Cardno
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Marine and Freshwater Studies

Entrance Channel Dredging
Ecological Impact Study

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Cardno Ecology Lab Pty Ltd

ABN 73 002 379 473
4 Green Street
Brookvale
New South Wales 2100
Australia
Telephone: 02 9907 4440
Facsimile: 02 9907 4446
International: +61 2 9907 4440
ecologylab@cardno.com.au
www.cardno.com.au

Cover Image: The Entrance, Tuggerah. Photograph Chris Roberts, Cardno Ecology Lab

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Executive Summary

Wyong Shire Council (WSC) recently adopted an Estuary Management Plan (EMP) for Tuggerah Lakes. One of the knowledge gaps identified in the implementation of the EMP is the ecological effect of the current dredging program, aimed at keeping the mouth of estuary open and alleviating the effects of flooding. Wyong Shire Council commissioned Cardno Ecology Lab Pty Ltd to undertake a study of the ecological impacts of dredging on benthos in the entrance channel and to review existing information on the effects of dredging on the Tuggerah Lakes. The study also included an assessment of options for managing the entrance channel.

Two surveys of macro- and meiobenthos in dredged and undredged locations in the entrance channel, Tuggerah were undertaken autumn/winter 2009. The area was found to support abundant and diverse macrobenthos, dominated by polychaete worms and crustaceans. While there were no significant differences between dredged locations, these did differ from undredged locations which supported smaller numbers of macrobenthos. The undredged locations were also more spatially variable than dredged locations, reflecting the homogenising effect of dredging. Despite regular dredging, however, the dredged locations had large numbers of macrobenthos, indicating fairly rapid colonization after dredging. Tuggerah supported significantly larger numbers of macrobenthos than other coastal lagoons, but was most similar to other lagoons that are maintained as open systems.

There were significant differences in meiobenthos between dredged and undredged locations, with some dredged sites supporting larger numbers of nematodes and flatworms. Apart from this, however, the differences were generally small and the data indicated that meiobenthos had recovered rapidly after dredging. There were also significant differences in meiobenthos between Tuggerah and other coastal lagoons, but no clear patterns were evident. It is concluded that Tuggerah is not exceptional in terms of meiobenthos.

The conclusion from the field surveys is that the benthos exhibit considerable resilience to dredging disturbance and it is therefore unlikely that the benthic ecology of the system is impaired beyond the immediate vicinity of dredging and this would be temporary.

Three options for the future management of the entrance to Tuggerah Lakes were assessed. These are:

- no intervention, in which the mouth is allowed to open and close naturally;
- maintain the *status quo*, with regular (approximately annual in summer) dredging of the main channel and dredging of other areas as required or;
- adopt alternatives to dredging, such as stabilization of the entrance channel, construction of training walls, creating a second entrance or creating a link with Lake Macquarie.

The first option was considered unrealistic given the extent of development and human pressure on the lakes' catchment, while the last has been extensively investigated and found to be impractical and prohibitively expensive. Given the results of the study and the recent historical and current condition of the lakes system, it is recommended that option two be continued with the modification that dredging be done in summer when the lagoon would naturally open.

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1 Background

Wyong Shire Council (WSC) recently adopted an Estuary Management Plan (EMP) for Tuggerah Lakes. The EMP is divided into four Action Plans; Socio-Economic, Water Quality, Ecology and Knowledge and Management. One of the knowledge gaps identified in the implementation of the EMP is the ecological effect of the current dredging program in The Entrance channel, aimed at keeping the mouth of estuary open and alleviating the effects of flooding. WSC has commissioned Cardno Ecology Lab to assess the ecological impacts of dredging the channel at The Entrance to Tuggerah Lakes.

The scope of works for this study includes:

1. Background Research
2. Field Investigations
3. Reporting
4. Meetings and Consultations

1.1 Existing Information

1.1.1 Tuggerah Lakes and Other Coastal Lagoons

The extensive development that has taken place around Tuggerah Lakes and resulting decrease in environmental quality during the twentieth century has focussed attention on the hydrology and ecology of this system. As a result, numerous studies have been done on issues ranging from sediment dynamics (Dickinson and Roberts 2000), hydrodynamics and floods (van Senden 1997, WSC 1994), water quality and nutrient budgets (Higginson 1971, King and Hodgson 1995, Cheng 1996, Garofalow 1998).

There have also been several studies of aquatic biota, including seagrasses (Higginson 1965, Batley *et al.* 1990, King and Hodgson 1995, Daley 1997), macroalgae (Cheng 1990, King and Hodgson 1995, Roberts 2001), phytoplankton (Cummins *et al.* 2000, Roberts 2001), benthic macro invertebrates (Powis and Robinson 1980, Roberts 2001), meiofauna (Dye 2004) and zooplankton (Hodgson 1979, Cheng 1994, Roberts 2001).

Most of these studies involve what have been termed "static" measures of estuarine condition (Fairweather 1999) and there have been few studies of ecological (as opposed to physical) processes in Tuggerah. One exception is a study of decomposition of seagrass (Dye 2006a). Except for Dye (2004, 2006a), the earlier studies in Tuggerah were summarised by Roberts (2001) and Roberts and Dickinson (2005).

