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Comparison of demersal zooplankton in regions with differing extractive-dredging history, in the subtropical Brisbane River estuary

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Abstract: The composition and distribution of demersal zooplankton assemblages in the Brisbane River estuary (Queensland, Australia) were examined following a history of selective dredging for gravel extraction. The study provided base-line information on the biological condition of the estuary at a time just prior to the cessation of dredging, and examined whether the abundance of these substrate-related zooplankters varied in relation to areas having different dredging histories. Comparisons were made between regions that had never been dredged, regions recently dredged (0–2 years ago), and those previously dredged (3–5 years ago). The general zooplankton community collected from 64 sledge-net trawls consisted of 90 different taxa (82,350 indiv.) of which 33 were selected as being part of the demersal zooplankton assemblage. The demersal fauna was dominated by 4 species of calanoid copepods, 2 of mysids, 2 of shrimps, and a goby. Species assemblages were significantly different between the upper and lower regions of the estuary, and were hence examined separately by univariate and multivariate analyses. In the more intensively dredged lower-estuary there was a significant correlation between dredge-history and plankton abundance. This correlated with differences especially in the distribution of the shrimp *Acetes sibogae* and a species of the calanoid copepod *Pseudodiaptomus*, and trends in the distribution of the mysid *Rhopalophthalmus brisbanensis*. Despite these individual taxon patterns and indications of impact from recently dredged areas in the lower-estuary, no consistent relationships were found between faunal-assemblage composition and dredge history in either the upper-estuary or lower-estuary. High variability between samples within 'treatments' in the upper-estuary was possibly due to patchy and light dredging activity. A decline in abundance and diversity of demersal plankton in the system over the previous 20–30 years is suggested.

Key words: zooplankton, demersal, estuarine, dredging, Australia

Introduction

Gravel-dredging operations can cause major modifications to both the bottom substratum and the water column, and hence have the potential to cause correlated changes in the composition of demersal zooplankton assemblages. Habitat modifications that can arise from dredging include changed sedimentary structure, with consequent changes in nutrient and other fluxes including toxicants across the sediment/water interface (e.g. Lau et al. 1993). Such changes influence productivity and survival of planktonic and benthic organisms, as indeed can modified water turbidity from re-suspension of fine silts (Chester 1990) though these latter effects may be short-term (Sloth et al. 1996). Similarly, dredging can cause changes in sediment grain size, and in topography of the estuary floor, which modify the nature and complexity of that habitat for demersal forms in a manner that may be species-selective (Iannuzzi et al. 1996), or lead to secondary effects such as localised oxygen depletion in excavations (Riemann & Hoffman 1991). Other secondary influences arising from dredging include modification to tidal flushing regimes through changes in channel morphology. Any such changes have the potential to selec-

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tively impact the demersal zooplankton assemblage in a manner dependant upon their swimming/behavioural or other site-retention mechanisms. Biological impacts on the demersal forms, such as predation efficiency, may similarly be modified through diminished visibility in turbid waters (Minello et al. 1987).

Parts of the Brisbane River estuary (Lat. 27°30′S; Long. 153°00′E) have been dredged for navigational purposes since 1862 (McLeod 1978), though most of this has been in regions near the mouth during port development (Greenwood 1993). However, from 1900 to 1970 commercial gravel extraction removed at least $12 \times 10^6\,m^3$ of material (O'Flynn & Thornton 1990). Since the 1960s there has been an extensive and recorded history of extractive-dredging for gravel in controlled zones along most of the estuarine reaches of the Brisbane River. Overall, sufficient material has been removed to have increased river volume to the point where the flood volume required to flush freshwater to its mouth is now 2.5 times greater ($2 \times 10^9\,m^3$) than it was in 1962 (Dennison & Abal 1999: p. 42). Extractive dredging ceased in late 1998, but navigational dredging continues associated with port developments around the mouth. Related information on the distribution of salinity, water chemistry and turbidity in the regions of the Brisbane River estuary studied here are available in Cox (1998a, b).

A literature search indicates that the effects of dredging on demersal zooplankton assemblages appear not to have been previously studied. The aims of this study were: to provide a general description of the demersal zooplankton found in the Brisbane River estuary; to provide base-line information on the biological condition of the estuary at a time just prior to the cessation of extractive dredging; and to examine whether the abundance of these animals in different parts of the estuary varied in relation to differences in the history of dredging. The approach taken was to compare the abundance and structure of demersal zooplankton assemblages in zones along the river with known differences in their history of extractive gravel-dredging. Specifically, we compared assemblages in zones that had never been dredged with zones that had been dredged recently (within the last 18–24 months) and zones that had been dredged 3–5 years ago.

Materials and Methods

Because the abundances of different groups of organisms can vary at different spatial and temporal scales, depending on their particular life-styles and habits (Andrew & Mapstone 1987), it was necessary to adopt a sampling strategy that would allow patterns of such variability in the structure of the assemblages (Clarke 1993) and the abundance of individual taxa (Underwood 1993) to be identified.

