Great Forester	6				2.0	1.7	29.0	1.0	2.7	31.5	**1.7**
Tomahawk	4	M	0.5		M	21.1		M	34.3		**19.8**
Boobyalla Inlet	1				M	0.0					**0**
Little Musselroe	5				M	32.4		M	34.6		**32.4**
Great Musselroe	6				M	4.5		M	19.3		**5.0**
Ansons Bay	10	1.0	1.1	28.4	0.5	18.6	29.2	M	33.3		**22.7**
Big Lagoon	2							1.0	4.9	17.2	**1.7**
Sloop Lagoon	2							2.0	5.8	21.4	**1.8**
Grants Lagoon	3							M	23.8		**12.8**
Georges Bay	4	1.0	4.7	31.0	M	28.1		M	35.0		**30.0**

APPENDIX 4b (cont.). Mean salinity in different sections of estuaries as recorded during winter field trips.

Estuary	Stations	Upstream			Mid			Downstream			Rank
		Therm. (m)	Surface (‰)	Bottom (‰)	Therm. (m)	Surface (‰)	Bottom (‰)	Therm. (m)	Surface (‰)	Bottom (‰)	
Scamander	8	3.0	0.6	25.5				2.0	2.4	29.0	**2.2**
Hendersons Lagoon	5				M	30.0		M	34.3		**31.0**
Templestowe	1				M	27.0					**24.9**
Douglas											0.6
Denison	1							0.5	8.8	29.2	**2.2**
Saltwater Lagoon	1				M	24.1					**18.1**
Freshwater Lagoon	2				1.0	26.0	34.5				**28.6**
Bryans Lagoon											12.8
Great Swanport	10	2.0	3.3	15.3	M	25.0		M	32.6		**25.6**
Meredith	1							0.5	20.0	30.4	**8.7**
Stoney	1							M	23.9		**14.2**
Buxton											8.8
Lisdillon	2							0.5	20.2	33.0	**10.0**
Little Swanport	13	0.5	0.3	19.1	M	26.2		M	34.0		**18.1**
Grindstone	2				M	31.2		M	31.4		**27.5**
Spring Bay	2	M	33.2					M	33.1		**31.0**
Prosser	8							1.0	6.1	33.3	**1.9**
Earlham Lagoon	3				M	33.4					**33.5**
Blackman Bay[1]	3	0.5	11.5	32.5		31.5		M	32.9		**30.7**
Carlton	9	0.5	11.9	30.2	M	30.7		M	33.3		**31.0**
Pittwater	13	0.5	1.3	15.4	M	28.6		M	31.6		**24.1**
Pipeclay Lagoon	2				M	34.5		M	35.5		**34.5**
Derwent	12	M	0.3		4.0	6.1	27.6	1.0	25.4	33.3	**4.1**
Browns	4				0.5	1.9	29.3	0.5	1.2	31.3	**1.8**
North West Bay	2					25.0		M	32.3		**23.7**
Garden Island	2	M	0.4					M	32.3		**12.4**
Port Cygnet	3	M	0.7			10.8		M	32.9		**16.2**
Huon	19	3.0	0.8	29.9	2.0	5.9	31.8	M	29.4		**11.1**
Crooks											32.9
Esperance	10	4.0	0.8	32.2	2.0	3.7	31.8	0.5	18.4	33.2	**5.9**
Lune	8	4.0	0.4	11.9	1.0	1.6	31.5	1.0	17.2	31.4	**1.9**
Southport Lagoon											32.7
Cloudy Bay[1]	1				M	33.4					**32.7**
Catamaran	1				0.5	0.8	32.5				**0.5**
D`Entrecasteaux											12.1
Cockle Ck.[1]	1					22.0		M	32.6		**22.3**
South Cape Rt.											0.6
New River Lagoon											5.0
Louisa R.											12.1
Louisa Ck.											1.8
Freney											1.7
Bathurst Harbour[2]		1.5	6.0	32.0	2.0	10.0	32.0	M	32.0		**21.7**
Payne Bay[2]								M	33.1		21.7
Mulcahy											12.1
Giblin											1.9
Lewis											1.9
Mainwaring											0.5
Wanderer											0
Spero											0.5
Hibbs Lagoon											1.7
Macquarie Harbour[3]	4	6.0	2.0	10.0	10.0	10.0	31.0	10.0	17.0	31.0	**10.9**
Henty											0
Little Henty											5.9
Pieman	1	M	0								1.9
Lagoon											8.8
Pedder											8.8
Nelson Bay											8.8
Arthur	1							5.0	1.3	25.8	**1.9**

APPENDIX 5. Area (km^2) within each Tasmanian estuarine catchment of major geological classes (alkaline intrusion, basalt, Cambrian acid volcanics, Cambrian ore deposits, carbonaceous, dolerite, dolomite, granite, lake, limestone, metamorphic and sedimentary).

Estuary	*kaline*	*Basalt*	*CAV*	*COD*	*Carb*	*Doler*	*Dolom*	*Granite*	*Lake*	*Lime*	*Metam*	*Sedim*	*Total*
Sea Elephant	0	1	0	0	0	0	0	12	0	0	63	219	295
Yarra	0	0	0	0	0	0	0	1	0	0	1	36	38
Ettrick	0	0	0	0	0	0	0	0	0	0	14	32	45
Seal	0	0	0	1	0	0	0	0	0	0	23	53	78
Yellow Rock	0	0	0	0	0	0	0	8	0	0	48	64	119
North East Inlet	0	0	0	0	0	0	0	38	5	5	0	76	124
Foochow Inlet	0	0	0	0	0	0	0	9	0	0	0	58	67
Middle Inlet	0	0	0	0	0	0	0	0	0	10	0	51	61
Patriarch	0	0	0	0	0	0	0	31	0	34	0	114	178
Sellars Lagoon	0	0	0	0	0	0	0	2	2	0	0	40	44
Cameron Inlet	0	4	0	0	0	0	0	48	0	27	0	114	192
Logans Lagoon	0	0	0	0	0	0	0	1	2	0	0	67	70
Pats	0	1	0	0	0	0	0	36	0	0	0	32	70
Mines	0	0	0	0	0	0	0	15	0	0	0	6	21
Dover	0	0	0	0	0	0	0	14	0	0	0	18	32
Lee	0	0	0	0	0	0	0	33	0	0	0	28	61
Shag Rock	0	0	0	0	0	0	0	21	0	0	0	19	39
Modder	0	0	0	0	0	0	0	26	0	0	0	19	45
Rices	0	0	0	0	0	0	0	12	0	0	0	18	30
Rocky Head	0	0	0	0	0	0	0	8	0	0	0	7	15
Thirsty Lagoon	0	0	0	0	0	0	0	3	0	0	0	11	13
Welcome	0	16	0	58	0	0	4	0	0	1	0	226	304
Montagu	0	0	0	105	0	0	49	0	0	0	0	174	327
Mosquito Inlet	0	2	0	0	0	0	0	0	0	0	0	26	28
Duck Bay	0	64	0	199	0	0	47	0	0	0	0	238	548
West Inlet	0	8	0	2	0	0	0	0	0	0	0	13	22
East Inlet	0	10	0	0	0	0	0	0	0	0	0	11	21
Black	0	62	0	0	0	0	1	0	0	0	0	282	345
Crayfish	0	3	0	0	0	0	0	0	0	0	0	41	44
Detention	0	28	0	0	0	0	0	0	0	0	0	124	152
Inglis	0	231	0	0	0	19	0	0	0	2	54	198	505
Cam	0	170	0	0	2	3	0	0	0	0	0	76	249
Emu	0	142	3	7	0	0	0	39	1	10	0	41	243
Blythe	0	92	0	6	0	0	0	106	0	5	0	68	277
Leven	0	236	13	194	0	0	0	4	0	36	6	207	697
Forth	0	252	45	107	0	15	0	7	21	5	316	357	1124
Don	0	51	0	17	6	4	0	0	0	2	8	53	135
Mersey	0	178	55	79	2	309	0	3	13	69	90	955	1752
Port Sorell	0	57	0	18	55	153	0	0	0	0	0	412	640
Tamar	0	377	0	63	2	4593	0	495	264	1	4	5784	11582
Curries	0	0	0	0	133	1	0	0	0	0	0	83	84
Piper	0	26	0	0	0	64	0	0	0	0	0	374	464
Little Forester	0	2	0	0	2	1	0	5	0	0	0	339	347
Brid/Great Forester	0	37	0	0	0	0	0	237	0	0	0	502	776
Tomahawk	0	0	0	0	0	0	0	54	0	0	0	90	144
Boobyalla Inlet	0	105	0	0	0	8	0	516	0	0	0	558	1186
Little Musselroe	0	0	0	0	0	19	0	1	0	0	0	59	79
Great Musselroe	0	1	0	0	0	4	0	172	0	0	0	254	431
Ansons Bay	0	0	0	0	0	0	0	143	0	0	0	115	258
Big Lagoon	0	0	0	0	0	0	0	15	0	0	0	2	17
Sloop Lagoon	0	0	0	0	0	0	0	9	0	0	0	1	11
Grants Lagoon	0	0	0	0	0	0	0	6	0	0	0	1	7
Georges Bay	0	17	0	0	0	0	0	370	0	0	0	169	555
Scamander	0	1	0	0	0	0	0	49	0	0	0	289	339

APPENDIX 5 (cont.). Area (km^2) within each Tasmanian estuarine catchment of major geological classes.

Estuary	'kaline	Basalt	CAV	COD	Carb	Doler	Dolom	Granite	Lake	Lime	Metam	Sedim	Total
Hendersons Lagoon	0	0	0	0	0	0	0	26	0	0	0	24	50
Templestowe	0	0	0	0	3	11	0	0	0	0	0	11	25
Douglas	0	0	0	0	16	51	0	0	0	0	0	6	73
Denison	0	0	0	0	9	14	0	0	0	0	0	3	27
Saltwater Lagoon	0	0	0	0	1	1	0	1	0	0	0	7	9
Freshwater Lagoon	0	0	0	0	0	0	0	9	0	0	0	3	12
Bryans Lagoon	0	0	0	0	0	1	0	4	0	0	0	1	5
Great Swanport	0	0	0	0	45	778	0	18	0	0	0	187	1027
Meredith	0	0	0	0	0	95	0	0	0	0	0	3	98
Stoney	0	0	0	0	0	25	0	0	0	0	0	2	27
Buxton	0	0	0	0	0	58	0	0	0	0	0	2	60
Lisdillon	0	0	0	0	0	48	0	0	0	0	0	3	51
Little Swanport	0	6	0	0	0	508	0	0	0	0	0	218	732
Grindstone	0	0	0	0	0	12	0	0	0	0	0	19	30
Spring Bay	0	1	0	0	2	73	0	0	0	0	0	23	97
Prosser	0	6	0	0	0	410	0	0	0	0	0	285	701
Earlham Lagoon	0	0	0	0	0	97	0	0	0	0	0	12	110
Blackman Bay	0	5	0	0	0	50	0	0	0	0	0	46	101
Carlton	0	4	0	0	0	97	0	0	0	0	0	63	164
Pittwater	0	39	0	0	15	366	0	0	0	0	0	515	920
Pipeclay Lagoon	0	0	0	0	0	3	0	0	0	0	0	13	16
Derwent	0	572	0	9	106	4456	24	0	296	142	0	3750	9249
Browns	0	2	0	0	3	29	0	0	0	0	0	29	60
North West Bay	0	3	0	0	1	86	0	0	0	0	0	87	176
Garden Island	0	0	0	0	0	18	0	0	0	0	0	24	42
Port Cygnet	3	0	0	0	2	39	0	0	0	0	0	98	140
Huon	6	0	0	6	8	849	73	0	4	8	90	2002	3037
Crooks	0	0	0	0	0	91	0	0	0	0	0	49	139
Esperance	0	0	0	0	0	93	0	0	0	0	0	164	257
Lune	0	2	0	0	2	44	3	0	0	2	0	120	172
Southport Lagoon	0	2	0	0	0	10	0	0	0	0	0	15	27
Cloudy Bay	0	0	0	0	0	33	0	0	0	0	0	9	42
Catamaran	0	0	0	0	1	11	0	0	0	0	0	58	69
D`Entrecasteaux	0	0	0	0	4	8	0	0	0	9	0	61	79
Cockle Ck.	0	0	0	0	0	14	0	0	0	0	0	3	17
South Cape Rt.	0	0	0	0	0	4	0	0	0	0	0	49	53
New River Lagoon	0	0	0	3	0	6	0	0	0	14	64	211	298
Louisa R.	0	0	0	0	0	0	0	0	0	0	34	49	83
Louisa Ck.	0	0	0	0	0	0	0	0	0	0	41	16	57
Freney	0	0	0	0	0	0	0	0	0	0	14	5	19
Bathurst Harbour	0	0	0	0	0	0	0	0	0	0	746	316	1062
Payne Bay	0	0	0	0	0	0	0	0	0	1	577	344	922
Mulcahy	0	0	0	0	0	0	0	0	0	0	45	13	58
Giblin	0	0	0	0	0	0	0	0	0	14	212	97	323
Lewis	0	0	95	0	0	0	0	2	0	0	91	25	213
Mainwaring	0	0	9	22	0	0	0	0	0	0	0	21	51
Wanderer	0	0	40	40	0	0	0	0	0	0	97	176	354
Spero	0	0	0	43	0	0	0	0	0	0	0	73	116
Hibbs Lagoon	0	0	0	44	6	0	0	0	0	1	0	8	52
Macquarie Harbour	0	1	332	617	0	143	209	7	1073	416	4967	5358	13123
Henty	0	0	74	101	6	2	0	0	2	9	0	313	502
Little Henty	0	0	0	95	7	7	0	9	0	11	2	206	329
Pieman	0	194	326	590	16	52	14	345	3	26	948	1366	3864
Lagoon	0	3	0	0	0	0	0	2	0	0	0	81	87
Pedder	0	0	0	0	0	0	0	0	0	0	0	83	83
Nelson Bay	0	1	0	0	0	0	0	0	0	0	0	70	71
Arthur	0	383	0	239	20	8	151	0	3	0	144	1568	2495
Outside catchments	2	337	48	272	0	950	0	933	21	6	482	3910	6967

APPENDIX 6. Estimated population and number of dwellings in catchment areas as derived using GIS, counts of number of dwellings from map sheets for sparsely-populated catchments, estimated population for sparsely-populated catchments as calculated using number of dwellings from count data and number of persons per dwelling from GIS data. Also shown are overall population estimates based on GIS for densely-populated catchments and dwelling counts for sparsely-populated catchments, and overall population density (/km^2).

Estuary	*Estuarine catchment area*						*Estuarine drainage area*					
	GIS Pop.	*GIS Dwell.*	*Count Dwell.*	*Count Pop.*	*Esteem. Pop.*	*Density (/km^2)*	*GIS Pop.*	*GIS Dwell.*	*Count Dwell.*	*Count Pop.*	*Estim. Pop.*	*Density (/km^2)*
Sea Elephant	255	108	58	137	137	0.46	15	7	0	0	0	0.00
Yarra	41	19	89	192	192	5.04	0	0	4	9	9	23.33
Ettrick	46	19	17	41	41	0.91	0	0	0	0	0	0.00
Seal	47	23	53	108	108	1.40	4	2	0	0	0	0.00
Yellow Rock	56	23	33	80	80	0.67	1	0	1	2	2	1.73
North East Inlet	34	24	3	4	4	0.03	6	4	3	5	5	0.21
Foochow Inlet	19	13	0	0	0	0.00	1	1	0	0	0	0.00
Middle Inlet	16	11	0	0	0	0.00	0	0	0	0	0	0.00
Patriarch	68	40	13	22	22	0.12	2	1	0	0	0	0.00
Sellars Lagoon	26	13	0	0	0	0.00	26	13	0	0	0	0.00
Cameron Inlet	109	56	23	45	45	0.23	26	13	0	0	0	0.00
Logans Lagoon	41	21	5	10	10	0.14	41	21	0	0	0	0.00
Pats	20	12	18	30	30	0.43	0	0	3	5	5	4.10
Mines	6	4	0	0	0	0.00	0	0	0	0	0	0.00
Dover	10	5	0	0	0	0.00	1	0	0	0	0	0.00
Lee	19	10	0	0	0	0.00	0	0	0	0	0	0.00
Shag Rock	12	7	0	0	0	0.00	1	1	0	0	0	0.00
Modder	14	7	0	0	0	0.00	1	0	0	0	0	0.00
Rices	10	5	0	0	0	0.00	1	0	0	0	0	0.00
Rocky Head	4	2	0	0	0	0.00	0	0	0	0	0	0.00
Thirsty Lagoon	4	2	0	0	0	0.00	4	2	0	0	0	0.00
Welcome	117	52		0	117	0.38	6	2	3	9	9	0.75
Montagu	402	140		0	402	1.23	7	3	15	35	35	3.46
Mosquito Inlet	14	6	0	0	0	0.00	14	6	0	0	0	0.00
Duck Bay	5020	1601		0	5020	9.14	1981	648		0	1981	25.36
West Inlet	107	34	24	76	76	3.34	15	5	9	27	27	7.92
East Inlet	209	79		0	209	9.83	18	8	11	25	25	5.40
Black	605	277		0	605	1.75	34	21	11	18	18	1.81
Crayfish	95	59	13	21	21	0.47	1	1	10	10	10	25.64
Detention	187	75		0	187	1.23	9	5	20	36	36	6.49
Inglis	6404	2055		0	6404	12.68	2255	694		0	2255	375.83
Cam	2929	959		0	2929	11.75	1275	416		0	1275	136.95
Emu	1608	562		0	1608	6.61	254	97		0	254	217.09
Blythe	1095	370		0	1095	3.95	220	82		0	220	47.52
Leven	7957	2640		0	7957	11.40	6295	2090		0	6295	131.75
Forth	2763	942		0	2763	2.46	1032	335		0	1032	69.87
Don	3390	1162		0	3390	25.01	1618	559		0	1618	278.49
Mersey	20108	6770		0	20108	11.47	12558	4201		0	12558	285.41
Port Sorell	3134	1292		0	3134	4.87	1508	685		0	1508	18.86
Tamar	110350	37292		0	110350	9.52	39092	12709		0	39092	70.02
Curries	122	52	117	275	275	3.27	2	1	55	110	110	65.87
Piper	1656	748		0	1656	3.56	34	42	50	40	40	2.85
Little Forester	820	331		0	820	2.36	10	7	23	33	33	7.79
Brid/Great Forester	3674	1320	0	0	3674	11.45	386	177	0	0	385	28.71
Tomahawk	55	29	13	25	25	0.17	1	1	6	6	6	1.08
Boobyalla Inlet	1934	833		0	1934	1.63	3	3	11	11	11	0.69
Little Musselroe	17	15	22	25	25	0.31	1	1	3	3	3	0.47
Great Musselroe	143	175		0	143	0.33	20	27	56	41	41	0.58
Ansons Bay	149	170		0	149	0.58	11	14	141	111	111	5.07
Big Lagoon	21	18	2	2	2	0.14	21	18	2	2	2	0.14
Sloop Lagoon	13	12	4	4	4	0.40	13	12	4	4	4	0.40
Grants Lagoon	8	7	43	49	49	7.25	8	7	43	49	49	7.25
Georges Bay	1768	935		0	1768	3.18	1106	566		0	1106	32.31
Scamander	611	322		0	611	1.79	263	160		0	263	19.06

APPENDIX 6 (cont.). Estimated population, number of dwellings and population density in catchment areas .

Estuary	*Estuarine catchment area*						*Estuarine drainage area*					
	GIS Pop.	*GIS Dwell.*	*Count Dwell.*	*Count Pop.*	*Estim. Pop.*	*Density (/km^2)*	*GIS Pop.*	*GIS Dwell.*	*Count Dwell.*	*Count Pop.*	*Estim. Pop.*	*Density (/km^2)*
Hendersons Lagoon	60	35	39	67	67	1.33	60	35	22	38	38	0.75
Templestowe	30	18	19	32	32	1.25	30	18	19	32	32	1.25
Douglas	88	51	11	19	19	0.26	4	2	4	8	8	2.54
Denison	28	18	16	25	25	0.93	0	0	16	25	25	77.78
Saltwater Lagoon	5	5	0	0	0	0.00	5	5	0	0	0	0.00
Freshwater Lagoon	9	14	2	1	1	0.11	9	14	1	1	1	0.05
Bryans Lagoon	6	9	0	0	0	0.00	6	9	0	0	0	0.00
Great Swanport	360	263		0	360	0.35	63	57	65	72	72	0.51
Meredith	79	54	21	31	31	0.31	1	1	18	18	18	11.25
Stoney	21	14	13	20	20	0.73	0	0	7	0	0	0.00
Buxton	49	33	9	13	13	0.22	1	1	9	9	9	7.89
Lisdillon	42	28	17	26	26	0.50	3	2	15	23	23	6.82
Little Swanport	437	216		0	437	0.60	36	22	70	115	115	2.05
Grindstone	14	8	17	30	30	0.97	3	2	0	0	0	0.00
Spring Bay	806	294		0	806	8.31	612	215		0	612	90.27
Prosser	947	440		0	947	1.35	276	170		0	276	19.31
Earlham Lagoon	98	56	10	18	18	0.16	15	9	7	12	12	0.68
Blackman Bay	357	210		0	357	3.49	302	162		0	302	4.97
Carlton	675	404		0	675	4.10	314	231		0	314	13.49
Pittwater	8215	2961		0	8215	8.90	4820	1763		0	4820	44.05
Pipeclay Lagoon	724	311		0	724	43.85	724	311		0	724	43.85
Derwent	148037	46503		0	148037	16.00	131890	40304		0	131890	312.01
Browns	6167	1889		0	6167	103.58	646	213		0	646	454.93
North West Bay	6949	2248		0	6949	39.33	4425	1398		0	4425	126.32
Garden Island	362	267	60	81	81	1.93	20	18	20	22	22	10.06
Port Cygnet	2071	796		0	2071	14.71	699	317		0	699	19.22
Huon	11027	4140		0	11027	3.63	3794	1370		0	3794	12.21
Crooks	1303	465		0	1303	9.34	161	60		0	161	23.13
Esperance	336	170		0	336	1.30	119	50		0	119	5.51
Lune	69	69	122	122	122	0.71	12	12	36	36	36	1.19
Southport Lagoon	10	10	0	0	0	0.00	5	5	0	0	0	0.00
Cloudy Bay	64	66	20	19	19	0.45	32	30	3	3	3	0.18
Catamaran	28	28	0	0	0	0.00	1	1	0	0	0	0.00
D`Entrecasteaux	31	31	0	0	0	0.00	2	2	0	0	0	0.00
Cockle Ck.	6	6	15	15	15	0.89	2	2	15	15	15	2.57
South Cape Rt.	10	9	0	0	0	0.00	0	0	0	0	0	0.00
New River Lagoon	17	7	0	0	0	0.00	4	2	0	0	0	0.00
Louisa R.	5	2	0	0	0	0.00	0	0	0	0	0	0.00
Louisa Ck.	3	1	0	0	0	0.00	0	0	0	0	0	0.00
Freney	1	0	0	0	0	0.00	1	0	0	0	0	0.00
Bathurst Harbour	62	26	5	12	12	0.01	12	5	5	12	12	0.06
Payne Bay	31	13	0	0	0	0.00	5	2	0	0	0	0.00
Mulcahy	0	0	0	0	0	0.00	0	0	0	0	0	0.00
Giblin	0	0	0	0	0	0.00	0	0	0	0	0	0.00
Lewis	0	0	0	0	0	0.00	0	0	0	0	0	0.00
Mainwaring	0	0	0	0	0	0.00	0	0	0	0	0	0.00
Wanderer	0	0	0	0	0	0.00	0	0	0	0	0	0.00
Spero	0	0	0	0	0	0.00	0	0	0	0	0	0.00
Hibbs Lagoon	0	0	0	0	0	0.00	0	0	0	0	0	0.00
Macquarie Harbour	8189	3218	0	0	8189	4.813	593	296	5	0	593	1.067
Henty	4	2	36	72	72	0.14	0	0	3	0	0	0.00
Little Henty	1128	463		0	1128	3.42	0	1	0	0	0	0.00
Pieman	2933	1097		0	2933	0.76	1	2	17	9	9	0.30
Lagoon	4	6	0	0	0	0.00	0	0	0	0	0	0.00
Pedder	3	6	0	0	0	0.00	0	0	0	0	0	0.00
Nelson Bay	3	5	0	0	0	0.00	0	0	0	0	0	0.00
Arthur	772	392		0	772	0.31	4	7	53	30	30	0.32
Outside Catchments	73981	28832			73977	10.37						

APPENDIX 7. Area (km^2) within each estuarine catchment area and estuarine drainage area that consists of national park, reserved crown land, exploited crown land and private land.