A considerable amount of literature exists on the ecology and hydrology of coastal lagoons and estuaries elsewhere in New South Wales. Many of these estuaries open to the sea only intermittently, either naturally, after periods of heavy rain or storms at sea, or after being artificially opened by dredging or bulldozing of sand bars. Estuaries that are mainly closed differ in several key respects from those that open for long periods. Recent studies of open and closed coastal lagoons in New South Wales found that salinity, for example, is usually more variable in closed systems, as it ranges from hyposaline after rain to hypersaline after prolonged drought (Dye and Barros 2005a and b, Dye, 2005, 2006b). Temperature and nutrients are also more variable in closed systems, which are prone to algal blooms and anoxic episodes. Closed systems may also experience drastic and sudden changes in physical conditions when their mouths are breached after rain or artificially (Millet and Guelorget 1994, Roy *et al.* 2001). At such times, lagoon water may be rapidly replaced by oceanic water with different physical and chemical characteristics. While some species are adapted to such changes, there may also be abrupt changes in species composition (Marzano *et al.* 2003). Furthermore, such variability in physical conditions and water quality do not suit the requirements of human beings and local authorities are continually under pressure to maintain an open connection with the sea, to improve water quality, reduce the risk of flooding and for navigation.

1.1.2 Recent Dredging History

Dredging of channels and sumps in The Entrance occurs through a combination of annual dredging, such as in the main channel to the east of the road bridge (Figure 1) , the northern channel through the flood tide shoal and the southern tip of the main sand spit, to biennial dredging, such as the northern channel just downstream of the road bridge, and occasional dredging, such as in the Terilbah Channel (every five years) and main channel to the west of the road bridge (most recently in 1995) (Worley Parsons, 2009).

1.1.3 Effects of Dredging

Of particular relevance to the present study is the issue of how dredging affects the ecology of estuaries. There are two aspects to this; the direct effects of dredging on plants and animals, particularly benthos, and the indirect effects on the entire estuarine system.

The direct effects of dredging include physical disturbance and mortality of benthos and effects of fine sediment dispersed into the water column during dredging operations. For example, sediment plumes can have adverse effects on benthic animals by affecting larval development as well as respiration and feeding (Wilber and Clarke 2001). Sediment plumes may also cause *partial smothering of seagrasses, reducing light penetration and photosynthesis* (Sleeman *et al.* 2005). Recovery of benthic assemblages after disturbance depends on the type of disturbance and the nature of the assemblage, but is facilitated mainly by recruitment from surrounding areas of undisturbed sediment (Hall 1994). Larvae may also be transported by currents from elsewhere in the lagoon and from the ocean when the entrance is open (Armonies 1994, Bolam *et al.* 2004). If these sources of recruits are available, recolonisation can be fairly rapid, in the order of months (Hall and Frid 1998, Newell *et al.* 1998, Dernie *et al.* 2003, Cruz-Motta and Collins 2004).

The system-wide effects of artificial opening arise mainly through greater tidal flushing which reduces salinity fluctuations, flushes out nutrients, allows exchange of larvae with the ocean and reduces the risk of flooding. These factors change the structure of macro- and meiobenthic communities. On one hand, this can result in greater resilience through high turnover and rapid recruitment compared with closed systems (Giangrande and Fraschetti 1996, Bilton *et al.* 2002, Coull 1999). On the other hand, maintaining an open system reduces the natural variability in water quality, threatening those species that evolved in largely isolated systems (Hadwen and Arthington 2006). Wetlands around the margins of the system are also exposed for longer because of lower water levels compared to periods when the system is closed and may die back as a result. Increased tidal flow may, however, cause erosion and deepening of channels. This may, in turn, have adverse effects on macrophytes in these areas, which may be unable to grow at greater water depths due to insufficient light.

1.2 Aims of this Study

The primary aim of this study was to assess the effects of previous dredging of The Entrance channel on macro- and meiobenthos. A secondary aim was to assess the wider effects of dredging on Tuggerah Lakes and comment on different scenarios in relation to maintaining a connection with the sea. To assist in achieving these aims, data obtained from surveys of benthos were analysed in relation to existing data from other coastal lagoons in New South Wales (see Section 2).

2 Study Methods

2.1 Sampling Design

To assess the effects of dredging, four benthos samples were collected from two sites within each of two dredged locations (last dredged in 2008) in the entrance channel of Tuggerah Lakes. These were compared with samples taken from two sites in each of two undredged locations (Figure 1). Samples were collected on two occasions six weeks apart in autumn/winter 2009. Cardno Ecology Lab also had access to an extensive set of data collected in the same seasons in 2002/3 as part of a broad study of the effects of closure on macro- and meiobenthos in eight coastal lagoons in New South Wales (Dye 2005, Dye and Barros 2005a and b, Dye 2006b). These lagoons were classified into four management types, viz. natural, mainly open (Burrill and Conjola); natural, mainly closed (Durras and Wamberal); managed, mainly open (Illawarra and Narrabeen and to which Tuggerah belongs) and managed, mainly closed (Curl Curl and Dee Why) (Dye and Barros 2005a). Data collected in the mouths of these lagoons were used as a baseline against which the new data from Tuggerah were compared.

2.2 Sampling Methodology

Samples of sediment were collected by SCUBA divers using hand-held PVC cores. For macrobenthos and sediment grain size, the 10 cm wide cores were pushed into the sediment to a depth of 20 cm. The sediment samples were transferred to plastic bags and benthos preserved in 10% formaldehyde solution containing Rose Bengal dye before being secured. Sediment grain size samples were not preserved, but frozen upon return to the laboratory.

The sampling procedure for meiobenthos was similar to that described above except that the corer used was 40 mm in diameter.