Because of the highly variable history of extractive gravel-dredging in different parts of the Brisbane River estuary, detectable differences in the abundance and community structure of planktonic organisms were examined separately in two 'regions' (Fig. 1), that in the 'upper-estuary' being between 54–59 km, and that in the 'lower-estuary' between 25–28 km, from the estuary mouth. In both regions all dredging was undertaken for extraction of gravel, primarily for the building industry. Within each region, comparisons were made among four (treatment) 'zones', each of which contained approximately 300 m of estuary length and had a known history of dredging activity (Table 1). In the upper estuary two 'control' zones were sampled, and in the lower estuary two 'recently dredged' zones were similarly sampled, to enable examination of spatial variability between zones within a single treatment, in each of these regions. The selected zones were isolated from areas of differing dredge-history so that independence among treatments was maintained (Underwood 1981). At each of the zones, two 'plots' were each sampled in quadruplicate. Each plot extended for 50% of the length of a treatment site, as indicated by shoreline markers at either end. Abiotic features of the treatment zones at the time of sampling are summarised in Table 1. Salinity and temperature data were recorded from near-bottom water.

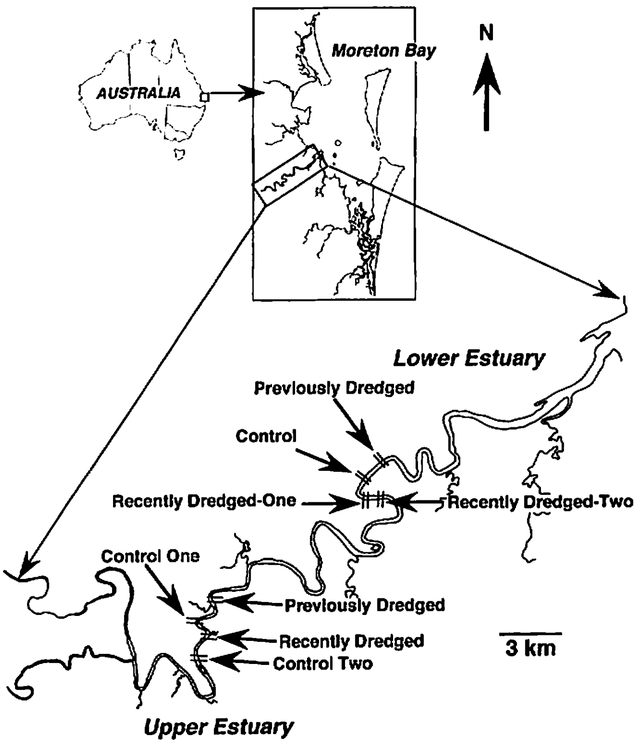

Fig. 1. The Moreton Bay region of Australia showing the location of the Brisbane River. The enlarged section shows the Brisbane River estuary, and location of the upper-estuary and lower-estuary sites sampled for demersal and other zooplankton.

Zooplankton was sampled during the period 8–11 April 1997 by use of a sledge-mounted rectangular-mouthed (500 mm wide by 300 mm deep) net of 200-μm mesh, having a centrally-mounted flow meter (Oceanics 2030) fitted with a low velocity rotor. When deployed, the net rode approximately 5 cm above the substratum. During operation, the

Table 1. Features of the extractive gravel-dredging 'treatment' zones in the Brisbane River estuary in which zooplankton were sampled.

Region	Treatment zones	Period when dredged	Gravel extracted (tonnes)	Distance up-est. (km)	Mean depth (m)	Ambient salinity (psu)	Ambient temp. (°C)
Upper estuary	Control 1 (never dredged)	—	—	56	11.3	3.15	27.3
	Control 2 (never dredged)	—	—	59	6.5	1.44	27
	Recently dredged	Jul. '92–Oct. '96	3900	57	6.7	1.48	26.8
	Previously dredged (3–5 yrs ago)	Aug–Sept. '93	6550	54	9.8	3.34	27.3
Lower estuary	Control (never dredged)	—	—	26	8.5	22.2	27.3
	Recently Dredged 1	1992–1996	202,500	27	6.6	21.9	27.3
	Recently Dredged 2	Feb.–Dec. '96	125,783	28	9	21.8	27.5
	Previous Dredged (3–5 yrs ago)	Feb.90–Dec. '92	122,950	25	10	22.4	27.2

net was rapidly lowered to the substratum, towed horizontally in that position along the axis of the estuary at approximately $3\,\mathrm{km\,h^{-1}}$ for the desired distance, then retrieved to the surface and the catch preserved in 4% neutral formalin. Replicate tow samples were taken along the length of each plot on approximately parallel lines around mid-stream. Each plankton sample tow-track was therefore approximately 150 m in length. All samples were taken within 2 h either side of a middle-of-the-day slack high-water, so that tidal current effects were minimised. Day slack water was chosen both for logistical reasons and so that demersal taxa would be best sampled. At night, these same species would be further dispersed upward through the water column and hence less effectively sampled with a sledge net.

