NHT/NAP FINAL REPORT

ECOLOGICAL STATUS OF THE DERWENT AND HUON ESTUARIES

Catriona Macleod and Fay Helidoniotis

November 2005

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Ph. (03) 6227 7277 Fax (03) 6227 8035

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Executive Summary

This study was undertaken to fill a significant gap in our understanding of the system ecology of the two main estuaries in southern Tasmania and to provide baseline information to assist in the ongoing management of these systems. The Derwent and Huon estuaries are similar in their biogeographical, climatic and physical characteristics but differ markedly in their levels of industrialisation. The Derwent estuary is highly impacted with several major industrial and urban contamination sources throughout its catchment. Heavy metals in particular, represent a considerable threat to the system. In contrast the Huon estuary is largely unimpacted, finfish aquaculture being the only major industry affecting the system, although there is potential for future development and industrialisation. Both the Derwent and the Huon estuaries are strongly depositional with the majority of the estuary composed of soft sediments. These sediments will act as a repository for any contaminants to the system and the benthic infauna will in turn reflect the cumulative effects of these pollutants. There is considerable information on the various anthropogenic loadings to the Derwent and on the effects of these on water quality, but prior to this study there was very little information on the biological consequences of these contaminants. Information on the benthic ecology is an essential pre-requisite to any effective management strategy. Accordingly, in order to determine the overall impact in the estuary or to evaluate future remediation, baseline information on the current biological condition of the system was essential.

This study undertook a broad assessment of the ecological changes in both estuaries. Extensive spatial sampling was undertaken throughout the estuaries in order to characterise the benthic communities. These communities were then evaluated in relation to the changes in the natural environmental conditions as well as changes in the level of organic enrichment and metal contamination. Infaunal samples in the Derwent were taken at 55 sites which coincided with sediment sampling previously undertaken by the Department of Primary Industry, Water and Environment (DPIWE) for analysis of sediment composition, metal contamination levels and organic carbon content. In the Huon a further 25 infaunal samples were collected from sites selected to give a broad overview of the ecology of the system. Sediment samples were also collected from the Huon for sediment particle size analysis, and evaluation of metal levels and organic carbon content.

The results of this study found that there were similarities in the pattern of community distribution along the estuaries. In neither system were there any areas where fauna was completely absent, in fact diversity was high throughout most of the sample sites. The faunal community in both estuaries was most strongly related to the natural geomorphology and salinity gradient of the estuaries, and in turn to the depositional character of the system and the organic content. Changes throughout the estuaries were gradual but several discrete communities were identified within each estuary and the species which most strongly characterised these communities are described. The community distribution in the Derwent was slightly more complex than the Huon, as in addition to the natural gradient there were also multiple anthropogenic gradients. Prior to this study it was anticipated that the extremely high concentrations of metals throughout the Derwent would be the most significant structuring influence on the ecology of the system. However, the results show that metal contamination was not the overriding determinant of benthic infaunal community composition, although both organic enrichment and metal contamination had a significant influence on the community structure in localised areas. Contrary to our expectations, areas with very high metal concentrations, including areas containing toxic metals (i.e. mercury and arsenic), had an abundant fauna which suggests that somehow these metals were not biologically available. This raises an interesting question regarding how the infauna avoid this toxicity. The metals may be chemically bound in the sediments or perhaps the infauna are actively circumventing any toxic effects by avoiding, compartmentalising or excreting the metals. If the toxicity is managed through biochemical stabilisation of the sediments then any changes in the sediment chemistry of the estuary could have a serious and detrimental effect. On the other hand if the toxicants are being stabilised within the animals then this represents a significant bioaccumulation risk through the food chain.

This study shows that the Huon is a relevant and valuable biological reference point for comparison with the Derwent and consequently can provide useful parameters for developing management guidelines for both the Derwent and Huon. The biological information provides an important resource for researchers and managers. It represents a baseline ecological reference for any future assessment of sediment condition and ecological status. The study defines species indicative of communities characterising particular regions within the system. These biological zonation patterns will enable environmental managers to locate biologically relevant monitoring sites and to evaluate improvements and deterioration in the estuarine condition both spatially and temporally.

Invasive species are considered to be one of the most significant threats to global biodiversity. Prior to this study it was well known that there were several key introduced species in the Derwent, particularly around the port of Hobart, but the distribution of species throughout the rest of the system or in the Huon estuary was largely unknown. This study mapped the current status of invasive species in both estuaries providing a point of reference to monitor and manage their spread and distribution. Examination of the environmental preferences of these species suggests that in general their environmental tolerances are broad and that range extension is more likely to result from opportunity and reduction in competitive pressure rather than any particular environmental preference. This has significant implications for the management of these ecologically and potentially economically important species.

Although this study was specifically focussed on the Derwent and Huon estuaries, the findings can be applied in a much broader spatial context. Comparison of the faunal information for the lower estuary regions with other local studies suggests that the community characterisation would be applicable to other estuaries in south-eastern Tasmania. The general response of the main species and infaunal community groups to metal contamination could potentially be applicable throughout southern temperate Australia, whilst the functional community response and invasive species information has even wider application.

Table of Contents

EXECUTIVE SUMMARY 1

1. INTRODUCTION 5
   - 1.1 BACKGROUND 5
   - 1.2 NEED 6
   - 1.3 AIMS 7
   - 1.4 STUDY CONTEXT 7

2. METHODS 12
   - 2.1 SAMPLE COLLECTION AND PROCESSING 12
   - 2.1.1 Site location 12
   - 2.1.2 Physical chemical sampling. 12
   - 2.1.3 Faunal sampling 13
   - 2.1.4 Video footage 13
   - 2.2 STATISTICAL ANALYSES 14
   - 2.2.1 Univariate 14
   - 2.2.2 Multivariate 15

3. RESULTS AND DISCUSSION 16
   - 3.1 PHYSICAL-CHEMICAL CHARACTERISATION OF THE SYSTEMS 16
   - 3.1.1 Huon Estuary 16
   - 3.1.2 Derwent Estuary 25
   - 3.2 ECOLOGICAL STATUS OF THE HUON ESTUARY 38
   - 3.2.1 Biota data 38
   - 3.3 ECOLOGICAL STATUS OF THE DERWENT ESTUARY 51
   - 3.3.1 Biota data 51
   - 3.4 ECOLOGICAL COMPARISONS OF THE HUON AND DERWENT ESTUARIES 72
   - 3.5 INTRODUCED SPECIES DYNAMICS 82
   - 3.6 EVALUATION OF VIDEO AS POTENTIAL MONITORING TOOL 92

4. CONCLUSIONS 97

5. ACKNOWLEDGMENTS 103

6. REFERENCES 104

1. Introduction

1.1 Background

The Huon and Derwent estuaries are the largest and most economically important estuaries in the southern Tasmanian region. The Huon estuary was described in a recent study (CSIRO, 2000) as a “substantially natural” waterway with high environmental quality which had not changed dramatically from its historical baseline. However, the environment is under increasing pressure from expanding aquaculture operations and introduced marine pests are a growing concern. In contrast the Derwent Estuary is severely degraded (Bloom and Ayling, 1977; Coughanowr, 1997) by point sources of pollution arising from industrialized developments, leading to high heavy metal contamination. Concentrations of lead, zinc and mercury in Derwent estuary sediments greatly exceed the ANZECC (2000) sediment quality guidelines (SQG) over most of the estuary (Green and Coughnaowr, 2003). There is nutrient enrichment linked with sewage treatment plant discharges, organic enrichment of sediments and depressed oxygen levels in the upper estuary associated with historic pulp mill discharges, and markedly increased sedimentation rates (Jordan et al., 2003).

Physical data from these estuaries suggest that in the absence of human influences the two systems would have many ecological similarities and that the benthic communities in the Huon would provide an extremely useful comparison to those of the Derwent. There have been several studies which have looked at the biota of the Huon estuary, particularly in reference to the aquaculture operations throughout the system. However, the sediment chemistry of this system is poorly defined and there has not been the same level of fine scale mapping as is available for the Derwent. In contrast, previous studies have provided considerable information on the physical and chemical characteristics of the Derwent but there is very little information on the benthic status. The few studies that have been undertaken have been restricted to the effects of pulp mill effluent on the upper estuary (Horwitz and Blake, 1992, Aquenal, 2002, unpublished reports to industry) and a port survey for introduced marine pests (Aquenal, 2002).

Characterisation of the benthic infaunal community is one of the most sensitive and reliable indicators of environmental status (Weston, 1990, Johannessen et al., 1994, Codling et al., 1995, Cairns et al., 1993). Changes in the infaunal community characterize the integrated effect of all environmental stresses (physical, chemical and biological) to which a system has been subjected. Therefore faunal assessment is a more reliable approach for determining ecosystem condition than direct physical and chemical measures (Cairns et al., 1993). Furthermore, in soft sediment environments alternative techniques such as seagrass and algal monitoring are not applicable and the benthic infauna is the only feature that will reliably reflect environmental change. Benthic communities also play a critical role in regulating sediment processes, such as denitrification and aeration of sediments. This is particularly significant in the Derwent Estuary where soft-sediment habitats represent around 96% of the seabed area (Jordan et al., 2001).

1.2 Need

The primary aim of this project was to fill information gaps on the ecology and biological condition of the Huon and Derwent estuaries, consolidating the available information on the biological communities and filling gaps in our current understanding of sediment quality and the distribution of key introduced marine pest species. This information is essential if informed management strategies and relevant resource condition targets are to be developed. It is also critical for the establishment of effective phased recovery plans for the Derwent. The individual management plans for the Derwent (Coughanowr et al., 2001) and the Huon (Den Exter, 2002) recognise that an understanding of biological conditions is an essential prerequisite for effective and sustainable management. A major management initiative is currently underway to restore the Derwent, but this has been hampered by a lack of relevant biological indicators and targets. Without this information it is impossible to truly understand how systems function.

Several key introduced species (eg *Asterias amurensis*, *Maoricolpus roseus*) are present in the Derwent and the Huon estuaries. Some of these present a potential threat to local fishing and aquaculture industries. The significance of invasive species in relation to both ecosystem integrity and biodiversity is recognised both by the National Heritage Trust (NHT) as an overarching objective and as a regional target in the National Natural resource management (NRM) strategy. This study provides essential information on the prevalence and distribution of introduced species in both estuaries. Such information is urgently required by local councils and state government and will enable a better understanding of the extent of the threat that these species represent.

Once a clear picture of the system status within each estuary has been established it will be possible to identify appropriate and scientifically credible indicators of environmental integrity. This information can then be used by managers to make appropriately informed decisions regarding environmental planning and resource allocation. Maps defining the key communities within each of the estuaries have been produced from this study. These maps can then be linked in turn to the other available datasets (i.e. chemical and physical information) to produce a set of regional characterisation maps, identifying the characterising species and key physical/chemical drivers of community structure. Furthermore, these biological maps may be combined with existing habitat characterisation maps to provide a highly integrated and sensitive understanding of the system processes and environmental conditions, which in turn will enable establishment of ecologically relevant resource condition targets and development of informed management strategies.

Finally, the biological data resulting from this project will make a significant contribution to regional biodiversity maps. Biodiversity is a major issue for local (Coughanowr et al., 2001, Den Exter, 2002) and national resource management (NRM National Strategy, 2003). The Tasmanian fauna is particularly poorly described and, as already indicated, there is almost no information on the faunal composition of the Derwent estuary as a whole. This project will significantly improve our understanding of local ecology and diversity, which is essential if we wish to ensure that ecosystem biodiversity is preserved; a priority in both the national and regional NRM strategic frameworks.

1.3 Aims

This project had 4 principal objectives:

- provide critical baseline information and, functionally relevant indicators and targets for southern Tasmania's two largest estuaries;
- quantify the distribution and spread of key introduced marine pest species;
- support and add value to current management initiatives in the Derwent and Huon Estuaries;
- develop methods and provide information that can be extended to other estuaries/coastal waters in the southern region.

1.4 Study Context

The Derwent and Huon estuaries are located in SE Tasmania (Fig. 1) and have many similar biogeographical, climatic and physical characteristics (Jones et al. 2003). Butler (in press) provides a comprehensive review of the history, social significance, geography, geology and hydrology of the two estuaries. Both estuaries are drowned river valleys in a microtidal region with a highly stratified salt-wedge water column, currents are generally weak (≤0.2ms-1), particularly in subsurface waters, and the estuaries have similar depth ranges (Butler, in press) (Fig. 2).

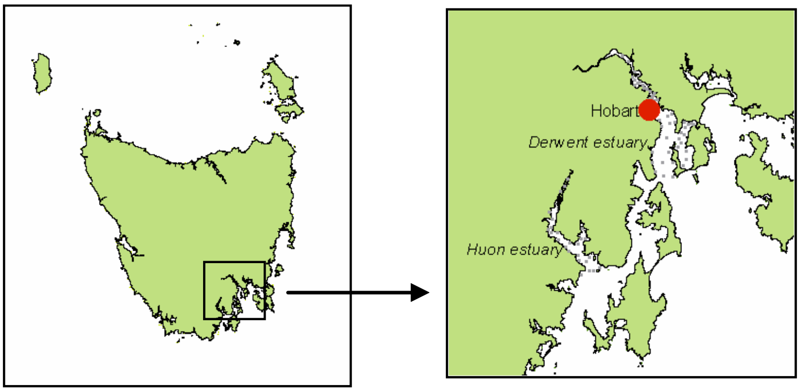


Fig. 1. Map of Tasmania with the Derwent and Huon estuaries enlarged.

However, these estuaries differ markedly in the extent of their human impacts. The Huon estuary is relatively uncontaminated, whilst the Derwent estuary is severely degraded. The main anthropogenic influences on the Huon catchment are largely agricultural, the area is sparsely populated, with only 2 sewage treatment plants discharging into the system, and there is very little industry. A relatively large wood pulp mill operated on the shore of Hospital Bay until 1991. Previous studies have reported a localised organic impact in addition to slight elevation in metal levels in this area (CSIRO, 2000). Currently, the most significant industry in the estuary is marine farming which began in the mid-1980's and is largely restricted to the mid-lower estuary (Butler, in press).

In contrast the Derwent estuary is highly industrialised, with the deepwater port in Hobart, an electrolytic zinc refinery and fertiliser plant at Risdon, a newsprint mill at Boyer and several smaller industries along the shore of the estuary around the city (Butler, in press). The population of Hobart is currently around 200,000. The effluent from 10 sewage treatments plants and numerous stormwater drains discharge directly into the Derwent (Green and Coughanowr, 2003). Although all of the main contaminant sources have environmental management strategies in place which aim to minimise their impacts, this still represents a major load of organic material and heavy metals to the estuary.

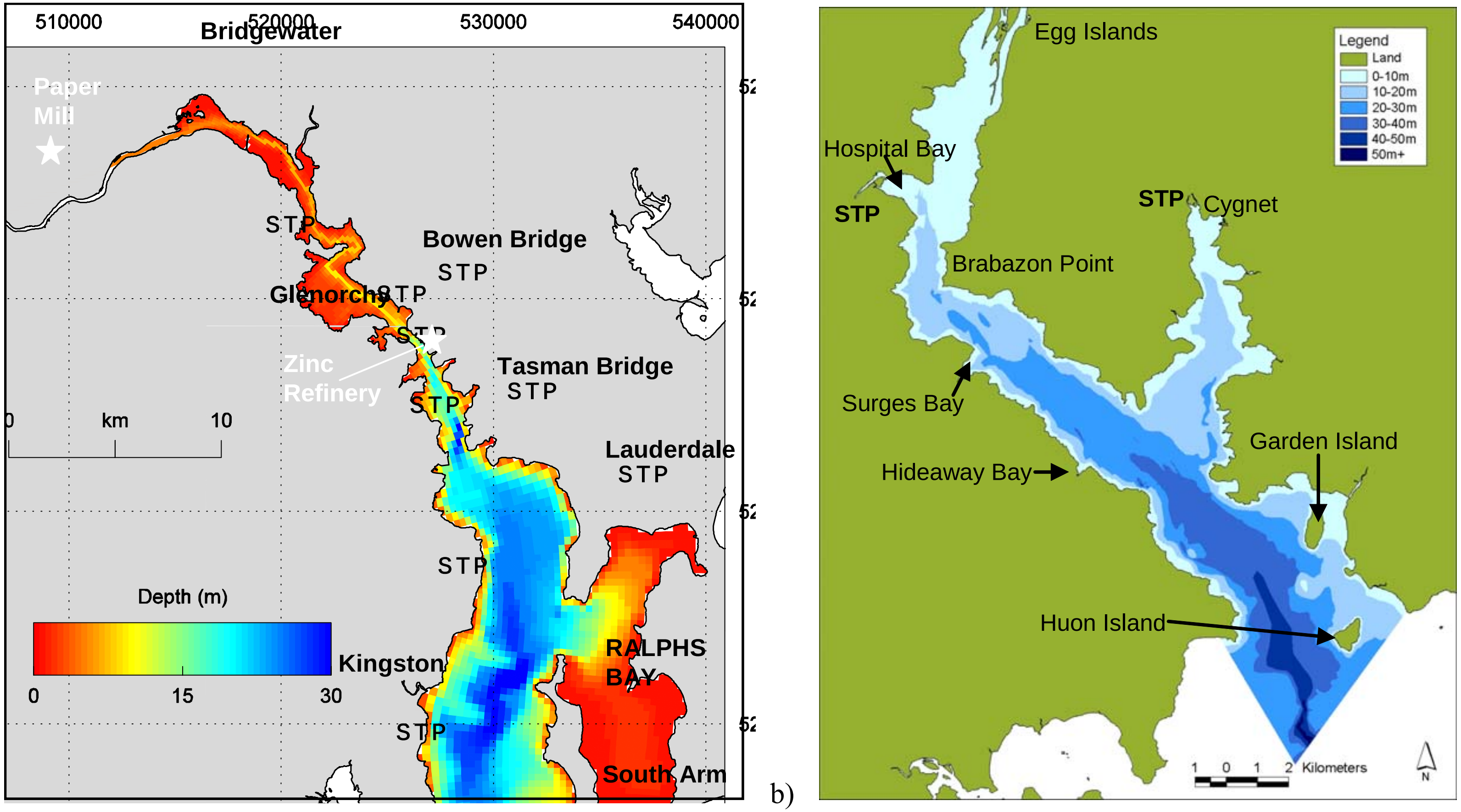
a) 

Fig. 2. Bathymetry, major landmarks and location of main land based discharges including sewage treatment plants (STP) within a) Derwent and b) Huon estuaries. Derwent bathymetry map courtesy of Mike Hertzfield, CSIRO Division of Marine & Atmospheric Research.

This study aimed to describe the spatial variability in the ecology of both estuaries and to determine the biological condition of the various communities. It was expected that the extremely high metal levels in the Derwent would have a structuring influence on the biological composition. Consequently, by comparing the biological information with the physico-chemical measures, in particular the heavy metal concentrations, it was hoped that it would be possible to broadly characterise the effects of heavy metal contamination on the community structure, define critical metal concentrations and examine the synergistic effects of multiple contaminants. Comparison between the Derwent and the relatively unimpacted Huon system would provide a fundamental point of reference in this assessment.

Sites in the Huon were selected so as to be both broadly representative of the range of environmental condition in the estuary and to be comparable with sites in the Derwent. The selection of sites in both estuaries was based on knowledge of local geography, hydrology, position of known impact sources to the area and the findings of recent studies. In the Huon there have been two recent studies; an extensive assessment of the hydrology and nutrient dynamics of the Huon estuary (CSIRO, 2000) and a comparison of the sediment chemistry of the Derwent and Huon estuaries (Jones et al., 2003) as well as a series of baseline environmental studies for the establishment of finfish aquaculture leases in the Huon (unpublished reports to industry).

In 2003 the Department of Primary Industries Water and Environment - Derwent Estuary Program (DPIWE-DEP) collected samples from 143 sites throughout the Derwent estuary for sediment metal concentrations, organic content and sediment particle size. It was felt that these data would be representative of the current environmental conditions, and a sub-set of 51 sites, representative of the conditions in the main body of the estuary, were resampled to provide additional information on depth, salinity, redox, sulphide and benthic infaunal community structure. Three additional sites from areas not sampled in the original DPIWE study were also included and samples were collected for analysis of all relevant measures at these sites. Similar datasets were reviewed for the Huon estuary but differences in the collection methods and analytical approaches made it prudent to obtain sediment samples directly for this system.

On the basis of the available information regarding contamination levels and hydrography each estuary was divided “a priori” into zones. The Huon was split into 4 zones, principally on the basis of differences in hydrography (Fig. 3). The upper Huon was defined as the region north of Hospital Bay including Egg islands, which is shallow and has relatively coarse sediments. The lower Huon zone was deeper (>25m in depth), generally with muddy sediments and comprised the broad area between Hospital Bay and just south of Garden Island. Cygnet Bay was quite distinct from the main system and therefore was zoned separately. The final zone was the mouth, this covered the area around Huon Island, the sites in this region were relatively deep (16 – 42 m), the sediments were generally coarser than in the lower estuary and were subject to fully marine influences.

a)
b)

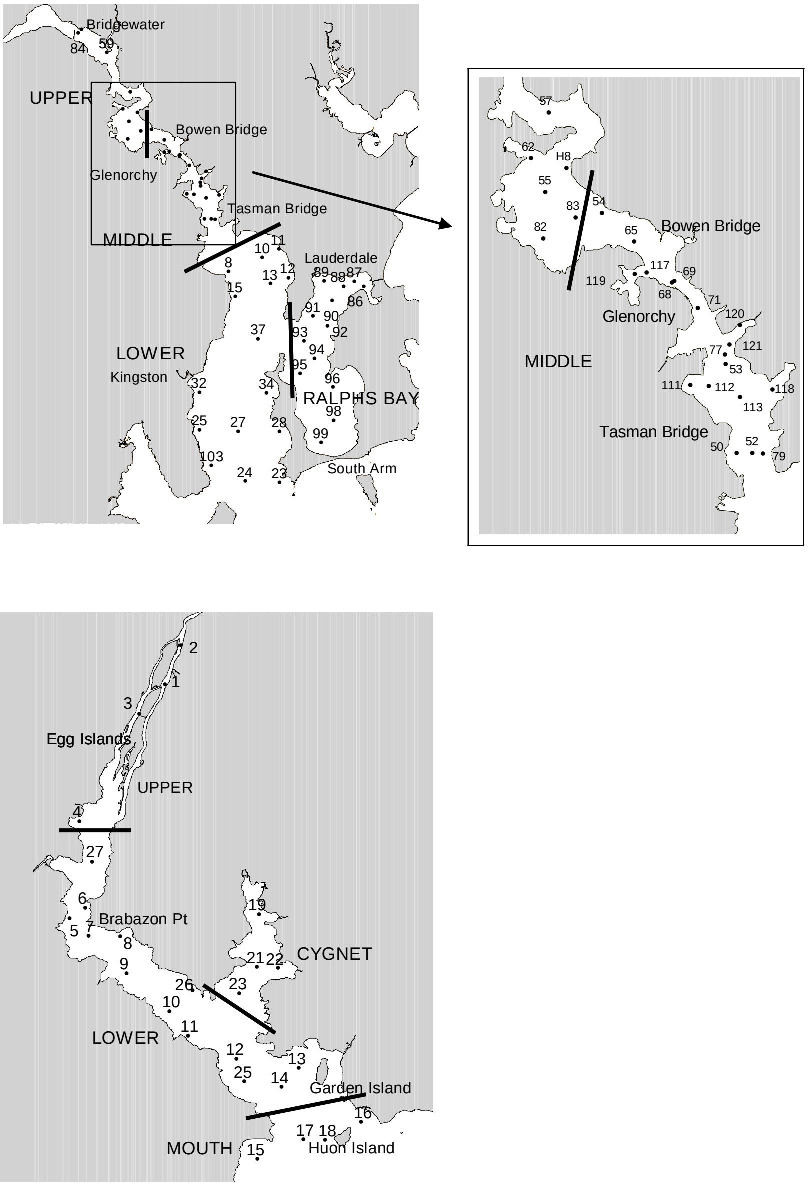


Fig. 3. Hydrogeographic zones within a) Derwent and b) Huon.

The Derwent was also classified into 4 zones (Fig. 3). As with Cygnet Bay in the Huon, Ralphs Bay was quite distinct from the main system and therefore was also zoned separately. The upper Derwent was classified as the region between Bridgewater and just south of Elwick Bay. This region is relatively shallow, strongly depositional, with a high proportion of organic material and is subject to periods of freshwater exposure. Metal contamination levels in this upper zone were moderate. The mid zone lies between the Bowen and the Tasman Bridges. Sites in this region were deeper (approx 20m) and were strongly contaminated with metals. The lower zone extends from the just below the Tasman Bridge to the mouth of the estuary. Sites in this zone were generally deeper, cleaner (i.e. less organics) and the substrate was often slightly sandier

2. Methods

Data for this study was obtained through a combination of re-analysis of existing datasets and field sampling.

2.1 Sample collection and processing

2.1.1 Site location

In total 79 sites were sampled in this study, 54 sites from the Derwent sampled 8-12th November 2004, and 25 sites from the Huon sampled 4-9th October 2004. The location of each site was recorded using a Garmin 135 GPS Map unit. In the Derwent 51 sites from the original DPIWE-DEP study (2003) were sampled for depth, salinity, redox, sulphide and benthic infaunal community structure. At 3 additional sites sediment metal concentrations, particle size and organic content were also evaluated. In the Huon all 25 sites were sampled for metal concentrations, particle size, organic content, depth, salinity, redox, sulphide and benthic infaunal community structure.

2.1.2 Physical chemical sampling.

In situ measurements of temperature and salinity were taken approximately 1m above the sediment surface using a WTW LF 197 ProfiLab conductivity meter.

Three replicate cores (perspex tubes 250mm length x 45mm internal diameter) were collected at each site. One core was used for measurement of redox potential and sediment sulphide concentration, the remaining cores were frozen and later used for granulometry analysis, organic content and metals analyses where necessary. Redox and sulphide were measured upon return to the lab, within 4 – 6 hours of sampling. Redox was measured using a WTW Redox Probe. Sulphide was measured using a Cole-Parmer 27502-40 silver/sulphide electrode according to the method described by Macleod et al. (2004). All measurements were taken at a depth of 3cm. Temperature of both the sediment and overlying water were recorded at the time of measurement.

For particle size analysis each sub-sample was dried at 30^{o}C and the weight recorded. The samples were then passed wet through a series of sieves (4mm, 2mm, 1mm, 500µm, 250µm, 125µm and 63µm), and the sediment retained on each sieve was collected, dried at 30^{o}C and weighed. The proportion of sediment retained on each sieve was then calculated as a percentage of the total sample weight. The proportion of sediment smaller than 63µm was determined by calculating the difference between the total sample weight and the summed weight of each retained fraction.

Analysis of trace metals was undertaken by Analytical Services Tasmania (DPIWE – AST) according to formal quality assurance protocols and standard procedures. Sediment samples were dried at 104^{o}C, each sample was then ground to a particle size <2mm and digested using Aqua regia (HCl/HNO3). Digests were analysed by ICP-AES (Inductively Coupled Plasma Atomic Emission).

2.1.3 Faunal sampling

At each station a Van Veen Grab (surface area – 0.0675m^2) was used to collect a sample for benthic in-faunal evaluation. Grab contents were transferred to mesh bags (mesh size 1mm) and rinsed. Samples were then wet sieved to 1mm and the retained material preserved in a solution of 10% formalin:seawater (4% formaldehyde). Samples were transferred to the laboratory for sorting and subsequent identification. The in-fauna were identified to the lowest possible taxonomic level and enumerated.

2.1.4 Video footage

Video footage was taken using a digital underwater camera system linked by an umbilical to a digital recorder on the surface. A minimum of three minutes footage was taken from each sample station.

Video was scored according to key features determined to be indicative of impacted or unimpacted conditions, as defined by previous research (Crawford et al., 2001; Macleod et al., 2004), background environmental information and information on the benthic community structure. Each feature/variable was weighted according to its sensitivity to detect impacts or no impacts. For example the presence of bacterial mats, *Beggiatoa* spp., is a well recognized indicator of environmental degradation (GESAMP, 1996), and therefore received a high weighting. Evidence of gas bubble emission received a very high weighting, as this would suggest a highly degraded system. The score for each feature could be either positive or negative, depending on whether the variable represented a positive or negative effect. Categorising the variables in this manner means that features indicative of good environmental conditions will tend to increase the final score, whilst those suggesting an impact would reduce the overall score. Therefore the higher the summed score, the better the sediment condition. The resulting scores can either be analysed using univariate techniques (i.e. summed as a single score for each zone) or can be set up as a matrix for multivariate analyses.

Table 1. Video features used in analysis with weighting and category indicated.
All fauna were scored as density estimates (ie. 1= few, 2 = many). *Beggiatoa* was scored by thickness of mat (patchy =1, thin = 2, thick = 3). % Algal cover scored as sparse (1), moderate (2) or dense (3), as was Burrow Density. All other features were scored as presence (1)/absence (0).

Feature	Weighting	Category
Gas Bubbles	10	-ve
Bacterial mats (*Beggiatoa sp.*)	1.5	-ve
Black/grey sediment	1	-ve
Anthropogenic debris	1	-ve
Burrow density	1.5	+ve
Algal cover	1.5	+ve
Worm tubes/casts	1	+ve
Faunal tracks	1	+ve
Specific Fauna		
Heart urchin	1	+ve
Brittlestar	1.5	+ve
Starfish 1. (*Patiriella* sp.)	1	+ve
Starfish 2. (*Coscinasterias* sp.)	1	+ve
Starfish **3.** (*Asterias* sp.)	1	+ve
Other seastars	1	+ve
NZ screwshell	1	+ve
Dog whelk	1	-ve
Scallops & clams	1	+ve
Side gilled seaslug	1	-ve
Swarming epibenthic crustaceans	1	+ve
Squat lobster	1	-ve
Other crustaceans	1	+ve
Echiurans & large annelids	1	+ve
Anemones	1	+ve
Sponges	1	+ve
Ascidians	1	+ve
Fish/ Other vertebrates	1	+ve

2.2 Statistical analyses

2.2.1 Univariate

Univariate data were analysed by Analysis of Variance (ANOVA). Various transformations were applied and these are noted in the results sections for the individual datasets.

A fixed effects model ANOVA was used to assess variations between zones and estuaries in redox potential, sulphide concentration, sediment metals, macro-invertebrate abundance, number of species, major faunal groups (Phyla) and diversity (Shannon Index) (Shannon and Weaver, 1963). Tukey's posthoc test was undertaken for subsequent pairwise comparisons to determine which treatments / groups were significantly different. In addition video scores were compared to Shannon index values for macro-faunal data using regression analysis.

For analyses of redox potential and sulphide concentration, a two-way fixed effects model ANOVA with factors site and zone was used to assess between treatment variations.

2.2.2 Multivariate

Patterns in the species community data and benthic assemblages were identified by ordination and classification procedures using the Plymouth Routines in Multivariate Ecological Research (PRIMER) software package. Cluster analysis and ordination techniques were used to determine patterns in the biotic, environmental and video assessment data. Biotic groups identified in cluster analysis were assessed using SIMPER analysis to determine the relative contribution of each species to the average similarity within groups and dissimilarity between groups. Abiotic groups identified in cluster analysis were assessed using BIOENV and BEST analysis to determine the relative contribution of abiotic factors to the average similarity within groups and dissimilarity between groups. The matrices underpinning the various datasets were compared to determine how well they correlated (RELATE analysis).

3. Results and Discussion

3.1 Physical-Chemical Characterisation of the Systems

Physical environmental conditions can have a major structuring influence on infaunal communities. Sediment characteristics will profoundly affect the type and function of the fauna. Grain size will influence the type of species that occupy the sediment interstices and very different communities will be present in well sorted clean sand environments from mud and silt sediments. Current flow will not only affect which species colonise an area, but will also determine the amount of suspended material in the water and therefore whether suspension and filter feeding species dominate. The salinity regime can also have a major influence on the community structure. Within an estuary, truly freshwater communities are quite discrete from fully marine benthic communities and each have comparatively narrow environmental ranges. In contrast true estuarine species often have extremely broad environmental tolerances. Many species are influenced by the oxic status of the sediments, only existing within specific ranges. Reducing environments are often, although not exclusively, associated with anthropogenic impacts and may be dominated by opportunistic species.

3.1.1 Huon Estuary

Salinity ranged between 24 – 35 ppt (Fig. 4). The bottom water salinity declined gradually up the estuary, but was essentially marine as far up as Brabazon Point. Jones et al. (2003) observed a similar pattern in surface salinity, with marine influences dominating the system to approximately 6km southeast of Hospital Bay and the remainder of the estuary, including Port Cygnet, showed normal marine salinity. Jones et al (2003) suggested that there was little tidal exchange in the upper estuary, however our data indicated that the bottom waters were still estuarine well above Egg Islands.

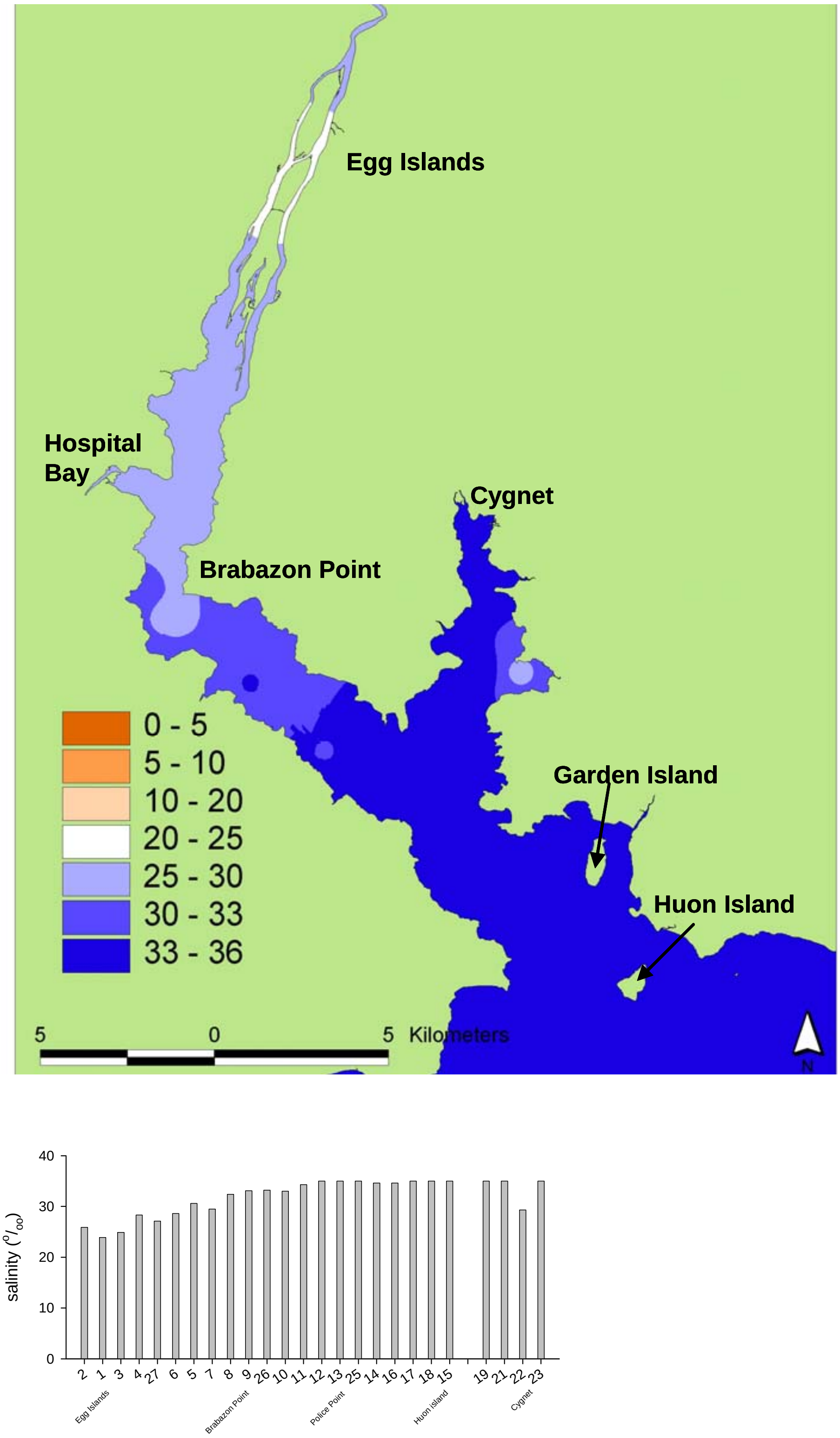


Fig. 4 Salinity ($^{o}/_{oo}$) at sites in the Huon estuary.