2.3 Laboratory Methods

Frozen sediment samples were sent to an accredited external laboratory for analysis of grain size.

Macrobenthos samples were decanted of excess formalin, which was disposed of according to EPA requirements, and rinsed through a 0.5-mm mesh sieve. All animals were removed and sorted into groups using a binocular microscope before being identified to the lowest practical taxonomic level, usually family level for major groups such as polychaetes, amphipods and molluscs. After checks on identifications, numbers of each type of animal were entered into spreadsheet format and data checked before analysis.

Meiobenthos samples were processed as follows: Preserved and stained sediment samples were washed with tap water through a 0.5 mm sieve suspended over a 63 μm sieve. The 0.5 mm fraction was discarded and the material on the 63 μm sieve washed into a 1L measuring cylinder where it was decanted with tap water three times, pouring the supernatant liquid through the 63 μm sieve each time. If counting could not be done immediately, the material on the 63 μm sieve was washed with 70% alcohol into a labeled 70 ml plastic vial. Animals were subsequently counted under a dissecting microscope and identified to order or phylum (Gee *et al.* 1992, Warwick and Clarke 1993). Numbers of each type of animal were entered into spreadsheet format and data checked before analysis.

2.4 Statistical Methods

2.4.1 Multivariate Analyses

Permanova+ in Primer v6, a permutation program for fitting linear analysis of variance models (Anderson *et al.* 2008), was used to examine differences between sediment and assemblages at the dredged localities and those at undredged localities. A matrix of differences in the types and relative abundance of the taxa between all possible pairs of samples was compiled by calculating their respective Bray-Curtis dissimilarity coefficients (Euclidean distance for sediment data), after transforming abundance data to their fourth root. This transformation downweights the importance of the most abundant groups of animals and thereby ensures that dissimilarities reflect groups of animals with large and moderate abundances (Warwick 1993). The underlying distribution of the data was determined by repeated randomisation of the samples in the dissimilarity matrix, enabling exact tests for all levels of the experimental design (Anderson *et al.* 2008). The relative importance of factors and their interactions to the overall variance of the data was assessed by examining their respective components of variance.

The experimental design was: Treatment (Fixed, two levels: dredged vs. non-dredged), Locations (Random, two levels, nested in Treatment) and Sites (Random, two levels, nested in Location). *Post hoc* permutational t-tests using Permanova+ were performed to examine significant interactions or main effects.

Spatial and temporal patterns in the composition of the assemblages were examined by means of non-metric Multi Dimensional Scaling (nMDS) ordinations (Warwick 1993). nMDS provides a graphical representation of the assemblages in the samples based on their similarity within and among places or times sampled. In nMDS plots, samples with similar sets of taxa (plant and animal groups) cluster closer together than those containing different sets. The stress value for each plot indicates how well the data fit the two dimensional representation. The lower the value, the better the fit of data, and values lower than 0.2 are considered acceptable (Clarke and Warwick 2001).

Differences in the dispersion of data within each level of the factors in the design (Disturbance, Location and Site) were examined using the Permdisp routine in Permanova+. This routine is used to separate the effects of differences in dispersion of points within clusters (in this case indicating spatial variability within Location) from differences in the relative positions of the clusters (indicating differences between Locations) (Anderson *et al.* 2008).

Multivariate relationships between assemblages and sediment grain size were examined using the RELATE routine in PRIMER v6 (Clarke and Gorley 2006). SIMPER analyses were used to identify taxa that contributed most to dissimilarities between assemblages at dredged and non-dredged locations at each time.

2.4.2 Univariate Analyses

Analysis of variance was used to examine differences in number of taxa, total abundance and *Shannon-Wiener Diversity* (H') *between assemblages in dredged and undredged locations in* Tuggerah and in comparison with other lagoons. Permanova + was used to perform permutational analysis of variance as this approach does not require that the data come from a normal distribution or that variances are homogeneous, as is the case with "traditional" ANOVA. After calculating a Euclidean distance matrix of all possible pairs of samples of the variable of interest, the underlying distribution of the data was determined by repeated randomisation of the samples in the matrix, enabling exact tests for all levels of the experimental design (Anderson *et al.* 2008). The relative importance of factors and their interactions to the overall variance of the data was assessed by examining their respective components of variance.

The experimental design for analyses of sediment data within Tuggerah was: Locations (Random, four levels) and Sites (Random, two levels, nested in Location). For analyses of other factors within Tuggerah, the design was Survey (Random, two levels and orthogonal), Locations (Random, four levels and orthogonal) and Sites (Random, two levels, nested in Locations). For comparisons with other lagoons, the design was: Lagoon type (Fixed, five levels including Tuggerah) and Sites (Random, two levels, nested in Lagoon type). *Post hoc* permutational t-tests using Permanova+ were performed to examine significant interactions or main effects.

3 Results

3.1 Description of Locations

Two previously dredged locations were sampled on 12th May and 23rd June 2009. D1 was located in Terilbah Channel and D2 was just upstream from the entrance (Figure 1). At the same times, locations which had not been dredged for several years, were also sampled. These were situated on the sand mass at the entrance (Und 1) and 150m upstream of the road bridge (Und 2). GPS positions for the sites within these locations are given in Appendix 1.