In the laboratory, entire zooplankton samples were sorted wherever possible, the taxa identified to the lowest practicable level and enumerated. Where sample size was large, the samples were sub-sampled with a Folsom splitter to yield fractions of either 1/2 or 1/4 sample containing not less than 600 indiv. A wide range of taxa was sampled, some of which were typically demersal (sensu stricto, Jacoby & Greenwood 1989, 1991), some others of which were bottom-related for at least part of the diel/tidal cycle, and others of which were fully planktonic or nektonic. To maximise the information available for analyses, a broad definition of "demersal" was adopted to those organisms included in both of the first two categories mentioned above. The mean number (SD) of individuals estimated per sample was 1396 (524). The mean volume of water filtered in obtaining samples was 16.50 (4.7) m^3, hence all species-count-data were standardised to numbers per $20\,\mathrm{m}^3$ of water filtered, prior to numerical analyses.

Data on overall demersal plankton abundance and abundance of the more numerous taxa were analysed for significant differences using univariate methods (hierarchical ANOVA) of data transformed to $\log_e(X)$ or $\log_e(X+1)$ as necessary to meet the assumptions of homoscedasticity of variances (Underwood 1981). Post-hoc SNK (Student Newman Keuls) tests were then used to identify which of the treatments was significantly different. Differences in composition of demersal zooplankton assemblages at each of the 4 dredge treatment zones were compared by non-metric multi-dimensional scaling (nMDS; Clarke 1993) on unstandardised 4th root transformed data using the Bray-Curtis similarity measure. ANOSIM was then used to assess the significance of any differences between the predefined groups (Warwick et al. 1990; Clarke 1993).

Results

Ninety zooplankton taxa were differentiated amongst the 82,350 indiv. captured in the 64 zooplankton samples (Table 2), with a mean total numerical density (across all samples) of $83.3\,\mathrm{m}^{-3}$. Of these 90 taxa, 33 were treated as belonging to the demersal zooplankton sensu lato (indicated by asterisks in Table 2), and it is mainly upon these taxa that this paper focuses. MDS ordination showed a total dissimilarity in the demersal zooplankton assemblages of the upper and lower regions of the estuary. Data from these regions are therefore considered separately in the following comparisons between treatments.

Overall abundance of demersal forms

In the lower-estuary zones there were significant differences in mean abundances of demersal plankters between zones in different stages of the dredging pattern (treatments) (ANOVA, $P<0.0001$). Zones that had recently been dredged had fewer demersal zooplankters than did the other zones (Fig. 2A), but SNK tests were unable to distinguish

Table 2. Zooplankton taxa recorded from the Brisbane River estuary in April 1997, and total numbers captured. Asterisk indicates those taxa treated in analyses as being demersal.

	Taxon	Number		Taxon	Number
Cnidaria			Amphipoda		
	Antho- and Leptomedusae	4975		*_Caprella_ sp. A	39
	Scyphomedusa	3670		*Gammaridae sp. B	193
	Catostylus mosaicus	18	Isopoda		
	Steenstrupia	17		_Gnathia_	9
	Aurelia? ephyra	12		*Flabellifera sp. A	73
	Lensia	6		*Valvifera sp. A	4
Ctenophora				*_Haloniscus searli_	1
	Pleurobrachia pileus	4466		_Cryptoniscus_ larvae	2
Chaetognatha				*Other Isopoda	2
	Sagitta bipunctata	9285	Tanaidacea		
Annelida				*Tanaidacea	43
	Ampharetidae	1	Stomatopoda		
	Sigalionidae	10		_Squilla_	2
	Spionidae	1	Decapoda		
	Phyllodocidae	1		*_Metapenaeus bennettae_	110
	Poecilochaetidae	2		*_Acetes sibogae_	695
	Opheliidae _Amandia_	4		*_Lucifer hanseni_	22
	Stacey's oligochaete	46		*_Leander tenuicornis_	83
Cladocera				*Other Caridea	217
	Evadne	9		Brachyuran larvae	
Ostracoda				_Amarinus_ sp. zoeae	37
	Ostracoda	4		_Amarinus paralacustris_ zoea	228
Copepoda				_Helograpsus haswellianus_ zoeae	147
Calanoida	_Acartia_ spp.	388		_Paracleistostoma mcneill_ zoeae	28
	Acrocalanus gibber	333		_Pilumnopeus serratifrons_ zoeae	3
	Bestiolina similis	3190		_Sesarma erythrodactylus_ zoea	1747
	Calanopia australica	1099		Brachyuran A megalopae	111
	Calanopia elliptica	39		_Scylla_ sp. C megalopae	4
	Canthocalanus pauper	39		Grapsidae sp. B megalopae	14
	Centropages orsinii	4	Mollusca		
	*_Gladioferens pectinatus_	29380		Bivalvia veliger sp. A	168
	Labidocera moretoni	36		Bivalvia sp. B	6
	Paracalanus parvus sensu lato	488		Bivalvia veliger sp. C	24
	Pontellopsis tasmanensis	0		Gastropoda veliger sp. A	32
	*_Pseudodiaptomus aurivilli_	2091		Gastropoda veliger sp. B	26
	*_Pseudodiaptomus colefaxi_	1452		Gastropoda veliger sp. C	2
	*_Pseudodiaptomus mertoni_	842	Pisces		
	*_Stephos morii_	2		_Ambassis marianus_	6
	Sulcanus conflictus	4226		*Bleniidae (2 unknown sp)	3
	Temora turbinata	6		Congridae eel	1
	Tortanus barbatus	5		*_Favonigobius_ sp.	4
	Undinula vulgaris	1		*_Gobiopterus semivestita_	258
Cyclopoida	_Corycaeus_ sp.	2		*Teleost sp. A	13
	Oithona similis	43		*Goby type A	84
	Other Cyclopoida	126		_Hyperlophus translucidus_	16
Harpacticoida	*_Brianola_	4		*_Omobranchus_ sp.	18
Caligoida	Caligoida	5		*_Pegasus volitans_	2
Monstrilloida	_Monstrilla_ sp.	5		*Pleuronectidae	2
Cirrepedia				*_Pseudogobius_ sp.	27
	Cypris larvae	16		_Stolephorus_ devisi	1
Mysidacea					
	*_Doxomysis_ undescribed sp.	2			
	*_Haplostylus udrescui_	13667			
	*_Rhopalophthalmus brisbanensis_	2313			
	*_Siriella_ undescribed sp.	19		Total	82350