Estuary	*Estuarine catchment area*					*Estuarine drainage area*				
	National Park	*Crown Reserve*	*Crown Exploited*	*Private*	*Total*	*National Park*	*Crown Reserve*	*Crown Exploited*	*Private*	*Total*
Sea Elephant	0	44.5	33.7	216.4	294.6	0	3.7	6.5	3.8	14.1
Yarra	0	0	0	38.1	38.1	0	0	0	0.3	0.3
Ettrick	0	0.3	0.2	44.9	45.5	0	0	0	0.1	0.1
Seal	0	0.8	13.3	63.5	77.5	0	0.4	0.6	5.5	6.5
Yellow Rock	0	2.2	0.2	116.9	119.2	0	0	0.2	1.2	1.4
North East Inlet	0	73.4	20.3	31.5	125.2	0	8.6	0.3	12.7	21.6
Foochow Inlet	0	10.9	13.2	43.0	67.1	0	0	2.4	0.2	2.5
Middle Inlet	0	0	7.5	53.7	61.2	0	0	1.5	0	1.5
Patriarch	0	0.3	34.4	143.1	177.8	0	0	3.5	0.7	4.3
Sellars Lagoon	0	0	42.7	1.3	44.1	0	0	42.7	1.3	44.1
Cameron Inlet	0	0.5	82.3	109.4	192.2	0	0	34.7	8.0	42.7
Logans Lagoon	0	0.0	30.4	39.3	69.7	0	0.0	30.4	39.3	69.7
Pats	0	0.5	36.5	32.7	69.6	0	0.4	0	0.8	1.2
Mines	0	12.5	5.6	3.1	21.2	0	0	0	0.2	0.2
Dover	0	0	32.1	0	32.1	0	0	2.2	0	2.2
Lee	0	0	61.5	0	61.5	0	0	0.4	0	0.4
Shag Rock	0	0	39.2	0	39.2	0	0	3.5	0	3.5
Modder	0	0	45.2	0	45.2	0	0	2.1	0	2.1
Rices	0	0	29.8	0	29.8	0	0	1.7	0	1.7
Rocky Head	0	0	15.5	0	15.5	0	0	1.0	0	1.0
Thirsty Lagoon	0	0.1	13.7	0	13.8	0	0.1	13.7	0	13.8
Welcome	0	12.3	62.3	229.5	304.2	0	0	0	11.9	11.9
Montagu	0	7.0	166.7	153.6	327.3	0	0	0	10.0	10.0
Mosquito Inlet	0	0	0	28.5	28.5	0	0	0	28.5	28.5
Duck Bay	0	13.6	120.0	414.7	548.2	0	0.3	18.2	58.6	77.0
West Inlet	0	0	0	22.4	22.4	0	0	0	3.2	3.2
East Inlet	0	0	0	21.2	21.2	0	0	0	4.5	4.5
Black	0	29.0	223.9	91.8	344.7	0	0.6	0.2	8.8	9.5
Crayfish	0	0.1	35.5	8.7	44.3	0	0.1	0	0.3	0.4
Detention	7.6	0.2	80.0	64.1	151.9	0.1	0.1	0.1	5.3	5.5
Inglis	0	27.3	156.2	321.3	504.8	0	0.1	0	5.7	5.8
Cam	0	4.6	21.9	222.6	249.2	0	0.1	0	9.2	9.3
Emu	0	3.4	44.0	195.8	243.2	0	0.1	0	1.1	1.2
Blythe	0	4.5	135.2	137.1	276.8	0	0.7	0.9	2.9	4.4
Leven	0	9.4	284.4	403.3	697.0	0	2.7	1.9	42.3	46.9
Forth	364.7	8.6	441.0	310.1	1124.4	0	0.5	0	14.0	14.6
Don	0	4.3	3.3	127.7	135.3	0	0	0	5.5	5.5
Mersey	333.3	198.2	608.6	611.8	1751.9	0	0	0	42.6	42.6
Port Sorell	14.0	24.9	198.2	403.5	640.6	13.6	2.6	12.3	49.0	77.4
Tamar	168.2	510.9	3086.0	7820.2	11585.3	0	26.8	28.8	499.2	554.8
Curries	0	22.6	34.6	26.7	83.9	0	0.4	0.3	1.0	1.7
Piper	0	7.7	134.5	321.8	464.0	0	0.0	0.6	12.9	13.6
Little Forester	0	0.6	152.0	194.5	347.1	0	0.6	0.1	3.4	4.1
Brid/Great Forester	0	24.8	355.4	396.1	776.3	0	0	2.9	11.9	14.9
Tomahawk	0	2.7	71.3	70.3	144.3	0	2.1	0	3.2	5.3
Boobyalla Inlet	0	45.1	733.5	407.8	1186.4	0	4.0	0.5	10.9	15.4
Little Musselroe	0	0.8	0	78.5	79.3	0	0.6	0	5.6	6.2
Great Musselroe	24.7	8.8	166.7	230.8	431.1	12.8	7.6	0	50.3	70.7
Ansons Bay	0.8	20.8	169.8	67.0	258.5	0.8	2.0	11.2	7.3	21.3
Big Lagoon	0	7.3	9.6	0.2	17.2	0	7.3	9.6	0.2	17.2
Sloop Lagoon	0	1.6	9.1	0	10.8	0	1.6	9.1	0	10.8
Grants Lagoon	0	1.6	2.7	2.3	6.5	0	1.6	2.7	2.3	6.5
Georges Bay	0	44.7	337.7	173.0	555.4	0	13.0	3.6	16.3	32.9
Scamander	0	20.1	300.5	19.1	339.8	0	2.3	3.2	7.3	12.8
Hendersons Lagoon	0	4.1	14.5	31.1	49.6	0	4.1	14.5	31.1	49.6

APPENDIX 7 (cont.). Area (km^2) within each estuarine catchment area and estuarine drainage area that consists of national park, reserved crown land, exploited crown land and private land.

Estuary	*Estuarine catchment area*					*Estuarine drainage area*				
	National Park	*Crown Reserve*	*Crown Exploited*	*Private*	*Total*	*National Park*	*Crown Reserve*	*Crown Exploited*	*Private*	*Total*
Templestowe	15.0	0	0.8	9.5	25.2	15.0	0	0.8	9.5	25.2
Douglas	66.9	0	0.9	5.7	73.5	0	0	0	3.1	3.1
Denison	22.9	0	0	3.9	26.8	0	0	0	0.3	0.3
Saltwater Lagoon	0.8	0	3.3	4.5	8.6	0.8	0	3.3	4.5	8.6
Freshwater Lagoon	3.4	0	8.4	0	11.8	3.4	0	8.4	0	11.8
Bryans Lagoon	5.4	0	0	0	5.4	5.4	0	0	0	5.4
Great Swanport	55.7	44.4	463.9	467.3	1031.2	1.0	7.9	16.2	115.6	140.8
Meredith	0	1.9	44.4	51.8	98.2	0	0	0	1.5	1.5
Stoney	0	0	0	26.7	26.7	0	0	0	0.3	0.3
Buxton	0	11.0	33.5	15.8	60.4	0	0	0	0.9	0.9
Lisdillon	0	0.7	22.2	27.8	50.6	0	0	0	2.7	2.7
Little Swanport	0	96.3	62.1	573.9	732.2	0	0.0	1.8	52.7	54.5
Grindstone	0	0	0.5	30.0	30.5	0	0	0	6.7	6.7
Spring Bay	0	48.7	4.5	43.5	96.7	0	0.0	0	6.5	6.5
Prosser	0	83.3	122.4	495.2	700.9	0	2.7	1.2	10.1	14.0
Earlham Lagoon	0	2.3	57.0	50.4	109.7	0	0	1.0	16.1	17.1
Blackman Bay	0	4.8	32.5	63.9	101.2	0	0	1.5	58.2	59.7
Carlton	0	0.2	18.3	145.2	163.7	0	0	0	22.3	22.3
Pittwater	0	32.1	64.2	823.3	919.5	0	13.9	0	92.2	106.0
Pipeclay Lagoon	0	0	0	16.1	16.1	0	0	0	16.1	16.1
Derwent	1007.9	713.2	2609.2	4923.1	9253.4	0	61.8	13.1	346.4	421.3
Browns	0	3.8	0	55.7	59.5	0	0	0	1.4	1.4
North West Bay	0	20.1	23.5	132.2	175.9	0	4.0	1.2	29.1	34.2
Garden Island	0	0	18.6	23.6	42.2	0	0	0	2.2	2.2
Port Cygnet	0	4.3	9.2	126.4	139.9	0	0	0.9	34.6	35.5
Huon	1409.7	63.2	866.6	698.1	3037.5	0	2.8	49.9	209.3	262.0
Crooks	0	0	83.6	55.7	139.3	0	0	0	6.8	6.8
Esperance	30.9	1.8	210.7	13.9	257.3	0	0.3	14.2	6.9	21.4
Lune	76.9	5.8	80.0	9.2	171.9	0.0	4.1	16.8	8.5	29.5
Southport Lagoon	0.0	0	22.1	5.1	27.2	0	0	10.2	3.6	13.8
Cloudy Bay	0	5.9	15.1	21.2	42.2	0	1.2	2.9	13.7	17.7
Catamaran	46.4	0.3	21.9	0	68.6	0	0.3	1.6	0	1.9
D`Entrecasteaux	48.5	0.1	28.5	1.4	78.5	0	0.1	3.8	1.1	5.1
Cockle Ck.	11.6	0.1	5.0	0	16.7	3.0	0.1	2.6	0	5.7
South Cape Rt.	52.7	0	0.3	0	53.0	4.9	0	0	0	4.9
New River Lagoon	298.2	0	0	0	298.2	75.3	0	0	0	75.3
Louisa R.	83.3	0	0	0	83.3	4.0	0	0	0	4.0
Louisa Ck.	56.6	0	0	0	56.6	2.5	0	0	0	2.5
Freney	5.6	0	14.0	0	19.6	5.6	0	14.0	0	19.6
Bathurst Harbour	1049.9	0	17.7	0	1067.6	211.0	0	2.1	0	213.1
Payne Bay	924.8	0	0	0	924.8	130.7	0	0	0	130.7
Mulcahy	57.9	0	0	0	57.9	3.0	0	0	0	3.0
Giblin	323.4	0	0	0	323.4	13.7	0	0	0	13.7
Lewis	73.3	0	139.9	0	213.1	0	0	18.7	0	18.7
Mainwaring	0	0	51.1	0	51.1	0	0	2.9	0	2.9
Wanderer	36.7	0	316.8	0	353.6	0.0	0	70.2	0	70.3
Spero	40.5	0	75.5	0	116.0	0	0	3.0	0	3.0
Hibbs Lagoon	0	0	52.2	0	52.2	0	0	4.8	0	4.8
Macquarie Harbour	10189.3	123.8	2804.0	17.9	13134.9	161.4	88.2	407.2	8.9	665.6
Henty	0	6.3	489.1	6.6	501.9	0	0	9.9	2.9	12.8
Little Henty	0	1.4	326.1	2.0	329.4	0	0.9	47.2	0.3	48.3
Pieman	730.1	99.5	2936.9	97.5	3864.0	0	19.2	7.3	0	26.5
Lagoon	0	86.5	0	0	86.5	0	0.7	0	0	0.7
Pedder	0	66.7	15.8	0	82.5	0	1.5	0.0	0	1.5
Nelson Bay	0	51.7	19.0	0	70.7	0	2.2	0.4	0	2.6
Arthur	0	302.6	1793.1	399.4	2495.1	0	17.8	28.3	49.4	95.5
Outside Catchments	864.9	1023.7	2046.0	3044.9	6979.5					

APPENDIX 8. Area (km^2) within each estuarine catchment area and estuarine drainage area that consists of woody vegetation, herbaceous vegetation, bare ground, water, cleared land and urban land, as inferred from satellite images.

Estuary	*Estuarine catchment area*						*Estuarine drainage area*					
	Woody	*Herb*	*Bare*	*Water*	*Cleared*	*Urban*	*Woody*	*Herb*	*Bare*	*Water*	*Cleared*	*Urban*
Welcome	127.6	110.9	16.6	0.2	49.1	0	2.1	5.9	0.7	0.0	3.4	0
Montagu	164.2	76.7	11.1	0.1	75.2	0	0.8	2.6	0.5	0.0	6.2	0
Mosquito Inlet	0.8	26.0	1.4	0.0	0.4	0	0.8	26.0	1.4	0.0	0.4	0
Duck Bay	152.4	91.8	24.8	1.4	279.0	0	20.1	13.0	5.3	0.3	39.4	0
West Inlet	1.0	4.7	2.5	0.2	14.2	0	0.2	1.3	0.6	0.1	1.2	0
East Inlet	1.9	3.7	3.4	0.1	12.2	0	0.9	1.2	0.5	0.0	1.9	0
Black	225.5	62.2	11.1	0.3	45.9	0	1.4	2.1	1.1	0.1	5.2	0
Crayfish	29.3	11.7	2.0	0.0	1.3	0	0.1	0.3	0.1	0	0	0
Detention	66.8	48.5	6.3	0.4	29.9	0	0.7	1.7	0.4	0.1	2.6	0
Inglis	238.5	66.0	27.4	0.4	172.8	0	0.1	0.6	1.8	0.1	3.5	0
Cam	153.2	5.4	1.4	0.4	87.9	0.7	1.4	0.7	0.3	0.0	6.4	0.3
Emu	174.1	3.5	0.5	0.9	63.4	0.8	0.3	0.0	0.1	0.0	0.4	0.3
Blythe	200.2	3.6	0.7	0.1	72.1	0.4	3.0	0.0	0.1	0.0	1.2	0.2
Leven	514.1	10.9	2.2	0.4	167.6	2.7	14.4	0.9	0.4	0.2	29.5	2.3
Forth	877.6	60.0	5.1	15.8	156.5	0.6	2.5	0.3	0.1	0.1	11.6	0.3
Don	47.7	1.4	0.5	0.2	84.6	1.2	1.2	0.1	0.1	0.1	3.8	0.7
Mersey	1068.0	231.9	29.6	30.3	365.2	7.5	11.4	0.9	0.6	0.3	25.5	5.3
Port Sorell	390.9	19.5	4.9	1.7	223.9	2.1	54.6	2.1	0.4	1.0	20.7	1.2
Tamar	5738.6	1214.8	220.4	240.3	4128.7	42.7	268.9	66.2	18.8	3.6	187.1	13.7
Curries	59.2	7.0	1.4	1.8	14.1	0.6	0.4	0.2	0.1	0	0.9	0.1
Piper	257.8	24.7	7.2	0.4	172.8	1.9	8.8	1.9	0.5	0.2	2.6	0.2
Little Forester	227.5	18.6	5.5	0.5	94.1	1.0	0.6	0.2	0.1	0.2	3.1	0
Brid/Great Forester	473.5	45.3	12.0	0.8	242.4	2.5	4.6	0.9	0.4	0.4	8.5	0.3
Tomahawk	80.6	8.1	3.4	0.2	51.9	0.3	1.1	0.4	0.2	0.1	3.7	0.1
Boobyalla Inlet	789.6	83.2	16.6	6.3	289.5	2.0	4.5	0.9	1.2	0.3	9.1	0.1
Little Musselroe	16.8	4.5	2.1	0.2	55.9	0.1	0.8	0.3	0.2	0.2	4.8	0.0
Great Musselroe	261.0	29.5	10.9	0.8	128.0	1.4	35.9	7.2	2.8	0.4	24.7	0.4
Ansons Bay	196.7	22.2	21.9	0.4	16.8	0.9	15.3	3.1	1.0	0.4	1.8	0.3
Big Lagoon	13.7	2.7	0.6	0.0	0.2	0.1	13.7	2.7	0.6	0.0	0.2	0.1
Sloop Lagoon	8.0	2.3	0.3	0.0	0.1	0.1	8.0	2.3	0.3	0.0	0.1	0.1
Grants Lagoon	5.1	1.0	0.4	0.1	0.1	0.1	5.1	1.0	0.4	0.1	0.1	0.1
Georges Bay	419.2	41.7	12.6	1.6	79.6	2.0	21.3	4.5	2.0	0.8	4.6	1.1
Scamander	286.4	28.2	11.9	0.7	12.9	0.8	9.3	1.2	0.9	0.5	1.6	0.3
Hendersons Lagoon	33.4	2.8	0.9	0.4	12.9	0.1	33.4	2.8	0.9	0.4	12.9	0.1
Templestowe	16.3	2.2	0.4	0.6	5.7	0.1	16.3	2.2	0.4	0.6	5.7	0.1
Douglas	66.1	3.8	0.6	0.1	2.9	0.1	0.5	0.2	0.2	0.0	2.2	0.0
Denison	20.6	4.9	0.3	0.0	0.9	0.1	0.0	0.1	0.1	0.0	0.1	0.1
Saltwater Lagoon	4.1	3.1	0.2	0.2	0.9	0.1	4.1	3.1	0.2	0.2	0.9	0.1
Freshwater Lagoon	4.6	5.9	1.0	0.2	0.1	0.0	4.6	5.9	1.0	0.2	0.1	0.0
Bryans Lagoon	4.3	1.4	0.1	0.0	0.0	0.0	4.3	1.4	0.1	0.0	0.0	0.0
Great Swanport	699.6	132.1	24.7	3.6	170.0	1.2	68.0	25.0	4.2	2.8	40.3	0.6
Meredith	68.6	14.7	2.0	0.1	12.8	0.1	0.3	0.1	0.1	0.0	1.1	0
Stoney	13.5	3.2	0.9	0	9.0	0.1	0.1	0.0	0.1	0	0.2	0.0
Buxton	47.9	7.0	0.5	0.1	5.2	0.0	0.3	0.0	0.1	0.1	0.6	0.0
Lisdillon	37.6	6.1	0.3	0.1	7.1	0.0	0.6	0.1	0.2	0.1	2.4	0.0
Little Swanport	392.0	74.9	15.3	1.8	248.7	1.0	23.7	6.1	1.3	0.4	24.4	0.2
Grindstone	8.6	2.4	0.5	0.1	19.0	0.0	0.9	0.9	0.3	0.0	4.8	0
Spring Bay	59.4	13.1	0.6	0.5	22.9	0.4	1.6	0.7	0.1	0.0	4.1	0.3
Prosser	442.6	94.1	4.3	0.5	158.6	0.3	9.9	2.4	0.1	0.1	1.8	0.1
Earlham Lagoon	72.2	20.5	0.2	0.0	16.5	0.0	8.4	1.6	0.1	0.0	7.1	0.0
Blackman Bay	55.5	21.6	0.8	0.0	23.4	0.4	30.0	6.1	0.7	0.0	23.2	0.4
Carlton	99.7	19.4	0.6	0.1	43.9	0.3	10.2	2.1	0.3	0.0	10.5	0.1
Pittwater	380.4	77.0	16.5	2.0	437.3	8.5	30.1	5.5	4.1	0.1	65.3	4.1

APPENDIX 8 (cont.). Area (km^2) within each estuarine catchment area and estuarine drainage area that consists of woody vegetation, herbaceous vegetation, bare ground, water, cleared land and urban land.