The mean depth of the dredged locations was 1.9m during high tide, while that at the undredged locations was 1.3m. The substratum at all locations was unvegetated and consisted of medium to coarse sand with varying amounts of fine material (Appendix 2). Median grain size did not differ significantly between dredged and undredged locations (Table 1, Figure 2A), ranging from 0.15 to 0.6 mm in both. The amount of fine material in the undredged locations ranged from 2.0 to 12.0%, compared with a range of 0.5 to 2.0% in the dredged sites, but the difference was not statistically significant (Table 1, Figure 2B). While the source of the fine material at undredged 1 is unknown, the other undredged location was close to a bed of *Zostera capricornii*, which probably contributed additional fine material at that location.

The median grain size in the undredged locations at Tuggerah did not differ significantly from that in the mouths of other coastal lagoons (Table 2, Figure 3A). However, the sediment in the dredged areas had a significantly smaller median grain size than most of the other lagoons, with the exceptions of those that are naturally mainly open (Table 2). These differences, however, were not large and arose mainly because of the very small variances in the data from the other lagoons (Figure 3A). Small scale spatial variability (at the scale of sites) also differed significantly among lagoon types. Sediment at the undredged locations at Tuggerah had significantly more fine material than in any of the other lagoon types. There was also significantly more fine material at dredged locations in Tuggerah compared with other lagoons and some evidence of small scale variation among lagoon types (Table 2, Figure 3B).

3.2 Macrobenthos

3.2.1 Dredged vs. Undredged Locations

A total of 15100 individuals comprising 49 taxa (50% of which were polychaetes and 20% crustaceans) were found in the surveys (Appendix 3). Macrobenthic assemblages did not differ between surveys or between dredged locations, but there were significant differences between dredged and undredged locations and between the two undredged locations (Table 3). Contributing factors were differences in spatial variability within locations, as indicated in the multivariate dispersions (Table 3) and the spread of samples in the MDS plots (Figure 4), which show the undredged locations (particularly Und1) to be much more spatially variable than the dredged locations, which did not differ significantly from each other.

In the first survey, Und 1 was notably depauperate by comparison with Und 2 and the dredged locations, with dissimilarities ranging from 82% to 88% (Table 4). Among taxa contributing collectively 50% or more to dissimilarities, only saccocirrid polychaetes were more abundant at Und 1. In contrast, the dissimilarity between Und 2 and the dredged locations was much less at around 45% to 50%. Und 2 had larger numbers of sabellid, spionid, capitellid and hesionid polychaetes and also more oligochaetes than D1. In comparison with D2, Und 2 had more nematodes and more sabellid, hesionid and capitellid polychaetes (Table 4).

A similar pattern was evident in the second survey with Und 1 again depauperate by comparison with Und 2. The only taxon more abundant in Und 1 in comparison with D1 was Nemertea (Table 4). The dissimilarities were again smaller between Und 2 and the dredged locations at around 42%. In comparison with D1, Und 2 had more spionid, ophelid, sabellid and capitellid polychaetes and more thalassinid and tanaiid crustaceans. In comparison with D2, this location had more capitellids, opheliids, spionids and sabellids and more tanaiids (Table 4).

The number of taxa differed significantly between locations and among sites within location, but differences between surveys were of marginal statistical significance (Table 5, Figure 5). *Post hoc* tests indicated that these differences arose only between undredged locations with Und 2 supporting three times the number of taxa than Und 1. A significant interaction was found between survey and location for total abundance such that in the first survey, Und 1 differed from both Und 2 and Dredged 2, while in the second survey, Und 1 differed from Und 2 and Dredged 1 and 2. In addition, Und 2 differed from Dredged 2, while the two dredged locations also differed from each other (Table 5, Figure 5).

Diversity varied from 1.25 to 1.8 in both surveys (Figure 5) and differed significantly among locations, but not between surveys (Table 5, Figure 5). *Post hoc* tests showed that Und 1 differed from Und 2, while the latter also differed from Dredged 2 and the two dredged locations differed from each other.

There were no significant correlations between macrobenthos and sediment characteristics in undredged locations (Table 6), although number of taxa correlated negatively with median grain size at $p \leq 0.07$. In dredged locations, however, number of taxa ($p \leq 0.07$) and diversity correlated negatively with median grain size, while total abundance correlated positively with median grain size. Number of taxa ($p \leq 0.07$) and total abundance correlated positively with percent fines, while diversity correlated negatively with percent fines.

3.2.2 Tuggerah vs. Other ICOLLs

Macrobenthic assemblages in both dredged and undredged locations in Tuggerah differed significantly from those in the mouths of all other ICOLLs surveyed by Dye and Barros (2005a) (Table 7). This is reflected in the nMDS plots which indicate a clear separation of locations in Tuggerah from those in other ICOLLs, although, as would be expected, Tuggerah is more similar to other managed open lagoons than to those in the other management categories (Figure 6). There were large dissimilarities between dredged locations in Tuggerah and locations in the mouths of other ICOLLs although it is notable that the smallest dissimilarity was with other managed open lagoons (Table 8). Tuggerah supported substantially larger numbers of macrobenthos than the other lagoons, with nematodes contributing most to the differences, followed by flatworms, oligochaetes and syllid polychaetes. A similar pattern was evident for the undredged locations in Tuggerah where Nemertea, nematodes and oligochaetes accounted for most of the dissimilarity with other ICOLLs (Table 8). Again, the smallest dissimilarity was with other managed open lagoons. However, there were more nereidids, syllids and amphipods than in the latter than in undredged locations in Tuggerah.