Sampling sites were located in a variety of depths, (Fig. 5). Sites in the upper reaches, north of Hospital Bay were very shallow (2m or less), and were flanked by extensive mudflats. Below Hospital Bay the depth increased gradually from 10 to 35m near the mouth of the estuary. At the estuary mouth, there was quite a wide range of depths, the eastern shore being shallower (16m at site 16) whilst to the west of Huon Island site 17 was situated in 42m, at the end of a deep gutter (Fig.2).

Jones et al (2003) characterized the Huon as being predominantly dark carbonaceous silt and clay with clean fine to medium grained sand in the main channels. The sites sampled in this study provided a good representation of all these sediment types (Fig. 6). A large proportion of the sediments were >90% mud, with the majority containing >50% mud. Only sites at the mouth of the estuary and several sites north of Hospital Bay were silty sand (mean particle size - diameter of 0.063 - 0.25 mm). These coarser sediments were generally in areas with either higher current flows or greater levels of exposure. However, the depth of the estuary ensures that on the whole the tidal current velocities are low, which accounts for the dominance of mud and dark organic-rich sediments (Jones et al, 2003).

Total organic carbon content for the Huon sediments was comparable to that reported in the Huon study (CSIRO Huon Estuary Study Team, 2000) and was sufficiently enriched for the system to be mesotrophic (Butler, in press). The highest levels (approximately 8%) were in the upper estuary, north of Brabazon Point and around the mouth of Hospital Bay. Organic content was markedly reduced in all of the sandy sites around Egg Islands. Beyond the elbow at Brabazon Point levels tended to decline, with organic content varying between 4-6% for much of the lower estuary. Organic carbon content was not strongly correlated with grain size (r^2=0.57) which suggests that the levels were influenced by more than just the depositional nature of the environment. The higher levels in the area around Hospital Bay probably reflect wood fibre accumulation from past pulp mill operations. The Huon estuary study also noted increased levels of the terrestrial plant biomarker, sitosterol, in this region and suggested that the pulp mill had had a significant influence on the organic carbon content of the adjacent surface sediments (CSIRO Huon Estuary Study Team, 2000).

Sulphide concentration was on the whole low throughout the system (<30 µM) which suggests that although the total organic content was relatively high over a large part of the estuary, this material was probably refractory since conditions were not significantly reducing. Levels increased slightly at sites between Hospital Bay (site 4) and Brabazon Point (site 8) and this is likely to again be in response to an accumulation of organic material in the sediments resulting from the wood chip processing plant which operated in the bay between 1962-1991. The effluent discharged from this neutral sulfite semi-chemical mill was reported to have been the cause of the soft, sticky mud which forms the surface sediments in Hospital Bay and for the formation of an anaerobic blanket of hydrogen sulphide on the sediment surface (CSIRO Huon Estuary Study Team, 2000). However, in the current study the reported levels were still well below that considered indicative of any notable impact (Crawford et al., 2002, Macleod et al., 2004) (Fig. 8).

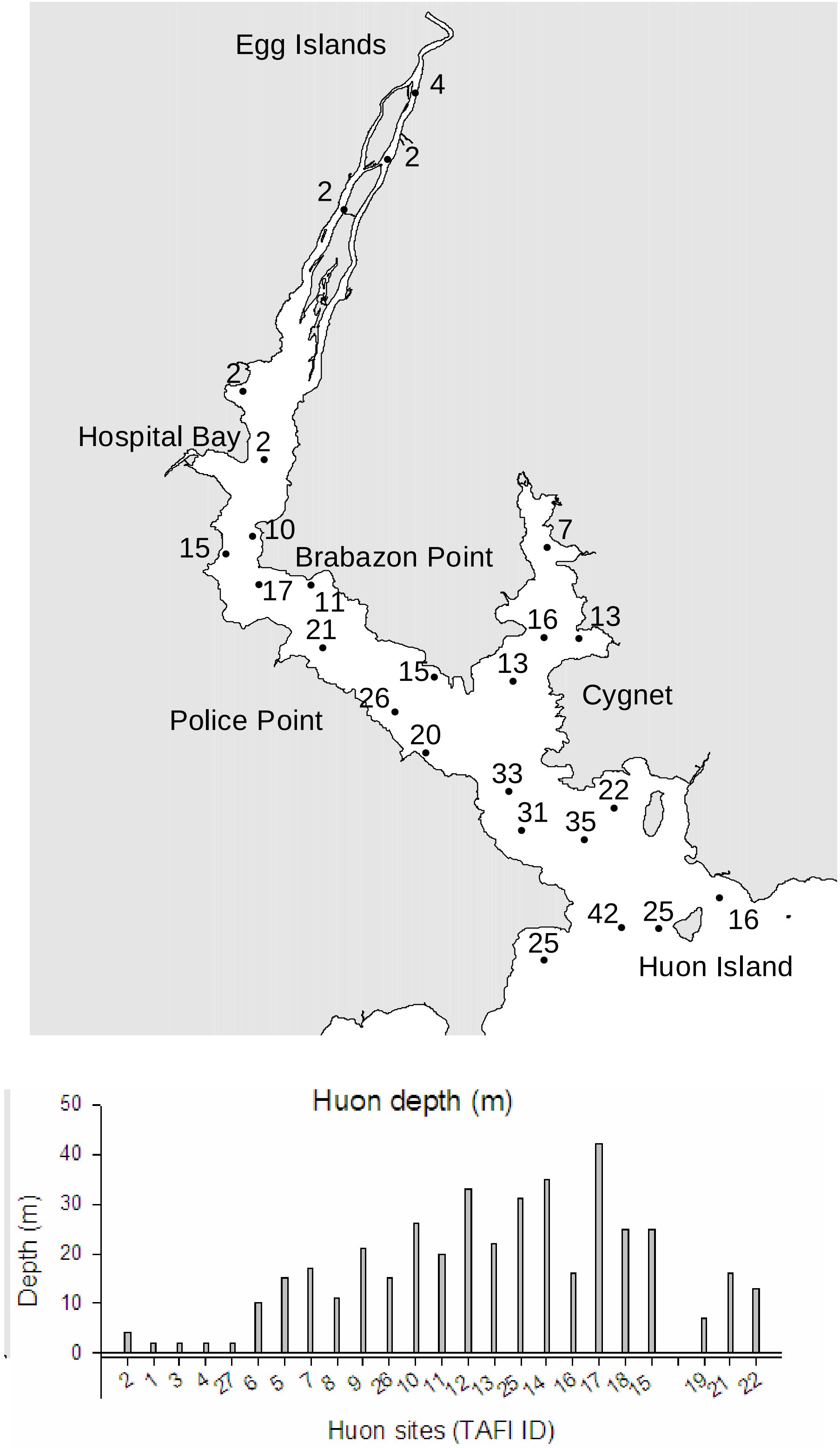


Fig. 5 Depth (m) of sampling positions in Huon estuary.

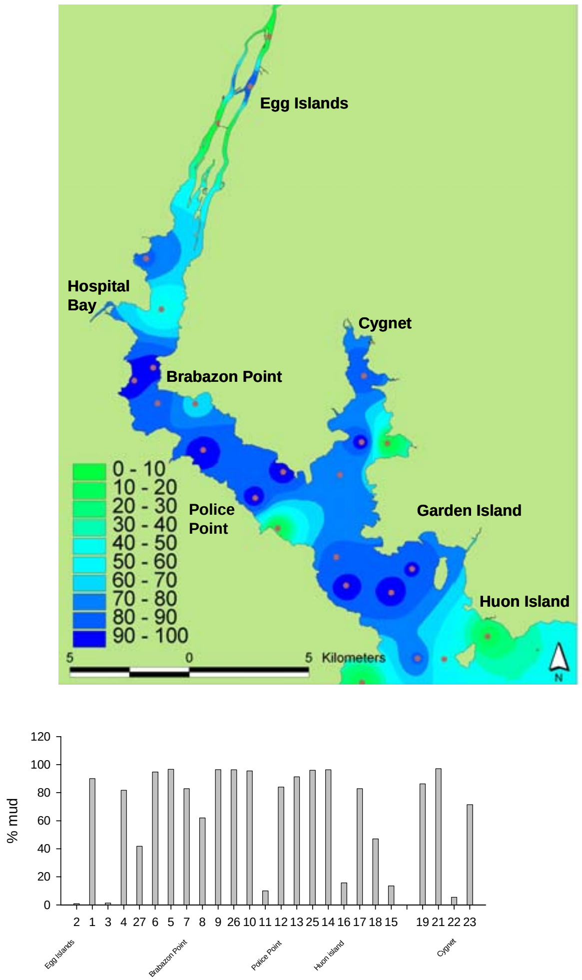


Fig. 6 Percentage silt-clay in sediment at sampling positions in the Huon estuary.

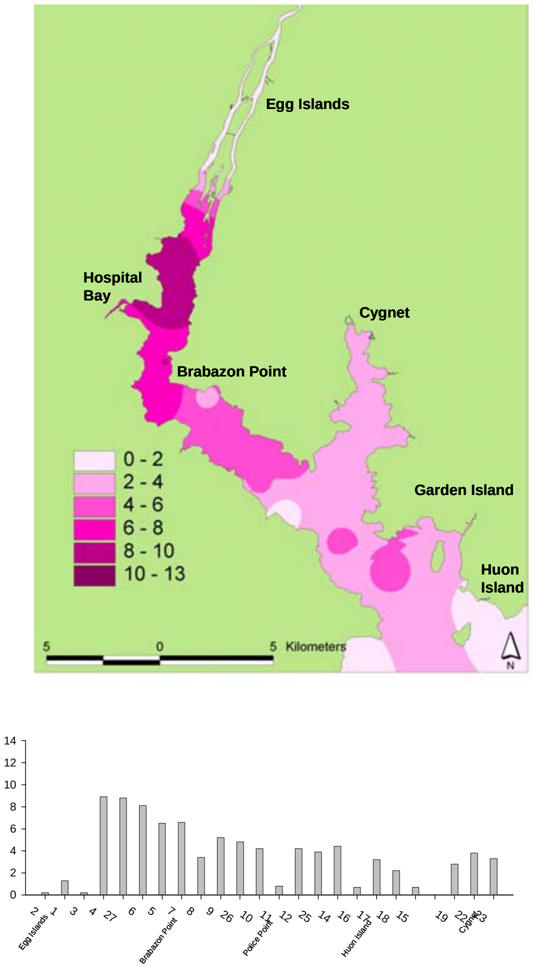


Fig. 7. Percentage total organic carbon content (% w/w DMB) in sediment at sampling positions in the Huon estuary.

Redox levels were consistent with the results for sulphide concentration (Fig. 9). At sites north of Hospital Bay redox levels were consistently well above 100mV. These sites were relatively shallow and the sediment was sandy. The data suggest that the conditions at these sites might be relatively turbulent with wind driven resuspension and oxygenation of the sediments. Below Hospital Bay redox levels generally declined (<100mV), suggesting more reducing conditions and once again consistent with an increase in accumulated organic material from historical wood chipping operations (Butler, in press). Redox level remained low through the mid-estuary, from site 4 to site 14. Levels were particularly low in the area between site 8 and site 10, south of Brabazon Point. This area contains several aquaculture leases and these may be contributing to the reduction in sediment condition. These results appear to be an improvement on the observations of Jones et al. (2003) who found reduced sediments throughout the system, noting particularly low redox values in the upper reaches of the estuary where freshwater influences were greatest.

Metals are generally not biodegradable: the only way to reduce levels in specific areas or avoid accumulation is by removal and/or dispersal by natural environmental mechanisms. These mechanisms can be either biological (i.e. bioturbation/ resuspension) or hydrodynamic (resuspension). Metal concentrations in the sediments of the Huon were generally low. Data from the Huon estuary study was used by Butler (in press) to characterise baseline metal levels for sediments considered to be uncontaminated (Table 2) and the results of the present study were consistent with these findings. No sites were above the high trigger levels specified in the ANZECC guidelines. If we assume, as the data suggests, that the major metal contamination within this system is a result of residual inputs from historic contamination in Hospital Bay then we might expect sites in the vicinity of the Bay to have elevated metal concentrations. Concentrations of copper, arsenic and nickel exceeded low trigger levels in the sediments south of Hospital Bay (Fig. 10). Nickel was elevated in most sites south of Egg Islands but was lower in the bay itself. Arsenic was slightly elevated at sites 5-26 & 23, between Hospital Bay and the entrance to Cygnet Bay as well as at site 14, in the centre of the channel near Garden Island. It is likely that these levels are also a legacy of the wood chipping operations in Hospital Bay, since arsenic is used as a timber preservative and is commonly found in the wastewater streams from Pulp mills. However, arsenic may also be present in agricultural pesticides, herbicides and fertilisers and so may contribute to soil and groundwater contamination. Inorganic arsenic is very toxic to mammals and has been classified as a human carcinogen, however it has not been shown to bioaccumulate to any great extent in aquatic organisms (USEPA, 2000 in Green & Coughanowr, 2003).

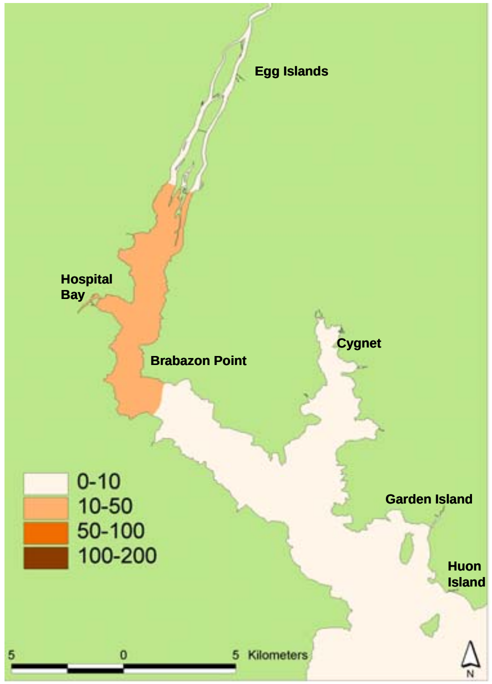


Fig. 8 .0 Sulphide concentration (uM) at sampling positions in the Huon estuary.

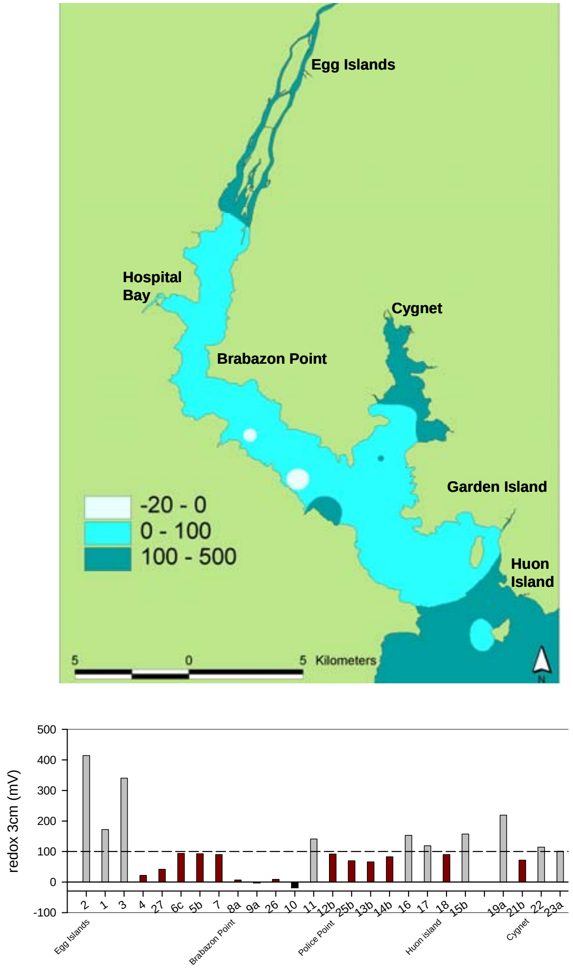


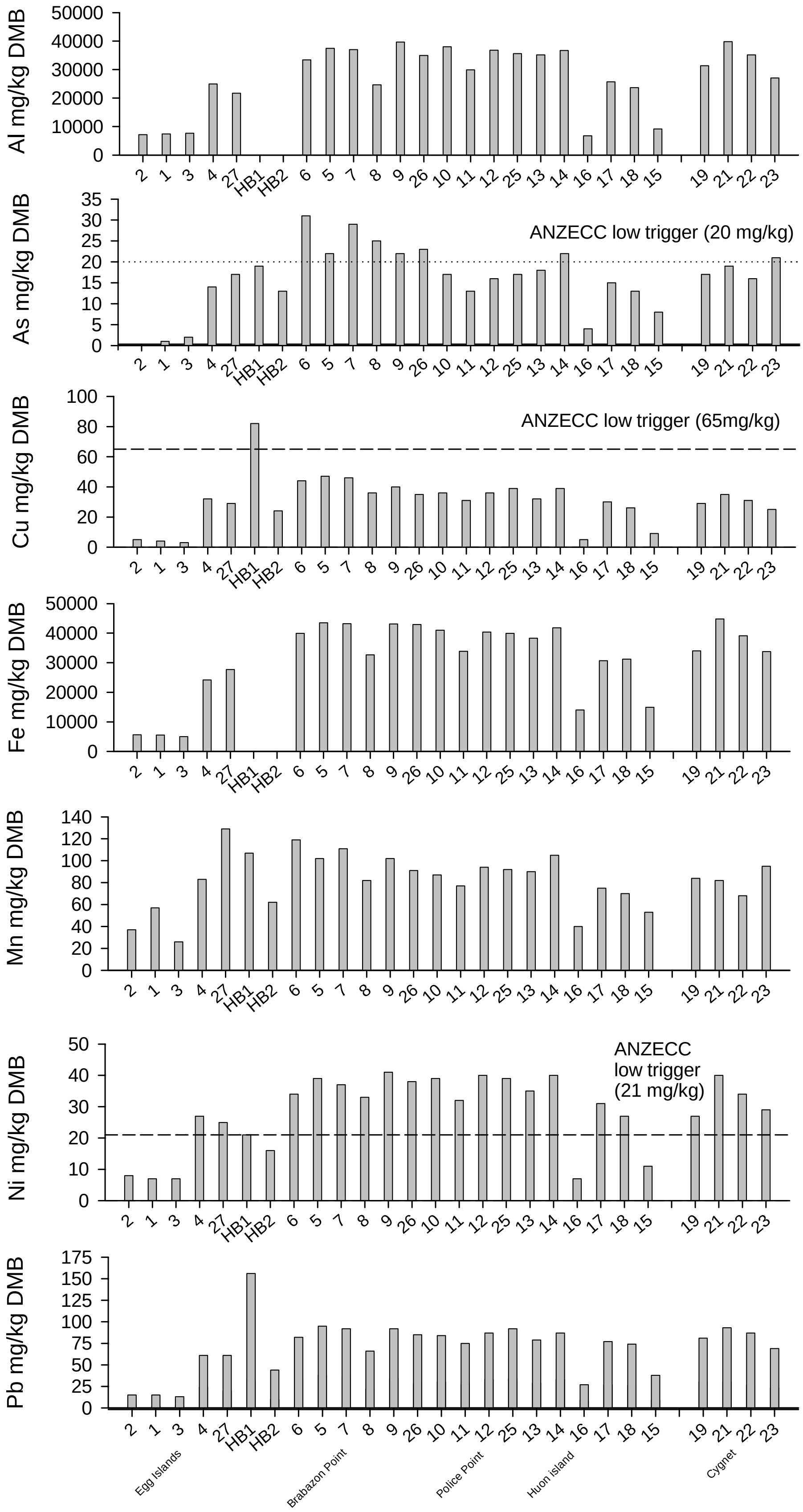
Fig. 9 Redox potential (mV) at sampling positions in the Huon estuary.

Table 2. Baseline values for metal levels (mg/kg DMB) in uncontaminated sediment from the Huon (from Butler, 2006). ANZECC Interim Sediment Quality Guidelines (ISQG) high and low trigger values, (ISQG-high level indicates adverse affect 50% of the time ISQG-low level indicates adverse affects 10% of the time), 'nr' indicates where values are not reported.

	Huon Baseline	**ANZECC guidelines**	
	(Mean values)	Low Trigger	High Trigger
Aluminium	nr	nr	nr
Arsenic	25-28	20	70
Copper	35-47	65	270
Iron	4	nr	nr
Lead	<0.2	50	220
Manganese	87	nr	nr
Mercury	nr	0.15	1
Nickel	21-28	21	52
Zinc	20-30	200	410

Copper was above the low trigger levels at a single site in Hospital Bay. Most of the literature on the effects of Cu on the biota has focused on levels in the ambient seawater with little information on the effects on sediment organisms. The toxicity of Cu is a function of its speciation, in organically rich environments Cu may bind with organic ligands and therefore be biologically unavailable (Harrison et al., 1987). The release of Cu is significantly more pronounced in oxidizing than reducing environments and was slightly more pronounced in coarser sediments (Lu and Chen, 1977). Consequently Cu accumulated in fine, anaerobic sediments is less likely to be biologically available/toxic than equivalent levels in coarser aerobic, sediments. However, there is a lack of information on the relative toxicity of different Cu species/complexes. Although Zinc did not exceed trigger levels it was substantially increased in Hospital Bay, once again probably associated with historic discharges from the woodchip mill.

Sites (1-3) in the upper estuary, north of Crowthers Bay around Egg Islands had consistently low metal levels. Flow and sediment characteristics suggest that this area is probably erosional rather than depositional and this in conjunction with the upstream location of these sites explains the low metals levels. However, elevated metals levels at site 4, which is also upstream of Hospital Bay (almost 2.5 km north), suggest that there may be upward as well as downward distribution of contaminants.


Al mg/kg DMB
As mg/kg DMB
ANZECC low trigger (20 mg/kg)
Cu mg/kg DMB
ANZECC low trigger (65mg/kg)
Fe mg/kg DMB
Mn mg/kg DMB
Ni mg/kg DMB
ANZECC
low trigger
(21 mg/kg)
Pb mg/kg DMB
2 1 3 4 27 HB1 HB2 6 5 7 8 9 26 10 11 12 25 13 14 16 17 18 15 19 21 22 23
Egg Islands
Brabazon Point
Police Point
Huon island
Cygnet

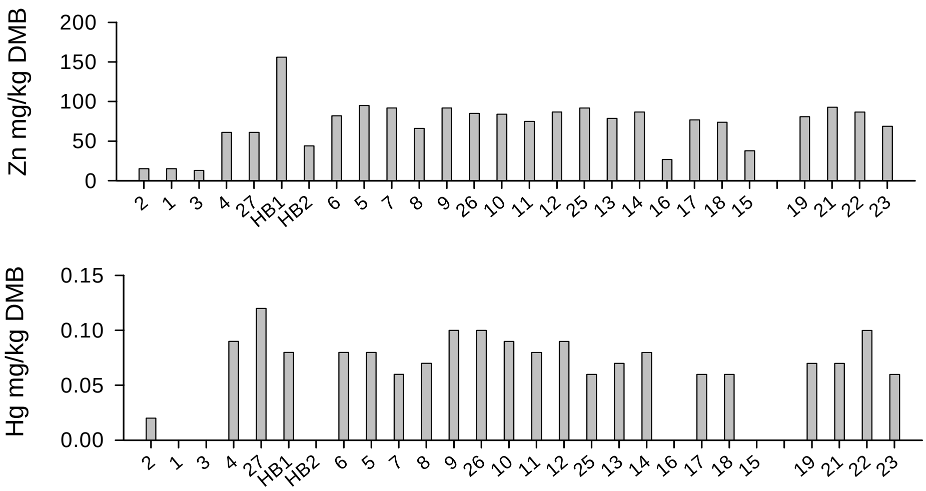


Fig. 10. Concentration of metals in the sediments at the sampling positions in the Huon estuary. ANZECC low trigger levels indicated where levels exceeded the trigger value.

3.1.2 Derwent Estuary

Water depth can affect the benthic infaunal community in several ways. Clearly light penetration will be greater in shallow waters, and will influence the extent of seagrass, algal and microphytobenthos colonisation which in turn will have a direct effect on the types of organisms that occur. In deeper waters reduced light penetration may lessen the efficacy of visual predation as a nutritional strategy and will therefore once again have an effect on the system ecology. Deeper waters are often depositional and as such provide habitats for suspension and surface deposit feeders. Very shallow waters can be subject to wind driven resuspension of sediments which in turn reduces both the sediment stability and light penetration as a result of increasing turbidity. This will have both direct and indirect affects on the community structure, unstable sediments are not condusive to the settlement of sessile organisms or epibenthic suspension/ filter feeders and reduced light levels will, as already described, limit feeding strategies. Temperature can also be a significant ecological constraint in shallow waters, particularly in areas such as mudflats which may be subject to intertidal exposure and therefore potentially quite high /low temperatures.

In the Derwent the sampled sites cover a range of depths from <1m to >50m (Fig.11). The shallowest sites tended to be in the upper estuary, around the margins and in Ralphs Bay. Sites in Ralphs Bay were mostly shallow, ranging between 0-10m, and many of the inshore sites may be subject to wind driven sediment resuspension. The deepest site in the survey (site 79 at 54m) was located off Rosny Point, between the Tasman bridge and the mouth of Ralphs Bay. Bathymetric information shows clearly a deeper channel tracking down centre of the estuary (Fig.2). Generally the lower estuary (below Tasman Bridge) ranged between 15-25m, whilst the upper estuary (above Tasman bridge) was generally <10m. The area around the Zinifex wharf is relatively shallow between 5-10m.

The salinity profile obtained for the Derwent is fairly typical of a salt wedge estuary (Fig. 12). Previous studies have shown that the salt-wedge extends as far as New Norfolk (Green and Coughanowr, 2003); Butler, in press). Salinity was generally above 30 ppt, with most of the sampling sites in the main estuary (below the Tasman Bridge) classified as marine (>34 ppt). However, in the current study salinity dropped markedly from 30 to 15 ppt north of Dogshear Point (i.e above site 55) over a distance of only 1500m, salinity subsequently decreased steadily over the next 7 km stretch. Previous studies have suggested that Ralphs Bay is unaffected by freshwater flows (Edgar et al., 1999a). However, the current data suggest that the salinity in Ralphs Bay was comparable to elsewhere in the estuary. Sampling was undertaken during a period of relatively high rainfall, November 2004 had the second highest monthly rainfall for the year (54.1mm; www.bom.au).

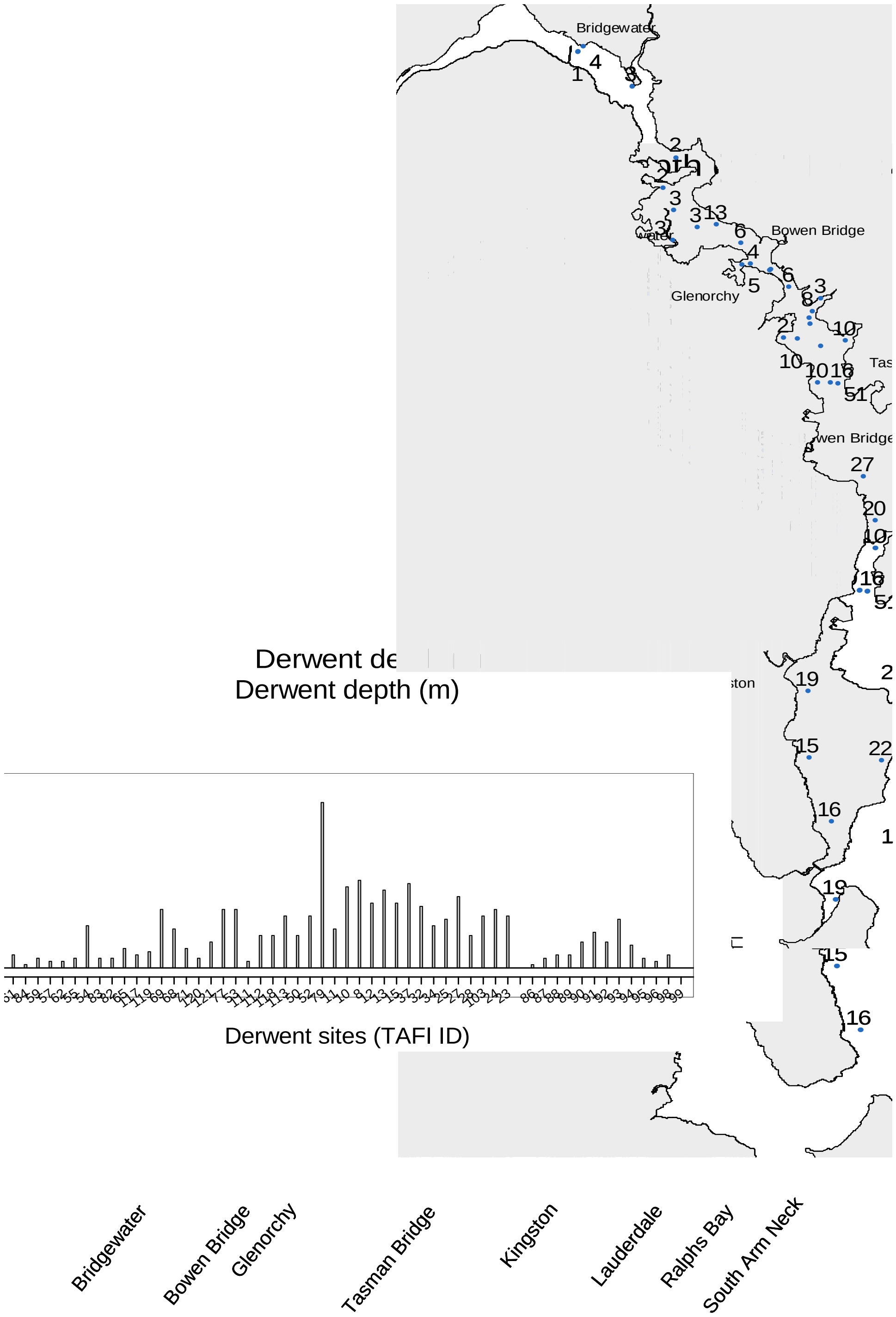


Fig. 11 Depth of sampling positions in Derwent estuary.

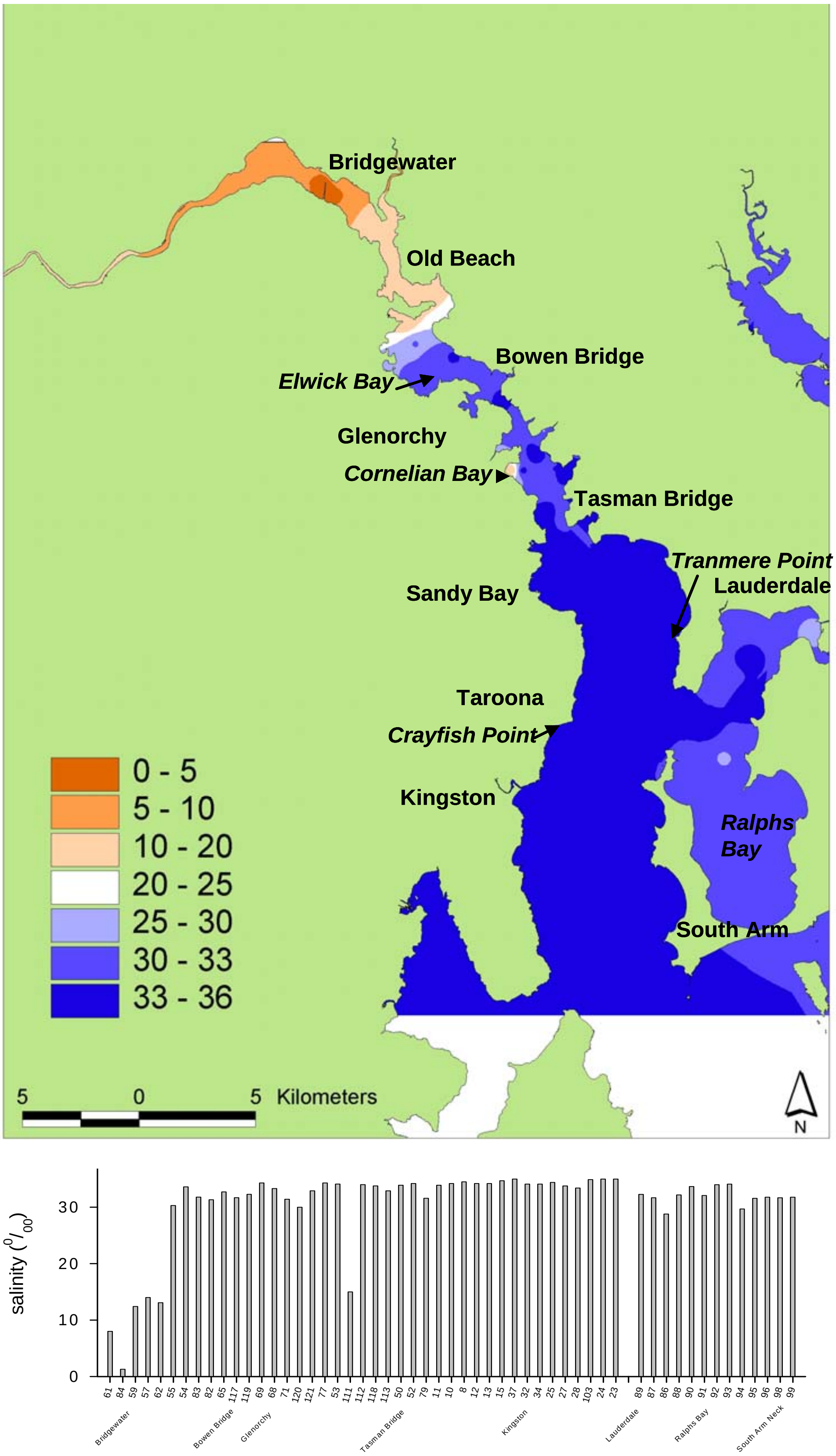


Fig. 12 Salinity ($^{o}/_{oo}$) at sites in the Derwent estuary.