Estuary	*Estuarine catchment area*						*Estuarine drainage area*					
	Woody	*Herb*	*Bare*	*Water*	*Cleared*	*Urban*	*Woody*	*Herb*	*Bare*	*Water*	*Cleared*	*Urban*
Pipeclay Lagoon	3.2	1.1	0.8	0.0	11.0	0.5	3.2	1.1	0.8	0.0	11.0	0.5
Derwent	4439.6	1930.9	175.6	308.4	2301.3	48.9	199.4	64.1	4.9	1.1	107.4	41.6
Browns	37.0	11.1	0.6	0.1	9.5	1.2	0.8	0.2	0.1	0	0.3	0.1
North West Bay	94.5	44.1	2.3	0.1	33.6	2.0	18.2	4.9	1.0	0.1	9.6	1.3
Garden Island	32.6	8.1	0.0	0.0	1.4	0	0.9	1.0	0.0	0.0	0.3	0
Port Cygnet	81.5	26.2	1.2	0.3	30.8	0.5	16.6	8.5	0.3	0.2	10.5	0.2
Huon	2002.9	841.2	17.2	8.5	166.8	3.9	145.1	66.7	2.8	0.4	48.1	1.7
Crooks	91.3	29.5	1.9	0.2	16.1	0.5	2.9	2.0	0.1	0.0	1.7	0.2
Esperance	194.9	56.0	2.9	0.1	3.4	0.2	13.2	5.8	0.2	0.1	2.1	0.1
Lune	120.4	50.1	1.3	0.2	0.5	0.0	14.0	15.6	0.1	0.2	0.2	0.0
Southport Lagoon	6.5	20.5	0.1	0.1	0	0	0.9	12.7	0.1	0.1	0	0
Cloudy Bay	30.8	8.5	0.1	0.1	3.0	0.2	10.2	5.3	0.0	0.1	2.4	0.1
Catamaran	57.7	10.4	0.2	0.2	0	0	1.6	0.4	0	0	0	0
D`Entrecasteaux	55.3	23.0	0.3	0.0	0	0	2.6	2.6	0	0.0	0	0
Cockle Ck.	12.1	4.7	0	0.0	0	0	4.3	1.5	0	0.0	0	0
South Cape Rt.	41.4	11.3	0.0	0.4	0	0	3.7	1.2	0.0	0	0	0
New River Lagoon	221.5	75.3	0.3	1.2	0.0	0	52.0	22.6	0.2	0.6	0.0	0
Louisa R.	40.1	43.0	0.1	0.2	0	0	0.3	3.6	0.1	0.0	0	0
Louisa Ck.	22.1	34.5	0	0.0	0	0	0.1	2.4	0	0.0	0	0
Freney	3.6	15.7	0.2	0.2	0	0	3.6	15.7	0.2	0.2	0	0
Bathurst Harbour	385.4	668.3	11.4	1.9	0.6	0	35.1	172.5	3.9	1.4	0.3	0
Payne Bay	352.9	552.0	16.3	2.5	1.0	0	21.3	104.9	4.1	0.4	0.1	0
Mulcahy	9.2	45.6	3.1	0.0	0.1	0	0.5	2.4	0.3	0.0	0.0	0
Giblin	88.4	226.0	8.9	0.1	0.2	0	0.8	11.8	1.2	0.0	0.0	0
Lewis	69.0	136.6	7.5	0.1	0.0	0	1.2	15.8	1.7	0.1	0	0
Mainwaring	25.4	24.3	1.4	0.0	0	0	2.2	0.7	0.0	0.0	0	0
Wanderer	104.2	234.4	14.8	0.1	0.1	0	36.6	30.6	3.1	0.1	0.0	0
Spero	47.1	59.8	8.9	0.1	0.1	0	2.4	0.6	0.0	0.0	0	0
Hibbs Lagoon	41.6	10.1	0.0	0.5	0	0	3.1	1.3	0.0	0.5	0	0
Macquarie Harbour	6819.3	4947.3	262.4	1008.3	47.8	0	367.6	279.2	16.5	2.9	1.7	0
Henty	288.9	188.5	19.7	3.5	1.9	0.0	2.7	5.4	4.7	0.1	0.4	0
Little Henty	171.0	139.0	15.8	0.9	2.9	0	24.6	17.3	6.0	0.2	0.2	0
Pieman	2668.2	965.0	82.3	65.4	71.5	2.9	14.5	13.1	0.1	0.5	0.0	0
Lagoon	22.1	63.1	1.4	0.0	0.0	0	0.1	0.4	0.2	0.0	0	0
Pedder	17.4	62.6	2.1	0.0	0.5	0	0.1	0.6	0.5	0	0.4	0
Nelson Bay	7.4	56.7	5.7	0.0	0.9	0	0.2	2.1	0.3	0	0.0	0
Arthur	1696.2	639.1	55.7	5.4	98.7	0.1	27.3	32.8	5.9	0.3	29.2	0
Outside Catchments	2424.5	1851.6	301.0	38.4	1051.6	41.4						

APPENDIX 9a. Total numbers of invertebrate species collected in cores at different sites on King Island and in northwest Tasmania, with day and month of collection (see Table 2.6).

Site	*Sea*	*ellowr*		*osqui*		*Black*		*Cam*		*Leven*		*Don*	
	lephar		*Welcon*		*East*		*etentic*		*Blythe*		*Leven*		*queak*
Date	*24/2*	*23/2*	*21/2*	*22/2*	*15/1*	*14/1*	*13/1*	*26/9*	*16/1*	*25/9*	*17/5*	*24/9*	*17/1*
Araneae spp.	0	6	0	0	0	0	0	0	0	0	0	0	0
Sphageris phycodes	0	0	0	0	1	0	0	13	0	1	0	0	0
Curculionid spp.	0	0	0	0	1	0	0	4	0	0	0	0	0
Coleoptera sp.	0	0	0	0	0	0	0	2	0	1	0	0	0
Staphylinidae spp.	0	3	0	0	0	0	0	3	0	0	1	0	0
Chironomid spp.	59	560	3	0	0	0	0	0	6	0	0	0	0
Notonectid sp.	0	5	0	0	0	0	0	0	0	0	0	0	0
Insect larvae indet.	4	30	1	0	0	2	1	0	4	0	0	10	1
Odonata sp.	0	20	0	0	0	0	0	0	0	0	0	0	0
Diplopoda sp.	0	0	0	0	0	0	0	1	0	0	0	0	0
Ampithoe sp.*2*	0	0	4	0	0	0	0	0	0	0	0	0	0
Cymadusa sp.*2*	0	0	6	0	0	0	0	0	0	0	0	0	0
Corophium sp.	0	0	0	0	0	0	0	0	0	0	0	0	11
Paracorophium cf excavatum	15	48	0	1	0	2	0	1630	359	0	0	252	0
Atylus sp.	0	0	0	0	1	0	0	0	0	0	0	0	0
Tethygeneia sp.	0	0	0	0	1	0	0	0	1	0	0	0	1
Eusirid sp.	0	0	0	0	0	0	0	0	5	0	0	0	0
Paracalliope australis	6	29	0	0	0	0	0	0	14	0	0	0	0
Paracalliope vicinus	0	0	0	0	0	0	0	0	0	0	0	1	0
Paracalliope lowryi	0	0	0	0	0	0	0	5	66	0	0	0	0
Allorchestes compressa	0	0	3	0	1	0	0	0	0	0	0	0	0
Gammaropsis sp.*1*	4	0	1	0	1	5	0	159	43	4	4	0	0
Gammaropsis sp.*2*	0	0	0	0	0	0	0	0	212	0	0	0	0
Erichthonius pugnax	0	0	1	0	0	0	0	0	0	0	0	0	0
Lyssianassid sp.	0	0	0	0	0	0	0	0	0	0	0	0	1
Parawaldeckia stebbingi	0	0	2	0	0	0	0	0	0	0	0	0	0
Melita sp.	47	19	0	0	0	0	0	0	0	0	5	1	0
Melitid sp.1	0	0	0	0	3	0	0	0	0	0	0	0	0
Exoediceroides latrans	0	0	0	0	0	0	1	0	0	0	0	0	0
Oedicerotid sp.1	0	0	1	0	0	0	0	0	0	0	0	0	0
Oedicerotid sp.2	0	0	0	2	0	0	2	0	0	0	0	0	0
Exoediceroides ?maculosus	0	0	0	0	3	0	0	32	0	0	0	0	0
Parexoediceros sp.	0	0	0	0	3	0	0	0	0	0	0	0	0
Oedicerotid sp.4	0	0	0	0	0	0	0	0	0	0	0	0	1
Limnoporeia yarrague	0	0	1	0	0	1	0	0	22	0	0	0	0
Birubius muldarpus	0	0	11	2	2	0	0	0	0	0	0	0	16
Limnoporeia kingi	9	0	0	0	0	0	1	0	2	0	0	0	0
Birubius maldus	0	0	0	0	6	0	0	0	0	0	0	0	0
Birubius sp.*1*	0	0	0	0	1	0	0	0	0	0	0	0	0
Birubius ?wirakus	0	0	0	0	0	0	0	0	0	0	0	0	1
Birubius sp.*2*	0	0	0	0	0	0	0	0	0	0	0	0	2
?Limnoporeia sp.	0	0	0	0	0	0	0	0	1	0	0	0	0
Limnnoporeia sp.	0	0	0	1	0	0	0	0	0	0	0	0	0
Aora maculata	0	0	1	0	0	0	0	0	0	0	0	0	11
Talitrid TA271	0	0	0	0	0	0	0	4	0	0	0	0	0
Talitrid TA281	0	118	0	0	0	0	0	0	0	0	0	0	0
Eorchestia palustris	0	0	0	0	0	0	0	0	0	0	0	2	0
Talitrid TA128	0	0	0	0	0	0	0	4	0	0	0	0	0
Talitrid TA121	0	12	0	0	0	0	0	0	0	0	0	0	0
Talitrid sp.	0	0	0	2	0	0	0	0	0	0	0	0	0
Talitrid TA122a	0	0	3	0	0	0	0	0	0	0	0	0	0
Urohaustorius halei	0	0	0	44	70	1	21	0	0	0	0	0	0
Urohaustorius sp.*1*	0	0	0	0	6	0	0	0	0	0	0	0	0
Urohaustorid sp.*3*	0	0	0	6	2	0	0	0	0	0	0	0	0
Hyperiiid sp.	0	0	0	0	0	0	0	0	0	0	1	0	0
Paragrapsus gaimardii	0	0	28	2	0	6	0	2	6	0	1	8	4
Helograpsus haswellianus	0	0	0	0	0	0	0	0	3	1	0	9	0

APPENDIX 9a (cont.). Total numbers of invertebrate species collected in cores at different sites on King Island and in northwest Tasmania.

Site	Sea	ellowr		osqui		Black		Cam		Leven		Don	
	lephar		Velcon		East		etentic		Blythe		Leven		queak
Date	24/2	23/2	21/2	22/2	15/1	14/1	13/1	26/9	16/1	25/9	17/5	24/9	17/1
Amarinus lacustris	49	8	0	0	0	0	0	0	0	0	0	0	0
Halicarcinus ovata	0	0	0	0	0	0	0	0	0	0	0	0	2
Halicarcinus rostratus	0	0	0	0	1	0	0	0	0	0	0	0	0
Ebalia intermedia	0	0	5	0	0	0	0	0	0	0	0	0	3
Notomithrax ursus	0	0	1	0	0	0	0	0	0	0	0	0	0
Macropthalmus latifrons	0	3	0	0	0	1	0	0	4	0	6	5	10
Heloecius cordiformis	0	0	0	0	0	0	0	0	14	0	4	24	9
Carcinus maenas	0	0	0	0	1	1	3	0	0	0	0	0	0
Nectocarcinus integrifrons	0	0	0	0	1	0	0	0	0	0	0	0	0
Mictyris platycheles	0	0	2	131	36	34	48	5	0	0	0	0	5
Caprella sp.	0	0	0	0	0	0	0	0	0	0	0	0	5
Alpheus euphrosyne	0	0	0	0	0	0	0	0	0	0	1	0	0
Callianassa ceramica	0	0	0	2	11	1	0	0	0	3	6	0	0
Callianassa arenosa	0	0	0	0	0	4	2	0	0	0	0	0	10
Macrobrachium intermedium	0	0	0	0	0	0	0	0	0	0	0	0	4
Natatolana woodjonesi	0	0	12	0	1	0	0	0	0	0	0	0	1
Pseudolana concinna	0	4	0	6	5	0	3	0	1	1	12	0	0
Natatolana corpulenta	0	0	0	0	0	1	0	0	0	0	0	0	0
Actaecia bipleura	75	415	4	0	53	65	75	56	0	133	236	0	2
Synischia levidensis	0	0	1	0	1	0	0	0	0	0	0	0	0
Amakusanthura olearia	0	0	2	0	0	0	0	0	0	0	0	0	0
Haliophasma yarra	0	0	0	0	0	0	0	0	0	0	0	0	1
Apanthura sp.	0	0	0	0	0	0	0	0	0	0	0	0	1
Sphaeromatid sp.2	0	0	0	0	0	0	0	0	0	0	0	0	1
Exosphaeroma sp.	1	0	131	6	34	0	0	0	3	0	2	0	0
Gasterosaccus sp.	0	0	2	0	0	1	1	0	0	0	0	0	1
Australomysis incisa	0	0	0	0	0	0	0	0	0	0	0	0	1
Leptochelia sp.	0	0	8	1	0	0	0	0	0	0	0	0	0
Pseudoleptochelia sp.	0	0	1	0	0	0	0	0	0	0	0	0	0
Dimorphostylis colefaxi	0	0	8	2	0	2	0	0	1	2	0	0	0
Cyclaspis caprella	0	0	6	0	1	0	0	0	0	0	0	0	1
Dimorphostylis sp.	0	0	0	0	2	0	0	0	0	0	0	0	0
Cyclaspis ?persculpta	0	0	0	0	2	0	0	0	0	0	0	0	0
Leptosynapta dolabrifera	0	0	0	2	3	0	0	0	0	0	0	0	1
Amphipholis squamata	0	0	0	0	0	0	0	0	0	0	0	0	1
Acanthochiton coxi	0	0	2	0	0	0	0	0	0	0	0	0	0
Chiazacmaea flammea	0	0	0	0	0	0	0	0	0	0	0	0	2
Notoacmaea alta	0	0	10	0	0	0	0	0	0	0	0	0	0
Dentimitrella tayloriana	0	0	0	0	1	0	0	0	0	0	0	0	0
?Cominella lineolatus	0	0	1	0	2	0	0	0	0	0	0	0	0
Sigapatella calyptraeformis	0	0	0	0	0	0	0	0	0	0	0	0	7
Ophicardelus ornatus	0	0	0	0	0	0	0	0	2	0	0	5	0
Ascorhis victoriae	2234	2899	0	0	0	0	0	0	1	0	0	0	0
Salinator fragilis	5	0	104	7	2	380	13	0	0	2	2	4	2
Salinator solida	0	0	0	0	0	0	0	0	10	0	0	9	0
Bembicium melanostomum	0	0	0	1	0	0	0	0	0	0	0	0	0
Littorina praetermissa	0	0	1	0	0	0	0	0	0	0	0	0	0
Lepsiella vinosa	0	0	5	0	1	0	0	0	0	0	0	0	0
Nassarius pauperatus	0	0	19	27	182	190	0	0	3	5	2	0	14
Nassarius burchardi	0	0	0	0	0	0	6	0	0	0	0	0	0
Odostomia deplexa	0	0	1	0	0	0	0	0	0	0	0	0	0
Eubittium lawleyanum	5	0	76	0	0	0	0	0	0	0	0	0	0
Zeacumantus diemenensis	3	0	137	0	0	0	0	0	0	0	1	0	0
Retusa atkinsoni	0	0	0	0	0	0	0	0	0	0	0	0	1
Retusa campanula	0	0	2	0	0	0	0	0	0	0	0	0	0
Austrocochlea brevis	0	0	10	0	2	0	0	0	0	0	0	0	0
Austrocochlea porcata	0	0	1	0	0	0	0	0	0	0	0	0	0

APPENDIX 9a (cont.). Total numbers of invertebrate species collected in cores at different sites on King Island and in northwest Tasmania.

Site	*Sea*	*ellowr*		*osqui*		*Black*		*Cam*		*Leven*		*Don*	
	lephar		*elcom*		*East*		*etentic*		*Blythe*		*Leven*		*queak*
Date	*24/2*	*23/2*	*21/2*	*22/2*	*15/1*	*14/1*	*13/1*	*26/9*	*16/1*	*25/9*	*17/5*	*24/9*	*17/1*
Phasianotrochus irisidontes	0	0	19	0	0	0	0	0	0	0	0	0	0
Eulima sp.	0	0	0	0	0	0	0	0	9	0	0	0	0
Assiminea buccinoides	0	0	0	0	0	0	0	0	0	1	0	0	0
Hydrococcus brazieri	0	0	3584	311	920	58	0	0	0	0	0	0	0
Laternula gracilis	0	0	0	0	1	0	0	0	0	0	0	0	1
Electroma georgiana	0	0	1	0	0	0	0	0	0	0	0	0	0
Mysella donaciformis	3	0	61	73	142	2	12	0	0	111	124	0	101
?Mysella sp.	0	0	13	3	2	3	0	0	0	0	10	0	8
Lasaea australis	0	0	0	0	0	0	1	0	0	0	0	0	0
Bornia trigonale	0	0	0	2	37	0	0	0	0	0	0	0	0
Arthritica semen	1444	0	66	0	0	12	1	1	45	72	30	48	31
?Notolepton sp.	0	0	0	0	0	0	0	0	0	1	0	0	0
Xenostrobus inconstans	23	0	12	0	0	0	0	0	0	0	0	0	0
?Xenostrobus securis	30	0	0	1	0	0	0	0	0	0	0	0	0
Soletellina biradiata	0	0	0	3	0	0	0	0	0	0	0	0	0
Soletellina donacioides	0	0	0	0	1	1	0	0	0	0	0	0	0
Solemya sp.	0	0	5	0	0	0	0	0	0	0	0	0	0
Tellina deltoidalis	0	0	0	2	1	20	0	0	3	31	28	6	6
Tellinid sp.	0	0	0	0	1	0	0	0	0	0	0	0	0
Wallucina assimilis	0	0	10	0	0	0	0	0	0	0	0	0	0
Katelysia scalarina	0	0	2	76	7	5	1	0	0	18	19	0	23
Katelysia rhytiphora	0	0	19	0	0	0	0	0	0	3	9	0	52
Eumarcia fumigata	0	0	0	0	2	0	0	0	6	0	1	0	0
Paphies erycinea	0	0	0	0	0	8	0	1	6	0	0	0	0
Paphies elongata	0	0	0	0	0	0	1	0	0	0	0	0	0
Anapella cycladea	0	0	47	33	0	0	0	0	0	104	18	0	12
Paphies cuneata	0	0	0	239	696	0	187	0	0	15	10	0	0
Platyhelminth sp.2	0	0	1	0	0	0	0	0	0	0	0	0	0
Actiniarian sp.*1*	0	0	2	0	0	0	0	0	0	0	0	0	0
Edwardsia sp.*1*	0	0	0	0	2	0	0	0	1	0	1	0	0
Actiniarian sp.*2*	0	0	1	0	0	0	0	0	0	0	0	0	0
Enteropneust sp.	0	0	0	0	0	0	0	0	0	0	0	0	4
Nemertean sp.*1*	1	0	0	1	1	0	0	0	0	3	0	0	0
Nemertean sp.*3*	0	0	1	0	0	0	0	0	0	0	0	0	0
Nemertean sp.*5*	0	0	0	0	0	2	0	0	0	0	0	0	0
Oligochaeta spp.	6	7	6	0	0	0	0	0	25	0	4	1	0
Earthworm sp.	1	0	0	0	0	0	0	0	0	1	0	0	0
Ophelinid sp.2	0	0	4	0	0	0	0	0	0	0	0	0	0
Euzonus sp.	0	0	22	20	15	0	7	0	0	0	0	0	0
Armandia sp.*1*	0	0	2	0	0	0	0	0	0	0	0	0	3
Phyllodoce sp.	0	0	0	0	0	1	0	0	3	4	20	0	0
Barantolla lepte	0	0	0	0	0	0	0	0	2	0	0	1	0
Capitella sp.*2*	0	0	3	0	0	0	0	0	0	0	0	0	0
Heteromastus sp. *MOV 858*	0	0	0	27	9	18	0	2	55	23	24	0	11
Dorvillea sp.*2*	0	0	0	0	0	0	0	0	0	0	0	0	1
Nephtys australiensis	0	0	38	17	64	47	19	0	17	22	17	9	36
Nephtys longipes	0	0	0	3	1	0	0	0	0	1	0	0	0
Nephtys gravieri	0	0	0	0	0	0	0	0	0	1	0	0	0
Glycerid sp.1	0	0	0	2	0	0	0	0	0	0	0	0	0
Glycerid sp.2	0	0	0	0	5	0	0	0	1	0	0	0	1
Hesionid sp.	0	0	0	0	0	1	0	0	0	0	0	0	2
Lumbrineris sp.*1*	0	0	2	0	1	0	0	0	4	9	17	0	3
Lumbrineris sp.*2*	0	0	0	0	0	0	0	0	0	0	1	0	0
Maldane sp.	0	0	0	0	0	0	0	0	0	0	0	0	14
Neanthes vaalii	0	0	6	1	1	0	0	1	0	5	0	17	0
Australonereis ehlersi	0	0	0	1	0	0	0	0	0	0	0	0	0
Perinereis vallata	0	0	0	0	0	0	0	0	1	0	0	1	0

APPENDIX 9a (cont.). Total numbers of invertebrate species collected in cores at different sites on King Island and in northwest Tasmania.

Site	*Sea*	*ellowr*		*osqui*		*Black*		*Cam*		*Leven*		*Don*	
	lephar		*elcon*		*East*		*etentic*		*Blythe*		*Leven*		*queak*
Date	*24/2*	*23/2*	*21/2*	*22/2*	*15/1*	*14/1*	*13/1*	*26/9*	*16/1*	*25/9*	*17/5*	*24/9*	*17/1*
Simplisetia aequisetis	504	0	0	0	0	0	0	0	0	0	0	0	0
Namanereis littoralis	0	0	0	0	0	0	0	0	0	0	0	8	0
Olganereis edmonsi	0	0	33	4	5	1	0	0	0	0	0	0	0
Leitoscoloplos sp.	0	0	35	7	0	0	0	0	0	0	0	0	0
Leitoscoloplos normalis	24	0	8	0	0	12	6	0	1	0	2	12	0
Scoloplos simplex	0	0	0	0	1	0	0	0	0	29	45	0	5
Scoloplos novaehollandiae	0	0	0	0	10	0	0	0	0	0	0	0	0
Orbinid sp.	0	0	0	0	0	0	0	0	0	0	0	0	1
Microspio ?granulata	0	0	0	0	7	0	1	0	0	0	0	0	0
Carazziella victoriensis	0	0	0	0	1	0	0	0	0	0	0	0	0
Boccardiella sp.	319	0	0	0	0	0	0	0	0	0	0	0	0
Prionospio yuriel	0	0	0	0	1	0	0	0	0	0	0	0	0
Prionospio multipinnulata	0	0	0	1	1	0	0	0	0	0	23	0	3
Boccardia sp.	0	0	0	0	0	0	0	0	0	0	0	13	0
Magelona sp.	0	0	0	7	15	46	24	0	50	89	75	1	21
Aricidea sp.	0	0	0	0	0	0	0	0	0	1	4	0	0
Paraonid sp.	0	0	0	0	16	0	0	0	14	0	0	0	0
Cirratulid sp.2	0	0	0	0	0	0	0	0	0	0	1	0	0
Cirratulid sp.3	0	0	4	0	0	0	0	0	0	0	0	0	0
Polycirrus sp.	0	0	0	0	2	0	0	0	0	0	0	0	0
Thelepus extensus	0	0	0	0	0	0	0	0	0	0	0	0	4
Amaena trilobata	0	0	35	0	0	0	0	0	0	0	0	0	1
Sigalionid sp.	0	0	0	0	2	0	0	0	0	0	0	0	0
Diopatra sp.	0	0	1	0	0	0	0	0	0	0	0	0	0
Abarenicola affinis	0	0	8	0	0	0	0	0	0	0	0	0	0
Total abundance	4871	4186	4669	1079	2414	934	437	1925	1026	697	767	447	478
Total species	24	17	71	40	66	33	24	18	40	31	37	23	56

APPENDIX 9b. Total numbers of invertebrate species collected in cores at different sites in eastern north Tasmania and the Furneaux Group, with day and month of collection (see Table 2.6).