The number of taxa was significantly greater in dredged locations in Tuggerah than in most of the other lagoons, with the exception of the other managed open systems which were not significantly different from Tuggerah. The number of taxa in undredged locations in Tuggerah was, however, significantly greater than in all other lagoons (Table 9, Figure 7). Similarly, the total abundance of macrobenthos in dredged locations in Tuggerah was significantly greater than in all other lagoons, but there was no significant difference between undredged locations in Tuggerah and other managed open lagoons. The diversity of macrobenthos in both dredged and undredged locations in Tuggerah differed significantly only from that in naturally mainly open and managed mainly closed lagoons (Table 9, Figure 7).

3.3 Meiobenthos

3.3.1 Dredged vs. Undredged Locations

Ten meiobenthic taxa were recorded, comprising mainly nematodes, harpacticoid copepods and flatworms (Appendix 4). Meiobenthic assemblages differed among and between dredged and undredged locations in both surveys, but only Und 1 differed between surveys (Table 10). These differences were mainly due to differences in spatial variability within locations, as indicated in the multivariate dispersions (Table 10) and the spread of samples in the MDS plots (Figure 8), which show the undredged locations to be much more spatially variable than the dredged locations, while the two clusters of points are not separated.

In the first survey, Und1 had larger numbers of nematodes, halacarids (only found at Und1) and harpacticoid copepods than Und2, but both had generally fewer animals than either of the dredged locations (Table 11). Dg2 had a large number of flatworms (Platyhelminthes) compared to the other locations. A similar pattern was evident in the second survey with the exception of nematodes which were more abundant at Und 1 than at other locations.

Despite a significant Survey effect, *post hoc* tests did not detect significant differences between surveys for any location (Table 12). There were few significant differences in the number of taxa between locations with Dg1 differing only from the undredged locations. Similarly, the total abundance of meiofauna differed only between Dg2 and the undredged locations. Diversity did not differ significantly between surveys or among locations (Figure 9).

Diversity in dredged locations correlated positively with median grain size and negatively with percent fines, but there were no significant correlations between sediment characteristics and number of taxa or total abundance in any location (Table 13).

3.3.2 Tuggerah vs. Other ICOLLs

Meiobenthic assemblages in dredged and undredged locations in the mouth of Tuggerah differed significantly from those in other ICOLLs, the only exception being that those in undredged locations did not differ from those in naturally open lagoons (Table 14). Tuggerah supported larger numbers of nematodes, ostracods and foraminifera (Table 15) while harpacticoid copepds were several-fold more abundant in the other ICOLLs. These differences are reflected in the wide separation of Tuggerah from the other ICOLLs in the MDS plots (Figure 10).

There were significant differences in the mean number of taxa per sample, with Tuggerah supporting twice as many (six to eight) as in other ICOLLs (Figure 11), although some of these were rare with small abundances (Appendix 4), including two (molluscs and flatworms) which were juvenile forms of macrobenthic animals.. Total abundance was more variable with dredged locations in Tuggerah being similar to closed ICOLLs and undredged locations similar to open lagoons (Table 16, Figure 11). Diversity did not differ significantly among lagoons (Table 16), although diversity tended to be lowest and more variable in undredged locations in Tuggerah (Figure 11).

4 Discussion

4.1 Effects of Dredging on Macrobenthos

The surveys have revealed considerable spatial variability in composition and abundance of macrobenthos, which is common in soft sediment environments. The differences in abundance of macrobenthos (particularly nematodes and flat worms in dredged areas) between the surveys are almost certainly due to small-scale spatial variability because the time between surveys was too short for significant changes due to recruitment processes (Morrisey *et al.* 1992a and b). Physical disturbance in soft sediments, such as that caused by dredging, often results in partial or complete loss of fauna through mortality and displacement from disturbed areas. In addition, alterations to sediment properties, such as grain size and surface texture, will affect the rate at which the sediment is recolonized by macrobenthos (Peterson *et al.* 1987, Hall *et al.* 1990, Hall and Harding 1997), as do the extent and intensity of disturbance (Dernie *et al.* 2003, Poiner and Kennedy 2004). This results in a patchy distribution of fauna.

Given these factors, it is not surprising that differences in macrobenthic assemblages were found between dredged and undredged locations in the mouth of Tuggerah Lakes or that these differences were not spatially consistent. The undredged locations were more spatially variable than dredged areas. Because dredging has a similar affect (i.e. loss of fauna) wherever it occurs, areas dredged on a regular basis would be expected to be more homogeneous than undredged areas. What may be surprising is the magnitude of the difference between the two undredged areas. Und 1, located at the mouth, was dominated by saccocirrid polychaetes and virtually nothing else, while Und 2, upstream of the road bridge, had an abundant and diverse macrofauna. This suggests two things; first, that the downstream location is subject to some form of continuous disturbance other than dredging (e.g. tidal sediment movement and deposition) and, second, that the upstream location is more stable and probably contains more organic matter which serves as substrata for microbes and food for macrobenthos. The larger amount of fine material in the sediment at this location supports this contention. The large median grain size in the downstream location may be the result of continuous reworking of the sediment by tides and waves which would tend to remove fine material (Roy *et al.* 2001).