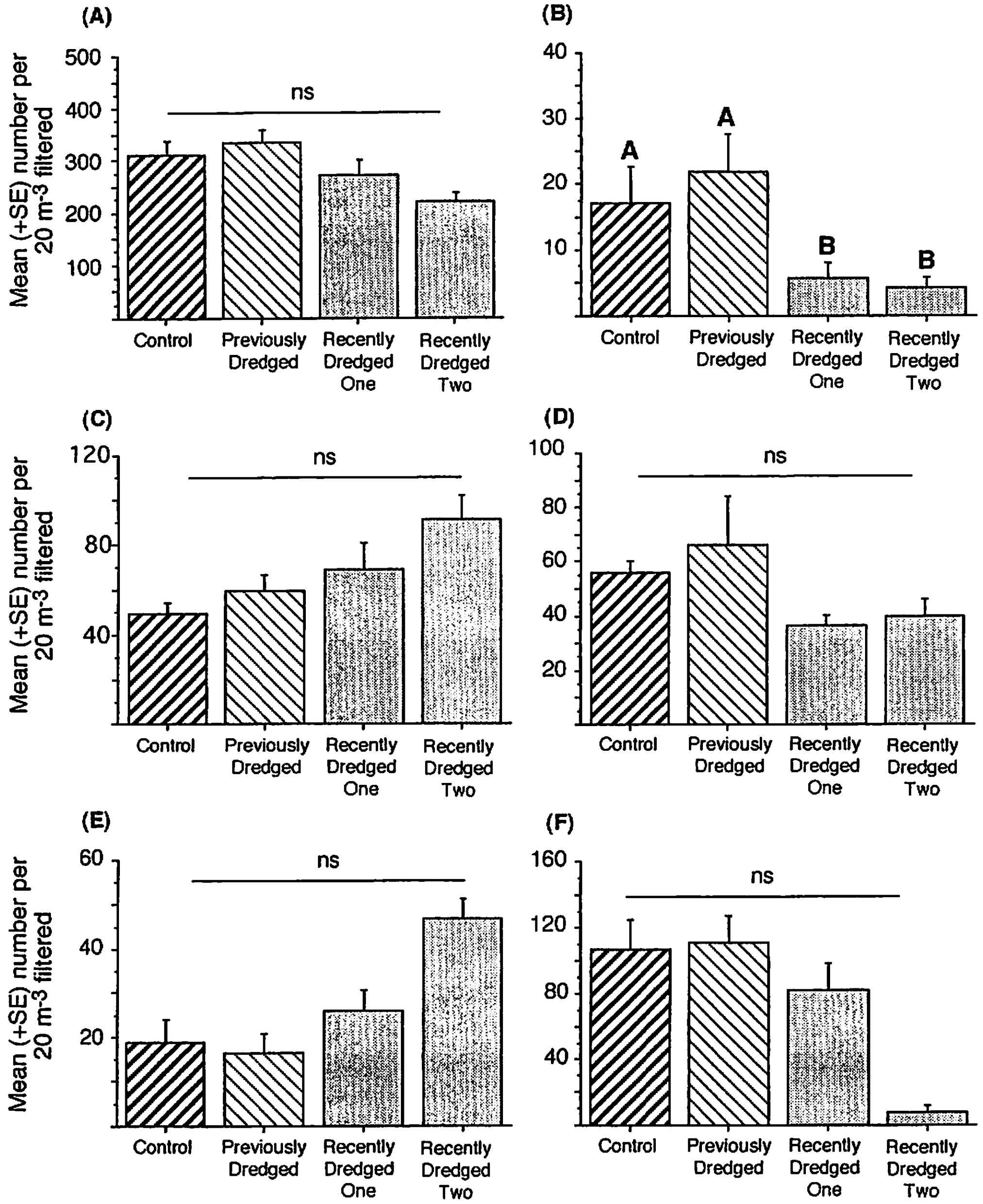

Fig. 2. Mean abundances of demersal zooplankters (standardised to numbers per 20 m^3 of water filtered) in each of the 4 treatment zones in the lower-estuary region of the Brisbane River. **A.** all demersal taxa. **B.** *Acetes sibogae*. **C.** *Pseudodiaptomus baylyi*. **D.** *Pseudodiaptomus colefaxi*. **E.** *Pseudodiaptomus mertoni*. **F.** *Rhopalophthalmus brisbanensis*. A line across the top of treatments indicates SNK tests could not distinguish which treatments were significantly different from each other.