Site	*Low*	*Paper*		*Pipers*		*ngaroo*	*L.*	*orth Ea*		*amerc*		*Rices*
	Head		*Paper*		*omaha*		*usselr*		*Patriarc*		*Modde*	
Date	*16/12*	*17/12*	*17/6*	*20/11*	*22/11*	*19/11*	*14/11*	*8/5*	*9/5*	*9/5*	*12/5*	*6/5*
Sphageris phycodes	0	0	0	2	0	0	0	0	0	0	0	0
Curculionid spp.	0	0	0	6	0	0	0	1	0	0	1	0
Staphylinidae spp.	0	0	0	0	1	0	0	0	0	0	0	0
Chironomid spp.	0	0	0	0	0	5	128	0	0	17	41	2
Hymenoptera spp.	0	0	0	0	0	0	1	0	0	0	0	0
Insect larvae indet.	0	0	1	1	3	44	33	4	2	0	55	1
Cymadusa sp.*1*	2	0	0	0	0	0	0	0	0	0	0	0
Ampithoe sp.*2*	1	0	0	0	0	0	0	12	0	0	0	16
Cymadusa sp.*2*	13	4	0	0	0	0	0	9	0	0	0	6
Corophium sp.	0	1	0	0	0	0	0	0	0	0	0	0
Paracorophium cf excavatum	0	0	0	0	4	925	0	1	0	59	324	54
Atylus sp.	3	0	0	0	0	0	0	0	0	0	0	0
Paradexamine dandaloo	3	0	0	0	0	0	0	0	0	0	0	0
Paradexamine churinga	2	0	0	0	0	0	0	0	0	0	0	2
Paradexamine windarra	0	0	0	0	0	0	0	3	0	0	0	0
Paradexamine alkoomie	1	0	0	0	0	0	0	0	0	0	0	0
Tethygeneia sp.	1	0	0	0	0	0	0	4	0	0	0	0
Paracalliope australis	0	0	0	0	0	0	0	0	0	0	1	0
Paracalliope vicinus	0	0	0	0	0	1	0	0	0	0	0	0
Paracalliope lowryi	0	2	0	0	0	6	0	0	0	0	0	0
Allorchestes compressa	0	0	0	0	0	0	36	0	0	0	0	0
Gammaropsis sp.*1*	0	8	2	0	6	257	11	0	0	0	0	29
Gammaropsis sp.*2*	0	0	0	0	0	4	0	0	0	0	0	0
Parawaldeckia yamba	6	0	0	0	0	0	0	0	0	0	0	0
Parawaldeckia dilkera	52	0	0	0	0	0	0	0	0	0	0	0
Parawaldeckia stebbingi	7	0	0	0	0	0	0	3	0	0	0	0
Parawaldeckia sp.	0	0	0	0	0	0	0	3	0	0	0	0
Melita sp.	0	0	0	0	0	1	0	0	0	0	1	3
Melitid sp.1	2	0	0	0	0	0	0	0	0	0	0	0
Melitid sp.2	0	0	0	0	0	0	0	5	0	0	0	0
Exoediceroides latrans	181	0	0	0	0	0	0	0	0	0	0	0
Oedicerotid sp.1	38	0	0	0	0	0	0	0	0	0	0	0
Oedicerotid sp.2	4	0	0	0	0	0	0	0	0	0	0	0
Exoediceroides ?maculosus	0	53	3	18	0	28	0	7	5	0	12	1
Oedicerotid sp.3	5	0	0	0	0	0	0	0	0	0	0	0
Tomituka doowi	1	0	0	0	0	0	0	0	0	0	0	0
Booranus wangoorus	3	0	0	0	0	0	0	0	0	0	0	0
Limnoporeia woorake	4	0	0	0	0	0	0	0	0	0	0	0
Birubius sp.*3*	1	0	0	0	0	0	0	1	0	0	0	0
Birubius ?jirandus	12	0	0	0	0	0	0	0	0	0	0	0
Limnoporeia yarrague	0	0	0	0	0	1	0	0	0	0	0	1
Limnoporeia kingi	0	0	1	0	1	6	2	0	9	0	20	5
Birubius maldus	5	0	0	0	0	0	0	10	0	0	0	0
Birubius cf eake	1	0	0	0	0	0	0	0	0	0	0	0
?Bumeralius buchalis	0	0	0	4	0	0	0	0	0	0	0	0
Limnoporeia sp.	2	0	0	0	0	0	0	0	0	0	0	1
Birubius ularitus	0	0	0	0	0	0	0	1	0	0	0	0
Birubius thalmus	0	0	0	0	0	0	0	15	0	0	0	0
Birubius ?wirakus	0	0	0	0	0	0	0	2	0	0	0	0
Birubius mayimayi	0	0	0	0	0	0	0	5	0	0	0	0
Tipimegus ?djinjerrus	0	0	0	0	0	0	0	3	0	0	0	0
Birubius ?apari	2	0	0	0	0	0	0	11	0	0	0	1
Aora maculata	4	0	0	0	0	0	0	3	0	0	0	6
?Aorid sp.	2	0	0	0	0	0	0	0	0	0	0	0
Lembos sp.	2	0	0	0	0	0	0	0	0	0	0	0
Talitrid TA271	0	0	0	0	0	0	0	0	0	0	0	1
Talitrid TA128	3	0	0	0	0	0	0	0	0	0	0	0

APPENDIX 9b (cont.). Total numbers of invertebrate species collected in cores at different sites in eastern north Tasmania and the Furneaux Group.

Site	*Low*	*Paper*		*Pipers*		*ngaroo*	*L.*	*orth E*		*amer*		*Rices*
	Head		*Paper*		*omaha*		*Musselr*		*Patriarc*		*Modde*	
Date	*16/12*	*17/12*	*17/6*	*20/11*	*22/11*	*19/11*	*14/11*	*8/5*	*9/5*	*9/5*	*12/5*	*6/5*
Urohaustorius halei	1	0	0	28	1	0	0	4	99	0	0	0
Urohaustorius sp.*2*	14	0	0	0	0	0	0	0	0	0	0	0
Paragrapsus gaimardii	0	0	0	0	0	0	1	2	19	0	0	7
Amarinus lacustris	0	0	0	0	0	2	0	0	0	0	11	10
Halicarcinus ovata	27	0	0	0	0	0	0	5	0	0	0	1
Litocheira bispinosus	0	0	0	0	0	0	0	1	0	0	0	0
Macropthalmus latifrons	0	2	0	0	0	3	0	1	0	0	0	0
Carcinus maenas	0	0	0	1	0	0	2	0	0	0	0	0
Nectocarcinus integrifrons	0	0	0	0	0	0	5	0	0	0	0	0
Mictyris platycheles	12	3	0	28	0	0	0	33	57	0	0	0
Callianassa ceramica	3	0	0	0	0	0	0	1	0	0	0	0
Callianassa arenosa	2	1	0	0	0	0	0	0	0	0	0	0
Macrobrachium intermedium	0	2	0	0	0	0	0	0	0	0	0	5
Macrobrachium sp.	0	0	0	0	0	0	0	0	0	0	0	6
Axius sp.	0	0	0	0	0	0	0	1	0	0	0	0
Ianiropsis sp.	0	0	0	0	0	0	0	3	0	0	0	0
Austrochaetilia capeli	2	0	0	0	0	0	0	0	0	0	0	0
Natatolana woodjonesi	0	0	0	0	0	0	0	18	0	0	0	0
Pseudolana concinna	2	0	0	13	0	214	0	2	11	0	45	0
Natatolana corpulenta	5	0	0	0	0	0	0	0	0	0	0	0
Actaecia bipleura	5	5	35	71	0	3	55	26	1	41	426	29
Actaecia thompsoni	0	0	0	1	0	0	0	0	0	0	0	0
Synischia levidensis	0	0	0	0	0	0	1	0	0	0	0	1
Paridotea munda	0	0	0	0	0	0	0	0	0	0	0	1
Amakusanthura olearia	5	0	0	0	0	0	0	4	0	0	0	0
Haliophasma yarra	0	0	0	0	0	0	0	1	0	0	0	0
Ulakanthura lara	1	0	0	0	0	0	0	0	0	0	0	0
Paranthura sp.	0	0	0	0	0	0	0	0	0	0	0	1
Exosphaeroma sp.	1	0	0	0	0	0	17	21	15	0	0	11
Cerceis acuticaudata	1	0	0	0	0	0	2	0	0	0	0	0
Pseudosphaeroma cambellense	0	0	0	0	0	0	1	0	0	0	0	0
Platynympha longicaudata	6	0	0	0	0	0	0	1	0	0	0	3
Gasterosaccus sp.	0	0	0	2	1	1	0	0	0	0	0	1
Nebalia sp.	2	0	0	0	0	0	0	4	0	0	0	0
Ostracod sp.2	0	0	0	0	0	0	74	1	0	0	0	0
Leptochelia sp.	2	0	0	0	0	0	0	11	0	0	0	0
Zeuxo sp.*1*	14	0	0	0	0	0	0	0	0	0	0	0
Zeuxo sp.*2*	16	0	0	0	0	0	0	0	0	0	0	0
Zeuxo sp.*3*	5	0	0	0	0	0	0	0	0	0	0	0
Dimorphostylis colefaxi	0	0	0	1	0	0	4	0	0	0	0	0
Cyclaspis caprella	0	0	0	0	0	0	0	10	0	0	0	1
Diastylid sp.	0	0	0	0	0	0	0	16	0	0	0	0
Cyclaspis sp.	0	0	0	0	0	0	0	2	0	0	0	0
?Cyclaspis sp.	0	0	0	0	0	0	6	0	0	0	0	0
Patiriella brevispina	0	0	0	0	0	0	0	2	0	0	0	0
Leptosynapta dolabrifera	1	0	0	0	0	0	0	6	0	0	0	0
Ophiacantha sp.	8	0	0	0	0	0	0	0	0	0	0	0
Amphipholis squamata	0	0	0	0	0	0	0	2	0	0	0	0
Acanthochiton coxi	0	0	0	0	0	0	0	0	0	0	0	1
Dentimitrella tayloriana	2	0	0	0	0	0	0	0	0	0	0	0
Zafra angasi	1	0	0	0	0	0	0	0	0	0	0	0
Zafra atkinsoni	1	0	0	0	0	0	0	3	0	0	0	0
Cacozeliana granarium	1	0	0	0	0	0	0	2	0	0	0	0
?Cominella lineolatus	0	0	0	0	0	0	0	1	0	0	0	0
Diala suturalis	0	0	0	0	0	0	0	28	0	0	0	1
Pisinna frenchiensis	1	0	0	0	0	0	0	0	0	0	0	0

APPENDIX 9b (cont.). Total numbers of invertebrate species collected in cores at different sites in eastern north Tasmania and the Furneaux Group.

Site	Low	Paper		Pipers		ngaroo	L.	orth Ea		amer		Rices
	Head		Paper		omaha		Mussel		Patriar		Modde	
Date	16/12	17/12	17/6	20/11	22/11	19/11	14/11	8/5	9/5	9/5	12/5	6/5
Ascorhis victoriae	0	0	0	0	0	20	0	0	0	0	123	329
Potamopyrgus antipodarum	0	0	0	0	0	4	0	0	0	0	1	0
Tatea rufilabrus	0	0	1	0	0	0	0	0	0	0	36	0
Philine sp.	2	0	0	0	0	0	0	0	0	0	0	0
Salinator fragilis	0	0	14	1	4	0	0	0	4	23	1	1
Salinator solida	0	0	0	0	0	4	0	0	0	0	0	0
Akera tasmanica	2	2	0	0	0	0	0	0	0	0	0	0
Bembicium auratum	0	0	0	0	0	0	0	0	7	0	0	0
Bembicium melanostomum	0	0	0	0	0	0	0	1	0	0	0	0
Nassarius pauperatus	2	22	20	0	6	0	0	4	11	0	0	0
Nassarius nigellus	0	0	0	0	0	0	0	1	0	0	0	0
Nassarius burchardi	0	2	0	0	0	0	0	0	0	0	0	0
Nassarius pyrrhus	0	0	0	0	0	0	0	1	0	0	0	0
Astralium aureum	3	0	0	0	0	0	0	0	0	0	0	0
Odostomia occultidens	0	1	0	0	0	0	0	0	0	0	0	0
Eubittium lawleyanum	0	0	0	0	0	2	1356	1	46	0	0	788
Zeacumantus diemenensis	0	0	0	0	0	0	10	30	0	0	0	219
Retusa pelyx	0	0	0	0	0	0	0	2	0	0	0	0
Retusa atkinsoni	0	0	0	0	0	0	13	0	0	0	0	0
Styliferinid sp.	0	0	0	0	0	0	0	2	0	0	0	22
Styliferina translucida	0	0	0	0	0	0	0	1	0	0	0	0
Austrocochlea brevis	0	0	0	0	0	0	3	5	0	0	0	109
Austrocochlea porcata	0	0	0	0	0	0	8	0	0	0	0	1
Phasianotrochus irisidontes	15	0	0	0	0	0	0	0	0	0	0	0
?Thalotia sp.	9	0	0	0	0	0	0	0	0	0	0	0
Pseudoliotia micans	0	1	5	0	0	0	0	0	0	0	0	0
Haminoea maugensis	0	0	0	0	0	0	0	2	0	0	0	7
Assiminea buccinoides	0	0	4	0	0	0	0	0	0	0	0	0
Hydrococcus brazieri	0	0	0	8	0	0	243	15	241	11	0	46
Notospisula trigonella	0	11	220	0	0	0	0	0	0	0	0	0
Mysella donaciformis	155	101	55	7	0	0	801	93	81	0	0	13
?Mysella sp.	0	0	0	0	5	0	2	3	2	0	0	0
Hiatella australis	1	0	0	0	0	0	0	0	0	0	0	0
Bornia trigonale	7	0	0	0	0	0	0	0	0	0	0	0
Arthritica semen	0	5	7	9	84	514	0	0	15	0	489	94
Lucinid sp.1	2	0	0	0	0	0	0	0	0	0	0	0
Xenostrobus inconstans	0	0	0	0	0	0	0	8	11	0	0	0
Musculista senhousia	0	2	0	0	0	0	0	0	0	0	0	0
Brachidontes erosus	0	0	0	0	0	0	0	0	0	0	0	2
Modiolus cottoni	0	0	1	0	0	0	0	0	0	0	0	0
Nucula pusilla	16	0	0	0	0	0	138	5	0	0	0	2
Soletellina donacioides	0	0	0	0	1	0	0	2	1	0	0	0
Solemya sp.	0	0	0	0	0	0	0	39	0	0	0	0
Tellina deltoidalis	1	69	82	0	2	0	0	0	0	0	0	0
Tellina margaritina	0	0	0	0	0	0	0	15	0	0	0	0
Wallucina assimilis	0	0	0	0	0	0	35	46	0	0	0	0
Lucinid sp.2	2	0	0	0	0	0	0	0	0	0	0	0
Lucinid sp.3	0	0	0	0	0	0	0	2	0	0	0	0
Katelysia scalarina	2	0	0	1	14	0	2	15	21	0	0	0
Eumarcia fumigata	1	0	0	0	1	0	1	0	0	0	0	0
Placamen placida	1	1	0	0	0	0	0	0	0	0	0	0
Paphies erycinea	0	0	0	0	18	0	0	0	0	0	0	0
Paphies elongata	2	0	0	0	0	0	0	0	6	0	0	0
Anapella cycladea	0	0	0	0	10	0	0	13	3	0	0	0
Paphies cuneata	1	0	0	96	6	0	0	78	3	0	0	8
Cyamiomacra mactroides	0	0	0	0	0	0	118	95	0	0	0	0
Sipunculan sp.2	0	0	0	0	0	0	0	1	0	0	0	0

APPENDIX 9b (cont.). Total numbers of invertebrate species collected in cores at different sites in eastern north Tasmania and the Furneaux Group.

Site	*Low*	*Paper*		*Pipers*		*ngaroo*	*L.*	*orth E*		*amer*		*Rices*
	Head		*Paper*		*omaha*		*ussel*		*Patriar*		*Modde*	
Date	*16/12*	*17/12*	*17/6*	*20/11*	*22/11*	*19/11*	*14/11*	*8/5*	*9/5*	*9/5*	*12/5*	*6/5*
Actiniarian sp.*1*	0	0	0	0	0	0	117	14	0	0	0	0
Edwardsia sp.*1*	0	0	3	0	1	0	0	0	0	0	0	0
Edwardsia sp.*2*	0	0	0	0	0	0	0	12	0	0	0	0
Nemertean sp.*1*	0	0	0	0	0	0	38	0	1	0	0	9
Nemertean sp.*2*	0	0	0	0	0	0	5	0	1	0	0	0
Nemertean sp.*4*	3	0	0	0	0	0	0	3	0	0	0	0
Nemertean sp.*5*	0	2	1	0	0	0	0	0	0	0	0	0
Oligochaeta spp.	3	29	42	0	2	1	249	3	9	1	8	46
Earthworm sp.	0	0	0	0	0	0	0	2	2	0	1	0
Armandia sp.*2*	0	0	0	0	0	0	0	0	1	0	0	0
Ophelinid sp.1	2	0	0	0	0	0	0	0	0	0	0	0
Euzonus sp.	119	14	0	21	1	0	10	77	99	0	0	0
Armandia sp.*1*	2	0	0	0	0	0	0	1	0	0	0	5
Phyllodoce sp.	2	2	2	0	0	0	0	0	0	0	0	0
Barantolla lepte	0	0	0	1	0	0	0	0	0	0	0	0
Notomastus sp.	1	0	0	0	0	0	104	28	0	0	0	0
Capitella sp.*2*	0	0	0	0	0	0	164	9	0	558	0	35
Heteromastus sp. *MOV 858*	15	10	6	2	0	4	0	11	2	0	0	0
Capitellid sp.	0	0	0	0	0	0	0	0	21	0	0	0
Notomastus cf hemipodus	4	0	0	0	0	0	0	0	0	0	0	0
Dorvillea sp.*2*	1	0	0	0	0	0	0	2	0	0	0	0
Nephtys australiensis	7	82	47	23	15	0	0	0	0	0	0	0
Nephtys longipes	0	0	0	1	0	0	0	0	0	0	0	0
Glycerid sp.2	4	0	0	0	0	0	0	0	0	0	0	0
Spirorbid sp.1	199	0	0	0	0	0	0	0	0	0	0	0
Spirorbid sp.2	1	0	0	0	0	0	0	0	0	0	0	0
Serpulid sp.	0	0	0	0	0	0	2	0	0	0	0	0
Sabellid sp.2	0	0	0	0	0	0	0	1	0	0	0	0
Sabellid sp.1	1	0	0	0	0	0	0	0	0	0	0	0
Lumbrineris sp.*1*	0	4	4	4	0	0	0	8	0	0	0	0
Maldanid sp.2	0	0	0	0	0	0	0	12	0	0	0	0
Maldanid sp.4	0	0	0	0	0	0	24	0	0	0	0	0
cf. Maldanid sp.	1	0	0	0	0	0	0	0	0	0	0	0
Neanthes vaalii	0	0	0	0	0	0	0	5	0	0	0	0
Australonereis ehlersi	0	0	1	0	13	1	0	0	0	0	0	0
Perinereis vallata	0	16	0	0	0	0	207	210	26	0	0	36
Simplisetia aequisetis	3	0	0	0	0	86	0	0	0	399	0	63
Nereid sp.	4	0	0	0	0	0	0	0	0	0	0	0
Simplisetia amphidonta	6	0	0	0	0	0	0	0	0	0	0	0
Neanthes cricognatha	0	0	0	0	0	0	0	74	0	0	0	0
?Nereid sp.	0	0	0	0	0	0	0	1	0	0	0	0
Platynereis antipoda	1	0	0	0	0	0	0	0	0	0	0	0
Olganereis edmonsi	1	0	0	0	0	0	0	1	0	0	0	0
Leitoscoloplos sp.	2	0	0	0	0	0	0	0	0	0	0	0
Leitoscoloplos latibranchus	0	0	0	0	0	0	133	77	0	0	0	0
Leitoscoloplos normalis	3	0	3	7	26	0	0	0	63	0	0	50
Scoloplos novaehollandiae	6	0	0	1	0	0	0	3	0	0	0	0
Leitoscoloplos bifurcatus	2	0	0	0	0	0	0	0	0	0	0	0
Australospio trifida	1	0	0	0	0	0	0	9	0	0	0	0
cf. Carazella hirsutiseta	1	0	0	0	0	0	0	0	0	0	0	0
Scolecolepides aciculatus	0	0	0	0	0	0	39	0	0	0	0	0
Malacoceros sp.	0	0	0	0	0	0	0	1	0	0	0	0
Prionospio tatura	0	4	0	0	0	0	0	0	0	0	0	0
Carazziella victoriensis	0	0	0	2	2	0	0	0	0	0	0	0
Boccardiella sp.	0	0	0	0	0	10	0	0	0	0	218	12
Scolepis cf carunculata	7	0	0	0	1	0	0	0	0	0	0	0
Scolecolepides sp.	0	0	0	0	0	0	0	5	7	0	0	1

APPENDIX 9b (cont.). Total numbers of invertebrate species collected in cores at different sites in eastern north Tasmania and the Furneaux Group.