The lack of correlation between macrobenthos and sediment characteristics in the mouths of ICOLLs has been reported previously. Dye and Barros (2005a) found a positive correlation between median grain size and macrobenthos only when data from the mouths of eight ICOLLs were combined and it appears that significant correlations with sediment characteristics are more likely at large (kilometre) than small (10s – 100s m) spatial scales (Dye 2006c). In the present case, however, the large variability in sediment data would certainly have contributed to the weak correlations. In the dredged locations, colonization by opportunistic species, such as nematodes and predatory flat worms, which were very abundant, if patchy in distribution, is reflected in the positive correlation between sediment characteristics and total abundance, but negative correlation between these variables and diversity.

The fact that the dredged locations supported an abundant and diverse macrobenthos less than a year after dredging indicates that recolonisation is rapid. Rapid recolonisation of macrobenthos after disturbance, particularly in sandy habitats, has been widely reported (Hall *et al.* 1991, Ferns et al. 2000). The greater depth of the dredged areas, in comparison to the undredged area near the mouth, may provide a more sheltered habitat which would also promote recruitment. Local recruitment is known to be an important factor in recovery of benthic communities after disturbance (Hall and Frid 1998, Newell *et al.* 1998) and the similarity between the dredged areas and the upstream undredged location suggests that this could be a source of recruits for dredged areas. In contrast, the impoverished nature of the downstream undredged location precludes any contribution to recovery of dredged areas from this source.

Dye and Barros (2005a), found a similar pattern of low abundance of macrobenthos in the mouths of ICOLLs compared with upstream locations. What sets Tuggerah apart from these lagoons, however, is the much greater abundance of macrobenthos, particularly in comparison with lagoons that are mainly closed. This puts Tuggerah at the extreme of a trend identified by Dye and Barros (2005a) in which lagoons that are managed as open systems tend to support greater abundances and diversity of macrobenthos than those that are closed for longer periods. It is interesting that a similar trend appears to apply to fish communities, particularly with respect to diversity (Pollard 1994a). Additionally, it may be that there is a geographic trend of increasing abundance of macrobenthos in warmer waters. Tuggerah is the most northerly managed open lagoon in the data set and it would be interesting to survey macrobenthos in the mouths of other similar systems to the north of Tuggerah.

A large number of studies have indicated that recovery of macrobenthos following disturbance can be rapid (Beukema *et al.* 1999, Bolam and Fernandes 2002, Lewis *et al.* 2003). While recruitment into dredged areas may be rapid, the colonists will be opportunistic species, such as nematodes, that can take advantage of disturbed habitats. These in turn will attract the predatory species, such as polychaetes and flatworms, which were found in the surveys. Thus, while the abundances may approximate that of upstream undisturbed areas, it is unlikely that the composition of the macrobenthos will be similar, particularly as recolonisation is reset by dredging on a regular basis. This would, however, not be expected to have a measurable effect on the benthic ecology of Tuggerah beyond the dredged areas, because the species that do colonize are functionally similar to those in undredged areas.

4.2 Effects of Dredging on Meiobenthos

Despite their acknowledged importance in key ecological processes, such as decomposition, there have been few studies of the effects of dredging (or other disturbances) on recovery of meiobenthos and much of this work has focused on intertidal habitats (Shull1997, Schratzberger *et al.* 2004, 2006). Like macrobenthos, however, meiofauna have the capacity to recover rapidly after disturbance due to their fast rates of reproduction (Sherman and Coull 1980) with those from sandy substrata being more resilient to disturbance than those from mud (Schratzberger and Warwick 1998, 1999). Furthermore, repeated disturbance, such as results from regular dredging, tends to reduce spatial variability and favour the establishment of dense populations of opportunistic species. In the present study, there was relatively little difference in meiobenthic assemblages between dredged and undredged locations, except for spatial variability which, as would be expected, was less in the latter. The relatively large density of turbellarian flatworms in one of the dredged locations, however, illustrates the opportunistic nature of meiobenthic recolonisation. Turbellarians are predators that are particularly common in sandy sediments subject to disturbance (Martens and Schockaert 2004), where they prey *inter alia* on nematodes and small crustaceans, such as harpacticoid copepods (abundant in the dredged locations) and can be present in large numbers.

It is interesting that no significant patterns of correlation with sediment characteristics were *found, but this accords with the findings of Dye and Barros (2005b) that factors other than* sediment characteristics are responsible for spatial differences in abundance and composition of meiobenthos in these systems.

There are no previous data on meiobenthos from the mouth of Tuggerah. Dye (2004) surveyed meiobenthos in Tuggerah, Budgewoi and Munmorah, but that study did not include samples from the entrance channel. For this reason, comparisons were made with data from a study of eight ICOLLs in NSW from which samples were obtained from the mouths, as well as inner reaches (Dye and Barros 2005b, Dye 2005). Differences between Tuggerah and other ICOLLs, while significant, indicate that Tuggerah is not exceptional in terms of meiobenthos. Some taxa are more abundant in Tuggerah, while others are more so in other ICOLLs. However, diversity is similar, as is mean total abundance.

The results of the present study suggest that the meiobenthos had recovered since the last dredging and exhibits considerable resilience to this form of disturbance. It is therefore unlikely that regular dredging, as practiced to date, has any lasting deleterious effects on meiobenthos or their role in the ecology of the system.

4.3 Hydrological and Ecological Consequences of an Open Entrance

Maintaining an open connection with the sea affects the hydrology and ecology of Tuggerah Lakes in several ways. Hydrological studies have shown that tidal flows account for around 40% of the flushing of the estuary, which is estimated to require between 60 and 100 days (Roberts 2001). During flood tides, ocean water flows into the lakes along the bottom because it is more saline and hence denser than the estuarine water. Ebb tide flows are weaker and only surface water located near the entrance flows out to sea (van Senden 1997), resulting in an efficient exchange of water.