which of the 4 zones were different from each other. In the upper-estuary zones (Fig. 3A), there were no significant differences in mean abundances of demersal plankton among the 4 treatment zones (P=0.088), but highly significant differences were found among means for the 2 plots within each of the zones (P<0.0001; Fig. 3B). Most of this between-plot variability arose from the zone that had been dredged 3–5 years previously (asterisk in Fig. 3B), suggesting there may be considerable heterogeneity in the nature of the residual substratum in that dredged zone.

Distribution of the more abundant individual taxa

Separate (univariate) examination was made of the following 7 taxa, the numbers of which exceeded 500 indiv. and hence were amenable to statistical analysis at the species level. In all cases these taxa were abundant in either the upper-estuary or the lower-estuary zones, but not in both. The following analyses therefore sought to examine distribution within the appropriate region of abundance.

(a) Species most abundant in the lower-estuary zones

The sergestid shrimp *Acetes sibogae* was almost exclu-

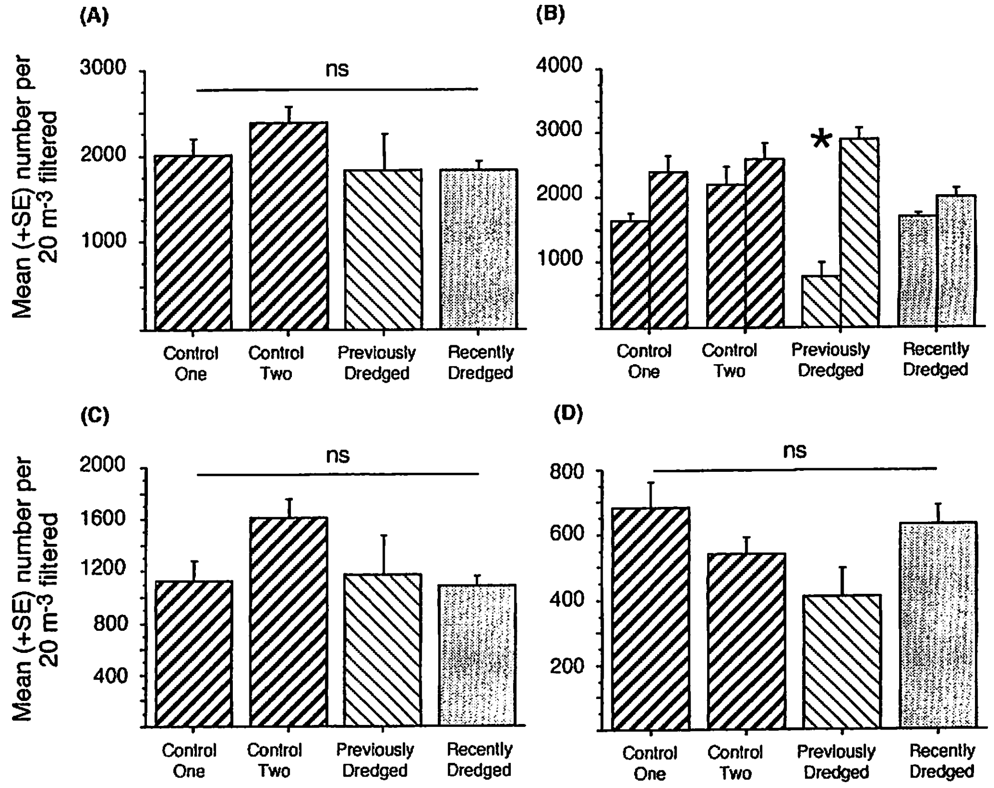

Fig. 3. Mean abundances of demersal zooplankters (standardised to numbers per 20 m^3 of water filtered) in each of the 4 treatment zones in the upper-estuary region of the Brisbane River. **A.** all demersal taxa. **B.** all individuals from the two plots in each treatment zone. **C.** *Gladioferens pectinatus*. **D.** *Haplostylus udrescui*. A line across the top of treatments indicates SNK tests could not distinguish which treatments were significantly different from each other.

sively taken in the lower-estuary zones ($P<0.0001$). Within that region, significantly more individuals were present in zones that had either never been dredged or had been dredged several years before, than in the recently dredged zones (Fig. 2B).