Site	*Low Head*	*Paper*	*Paper*	*Pipers*	*omaha*	*ngaroo*	*L. Mussel*	*orth E*	*Patriar*	*amer*	*Modde*	*Rices*
Date	*16/12*	*17/12*	*17/6*	*20/11*	*22/11*	*19/11*	*14/11*	*8/5*	*9/5*	*9/5*	*12/5*	*6/5*
Prionospio multipinnulata	0	0	0	0	0	0	0	67	0	0	0	0
Boccardia sp.	0	0	0	0	0	0	0	3	0	0	0	0
Aonides oxycephala	38	0	0	0	0	0	0	0	0	0	0	0
Spio pacifica	2	0	0	0	0	0	0	2	0	0	0	0
Magelona sp.	1	293	202	2	0	0	0	0	0	0	0	0
Paraonidae sp.	1	0	0	0	0	0	0	0	0	0	0	0
Cirratulid sp.1	0	0	0	0	0	0	0	3	0	0	0	0
Cirratulid sp.2	0	0	0	0	0	0	10	0	0	0	0	0
Cirratulid sp.3	0	0	0	0	0	0	11	34	0	0	0	0
Cirratulid sp.4	0	0	0	0	0	0	1	2	0	0	0	0
Exogone sp.*2*	0	0	0	0	0	0	1	0	0	0	0	0
Syllid sp.4	0	0	0	0	0	0	0	2	0	0	0	0
Syllid sp.1	0	0	0	0	0	0	0	1	0	0	0	0
Syllid sp.2	0	0	0	0	0	0	0	1	0	0	0	0
Exogonid sp.	0	0	0	0	0	0	0	1	0	0	0	0
Syllides sp.	0	0	0	0	0	0	232	2	1	0	0	0
Exogone sp.*1*	1	0	0	0	0	0	27	2	0	0	0	0
Lanassa exelysis	0	0	0	0	0	0	0	9	0	0	0	0
Pista australis	1	0	0	0	0	0	0	2	0	0	0	0
Eupolymnia koorangia	2	0	0	0	0	0	32	73	0	0	0	10
Lanicides fascia	7	0	0	0	0	0	0	0	0	0	0	0
Amaena trilobata	0	0	0	0	0	0	0	3	0	0	0	0
Terrebellides sp.	2	0	0	0	0	0	0	0	0	0	0	0
Ampharetid sp.1	1	0	0	0	0	0	0	0	0	0	0	0
Pectinaria sp.	0	0	0	0	0	0	0	1	0	0	0	0
Polynoid sp.	1	2	0	0	0	0	0	0	0	0	0	0
Sigalionid sp.	0	0	0	0	0	0	0	1	0	0	0	0
Diopatra sp.	3	0	0	0	0	0	0	4	0	0	0	0
Eunicid sp.1	3	0	0	0	0	0	0	1	0	0	0	0
Eunicid sp.2	4	0	0	0	0	0	0	2	0	0	0	0
Total abundance	1197	756	762	362	229	2147	4515	1580	903	1109	1814	2116
Total species	116	32	25	29	26	26	49	120	35	8	19	54

APPENDIX 9c. Total numbers of invertebrate species collected in cores at different sites in northeastern Tasmania, with day and month of collection (see Table 2.6).

Site	*Ansons*	*Big*	*Georges*		*Bryans*		*Lisdillon*		*Earlhar*	
	Bay	*Lagoon*	*Bay*	*Henderso*		*Woolshe*		*Prosse*		*Pittwate*
Date	*12/11*	*13/11*	*11/11*	*13/11*	*13/5*	*23/12*	*17/9*	*16/9*	*20/8*	*23/10*
Hellyethira ?malleoforma	0	0	0	0	7	0	0	0	0	0
Curculionid spp.	0	0	3	0	0	0	0	0	0	0
Staphylinidae spp.	0	0	0	2	0	0	0	0	0	0
Chironomid spp.	1	2	0	0	51	26	85	99	4	0
Insect larvae indet.	1	2	0	12	9	0	13	4	18	0
Cymadusa sp.*2*	3	0	0	0	0	0	0	0	0	0
Corophium sp.	0	0	2	0	0	0	0	0	0	0
Paracorophium cf excavatum	0	132	0	65	1034	383	592	1021	106	0
Paracorophium sp.	0	0	0	0	0	9	45	11	0	0
Paradexamine churinga	0	0	0	0	0	15	0	0	0	0
Paracalliope australis	2	14	0	0	49	14	516	6	9	0
Paracalliope lowryi	0	17	0	0	0	0	0	0	0	0
Allorchestes compressa	0	0	0	1	0	18	0	0	0	0
Gammaropsis sp.*1*	0	0	1	4	0	53	4	56	32	1
Melita sp.	1	105	0	0	85	55	134	22	25	0
Exoediceroides latrans	0	0	0	0	0	0	0	0	0	1
Oedicerotid sp.2	0	0	3	0	0	0	0	0	0	3
Exoediceroides ?maculosus	22	0	36	0	0	0	0	25	0	0
Limnoporeia yarrague	1	2	5	5	0	42	6	3	10	10
Birubius muldarpus	0	0	0	0	0	0	0	0	0	27
Limnoporeia kingi	0	1	0	0	0	6	0	0	0	0
?Kuritus sp.	0	0	0	0	0	0	0	0	0	1
?Limnoporeia sp.*1*	0	0	1	0	0	0	0	0	0	0
Talitrid TA59	0	0	0	0	0	4	0	0	0	0
Talitrid TA139	0	0	0	3	0	0	0	0	0	0
Urohaustorius halei	0	0	0	0	0	0	0	0	0	1
Paragrapsus gaimardii	0	0	0	1	0	2	5	22	6	0
Helograpsus haswellianus	0	0	0	1	0	0	2	0	0	0
Amarinus lacustris	0	40	0	0	47	33	3	0	1	0
Brachyura sp.	0	0	0	1	0	0	0	0	1	0
Philyra laevis	0	0	0	0	0	0	0	0	0	1
Macropthalmus latifrons	1	0	0	3	0	0	4	5	2	0
Carcinus maenas	0	0	0	0	0	0	2	0	0	0
Mictyris platycheles	0	0	0	1	0	1	0	25	0	0
Callianassa arenosa	0	0	1	0	0	0	0	2	0	3
Macrobrachium intermedium	1	0	0	0	0	4	21	3	1	0
Macrobrachium sp.	0	0	1	0	0	0	0	1	0	0
Pseudolana concinna	0	0	0	0	0	0	0	1	0	0
Actaecia bipleura	240	49	263	0	0	16	0	19	0	10
Paridotea munda	8	0	0	0	0	0	0	0	0	0
Exosphaeroma sp.	0	0	0	2	0	79	2	6	30	0
Tasmanomysis oculata	0	0	1	0	0	0	0	0	0	0
Australomysis acuta	0	0	1	0	0	0	0	0	0	0
Ostracod sp.1	0	0	0	0	0	0	0	1	0	0
Ostracod sp.2	0	0	2	0	0	0	0	0	0	0
Dimorphostylis colefaxi	0	0	0	3	0	0	6	0	0	0
Echinocardium cordatum	0	0	1	0	0	0	0	0	0	0
Diala suturalis	5	0	0	0	0	0	0	0	0	0
Ascorhis victoriae	82	611	0	4	3516	474	654	118	51	0
Tatea rufilabrus	0	3099	0	0	251	191	92	7	0	0
Salinator fragilis	1	5	0	8	0	16	0	0	9	1
Bembicium auratum	0	0	0	0	0	0	0	12	0	0
Nassarius pauperatus	2	0	18	0	0	2	19	20	6	15
Nassarius nigellus	0	0	7	0	0	0	0	0	0	8
Nassarius burchardi	32	0	0	0	0	26	27	76	0	0
Eubittium lawleyanum	0	0	0	0	0	3	0	0	480	0
Zeacumantus diemenensis	18	0	0	0	0	0	0	0	3	3

APPENDIX 9c (cont.). Total numbers of invertebrate species collected in cores at different sites in northeastern Tasmania.

Site	*Ansons*	*Big*	*Georges*		*Bryans*		*Lisdillon*		*Earlhar*	
	Bay	*Lagoon*	*Bay*	*Henderso*		*Woolshe*		*Prosse*		*Pittwate*
Date	*12/11*	*13/11*	*11/11*	*13/11*	*13/5*	*23/12*	*17/9*	*16/9*	*20/8*	*23/10*
Batillaria australis	0	0	0	0	0	0	19	1	12	11
Retusa pelyx	0	0	0	0	0	0	0	0	0	1
Diala monile	0	0	1	0	0	0	0	0	0	0
Austrocochlea brevis	0	0	0	0	0	2	0	0	4	6
Austrocochlea porcata	13	0	0	0	0	0	0	18	0	0
Pseudoliotia micans	0	0	0	0	0	59	10	81	0	0
Assiminea buccinoides	0	0	0	0	0	0	11	0	0	0
Hydrococcus brazieri	0	0	0	0	0	0	0	1	0	511
Laternula gracilis	1	0	0	3	0	0	0	4	0	0
Bivalvia sp.	0	0	1	0	0	0	0	0	0	0
Fulvia tenuicostata	0	0	1	0	0	0	0	0	0	0
Notospisula trigonella	2	0	13	0	0	0	0	0	0	209
Mysella donaciformis	162	0	16	1	0	0	0	0	17	70
?Mysella sp.	1	0	0	1	0	0	0	0	0	0
Theora lubrica	0	0	4	0	0	0	0	0	0	0
Arthritica semen	155	389	0	282	1072	2480	645	137	377	4
Xenostrobus inconstans	4	1254	0	0	0	3	35	0	2	0
Mytilus edulis	2	0	0	0	0	0	0	0	0	0
Soletellina donacioides	10	0	0	0	0	0	0	0	0	0
Tellina deltoidalis	4	0	12	6	0	1	0	22	1	2
Wallucina assimilis	0	0	0	0	0	0	0	0	0	1
Katelysia scalarina	1	0	1	0	0	0	0	1	2	10
Irus carditoides	0	0	1	0	0	0	0	0	1	0
Katelysia rhitiphora	0	0	1	0	0	0	0	0	0	0
Eumarcia fumigata	1	0	3	0	0	0	0	0	0	1
Placamen placida	0	0	0	0	0	0	0	0	0	1
Venerupis galactites	0	0	1	0	0	0	0	0	0	0
Anapella cycladea	0	0	0	0	0	0	0	0	0	18
Cyamiomacra mactroides	0	0	0	0	0	0	0	0	0	80
Sipunculan sp.1	0	0	2	0	0	0	0	0	0	0
Actiniarian sp.*1*	0	0	4	4	0	0	0	0	0	0
Edwardsia sp.*1*	0	0	5	0	0	0	0	0	0	0
Nemertean sp.*1*	1	0	9	1	0	3	0	0	3	0
Nemertean sp.*2*	0	0	0	0	0	0	0	0	0	1
Nemertean sp.*5*	0	0	0	0	0	0	2	0	0	0
Oligochaeta spp.	5	3	0	6	52	22	279	5	5	0
Earthworm sp.	0	0	0	0	1	0	0	0	0	0
Euzonus sp.	9	0	86	0	0	0	0	0	0	0
Phyllodoce sp.	1	0	4	0	0	0	0	9	0	0
Capitella sp.*2*	1	0	0	50	0	0	196	0	30	0
Heteromastus sp. *MOV 858*	9	2	83	0	0	0	0	0	0	3
Nephtys australiensis	4	0	40	1	0	53	0	3	0	22
Glycerid sp.1	0	0	0	0	0	0	0	0	0	2
Glycerid sp.2	1	0	1	0	0	0	0	0	0	0
Serpulid sp.	0	0	0	0	3	1	0	0	0	0
Lumbrineris sp.*1*	0	0	3	0	0	0	0	20	0	4
Maldanid sp.3	0	0	0	26	0	0	0	0	0	0
Australonereis ehlersi	0	0	0	0	3	0	1	94	0	0
Perinereis vallata	6	0	76	0	0	267	210	5	104	3
Simplisetia aequisetis	0	16	0	91	160	0	5	0	25	0
Leitoscoloplos sp.	0	0	4	0	0	0	0	0	0	0
Leitoscoloplos normalis	26	6	6	20	27	20	1	6	3	0
Orthoprionospio cirriformia	0	8	0	0	131	0	2	0	0	0
Prionospio tatura	4	0	7	0	0	0	0	2	0	0
Carazziella victoriensis	0	0	2	0	0	0	1	0	0	0
Boccardiella sp.	0	22	0	4	43	19	224	3	111	0
Scolecolepides sp.	0	0	0	1	0	0	0	0	16	0

APPENDIX 9c (cont.). Total numbers of invertebrate species collected in cores at different sites in northeastern Tasmania.

Site	*Ansons*	*Big*	*Georges*		*Bryans*		*Lisdillon*		*Earlhar*	
	Bay	*Lagoon*	*Bay*	*Henderso*		*Woolshe*		*Prosse*		*Pittwate*
Date	*12/11*	*13/11*	*11/11*	*13/11*	*13/5*	*23/12*	*17/9*	*16/9*	*20/8*	*23/10*
Prionospio yuriel	0	0	0	0	0	0	4	1	0	0
Prionospio multipinnulata	3	0	0	13	0	0	0	0	0	0
Boccardia sp.	0	0	0	77	0	0	0	0	0	0
Magelona sp.	0	0	23	0	0	4	0	0	0	19
Cirratulid sp.3	0	0	0	9	0	0	0	0	0	0
Pista australis	0	0	5	0	0	0	0	0	0	0
Polynoid sp.	0	0	2	0	0	0	0	0	0	0
Abarenicola affinis	0	0	0	0	0	0	0	0	1	0
Total abundance	847	5779	763	712	6541	4406	3877	1978	1508	1064
Total species	41	21	46	34	18	36	36	42	35	35

APPENDIX 9d. Total numbers of invertebrate species collected in cores at different sites in southeastern Tasmania, with day and month of collection (see Table 2.6).

Site	*orneliar*		*ridgewa*		*Browns*	*Eggs*	*Brabaz*		*Cradoc*		*Southpo*		*Cloudy (*
		Cornelia		*aremor*		*& Baco*		*Cradoc*		*Lune*		*Cloudy*	
Date	*24/4*	*13/2*	*21/10*	*21/10*	*2/7*	*31/10*	*6/11*	*5/11*	*16/5*	*9/1*	*19/6*	*18/5*	*24/5*
Hellyethira ?malleoforma	0	0	0	0	0	0	0	0	2	0	0	0	0
Chironomid spp.	0	0	158	10	0	0	0	9	106	52	13	0	13
Hymenoptera spp.	2	0	0	0	0	0	0	0	0	0	0	0	0
Insect larvae indet.	0	3	166	2	3	0	0	18	9	0	12	1	6
Austrolestes annulosus	0	0	1	0	0	0	0	0	0	0	0	0	0
Ampithoe sp.*1*	0	0	0	0	0	0	0	0	0	2	0	0	0
Ampithoe sp.*2*	0	0	0	0	0	0	0	0	0	0	0	0	13
Cymadusa sp.*2*	0	0	0	0	0	0	0	0	0	0	0	1	11
Corophium sp.	0	2	0	0	0	389	7	0	0	0	0	0	0
Paracorophium cf excavatum	202	255	1116	297	3	108	0	281	927	449	1	0	112
Paracorophium sp.	0	0	0	18	0	0	0	0	0	24	0	0	4
Paradexamine dandaloo	0	0	0	0	0	14	0	0	0	0	0	0	0
Paradexamine churinga	0	0	0	0	0	0	0	0	0	0	0	0	1
Tethygeneia sp.	0	0	0	0	0	39	0	0	0	0	0	1	4
Paracalliope australis	4	3	0	335	0	0	0	0	0	0	0	0	0
Paracalliope vicinus	0	0	214	0	0	0	0	46	142	0	0	0	2
Paracalliope lowryi	0	0	33	0	0	0	0	3	18	0	0	0	0
Allorchestes compressa	0	0	0	0	0	0	0	0	0	0	0	5	1
Gammaropsis sp.*1*	0	223	0	0	1	0	6	0	3	0	0	0	0
Cheiriphotis sp.	0	0	0	0	0	0	0	0	0	0	0	3	0
Melita sp.	0	0	185	1	0	0	0	0	0	0	0	0	0
Exoediceroides latrans	0	0	0	0	2	36	2	0	0	0	4	1	0
Limnoporeia yarrague	7	15	0	0	0	2	2	0	0	21	0	0	0
Birubius muldarpus	0	0	0	0	0	4	0	0	0	0	11	6	2
Limnoporeia kingi	0	0	0	0	0	0	0	0	0	2	0	0	0
?Kuritus sp.	0	0	0	0	0	1	0	0	0	0	0	0	0
Birubius cf eake	0	0	0	0	0	0	0	0	0	0	1	0	0
Birubius panamunus	0	0	0	0	0	0	0	0	0	0	14	0	0
Tipimegus thalerus	0	0	0	0	0	0	0	0	0	0	0	1	0
Birubius ?apari	0	0	0	0	0	0	0	0	0	0	1	0	0
Limnoporeia ?kalduke	0	0	0	0	0	0	0	0	0	0	1	0	0
Aora maculata	0	0	0	0	0	123	0	0	0	0	0	1	0
Talitrid TA59	1	0	148	25	3	1	0	5	2	0	0	0	0
Eorchestia palustris	0	0	2	0	0	0	0	17	22	0	0	0	0
Urohaustorius halei	0	0	0	0	119	0	0	0	0	0	0	0	0
Urohaustorius sp.*2*	0	0	0	0	0	0	0	0	0	0	0	1	12
Paragrapsus gaimardii	39	39	5	8	0	1	0	0	0	2	0	0	3
Amarinus lacustris	0	0	8	0	0	0	0	4	0	0	0	0	0
Halicarcinus ovata	0	0	0	0	0	3	0	0	0	0	0	0	0
Amarinus laevis	0	0	0	0	0	0	0	0	0	3	0	0	0
Brachyura sp.	0	0	0	0	0	1	0	0	0	0	0	0	0
Philyra laevis	0	0	0	0	0	0	0	0	0	0	0	1	0
Ebalia intermedia	0	0	0	0	0	0	0	0	0	0	0	1	0
Macropthalmus latifrons	0	0	0	2	3	0	1	0	0	0	0	0	0
Mictyris platycheles	3	4	0	0	9	1	0	0	0	0	0	15	1
Caprella sp.	0	0	0	0	0	0	0	0	0	1	0	0	0
Callianassa ceramica	0	0	0	0	0	0	0	0	0	0	0	4	1
Callianassa arenosa	0	0	0	0	1	0	3	0	0	1	0	0	1
Macrobrachium intermedium	2	0	0	1	0	2	0	0	0	0	0	0	0
Macrobrachium sp.	2	4	0	4	0	1	0	0	0	5	0	1	4
Pseudolana concinna	0	0	0	0	58	0	0	0	0	0	0	0	0
Actaecia bipleura	50	232	0	0	36	113	0	0	0	0	2	15	0
Paridotea munda	0	0	0	0	0	1	0	0	0	0	0	0	0
Amakusanthura olearia	0	0	0	0	0	0	0	0	0	0	13	0	0
Exosphaeroma sp.	0	0	0	0	0	0	0	0	0	0	35	1	13
Cymodetta gambosa	0	0	25	0	0	0	0	0	0	0	0	0	0

APPENDIX 9d (cont.). Total numbers of invertebrate species collected in cores at different sites in southeastern Tasmania.

Site	*orneliar*		*ridgewa*		*Browns*	*Eggs*	*Brabaz*		*Cradoc*		*outhpo*		*Cloudy C*
		Cornelia		*aremor*		*& Baco*		*Cradoc*		*Lune*		*Cloudy*	
Date	*24/4*	*13/2*	*21/10*	*21/10*	*2/7*	*31/10*	*6/11*	*5/11*	*16/5*	*9/1*	*19/6*	*18/5*	*24/5*
Sphaeromatid sp.1	0	0	0	0	0	1	2	0	0	0	0	0	0
Tasmanomysis oculata	0	0	0	0	0	0	0	0	0	0	0	1	5
?Heteromysis sp.	0	0	0	0	0	0	0	0	0	1	0	0	0
Siriella sp.	0	0	0	0	0	0	0	0	0	0	0	0	1
Australomysis incisa	0	0	0	0	0	0	0	0	0	0	9	0	0
Ostracod sp.2	0	4	0	0	0	0	0	0	0	0	4	0	0
Ostracod sp.3	0	0	0	0	0	0	0	0	0	0	1	0	0
Ostracod sp.4	0	0	0	0	0	0	0	0	0	0	0	1	0
Sinelobus stanfordi	0	0	0	0	0	0	0	39	10	0	0	0	0
Dimorphostylis colefaxi	0	0	0	2	1	0	0	0	5	0	0	0	0
Cyclaspis caprella	0	0	0	0	0	0	0	0	0	0	0	4	0
Patiriella exigua	0	0	0	0	0	1	0	0	0	0	0	0	0
Leptosynapta dolabrifera	0	0	0	0	0	0	0	0	0	0	1	0	0
Acanthochiton coxi	0	0	0	0	0	2	0	0	0	0	0	0	0
Chiazacmaea flammea	0	0	0	0	0	0	0	0	0	1	0	0	0
Diala suturalis	0	0	0	0	0	0	0	0	0	0	0	37	446
Tatea huonensis	83	301	4058	572	0	0	0	523	436	0	0	0	10
Ascorhis victoriae	0	0	255	78	0	0	0	8	27	0	0	0	17
Potamopyrgus antipodarum	0	0	799	6	0	0	0	7	26	0	0	0	0
Tatea rufilabrus	2	76	0	0	0	0	0	476	268	1	0	0	18
Salinator fragilis	0	7	0	11	2	0	0	1	0	0	9	56	144
Salinator solida	0	0	8	0	0	0	0	5	1	0	0	0	0
Nassarius pauperatus	0	1	0	1	0	13	9	0	0	6	3	42	22
Nassarius nigellus	0	0	0	0	0	12	0	0	0	0	0	0	0
Nassarius burchardi	139	312	0	0	3	4	1	0	0	5	0	7	0
Agatha metcalfi	0	0	0	0	0	0	0	0	0	0	4	1	0
Eubittium lawleyanum	0	0	0	0	0	0	0	0	0	0	1905	12	15
Zeacumantus diemenensis	0	0	0	0	0	18	0	0	0	2	1	0	138
Austrocochlea brevis	0	0	0	0	0	0	0	0	0	1	0	0	1
Phasianotrochus irisidontes	0	0	0	0	0	0	0	0	0	0	0	0	4
Cantharidella hisseyana	0	0	0	0	0	0	0	0	0	0	31	0	0
Pseudoliotia micans	0	0	0	0	0	0	0	0	0	54	0	0	0
Haminoea maugensis	0	0	0	0	0	0	0	0	0	0	0	1	0
Assiminea buccinoides	0	0	0	0	0	0	0	82	34	0	0	0	0
Hydrococcus brazieri	0	0	0	0	0	0	0	0	0	0	1	621	717
Laternula gracilis	0	1	0	0	0	0	3	0	0	0	0	2	0
Notospisula trigonella	1	1	0	0	1	0	0	0	0	0	0	0	0
Mysella donaciformis	0	0	0	0	0	0	0	0	0	0	615	0	0
?Mysella sp.	0	0	0	0	0	0	0	0	0	0	506	91	55
Bornia trigonale	0	0	0	0	0	0	0	0	0	0	0	13	2
Arthritica semen	68	119	719	180	7	0	2	292	128	113	173	111	257
Xenostrobus inconstans	0	2	20	8	0	1	0	5	0	3	0	0	1
Mytilus edulis	0	0	0	0	0	1	0	0	0	0	0	0	0
Nucula pusilla	0	0	0	0	0	0	0	0	0	0	10	0	0
Soletellina biradiata	0	0	0	1	0	1	0	0	0	1	0	0	0
Soletellina donacioides	0	3	0	0	0	0	3	0	0	3	2	0	0
Radiocondyle pectinata	0	0	0	0	0	0	0	0	0	0	3	0	0
Solemya sp.	0	0	0	0	0	0	0	0	0	0	89	4	0
Tellina deltoidalis	0	3	0	2	3	1	1	0	0	2	0	0	1
Wallucina assimilis	0	0	0	0	0	0	0	0	0	0	84	41	64
Katelysia scalarina	0	0	0	0	0	0	0	0	0	0	23	0	10
Irus carditoides	0	0	0	0	0	3	1	0	0	1	0	0	0
Katelysia rhitiphora	0	0	0	0	0	8	0	0	0	0	2	2	7
Venerupis sp.	0	0	0	0	0	1	0	0	0	0	0	0	0
Paphies erycinea	1	1	0	0	0	40	0	0	0	0	0	0	0
Paphies elongata	0	0	0	0	3	0	0	0	0	0	0	0	0
Anapella cycladea	0	0	0	0	0	0	0	0	0	0	0	3	0

APPENDIX 9d (cont.). Total numbers of invertebrates collected in cores at different sites in southeastern Tasmania.