Tuggerah Lakes receive over 90% of the runoff from the Wyong catchment and the system is therefore prone to flooding. When the estuary is open, it is estimated that the Entrance channel would carry 1200 - 1500 m3 s-1 during severe flooding and an open entrance is therefore considered important in mitigating floods (Roberts 2001). Together with biogeochemical processes, tidal flushing acts to limit the accumulation of nutrients and reduce the incidences of algal blooms and periods of low water quality. Without dredging, marine sediments accumulate in the mouth, leading to gradual closure which can last for many months, particularly during drought periods.

An open connection with the sea affects the ecology of the system, not only by changing water quality, but also by allowing exchange of propagules, larvae and adult marine fauna between the estuary and the sea. While this exchange may promote the marine biodiversity of the system by maintaining populations of invertebrates and fish that require access to the sea during their life cycles (The Ecology Lab 2007), it also creates the potential for invasive species to become established in the system (Bunn and Arthington 2002). Nevertheless, even those plants and animals that are exclusively estuarine still require regular incursions of ocean water to maintain the salinity profiles that characterise estuarine systems.

Numerous studies have shown that lagoon systems that remain isolated from the sea for protracted periods experience large fluctuations in physical and chemical conditions when reconnected with the sea (Millet and Guelorget 1994), sometimes with disastrous consequences for fauna and flora (Pollard 1994b, Branch et al. 1985). Marine biodiversity in such systems is low as only a few highly adapted species can tolerate these conditions (Teske and Wooldridge 2001, Dye and Barros 2005a and b). In contrast, conditions in systems that open (or are opened) regularly are far less variable and less susceptible to dystrophic episodes.

There are clearly ecological benefits and drawbacks to maintaining an open connection with the sea. Given the extensive and increasing development in the catchments and around the margins of many ICOLLs, it has been suggested that since artificial opening is the only feasible management option, it should be carried out when the fauna are most resilient to the changes that follow opening (Hadwen and Arthington 2006).. Unfortunately, there is little information on the majority of animals (mainly small invertebrates and meiofauna) to inform a decision about when the most appropriate time would be to open a given system. Most of the available information relates to fish and from this it is clear that there is in fact no "best' time as each species has its own unique requirements (The Ecology Lab 2008). It is very likely, therefore, that the same applies to the majority of the benthic fauna. This being the case, the best approach would be to ensure that dredging is confined to late summer and autumn when, historically, the mouth would be most likely to breach due to seasonal rain events (Pollard 1994. Bureau of Meteorology 2009).

4.4 Options for Management of The Entrance Channel

There are three options for the future management of the entrance to Tuggerah Lakes. These are:

- no intervention, in which the mouth is allowed to open and close naturally;

- maintain the *status quo*, with regular (approximately annual) dredging of the main channel and dredging of other areas as required or;
- adopt alternatives to dredging, such as stabilization of the entrance channel, construction of training walls, creating a second entrance or creating a link with Lake Macquarie.

From the above discussion, it is clear that maintaining an open entrance has many positive effects on the physical and ecological environment of the Tuggerah Lakes. Apart from these, however, there are a number of socio-economic implications that must be considered in decisions about whether or not to maintain an open entrance. Most of these relate to the recreational use of the lakes and their resources and include recreational angling, boating, canoeing, wind surfing and swimming, while other activities, such as scuba diving and spear fishing, often require boat access to the sea. All of these activities are important for the local economy, particularly during holiday periods, and many businesses, such as bait and tackle shops, caravan parks, supermarkets and restaurants, benefit from the trade created by those wishing to enjoy the amenities of the lakes.

Another important consideration is flood mitigation. Residents and business in low-lying areas enjoy some protection from floods when the mouth is open, potentially saving millions of dollars in flood damage and preventing loss of amenity. It has been estimated, for example, that for every centimetre rise in water level during floods, 20 additional properties near the lakes would be flooded (Roberts 2001). Apart from damage to property, there would also be disruption to vital infrastructure, such as sewerage, with potentially serious consequences for public health.

The extensive development and investment around Tuggerah Lakes and indeed around many coastal lagoons in New South Wales and elsewhere (Hadwen and Arthington 2006), makes it difficult, if not impossible, to justify a policy of no intervention. The question, therefore, is not whether to maintain an open entrance, but how best to achieve this. The alternatives to dredging that have been suggested have been extensively evaluated a number of times over the years and were considered unfeasible on the grounds of cost and/or environmental impact (PWD 1988, Roberts and Dickinson 2005, Dickinson *et al.* 2006).

The condition of Tuggerah Lakes has improved considerably over the last 20 years (Roberts 2001), probably as a result of improvements in sewage treatment and storm water management (Roberts and Dickinson 2005). During most of this time the entrance has been artificially maintained and the present regime of dredging (i.e. as required) should be maintained with the proviso that dredging should be done in late summer or autumn.

5 Conclusions and Recommendations

Macrobenthic communities in the mouth of Tuggerah are among the richest of many coastal lagoons in New South Wales, despite (or perhaps because of) dredging on a regular basis. Macrobenthos appears to recolonize dredged areas rapidly and, while the composition may be somewhat different from that in undredged locations, the functional similarity minimizes the possible deleterious effects of dredging.