Three coexisting species of *Pseudodiaptomus* were taken either exclusively in the lower-estuary zones (*P. colefaxi*, *P. mertoni*), or in significantly greater numbers than in the upper-estuary (*P. baylyi*, $P<0.0001$). Abundance of *Pseudodiaptomus baylyi* did not differ significantly among the 4 treatment zones (Fig. 2C, $P>0.25$), nor did it differ overall between the plots within the 4 zones ($P>0.05$). There was, however, a trend toward more of this species in those zones that had been recently dredged (Fig. 2C). *Pseudodiaptomus colefaxi* abundance (Fig. 2D) also did not differ significantly among the 4 treatment zones ($P>0.16$), but in contrast with *P. baylyi*, there was a trend toward *reduced* abundance in the recently dredged zones. As with the previous 2 species, there were no significant differences in abundance of *Pseudodiaptomus mertoni* among the treatment zones (Fig. 2E, $P>0.09$). There was substantial variability in abundance between plots in the 2 zones that had either never been dredged (means 28 : 15), or were dredged 3–5 years previously (means 26.5 : 8). The species showed a clear trend of greater abundance in the recently dredged zones than elsewhere, a pattern similar to that of its congener *P. baylyi* and contrasting with that of *P. colefaxi*.

The mysid shrimp *Rhopalophthalmus brisbanensis* was significantly more abundant in the lower-estuary zones than elsewhere (Fig. 2F, $P<0.0005$). No significant difference was found in abundance among the treatment zones ($P>0.07$), despite the fact that numbers present at the recently dredged zone were an order of magnitude less than in the other zones. There was substantial variability between abundances in the 2 plots of each zone, especially those in the site dredged 3–5 years previously (means 143 : 78).

(b) Species most abundant in the upper-estuary zones

The estuarine copepod *Gladioferens pectinatus* was significantly more abundant in the upper-estuary than elsewhere (ANOVA, $P<0.005$). Although there was no evidence of significant differences in abundance among the 4 treatment zones (Fig. 3C, $P>0.79$), there were highly significant differences between the 2 plots within each zone, especially for the site dredged 3–5 years previously (means 1920 : 410) ($P<0.0001$).

Abundance of the mysid *Haplostylus udrescui* was also much greater in the upper-estuary zones than elsewhere

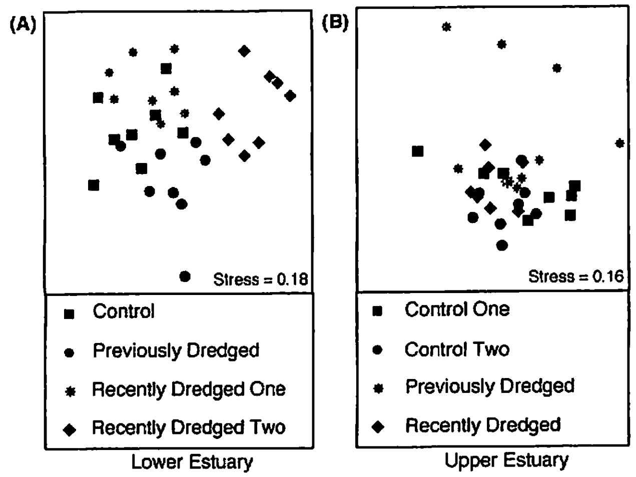

Fig. 4. nMDS ordinations on fourth root transformed data on abundance of all demersal zooplankton taxa in species assemblages from all samples (4 replicate samples from each of 2 plots in each treatment zone). **A.** lower-estuary region. **B.** upper-estuary region.

($P<0.0001$). There were significant differences in abundance among the 4 treatment zones ($P<0.029$), but SNK tests were unable to identify which zones caused the differences (Fig. 3D). There was however a trend toward lower abundance at the site dredged 3–5 years previously.

Composition of the demersal zooplankton assemblage

Ordination of the abundance data show that there was total dissimilarity between species assemblages in the upper- and lower-estuary regions of the Brisbane River. Because of this clear distinction, further analyses were undertaken separately on the 2 assemblages to determine whether there were any significant differences in 'community' structure amongst the 4 treatment zones in each region.

(a) Lower estuary zones

Significant differences were found in the structure of demersal plankton assemblages amongst the 4 treatment zones (one way ANOSIM, $P<0.0001$). Multiple comparison tests (corrected for multiple testing) clearly indicate 2 distinct groups of zones exist (Fig. 4A), the community in the 'recently dredged two' zone (RD2) being significantly different from that in all other zones. It is also notable that demersal plankton assemblages in the 2 zones 'control' and RD1 did not differ from each other, nor were they different from the zone which had been 'previously dredged' (3–5 years ago).

(b) Upper estuary zones

One way ANOSIM again indicated there were significant differences ($P<0.0001$) among the treatment zones, but the (nMDS) separation of treatments (Fig. 4B) was not as clear as that for the lower-estuary zones. This was true even for the 'recently dredged' zone, where the demersal zooplankton assemblage did not differ significantly from that of either of the 'never dredged' (control) zones. The only zone to clearly differ faunistically from the others was that where dredging had taken place 3–5 years previously, but this distinction was only evident in samples from one of the 2 plots in that zone

Discussion

In the down-estuary region, where gravel extraction had been most intensive, the significant differences in the total number of demersal plankters were correlated with dredging history, the trend being toward fewer plankters in those 2 zones that had been recently dredged than in the less disturbed zones. In contrast, the total number of demersal plankters did not differ significantly among the 4 zones in the up-estuary section, but there was considerable variability at all spatial scales examined, including between plots. This may derive from an enhancement of natural variability in the substratum of the upper-estuary region through dredging. Relatively small total amounts of dredge material were removed from this region, which may have created a mosaic of siltation basins, for between-plot variability was less evident here in the un-dredged 'control 1' zone.