Site	orneliar		idgewa		rowns	Eggs	Brabaz		Cradoc		outhpo		loudy C
		ornelia		aremor		& Baco		Cradoc		Lune		loudy	
Date	24/4	13/2	21/10	21/10	2/7	31/10	6/11	5/11	16/5	9/1	19/6	18/5	24/5
Cyamiomacra mactroides	0	0	0	0	0	1	0	0	0	0	788	281	103
Phoronid sp.	0	0	0	0	1	0	0	0	0	0	0	0	0
Actiniarian sp.*1*	5	5	0	0	0	0	0	0	0	0	0	0	0
Edwardsia sp.*1*	0	0	0	0	0	0	0	0	0	0	0	0	2
Edwardsia sp.*3*	0	0	0	0	0	0	0	0	0	0	2	0	0
Hirudinean sp.1	0	0	1	0	0	0	0	0	0	0	0	0	1
Nemertean sp.*1*	5	3	0	0	0	1	0	0	0	3	0	0	0
Nemertean sp.*2*	0	0	0	0	0	1	0	0	0	0	0	0	0
Nemertean sp.*3*	0	0	0	0	0	0	1	0	0	0	0	0	1
Nemertean sp.*5*	0	0	0	0	0	0	0	0	0	0	2	0	0
Oligochaeta spp.	0	9	8	2	0	3	13	1	4	0	7	0	0
Earthworm sp.	0	0	18	5	0	0	0	6	20	0	14	0	0
Euzonus sp.	0	0	0	0	0	6	0	0	0	0	59	6	13
Armandia sp.*1*	0	0	0	0	0	0	0	0	0	0	13	7	4
Phyllodoce sp.	0	0	0	0	0	0	0	0	0	5	2	7	2
Capitella sp.*1*	0	0	0	0	0	0	0	0	0	0	0	0	36
Barantolla lepte	3	0	0	0	0	0	0	0	0	0	0	0	0
Notomastus sp.	0	0	0	0	0	0	1	0	0	0	0	0	0
Capitella sp.*2*	2	101	0	0	0	1	1	0	0	0	8	0	0
Heteromastus sp. *MOV 858*	0	0	0	0	0	10	0	0	0	17	36	5	10
Capitellid sp.	1	0	0	0	0	0	0	0	0	0	0	0	0
Dorvillea sp.*1*	0	0	0	0	0	1	0	0	0	0	0	0	0
Nephtys australiensis	5	2	3	67	15	1	6	57	30	103	0	25	68
Glycerid sp.1	0	0	0	0	0	1	0	0	0	0	6	1	5
Glycerid sp.2	0	0	0	0	0	0	1	0	0	0	0	0	0
Hesionid sp.	0	0	0	0	0	0	0	0	0	0	0	0	1
Lumbrineris sp.*1*	1	14	0	0	2	0	1	0	0	0	0	1	0
Maldanid sp.1	0	0	0	0	0	0	0	0	0	0	0	7	1
Maldanid sp.4	0	0	0	0	0	0	0	0	0	0	9	0	0
Neanthes vaalii	7	119	0	0	0	11	0	0	0	2	0	0	20
Australonereis ehlersi	14	1	0	0	10	0	5	0	0	0	0	15	13
Perinereis vallata	0	0	0	0	0	0	5	0	0	0	24	0	2
Simplisetia aequisetis	0	0	27	243	0	0	0	0	7	0	0	0	15
Namanereis littoralis	0	0	0	0	0	0	0	0	0	0	0	0	1
Platynereis antipoda	0	0	0	0	0	136	0	0	0	0	0	0	0
Olganereis edmonsi	0	0	0	0	0	0	0	0	0	0	130	12	9
Leitoscoloplos sp.	0	0	0	0	0	0	0	0	0	0	0	16	0
Leitoscoloplos normalis	23	58	0	4	0	14	0	2	2	16	1	7	26
cf. Carazella hirsutiseta	0	0	0	0	0	0	0	0	0	0	0	1	0
Scolecolepides aciculatus	0	0	0	0	0	2	2	0	0	0	0	0	0
Prionospio ?wambiri	0	0	0	0	0	0	1	0	0	0	0	0	0
Malacoceros sp.	0	0	0	0	0	1	0	0	0	0	0	0	0
Microspio ?granulata	0	0	0	0	0	3	0	0	0	0	0	0	0
Orthoprionospio cirriformia	0	0	5	0	0	0	0	0	0	0	0	0	0
Prionospio tatura	3	9	0	0	0	0	0	0	0	11	0	0	0
Carazziella victoriensis	1	0	0	0	0	0	4	0	0	1	0	0	2
Boccardiella sp.	0	4	326	138	0	0	0	47	23	1	0	0	1
Scolepis cf carunculata	0	0	0	0	0	1	0	0	0	0	0	0	0
Scolecolepides sp.	0	0	0	0	0	0	0	0	0	0	84	0	0
Magelona sp.	0	1	0	0	0	1	4	0	0	20	1	0	0
Cirratulid sp.4	0	0	0	0	0	0	0	0	0	0	0	7	0
Syllid sp.3	0	0	0	0	0	0	0	0	0	0	5	0	1
Exogone sp.*1*	0	0	0	0	0	0	0	0	0	0	0	0	2
Terrebellides sp.	0	0	0	0	0	0	0	0	0	1	0	0	0
Ampharetid sp.2	0	0	0	0	0	0	0	0	0	1	0	0	0
Abarenicola affinis	0	0	0	0	0	0	0	0	0	0	0	0	8
Total abundance	676	1937	8308	2023	286	1142	88	1934	2252	937	4775	1507	2486
Total species	28	35	25	27	22	51	27	23	24	37	51	51	64

APPENDIX 9e. Total numbers of invertebrate species collected in cores at different sites in southern and western Tasmania, with day and month of collection (see Table 2.6).

Site	Cockle	New	Old	Kelly	Wandere		Swan		Piemar		Arthur
		River		Basin		Macquari	Basin	Henty		Nelson	
Date	7/1	18/2	19/2	19/2	20/2	30/9	23/6	25/6	24/6	14/1	13/1
Hellyethira ?malleoforma	0	0	0	0	0	0	82	0	0	0	0
Chironomid spp.	3	7	3	7	0	1	68	0	12	1	5
Hymenoptera spp.	0	0	0	0	0	0	0	0	0	0	0
Insect larvae indet.	13	8	0	13	0	1	47	0	1	4	0
Austrolestes annulosus	0	0	0	0	0	0	0	0	0	0	0
Oecetis sp.	0	11	0	0	0	0	1	0	3	0	0
Paracorophium cf excavatum	1	149	155	31	0	186	104	0	154	604	481
Paracalliope australis	0	0	6	0	1	0	0	0	0	0	13
Paracalliope vicinus	0	3	0	0	0	46	25	0	0	0	0
Paracalliope lowryi	0	7	2	0	0	0	0	0	0	0	36
Allorchestes compressa	0	0	0	0	0	0	0	0	0	0	2
Gammaropsis sp.*1*	3	0	0	0	2	248	90	0	126	0	0
Gammaropsis sp.*2*	0	3	0	0	0	1	13	0	0	0	0
Melita sp.	0	0	18	0	0	0	0	0	0	0	0
Exoediceroides ?maculosus	0	0	0	0	0	0	3	0	35	0	193
?Exoediceroides sp.	0	0	0	0	0	0	0	293	181	643	65
Limnoporeia yarrague	12	0	0	0	0	25	0	0	0	0	0
Limnoporeia kingi	0	0	3	6	0	0	4	0	3	8	12
Kulgaphoxus sp.	1	0	0	0	0	0	0	0	0	0	0
Talitrid TA283	0	0	0	0	0	0	0	0	0	16	0
Talitrid TA271	1	0	0	0	0	0	0	0	0	154	7
Talitrid TA281	0	0	0	18	0	8	0	0	0	0	0
Eorchestia palustris	0	0	0	1	0	0	2	0	0	0	0
Talitrid TA121	0	0	0	0	0	0	0	0	1	0	0
Paragrapsus gaimardii	7	0	0	4	0	1	0	0	0	0	0
Amarinus lacustris	0	30	4	0	0	0	9	0	0	0	5
Halicarcinus rostratus	0	0	0	1	0	0	0	0	0	0	0
Mictyris platycheles	53	0	0	0	0	0	0	0	0	0	0
Callianassa ceramica	1	0	0	1	0	0	0	0	0	0	0
Callianassa arenosa	1	0	0	0	0	0	0	0	0	0	0
Macrobrachium sp.	0	0	1	1	0	0	0	0	0	0	0
Actaecia bipleura	453	0	0	1	0	0	0	0	0	44	0
Actaecia thompsoni	0	0	0	0	0	0	0	0	0	74	8
Ischyromene rubida	0	0	0	0	0	0	0	0	0	1	1
Tasmanomysis oculata	1	0	0	0	0	0	0	0	0	0	0
Ostracod sp.2	2	0	0	4	0	0	0	0	0	0	0
Ostracod sp.3	0	0	0	3	0	0	0	0	0	0	0
Leptosynapta dolabrifera	0	0	0	1	0	0	0	0	0	0	0
Diala suturalis	0	0	0	12	0	0	0	0	0	0	0
Eatoniellid sp.	0	0	0	0	0	0	0	0	0	0	2
Ophicardelus ornatus	2	0	0	0	0	0	0	0	0	0	0
Tatea huonensis	0	22	126	2	0	0	0	0	0	0	0
Ascorhis victoriae	0	319	4	18	0	0	32	0	0	4	206
Potamopyrgus antipodarum	0	150	0	0	0	0	12	0	68	0	269
Tatea rufilabrus	0	0	945	0	0	0	0	0	0	7	0
Salinator fragilis	12	0	0	90	0	0	0	0	0	1	0
Bembicium auratum	0	0	0	1	0	0	0	0	0	0	0
Nassarius pauperatus	47	0	0	14	0	0	0	0	0	0	0
Nassarius burchardi	6	0	0	0	0	0	0	0	0	0	0
Retusa pelyx	0	0	0	1	0	0	0	0	0	0	0
Austrocochlea brevis	2	0	0	0	0	0	0	0	0	0	0
Hydrococcus brazieri	0	0	0	1735	0	0	0	0	0	0	0
Laternula gracilis	0	0	0	1	0	0	0	0	0	0	0
Mysella donaciformis	2	0	0	0	0	0	0	0	0	0	0
?Mysella sp.	53	0	0	3	0	0	0	0	0	0	0

APPENDIX 9e (cont.). Total numbers of invertebrate species collected in cores at different sites in southern and western Tasmania.

Site	Cockle	New	Old	Kelly	Wandere		Swan		Piemar		Arthur
		River		Basin		lacquari	Basin	Henty		Nelson	
Date	7/1	18/2	19/2	19/2	20/2	30/9	23/6	25/6	24/6	14/1	13/1
Bornia trigonale	0	0	0	3	0	0	0	0	0	0	0
Arthritica semen	2	113	222	128	0	272	48	0	0	0	0
Soletellina donacioides	0	0	0	2	0	0	0	0	0	0	0
Tellina deltoidalis	1	0	0	2	0	0	0	0	0	0	0
Wallucina assimilis	0	0	0	37	0	0	0	0	0	0	0
Katelysia scalarina	6	0	0	12	0	0	0	0	0	0	0
Katelysia rhitiphora	0	0	0	5	0	0	0	0	0	0	0
Paphies erycinea	1	0	0	0	0	15	0	0	0	0	0
Cyamiomacra mactroides	131	0	0	0	0	0	0	0	0	0	0
Platyhelminth sp.1	0	0	0	1	0	0	0	0	0	0	0
Hirudinean sp.2	0	0	1	0	0	0	0	0	0	0	0
Nemertean sp.*1*	0	0	1	3	0	2	0	0	0	0	0
Oligochaeta spp.	0	17	1	701	0	8	121	1	0	0	4
Earthworm sp.	0	0	0	0	0	0	3	0	1	1	0
Euzonus sp.	0	0	1	0	0	0	0	0	0	0	0
Phyllodoce sp.	0	0	0	2	0	0	0	0	0	0	0
Heteromastus sp. *MOV 858*	9	1	0	95	0	0	0	0	0	0	0
Dorvillea sp.*1*	0	0	0	1	0	0	0	0	0	0	0
Nephtys australiensis	46	2	38	19	0	0	0	0	0	0	0
Nephtys longipes	0	0	0	0	0	1	0	0	0	0	0
Nephtys inornata	0	0	0	1	0	0	0	0	0	0	0
Glycerid sp.1	0	0	0	7	0	0	0	0	0	0	0
Lumbrineris sp.*1*	1	0	1	9	0	0	0	0	0	0	0
Australonereis ehlersi	2	0	0	0	0	9	1	0	0	0	0
Perinereis vallata	0	0	0	61	0	0	0	0	0	0	0
Olganereis edmonsi	0	0	0	6	0	0	0	0	0	0	0
Leitoscoloplos normalis	39	2	8	41	0	14	15	0	0	0	0
Scoloplos simplex	0	0	0	3	0	0	0	0	0	0	0
Boccardiella sp.	0	210	2	1	0	28	0	0	8	0	242
Prionospio multipinnulata	0	0	0	1	0	0	0	0	0	0	0
Boccardia sp.	0	0	0	0	0	0	0	0	0	3	0
Magelona sp.	352	0	0	0	0	0	0	0	0	0	0
Ampharetid sp.2	0	0	0	14	0	0	0	0	0	0	0
Sigalionid sp.	0	0	0	1	0	0	0	0	0	0	0
Total abundance	1266	1054	1542	3125	3	866	680	294	593	1565	1551
Total species	32	17	20	49	2	17	19	2	12	15	17

APPENDIX 10a. Mean log$_3$ density of fish species collected at sites in estuaries on King Island and in the north west region. Total number of sampling occasions for all sites within each estuary is also shown.

		Yarra		Yellow	Velcome		Duck		East		Crayfisl	
	a Elepha		Ettrick	Rock		Iosquito		West		Black		)etention
Acanthaluteres spilomelanurus	0.7	0	0	0	4.0	0	0	0	2.6	0	0	0
Acanthaluteres vittiger	0	0	0	0	1.0	0	0	0	0	0	0	0
Aldrichetta forsteri	3.1	8.0	0	1.9	0	0	1.2	2.0	1.3	0	8.0	3.4
Ammotretis rostratus	3.7	0	0	0	2.0	0	0.9	0	0.9	1.0	2.0	1.0
Arenigobius bifrenatus	0	0	0	0	0	0	0.1	0	0	0	0	0
Arripus spp.	1.9	0	0	2.0	0	0	0.9	0	0.1	0	0	0.6
Atherinasoma microstoma	6.1	0	0	1.1	0	0	0.4	2.0	0	0	0	0
Contusus brevicaudus	0	0	0	0	0	0	0	0	0.7	0	0	0
Contusus richei	0	0	0	0	0	0	0.2	0	0	0	0	0
Cristiceps argyropleura	0.3	0	0	0	0	0	0	0	0	0	0	0
Cristiceps australis	0.9	0	0	0	0	0	0	0	0	0	0	0
Diodon nichthemerus	0	0	0	0	0	0	0	0	0.1	0	0	0
Engraulis australis	0	0	0	0	0	0	0	0	0.1	0	0	0
Favonigobius lateralis	0	0	0	0	0	0	0	1.5	0	0	0	0
Favonigobius tamarensis	1.6	0	0	0	0	0	0.7	0	0	0	0	0
Galaxias maculatus	2.9	2.0	0	1.0	0	0	3.0	4.0	0	0	0	1.8
Girella tricuspidata	0	0	0	0	0	0	0	0	0.1	0	0	0
Gobiidae (indet)	0.1	0	0	0	0	0	0	0	0	0	0	0
Gymnapistes marmoratus	0	0	0	0	1.0	0	0	0	0.1	0	0	0
Haletta semifasciata	0	0	0	0	1.0	0	0	0	0.4	0	0	0
Heteroclinus forsteri	0.4	0	0	0	0	0	0	0	0	0	0	0
Heteroclinus heptaeolus	0.3	0	0	0	0	0	0	0	0	0	0	0
Heteroclinus perspicillatus	0.4	0	0	0	0	0	0	0	0	0	0	0
Kestratherina brevirostris	0	0	0	0	0	0	0.5	0	0	0	0	0
Leptatherina presbyteroides	0	0	0	0.1	0	0	0.2	4.5	3.1	0	0	0.8
Lesueurina platycephala	0	0	0	0.3	0	0	0	0	0	0	0	0
Lovettia sealii	0	0	0	0	0	0	0.1	0	0	0	0	0
Meuschenia freycineti	0	0	0	0	2.0	0	0	0	0.9	0	0	0
Mitotichthys semistriatus	0	0	0	0	1.0	0	0	0	0	0	0	0
Neoodax balteatus	0	0	0	0	1.0	0	0	0	0.3	0	0	0
Neosebastes scorpaenoides	0	0	0	0	0	0	0.1	0	0	0	0	0
Nesogobius hindsbyi	0	0	0	0	0	0	0.1	0	0	0	0	0
Nesogobius sp.2	1.6	0	0	0	4.0	4.0	0.9	0	2.1	1.0	3.0	1.8
Notolabrus tetricus	0.1	0	0	0	0	0	0	0	0.1	0	0	0
Platycephalus bassensis	0	0	0	0	3.0	0	0.1	0	0	0	0	0
Platycephalus laevigatus	0	0	0	0	2.0	0	0	0	0	0	0	0
Prototroctes maraena	0	0	1.5	0	0	0	0	0	0	0	0	0
Pseudaphritis urvillii	0.1	0	0	1.0	0	0	0.2	0	0	0	0	0
Pseudogobius olorum	0	0	0	0	0	0	0.2	1.0	0	0	0	0
Pseudophycis barbatus	0.3	0	0	0	0	0	0	0	0.1	0	0	0
Retropinna tasmanica	0	1.0	0	0	0	0	1.2	0	0	0	0	0
Rhombosolea tapirina	0	0	0	0	0	3.0	1.1	1.0	3.0	8.0	3.0	1.4
Stigmatopora nigra	0	0	0	0	4.0	0	0.2	0	0.6	0	0	0
Tasmanogobius lasti	1.4	0	0	1.4	0	0	0.9	0	0	0	0	0
Tasmanogobius lordi	0	0	0	0	0	0	1.5	0	0	0	0	0
Tetractenos glaber	0	0	0	0	0	0	0.8	0	0.3	0	0	0
Vanacampus phillipi	0	0	0	0	3.0	0	0	0	0	0	0	0
Total Species	18	3	1	8	13	2	23	7	19	3	4	7
Sample number	7	1	2	7	1	1	11	2	7	1	1	5

APPENDIX 10b. Mean $\log_3$ density of fish species collected at sites in estuaries in the central north region. Total number of sampling occasions for all sites within each estuary is also shown.

	Inglis	Cam	Emu	Blythe	Leve	Forth	Don	Merse	Port Sorell
Aldrichetta forsteri	5.7	0.3	7.0	4.0	3.5	3.3	0	3.7	4.0
Ammotretis rostratus	1.3	1.7	0	0.5	1.0	0.6	0	0.2	1.0
Anguilla australis	0	0	0	0	0	0	0	0.2	0
Arnoglossus bassensis	0	0	0	0	0	0	0	0	0.1
Arripus spp.	0.7	0.7	0	0	1.2	1.0	0	0.5	1.8
Atherinasoma microstoma	0	0	0	0	2.7	2.6	3.0	1.8	0.3
Contusus brevicaudus	0	0	0	0	0	0	0	0	0.9
Contusus richei	0.7	0	0	0	0	0	0	0	1.1
Crapatalus munroi	0	0	0	0	0	0	0	0	0.1
Engraulis australis	0	0	0	0	0	0	0	0.3	0
Favonigobius lateralis	0	0	0	0	0.5	0	0	0	0.5
Favonigobius tamarensis	0	0	0	4.0	0.3	0.1	2.0	1.2	0.3
Galaxias maculatus	0	3.0	0	0	1.3	1.7	8.0	1.5	0.3
Galaxias truttaceus	0	1.0	0	0	0.3	0.4	0	0	0
Leptatherina presbyteroides	1.0	3.0	0	0	1.7	0	0	0	0.4
Lovettia sealii	0	0	0	0	0.7	1.1	0	1.3	0.1
Nesogobius sp.2	0.7	1.0	0	0	0	0	0	0	0
Oncorhynchus mykiss	0	0	0	0	0.2	0	0	0	0
Philypnodon grandiceps	0	0	0	0	0	0	0	0.3	0
Platycephalus bassensis	0	0.3	0	0	0.2	0	0	0	0.2
Pseudaphritis urvillii	0	0	0	0	0.2	0	0	0	0
Pseudocaranx dentex	0	0	0	0	0.2	0	0	0	0
Pseudogobius olorum	0	0	0	0	0	0.1	0	0.5	0
Retropinna tasmanica	0	0	0	0	1.3	0.3	0	1.7	0.9
Rhombosolea tapirina	2.7	4.0	0	1.0	1.5	1.9	1.0	1.0	2.3
Tasmanogobius lasti	0.3	0	0	0	0.3	0	1.0	0	0
Tasmanogobius lordi	2.7	1.0	0	0	0.5	0.6	0	0.5	0.3
Tetractenos glaber	0	0	0	0	2.0	0.1	0	0.5	1.2
Total Species	9	10	1	4	19	13	5	15	18
Sample number	3	3	1	2	6	7	1	6	8

APPENDIX 10c. Mean $\log_3$ density of fish species collected at sites in estuaries in eastern north and Furneaux Group regions. Total number of sampling occasions for all sites within each estuary is also shown.