Most of the Derwent is unvegetated and 99% of the substrata can be classified as soft sediments (sand, silty sand, and mud). There is very little reef or other rocky habitat (Jordan et al., 2003). However, there are large differences in the type of soft sediment throughout the upper, mid and lower reaches of the estuary (Jordan et al., 2003). Sediment composition is one of the most important factors controlling community composition in unconsolidated sediments (Snelgrove & Butman, 1994, Hall, 1994).

Jordan et al. (2003) indicated the seabed in the middle Derwent was dominated by silt, with sand occurring in the shallower regions close to shore, particularly along the eastern shore. The hydrography of the system promotes increased downstream water movement along the eastern shore of the estuary which may increase the proportion of sand in the sediments and an associated "Coriolis effect" which may be responsible for the increased deposition of silt in the mid-estuary (Butler, in press). The data from the present study suggest that the estuary can be differentiated both along (north/south) and across (east/west) the estuary based on the proportion of mud in the sediments (Fig. 13). The sediments between Bridgewater and the mouth of Ralph's Bay were predominantly mud (Fig. 13), with the finest sediments towards the centre of the estuary. Along the margins on the eastern shore south of the Tasman Bridge, within Ralphs Bay and to the south of this the proportion of mud in the sediments declined rapidly (from >90% to <50% mud), with sites in these areas more appropriately classed as sand (<50% mud). Sediment composition is strongly correlated with current flow (Snelgrove & Butman, 1994). These sandy sites encompassed a variety of different depths. There is a shoaling effect at the mouth of the estuary due to an accumulation of coarse sand and shell debris resulting from tidal and wave action.

Total organic carbon content in the Derwent was extremely high at several sites, notably sites 54 and 83, towards the eastern shore opposite Elwick Bay, where levels were in excess of 10% (Fig. 15). For the bulk of the upper estuary levels were high, greater than 6%. Just north of the Tasman bridge the levels generally dropped to approximately 4% and remained at this level through to site 37 (opposite the entrance to Ralphs Bay). However, within this section there was a single significant anomaly, site 79, where the sediments had markedly increased organic carbon content (8.9%). This site is located off Rosny Point and adjacent to one of the larger sewage treatment plants on the estuary and suggests that there may be an accumulation of organic material from the sewage treatment operations, which may in turn have a localised affect on the infaunal community structure. Ralphs Bay and all sites south of the entrance to Ralphs Bay, with the exception of site 92, had noticeably reduced organic carbon levels (<2%). Site 92 was in the central region of Ralphs Bay and the carbon level was comparable to that of the lower mid-Derwent (~4%). There is no obvious reason why this site should be greater than the other sites in Ralphs Bay and this finding may be anomalous, a result of an isolated accumulation of organic debris such as seaweed.

In the Derwent the organic carbon levels were relatively well correlated with sediment type ($r2=0.73$), with the highest levels associated with the areas of finest sediments. The greatest input of organic material to this system is likely to come from the paper mill at Boyer. This is located above the area sampled in this study and therefore is not possible to partition the relative contributions from natural and anthropogenic sources.

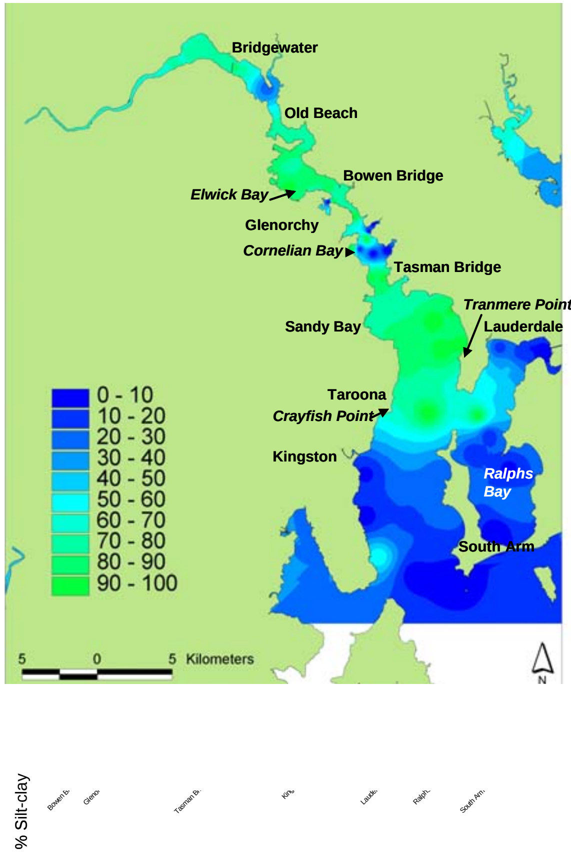


Fig. 13. Percentage silt-clay in the sediment at sampling positions in the Derwent estuary.

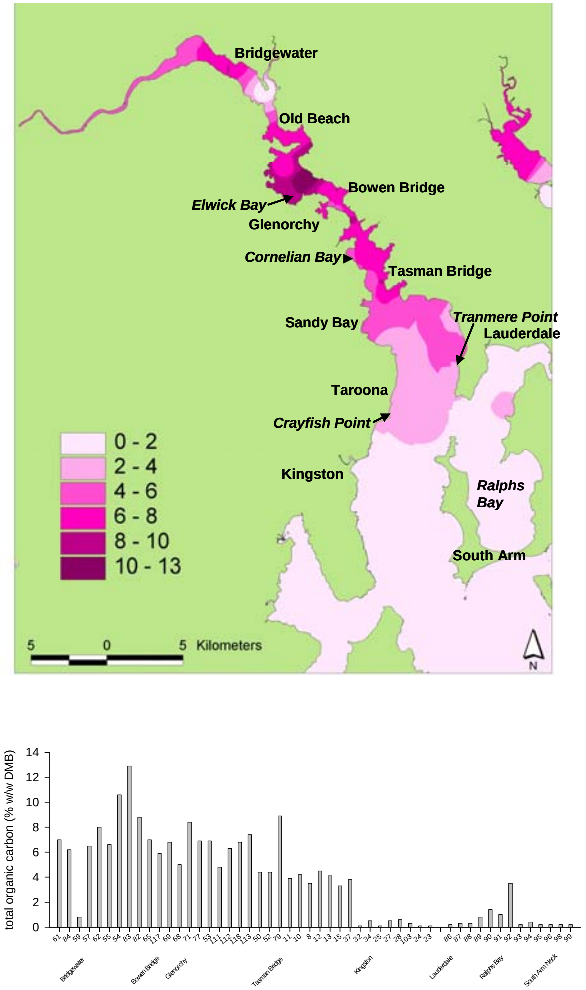


Fig. 14. Percentage total organic carbon content (% w/w DMB) in sediment at sampling positions in the Derwent estuary.

Although redox potential was variable throughout the estuary there were several areas where redox levels were generally reduced (<100mV). Most of the sites in the upper estuary, between Bridgewater and Selfs Point, had low redox potential, and for the greater proportion of sites a moderate impact was indicated. This result is consistent with the findings for organic content of the sites (Fig. 14). Sites 84, 59, 65, 117 and 69 were particularly low, possibly indicative of reducing sediment conditions. The oxic status of the sediments will have a significant effect on the biological composition. When the oxygen environment deteriorates markedly, even if only for a short period, many of the normal community species will be unable to survive and they may be replaced by other species more tolerant of low oxygen conditions if conditions persist. The Norske Skog pulp mill at Boyer still emits effluent with a relatively high organic content into the Derwent. The total suspended solids discharged in 2002 were 1,095 tonnes, with 40 tonnes of resin acids and a biological oxygen demand of 8,980 tonnes (Green and Coughanowr, 2003). The depositional nature of many of the upper estuary sites would mean that most of these sites are likely to experience some level of organic enrichment as a result of the pulp mill.

In the lower reaches of the estuary, below Tranmere (site 13, Fig. 3), redox levels were high, although a few sites (86, 87, 88 and 98) in the shallower areas of Ralphs Bay had redox potential <100mV. These sites are shallow and may be subject to some relatively severe environmental conditions, particularly at low tide when the reduced water depth can result in increases in temperature and/or periods of low tidal mixing or sediment disturbance due to wind/wave action. Site 86 was occasionally completely exposed at low tide. However, no sites showed negative redox levels.

The highest sulphide values (> 50 μM) were found in the upper Derwent, north of the Bowen Bridge (Fig.16) and occurred at sites where redox was also low (Fig.15) and organic content high (Fig.14). Based on previous studies characterising sediment conditions associated with organic enrichment, this combination of high sulphide, low redox and increased organic content is indicative of an area of organic enrichment (Wildish et al., 1999), Macleod et al., 2004). Increasing organic material to levels above that which the natural community can assimilate will result in a deterioration in environmental conditions including a reduction in available oxygen and an increase in sediment sulphide levels which will in turn affect the faunal composition (Macleod et al., 2004). However, the overall correlation between redox, sulphide and organic content was poor. The best correlation being between redox and organic content at only r^2=0.48. This may have been due to the considerable variability in low impact areas, where the results are probably confounded by the effects of substrate type, hydrographic differences and other contaminants.

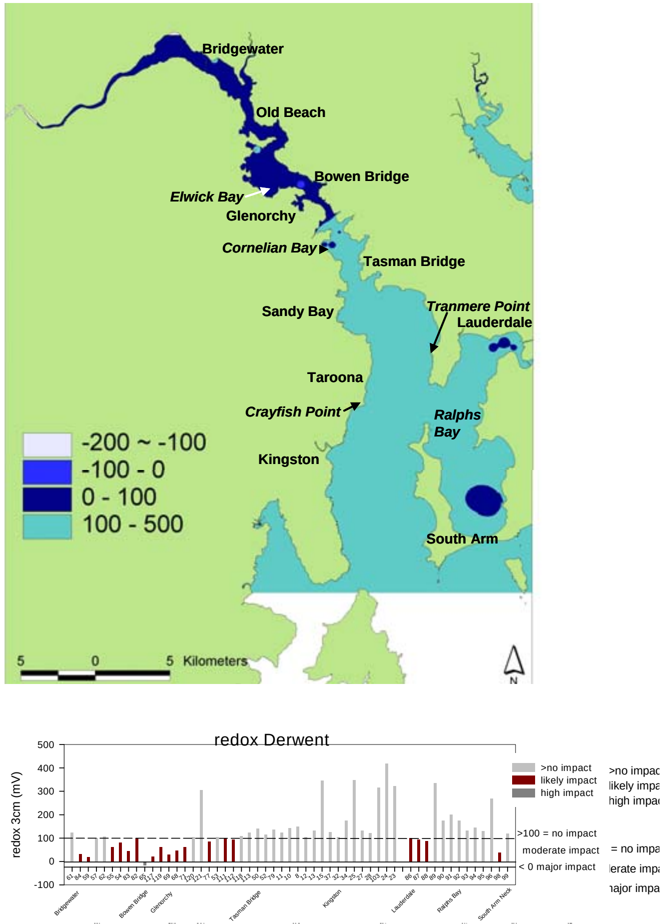


Fig. 15 Redox potential (mV) at sampling positions in the Derwent estuary.

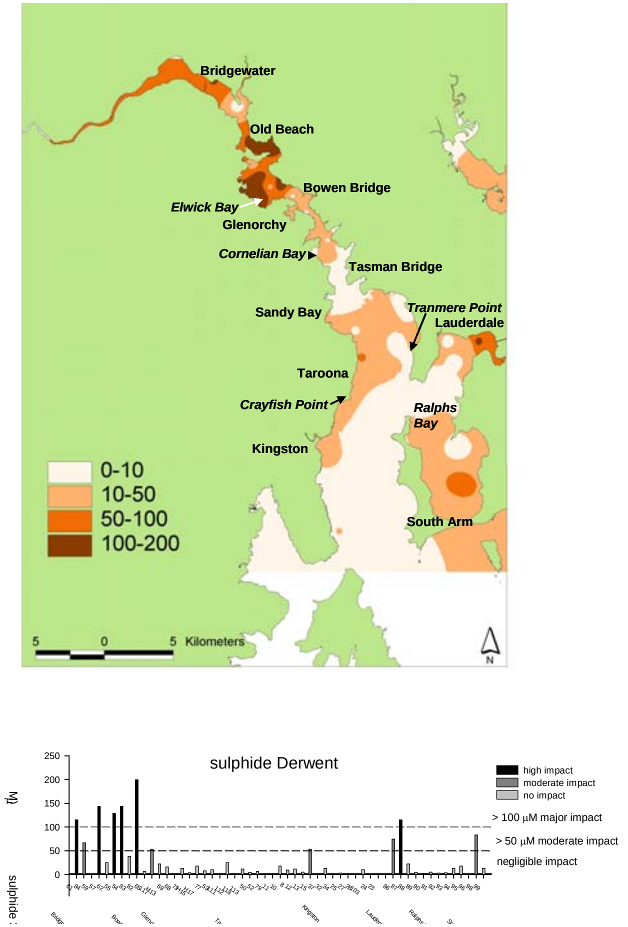


Fig. 16. Sulphide concentration (uM) at sampling positions in the Derwent estuary

Heavy metal distribution:

The Derwent is known to be severely degraded by point sources of pollution arising from industrialized developments, leading to high heavy metal contamination. Several trace metals (Zn, Pb, Cd, Cu, Hg and the metalloid Arsenic) have been reported to be at levels considerably above that defined as maximum trigger values in the ANZECC guidelines (Green and Coughanowr, 2003, Jones et al., 2003, ANZECC, 2000, Jordan et al., 2003). Sediment long cores (representing a time span of approximately 100 years) clearly show the point at which a sudden and simultaneous increase in zinc, lead, cadmium, copper and the metaloid arsenic in excess of the ANZECC high trigger values occurred, indicating the onset of anthropogenic inputs (Jordan et al., 2003). The Zinifex zinc refinery has historically been a major source of metals contamination. Little is known about the biological ramifications of heavy metal contamination on such a large scale. The toxic effects on humans of many metals are well known and of particular concern as regards the contamination in the Derwent. Several studies have been focused on this area. The metals identified as having the greatest potential toxicity to humans via ingestion of contaminated fish and shellfish are mercury, arsenic and cadmium (USEPA, 2000 in Green & Coughanowr, 2003). The toxicological effects of metals in the water column are also quite well described (Rainbow et al., 2004, Fichet et al., 1999, Adamo et al., In Press, Eggleton and Thomas, 2004, Hatje et al., 2001). However, little is known about the impact of metal contamination on the associated sediment ecology in Tasmania.

Contaminant distribution is inversely related to tidal-flow velocities and is most prominent in lower energy muddy substrates (Cave et al., 2005). Previous studies have shown that metals from the refinery generally tend to be distributed downstream by a combination of fluvial and tidal activity (Coughanowr, 2003). During dry periods, contaminants may be carried upstream however significant upstream contamination is limited by the remobilisation of these sediments during flood periods (Coughanowr, 2003). The bottom currents in the mid to lower Derwent are generally slow (0.02 – 0.05 m/sec) (Coughanowr, 2003) consequently it might be expected that a large proportion of the metals would be retained in these sediments. Trace-metal levels in the more recent surficial aquatic sediments are slightly lower than those recorded in previous studies from the area (Jones, et al., 2003, Jordan et al, 2003), suggesting that conditions may be improving, possibly reflecting the stricter environmental controls now operating.

Interim sediment quality guidelines (ISQG) can be used as a surrogate indicator of possible ecological effects associated with contaminant level (ANZECC, 2000). Low and high trigger values correspond to the low and median effects levels identified in the US National Ocean and Atmospheric Administration (NOAA) listing. Trigger values represent a statistical probability that biotic change will eventuate; low trigger values indicate a 10% probability and high trigger values indicate a 50% probability of effect. The sites exceeding the high trigger levels were all located in the vicinity of the Zinifex wharf, and suggest a gradient of impact out from this position. High levels for arsenic were restricted to 5 sites near the Zinifex wharf (site 68, 69, 117, 65, 71) (Fig. 17). Copper levels in excess of the high trigger value were present at 6 sites with slightly increased distance from the wharf (site 68, 69, 117, 65, 71, 53) (Fig. 17). Cadmium was above the high trigger level at a further 16 sites from a large area of the upper and mid estuary, between the Tasman Bridge and just south of Bridgewater. Finally, levels of lead, zinc and mercury were elevated immediately adjacent to the wharf as well as to the north as far as Dogshear Point and to the south well in to the entrance to Ralphs Bay (Fig. 17).

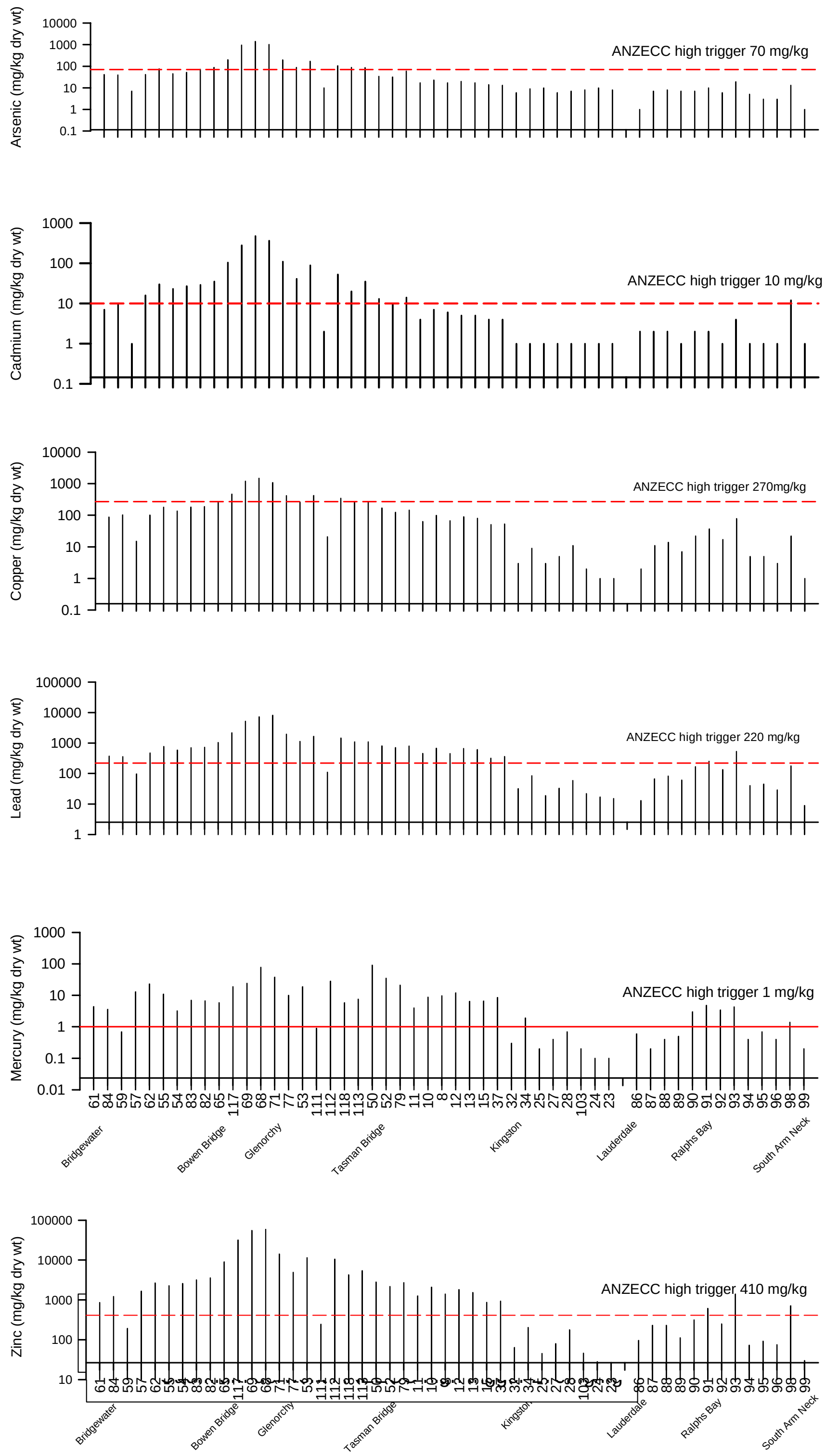


Fig. 17 Distribution of a) Lead (Pb), b) Cadmium (Cd), c) Copper (Cu), d) Arsenic (As) e) Zinc (Zn) and f) Mercury throughout the Derwent. High ISQG trigger values are indicated on the bar charts in red. (Data courtesy of (DPIWE-DEP).

These individual plots can be combined to reflect the collective effects of metals within the system (Fig. 18). This clearly shows the geographic extent of the total metal contamination. The region between Dogshear Point and the Tasman Bridge is extremely contaminated, high levels of contamination extend upwards to Gagebrook/Old Beach and south into the mouth of Ralphs Bay whilst most of the shallow regions of Ralphs Bay, the remaining areas in the upper estuary and the lower estuary as far south as Taroona remained moderately contaminated. Only a few of the deeper sites in Ralphs Bay and the lowest part of the estuary, south of Kingston appear relatively unaffected by metals.

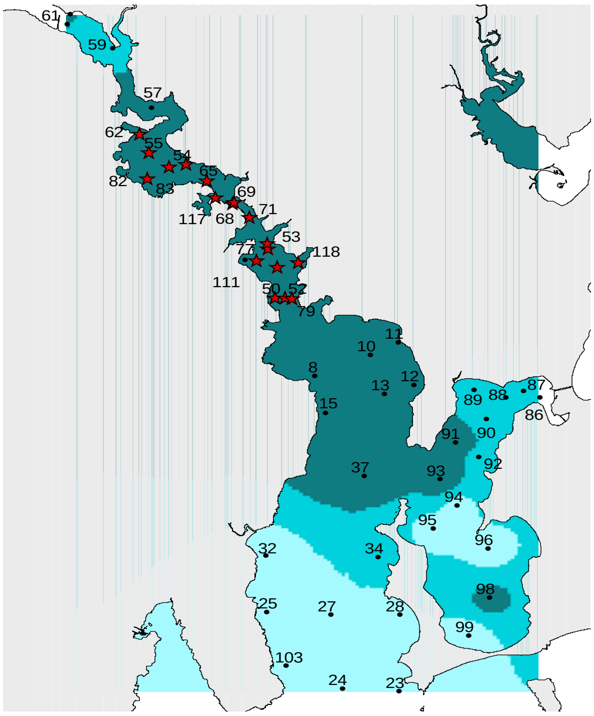


Fig. 18. Cumulative metal characterisation. Red sites indicate sites where all metal concentrations were above high trigger. Dark green is where Zn, Hg & Pb concentrations were above high trigger, Mid-green is where Zn, Hg & Pb were between low and high trigger, light green is where the concentration of all metals were below low trigger (metals levels as total concentration).

All of the metals were highly intercorrelated with the exception of Al and the metalloid Ca (Table 3). Calcium was poorly correlated with other metals; its strongest relationships were with Fe, Mn and Al (r = 0.57, 0.56 and 0.51 respectively), all metals which can occur naturally at relatively high levels. Although the concentration of aluminium still shows a relationship with the other metals (>0.59) the reduced correlation co-efficients suggest that this metal may be influenced by other factors.

Table 3. Correlation between log transformed metals for full data set (correlations greater than 0.75 shown in red).

	log Al	log As	log Cd	log Cu	log Fe	log Mn	log Pb	log Zn	log Hg
log Al									
log As	0.65								
log Cd	0.59	0.97							
log Cu	0.75	0.91	0.91						
log Fe	0.92	0.82	0.75	0.89					
log Mn	0.79	0.92	0.87	0.89	0.93				
log Pb	0.74	0.90	0.89	0.99	0.89	0.90			
log Zn	0.71	0.92	0.93	0.99	0.86	0.90	0.99		
log Hg	0.72	0.78	0.79	0.88	0.82	0.83	0.89	0.89	
log Ca	0.51	0.33	0.19	0.25	0.57	0.56	0.29	0.25	0.33

Al and Fe were weakly correlated with % mud (r = 0.51, 0.69 respectively) reflecting the depositional capacity of the areas, with concentrations tending to decline with increasing sediment particle size (Table 4). None of the other abiotic metrics measured showed any clear relationship with metals concentrations.

Table 4. Correlation between all abiotic factors (metals data log transformed)

	Sulphide	Redox	Salinity	Depth	%silt/clay	Org C	Al	As	Cu	Fe	Mn	Ni	Pb	Zn
Redox	-0.294													
Salinity	-0.386	-0.324												
Depth	-0.343	-0.327	0.747											
%silt/clay	0.207	-0.603	0.235	0.285										
Org C	0.812	-0.635	-0.143	-0.100	0.573									
Al	0.202	-0.690	0.413	0.407	0.623	0.625								
As	0.314	-0.796	0.475	0.377	0.558	0.658	0.890							
Cu	0.335	-0.743	0.410	0.397	0.608	0.697	0.970	0.923						
Fe	0.196	-0.769	0.563	0.489	0.549	0.589	0.943	0.949	0.961					
Mn	0.516	-0.760	0.289	0.255	0.709	0.786	0.850	0.848	0.900	0.852				
Ni	0.221	-0.728	0.447	0.457	0.607	0.623	0.989	0.901	0.984	0.953	0.859			
Pb	0.234	-0.731	0.561	0.490	0.551	0.614	0.939	0.932	0.967	0.990	0.844	0.948		
Zn	0.196	-0.747	0.559	0.503	0.558	0.593	0.955	0.940	0.971	0.993	0.854	0.963	0.992	
Hg	0.415	-0.680	0.188	0.150	0.443	0.731	0.873	0.757	0.872	0.815	0.811	0.875	0.809	0.819

The metals were quite strongly autocorrelated. The strongest relationship between the metal enrichment levels and other abiotic factors was with redox level although organic content and sediment grain size showed a similar response (Table 4). The highest metal levels were in the vicinity of Hospital Bay and are likely associated with historic outputs from the pulp mill, which was adding both organic and metal contaminants to the system whilst in operation. Organic carbon content has been shown in several studies to be strongly related to grain size and the depositional character of the system (CSIRO, 2000). Similarly many metals bind with organic lignands rendering them biologically unavailable and therefore would be strongly correlated with both the organic content and sediment structure (Di Toro et al., 1992). In the current study both organic carbon content and metal enrichment were lower in sandy sediments.

3.2 Ecological Status of the Huon Estuary

3.2.1 Biota data

Information on the benthic ecology of the Huon is limited. There is some biological information available through environmental impact assessments (EIAs) required as a component of the compliance monitoring conditions imposed on the salmonid aquaculture industry (Woods et al., 2004). However, these surveys were largely limited to the area immediately surrounding aquaculture leases in the mid-lower estuary, and so were restricted to the range of environmental conditions (i.e. flow & depth regimes) condusive to fish farming. Edgar et al., (2005) presents a summary of the baseline aquaculture information from southern Tasmania as a whole and this included some details for the Huon. Biological information from both the Huon and Derwent estuaries was included in a study characterising the conservation significance of Tasmanian estuaries (Edgar et al., (Edgar et al., 1999b). This study determined that there was a high level of invertebrate diversity in the Huon system, and the Huon was subsequently categorized as a class C estuary with moderate conservation significance. However, the infaunal community information in this study was limited; it was obtained from only 3 sites at Brabazon Point, Cradoc and Eggs and Bacon Bay.

The present study sampled a total of 25 sites throughout the Huon for biological evaluation, from the northern tip of Egg Islands down to Huon Island at the estuary mouth. Infaunal diversity fluctuated markedly over the length of the system, although overall the Shannon diversity index levels were comparatively high, generally above 2.0, suggesting that the communities were relatively undisturbed (Macleod et al., 2004). Comparison of the different "a priori" defined zones within the system (see section 2.1.1.) indicates that there were significant differences in species richness ($F=17.208$, $df= 26,3$, $p<0.001$) and diversity ($F=16.601$, $df= 26,3$, $p<0.001$). However, the total number of individuals did not vary significantly between zones ($F=2.764$, $df= 26,3$, $p=0.062$). There was a significant reduction in diversity in upper estuary compared with the other zones whilst diversity at the estuary mouth was significantly increased (Fig. 19). The reduction in diversity in the upper estuary was particularly evident around Egg Islands, where the number of individuals and taxa were markedly reduced (Fig. 20). This area was in the uppermost reaches of the estuary and relatively shallow and therefore will be subject to greater environmental extremes of both temperature and salinity, major limiting factors for the associated fauna (Snelgrove and Butman, 1994). Sites near the mouth of the estuary, around Redcliffs and Huon Island, had both a highly diverse and abundant fauna, which is consistent with the findings of Edgar et al. (1999a,b).

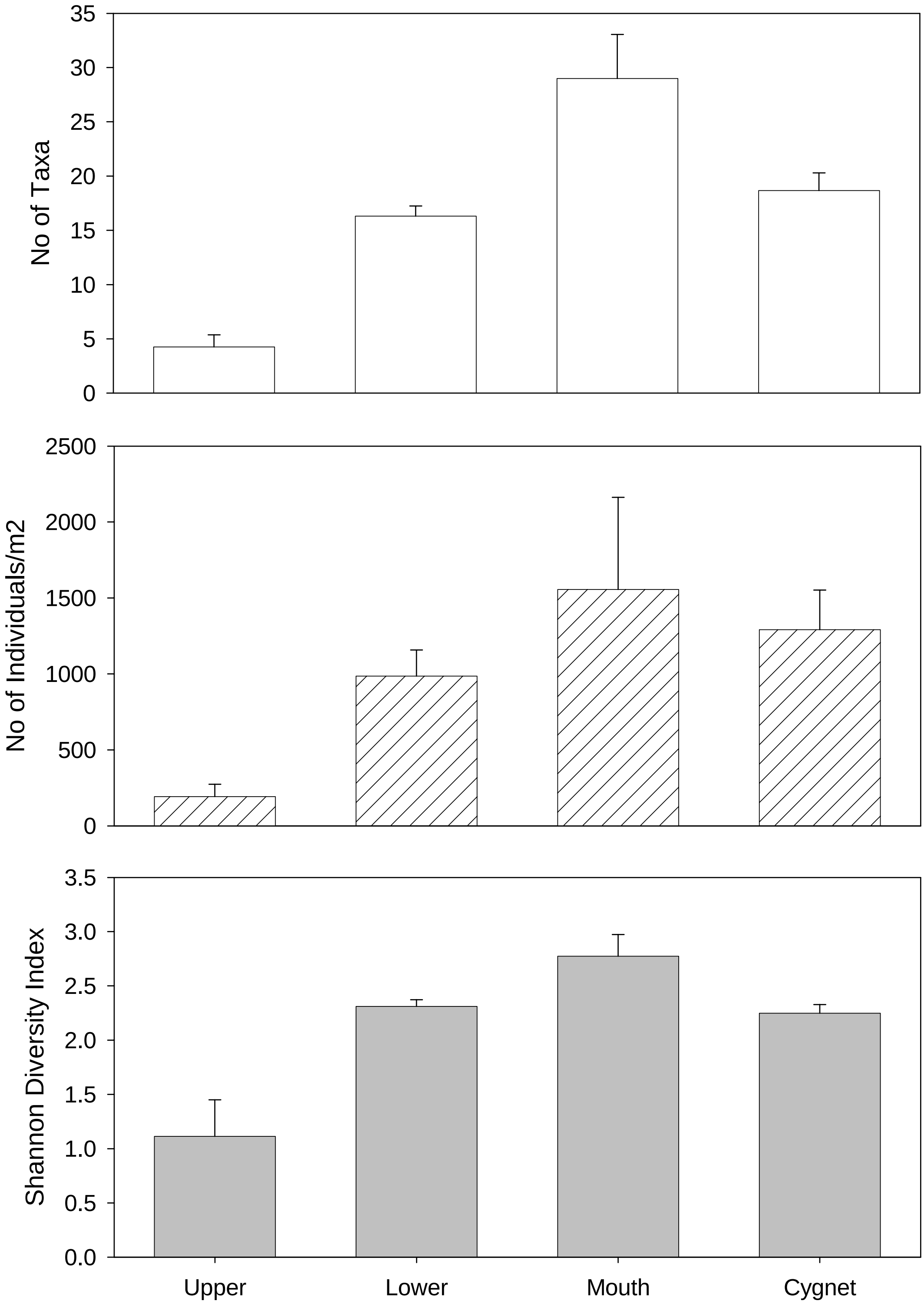


Fig. 19. Biotic indices for the Huon

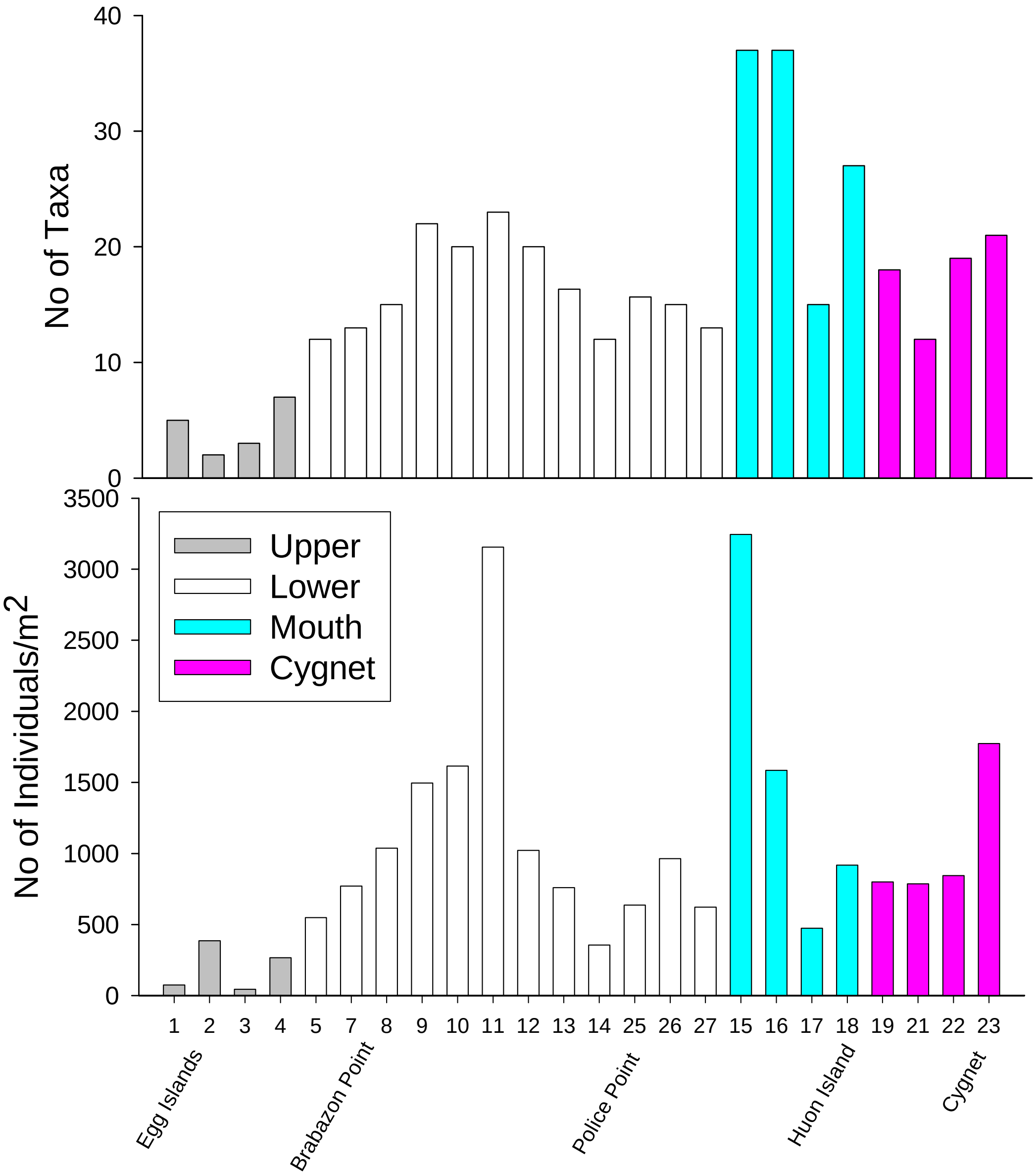


Fig. 20 Biotic indices at all sites in the Huon

ANOSIM analysis of the sites similarities based on the "a priori" defined zones shows that there were significant differences between the upper estuary and all other zones and between the mouth and Cygnet, but that the community in the lower estuary and Cygnet Bay were similar (Table 5).