When the occurrences of the more abundant demersal zooplankters are considered individually, there are some indications that the specific dredging history of a zone could, in some cases, be related to the differences in distribution and abundance from zone to zone. *Acetes sibogae* was found to occur mainly in zones that had not been recently disturbed. The biology of the species in the genus *Acetes* has been reviewed by Xiao & Greenwood (1993), and the distribution and behaviour of *A. sibogae* has been studied in a small estuary (Cabbage Tree Creek) just north of the Brisbane River in Moreton Bay (Xiao & Greenwood 1992). During the day, the bulk of *A. sibogae* populations are on or adjacent to the substratum, moving further into the water column during flood tides and at night (Xiao & Greenwood 1992), thus maintaining their distribution within the system. In addition to feeding on larger planktonic diatoms and small zooplankton, *A. sibogae* feed on benthos. Aravindakshan & Karbhai (1988) noted that *A. sibogae* stomachs contained a mixture of crustacean appendages, calanoid copepods, foraminiferan and molluscan remains in the form of shells and shell fragments, sand grains and debris. Their strong association with sediment suggests that differences in the nature of those sediments, both as a physical substratum for refuge during the day and as a source of food, could account for the observed differences in *A. sibogae* distribution. Nothing is known of their sediment preferences, but no major differences in sediment characteristics were detected among the zones here sampled (Skilleter, in press) although there was a trend towards lower organic content in the recently dredged sediments. The relationships between benthic animals and the physical features of sedimentary habitats are complex and may be at far finer spatial scales than can be examined in studies such as this (e.g. Watling 1988). Without more detailed studies, the causes behind any decreases in abundance of these shrimp in recently dredged zones can only be implied.

The three species of *Pseudodiaptomus*, all previously recorded from the Brisbane River estuary by Bayly (1965a, b, 1966), each showed variations in their abundance 'down-estuary' which could be related to the dredge history of the different zones. *Pseudodiaptomus mertoni* and *P. baylyi* both showed a tendency towards being more abundant in the recently dredged zones, compared with the zone that had never been dredged and the zone that had been dredged 3–5 years previously. In contrast, *P. colefaxi* was slightly less abundant in the recently dredged zones than in the other zones. Whilst none of these differences were statistically significant, when considered together they indicate there may be differences in abundances of these copepods in relation to the specific dredge history of a zone. Copepods of this genus are well known to be demersal in habit (Jacoby & Greenwood 1989, 1991), with varying degrees of affinity to the substratum. It has been suggested that increased diversity and coexistence of species of both *Pseudodiaptomus* and *Stephos* (also sampled in this study, see Table 1) is possible as a result of their adopting a demersal habit (Jacoby & Greenwood 1991). Individuals of species belonging to these genera move up into the water column nocturnally, and in greater numbers from structurally more complex than more uniform substrata (Jacoby & Greenwood 1989). *Pseudodiaptomus colefaxi* emerges in significantly greater numbers from substrata such as coral, coral rubble and seagrass, than from sand/mud substrata (Jacoby & Greenwood 1989). Any structural sedimentary differences between the dredge-history zones, such as decreased structural complexity when recently dredged, could therefore contribute to the noted decreased abundances. Similar to the present findings, the pattern of distribution of *Pseudodiaptomus mertoni* in Moreton Bay has been shown to differ from that of *P. colefaxi* (Jacoby & Greenwood 1989). The former species, whilst also emerging from more complex substrata in greater numbers, was found throughout the water column during the day but in greater numbers at night, and "should be considered as a demersal zooplankter loosely associated with the substratum" (Jacoby & Greenwood 1989: p. 144). This relatively lower level of substratum affinity in *P. mertoni* might explain why recent disturbances to the substratum (dredging) did not prevent it from being more abundant in those zones. In view of their similar between-zone distribution patterns, it may be that *P. baylyi* and *P. mertoni* have similar ecological requirements. Nothing is known from the literature about the habitat requirements and behaviour of *P. baylyi*.

A different pattern emerged for the mysid shrimp, *Rhopalophthalmus brisbanensis*. For this species, the differences between the 2 zones that had been recently dredged 'Down-River' were as great as the differences between zones with completely different dredging histories. Mysids in general, and the present 4 species in particular (Greenwood, personal observation), are commonly found in estuarine waters (Mauchline 1980; Grabe 1989), and with other peracarid crustaceans are frequently early colonisers of disturbed sediments (Oliver et al. 1977). The trend for this species to be most abundant in recently disturbed sites was masked (statistically) by within-zone variability, which may be attributable either to patchiness in sediment characteristics resulting from dredging, or to patchy distribution of populations arising from their swarming behaviour (Mauchline 1980).