	Tamar		Piper	Little	Brid		oobyall		Patriarc		Pats
		Curries		Foreste		mahawk		orth Ea		Camero	
Acanthaluteres spilomelanurus	1.3	0	0	0	0	0	0	0.8	0	0	0
Acanthaluteres vittiger	0.4	0	0	0	0	0	0	0.3	0	0	0
Aldrichetta forsteri	2.1	8.0	6.8	7.0	5.4	3.7	8.0	2.3	8.8	0.3	1.5
Ammotretis rostratus	0.7	0	0	1.0	0.2	1.3	0.5	0.7	0.3	0.5	0
Anguilla australis	0	0	0	0	0	0	0	0.3	0.5	0	1.5
Arenigobius frenatus	0.1	0	0	0	0	0	0	0	0	0	0
Arripis spp.	0.7	0	0.6	2.0	1.4	0	1.0	0.2	1.5	0.3	0
Atherinasoma microstoma	1.1	3.0	0.8	0	0.2	5.7	0	2.7	2.3	6.0	8.5
Atherinason hepsetoides	0.2	0	0	0	0	0	0	0	0	0	0
Bovichtus angustifrons	0.1	0	0	0	0.4	0	0	0	0	0	0
Brachaluteres jacksonianus	0	0	0	0	0	0	0	0.3	0	0	0
Chelidonichthys kumu	0	0	0	0	0	0	0	0.1	0	0	0
Contusus brevicaudus	0.1	0	0	2.0	0	0	0	0.3	0	0	0
Contusus richei	0.2	0	0	0	0	0	0	1.0	0.3	0	0
Crapatalus munroi	0	0	0	0	0	0	0	0.1	0	0	0
Cristiceps australis	0.2	0	0	0	0	0	0	0	0	0	0
Dicotylichtys myersi	0	0	0	0	0	0	0	0.3	0	0	0
Diodon nichthemerus	0	0	0	0	0	0	0	0.1	0	0	0
Engraulis australis	0.2	0	0	0	0	0	0	0	0	0	0
Enoplosus armatus	0.1	0	0	0	0	0	0	0	0	0	0
Favonigobius lateralis	0.1	0	0	0	2.2	0.3	0	1.2	0	0	0
Favonigobius tamarensis	0.7	0	0	0	0	0	0	1.2	0	0	1.0
Genypterus tigerinus	0	0	0	0	0	0	0	0.2	0	0	0
Girella tricuspidata	0	0	0	0	0	0	0	0.3	0	0	0
Gymnapistes marmoratus	0.2	0	0.2	0	0	0.3	0	0.9	0.3	1.0	0
Haletta semifasciata	0.1	0	0	0	0	0	0	0	0	0	0
Heteroclinus perspicillatus	0.4	0	0.2	0	0	0	0	0.2	0	0	0
Hyporhamphus melanochir	0	0	0	0	0	0	0	0.2	0	0	0
Kaupus costatus	0	0	0	0	0	0	0	0.1	0	0	0
Kestratherina brevirostris	0.6	0	0	0	0	0	0	0	0	0	0
Kestratherina esox	0.1	0	0	0	0	0	0	0	0	0	0
Leptatherina presbyteroides	4.2	0	1.6	7.0	0	0	0	4.2	0	0	0
Lovettia sealii	0	0	0	0	0.2	0	0	0	0	0	0
Meuschenia freycineti	0.1	0	0	0	0	0	0	0.3	0	0	0
Mugil cephalus	0	0	0	0	0	0	0	0.1	1.3	0	0
Myxus elongatus	0	0	0	0	0	0	0	0.4	0	0	0
Nannoperca australis	0	0	0	0	0.2	0	0	0	0	0	0
Neoodax balteatus	0.3	0	0	0	0	0	0	0	0	0	0
Nesogobius hindsbyi	0.1	0	0	0	0	0	0	0	0	0	0
Nesogobius sp.2	1.8	0	0.6	0	0	0	0	1.8	0	1.0	1.0
Nesogobius sp.3	0.1	0	0	0	0	0	0	0	0	0	0
Nesogobius sp.5	0.1	0	0	0	0	0	0	0	0	0	0
Notolabrus tetricus	0	0	0	1.0	0	0	0	0	0	0	0
Platycephalus bassensis	0.3	0	0.2	0	0	0	0	0.4	0	0	0
Platycephalus castelnaui	0.1	0	0.2	0	0	0	0	0.1	0	0	0
Platycephalus laevigatus	0	0	0	0	0	0	0	0.1	0	0	0
Pomatomus saltatrix	0	0	0	0	0	0	0	0.7	0	0	0
Pseudaphritis urvillii	0	0	0	0	0	0	0.5	0	0	0.8	1.0
Pseudocaranx dentex	0	0	0	0	0.2	0	0	0.3	0	0	0
Pseudogobius olorum	0	0	0	0	0	0	0	0	1.0	0	2.5
Pugnaso curtirostris	0.1	0	0	0	0	0	0	0	0	0	0
Retropinna tasmanica	0.3	0	0	0	0	0	0	0	0	0	0
Rhombosolea tapirina	1.9	0	0.4	1.0	0.6	0.7	1.0	1.4	1.5	1.0	0.5

APPENDIX 10c (cont.). Mean $\log_3$ density of fish species collected at sites in estuaries in eastern north and Furneaux Group regions. Total number of sampling occasions for all sites within each estuary is also shown.

	Tamar	Curries	Piper	Little Foreste	Brid	mahawk	oobyall	North Ea	Patriarc	Camero	Pats
Siphamia cephalotes	0.1	0	0	0	0	0	0	0	0	0	0
Siphonognathus radiatus	0.1	0	0	0	0	0	0	0	0	0	0
Spratelloides robustus	0.4	0	0	0	0	0	0	0.3	0	0	0
Stigmatopora argus	0.1	0	0	0	0	0	0	0.9	0	0	0
Stigmatopora nigra	0.2	0	0	0	0	0	0	0.3	0	0	0
Tasmanogobius lasti	0	0	0	0	0	0	0	0	0	1.3	0
Tasmanogobius lordi	0.2	0	0	0	0	0	0	0	0	0	0
Tetractenos glaber	1.9	0	2.2	1.0	2.0	0	1.0	0.7	1.0	0	0
Trachurus declivis	0	0	0	0	0	0	0	0.1	0	0	0
Upeneus tragula	0	0	0	0	0	0	0	0.1	0	0	0
Vanacampus phillipi	0.1	0	0	0	0	0	0	0.6	0	0	0
Total Species	41	2	11	8	11	6	6	40	11	9	8
Sample number	19	1	5	1	5	3	2	18	4	4	2

APPENDIX 10d. Mean log3 density of fish species collected at sites in estuaries in the upper and lower north east regions. Total number of sampling occasions for all sites within each estuary is also shown.

	. Mussel		Ansons		Sloop		Georges		Henderso		Douglas	
		. Mussel		Big		Grants		Scamand		emplesto		Denison
Acanthaluteres spilomelanurus	0.3	0	0.6	0	0	0	1.4	0	0	0	0	0
Acanthopagrus butcheri	0	0	0.1	0	0	0	0.0	0.8	0	0	0	3.0
Aldrichetta forsteri	2.7	3.5	2.2	0	0	1.0	1.9	1.3	2.3	2.4	5.0	3.5
Ammotretis liturata	0	0	0	0	0	0	0.4	0	0	0	0	0
Ammotretis rostratus	0.7	1.0	0.9	0	0	0	0.5	3.3	0.7	1.2	2.0	1.8
Anguilla australis	0	0	0.5	0	0	0	0	0	0	0	0	0
Apogon conspersus	0	0	0	0	0	0	0.0	0	0	0	0	0
Arenigobius bifrenatus	0	0	0.2	0	0	0	0.5	0	0	0	0	0
Arripus spp.	0.3	0	0.3	0	0	0	1.6	0	0.7	1.6	6.3	2.0
Atherinasoma microstoma	5.7	1.3	3.5	1.5	8.0	9.0	1.4	0	2.1	5.4	1.0	5.0
Atypichthys strigatus	0	0	0.1	0	0	0	0	0	0	0	0	0
Bovichtus angustifrons	0	0	0	0	0	0	0.1	0	0	0	0	0
Brachaluteres jacksonianus	0	0	0	0	0	0	0.0	0	0	0	0	0
Crapatalus munroi	0	0	0	0	0	0	0.1	0	0	0	0	0
Cristiceps australis	0	0	0	0	0	0	0.5	0	0	0	0	0
Diodon nichthemerus	0	0	0	0	0	0	0.1	0	0	0	0	0
Engraulis australis	0	0	0.1	0	0	0	0.4	0	0	0	0	0
Favonigobius lateralis	0	0.3	0.1	0	0	0	0.5	0.5	0.4	0.4	0	0
Favonigobius tamarensis	0	0.3	0.6	0	0	0	1.1	2.0	0.3	0.2	0	0
Galaxias maculatus	0	0	0.2	0	0	0	0	0.5	0	0	0	0
Girella tricuspidata	0	0	0.1	0	0	0	0.5	0	0	0	0	0
Gymnapistes marmoratus	0	0	0.2	0	0	0	0.5	0	0	0	0	0
Heteroclinus perspicillatus	0	0	0.3	0	0	0	0.7	0	0	0	0	0
Hyporamphus melanochir	0	0	0	0	0	0	0.2	0	0	0	0	0
Kestratherina brevirostris	0	0	0.1	0	0	0	0	0	0	0	0	0
Leptatherina presbyteroides	0	3.5	3.3	4.5	0	3.0	1.2	0	0	0	0	0
Meuschenia freycineti	0.3	0.3	0.2	0	0	0	0.7	0	0	0	0	0
Myxus elongatus	0	0	0.2	0	0	0	0	0	0.3	0	0	0
Neoodax balteatus	0	0	0.1	0	0	0	0	0	0	0	0	0
Nesogobius hindsbyi	0	0	0	0	0	0	0.2	0	0	0	0	0
Nesogobius pulchellus	0	0	0	0	0	0	0.2	0	0	0	0	0
Nesogobius sp.2	3.0	5.3	1.9	0	0	2.0	1.4	2.8	3.0	0	0	0
Nesogobius sp.5	0	0	0.2	0	0	0	0.3	0	0	0	0	0
Notolabrus tetricus	0	0	0.1	0	0	0	0	0	0	0	0	0
Platycephalus bassensis	0	0	0	0	0	0	0.2	0	0	0	0	0
Pomatomus saltatrix	0	0	0	0	0	0	0.1	0	0	0	0	0
Pseudaphritis urvillii	0	0	0.2	0	1.0	0	0.5	0	0.1	0.4	0	0.3
Pseudocaranx dentex	0.3	0	0.6	0	0	0	0.1	2.0	0	0	0	0
Pseudogobius olorum	0	0	0.4	0.5	3.0	0	0.3	0	0.1	0	0	0
Rhombosolea tapirina	1.7	1.3	1.8	0	0	0	1.7	1.0	1.7	1.0	0.3	0.8
Stigmatopora argus	0	0	0.6	0	0	0	0.5	0	0	0	0	0
Stigmatopora nigra	0	0	1.1	0	0	0	3.5	0	0	0	0	0
Tasmanogobius lasti	0	0	0	0	0	0	0	0	0	0.2	0	0
Tetractenos glaber	0.3	0	0.9	0	0	0	0.3	0	0.1	0	0	0
Urocampus carinirostris	0	0	0.4	0	0	0	0.3	0	0	0	0	0
Vanacampus phillipi	0	0	0.1	0	0	0	0.4	0	0	0	0	0
Vanacampus poecililaemus	0	0	0	0	0	0	0.1	0	0	0	0	0
Total Species	10	9	33	3	3	4	39	9	12	9	5	7
Sample number	3	4	15	2	1	1	19	4	7	5	3	4

APPENDIX 10e. Mean log$_3$ density of fish species collected at sites in estuaries in the eastern region. Total number of sampling occasions for all sites within each estuary is also shown.

	Bryans	G. Swanpo	Meredit	Buxton	Lisdillo	L. Swanpo	Spring	Prosser	Earlhan	Blackma
Acanthaluteres spilomelanurus	0	1.0	0	0	0	0	0	0	1.0	1.4
Acanthaluteres vittiger	0	0.3	0	0	0	0	0	0	0.3	0
Acanthopagrus butcheri	0	0.4	0	0	0	0	0	0	0	0
Aldrichetta forsteri	4.0	1.1	0	2.3	1.0	0.6	0	3.5	3.3	2.8
Ammotretis rostratus	3.0	0.9	7.0	1.0	1.5	1.8	6.0	0.8	0.7	0.8
Anguilla australis	0	0.1	0	0	0	0.2	0	0	0	0
Anguilla reinhardtii	0	0.1	0	0	0	0	0	0	0	0
Arripis spp.	1.0	1.5	0	0.3	1.5	0.6	1.0	3.3	0	0.4
Atherinasoma microstoma	9.0	3.7	0	2.7	4.5	2.8	1.0	0.5	0	1.2
Brachaluteres jacksonianus	0	0.1	0	0	0	0	0	0	0	0
Contusus richei	0	0.6	0	0	0	0	0	0.5	0.3	0
Cristiceps australis	0	0.3	0	0	0	0	0	0	0.3	0.8
Engraulis australis	0	0.1	0	0	0	0	0	0	0	0
Favonigobius lateralis	0	0	0	0	0	0	0	0	0.3	0
Favonigobius tamarensis	0	1.0	0	0	0	2.0	0	0.5	0	0
Galaxias maculatus	0	0.5	0	0	0	1.8	0	0.5	0.3	0
Gymnapistes marmoratus	0	0.8	0	0	0	0.2	0	0.3	0.7	1.4
Haletta semifasciata	0	0.2	0	0	0	0	0	0	0	0.4
Heteroclinus perspicillatus	0	0.1	0	0	0	0	0	0	0.7	0.6
Hyporamphus melanochir	0	0.2	0	0	0	0	0	0	0.3	0
Kestratherina esox	0	0	0	0	0	0	0	0	0	2.4
Latridopsis forsteri	0	0.1	0	0	0	0	0	0	0	0
Leptatherina presbyteroides	0	4.0	1.0	1.0	0	0	6.0	2.3	5.3	7.0
Lesueurina platycephala	0	0.1	0	2.3	0	0	0	0	0	0
Meuschenia freycineti	0	1.0	0	0	0	0	0	0	0.3	0
Myxus elongatus	0	0	0	0	0	0	0	0.3	0	0
Nemadactylus macropterus	0	0	0	0	0	0	0	0	0	0.2
Neoodax balteatus	0	0.6	0	0	0	0	0	0	0.7	1.8
Nesogobius sp.2	0	1.1	0	0.7	0.5	0.2	1.0	1.5	2.0	3.0
Nesogobius sp.5	0	0	0	0	0	0.2	0	0	0	0
Notolabrus tetricus	0	0	0	0	0	0	0	0	0	0.2
Platycephalus bassensis	0	0.3	0	0	0	0	0	0	0	0
Pseudaphritis urvillii	0	0.6	0	0	0	0.2	0	0	0.3	0
Pseudocaranx dentex	0	0.1	0	0	0	0	0	0.3	0	0
Pseudogobius olorum	2.0	0.1	0	0	0.5	0.6	0	0.3	0	0
Pseudophycis barbatus	0	0.1	0	0	0	0	0	0	0	0
Rhombosolea tapirina	0	1.0	2.0	4.0	5.0	0.8	0	3.0	1.7	2.8
Sillago flindersi	0	0.1	0	0	0	0	0	0	0	0
Stigmatopora argus	0	0.2	0	0	0	0	0	0.3	0	0.6
Stigmatopora nigra	0	1.6	0	0	0	0.4	0	2.5	3.3	0
Tasmanogobius lasti	0	0	0	0	0	0	0	0.3	0.7	0
Tasmanogobius lordi	0	0.1	0	0	0	0	0	0	0	0
Tetractenos glaber	0	0	0	0	0	0	0	1.3	0.3	0
Urocampus carinirostris	0	0.2	0	0	0	0	0	0	0	0
Vanacampus phillipi	0	0.1	0	0	0	0	0	0	0	0
Total Species	5	37	3	8	7	14	5	18	20	17
Sample number	1	14	1	3	2	5	1	4	3	5

APPENDIX 10f. Mean $\log_3$ density of fish species collected at sites in estuaries in the Huon and Derwent regions. Total number of sampling occasions for all sites within each estuary is also shown.

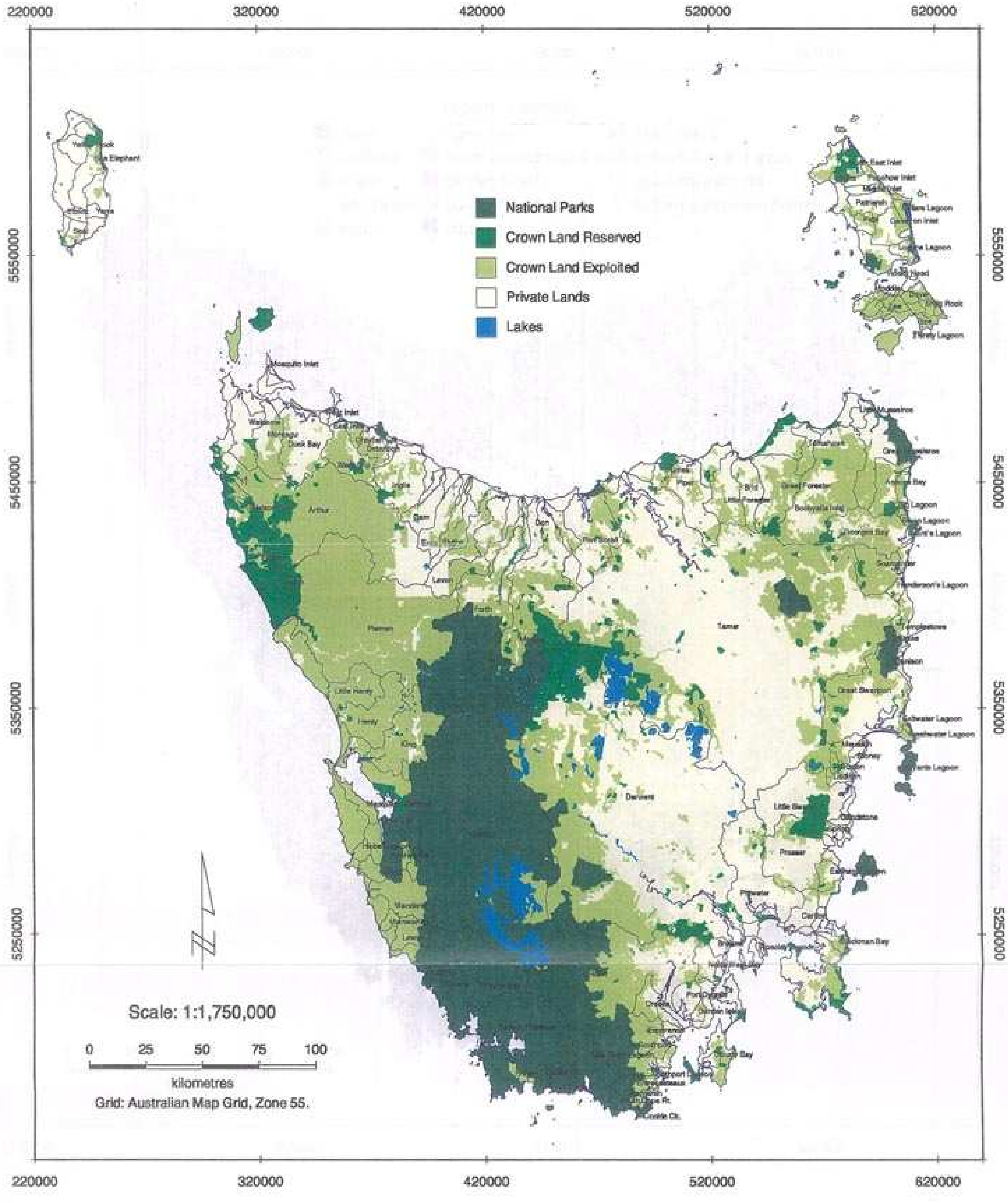
	Carlto		Pipecl		Brown		Huon		Lune		Cloudy
		Pittwat		Derwe		Port Cyg		Esperen		Southp	
Acanthaluteres spilomelanurus	0.5	0	0	0	0	0.3	0.8	1.2	0	1.0	1.5
Acanthaluteres vittiger	0	0	0	0	0	0	0.5	0	0	0	0
Acanthopagrus butcheri	0	0	0	0	1.5	0	0	0	0	0	0
Alabes dorsalis	0	0	0	0	0	0	0	0	0	0	1.2
Aldrichetta forsteri	2.1	1.0	1.0	1.7	3.5	0.5	0	0.4	0	0	0.5
Ammotretis liturata	0	0	0	0.0	0	0	0.3	0	0	0	0
Ammotretis rostratus	0.3	0.4	0	0.5	1.0	0	1.0	1.2	2.0	2.0	0.8
Anguilla australis	0	0	0	0.3	0	0	0	0	0	0	0
Aracana aurita	0	0	0	0	0	0	0.3	0.3	0	0	0
Arenigobius bifrenatus	0	0	0	0	0	0.3	0	0	0	0	0
Arripis spp.	0	0	0	1.4	3.0	0	0.5	0.8	0	2.0	0.3
Atherinasoma microstoma	4.5	3.4	0	2.1	0.8	1.0	0	0.5	0	0	0
Atherinason hepsetoides	0	0	0	0.1	0	0	0	0	0	0	0
Atypichthys strigatus	0	0	0	0	0	0	0.5	0	0	0	0
Brachaluteres jacksonianus	0	0	0	0	0	0	0	0.1	0	0	0
Brachionichthys hirsutus	0	0	0	0.0	0	0	0	0	0	0	0
Contusus richei	0	0	0	0	0	0	0	0.2	0	0	0
Crapatalus munroi	0	0	0	0	0	0	0	0	1.0	0	0
Cristiceps australis	0.3	0	0	0	0	0	0.3	0.3	0	0	1.0
Diodon nichthemerus	0	0	0	0.0	0	0	0	0	0	0	0
Engraulis australis	0.3	0	0	0.0	0	0	0	0	0	0	0
Favonigobius tamarensis	0.8	1.0	0	0.3	0.5	0.8	0.3	1.1	0	0	0
Galaxias maculatus	0.8	0	0	0.4	0	0	2.5	0.3	0	0	0
Galaxias truttaceus	0	0	0	0.0	0	0.3	0	0	0	0	0
Gobiidae (indet)	0	0	0	0	0	0	0	0	0	0	0.8
Gymnapistes marmoratus	0.8	0	0	0.7	0.8	0.8	0.7	0.5	0	2.0	0
Haletta semifasciata	0	0	0	0	0	0	0	0	0	0	0.2
Heteroclinus perspicillatus	0.1	0	0	0	0	0	0.5	0.3	0	1.0	1.3
Hippocampus abdominalis	0	0	0	0.1	0	0.3	0.2	0	0	0	0
Hippocampus breviceps	0	0	0	0	0	0	0	0.2	0	0	0
Hyporamphus melanochir	0	0	0	0.4	0	0	0	0	0	0	0
Kestratherina brevirostris	0	0	0	0.1	0	0.3	0.8	0	0	0	0
Kestratherina esox	0	0	0	0.2	0	0	0	0.1	0	2.0	0
Leptatherina presbyteroides	2.5	3.4	1.0	2.7	0.5	2.5	2.0	4.2	0	8.0	2.8
Lesueurina platycephala	0	0	0	0.0	0	0	0	0	0	0	0
Lovettia sealii	0	0	0	0.1	0	0	0	0	0	0	0
Meuschenia freycineti	0.3	0	0	0	0	0	0	0	0	0	0.5
Mitotichthys semistriatus	0	0	0	0	0	0	0.5	0.3	0	0	0.8
Myliobatis australis	0	0	0	0.0	0	0	0	0	0	0	0
Nemadactylus macropterus	0	0	0	0.1	0	0	0	0	0	0	0
Neoodax balteatus	0.2	0	0	0	0	0	0.5	0.5	0	0	1.5
Nesogobius hindsbyi	0.3	0.4	0	0.2	0.5	2.3	1.5	0.5	8.0	2.0	0
Nesogobius pulchellus	0	0	0	0	0	0	0.3	0	0	0	0
Nesogobius sp.2	1.3	2.1	5.5	1.7	1.0	2.0	1.3	3.1	3.0	3.0	4.0
Nesogobius sp.5	0.3	0	0	0	0	0.3	0.2	0	0	0	1.2
Nesogobius sp.7	0	0	0	0	0	0	0	0.2	0	0	0
Oncorhynchus mykiss	0	0	0	0	0.3	0	0	0	0	0	0
Ophiclinus gracilis	0	0	0	0	0	0	0	0	0	0	0.2
Platycephalus bassensis	0	0.1	0	0.1	0	0	0.6	0.3	1.0	0	0.3
Pseudaphritis urvillii	1.4	0	0	1.5	0.8	1.0	2.2	2.4	0	0	0.2
Pseudocaranx dentex	0	0	0	0	0	0	0.2	0.2	0	0	0
Pseudogobius olorum	1.4	0.1	0	0.6	0.3	0	0	0	0	0	0
Pseudophycis barbatus	0	0	0	0.1	0	0	0	0	0	0	0

APPENDIX 10f (Cont.). Mean $\log_3$ density of fish species collected at sites in estuaries in the Huon and Derwent regions. Total number of sampling occasions for all sites within each estuary is also shown.