Table 5. ANOSIM significance levels of zones in the Huon

Comparison	R statistic	Significance (p)
Upper, Lower	0.886	0.003
Upper, Mouth	0.500	0.029
Upper, Cygnet	0.604	0.029
Lower, Mouth	0.498	0.008
Lower, Cygnet	-0.023	0.486
Mouth, Cygnet	0.667	0.029

Cluster analysis of the benthic community data allows us to see more clearly the relationships between the individual sites in each zone (Fig. 21). The sites in the upper estuary were all highly dissimilar and the cluster groups suggest that the boundaries of the zones were not clearly defined.

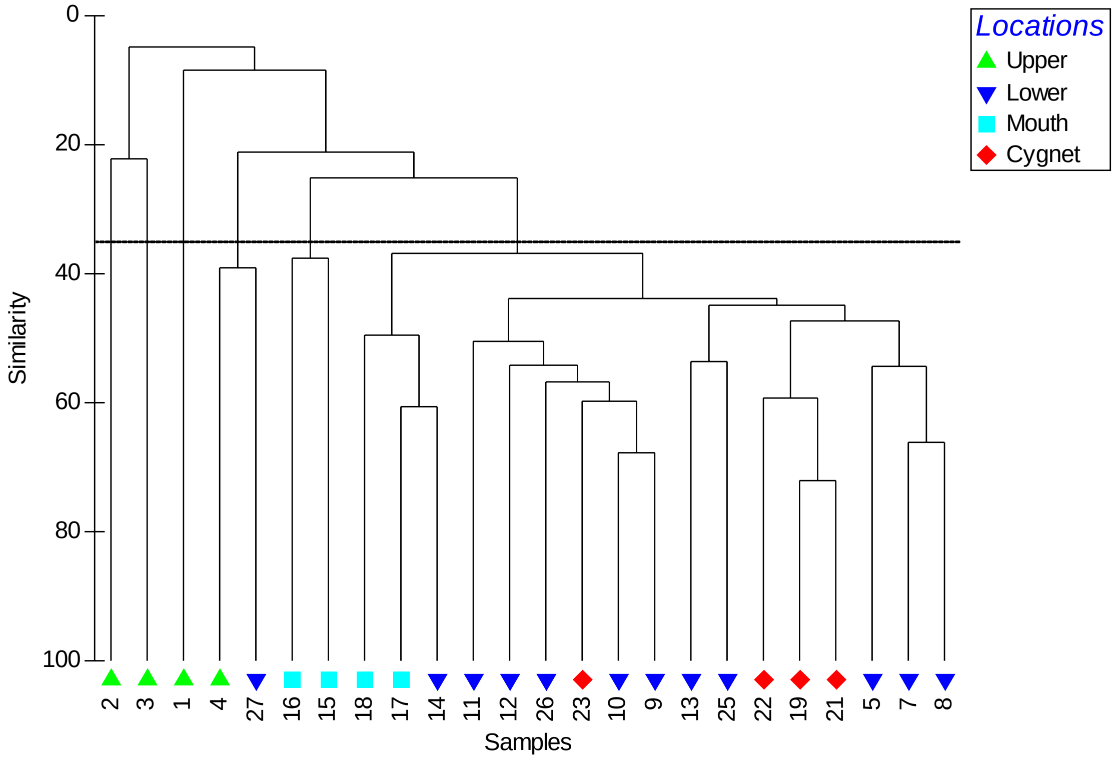


Fig. 21. Cluster analysis of the Huon benthic data (square root transformation applied).

Allowing the community composition to define where the separations occur within the system rather than imposing the constraint of “a priori” zones suggests that at an overall similarity level of 20% the upper estuary sites were clearly discernible from the rest of the estuary (Fig. 22.) However, these sites were also highly dissimilar to each other, as indicated by the low rank similarity levels in the dendrogram. Site 4 actually associates more closely with site 27, from the upper region of the lower estuary. This suggests that the “a priori” zone boundaries do not adequately reflect the benthic variability.

At an overall similarity level of 35%, cluster analysis distinguishes 6 groups of sites, although most sites were contained in only one group. The three upper estuary sites are clearly quite discrete (groups A, B & C) and the mid-lower estuary can be divided into three further community groups (D, E & F) (Fig. 22).

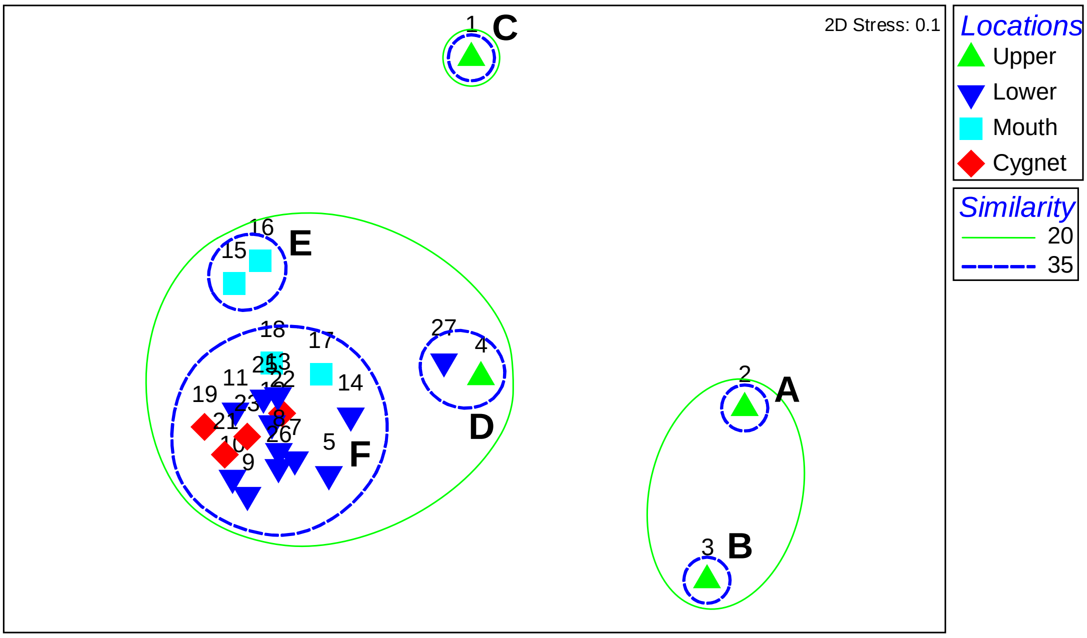


Fig. 22. Community groups at 20% & 35% overall similarity.

Groups A, B and C were represented by single sites and therefore although it is possible to define species indicative of these sites, they cannot be considered as representative communities. Only 2 species were recorded from group A (site 2), *Leitoscoloplos bifurcatus* and *Mediomastus australiensis* with *L. bifurcatus* present at relatively high density (370/m^2). At site 3 (Group B) there were only 3 individuals in total recorded, *M.australiensis*, *Glycera* sp.1 and a gammarid amphipod. Group C (site 1) contained 5 species but only one individual of each; *Nephtys australiensis*, *Notomastus* sp., *Nassarius nigellus*, *Nemocardium thetidis* and Nematoda.

The fauna from group D was strongly characterized by 3 species of worm (Table 6); *M.australiensis*, *Nemertea* sp.1 and *Nephtys australiensis*. *M.australiensis* and *N.australiensis* are both polychaetes whilst *Nemertea* is a ribbon worm. These animals do have some similarity in function, both nemerteans and *Nephtys* can be predatory epibenthic carnivores, although *N.australiensis* is an opportunist and can also function as a selective deposit feeder like *M.australiensis*. *M.australiensis* was identified as a species characteristic of fine mud/sand conditions in Western Port Bay, Victoria (Coleman et al., 1978) and is often found in areas where organic content has been slightly enhanced (Dauvin, 2000, Levin, 2000). *M.australiensis* has a familial relationship to the pollution indicator species *Capitella capitata*. This faunal information suggests that the group D sites, just north of Hospital Bay, were naturally organically enriched.

Table 6. Average abundance and relative % contribution to within group similarity of 3 most important characterising species for biotic groups D, E and F (35% overall similarity groups) (IB-infaunal bioturbator, EO-epibenthic opportunist, DF- deposit feeder, SDF- surface deposit feeder, SS- suspension feeder, C –carnivore, OS-opportunistic scavenger). Groups A, B and C were only single sites with few species but have used species information to define dominant group, habit and function.

Cluster Group	Species	No/m^2	Contrib.	Taxonomic Group	Habit	Function
D	*Mediomastus australiensis*	42	45.31	Polychaete	IB	SDF
	Nemertea sp.1	31	32.04	Nemertean	IB	C
	Nephtys australiensis	27	22.65	Polychaete	IB	C/SDF
E	*Prionospio kulin*	42	12.11	Polychaete	IB/EO	DF
	Ampelisca euroa	78	10.49	Amphipod	II	SDF/SS
	Byblis mildura	81	9.57	Amphipod	*Unknown*	
F	Nemertea sp.1	38	14.17	Nemertean	IB	C
	Sthenelais pettibonae	34	13.97	Polychaete	*Unknown*	
	Euphilomedes sp.(MoV18)	48	12.82	Ostracod	IB	DF

	Dominant Group	***Dominant Habit***	***Dominant Function***
A	Polychaete, Amphipod	IB	DF, C
B	Polychaete, Amphipod	IB	DF, C
C	Polychaete, Gastropod, Bivalve	IB, EO	DF, C/SDF, OS

Sites 15 and 16 located near the mouth of the estuary formed group E, which was defined by a broader range of species, although two species, the spionid polychaete *Prionospio kulin* and the gammarid amphipod *Ampelisca euroa* accounted for 23% of the group similarity. Spionid polychaetes are often associated with areas of high organic enrichment. *P.kulin* has been reported from several areas in southern Australia. It was a common feature in the fauna at aquaculture lease sites in the Huon (Woods et al.,2004) and was one of the species commonly associated with organically enriched sites in North West Bay (Macleod et al., 2002). Crustaceans are generally relatively sensitive to increased organic matter, sedimentation and low oxygen conditions, and are often amongst the first members of the infauna to be affected when environmental conditions deteriorate (Nilsson and Rosenberg, 1994). *Ampelisca* spp. are suspension/surface deposit feeding amphipods which are generally sensitive to increased organic loadings. *Ampelisca euroa* was one of the species found to be indicative of unimpacted reference conditions around fish farms associated with sandy sites around the Tasman peninsula (Macleod et al. 2004). *Byblis mildura*, the third most important characterising species, is one of the most common amphipods in soft muddy sediments in Southern Australia, densities of up to 1200 individuals per m^2 have been reported from Port Phillip Bay (Wilson et al., 1999). It is a tube dwelling amphipod which can change between suspension or surface deposit feeding depending on environmental conditions (Poore, 2000).

All the remaining sites cluster together at a relatively high similarity level (approximately 37%) to make up a single large community group (F) (Fig. 22). This group also contained a broad mix of species. However, Nemertean sp.1, *Sthenelais pettibonae* and *Euphilomedes* sp.(MoV 18) were all common at sites within this group. The ecology of *Nemertea* species has already been discussed. There is little information on the biology or ecology of the scale worm *Sthenelais pettibonae,* but it has been reported fairly commonly from soft sediments in southern-temperate Australia. It is most likely a burrowing predatory polychaete but may alter its feeding strategy to consume general organic material and detritus when necessary (Hutchings, 2000). The ecology of the ostracod *Euphilomedes* sp. (MoV 18) is also poorly understood, but it is most likely a burrowing deposit feeder and as such may be expected to survive in areas with increased organic material. Ecologically it may be similar to *Euphilomedes carcharodontabe* which has been described in conjunction with a bivalve (*Pavilucino tenuisculpta)* and *Capitella capitata* as one of the "three little pigs", a group of species which were indicative of organic enrichment at an ocean outfall in California (Maurer et al., 1998; Zmarzly et al., 1994).

Two additional species which were important contributors to the communities at group F sites were *Corbula gibba* and *Amphiura elandiformis*. Previous studies of biota in the Huon have shown the presence of brittlestars to be strongly indicative of unimpacted conditions (Macleod, 2000, Crawford et al., 2002, Macleod et al., 2004). Brittlestars, or ophiuroids, are often significant, even keystone, species in soft sediment communities (Heip et al., 1992, Rosenberg et al., 1997, Rumohr et al., 2001). *Amphiura elandiformis* is relatively common around Tasmania and is found on the North, South and East coasts (Dartnall, 1980, Edgar et al., 1999a). In spite of its prevalence there is very little known about the biology and ecology of this species. Video footage from previous studies of soft-sediment communities in Southern-Tasmania (Crawford et al., 2002, Macleod et al., 2004) have shown that although it is principally a surface deposit feeder, burying its basal disc in the sediment and using its arms to scavenge for food on the surface, it can also use its arms to remove particles from the water column. These observations suggest that this species may serve a very similar functional role in the local soft sediment ecosystem to the boreal *Amphiura* communities defined by *A. chiajei* and *A. filiformis*. *A. elandiformis* appears relatively intolerant of organic enrichment and low oxygen conditions (Crawford et al, 2002) and comparison of this and other field observations with available biological and ecological information on *A.chiajei* and *A.filiformis* (Nilsson, 1999) suggest that functionally *A.elandiformis* may more closely resemble *A.filiformis*. This species is likely to be important both in physically structuring the sediments and in nutrient cycling. Where present, brittle stars more or less continuously rework the sediments as a result of vertical and horizontal migration (Rosenberg et al., 1997). This bioturbation can also have important implications for the fate of contaminants (Mazik and Elliot, 2000, Gunnarsson et al., 2000). Bioturbation by *Amphiura* spp. may also stimulate both nitrification and dissimilatory nitrate reduction (Enoksson and Samuelsson, 1987).

Corbula gibba was introduced to Australia from the Mediterannean and has become a significant component of many temperate Australian soft-sediment communities (Wilson et al., 1998). *C.gibba* is well adapted to live in unstable mixed muddy bottoms, dominating where physical-chemical and sedimentary parameters show large variations and where the sediments are unstable (Crema et al., 1991). It generally resides in surface sediments and is a suspension-feeding bivalve, however, it can exhibit a high degree of particle selection (Kioerboe & Moehlenberg, 1981). It is extremely tolerant of low oxygen condition even periods of partial anoxia (Crema et al., 1991) and can survive levels of turbidity which would be prohibitive to many other suspension feeding species. It is widely distributed in the estuaries of Northern Europe and the Mediterranean, and is often abundant in eutrophic areas at the edge of anoxic/azoic zones (Jensen, 1990). Early studies suggested that it was relatively long-lived (>5yrs) and slow growing (Jones, 1956) although more recent studies suggest a life span of only 1-2yrs (Jensen, 1990). Once established *C.gibba* can become extremely abundant; densities of up to 2,600m-2 have been reported from Port Phillip Bay (Currie & Parry, 1999) whilst Jensen (1990) in a Danish study estimated densities of 67,000 m^2 were possible.

Polychaetes were the major faunal group in the Huon communities whilst deposit feeders were the dominant functional group (Table 6). This abundance of infaunal deposit feeders would result in considerable bioturbation within the system. In several groups infaunal carnivores (Nemertea and polychaetes) were a component of the fauna and these too would contribute to sediment bioturbation. Only in group E, near the mouth of the estuary, were benthic suspension feeders a significant feature of the fauna. This reflects both the highly depositional nature of the upper and mid-Huon system, where most suspension feeders would have difficulty coping with the high levels of sedimentation (Butler, in press), and the reduced organic content at the estuary mouth. Group E sites were in approx 15-25m of water, were sandier (cleaner) than the majority of the middle/lower estuary sites and would regularly be subject to strong tidal influences and incursions of fully marine water from the D'Entrecasteaux Channel. In the upper estuary groups the communities were less diverse than in the rest of the estuary and opportunistic species were a significant feature, suggesting that these areas were slightly stressed. Nevertheless there was still considerable overlap in the taxonomy and function of the faunal communities throughout the Huon.

Correlation of the biotic data matrix with that of the various abiotic factors available to this study (metals and physico-chemical measures) indicates that there were similarities between the matrices (Table 7).

Table 7. Spearman correlations between data matrices (H0- No relation between matrices)

Relationship	Rho statistic	Significance
Biota to metals	0.632	<0.001
Biota to other abiotic factors	0.694	<0.001
Biota to all abiotic factors	0.811	<0.001

No single abiotic factor explains the overall pattern of community distribution. Better definition was obtained with a combination of factors particularly those that integrated the changes in organic content, salinity and sediment redox regimes along the estuary best defined the ecological gradient (Table 8). The highest redox levels were associated with two sites (1 and 3) high in the upper estuary. These sites were shallow and sandy, which suggests that there may be increased water flows through this area and potentially wind driven resuspension of sediments. This would in turn would improve sediment redox levels as observed. All of the abiotic metrics are to some extent auto correlated (Fig. 23). Generally in a drowned river valley such as the Huon, depth will tend to increase down the system towards the mouth. As depth increases so flows may become reduced which will then increase sedimentation rates and enhance organic matter accumulation. This can then result in reducing conditions with an associated increase in sediment sulphides.

Table 8. BIOENV correlations Biota to all Abiotic factors (Data normalised).

Correlation	Variables
0.811	Redox, Salinity, Organic C, Fe, Zn
0.807	Redox, Salinity, Organic C, Fe, Ni
0.805	Redox, Salinity, Organic C, Fe, Al
0.802	Redox, Salinity, Organic C, Fe, Pb
0.720	Redox, Salinity, Organic C
Best metal:	
0.701	Iron
Best other factor:	
0.520	Redox

Iron concentration was the strongest single correlate with the overall biotic matrix. This was largely as a result of a marked decline in iron concentration in the upper estuary which distinguished groups A, B and C, a slight decline in iron concentration associated with group E and a slight decline associated with group D. It is unlikely that the communities are being directly influenced by changes in iron concentration, it is more likely that the variation in iron is reflecting changes in the geography and in the depositional conditions. Overall metal levels in the Huon were very low and with the exception of iron do not appear to have any relationship with the infaunal community structure (Fig. 24).

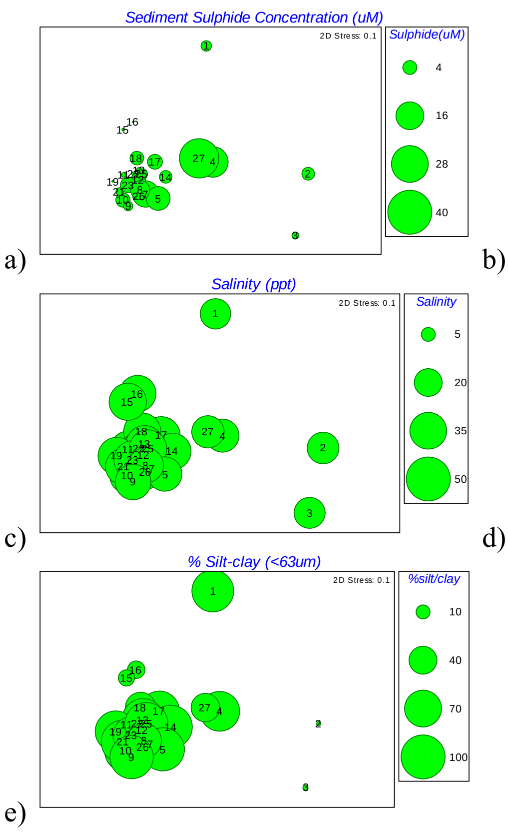


Fig. 23. Abiotic metrics for Huon sites a) sediment sulphide concentration, b) Redox potential, c) water column salinity, d) depth and e) percentage silt/clay.

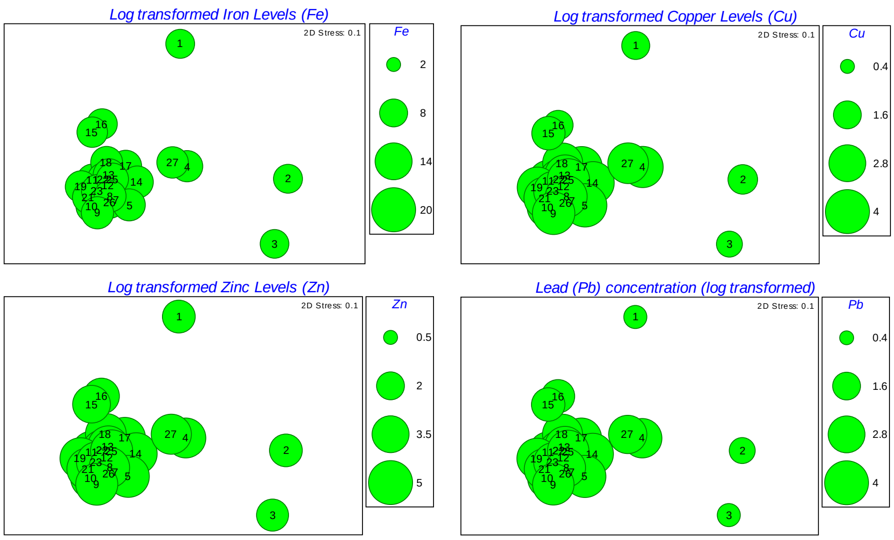


Fig. 24. Metal concentrations at Huon sites a) Iron, b) Copper, c) Zinc and d) Lead. All data log transformed.

Examination of the relationships between community structure and abiotic factors within the groupings indicated by multivariate ordination of the biotic data suggests that compared to other groups sites in group D, situated in the upper estuary, had appreciably increased sulphide levels and slightly elevated manganese concentrations. Group E sites were located near the mouth of the estuary and this group was best differentiated by a combination of depth and manganese, arsenic and zinc levels. These sites were markedly deeper than those in groups A-D and both redox levels and salinity were consistently higher. Group E sites also has mid-low range levels for all metals and this feature distinguishes them from group F sites, which had higher levels of zinc, manganese and arsenic. However, since the metals concentration at all sites were still well below the ANZECC trigger levels it is unlikely that the magnitude of the change described between sites/groups would have major effects on the ecology. It is more likely that the community change is in response to the differences in depth, sediment type and oxic status (redox/sulphide condition) of the sediments.

Only in group F was there sufficient replication to enable correlation of the abiotic variables and the only notable correlations were within the metals subset (Table 9). Al , Fe, Ni, Pb and Zn tended to co-vary but the concentrations of all of these metals were low. There only significant associations with any other measures of environmental or sediment condition was with organic content.

Table 9. Most significant correlations between Biotic ordination groups and abiotic data -BEST analysis.Abiotic factor correlations within Biotic Ordination Group F

Group F

	Sulphide	Redox	Salinity	Depth	%silt/clay	Org C	Al	As	Cu	Fe	Mn	Ni	Pb	Zn
Redox	-0.123													
Salinity	-0.353	0.271												
Depth	-0.053	-0.110	0.448											
%silt/clay	0.272	-0.334	0.205	0.258										
Org C	0.623	-0.384	-0.471	-0.059	0.609									
Al	0.052	-0.242	-0.319	0.041	0.397	0.663								
As	0.568	-0.406	-0.454	-0.354	0.493	0.756	0.327							
Cu	0.550	-0.389	-0.505	0.077	0.483	0.799	0.713	0.609						
Fe	0.210	-0.413	-0.427	-0.025	0.448	0.797	0.943	0.524	0.792					
Mn	0.493	-0.259	-0.073	0.014	0.719	0.737	0.613	0.744	0.700	0.701				
Ni	0.191	-0.598	-0.272	0.302	0.463	0.676	0.825	0.423	0.830	0.874	0.624			
Pb	0.340	0.010	-0.208	0.234	0.512	0.682	0.805	0.247	0.778	0.760	0.651	0.656		
Zn	0.145	-0.084	-0.323	0.179	0.410	0.700	0.891	0.215	0.722	0.849	0.512	0.718	0.928	
Hg	-0.400	-0.386	-0.297	-0.137	-0.055	0.216	0.603	0.041	0.240	0.571	0.029	0.543	0.168	0.393

Since the biotic changes along the Huon are in response to a gradual change in the natural environmental conditions rather than any specific human impacts it would be a relatively easy task to differentiate between communities which are spatially distinct however, it would be much harder to distinguish community groups which are geographically close (Table 10). Group D represents the upper estuary sites and the characteristic fauna reflects this with several of the main species from this group being common to the other upper estuary sites (Groups A, B and C). Group E sites are from the estuary mouth and the characterizing species were quite different to those from the upper estuary. Crustaceans were more prevalent in these sites than in the other groups, *Ampelisca euroa*, *Byblis mildura* and *Kalliapseudes* sp.1. Group F represents the greater part of the estuary. Although all of the characterizing species for this group are common to other groups they can still be discriminating by virtue of the relative abundance. The scaleworm *Sthenelais pettibonae*, the little ostracod *Euphilomedes* sp., the brittlestar *Amphiura elandiformis* and the introduced bivalve *Corbula gibba* were all strongly characteristic of this group and relatively abundant.

Table 10. Characterising species for main cluster groups; + indicates presence of species, * indicates species characteristic of the group (SIMPER), ** indicates present in markedly greater abundance compared with other groups.

Species/Group	A	B	C	D	E	F
Nephtys australiensis			*	*	+	
Euchone limnicola		*				
Sthenelais pettibonae				+	+	**
Prionspio kulin					**	+
Mediomastus australiensis	*	*		+	+	+
Leitoscoloplos bifurcatus	**			+		
Notomastus sp.			*			
Ampelisca euroa					**	+
Byblis mildura					**	+
Gammarid sp.1		*				
Euphilomedes sp. (MoV18)				+	+	**
Kalliapseudes sp.1					**	+
Nassarius nigellus			*		+	+
Nemocardium thetidis			*		+	+
Corbula gibba					+	**
Amphiura elandiformis				+	+	**
Nemertea sp.1				*	+	*
Nematoda sp.			*	+	+	+

The information in Table 10 could be used either to infer the likely location of a particular community type or to suggest the likely community in a particular location. However, since the communities have a considerable degree of commonality all decisions would need to be made on a "weight of evidence" basis and preferably with access to additional corroborating information. This information would also be useful as a baseline against which to evaluate temporal changes in the system.

On the whole the communities within the Huon appear relatively undisturbed and typical of that found in southeastern estuaries generally (Edgar et al., 1999a,b). Diversity was relatively high with lowest levels being in the uppermost reaches and the distribution of species throughout the estuary seems to be largely structured according to the prevailing salinity/geographical gradient, which is also in accordance with the findings of Edgar et al. (1999a,b). The sampled region was dominated by euryhaline and/or estuarine species with no specifically freshwater or marine species. The upper estuary contained a few opportunistic species generally associated with areas of environmental disturbance including some species commonly associated with areas of organic enrichment. However, the information currently available on human induced changes to the estuary suggest that any stresses affecting the upper estuary would be largely natural. The fauna in the mid-lower estuary was predominantly infaunal deposit feeders, accordingly the sediments were subject to a relatively high level of natural faunal bioturbation. Suspension feeders were not a significant component of the benthic community in the estuary, except at the mouth where suspension feeding crustaceans were comparatively abundant. The introduced sabellid worm, *Euchone limnicola*, is dealt with in the separate section on introduced species (Section 3.5) but was recorded in relatively low numbers from only a few sites in the vicinity of the fish farm operations.

By comparing all the known information on the estuary usages, the abiotic measures and the known biology and ecology of the dominant fauna it is possible to assign likely impact levels to the various community groups within the estuary (Table 11). The distribution of these impact ranks throughout the estuary is shown in figure 25.

Table 11. Likely impact ranks of community groups in Huon.

Community Group	Likely Impact Rank	Rank Descriptor
A	3	Naturally stressed environment
B	3	Naturally stressed environment
C	3	Naturally stressed environment
D	1.3	Normal upper-estuarine community
E	1.2	Normal marine community
F	1.1	Normal mid-estuarine community

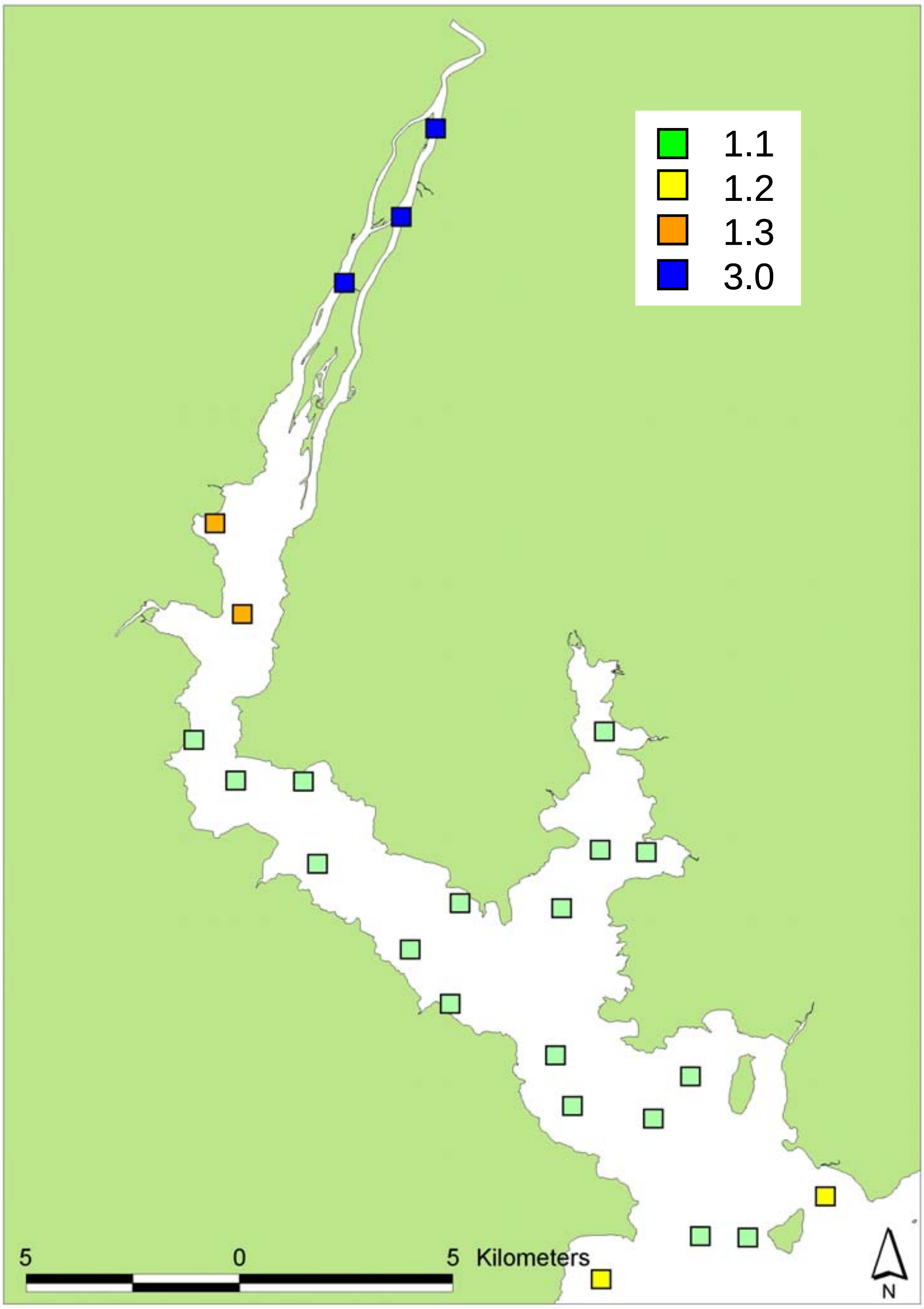


Figure 25. Distribution of biotic community impact ranks in Huon.

3.3 Ecological Status of the Derwent Estuary

3.3.1 Biota data

In the Derwent, diversity was surprisingly high throughout the estuary, although there were significant differences between the “a priori” zones (F=12.370, df=49,3, p<0.001). Diversity was significantly higher in the lower estuary and Ralphs Bay compared with the upper estuary and was also significantly higher in the lower estuary than in the mid zone (Fig. 26). On average more than 20 species per site were recorded from both the lower zone and Ralphs Bay.

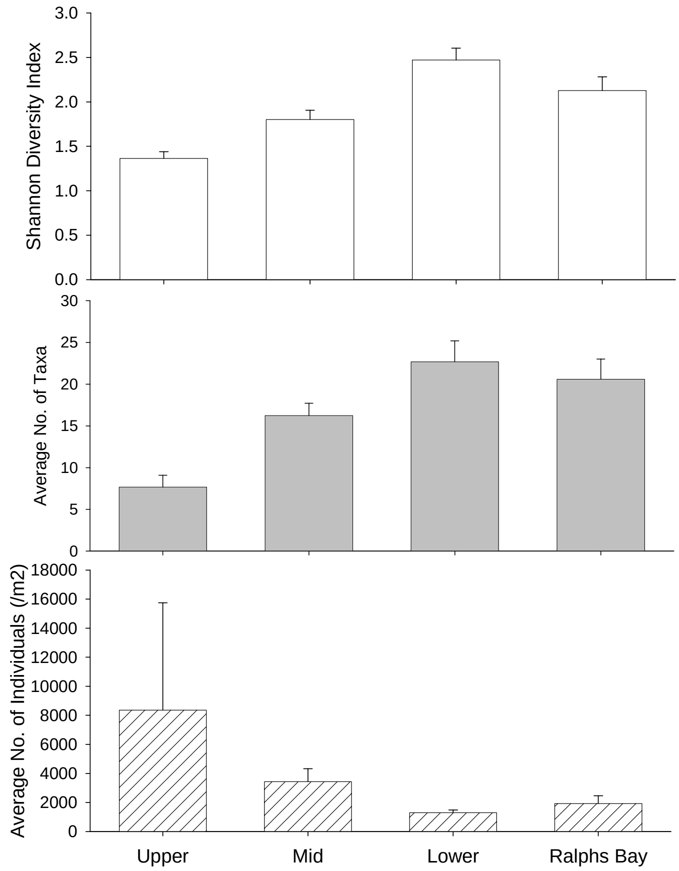


Fig. 26. Mean diversity, number of taxa and number of individuals at sites from "a priori" defined zones in the Derwent estuary.