Two species, a copepod and a mysid, were abundant in the upper-estuary region. A high degree of between-plot (replicate) variability was found in the distribution of *Gladioferens pectinatus*. Copepods of this genus are typically upper-estuarine in their distribution (Bayly 1965b) and have a remarkable ability to use their rough dorsal microstructure to adhere strongly to hard substrata during periods of stronger current velocity (Sheehy & Greenwood 1989). Little is known of the particular substrate surfaces to which these individuals may attach in the natural environment, but it is possible that any within-zone patchiness in the availability of hard substrates arising from dredging or other (natural) disturbance, could promote the observed regional differences in abundance of this species.

Hodge (1963) found the mysid *Haplostylus udrescui* (as *Gastrosaccus dakini*) to be more estuarine than *R. brisbanensis* (see above), occurring mainly in mid-reaches of the Brisbane River estuary in salinities of 5–15 ppt. As with other mysid shrimps, the nature of the substratum over which they settle during the day may influence their abundances. None of the other taxa of demersal zooplankton examined showed patterns of distribution and abundance consistent with variation attributable to the specifics of the dredging history of a zone.

Examination of the structure of the entire demersal zooplankton 'community' suggested that any differences were not so much due to the dredging history of a zone, as to other influential factors. In the down-estuary region, the 'recently dredged' zone 2 was significantly different in community composition from the other zones, including the other 'recently dredged' zone 1. Hence, differences between 2 zones with a similar history of dredging were as large as differences between zones with a different history. It is not therefore possible to attribute any faunistic differences in this region to the specifics of the dredging history of a particular zone. Less differentiation in faunal assemblages was evident in the upper-estuary region. However, gravel extraction from the recently dredged zone in the upper estuary region was less than 1/30, and from the previously dredged (3–5 years ago) zone less than 1/18, of that in the equivalent zones in the lower section (Table 1), hence a lesser impact is not surprising. However, the previously dredged (3–5 years ago) zone did separate off from the other zones, despite the small amount of material that had been removed, suggesting that any faunal differences are, in fact, not directly related to dredging in this sector of the river. One of the 2 plots in the 3–5 year dredged zone did have faunal assemblages that separated noticeably from the remaining data sets, indicating there may be within-zone variability in substrata at this site. Such variability was also noted above in the univariate analyses of individual taxa.

Few data on zooplankton abundance and diversity in the region are available for comparison with those of the present study, since there are considerable changes in composition of the estuarine fauna with latitude, and mesh size comparability is important in any comparisons (Greenwood 1980; Newton 1994). Previous studies from the region have been reviewed by Greenwood (1998). In his studies of Moreton Bay plankton Greenwood (1980) reported 52 general zooplankton taxa and 68 species of calanoid copepods alone, which is considerably more than the 19 calanoid species taken in the present study. Similarly, the present study found an average density of 83.3 indiv. m^{-3}, substantially less when compared with the average of 1690 indiv. m^{-3} found by Greenwood (1980) using nets of the same mesh size in Moreton Bay. The only previous study documenting zooplankton abundance in the Brisbane River estuary is that of Bayly (1965a, b). Although Bayly's study was quantitative, he focused only on certain copepod species, not the entire zooplankton assemblage, hence his data are not directly comparable with the present data set. Nevertheless, in his January 1964 sampling of zooplankton, using nets of the same mesh as those used in the present study, Bayly found near-bottom abundances for *Gladioferens pectinatus* alone of 15.9 indiv. m^{-3} at a (down-estuary) site near the present 'recently dredged'zone, and 486 indiv. m^{-3} at an upper estuary site near the present 'dredged 3–5 years' zone. This latter figure is considerably greater than the maximum of 115 indiv. m^{-3} recorded for that species in the present study, and greater even than the mean abundance noted above for all plankton. In August 1964, but using much finer nets which retain juvenile stages, Bayly found *G. pectinatus* at densities of 2200 indiv. m^{-3} in near-bottom waters at a site near the present upper-estuary region. These few data suggest that present-day zooplankton abundances in the Brisbane River estuary are not only low by absolute standards, but that there may have been a substantial decline in abundance of at least certain demersal copepods over a 35 year period. Unfortunately, no long-term data sets are available to test this observation. Additionally, during that period, not only has the estuary's morphology been modified through extractive dredging, but urban and industrial development has almost doubled in the region, generating a range of activities that impinge on the Brisbane River and its catchment on an on-going basis (Davie et al. 1990; Tibbetts et al. 1998; Dennison & Abal 1999). Multiple causes may therefore have contributed to such a decline.

Alternatively, the relatively small numbers of taxa found in the current study may simply represent a 'low-point' in natural temporal fluctuations of the estuarine biota. Natural disturbances are important sources of spatial and temporal variability in aquatic environments (Sousa 1984), and are an important mechanism by which new or different species can enter an assemblage (Skilleter 1995). Estuaries are frequently exposed to sudden, large-scale disturbances in the form of floods, and the Brisbane River is susceptible to such events (Cossins 1990; Dennison & Abal 1999). Only more detailed sampling, providing estimates of temporal variability at appropriate time-scales, could distinguish between such alternative explanations. With gravel extraction having ceased in December 1998, it will be of interest to follow future changes in the estuary's ecology.

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