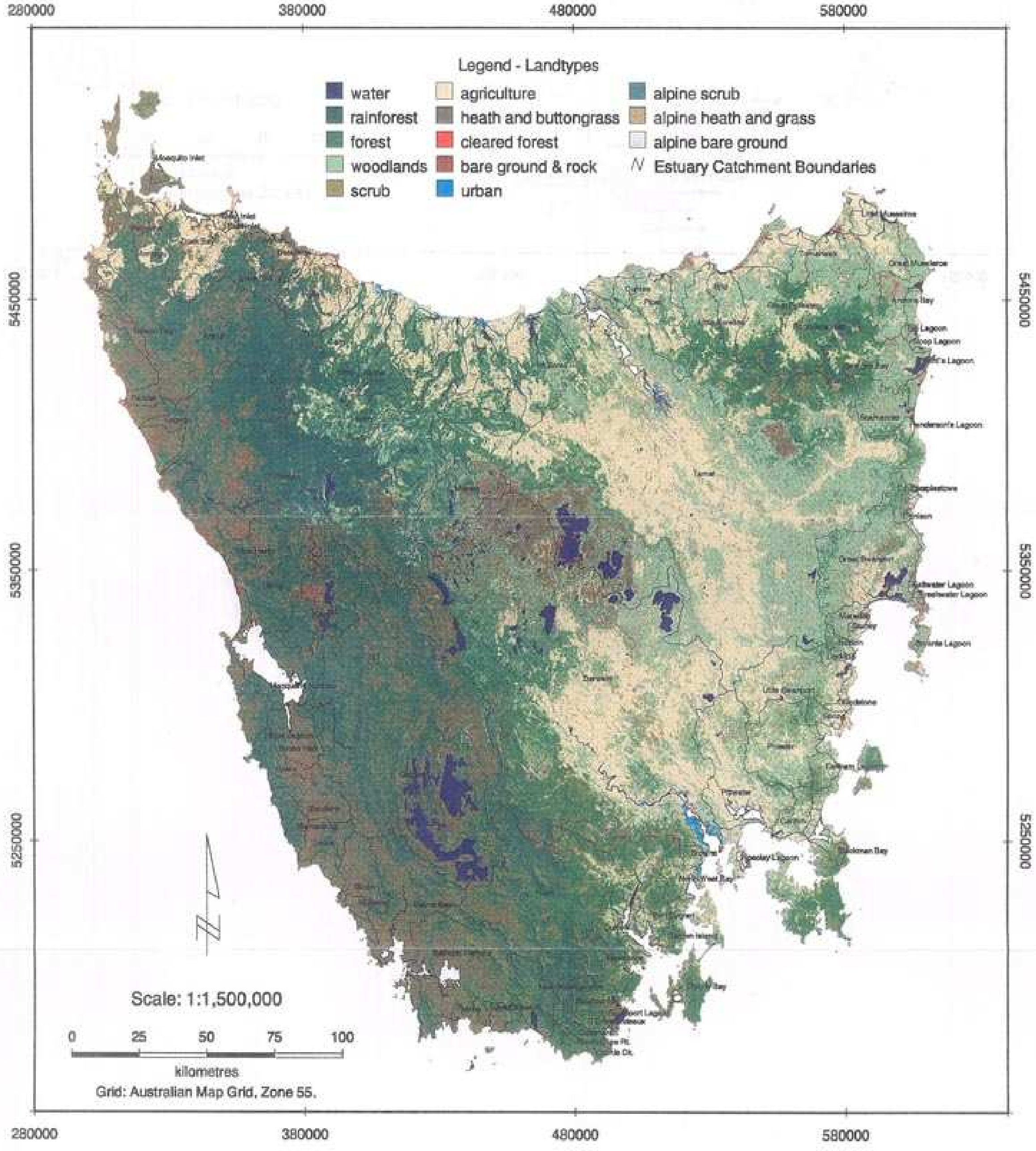
	Carlto	Pittwat	Pipecl	Derwe	Brow	Port Cyg	Huon	Esperen	Lune	Southp	Cloudy
Retropinna tasmanica	0	0	0	1.5	0.5	0.5	0.5	0	0	0	0
Rhombosolea tapirina	1.3	1.9	3.0	1.6	4.0	1.8	0.8	1.0	2.0	3.0	1.3
Stigmatopora argus	0	0	0	0	0	0.3	0.3	0.6	0	0	1.0
Stigmatopora nigra	0.5	0	0	0.1	0	0.8	0.2	0.4	1.0	0	0
Taratretis derwentensis	0	0	0	0.0	0	0	0	0	0	0	0
Tasmanogobius lasti	0	0	0	0.9	2.0	0	0.2	0.1	0	0	1.3
Tasmanogobius lordi	0	0	0	0.0	0	2.5	0	0	0	0	0
Tetractenos glaber	0	0	0	0	0.5	2.0	0.3	0.3	0	0	0
Urolophus cruciatus	0	0	0	0.1	0	0	0	0	0	0	0
Urolophus paucimaculatus	0	0	0	0.0	0	0	0	0	0	0	0
Vanacampus phillipi	0.2	0	0	0	0	0	0.2	0	0	0	0.7
Total Species	21	10	4	37	17	20	31	29	7	10	22
Sample number	7	7	2	27	4	4	4	10	1	1	6

APPENDIX 10g. Mean log3 density of fish species collected at sites in estuaries in the south and west. Total number of sampling occasions for all sites within each estuary is also shown.

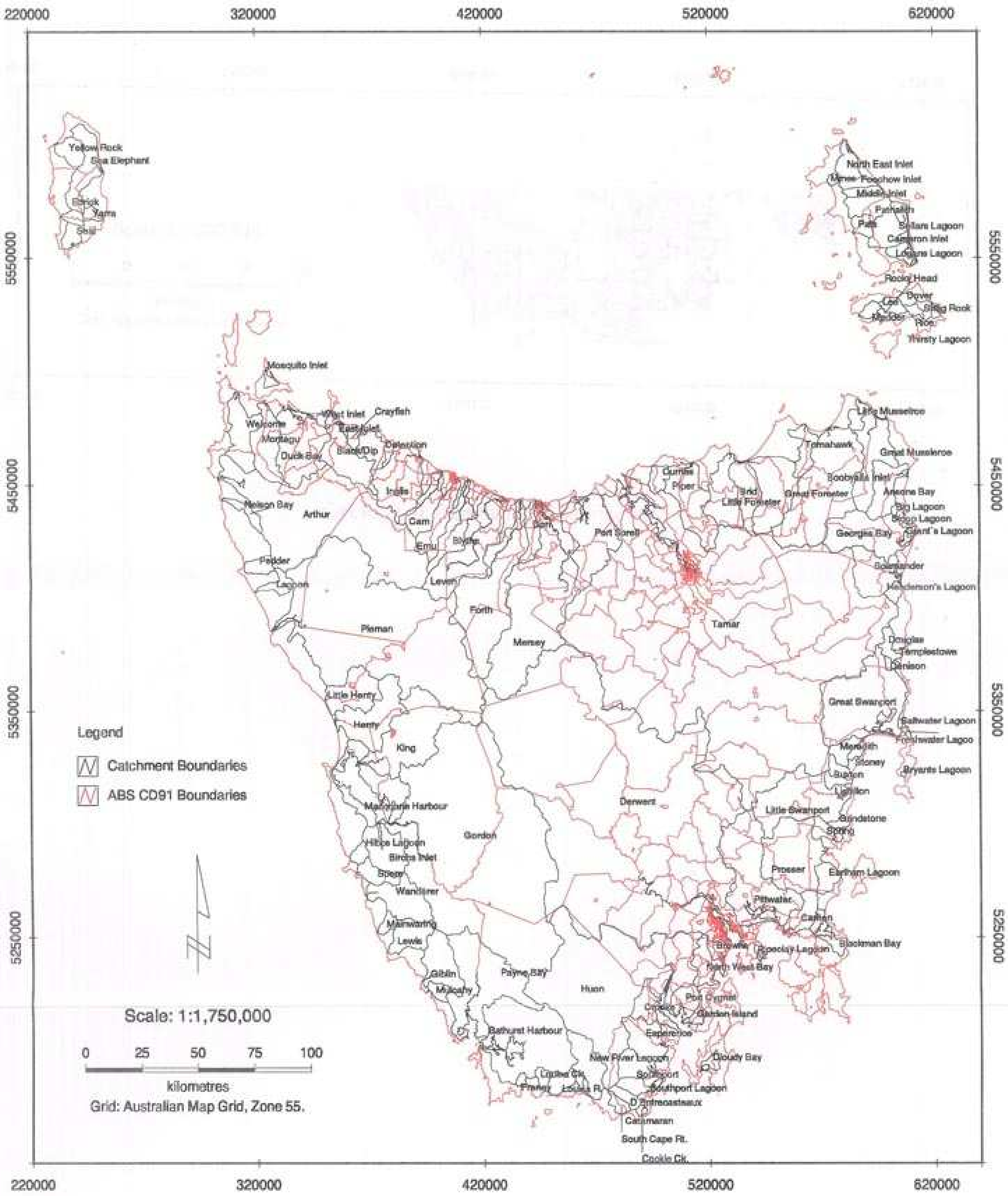
	Catamara	Entrecast	Cockle	New River	Bathurs	Payne	Macquar	Pieman	Nelson	Arthur
Acanthaluteres spilomelanurus	0	0	0	0	0	1.1	0.0	0	0	0
Aldrichetta forsteri	0	1.0	2.0	0	0.1	1.0	1.5	1.8	0	2.3
Ammotretis liturata	0	0	0	0	0	0.2	0.1	0	0	1.0
Ammotretis rostratus	0	0	0.5	0	0	0.5	0.3	0	0	2.0
Anguilla australis	0	0	0	0	0.3	0	0	0	0	0
Apogon conspersus	0	0	0	0	0	0.3	0	0	0	0
Arnoglossus bassensis	0	0	0	0	0	0	0.0	0	0	0
Arripis spp.	0	0	1.0	0	0	0.9	0.1	0	0	0
Atherinasoma microstoma	0	0	2.5	3.0	5.9	0.5	1.2	0	0	0
Cristiceps australis	0	0	0	0	0	0.3	0	0	0	0
Favonigobius tamarensis	6.0	0	0	0	0.7	0.6	0.0	0	0	0
Galaxias maculatus	0	2.0	0	0	1.1	0.4	0.8	3.8	1.0	1.7
Galaxias truttaceus	0	1.0	0	0	0	0.6	0.7	2.5	5.0	0.1
Gymnapistes marmoratus	0	0	0	0	0	0.7	0	0	0	0
Hippocampus abdominalis	0	0	0	0	0.1	0	0.0	0	0	0
Kathetostoma laeve	0	0	0	0	0	0.1	0	0	0	0
Kestratherina brevirostris	0	0	0	0	0	0.2	0	0	0	0
Leptatherina presbyteroides	0	0	6.0	0	0.3	4.6	2.4	0	0	0
Lesueurina platycephala	0	0	0	0	0	0.2	0.1	0	0	0
Lovettia sealii	0	2.0	0	0	0	0.8	0.1	0	0	0.4
Neoodax balteatus	0	0	0	0	0	1.0	0	0	0	0
Nesogobius hindsbyi	0	0	0	0	0	0.4	0.0	0	0	0
Nesogobius sp.2	0	0	5.5	0	0	1.5	0.2	0	0	0
Nesogobius sp.5	0	0	0	0	0	0.4	0.0	0	0	0
Platycephalus bassensis	0	0	0	0	0	0.1	0.0	0	0	0
Prototroctes maraena	0	0	0	0	0	0	0	0.8	0	2.4
Pseudaphritis urvillii	0	4.0	0	8.0	0.9	0.3	0.8	0.3	0	0.3
Pseudogobius olorum	0	3.0	0	0	0	0	0	0	0	0
Retropinna tasmanica	0	7.0	0	3.0	2.9	0.6	0.5	0	3.5	0
Rhombosolea tapirina	0	2.0	3.0	0	0	0.7	2.8	0.5	0	0.4
Stigmatopora argus	0	0	0	0	0.6	0.4	0	0	0	0
Stigmatopora nigra	0	0	0	0	0	0	0.2	0	0	0
Tasmanogobius lasti	7.0	0	0	5.0	0	0	0	0	0	0.1
Tasmanogobius lordi	0	0	0	0	0	0	0	0.8	0	0
Tetractenos glaber	0	0	0	0	0.1	0.5	0	0	0	0
Total Species	2	8	7	4	11	27	22	7	3	10
Sample number	1	1	2	1	7	11	27	4	2	7



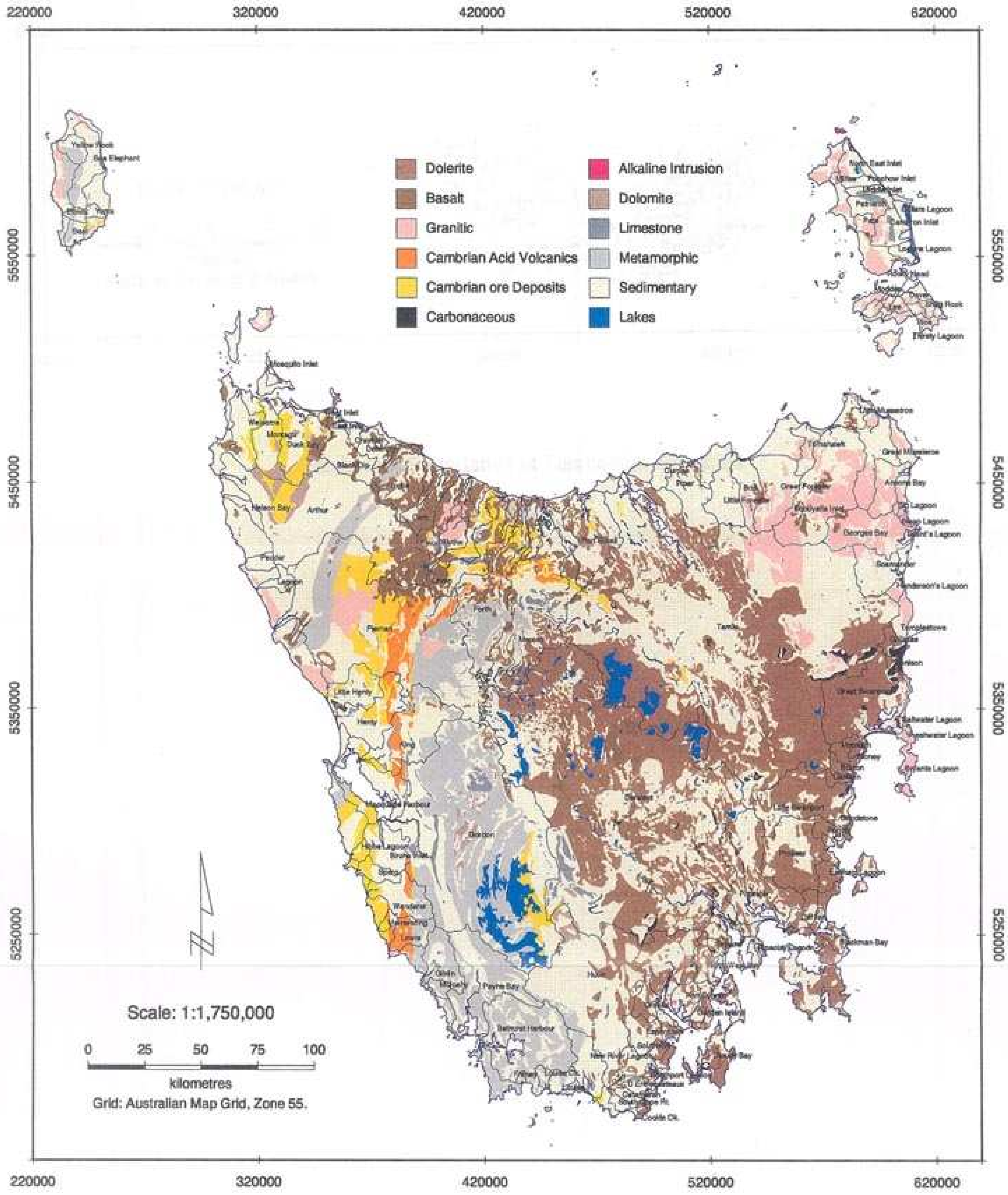
Land Tenure in Tasmanian Catchments



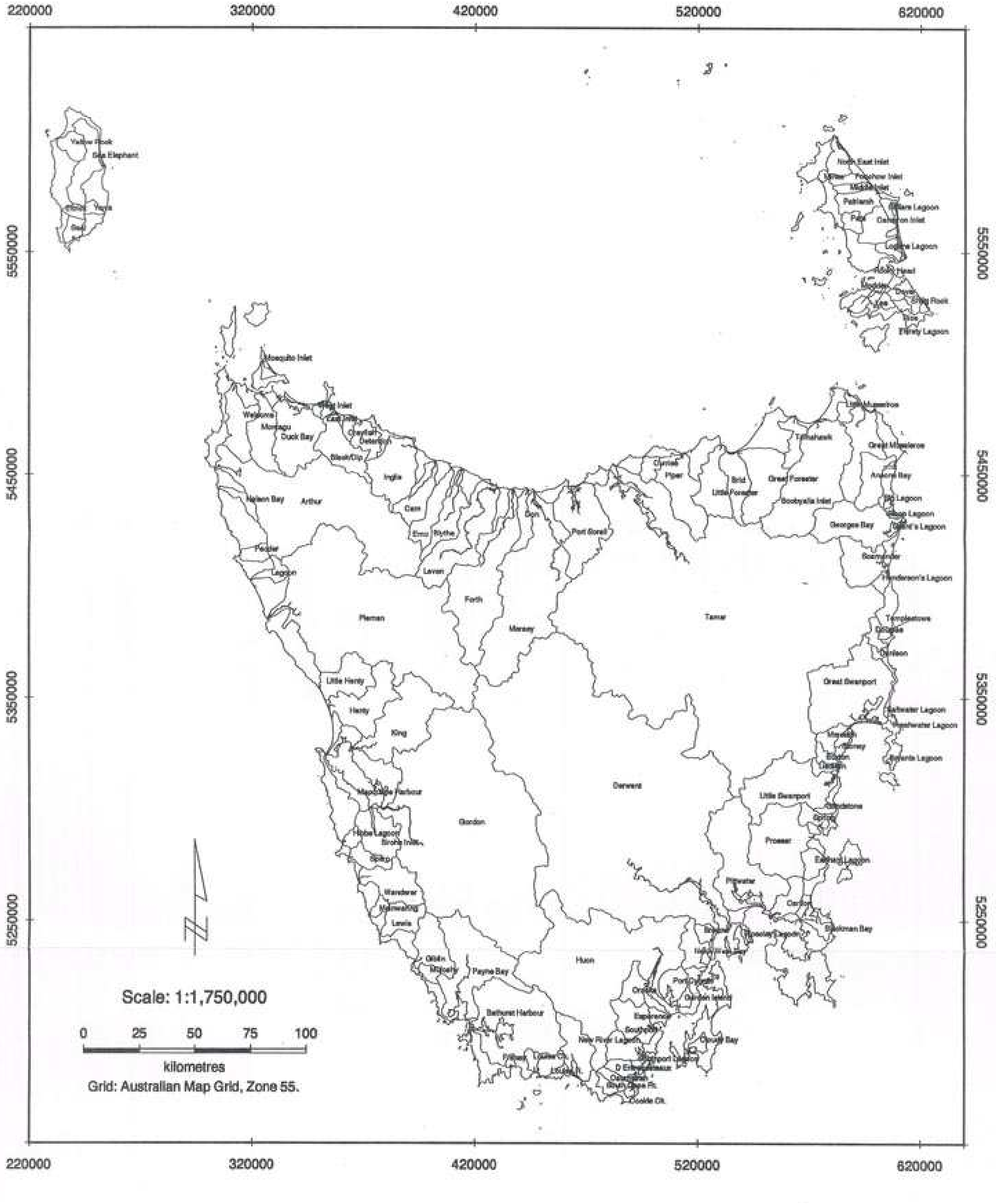
Land Type Categories in Mainland Tasmanian Catchments



ABS Census Districts and Catchment Boundaries of Tasmanian Estuaries



Geology of Tasmanian Catchments



Catchment Boundaries of Tasmanian Estuaries