Overall abundance declined down the estuary whilst the number of taxa increased. The number of taxa in the upper estuary was significantly lower than in any of the other zones ($F=7.936$, $df=49,3$, $p<0.001$) with an average of only 7.7 taxa per site (Fig.27) whilst the mean number of individuals was high. Low diversity with high abundance is frequently associated with impacted conditions (Pearson, 1978, Stark, 1998b, Lindegarth and Underwood, 2002), However, within group variability at this zone was such that the differences were not significant ($F=1.223$, $df=49,3$, $p=0.311$). In the upper zone the number of individuals was highly variable (8000 ± 7382) compared to the number of taxa recorded (Fig.26). This variability was largely due to a peak in abundance at site 84 (Fig.27) associated with 2 species in particular; *Paracorophium excavatuum* and *Arthritica semen*. Both these species are commonly found in upper estuarine areas with high organic loadings (Edgar et al., 1999b). Site 71, near Selfs Point, also had an extremely elevated abundance associated with the spionid polychaete *Spionidae* sp.9. Overall abundances were also high at sites 111 and 94. At site 111 in Cornelian Bay this was largely attributed to a large increase in the amphipod *Corophium ascherusicum* (up to 4,500 individuals/m2) although there was a reasonable contribution from the polychaete *Cirriformia cf filigera* (1,650 individuals/m^2). There is little biological information regarding *Corophium ascherusicum* specifically, but *Corophium* sp. are in general tube dwelling amphipods, suspension and surface deposit feeders and have frequently been found to be opportunistic (Harris and Musko, 1999), tolerant of anoxia and high sulphide levels (Gamenick et al., 1997), organic enrichment (Peletier, 1996) and euryhaline (Hyne and Everett, 1998). As a result of such broad tolerances *Corophium* sp. have been recommended as a particularly good species for testing sediment toxicity (Surtikanti and Hyne, 2000). In a study of Dunkerque's Harbour, an area with significant heavy metal contamination on the French North Sea coast, *Corophium* sp. were also found in conjunction with a local cirratulid (*Cirratulus cirratus*) to be amongst the main colonizing species (Diaz-Castaneda et al., 1989).

The abundance spike at site 94, in the middle of Ralphs Bay, was primarily due to an increase in numbers of *Spiophanes* sp. *Spiophanes* sp. is a tube building spionid polychaete and although there is no information on the biology of this particular species *Spiophanes* sp. are often a dominant component of soft sediment benthic communities, occurring at the sediment water interface as deposit or suspension feeders, often alternating between feeding strategies depending on the environmental conditions. They appear tolerant of low levels of organic enrichment and hypoxia (Quiroga et al., 1999) but may be smothered when levels of suspended material are very high (Maurer et al., 1998). They can be found at extremely high densities when environmental conditions permit (Featherstone and Risk, 1977), suggesting that they have a relatively short life cycle and opportunistic reproductive strategy, which may explain the high densities found at the Ralphs Bay site. They can be a significant component of the diet for benthic feeding fish such as flounder (Langton, 1983) and therefore could contribute to bioaccumulation of heavy metals at higher trophic levels.

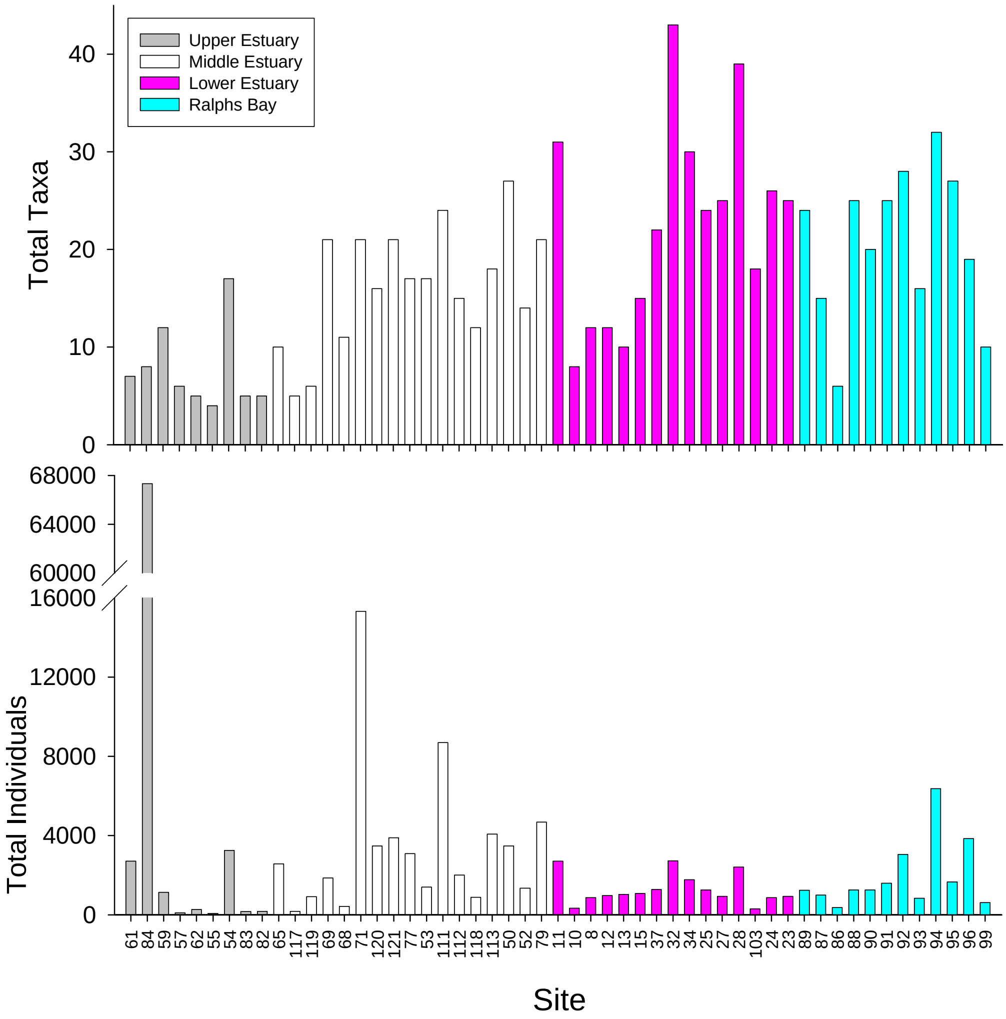


Fig. 27. Diversity, number of taxa and number of individuals at individual sites in the Derwent estuary.

Using cluster analysis to show the actual community relationships between the sites it is clear that site 84 is quite distinct from the other sites (group A), with a similarity level of only about 5% to the remaining sites (Fig. 28). Site 84 was high in the upper estuary, just below the Bridgewater causeway and close to the Bridgewater sewage treatment outfall. At this site a total of 8 species were recorded but 2 of these species, *Arthritica semen* and *Paracorophium* sp. accounted for more than 61,000 individuals/m^2. These two species were considerably more abundant at this site than at any other site (Table 12), which considering the ecological preferences of these species, suggests that this site was subject to a higher degree of organic enrichment than any other sites in the estuary.

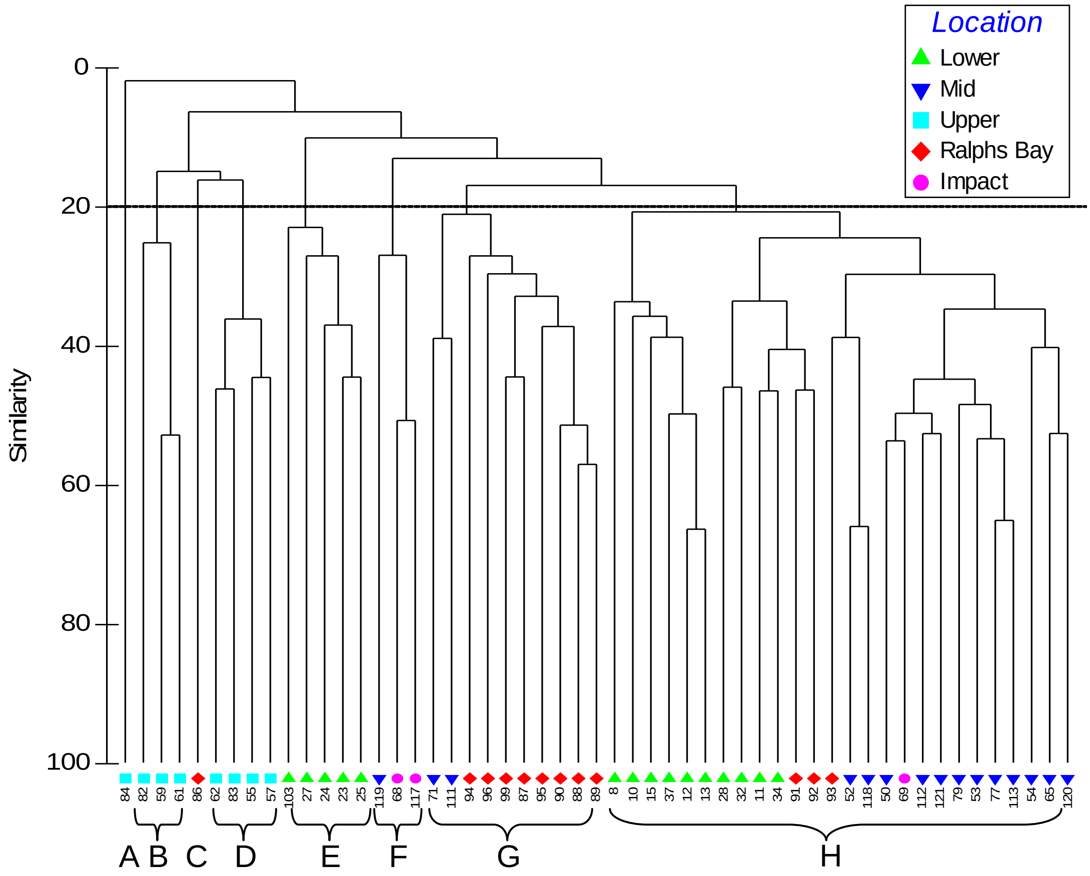


Fig. 28. Dendogram from cluster analysis of Derwent biota

At a similarity level of 10% the remaining upper estuary sites were differentiated. The upper estuary sites could be further separated at a similarity level of 15% into groups B and D. The crab *Macrophthalmus latifrons* was only found at group D sites. *Macrophthalmus latifrons* is a burrowing epibenthic scavenger commonly found intertidally in mud and silt sediments and amongst seagrass, which would explain its restriction to these shallow upper estuary sites. These crabs would be a premium prey item for wading seabirds and as such may represent a trophic bioaccumulation risk. Another significant distinction between groups B and D was the change in the relative abundance of the gastropods *Arthritica semen* and *Tatea* sp.(cf *huonensis*), with far more of each species in group B sites. Both of these species are commonly associated with elevated organic levels and reduced salinity. *Tatea* sp. is truly euryhaline and can adjust to salinities between 0-55ppt (Ponder et al., 2000). Fossorial phoxocephalid amphipods were commonly present at the group B sites and these too have been associated with areas of increased organic material (Macleod et al., 2000), which once again suggested that the infaunal community in the upper estuary is structured according to the salinity regime and organic content of the system.

Site 86 (group C) was distinguished at an overall similarity of approximately 17% and was somewhat anomalous. This site is situated in one of the shallowest areas of Ralphs Bay, right up in the north-east corner of the bay and consequently may be exposed at low tide. The fauna reflects these difficult environmental conditions, this site had the lowest abundance and diversity of all of the sites in Ralphs Bay. Epibenthic scavengers and predators which could come in and out with the tide were the main features of this depauperate community (*Nephtys australiensis* and a *Nassarid* gastropod).

Table 12. Abundance of *Paracorophium* sp and *Arthritica semen*.(no/m^2)

Location	Site	Paracorophium sp.	Arthritica semen
Upper	**84**	**38,667**	**22,355**
Upper	61		592
Upper	59		267
Upper	62		15
Middle	111	44	
Middle	112	15	
Middle	50	59	
Lower	32	30	
Lower	23	15	
Ralphs Bay	96		44
Impact	117		15
Impact	68	15	
Impact	69	15	

All of the sites from the lower and middle estuary, all the remaining sites from Ralphs Bay and the impacted sites cluster together only separating at similarity levels greater than 15%. Differentiation of these sites shows a hierarchical attrition rather than distinct dichotomies which suggests that the changes in the communities at these sites were gradual.

Table 13 Average abundance and relative % contribution to within group similarity of 3 most important characterising species for biotic groups B, D, E, F, G and H (35% overall similarity groups) (Habit key: IB-infaunal bioturbator, EO-epibenthic opportunist, II-infaunal bioirrigator), (Function key: DF- deposit feeder, SDF- surface deposit feeder, SS- suspension feeder, C –carnivore, H- Herbivore, OS-opportunistic scavenger). Groups A and C were only single sites with few species so have used all species information to define dominant group, habit and function.

Cluster Group	Species	No/m^2	Contrib.	Taxonomic Group	Habit	Function
B	Phoxocephalidae spp.	85	35.50	Amphipod	IB	DF
	Mediomastus australiensis	20	18.17	Polychaete	IB	DF
	Arthritica semen	52	16.10	Mollusc	EO	SDF
D	*Macrophthalmus latifrons*	24	56.19	Crustacean	EO/IB/II	SDF/H
	Nephtys australiensis	22	24.20	Polychaete	IB/EO	C/OS
	Euphilomedes sp.(MoV18)	24	13.02	Crustacean	IB	DF
	Gammaropsis sp.	42	10.98	Amphipod	II	SDF/SS
F	*Cirriformia cf filigera*	59	66.80	Polychaete	IB	SDF
	Nephtys australiensis	15	8.32	Polychaete	IB/EO	C/OS
	Monocorophium ascherusicum	10	8.32	Amphipod	II	SDF/SS
G	*Mediomastus australiensis*	73	21.67	Polychaete	IB	DF
	Nassarius nigellus	39	17.82	Mollusc	EO	OS
	Nephtys australiensis	31	11.87	Polychaete	IB/EO	C/OS
H	*Ampelisca euroa*	60	15.04	Amphipod	II	SDF/SS
	Nemertea sp.1	35	12.24	Nemertean	IB	C
	Theora lubrica	15	8.30	Mollusc	IB	DF

	Dominant Group	***Dominant Habit***	***Dominant Function***
A	Mollusc, Amphipod	II, EO	DF, C/SDF, OS
C	Polychaete, Mollusc	IB, EO	DF, C/SDF, OS

The remaining Ralphs Bay sites cluster together with two middle estuary sites, 71 (located just south of the Zinifex wharf) and 111 (in Cornelian Bay) to form group G at an overall similarity level of approximately 17%. These sites were characterized by 3 species *Mediomastus australiensis* , *Nassarius nigellus* and *Nephtys australiensis* none of which were extremely abundant (73, 39 and 31 individuals/m^2 respectively). These species are true estuarine species, with opportunistic tendencies and a relatively high tolerance for hypoxia and organic enrichment. This community mix does not instantly indicate disturbed or organically enriched conditions but the tolerances and feeding preferences once again suggest that the organic content of the sediments may be influencing the infaunal community structure (Table 13).

Group F contained two sites 68 and 117 putatively determined to be impacted and site 119 from the mid-estuary. Site 119 was in Prince of Wales Bay at a depth of only 5m. The cirratulid polychaete *Cirriformia cf filigera* was very common at all the sites in group F, it accounted for 67% of the overall group similarity. Although this species was present in some group G sites it was not as abundant as in group F (on average 36 cf 59 individuals/m^2). Cirratulids are generally considered to be surface deposit feeders but there is little information on the biology or ecology of Australian species. However, a recent study on the effects of organic enrichment in Antarctic waters noted the cirratulid *Aphelochaeta* sp amongst the dominant opportunists (Conlan et al., 2004) whilst in New Zealand Inglis and Kross (Inglis and Kross, 2000) found an increased abundance of cirratulid polychaetes in an estuary contaminated with heavy metals and hydrocarbons.

Another group of lower estuary sites (Group E -103, 27, 24, 23 and 25) separated out at a relatively low overall similarity level, approx. 10%. These sites were all located towards the mouth of the estuary in deeper water and where the sediment was sandier. This group contained a diverse range of species but crustaceans, particularly amphipods, appeared to be quite a distinctive component of this fauna, in particular *Euphilomedes* sp.(MoV18) and *Gammaropsis* sp. (Table 13). Amphipods are usually adversely affected by pollution (Rosenberg et al, 1997, Stark, 1998) and consequently crustaceans are generally indicative of relatively good environmental condition. Both *Euphilomedes* sp. (MoV18) and *Gammaropsis* sp. were absent from groups A, B, C and D in the upper estuary, and the amphipod *Gammaropsis* sp. (21153) was also not found in groups F and G.

The remaining lower estuary sites clustered together with the bulk of the mid-estuary sites and form a community group with an overall similarity level greater than 20% (group H). This group also included three sites from Ralphs Bay (91, 92 and 93) as well as site 69, previously considered impacted. Sites 91, 92 and 93 were located close together just inside the Bay, these sites were deeper than the other sites in Ralphs Bay (11m, 8m and 15m respectively) and the proportion of silt-clay in the sediments was 57%, 43% and 94% respectively. Site 69 adjacent to the Zinifex wharf was in 18m with sediments composed of approximately 80% silt-clay. The main species characterising this group were *Ampelisca euroa* and *Nemertea* sp.1 which together accounted for 27 % of the overall similarity within this group. *Ampelisca euroa* was consistently markedly more abundant at sites in this group than in any other group (an average of 60 individuals per m^2 in this group). *A.euroa* has been found to be associated with good environmental conditions (Macleod et al., 2004). Consequently, the presence of *A.euroa* in these samples is a good indicator that the environment associated with this group is relatively healthy.

Polychaetes were the main faunal group in the Derwent although crustaceans, in particular amphipods, were also strongly represented (Table 13). The dominant feeding strategy was infaunal or surface deposit feeding, with many of these species being either free living in the benthos or tube/burrow dwelling. Consequently, the sediments in most areas would be subject to significant infaunal bioturbation and bioirrigation. Deposit feeders were particularly prevalent in the upper estuary (groups A, B, and D) which suggests that organic content was higher in these sediments (Snelgrove and Butman, 1994). In contrast suspension feeders are often inhibited in areas with high levels of suspended and organic material (Snelgrove and Butman, 1994). Crustaceans with the ability to adjust between suspension and surface deposit feeding had a significant presence throughout much of the mid and lower estuary and were amongst the dominant species in the communities at groups E, F and H. Since crustaceans are often considered to be relatively sensitive to anthropogenic pollutants, the abundance of amphipods in the Derwent fauna suggests that the metal levels in the sediments are not the predominant determinants of the system ecology.

Correlation of the biotic dataset with the environmental dataset indicates that the overall pattern of community change in the Derwent is more strongly aligned with the salinity gradient of the system than with any particular metal or group of metal concentrations (Table 14) Since salinity was measured above the seabed it represents the conditions in the water column at the time of sampling rather than the sediment conditions directly. Consequently it is more likely that salinity is acting as a proxy for the geographic position of the sampling site rather than the actual salinity regime in the benthos. Sulphide, redox and organic carbon content were also important factors in explaining the overall community structure, suggesting that the oxic status and degree of organic enrichment of the sediments had a stronger influence than metal levels. Calcium was the only mineral to show any notable relationship with the faunal distribution and this would be influenced by shell deposits and hence sediment type and distribution. Accordingly, all of these other major correlates could also be considered surrogates for physical location or sediment structure.

Table 14 BIOENV correlations Biota to all Abiotic factors (Data normalised) (Abiotic data was not collected for sites 113,118 & 119 and consequently these sites have been excluded from this analysis).

Correlation	**Variables**
0.545	Salinity
0.506	Redox, Sulphide, Organic C, Salinity, Calcium
0.505	Redox, Sulphide, Organic C, Salinity
0.505	Redox, Sulphide, % silt-clay, Salinity
0.503	Redox, Sulphide, Organic C, Depth, Salinity
0.503	Redox, Sulphide, % silt-clay, Salinity, Calcium

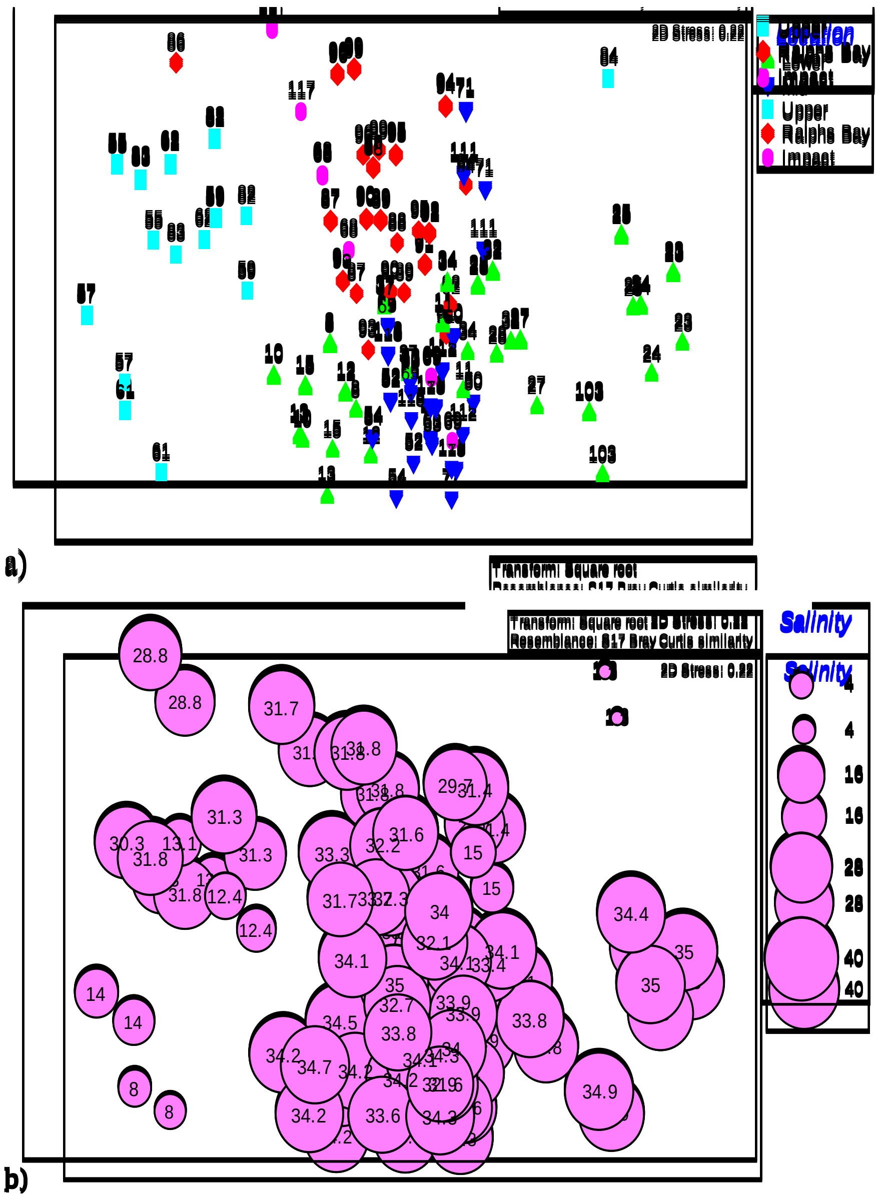


Fig. 29. Ordination plots a) Biotic data b) salinity levels superimposed on community ordination (Note that sites 113, 118, 119, 120, 121 have been excluded from this analysis due to missing environmental data). Data was square root transformed.

Comparing the biotic data matrix to that of the abiotic metrics shows that the strongest correlation was without the metals information and that there was no relationship between the biotic data and the metals alone. However, the correlations between the infaunal distribution and the abiotic metrics within each of the biotic MDS groups suggest that the physico-chemical factors influencing the faunal composition differed between the groupings (Table 15). The biotic matrices defining groups B and D were directly correlated with salinity and sulphide concentration respectively (Table 16). Group B is high in the upper estuary and relatively shallow and therefore would be subject to much stronger freshwater influences than sites from other groups. Most estuarine species can cope with limited variations in salinity but in areas where fluctuations are excessive, such as in the upper reaches of a salt-wedge estuary, diversity is often markedly reduced with just a few species able to tolerate such extremes. The species information for this group supports this, with the freshwater tolerant gastropods *Arthritica semen* and *Tatea* sp. common in this group.

Table 15. Spearman correlations between biotic and abiotic data matrices. (H0 is that there is no relationship between the datasets).

Relationship	Rho statistic	Significance
Biota to metals	0.097	0.124
Biota to other abiotic factors	0.498	<0.001
Biota to all abiotic factors	0.302	<0.001

Group D community is also in the upper estuary and includes sites in Elwick Bay. Sulphide concentration was a strong determinant of the community structure in these 3 sites. The sites in this group had uniformly high levels of organic material in the sediments (Fig.14), which will generally result in strongly reducing conditions, and which will in turn influence species composition. It is interesting that total organic carbon content was not itself strongly correlated with the community composition, since carbon levels would strongly influence the reducing conditions in the sediments and levels were uniformly high at these sites. It must be assumed that other factors (i.e. current flow and particle size) influenced the sediment condition and resulted in the sulphide concentration being a better indicator of the community changes. Lead was consistently above the high trigger level (ANZECC, 2000) for all the sites in this group and were as highly correlated as sulphide concentration for this group of sites.

Table 16. Highest rank correlation coefficients between biotic and abiotic matrices for individual MDS groups.

Cluster Group	Correlation (Spearman)	Variables
B	1.000	Salinity
D	1.000	Sulphide or Lead
E	0.842	% silt-clay, depth, (Sulphide)
G	0.680	% silt-clay, depth,
H	0.410	Organic C, depth
F	Insufficient replication (only abiotic data for 2 sites)	
A,C	Insufficient replication (only single sites)	

The community which forms group E contains sites located towards the mouth of the estuary. This group was most strongly characterized (R=0.842) by environmental metrics which are closely aligned with the physical structure of the sediment (i.e. particle-size and depth). The sediment at these sites was generally relatively coarse (sand or muddy sand) (Fig. 13) and was relatively deep (15-22m) compared to the upper estuary. Depth also distinguished these sites from those in Ralphs Bay with similar sediment grain size.

Group G which contains the bulk of the Ralphs Bay sites is characterized by the same physical metrics as group E but the criteria differ. Although the particle size of the sites within this group was similar to that of group E sites (sand / muddy sand) the depth of the sites differed markedly as group E sites were all in less than 10m of water (Fig.11). The shallow depths, wind patterns and fetch in the bay may result in considerable sediment disturbance at these sites. Opportunists were quite strongly represented in the fauna for this group and there were less suspension feeding species than in other groups, which may reflect the potentially dynamic environment associated with these shallower conditions.

Group H had a relatively poor relationship to any of the measured environmental metrics. Sulphide concentration, depth and iron concentration had the best correlation at only R=0.342 (Table 16). This is not very surprising since this was a large group of sites encompassing a relatively broad range of environmental conditions. The community relationships between the sites within group H, the largest group of sites, in the middle of the estuary appeared to be largely differentiated on the basis of organic carbon content and depth. This once again suggests that the level of organic enrichment and position within the estuary are stronger determinants of community structure than the heavy metal loadings.

Unfortunately there was insufficient information to establish the relationship between the abiotic factors and the community structure underpinning groups A, B and F. The faunal relationship between group F and other groups, determined from the average dissimilarity percentage (Table 17), indicates that on the whole it was quite different from the other groups, but that of all the groups it aligned most closely with the fauna in groups G and H. The fauna in group F was not as diverse or abundant as in other groups (Table 18) but it was distinctive, comprised of opportunists and surface deposit feeders (Table 13). The abiotic summary information (Table 20) shows that the environment conditions associated with this group had the highest metal concentrations, with levels up to 110 times that of the high trigger levels. Clearly fauna can survive under these extreme levels of contamination, living both on and in the sediments and utilizing these highly contaminated sediments as a food resource. This raises some very interesting questions in regard to how these animals avoid any toxic effects and whether they represent significant bioaccumulation risks.

Table 17. Average dissimilarity between group F and other biotic cluster groups.

Cluster Group	Average Dissimilarity
A	99.51
B	89.23
C	92.80
D	90.23
E	93.73
G	86.30
H	87.16

As with Group F it was not possible to undertake the matrix comparison for groups A and C since these groups were composed of single sites. The biological information clearly showed the unique nature of these sites and the summary information supports the assertion that group A in the upper estuary near Bridgewater was in an area subject to extreme salinity fluctuations, periods of exposure and with high organic content (Table 19). Similarly, site 86 (Group C) was also in an area subject to periodic exposure and therefore the natural stresses of marked salinity, temperature and dissolved oxygen fluctuations. The faunal diversity at these two locations suggests that they were amongst the poorest in the system and the specific faunal compositions, outlined earlier, clearly reflect these naturally stressed conditions.

Table 18. Group mean diversity measures for biological cluster groups

Cluster Group	Shannon Diversity	No. of Spp	No. of Indiv.
A	1.524	8	1896
B	2.216	15	281
C	1.685	6	163
D	2.215	12	104
E	3.892	64	489
F	2.291	12	163
G	3.860	93	726
H	4.011	125	637

The correlations between the abiotic metrics within each of the biotic MDS groups indicate that some factors were quite strongly associated, but that there were differences between the MDS groupings (Table 19). The metals concentrations were strongly related in most groups. In group B (deeper areas of upper estuary) there was a strong positive correlation between all of the metals. Metal concentrations were at moderate levels in this group and appeared to covary both with sulphide concentration, organic content and the proportion of silt/clay in the sediments. Sulphide concentration and organic carbon levels were higher in this group than in any others, and this may affect the metals speciation and potentially the toxicity.

In group G (deeper sites in and around mouth of Ralphs Bay) the metals were again strongly inter-correlated, but in this instance there was no evidence of an associated correlation with sulphide concentration. Sulphide levels were much lower and redox was relatively high suggesting that these sediments were oxic (Table 20). The metal concentrations in this group were markedly lower than those in the nearby group H sites. Metal levels were still strongly correlated with the organic carbon content which suggests that what metals there were in the sediments were bound in the organic component of the sediments.

Although the concentrations of all metals in group H (majority of mid/lower estuary) were still quite high, the correlation between them was poor. Some of the lower concentration metals (As, Cd and Cu) as well as zinc were still highly correlated, whilst others, such as aluminium and mercury showed no relationship to the other metals, even though mercury levels were still comparatively high, and well above ANZECC guidelines (Table 20). There was no correlation between metal concentrations, sediment type, redox, sulphide or any other other abiotic factor. The fauna underpinning this group was consistent with that found in southern estuaries generally (Edgar et al., 1999a) and suggests that there was little, if any, biological disturbance. It is unfortunate that we do not have sufficient replication to evaluate the relationships between the abiotic factors at the most impacted sites (group F) as this may help to explain the relationships at very high concentrations.

In group E (towards the mouth of the estuary) the total metal concentrations were markedly reduced, but there was still a strong relationship between the metals. In this instance metal concentrations were negatively correlated with redox and salinity. Redox and salinity were consistently high in this group and the percentage silt/clay was low, indicating that the sediments were sandy, clean and well oxygenated as might be expected considering the more exposed/ fully marine conditions in this area. However, once again the strong correlation between the metal concentration and the organic carbon content suggests that the metals are mostly contained in the organic component of the sediment.

The overall correlations between metals, organic carbon content and redox/ sulphide suggest that metals may be affected by the oxic status of the sediments and that they are mainly associated with the organic component of the sediments. This in turn results in a relationship between metals concentration and the proportion of silt/clay, since the depositional nature of the system will influence the sediment chemistry (i.e. fine sediments will have more organics and may be more reducing). Previous studies have indicated that metals may be preferentially bound in finer organic rich sediments (Harrison et al., 1987) and that depositional environments will result in accumulation of contaminants (Gray, 1979), conversely it may be inferred that metals would be reduced in clean sands. In addition the bioavailability, and consequently the toxic effect of pollutants, such as heavy metals, can be influenced by environmental factors such as sediment geochemistry, pH, temperature and dissolved oxygen (Hansen et al., 1996.), (Levin, 2000).

Table 19. Correlations of abiotic metrics for each biotic cluster group where there was sufficient replication.

Group B

	Eh	Sulphide	%silt-clay	Org C	Depth	Salinity	Al	As	Cd	Cu	Fe	Mn	Pb	Zn	Hg
Sulphide	0.788														
%silt-clay	0.752	0.998													
Org C	0.902	0.976	0.963												
Depth	0.684	0.090	0.034	0.303											
Salinity	0.115	0.702	0.741	0.532	-0.646										
Al	0.463	0.910	0.932	0.800	-0.330	0.934									
As	0.668	0.984	0.993	0.923	-0.086	0.816	0.969								
Cd	0.444	0.902	0.924	0.787	-0.350	0.941	1.000	0.963							
Cu	0.565	0.953	0.969	0.866	-0.215	0.884	0.993	0.992	0.990						
Fe	0.662	0.983	0.992	0.921	-0.093	0.820	0.971	1.000	0.965	0.992					
Mn	0.852	0.994	0.986	0.995	0.202	0.617	0.858	0.958	0.847	0.913	0.956				
Pb	0.550	0.948	0.964	0.856	-0.233	0.893	0.995	0.989	0.992	1.000	0.990	0.906			
Zn	0.464	0.911	0.933	0.801	-0.328	0.933	1.000	0.969	1.000	0.993	0.971	0.859	0.995		
Hg	0.814	0.999	0.995	0.985	0.134	0.670	0.891	0.976	0.882	0.939	0.974	0.998	0.933	0.892	
Ca	0.554	0.949	0.965	0.859	-0.228	0.891	0.994	0.990	0.992	1.000	0.991	0.908	1.000	0.995	0.934

Group D

	Eh	Sulphide	%silt-clay	Org C	Depth	Salinity	Al	As	Cd	Cu	Fe	Mn	Pb	Zn	Hg
Sulphide	0.083														
%silt-clay	0.274	-0.935													
Org C	-0.639	-0.681	0.431												
Depth	-0.974	-0.006	-0.340	0.479											
Salinity	-0.987	-0.013	-0.337	0.522	0.998										
Al	-0.045	-0.705	0.664	0.785	-0.162	-0.108									
As	-0.079	-1.000	0.937	0.683	0.000	0.008	0.711								
Cd	-0.284	-0.936	0.803	0.633	0.268	0.258	0.455	0.933							
Cu	-0.368	-0.949	0.785	0.761	0.315	0.317	0.577	0.947	0.984						
Fe	-0.212	-0.868	0.763	0.884	0.040	0.081	0.948	0.871	0.706	0.806					
Mn	-0.201	-0.981	0.876	0.805	0.090	0.110	0.797	0.982	0.900	0.947	0.940				
Pb	-0.199	-0.964	0.859	0.621	0.173	0.166	0.508	0.961	0.995	0.979	0.740	0.924			
Zn	-0.574	-0.863	0.630	0.872	0.502	0.514	0.585	0.861	0.919	0.968	0.809	0.904	0.898		
Hg	0.836	-0.328	0.613	-0.449	-0.763	-0.798	-0.023	0.328	0.235	0.107	-0.016	0.161	0.303	-0.145	
Ca	-0.191	-0.953	0.852	0.838	0.054	0.082	0.869	0.955	0.836	0.902	0.977	0.991	0.865	0.873	0.110

Group H

	Eh	Sulphide	%silt-clay	Org C	Depth	Salinity	Al	As	Cd	Cu	Fe	Mn	Pb	Zn	Hg
Sulphide	0.038														
%silt-clay	-0.076	0.096													
Org C	-0.427	0.489	0.469												
Depth	0.144	-0.103	0.366	0.259											
Salinity	0.144	0.055	0.068	-0.200	-0.169										
Al	-0.146	-0.146	0.040	0.095	0.012	-0.342									
As	-0.413	0.012	0.072	0.297	-0.017	0.074	-0.061								
Cd	-0.460	0.027	0.079	0.343	-0.055	0.062	-0.046	0.994							
Cu	-0.519	0.049	0.133	0.447	-0.058	0.036	0.043	0.968	0.986						
Fe	-0.545	-0.036	0.385	0.581	-0.003	-0.216	0.588	0.388	0.454	0.576					
Mn	-0.389	-0.005	0.072	0.282	0.007	0.095	-0.047	0.997	0.987	0.959	0.376				
Pb	-0.499	0.017	0.158	0.410	-0.027	0.047	0.034	0.980	0.991	0.995	0.552	0.975			
Zn	-0.440	0.015	0.064	0.345	-0.036	0.085	0.001	0.991	0.994	0.986	0.463	0.989	0.990		
Hg	-0.069	-0.119	0.196	0.222	-0.040	0.012	0.346	0.133	0.135	0.209	0.316	0.149	0.197	0.174	
Ca	0.166	-0.258	-0.106	-0.384	0.191	0.237	-0.242	-0.044	-0.088	-0.152	-0.336	-0.020	-0.116	-0.082	0.014

Group E

	Eh	Sulphide	%silt-clay	Org C	Depth	Salinity	Al	As	Cd	Cu	Fe	Mn	Pb	Zn	Hg
Sulphide	0.031														
%silt-clay	-0.204	0.928													
Org C	-0.903	0.229	0.498												
Depth	-0.739	-0.362	-0.042	0.781											
Salinity	0.838	0.160	0.056	-0.729	-0.676										
Al	-0.840	-0.249	-0.113	0.735	0.755	-0.992									
As	0.920	-0.048	-0.347	-0.869	-0.685	0.561	-0.576								
Cu	-0.863	0.005	0.114	0.802	0.653	-0.985	0.966	-0.607							
Fe	-0.652	0.132	0.126	0.626	0.428	-0.918	0.873	-0.329		0.941					
Mn	-0.727	0.560	0.758	0.930	0.549	-0.568	0.544	-0.712		0.689	0.602				
Pb	-0.904	0.100	0.326	0.963	0.816	-0.874	0.880	-0.768		0.919	0.786	0.864			
Zn	-0.890	0.126	0.292	0.913	0.724	-0.929	0.917	-0.697		0.972	0.884	0.830	0.982		
Hg	-0.919	0.087	0.260	0.913	0.731	-0.939	0.928	-0.732		0.976	0.871	0.810	0.980	0.997	
Ca	-0.951	-0.248	0.024	0.875	0.900	-0.859	0.895	-0.849		0.850	0.626	0.643	0.914	0.876	0.900

Group G

	Eh	Sulphide	%silt-clay	Org C	Depth	Salinity	Al	As	Cd	Cu	Fe	Mn	Pb	Zn	Hg
Sulphide	-0.347														
%silt-clay	-0.398	-0.256													
Org C	-0.398	-0.205	0.938												
Depth	-0.012	-0.133	0.245	0.230											
Salinity	0.245	0.178	-0.607	-0.399	0.272										
Al	-0.209	-0.211	0.581	0.612	0.662	0.201									
As	-0.372	-0.067	0.666	0.872	0.313	0.060	0.643								
Cd	-0.373	-0.067	0.648	0.861	0.302	0.079	0.640	0.999							
Cu	-0.381	-0.074	0.675	0.876	0.321	0.059	0.663	1.000	0.999						
Fe	-0.363	-0.104	0.700	0.878	0.404	0.081	0.759	0.987	0.985	0.990					
Mn	-0.379	-0.070	0.652	0.861	0.318	0.086	0.657	0.999	1.000	0.999	0.988				
Pb	-0.374	-0.079	0.678	0.876	0.341	0.068	0.682	0.999	0.998	1.000	0.994	0.999			
Zn	-0.372	-0.068	0.651	0.863	0.307	0.079	0.646	1.000	1.000	0.999	0.986	1.000	0.998		
Hg	-0.362	-0.095	0.662	0.867	0.340	0.087	0.687	0.997	0.998	0.999	0.993	0.999	0.999	0.998	
Ca	-0.386	-0.089	0.626	0.832	0.431	0.106	0.672	0.982	0.983	0.982	0.976	0.983	0.983	0.983	0.985

Table 20. Mean and (standard error) for abiotic factors in each biotic cluster group. Redox in millivolts (mV), sulphide as micromoles (uM), depth in meters (m), salinity as parts per thousand (ppt) and all metal concentrations in milligram per kilogram (mg/kg).

MDS Group	Eh	S2	%silt/clay	Depth	Salinity	Al	As	Cd	Cu	Fe	Mn	Pb	Zn	Hg	Ca
A	31	66	86	1	<15	43500	39	10	103	38600	242	355	1210	4	7130
B	80	104	61	3	17	17523	45	14	118	21607	175	503	1538	4	4817
	(4.3)	*(5.8)*	*(3.5)*	*(0.4)*	*(2.0)*	*(81.8)*	*(3.7)*	*(2.5)*	*(6.3)*	*(78.9)*	*(6.6)*	*(12.7)*	*(24.4)*	*(1.0)*	*(29.7)*
C	99	74	0	1	29	1240	1	2	2	901	7	13	96	1	405
D	77	84	80	3	22	23003	59	25	152	26475	192	641	2443	14	5998
	(2.7)	*(3.9)*	*(1.2)*	*(0.4)*	*(1.6)*	*(52.4)*	*(2.1)*	*(1.3)*	*(3.2)*	*(40.5)*	*(3.3)*	*(5.8)*	*(12.6)*	*(1.3)*	*(19.0)*
E	307	3	17	17	35	5238	8	1	2	5546	50	21	45	0	83980
	(4.6)	*(0.9)*	*(2.1)*	*(0.7)*	*(0.3)*	*(29.1)*	*(0.6)*	*(0.0)*	*(0.6)*	*(14.2)*	*(1.5)*	*(1.2)*	*(2.1)*	*(0.2)*	*(70.3)*
F	34	27	87	8	33	28800	979	323	1150	61950	3955	6685	45450	49	30425
	(8.1)	*(5.6)*	*(4.3)*	*(1.9)*	*(2.4)*	*(88.7)*	*(12.7)*	*(7.3)*	*(13.7)*	*(101.6)*	*(27.8)*	*(33.6)*	*(89.4)*	*(3.1)*	*(140.6)*
G	150	20	30	4	30	3119	25	12	51	6498	108	256	1560	4	5329
	(2.9)	*(1.8)*	*(1.9)*	*(0.5)*	*(0.73)*	*(20.9)*	*(2.4)*	*(1.8)*	*(3.6)*	*(35.3)*	*(5.5)*	*(7.7)*	*(21.1)*	*(1.1)*	*(32.5)*
H	127	16	75	18	34	16549	105	40	194	28967	624	973	5171	14	36031
	(1.7)	*(1.2)*	*(1.2)*	*(0.7)*	*(0.2)*	*(22.4)*	*(3.7)*	*(2.1)*	*(3.8)*	*(26.9)*	*(8.5)*	*(8.3)*	*(23.0)*	*(0.9)*	*(30.9)*

Zinc and mercury are arguably two of the most significant contaminants in the Derwent and there were similarities between the overall distributions of these metals (correlation r2=0.55), particularly where concentrations were high. The concentrations of these metals varied markedly between the various biotic groups (Table 20, Fig. 30, 31). In group E concentrations of both zinc and mercury were low. The highest concentrations of zinc were at sites close to the Zinifex plant (groups F and H). The sites in group D (upper estuary, intertidal) were uniformly higher in both metals than the other upper estuary sites (group B) or sites in group G, with the exception of site71 which was closer to Zinifex.

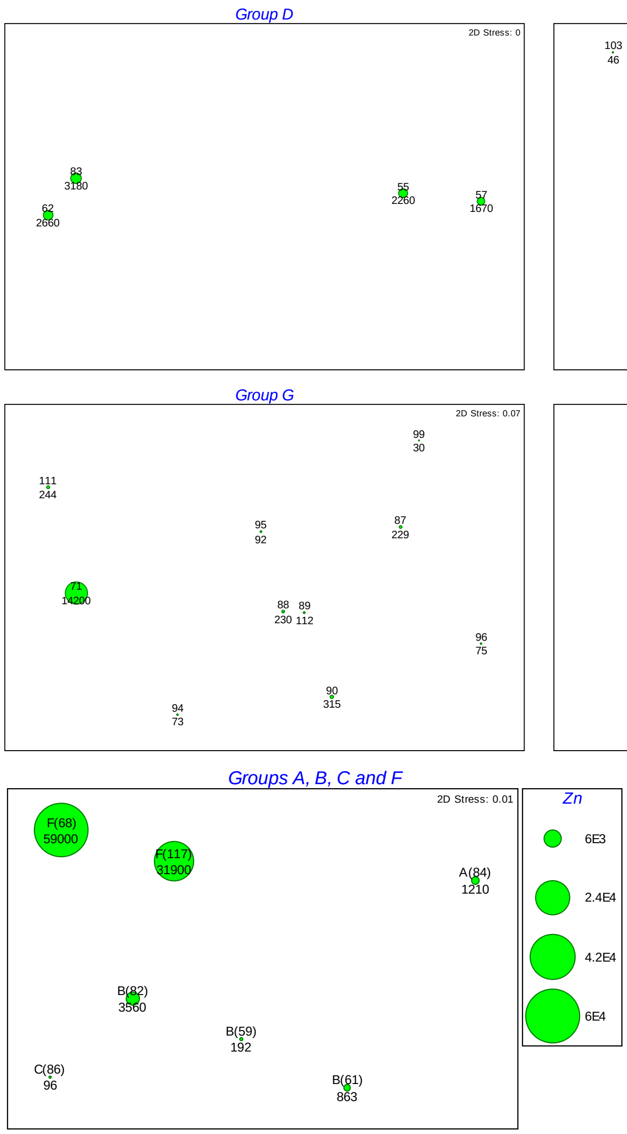


Fig. 30. MDS ordination of biotic data for each cluster group with zinc levels (log transformed) superimposed. Group D (low upper estuary), H (Mid/lower estuary), E (mouth), G (Ralphs Bay) and groups A, B, C and F combined.

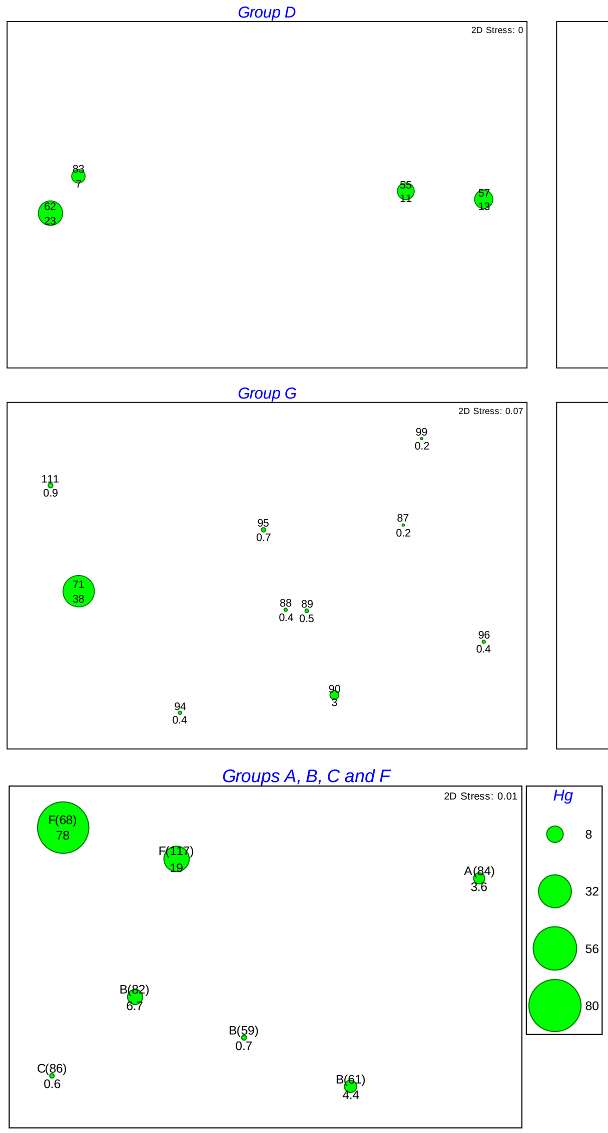


Fig. 31. MDS ordination of biotic data for each cluster group with mercury levels (log transformed) superimposed. Group D (low upper estuary), H (Mid/lower estuary), E (mouth), G (Ralphs Bay) and groups A, B, C and F combined.

All of the physico-chemical and biotic information so far suggests that characterization of the faunal communities is largely as a result of the sediment type and organic content and can therefore be broadly determined by geographic location within the estuary. Clearly although the “a priori” zonation of the estuary on the basis of information on hydrography and sediment type does broadly reflect the community differences, the true community boundaries and hierarchical relationships do differ from that original model.

Although there were many similarities between the community groups, indicating that the community changes were gradual rather than clear distinctions of any particular areas, there were also some good indicators for these communities (Table 21). Group A was differentiated by several unique and abundant species but unfortunately as it only contained a single site it would be inappropriate to derive any specific indicators from this group. However, data from previous studies suggest that the situation at site 84 may be indicative of conditions further up the estuary (Aquanel, 2000). There was a lot of variability in the remaining upper estuary sites but overall the communities were quite distinct from those of the mid/lower estuary groups and it would be relatively easy to differentiate these two generalised regions. Clearly distinguishing zones in the lower/mid-estuary would be more difficult as there was considerable overlap in the species composition, with much of the difference being a result of changes in relative abundance. However, brittle stars (*Amphiura* sp.) seem to be important indicators of relatively unimpacted conditions, which is consistent with the findings of previous local studies on the environmental effects of organic enrichment (Macleod et al.2004, (Crawford et al., 2002).

Table 21. Characterising species for main cluster groups/communities; + indicates presence of species, * indicates species characteristic of the group (SIMPER), ** indicates present in markedly greater abundance compared with other groups.

Region	**Upper Estuary**				**Lower**	**Impact**	**R.Bay**	**Low/Mid**
Species/Group	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**
Nephtys australiensis		+	+	*		+	*	+
Mediomastus australiensis		*		+	+	+	*	+
Apelochaeta sp.1						*	+	+
Spionid sp.9	**				+		+	
Ampelisca euroa				+	+		+	**
Haustoriidae sp.1					+			
Gammaropsis sp.1					*			+
Paracorophium excavatum	**				+		+	+
Euphilomedes sp. (MoV18)					*	+	+	+
Macropthalamus latifrons				*			+	+
Nassarius nigellus				+		+	*	+
Tatea sp.	**							
Arthritica semen	**	+		+			+	+
Nemertea sp.1	+				+	+	+	*
Amphiura elandiformis								+
Amphiura sp.2					+			+
Euchone limnicola		+			+	+	+	+
Corbula gibba					+	+	*	+
Theora fragilis							+	+

Surprisingly metal loadings do not appear to be a significant determinant of the benthic infaunal composition in the Derwent. All of the physico-chemical and biotic information suggests that characterization of the faunal communities is predominantly as a result of the sediment type and organic content and can largely be determined by location within the estuary. The Derwent has a relatively diverse fauna consistent with that found elsewhere in southeastern Tasmania (Edgar et al., 1999a,b). The lowest diversity was in the upper reaches and in areas subject to tidal emersion. The upper estuary contained species commonly associated with areas of organic enrichment and several opportunistic species.

Historic inputs of wood fibre from the Boyer newsprint mill have had a significant effect on the organic content of the sediments in the upper Derwent (Green and Coughanowr, 2003). Although loadings have been markedly reduced in recent years, the residual material has still been found to have a structuring influence on the benthic infauna in the estuary above the Bridgewater causeway (NSR, 2001). The fauna in the upper Derwent sites from the current study was consistent with that of this previous study (NSR, 2001) and suggests that the wood fibre enrichment extends beyond the Bridgewater causeway.

In the upper estuary where the sediments tended to have high organic content the greatest proportion of the fauna were infaunal deposit feeders or opportunistic scavengers. The latter were particularly prevalent where tidal exposure occurred. Suspension/filter feeders were rare, possibly due to increased suspended sediment loads in this region inhibiting their ability to feed. In the mid-lower estuary there was a greater proportion of surface deposit feeders, although many of these were tube dwelling and therefore would still represent an important source of bioirrigation. Suspension feeders were present throughout the mid-lower estuary, although many of these were species which could alternate between suspension and surface deposit feeding depending on the prevailing environmental conditions. Introduced species were an important feature in the Derwent and are dealt with separately in section 3.5.

Comparing information on the estuary usage, differences in the abiotic measures and the biology and ecology of the dominant fauna it is possible to categorise the various community groups according to potential impact levels (Table 22) and the distribution throughout the estuary of these various categories is shown in Fig.32.

Table 22. Likely impact ranks of community groups in Derwent.

Community Group	Likely Impact Rank	Rank Descriptor
A	4.1	Organic enrichment
B	2.2	Upper estuary (natural & anthro.stress)
C	3.3	Moderate impact (intertidal & mixed)
D	2.1	Low-moderate impact (intertidal)
E	1.2	Normal marine community
F	3.2	Moderate impact (anthropogenic)
G	3.1	Moderate impact (mixed source)
H	1.1	Normal estuarine community

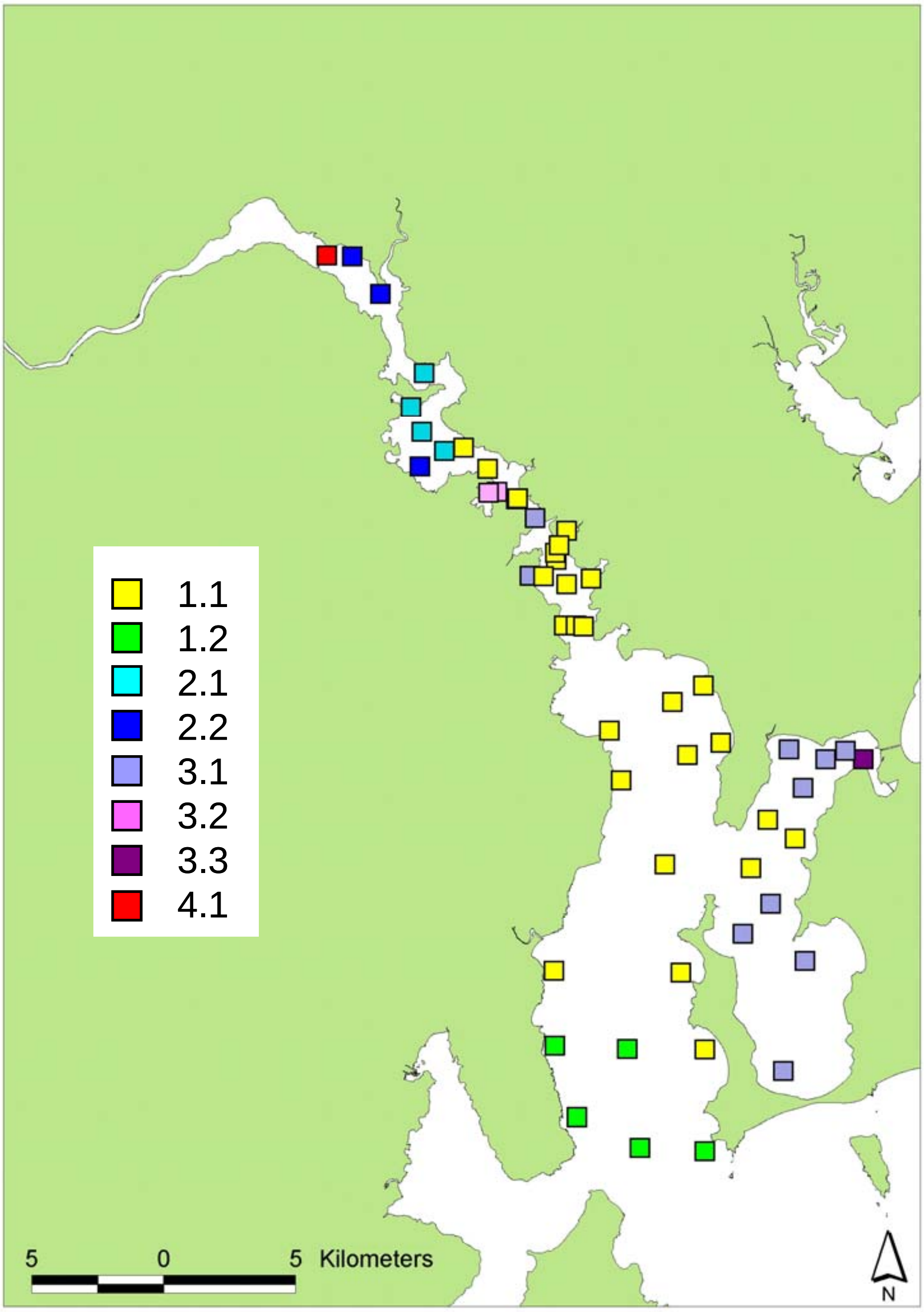


Figure 32. Distribution of biotic community impact ranks in Derwent.

3.4 Ecological Comparisons of the Huon and Derwent Estuaries

The Derwent and Huon estuaries are very similar in structure and function. They are both highly stratified salt-wedge estuaries in a microtidal region, although the Derwent is a wave dominated system whilst the Huon is intermediate between wave-dominated and tide-dominated (Butler, in press). The main distinction between the two systems is with respect to urban usage. The Huon is largely undeveloped, aquaculture being the only significant industry in the lower estuary. The Derwent on the other hand is a highly industrialized urban estuary with several significant pollution sources, in particular a zinc smelter and newsprint mill as well as the city of Hobart (population approx. 190,000) along its banks. Information on the biological status of these estuaries is very limited. Edgar et al. (1999a,b) classified the estuaries of Tasmania using a range of geographical, physico-chemical, biological and socio-economic factors. In this model the Huon and Derwent were both categorised as class C estuaries, i.e. estuaries with only moderate conservation significance, however, it was noted that the Huon in particular had a very diverse fauna. This classification was strongly based on the physical geomorphology, hydrology and anthropogenic usage; the biological information played a relatively small part in the overall classification. Infaunal samples were only collected from 4 zones in the Derwent and 3 in the Huon. However, it does suggest that the Huon has the potential to be an appropriate biological reference for the types of infaunal communities that might be expected in the Derwent if the anthropogenic inputs were not present.

With respect to the "a priori" zone distinctions identified for each individual estuary the findings indicated that there were significant differences between zones in both estuaries in diversity ($F=3.771$, $p=0.001$) and in number of taxa ($F=3.080$, $p=0.005$), (Fig.33). A large part of this distinction could be attributed to significantly lower levels of both measures in the upper Derwent. Abundance did not differ significantly between the groups. Although overall mean abundance was elevated in the upper Derwent group, the levels at the individual sites within this group were highly variable.

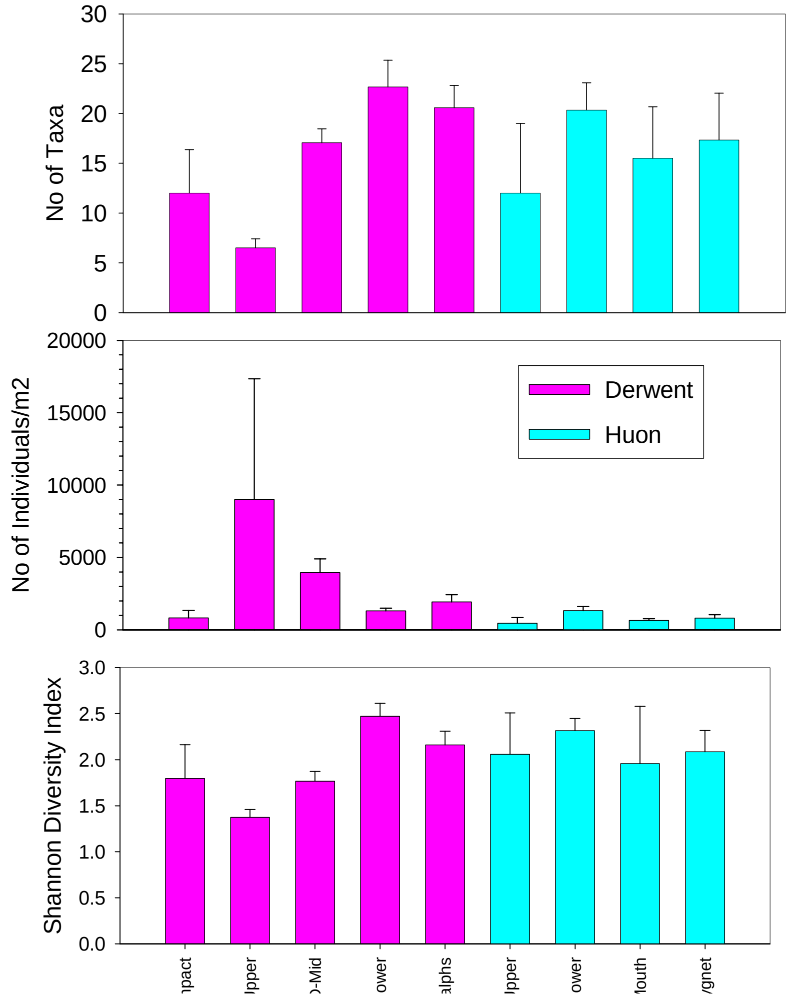


Fig. 33. Number of taxa, number of individuals and Shannon diversity for all "a priori" regions in the Derwent and Huon estuaries.

Although multivariate ordination of the biotic data shows some areas where there were distinct differences between the two systems, there was generally considerable overlap of the two data sets suggesting strong community similarities (Fig.34). Cluster analysis shows more clearly the areas of distinction and concordance (Fig. 35). The upper estuary sites for the two systems remained largely separate and fell in to broadly similar groupings to those established for the individual estuarine systems. Cluster groups A, D and G represent the single sites, D84, H1 and H4, separated in the individual estuary analyses and the species underpinning these sites separations remained the same. Group B contains Huon sites H2 and H3, which at a similarity level of 20% would have been clustered together in the Huon assessment. This group was strongly characterized by the capitellid polychaete *Mediomastus australiensis*, a moderate level opportunist (Table 23). However, the emphasis on this particular species may have been biased by the overall low diversity and abundance at the sites in this group. Infaunal deposit feeders were the predominant functional group at these sites. These communities would have the capacity to significantly rework and oxygenate the sediments, and this corresponds with the abiotic information for this area which suggests that the sediment was well oxidised (section 3.1.2, Fig.16).

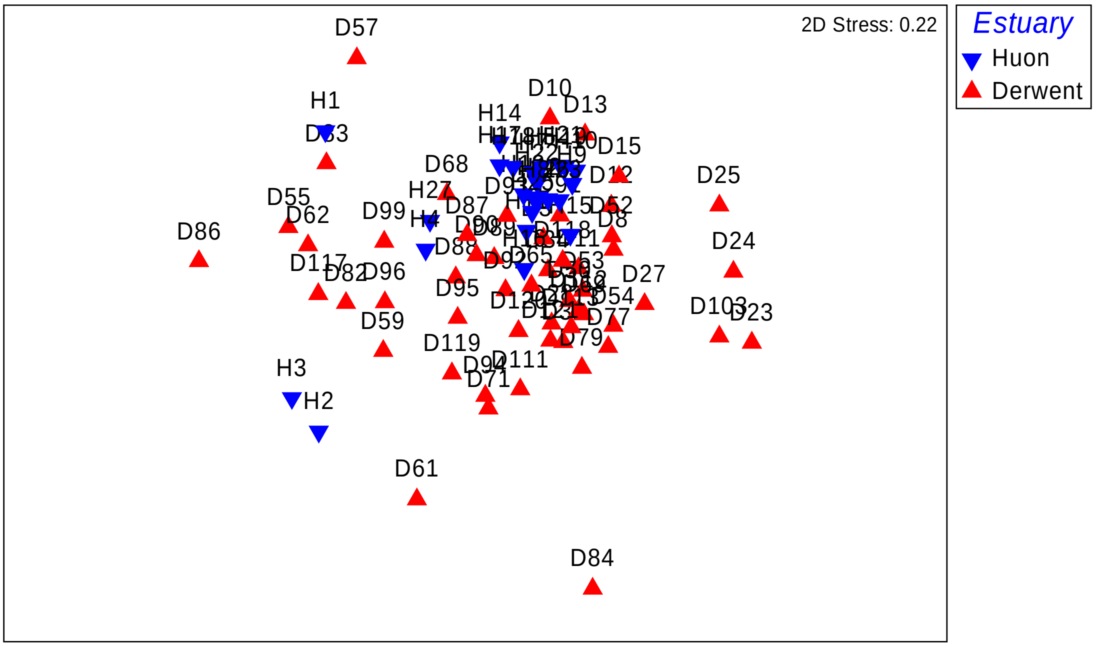


Fig. 34. Ordination of combined datasets for Huon & Derwent estuaries.

Group C contains Derwent sites D59 and D61, comparable to group B in the Derwent assessment. Groups E, F, I and K corresponds to groups D, C, E and G respectively in the Derwent evaluation. The species underpinning these groups are described in detail in the separate section on the Derwent (section 3.3). Group H contained 2 sites which had "a priori" been distinguished as potential impact sites (D119 and D68). Group H was characterized by a disturbed fauna dominated by benthic opportunists indicating that these sites were indeed impacted (Table 23).

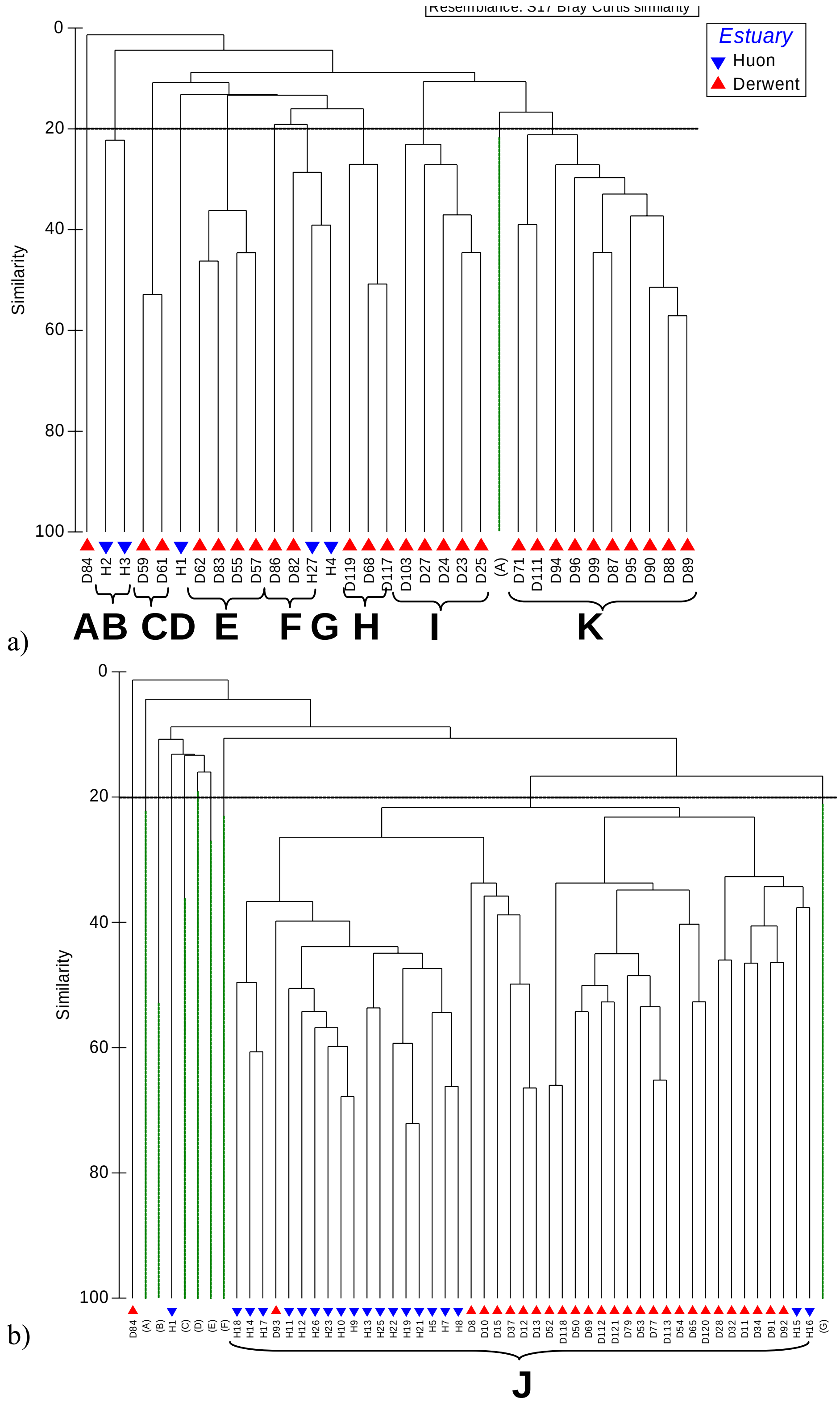


Fig. 35. Cluster analysis of all Huon and Derwent sites. Groupings shown are those where within group similarity levels are greater than 20%, a) details of groups A – I and K, and b) detail of sites within group J.

Table 23. Average abundance and relative % contribution to within group similarity of most important characterising species for biotic groups B, C, E, F, H, I, J and K (20% overall similarity groups) (Habit key: IB-infaunal bioturbator, EO-epibenthic opportunist, II-infaunal bioirrigator), (Function key: DF-deposit feeder, SDF- surface deposit feeder, SS- suspension feeder, C –carnivore, H- Herbivore, OS-opportunistic scavenger). Groups A, D and G were only single sites with few species but have used species information to define dominant group, habit and function.

Group	Species	No/m2	Contrib	Group	Habit	Function
B	*Mediomastus ausraliensis*	57	100	Polychaete	IB	DF
C	Phoxocephalidae *spp.*	464	24.48	Amphipod	IB	DF
	Arthritica semen	301	16.63	Mollusc	EO	SDF
	Mediomastus ausraliensis	78	3.92	Polychaete	IB	DF
E	*Macrophthalmus latifrons*	93	56.19	Crustacean	EO/IB/II	SDF/H
	Nephtys australiensis	85	24.20	Polychaete	IB/EO	C/OS
F	*Aphelochaeta* sp.	227	66.80	Polychaete	IB	SDF
	Nephtys australiensis	46	8.32	Polychaete	IB/EO	C/OS
	Corophium ascherusicuum	38	8.32	Amphipod	II	SDF/SS
H	*Mediomastus ausraliensis*	134	45.16	Polychaete	IB	DF
	Nephtys australiensis	112	41.83	Polychaete	IB/EO	C/OS
	Nemertea *sp.1*	80	13.01	Nemertean	IB	C
I	*Euphilomedes* sp. (MoV 18)	93	13.02	Ostracod	IB	DF
	Gammaropsis sp.	160	10.98	Amphipod	II	SDF/SS
	21149	70	7.38			
J	Nemertea *sp.1*	138	15.51	Nemertean	IB	C
	Euphilomedes sp. (MoV 18)	125	10.19	Ostracod	IB	DF
	Corbula gibba	96	7.74	Mollusc	IB	SDF/SS
K	*Mediomastus ausraliensis*	283	21.67	Polychaete	IB	DF
	Nassarius nigellus	150	17.82	Mollusc	EO	SDF/OS
	Nephtys australiensis	118	11.87	Polychaete	IB/EO	C/OS

Group	Dominant Group	Dominant Habit	Dominant Function
A	Mollusc, Amphipod	II, EO	DF, C/SDF, OS
D	Polychaete, Molusc	IB, EO	DF, C/SDF, OS
G	Polychaete, Mollusc	IB, EO	DF, C/SDF, OS

The greatest ecological similarities were in the lower estuary regions of both systems. Group J represents a mix of Huon group F and Derwent group H sites and was the largest community group containing 45 sites and encompassing a broad range of sediment conditions. This group comprised a functionally diverse fauna containing infaunal and epibenthic deposit feeders as well as suspension and filter feeders which in turn represent a broad mix of both sediment stabilizing and destabilizing (bioturbating) species. This will result in an environment where the sediments are well oxygenated but with a level of stability which allows for a highly complex and successionally well developed community. There were species in this community, such as brittlestars and ampeliscid amphipods, which have previously been found to be sensitive to polluted environmental conditions, particularly organic enrichment (Rosenberg et al., 1997, Macleod et al., 2004) which suggests that the ecological impact in this region is low.

Introduced species were featured in most community groups, within group J they were present at low levels and on the whole had relatively localized distributions (refer section on introduced species). There were also several species which are considered to be tolerant of organic enrichment (*Euphilomedes* sp,(MoV18) and *Mediomastus australiensis*). It is worth noting that species such as *Capitella capitata*, which is commonly associated with areas of high environmental disturbance, including organic enrichment and metal contamination, were not found in abundance in any of the community groups even at the sites where an impact was expected.

Group J suggests that there are areas within the two estuaries which have an equivalent community structure. However, the overall similarity level at which these sites were aggregated was relatively low (approx. 20%). At higher orders of separation the Huon & Derwent estuaries can still be discriminated (Figure 36, 37). At 23% overall similarity the mid-Derwent sites (J3) are distinguishable from all the other sites. Four community sub-groups form at an overall similarity level of 27%, these clearly distinguish the lower Derwent and majority of Ralphs Bay sites (J4) from the lower Huon estuary and Cygnet Bay sites (J1) and separates the lower Derwent sites into 2 groups (J2 and J4) with sites H15 & H16 (Huon Group E) at the mouth of the Huon estuary retaining a strong similarity (approximately 35%) to sites in the lower Derwent and near the mouth of Ralphs Bay (J4).

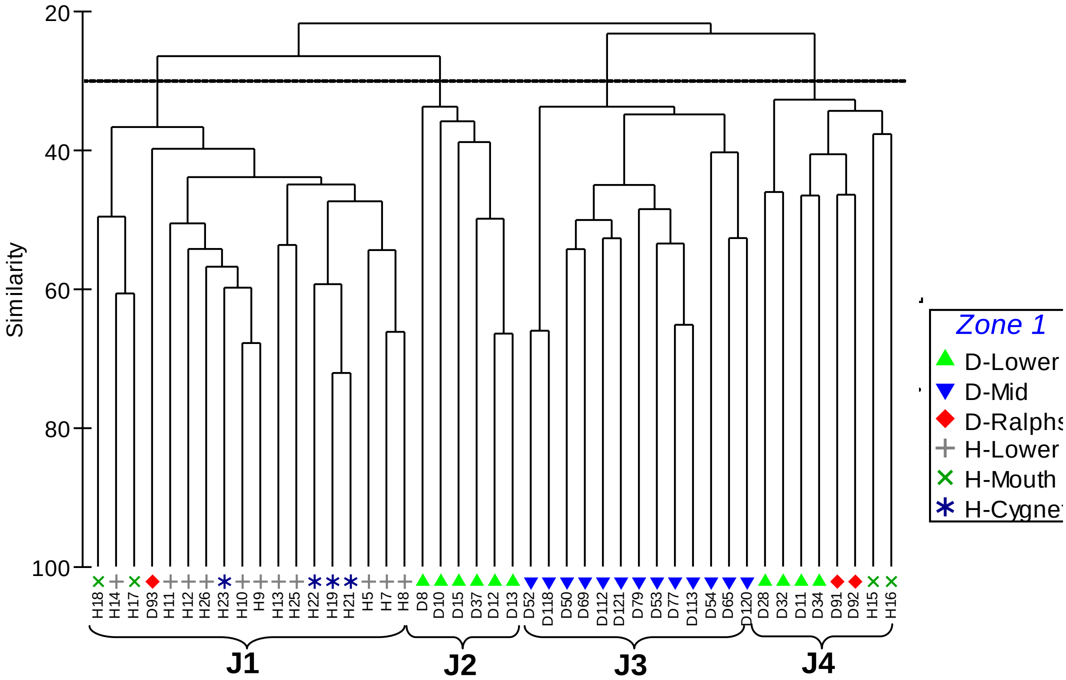


Fig. 36. Cluster analysis of subgroup J sites. Groupings shown are those where within group similarity levels are greater than 30%.

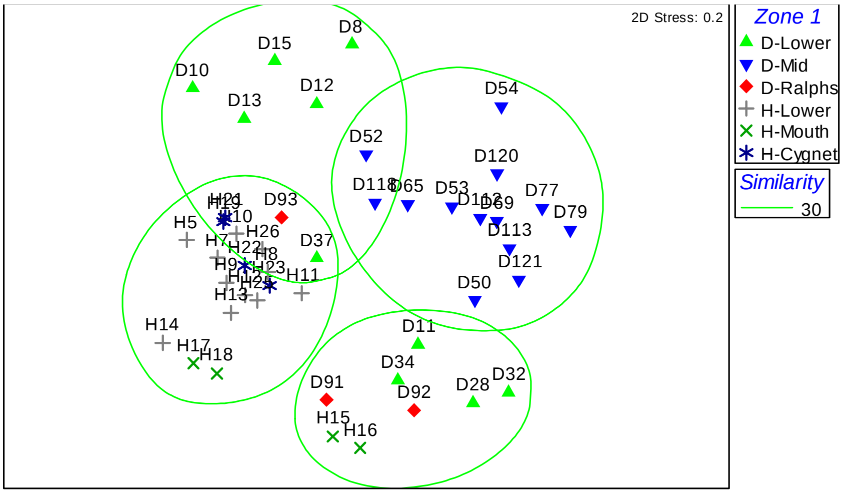


Fig. 37. Ordination of group J sites. Groupings shown are those where within group similarity levels are geater than 30%

Although in principle it is possible to differentiate these groups at increasingly higher similarity levels, in reality separating the communities beyond the initial groupings (A-K) would be very difficult. SIMPER analysis shows that the differences between the J sub-groups were relatively minor, resulting from changes in relative abundance of species rather than species distinctions (Table 24). As the species composition of each of the sub-group communities was very similar, it is likely that these areas function in an ecologically similar manner. Consequently, for the purposes of this study the communities could be considered equivalent.

Table 24. Relative abundances of 3 species which contribute most to the separation of the subgroups (SIMPER analysis).

Species			**Av.Dissim.%**	**Cum.%**
	J1	**J2**	**73.59**	
Theora lubrica	2.15	15.05		8.55
Euphilomedes sp. (MoV18)	12.55	3.04		15.44
Nucula pusilla	3.57	13.61		22.26
	J1	**J3**	**78.56**	
Ampelisca euroa	0.55	23.09		9.91
Euchone limnicola	3.26	25.80		16.33
Euphilomedes sp. (MoV18)	12.55	9.29		20.94
	J1	**J4**	**76.59**	
Ampelisca euroa	0.55	14.92		5.35
Asychis sp. (MoV907)	0.48	12.73		10.40
Euphilomedes sp. (MoV18)	12.55	1.92		14.57
	J2	**J3**	**79.88**	
Ampelisca euroa	3.12	23.09		9.67
Euchone limnicola	0.64	15.80		17.27
Nucula pusilla	13.61	0.30		23.86
	J2	**J4**	**79.97**	
Asychis sp. (MoV907)	0.64	12.73		5.13
Theora lubrica	15.05	1.92		10.20
Ampelisca euroa	3.12	14.92		14.70
	J3	**J4**	**76.84**	
Ampelisca euroa	23.09	14.92		5.24
Euchone limnicola	15.80	2.12		4.78
Asychis sp. (MoV907)	1.62	12.73		4.43

The distinction between group J and the other groups (A-K) is quite marked. Ignoring the single sites as anomalous, then there were clear differentiations between the groups (Table 23). The combination of factors which best describes the overall community distinctions between the 2 estuaries was redox, sulphide concentration, depth and total organic carbon content with a Spearman rank correlation of 0.444 (Table 25). As was the case for each of the individual estuaries it is broader environmental factors that appear to be driving the changes in community composition rather than any specific contamination variables.

In the J subgroups heavy metals seem to play a greater role although the best overall correlation between the abiotic and species datasets was still weak (Rho=0.459) (Table 25).

Table 25. Rank correlations between the biotic and environmental datasets for a) full dataset an b) J subgroup.

Correlation	**Variables**
0.444	Redox, Sulphide, Depth, Organic C
0.440	Redox, Sulphide, Organic C
0.436	Redox, Sulphide, Depth, Organic C, Iron

0.433	Redox, Sulphide, Depth, Organic C, Calcium

a)

Correlation	Variables
0.459	Sulphide, Organic C, Fe, Hg
0.452	Sulphide, Cu, Fe, Mn, Pb
0.450	Sulphide, Cu, Fe, Pb
0.449	Sulphide, Cu, Fe, Pb, Zn

b)

Areas of natural and human induced stress could be identified in each estuary. In the upper reaches of both systems areas of organic enrichment and salinity stress were a common feature. However, these stressed communities differed in their faunal compositions (Fig 38). It was in the unimpacted areas that the two estuaries had the greatest similarity. The communities associated with the mid-lower estuary regions in each system were ecologically quite similar, with several species common to both estuaries including some such as *Mediomastus australiensis* and *Nephtys australiensis* which are considered ubiquitous in south-eastern Australia (Poore, 1982).

As outlined in previous sections the community changes throughout the estuaries were gradual and largely in response to natural environmental gradients. However, several species were sufficiently localized in their distribution to be effective indicators of particular community groups or environmental conditions (Table 26). Groups within the upper estuary regions of both systems were perhaps the most distinctive, and it would be a relatively simple task to differentiate samples from these groups. It would be harder to distinguish the lower estuary communities on presence/absence data. However, a weight of evidence approach using a suite of species would go a long way to categorizing these sites. Introduced species were also significant indicators of particular regions within each estuary and are dealt with in more detail in section 3.5.

Table 26. Characterising species for main cluster groups; + indicates presence of species, * indicates species characteristic of the group (SIMPER), ** indicates present in markedly greater abundance compared with other groups.

Species/Group	A	B	C	D	E	F	G	H	I	J	K
Crustacea											
Ampelisca euroa									+	**	+
Euphilomedes sp.(MoV18)							+	+	*	+	+
Gammaropsis sp.1									+	+	
Macropthalmus latifrons					*					+	+
Paracorophium excavatuum	**								*	+	+
Spiondae sp.9	**								+		+
Mollusca											
Arthritica semen	**				+						
Corbula gibba								+	+	+	*
Nassarius nigellus				*	+			+		+	*
Nemocardium thetidis				*							
Tatea sp.	**										
Theora fragilis										+	+
Polychaeta											
Apelochaeta sp.1								*		*	+
Euchone limnicola		*	+						+	+	+
Leitoscolplos bifurcatus		**					+				
Mediomastus australiensis		*	*		+		+		+	+	*
Nephtys australiensis			+	*		*	*	+		+	*
Notomastus sp.				*							
Sthenelais pettibonae							+				
Echinodermata											
Amphiura elandiformis							+			+	
Amphiura sp.1									+	+	
Other											
Nemertea sp.1	+						*	+	+	*	+

Contrasting the biological and physico-chemical data with the available information on human induced impacts within each estuary allows an evaluation of the likely ecological impact status of the community groups (Table 27) and the distribution of these impact ranks throughout the estuary (Fig.38).

Table 27. Potential impact ranks for combined community groups in Derwent and Huon

Community Group	Impact Rank	Rank Descriptor
A	4.1	High impact (Upper estuary–salinity & organic)
B	3.2	Moderately impact (Upper estuary–turbulent)
C	2.2	Minor impact (Upper estuary-salinity stress)
D	3.1	Moderate impact (Upper estuary-tidal)
E	2.1	Minor impact (Upper estuary-salinity stress)
F	4.2	Moderate-high impact (intertidal)
G	3.3	Moderate impact (Upper estuary –turbulent)
H	3.4	Moderate impact (anthropogenic)
I	1.2	Normal marine community
J	1.1	Normal estuarine community
K	2.3	Minor impact (Ralphs Bay-turbulent)

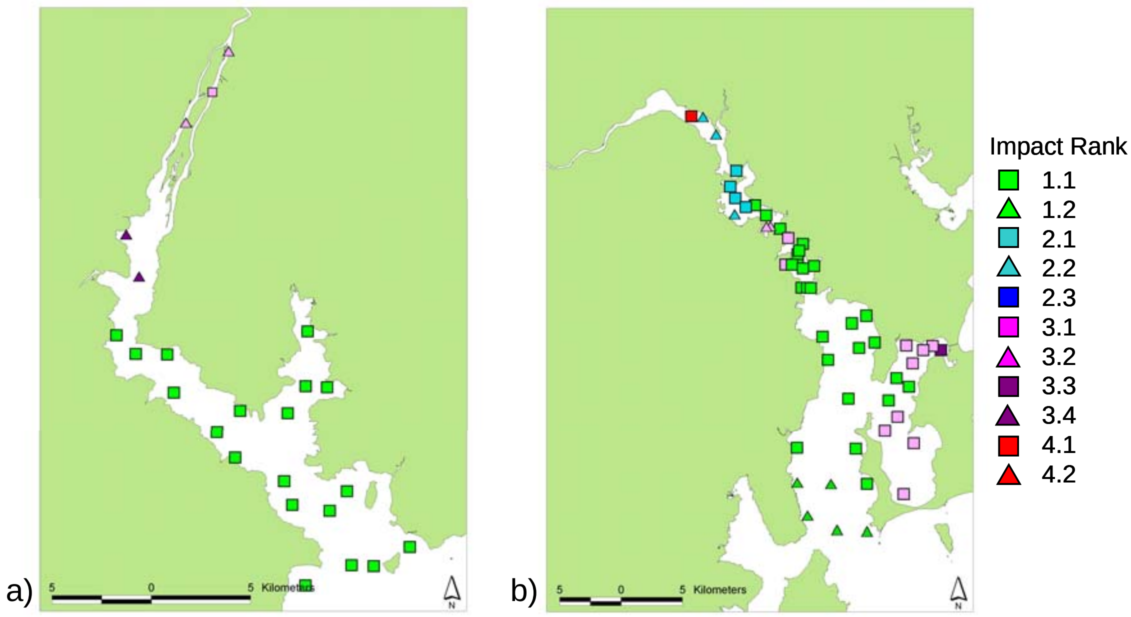


Figure 38. Distribution of overall biotic community impact ranks in a) Huon and b) Derwent estuaries.

3.5 Introduced Species Dynamics

Introduced species are a significant issue in the Derwent estuary. A recent survey by Aquenal (2002), commissioned by DPIWE and the Hobart Ports Corporation, identified 70 introduced species around the Hobart docks area. The final report on the status of exotic pests in the port of Hobart is available on-line (http://www.aquenal.com.au/reports.htm) and contains an excellent summary of the ecology, invasion history and potential impacts of these key introduced species.

Many of the introduced species in the list of 70 species are fouling organisms which would be associated with the physical structures within ports, others such as microalgae are pelagic whilst some are reef species and would not be found in unconsolidated sediments. If we restrict the list to those species which might be expected to colonise soft sediments then the total suite is reduced to a subset of 14 species, with only 3 target pests (Table 28). Information on the status of introduced pests in the Huon estuary is more limited. There is some information available through the baseline environmental surveys (Woods et al., 2004), which indicates that most of the common introduced and cryptogenic species found in the Derwent were also present in the Huon.

Table 28. Introduced and cryptogenic (unknown invasion status) species reported from the Derwent estuary (adapted from Green & Coughanowr, 2003).

Target Introduced Species	**Common Name**
Asterias amurensis	Northern Pacific seastar
Corbula gibba	European clam
Carcinus maenas	European shore crab
Other Species	**Status**
Molluscs	Introduced
Maoricolpus roseus	Introduced
Venerupis largillierti	Introduced
Neilo australis	Introduced
Theora lubrica	Introduced
Raeta pulchella	Introduced
Crustaceans	
Monocorophium ascherusicum	Cryptogenic
Monocorophium insidiosum	Cryptogenic
Jassa marmorata	Cryptogenic
Leptochelia dubia	Cryptogenic
Polychaetes	
Euchone limnicola	Introduced
Myxicola infundibulum	Cryptogenic

In the current study only 7 of the 14 introduced species previously recorded from the Derwent were identified (Table 29). Five species, *Asterias amurensis*, *Corbula gibba*, *Maoricolpus roseus*, *Theora lubrica* and *Euchone limnicola* were common to both systems, whilst *Corophium ascherusicum* and *Raeta pulchella* were only found in the Derwent (Table 29).

The sampling strategy in the current study was not specifically designed to sample for all introduced marine pests but rather to evaluate the distribution of the soft-sediment infaunal communities. The main sampling program was not designed to capture the distribution of large active epibenthic species such as crabs and starfish. It was hoped that the video surveys might be used to obtain information on the distribution of these species, but it must be recognised that this information was only semi-quantitative and the quality of the data was subject to the prevailing visual conditions. The European shore crab, *Carcinus maenas,* tends to be cryptic during the day, only coming out to feed at night. Consequently, the absence of *Carcinus maenas* from the sites sampled in the current study does not necessarily mean that it was not present in the estuary.

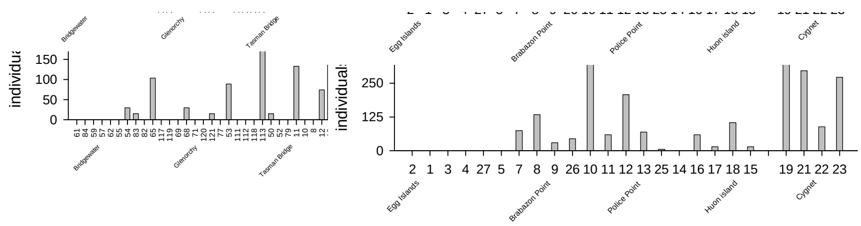
Table 29. Introduced and cryptogenic (unknown invasion status) species recorded from the Derwent and Huon estuaries in the present study.

Target Introduced Species	**Huon**	**Derwent**
Asterias amurensis	√	√
Corbula gibba	√	√
Carcinus maenas		
Other Introduced Species		
Molluscs		
Maoricolpus roseus	√	√
Venerupis largillierti		
Neilo australis		
Theora lubrica	√	√
Raeta pulchella		√
Crustaceans		
Monocorophium ascherusicum		√
Monocorophium insidiosum		
Jassa marmorata		
Leptochelia dubia		
Polychaetes		
Euchone limnicola	√	√
Myxicola infundibulum		

Venerupis largillierti was not encountered in this survey. This species had previously been reported from the Derwent by Greenhill (1965) and was found in very low abundances from 3 locations in the Hobart ports survey (Aquenal, 2002). The New Zealand bivalve, *Neilo australis*, was also not found in this study or in the Aquenal survey (2002), the only previous record of this species was from around Sandy Bay in 1965 (Greenhill, 1965). *Euchone limnicola* was a relatively common species in both systems whilst *Raeta pulchella* was restricted to the Derwent where it occurred sporadically (Table 29).

Video assessment appears to have been more useful than grab samples for evaluating the distribution of the introduced New Zealand screwshell, *Maoricolpus roseus*, since the video gave a better approximation of quantities for this large gastropod. Where there were large beds of *Maoricolpus* the shells often jammed in the grab jaws. However, it is important to note that the video footage does not distinguish live from dead shells. Video was also the most useful approach for determining the distribution of the introduced Northern Pacific seastar, *Asterias amurensis*.

The distribution of introduced species is not random but rather focussed on particular areas within each estuary (Figure 39). *Corbula gibba* was found at sites throughout the Derwent but was most abundant in the lower-middle estuary. *Corbula* was slightly more abundant in the Huon than in the Derwent with two population peaks, one in the middle estuary and another in Cygnet Bay. *Corbula gibba* was introduced to Australia from the Mediterannean and has become a significant component of many temperate Australian soft-sediment communities (Wilson et al., 1998). *C.gibba* is well adapted to live in unstable mixed muddy bottoms, dominating where physical-chemical and sedimentary parameters show large variations (Tomassetti et al., 1997) and where the sediments are unstable (Crema et al., 1991). It is a suspension-feeding bivalve (Moodley et al., 1998), which generally resides in the surface sediments; however,, it can exhibit a high degree of particle selection (Kioerboe & Moehlenberg, 1981). It is extremely tolerant of low oxygen conditions, even periods of partial anoxia (Christensen, 1970, Pearson and Rosenberg, 1978, Crema et al., 1991) and can survive levels of turbidity which would be prohibitive to many other suspension feeding species (Bonvincini-Pagliai et al., 1985). It is widely distributed in the estuaries of Northern Europe and the Mediterranean, and is often abundant in eutrophic areas at the edge of anoxic/azoic zones (Jensen, 1990). Early studies suggested that it was relatively long-lived (>5yrs) and slow growing (Jensen, 1990, Jones, 1956) but more recent studies suggest a life span of only 1-2yrs. Consequently, this species has the capacity to have a significant ecological impact wherever it becomes established.



a)

b)

c)

Raeta Huon
(Not applicable)

d)

Fig. 39. Distribution of introduced species a) Corbula gibba, b) Theora lubrica, c) Euchone limnicola and d) Raeta pulchella within the Derwent and Huon estuaries.

Theora lubrica originates from Japan and around the Korean peninsula. It has been widely reported around Australia and New Zealand (Wilson et al., 1998, Parry et al, 1997, Hayward et al., 1997) and is often amongst the dominant species in soft sediment communities (Hayward et al., 1997, Wilson et al, 1998). In Tasmania it has been officially reported from the Derwent, Kettering, Georges Bay, St Helens, Triabunna, Burnie & the Tamar, although it may be considerably more widespread. In its native range it is a selective deposit-feeder commonly found in soft sediments (Imabayashi, 1986) and has several features making it particularly suitable as an invasive species. It is known to be tolerant of organic pollution, high particulate organic matter sedimentation rates (Saito et al., 1998) and hypoxic conditions (Tamai, 1996, Lim & Park, 1998). Like *Corbula gibba,* it can rapidly recover from transient pollution episodes (Tanaka et al., 1979). However, it is perhaps slightly less robust than *Corbula gibba* since it is susceptible to freshwater input and reduced salinity which will decrease both its density and life expectancy (Poore & Kudenov, 1978). This life history trait affects its distribution and as can be seen in Figure 39, it is generally restricted to the lower middle and lower estuary, south of the Tasman Bridge, in the Derwent and to the lower estuary in the Huon where the conditions are fully marine.

Euchone limnicola is a small sabellid fanworm that lives in muddy sediments and uses mucous to build firm burrow walls (Cohen et al., 2001). Little is known about the biology of this species. It was amongst the most abundant species recorded in Port Phillip Bay (Wilson, et al, 1998, Currie & Parry, 1998) and was widespread in the Hobart port survey (Aquenal, 2002). In the current study it was mostly found in the upper to upper-middle Derwent, in areas where there was generally a relatively high level of disturbance and was locally extremely abundant (in excess of 2,000 individuals /m2). In the Huon *Euchone* was largely confined to the area just north of Police Point and abundances were significantly less than in the Derwent.

Raeta pulchella is a small bivalve native to South-East Asia (Boyd, 1999). In the present study it was only recorded from the Derwent and its distribution was extremely patchy, although where it occurred numbers could exceed 2-300/m^2. Once again there is little known about the biology or ecology of this species and so it is hard to predict what the potential local impact might be.

Maoricolpus roseus is a relatively large screwshell which has been introduced to Tasmania and other temperate areas within Australia from New Zealand. It occurs in a wide range of habitats, from sand through pebble and boulder to rocky reef although it appears to prefer relatively stable soft sediments (Allmon et al., 1994). Competitive interaction between *Maoricolpus roseus* and the native Tasmanian turritellid, *Gazameda gunnii*, is believed to have been responsible for the demise of the native species, which is listed as vulnerable under the Threatened Species Act 1995. *Maoricolpus roseus* often cluster together forming dense aggregations, which can significantly alter habitat structure, and in this instance dead shells can be as disruptive to the ecology as the living animals. *Maoricolpus roseus* distribution appeared to be more accurately reflected in the video footage than by grab sampling. Screwshells were most common in the middle estuary in the area between Kingston and the northern tip of South Arm (Fig.40).

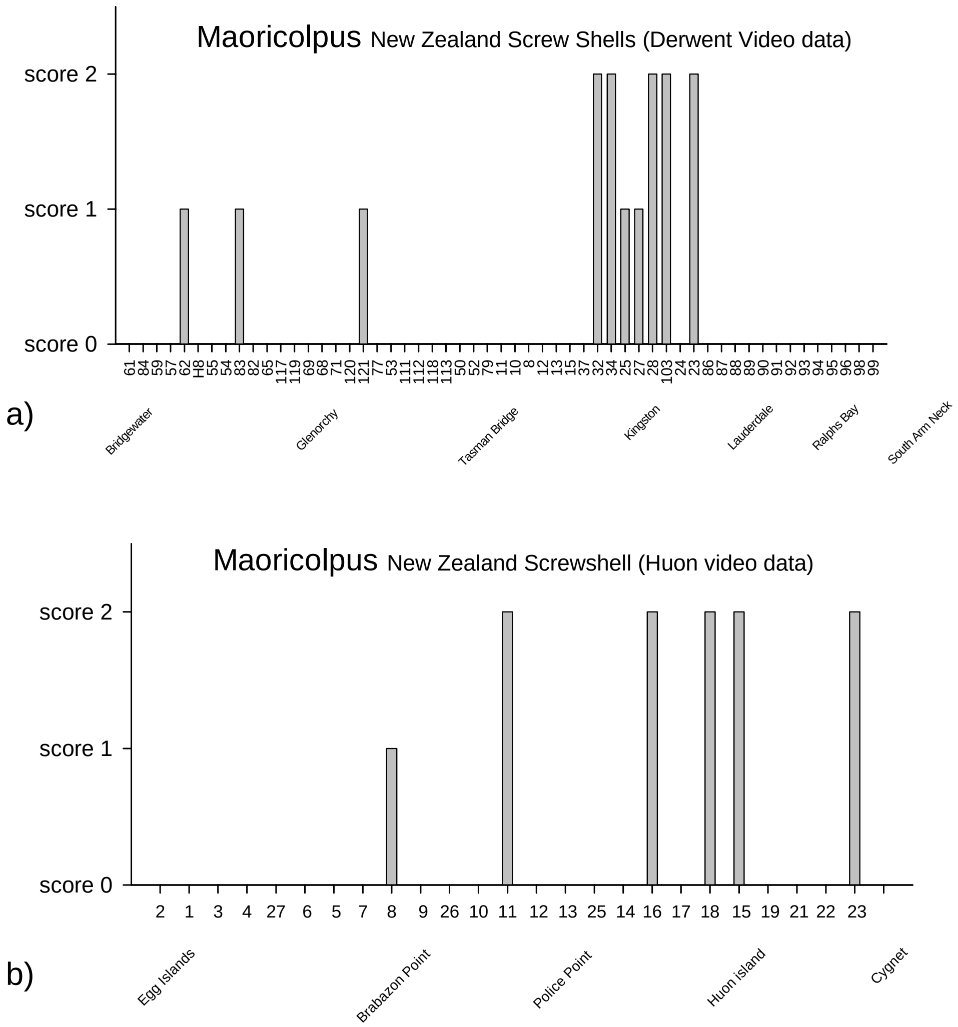


Fig. 40. Distribution and relative abundance of Maoricolpus roseus from video footage taken at sample sites in a) Derwent and b) Huon. Video score 0= not present, 1= few (1-2 individuals), 3= many (>2 individuals).

Asterias amurensis is believed to have spread to Tasmania in the early 1980s from its native range in the North Pacific (Turner, 1992). The seastar was subsequently translocated to Port Phillip Bay, where it is now very abundant (Cohen et al., 2001). *A.amurensis* is capable of colonising a wide variety of substrates, from reef to unconsolidated sand and mud. It is a voracious predator which has the capacity to significantly alter community composition in soft sediments, (Ross et al., 2003). *A.amurensis* distribution also appeared to be more accurately recorded through the video footage. The results show that the seastar was prevalent throughout the Derwent (Fig. 41). Only in the uppermost reaches, and in a band around Kingston, did there appear to be any reduction in numbers. *A.amurensis* was also relatively common in the Huon although its distribution appeared to be more localized with relatively discrete populations around Brabazon Point and Huon Island.

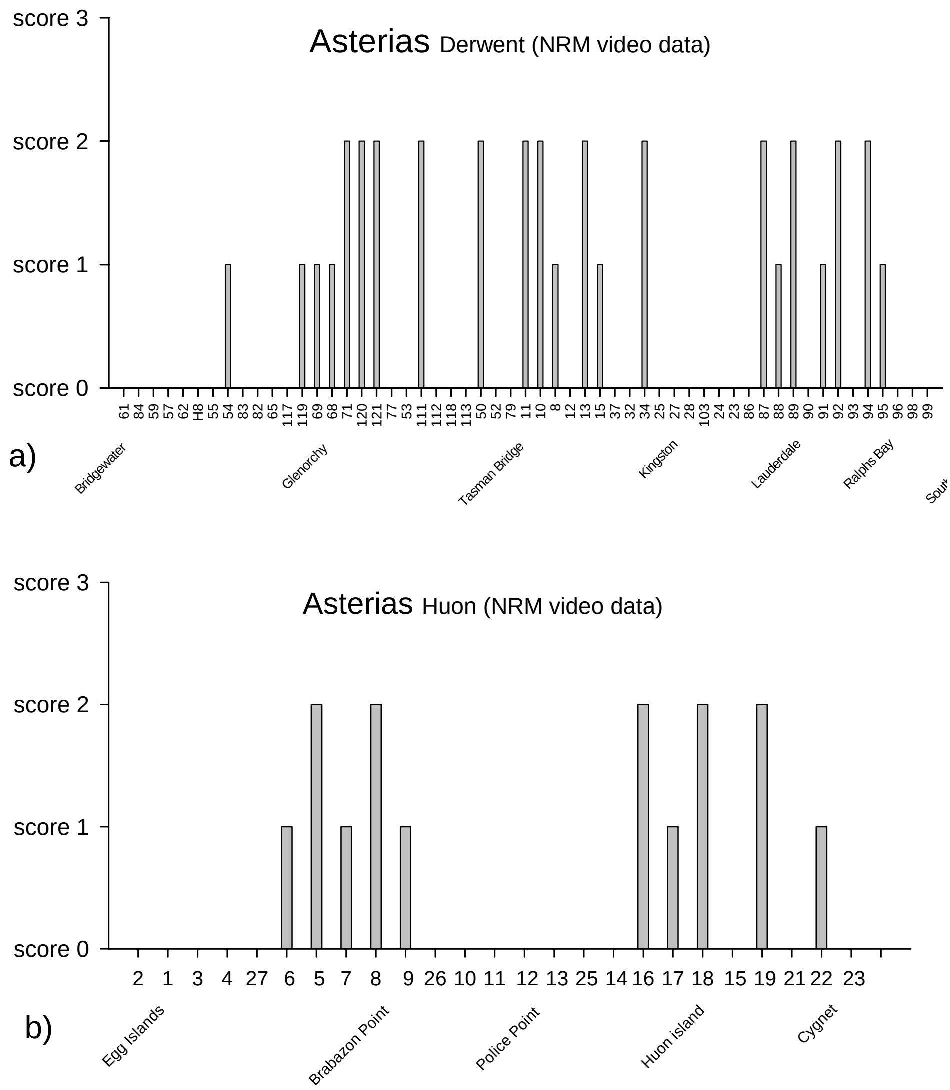


Fig. 41. Distribution and relative abundance of *Asterias amurensis* from video footage taken at sample sites in a) Derwent and b) Huon. Video score 0= not present, 1= few (1-2 individuals), 3= many (>2 individuals).

The abundance of introduced species was generally higher in the Derwent than in the Huon. *Euchone limnicola* was 10 times more abundant in the Derwent than the Huon, *Theora lubrica* was 5 times more abundant in the Derwent than the Huon, whilst *Raeta pulchella* was only recorded from the Derwent (Fig. 3939). In addition the distribution of these introduced species within each estuary was clearly not random, it varied both between and within the two estuaries. *Theora lubrica*, *Asterias amurensis*, *Euchone limnicola* and *Corbula gibba* were common and widespread throughout both estuaries. *Euchone limnicola*, *Maoricolpus roseus* and *Asterias amurensis* were present in equal proportions in each estuary (approx 40%, 20%, 40% respectively). However, *T. lubrica* was found in a greater proportion of sites from the Derwent (51%) than the Huon (32%). The inverse was true of *C.gibba* which was recorded from 68% of the Huon sites but only 35% of Derwent sites, whilst *R. pulchella* was only present at 15 % of the Derwent sites. These differences in abundance and distribution may be a result of environmental preferences, distribution relative to point of introduction or species interactions.

Depth and organic carbon content had limited effects on the abundance and distribution of the four key introduced species (*Corbula gibba, Theora lubrica, Euchone limnicola* and *Raeta pulchella*) (Fig. 42, 43). *T. lubrica* was present at all depths (0-50m), whilst *C.gibba* was not found at the deepest sites (>40m) and *R.pulchella* was largely restricted to sites around 20m (Fig. 3942). *E. limnicola* was also found at all depths but seemed to be most abundant in shallower areas (<15m). Since all of these species are suspension or deposit feeders, it is therefore not surprising that abundances were highest in areas where organic carbon levels were increased. Both *C.gibba* and *T. lubrica* appeared to thrive at organic carbon levels between 4% and 8%, *E. limnicola* was most abundant at levels between 6-8% whereas *R.pulchella* appeared to prefer still higher levels (8-10%). Interestingly none of these species appeared to have particular sediment particle size preferences as all species were found in both mud and sand sediments (Figure 44). Multiple regression of the metals concentrations with the four key introduced species indicated a high degree of colinearity in the metals data but no clear relationship between any of the four species and the sediment metal levels (Table 30). It is actually not very surprising that within the Derwent there were no clear environmental limits for these species since to be a successful introduced species they must be plastic in their habits and tolerances, and therefore able to exploit any environmental niche (Carlton et al., 1990). The environmental data for the Derwent suggests that the sediments were generally oxic (refer section 3.1.2) and that the metals although high were not toxic (refer section 3.3) which in turn suggests that the restricted distributions observed for these species may be related to the conditions surrounding the point of introduction or to competitive interactions with native and other species.

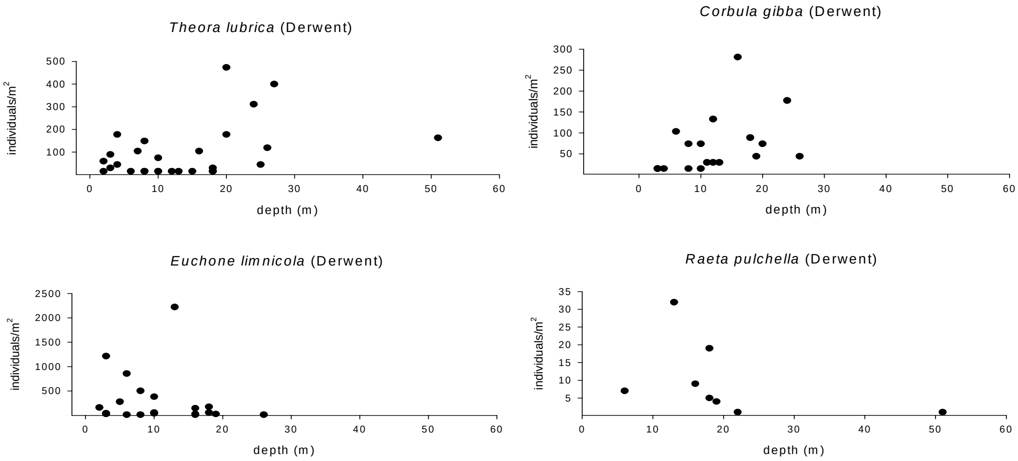


Fig. 42. Abundance versus depth distribution for 4 key invasive species in the Derwent (*Theora lubrica*, *Corbula gibba*, *Euchone limnicola* and *Raeta pulchella*).

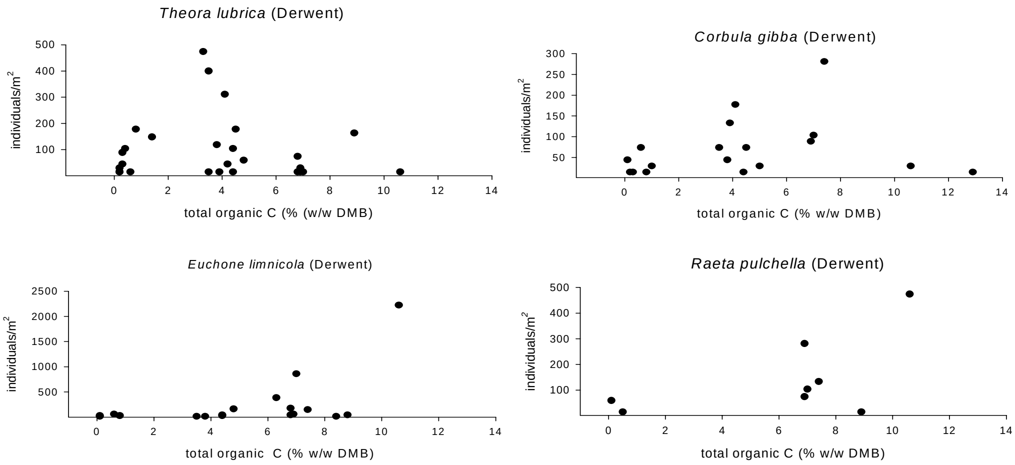


Fig. 43. Abundance versus organic content of the sediment for 4 key invasive species in the Derwent (*Theora lubrica*, *Corbula gibba*, *Euchone limnicola* and *Raeta pulchella*).

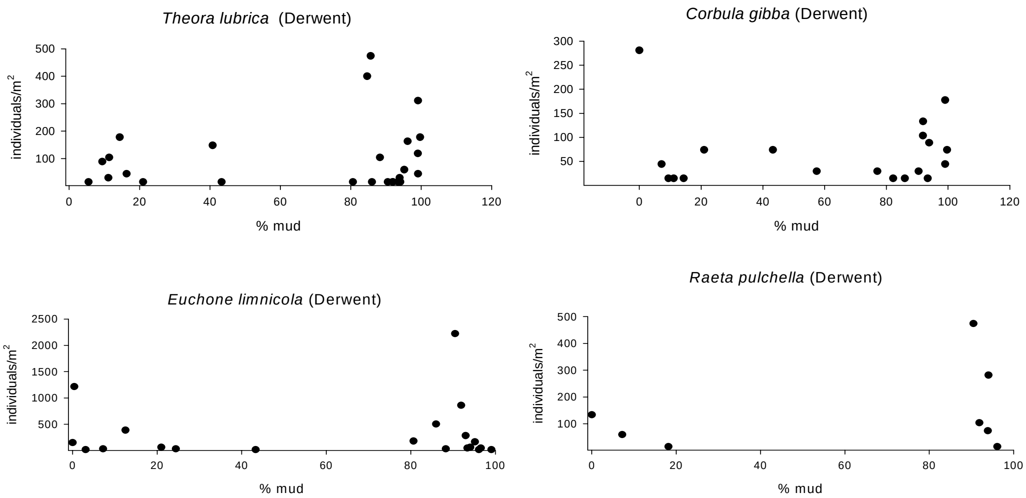


Fig. 44. Abundance versus % mud in the sediment for 4 key invasive species in the Derwent (*Theora lubrica*, *Corbula gibba*, *Euchone limnicola* and *Raeta pulchella*).

Table 30. Multiple regression parameters between metal concentrations (Aluminium, Arsenic, Cadmium, Copper, Iron, Lead, Manganese, Mercury and Zinc) and 4 key invasive species in the Derwent (*Corbula gibba, Theora lubrica, Euchone limnicola and Raeta pulchella*).

Species	Multiple r2	df	F	P
Corbula gibba	0.278	9,64	2.743	0.009
Theora lubrica	0.350	9,64	3.826	0.001
Euchone limnicola	0.208	9,64	1.868	0.073
Raeta pulchella	0.226	9,64	2.073	0.045

3.6 Evaluation of Video as Potential Monitoring Tool

Video footage from the Huon indicated a change in the visual features of the benthic environment throughout the estuary. The predetermined zones in the main estuary broadly characterised the main regions. Video footage taken in the upper Huon estuary was significantly different from that taken in the lower estuary (ANOSIM; R=0.494, P=0.018). Footage from the mouth was significantly different from both the lower estuary (ANOSIM; R=0.633, P=0.001) and Cygnet Bay (ANOSIM; R=0.450, P=0.024). Cygnet Bay had similarities with several of the zones from the rest of the estuary and did not differ from either the lower or upper estuary. The mouth of the estuary was similar to the upper estuary. These latter areas had similar grain size (coarser sediment types), which was visible in the video footage. They were also shallower, which would result in greater light penetration and potentially algae growth in these zones, a feature that would also be visually distinct (Fig.45).

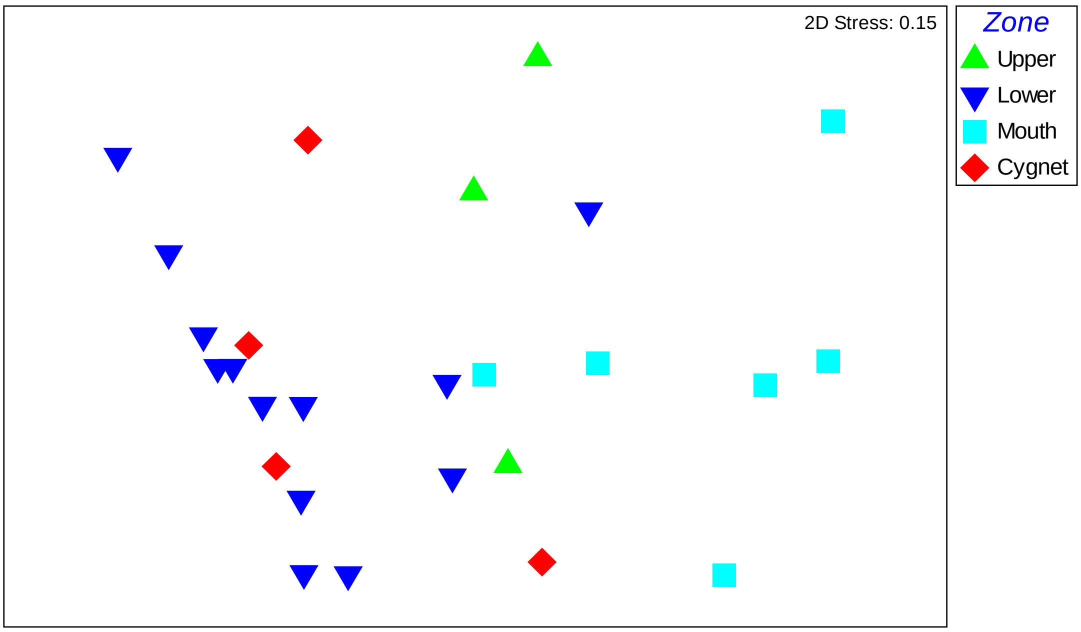


Fig. 45. Ordination of the Huon video fauna.

SIMPER analysis indicated that footage from the upper estuary was characterised by relatively profuse burrows and the presence of epibenthic algae (Table 30). The latter feature linking with the shallower depths in this area. Algae was also a major feature of footage from the mouth of the estuary, as were New Zealand screwshells (*Maoricolpus roseus*) and echiurans. *M.roseus* was also quite a strong feature of Cygnet Bay, as were other large epibenthic scavengers (seastars and crustaceans). *M.roseus* was not found in the upper estuary sites but increased densities were observed through the lower estuary and to the mouth. Screwshells are more prevalent in coarser sand sediments (Probst,T. unpublished data). *M.roseus* was easily observed in the video footage and was strongly aligned with particular areas.

	Estuary Zone	Video Feature	Rel. Contribution (%)
HUON	**Upper**	Burrow density	28.57
		Algal cover	21.43
	Lower	Epibenthic crustaceans	21.05
		Sea stars	15.44
		Burrow density	12.98
		Other crustaceans	10.88
	Mouth	Epibenthic crustaceans	19.46
		NZ screw shell	19.46
		Algal cover	19.46
	Cygnet	Epibenthic crustaceans	20.69
		NZ screw shell	20.69
		Sea stars	18.97
DERWENT	**Upper**	Burrow density	22.86
		Epibenthic crustaceans	13.71
		Algal cover	12.57
		Sea stars	11.14
	Middle	Fish	15.80
		Algal cover	14.97
		Sea stars	10.40
	Lower A	NZ screw shell	14.35
		Other fauna	13.90
		Sea stars	13.90
		Echiurans	13.90
		Epibenthic crustaceans	13.90
	Lower B	Epibenthic crustaceans	34.78
		Fish	18.84
		Sea stars	14.49
	Ralphs Bay	Algal cover	16.20
		Other crustaceans	15.71
		Burrow density	14.72
		Other fauna	12.76
		Sea stars	12.15

Table 30. Relative contribution (%) of main video features to overall similarity within each estuary zone.

Epibenthic crustaceans and seastars were also a major feature in the footage from the lower estuary. This in combination with the observations of prolific burrows suggests a relatively clean environment with the potential for considerable bioturbation. Brittlestars, which have been shown to be indicative of relatively clean environmental conditions (Rosenberg et al, 1997, Crawford et al., 2002), were also observed in the footage from the lower estuary, Cygnet Bay and the estuary mouth. Generally there was a greater diversity of fauna observed in the lower reaches and in Cygnet Bay than in the upper estuary.

With the exception of the middle and upper Derwent (ANOSIM; R = -0.016, P = 0.557) video footage distinguished each of the different regions identified "a priori" within the Derwent (i.e. upper, middle and lower estuary and Ralphs Bay) (Fig. 46). The Derwent video footage clearly shows an abundance of burrows and faunal tracks throughout the estuary. However, burrows and faunal tracks were most abundant in the Upper Derwent, where echiurans were also a consistent feature (Table 30). Burrows and faunal tracks were also evident in the mid-Derwent but not in such profusion. The quantity of burrows and tracks further diminished in the lower estuary, where algae and New Zealand screwshells (*Maoricolpus roseus*) were more significant features. Algae and other faunal species were significant in distinguishing Ralphs Bay.

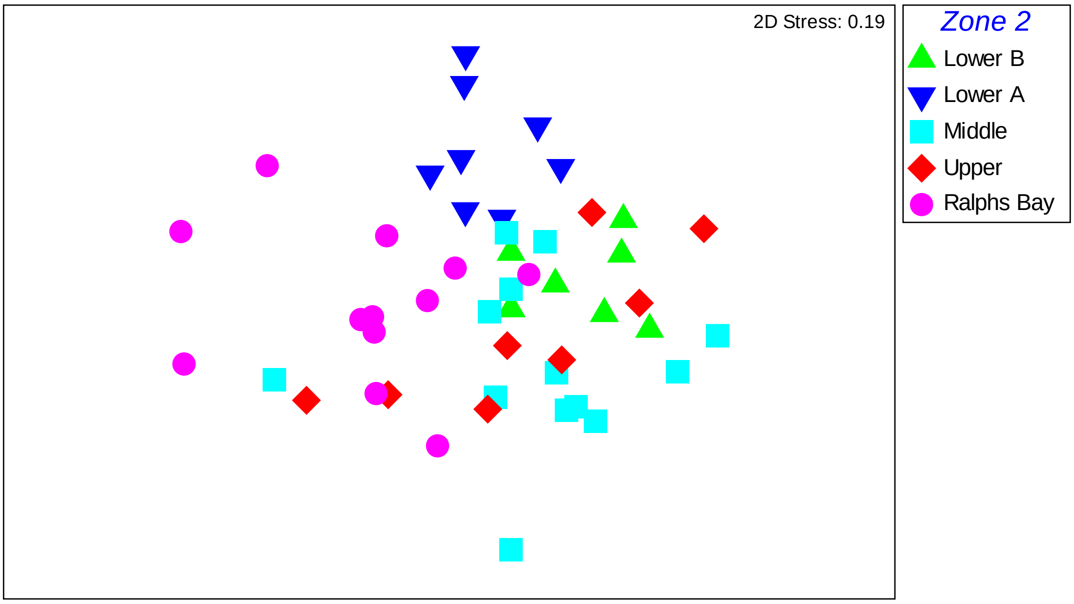


Fig. 46. Ordination of Derwent video.

Ordination of the video footage for the lower Derwent showed two distinctly different groups, which have been sub-divided as lower A and lower B (Fig.46), with lower A being closer to the mouth of the estuary (ANOSIM; R = 0.755, P = 0.003). New Zealand screwshells (*Maoricolpus roseus*) were amongst the major features distinguishing these two groups and abundances were higher towards the mouth (Fig. 40 in section 3.5). Epibenthic crustaceans were more abundant in the lower B group whilst algal cover increased in lower A. Although still significantly different lower B and mid-estuary sites were more similar than lower A and B (R = 0.16, P = 0.043).

Ralphs Bay was quite distinct from all the other Derwent sites, but was more similar to the upper (R = 0.307) and mid Derwent (R = 0.376) sites than it was to the lower Derwent sites (R = 0.538 (lower A), 0.635 (lower B)). Algal cover was an important visual characterisation feature in Ralphs Bay. The video footage also showed a diverse epifauna including several large sea stars (particularly *Patiriella* spp and *Asterias amurensis)*, anemones and ascidians.

Comparing the video footage from the most highly metal impacted sites (68 and 69) to the footage from the rest of the estuary shows that it was not possible to distinguish impact using video alone. There was no difference between the footage observed at the impact sites and that from the middle estuary in general (R=-0.348, P=0.949).

Comparison of the video footage for the Derwent and Huon systems shows that although there were significant differences between the two systems (ANOSIM; R=0.069, P=0.033), when the estuaries were categorised into zones there were areas of similarity (Fig. 47).

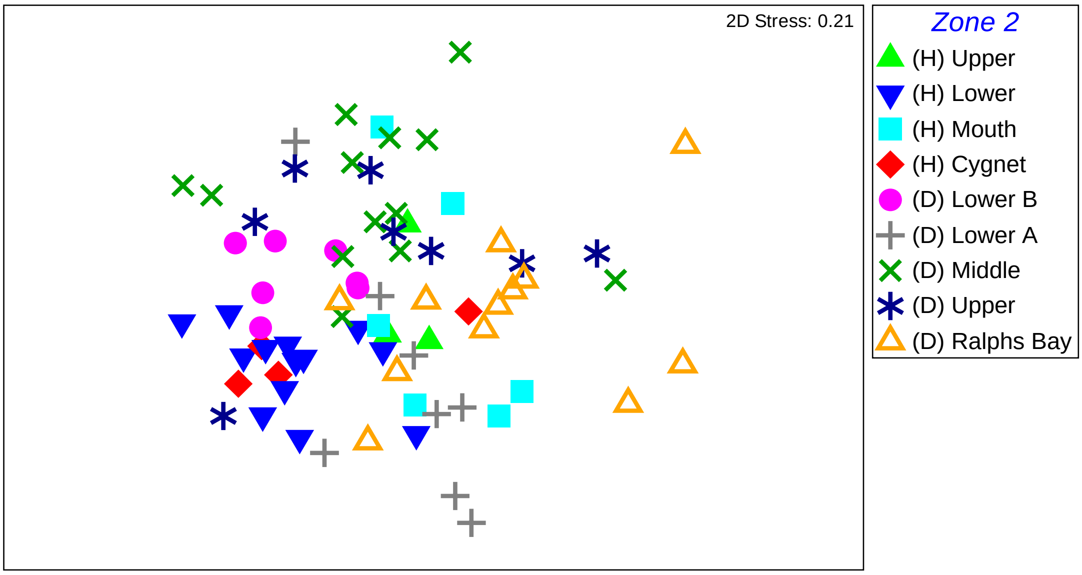


Fig. 47. Ordination of Huon and Derwent video.

The upper Huon estuary was visually very similar to the middle Derwent (ANOSIM; R=-0.022, P=0.60) (Fig.46). Whilst environmental conditions at the mouth of the Huon were similar to both the middle Derwent (ANOSIM; R=0.207, P=0.052) and Ralphs Bay (ANOSIM; R=0.168, P=0.096). Interestingly the embayments on each estuary, Cygnet Bay and Ralphs Bay, had much in common (ANOSIM; R=0.205, P=0.111); in both instances large epibenthic species such as seastars and crabs were widespread.

The main differences between the video assessment of the Huon and Derwent systems can be summarised as follows; the Huon had higher abundances of brittle stars, epibenthic crustaceans and NZ screw-shells, and a higher burrow density whilst the Derwent had higher abundances of echiurans and other fauna (e.g. anemones, sponges) and greater algal cover. Abundances of sea-stars, worm tubes and other crustaceans did not differ markedly between the two systems.

In conclusion, video footage appears to be quite good at characterising large scale spatial and geographical changes. There was greater distinction between regions in the Derwent than there was in the Huon. However, video assessment did not distinguish heavy metal contamination from natural variability and therefore would not be a useful approach for monitoring impact in the Derwent. Video showed considerable potential as a monitoring tool for evaluating the distribution of large mobile epibenthic species, and therefore could be a very useful approach for assessing the distribution of several key introduced species.

4. Conclusions

It was hoped that the findings of this study would provide critical baseline information and functionally relevant indicators and targets for southern Tasmania's two largest estuaries; that this study would quantify the distribution and spread of key introduced marine pest species; that the information would support and add value to current management initiatives in the Derwent and Huon estuaries and finally that the project would develop methods and provide information that could be extended to other estuaries or coastal waters in the southern region. A synopsis of the key findings addressing each of these issues is presented below.

1. Provide critical baseline information and functionally relevant indicators and targets for southern Tasmania's two largest estuaries.

Huon Estuary:

Sediment particle size is one of the most important factors in the determination of community structure (Hall, 1994). However, throughout most of the Huon the sediments were very similar. Mud was the predominant substrate, although there were sandier regions in the northern estuary around Egg Islands and in the estuary mouth. The salt wedge extends well up the estuary, with the bottom waters being strongly saline as far up as Brabazon Point. The oxic status of the sediments will also have a structuring effect on the biological communities and for much of the estuary the sediments were well oxygenated. However, redox potential levels and sulphide concentrations in the sediments around Hospital Bay suggested that conditions in this area were quite strongly reducing. This is probably a legacy of the wood chip operations that once occurred in the Bay and which have left a substantial organic loading (Butler, 2006). Redox levels were also slightly depressed and sulphide concentrations remained elevated in the samples collected around Brabazon Point, with redox levels remaining low as far south as Police Point. There are several aquaculture leases in this area and this may be contributing to local organic loadings. There was no evidence of any significant heavy metal contamination in the Huon other than in the vicinity of Hospital Bay where the main contaminants were arsenic, copper, nickel and zinc. There was some evidence to suggest that material may be being entrained out of the Bay, mainly to the south although there was also a slight increase at two sites just north of Hospital Bay.

For the most part the communities in the Huon were typical of those in southeastern estuaries (Edgar et al., 1999a) and appeared to be relatively undisturbed. The fauna was dominated by euryhaline and/or estuarine species, with no specifically freshwater or marine species collected within the sampling area. Species diversity throughout the system was relatively high (Shannon index >2.0), although levels were lower in the upper reaches and there were significant differences between the upper estuary and other regions. The main differences appeared to be in response to position within the estuary according to the prevailing salinity gradient. In the upper estuary, around Egg Islands, the diversity was low and the opportunistic species, *Nassarius nigellus* and the polychaete *Mediomastus australiensis* were relatively common. These species are often associated with areas where the organic content is elevated and therefore suggest that this area was organically enriched. *Mediomastus australiensis* was still a prominent feature in the communities in the mid-lower estuary, but these communities were considerably more diverse with infaunal deposit feeders being the main functional group. Nutritionally supporting this fauna would require quite high levels of organic material, and the total organic content results indicated high levels of organic carbon in the system. There was no evidence of any particularly dominant species in these communities, which suggests that the communities were relatively unimpacted and that the fauna and the resource availability were in balance. In processing this high carbon loading the fauna was also bioturbating and oxygenating the sediments, the result being a relatively healthy environment. Suspension feeding crustaceans (*Ampelisca euroa* and *Kalliapseudes* sp.1) were predominently found in samples from the estuary mouth. These species are generally not found where environmental conditions are degraded or where organic input is high, which is in keeping with the organic carbon findings for this region. Although the environmental conditions in the various regions of the estuary differed, the infaunal information suggests that on the whole the system was not unnaturally perturbed.

Derwent Estuary:

There was more variability in the unconsolidated sediments in the Derwent than there was in the Huon. Sediment type differed both with distance down the estuary and across the estuary. Between Bridgewater and the mouth of Ralphs Bay the sediments were mainly mud, but most of the sediments in Ralphs Bay itself and further south were sandy, whilst in the mouth of the estuary the sediments became coarser, with a large component of shell debris. A deeper channel runs down the mid estuary and the sediments within this gutter tended to be finer. The upper estuary, above the Tasman Bridge, was often quite shallow, particularly the side embayments where depths were commonly less than 5m. The lower estuary, below the Tasman Bridge, was deeper, generally between 15-25m, although Ralphs Bay was standardly shallower than 10m. In the deeper areas the sediment type was quite closely aligned with depth, probably as a function of the depositional characteristics. There was a deep hole off Rosny Point (54m) which may be of some concern as an accumulation zone for contaminants within the system.

The redox levels were low and sulphide concentration was high in the upper Derwent suggesting that the conditions in this area were reducing and that the environment was somewhat degraded. The metals data indicated that all of the metals were highly autocorrelated. Levels were significantly elevated throughout most of the estuary with extremely high levels around the Zinifex wharf. Only in the lowest reaches of the estuary, around Kingston, and in the deeper parts of Ralphs Bay, could the sediments be considered relatively uncontaminated. The metal concentrations were strongly coupled to both the sediment grain size and organic content of the sediments, since the metals are preferentially bound to the fine organic components (Harrison et al., 1987) which would in turn be dictated by the depositional characteristics of the system.

Considering the extremely high concentrations of metals throughout the estuary, including some which are known to be toxic (i.e. Hg and As), it is surprising that there were no azoic areas. In fact the reverse was generally found, with a diverse fauna in most areas. Even in the areas with the highest metal concentrations there were still several species present, albeit cryptogenic/ introduced species. This suggests that the metals were generally not biologically available, since the metal loadings did not appear to be a significant determinant of the benthic infaunal composition. There are a variety of mechanisms by which the fauna could either avoid or detoxify these metals. Infaunal species may actively avoid the metals in the sediment in some way, perhaps by adjusting their functional ecology, they may consume the sediments but detoxify the metals component by compartmentalising it within themselves or directly excreting it, or there may even be a biochemical process occurring in the sediments which binds the metals in a form that makes them less toxic. It is likely that the actual situation will involve some combination of all of these approaches.

Characterization of the faunal communities was predominantly a function of the sediment type and organic content and could largely be determined by geographic location within the estuary. The species composition was consistent with that previously described from South-Eastern Tasmania (Edgar et al., 1999a,b). The lowest diversity was in the upper reaches of the estuary and in areas subject to tidal emersion. As in the Huon, the species composition in the upper estuary suggested that this area was organically enriched. The fauna contained several species tolerant of high organic loadings (*Tatea* sp., *Arthritica semen*, *Mediomastus australiensis*) and was consistent with that of previous studies undertaken around the pulp mill outfall at Boyer (Moverley and Garland, 1995, Aquenal, 2000). This again suggests that the wood fibre enrichment from the Boyer pulp mill extends beyond the Bridgewater causeway.

The ecology of the community groups within the Derwent can be broken down into two main functional regions. The fauna in the upper estuary was dominated by infaunal deposit feeders or opportunistic scavengers, the latter particularly in areas which were subject to tidal exposure. The presence of large numbers of infaunal deposit feeders indicates both that there was a considerable amount of organic material available as a food resource and that the sediments were safe to eat. Suspension and filter feeders were rare in this area, possibly because the suspended sediment loads were sufficiently high as to inhibit them. In contrast the fauna in the mid-lower estuary was dominated by surface deposit feeders, many of which were tube dwelling and therefore important as bioirrigators. The reduction in infaunal deposit feeders in this region could be a result of of the reduction in the organic loadings or may indicate reduced palatability of contaminated sediments. Suspension feeders were present throughout this region, and are generally associated with relatively good environmental conditions, particularly when they are from a diverse range of taxa. However, since many suspension feeders can alternate between suspension and surface deposit feeding depending on the prevailing conditions, their presence should not be considered a categorical indicator of health.

Comparison of the Huon and Derwent Systems:

As has already been noted, although there were some strong ecological similarities between the Huon and Derwent estuaries but there were also some significant differences. The geography and physical structure of the two estuaries were broadly similar and there were many areas where the sediment characteristics were comparable. However, the sediment chemistry was quite different between the two systems. The data suggests that multiple environmental gradients operate within the Derwent, including some significant anthropogenic influences from both organic enrichment and metal contamination. The metal concentrations in the Derwent were significantly higher than in the Huon and sulphide concentration was high in a far greater proportion of sites in the Derwent than in the Huon.

The faunal diversity was broadly equivalent between the two systems, but there were areas where there were marked differences in the infaunal communities. Although there was a lot of similarity between the lower estuary communities, the community structure of the upper estuaries was quite distinct. Organic effects were clearly evident in the upper Derwent and had a marked influence on the infaunal community. The similarity between the lower estuary communities was largely due to similar abiotic factors driving the community structure. Geographic position within the estuary appears to be the strongest determinant of benthic community structure in both the Huon and Derwent. This was broadly related to many other factors, i.e. depth, salinity and organic content by virtue of the depositional nature of the environment. Although the metals concentrations were significantly higher in the Derwent than the Huon, they were not the major influence on community composition. Only in the most impacted areas was there any evidence of an "impact specific" community. There were very few classical indicator species associated with particular community groups but groups could be distinguished using a weight of evidence approach and a suite of characterising species as shown in Table 26.

2. Quantify the distribution and spread of key introduced marine pest species

In the recent port survey of Hobart (Aquenal, 2002) 70 introduced species were listed as being present in the Derwent. However, of these only 14 species would be likely to occur in soft sediments. The current study found only 7 of these species; *Asterias amurensis, Corbula gibba, Maoricolpus roseus, Theora lubrica, Euchone limnicola, Corophium ascherusicum* and *Raeta pulchella*, with all 7 species recorded from the Derwent but only 5 in the Huon, *Corophium ascherusicum* and *Raeta pulchella* were not recorded from the Huon. The 5 species common to both systems were a regular feature in the estuaries but were generally more abundant in the Derwent, with the exception of *Corbula gibba* which was more abundant in the Huon.

Carcinus maenas and *Venerupis largillierti* were identified amongst the local introductions in the Hobart port survey but were not found in current study, even though their ecology suggests that they should have been. However, the sampling strategy employed in the current study may underestimate these particular species as it does not accommodate their specific environmental preferences very well. Although the European green crab (*C.maenas*) can be found in sand and mud sediments it is a highly mobile scavenger which is most often found in the near shore areas particularly in association with reef areas or algae/seagrass and since these areas were not sampled in the current project it may have been missed. Similarly, in the Hobart port survey the large clam *V. largillierti* was largely found associated with the wharf structures (Aquenal, 2002) and these areas were also not sampled in the current study.

The suite of introduced species that were found in this study had very specific distribution patterns and were largely restricted to particular areas in each estuary. *Corbula gibba* was found in the low-mid estuary in the Derwent and in the mid-estuary and Cygnet Bay in the Huon, *Theora lubrica* was restricted to the middle to lower Derwent and the lower Huon whilst *Euchone limnicola* was only in the upper to upper middle reaches of the Derwent and the upper Huon. *Raeta pulchella* was only found in the Derwent and its distribution was very patchy. The distribution of the northern pacific seastar (*Asterias amurensis*) and the New Zealand screwshell (*Maoricolpus roseus*) were established using the video information and were different within the two systems. The seastar was relatively ubiquitous throughout the Derwent, with numbers only abating in the uppermost areas, whereas in the Huon this species was found in two discrete but quite large areas around Brabazon Point and Huon Island. The screwshell was largely confined to a band across the middle of the Derwent from Kingston to South Arm and was very patchy in the Huon.

None of the introduced species were strongly correlated with any particular environmental variables or contaminants and they were not key determinants of communities. This suggests that their distribution may be more focussed on opportunity and competition with other species (or perhaps the limitations of other species) rather than any particular environmental tolerances.

3. Support and add value to current management initiatives in the Derwent and Huon Estuaries.

This study provides baseline biological information on the infaunal communities for both the Huon and Derwent estuaries which is an essential starting point for any monitoring programme. The ecology will reflect the cumulative effects of all environmental contaminants (anthropogenic and natural), consequently the ability to evaluate the biological status will make future assessments of estuarine condition more effective. The biological zonation patterns established in this study will enable researchers and environmental mangers to locate biologically relevant monitoring sites and to better assess changes within these systems both spatially and temporally. The strong similarity in the ecology of the Huon and Derwent systems suggests that the Huon does represent a reasonable ecological reference for the Derwent. Consequently, information on the community status in the Huon may provide very useful parameters for developing management guidelines for the Derwent and vice versa.

This study has also enhanced our understanding of the interactions between contaminants such as heavy metals and the ecology of these two estuarine systems which will hopefully be transferable to other estuarine systems. It has provided information on the biology of the communities within the Derwent that will assist in management decisions regarding regulation of contaminant loadings and potential mitigation strategies. The likely ecological effect of changes in the contaminant loadings can now be critically assessed.

Finally, the introduced species assessment has created a point of reference to monitor and manage the spread and distribution of invasive species throughout the Huon and Derwent and has helped to define the distribution preferences of these ecologically and economically important species.

4. Develop methods and provide information that can be extended to other estuaries/coastal waters in the southern region.

The fauna described for both the Huon and Derwent estuaries in these baselines appears to be very similar to that in other Southern estuaries (Edgar et al., 1999a,b), therefore many of the patterns and associations observed would be comparable in other systems.

This study found that organic inputs were amongst the strongest determinants of faunal composition. Since organic content will also have a significant effect on the sediment chemistry, potentially influencing the toxicity of other contaminants, it is extremely important that in any assessment of estuarine health the organic inputs to estuaries are evaluated. These can be numerous and may range from large scale inputs such as industrial effluents and sewage outfalls to much smaller but locally significant impacts such as farm runoff and agricultural fertilisers, even certain land management practices such as land clearance can influence organic loadings.

Introduced species are a significant issue throughout Australia. Any information that assists in detection and monitoring for these species is valuable. The distribution patterns for the introduced species identified in the current study can be used as a benchmark from which to monitor the spread of these species within the study estuaries. However, the information on range preferences and distribution could also be used to develop monitoring strategies for detecting these species in other areas and to identify “early warning sites” in other systems. In particular video assessment was found to be a useful tool for broad environmental characterisation as well as a useful approach for monitoring larger and more mobile introduced species.

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