Tuggerah does not appear exceptional in terms of meiobenthos, although there were consistently larger numbers of some taxa compared to other ICOLLs. The similarity between meiobenthic assemblages in dredged and undredged locations suggests that recovery had occurred within the relatively short period of time since the last dredging operation and exhibits a high level of resilience to this form of disturbance. As with macrobenthos, the data do not suggest any deleterious effects on meiobenthos or their ecological function.

In the light of this study and the above discussion, it is clear that numerous benefits accrue from maintaining an open connection with the sea, while several deleterious ecological and socio-economic consequences would follow prolonged closure. It is therefore recommended that the current regime of dredging be maintained.

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8 Tables

Table 1: Permutational Analysis of Variance of median grain size and percent fines (<0.063 mm) at dredged and undredged locations at The Entrance, Tuggerah.

Source of variation	df	SS	MS	F	P
Median Grain Size					
Location	3	0.107	0.036	1.267	0.387
Sites(Location)	4	0.113	0.028	0.556	0.702
Residual	8	0.405	0.051		
Total	15	0.624			

Source of variation	df	SS	MS	F	P
Percent Fines					
Location	3	62.672	20.891	2.035	0.256
Sites(Location)	4	41.063	10.266	0.829	0.503
Residual	8	99.125	12.391		
Total	15	202.860			

Table 2: Permutational Analysis of Variance of median grain size and percent fines (<0.063 mm) in sediment from the mouths of four types of ICOLLs compared with dredged and undredged locations in The Entrance, Tuggerah. Data were untransformed. Significant factors/contrasts are in bold ($p \leq 0.05$). N = 4.

Source of variation	df	SS	MS	F	*P*
Median Grain Size: Tuggerah Undredged vs. Other Lakes					
Lagoon Type	4	0.021	0.005	0.520	0.779
Sites(Lagoon Type)	5	0.051	0.010	3.786	**0.005**
Residual	26	0.070	0.003		
Total	35	0.143			

Source of variation	df	SS	MS	F	*P*
Median Grain Size: Tuggerah Dredged vs. Other Lagoons					
Lagoon Type	4	0.026	0.006	43.581	**0.006**
Sites(Lagoon Type)	5	0.001	0.000	0.140	0.978
Residual	26	0.025	0.001		
Total	35	0.052			
Post hoc tests for Lagoon Type vs. Tuggerah		*t*	*P**		
Naturally mainly closed		5.895	**<0.001**		
Naturally mainly open		0.465	0.653		
Managed, mainly closed		6.781	**<0.001**		
Managed, mainly open		7.668	**<0.001**		

Source of variation	df	SS	MS	F	*P*
Percent Fines: Tuggerah Undredged vs. Other Lakes					
Lagoon Type	4	64.965	16.241	19.715	**0.002**
Sites(Lagoon Type)	5	4.120	0.824	1.021	0.425
Residual	26	20.975	0.807		
Total	35	90.060			
Post hoc tests for Lagoon Type vs. Tuggerah		*t*	*P**		
Naturally mainly closed		4.794	**0.023**		
Naturally mainly open		4.627	**0.023**		
Managed, mainly closed		5.193	**0.021**		
Managed, mainly open		4.556	**0.027**		

Source of variation	df	SS	MS	F	*P*
Percent Fines: Tuggerah Dredged vs. Other Lakes					
Lagoon Type	4	2.409	0.602	11.642	**0.004**
Sites(Lagoon Type)	5	0.261	0.052	2.678	**0.038**
Residual	26	0.506	0.019		
Total	35	3.176			
Post hoc tests for Lagoon Type vs. Tuggerah					
Naturally mainly closed		3.296	0.079		
Naturally mainly open		2.468	0.128		
Managed, mainly closed		5.679	**0.030**		
Managed, mainly open		1.788	0.209		

* Monte Carlo simulation used as number of unique permutations < 100.

Table 3: Permutational Analysis of Variance and post hoc tests comparing macrobenthic assemblages in dredged and undredged locations surveyed on two occasions in The Entrance, Tuggerah. Data were 4th root transformed. Significant factors/contrasts in bold. ns = not significant (p < 0.05). R = redundant term due to significant interaction.

Source of Variation	df	SS	MS	*F*	*P*
Survey	1	3236.3	3236.3		R
Locations	3	*52666.0*	*17555.0*		R
Sites(Locations)	4	6043.7	1510.9		R
Survey x Location	3	6388.0	2129.3	2.661	**0.022**
Survey x Sites(Location)	4	3200.6	800.2	1.182	0.270
Residual	47	31831.0	677.3		
Total	62	104170.0			
Post hoc tests for Survey x Location for pairs of the factor "Survey"					
Survey 1 vs. Survey 2					
Und1	0.153	0.147	ns		
Und2	0.167	**0.034**			
D1	0.491	0.372	ns		
D2	0.168	0.094	ns		
Post hoc tests for Survey x Location for pairs of the factor "Location"					
Survey 1	*t*	*P**			
Und1 vs. Und2	3.407	**0.007**			
Und1 vs. D1	2.563	**0.027**			
Und1 vs. D2	2.921	**0.014**			
Und2 vs. D1	2.137	**0.031**			
Und2 vs. D2	2.838	**0.004**			
D1 vs. D2	1.082	0.392	ns		
Survey 2	*t*	*P**			
Und1 vs. Und2	4.504	**0.001**			
Und1 vs. D1	4.084	**0.003**			
Und1 vs. D2	4.726	**0.001**			
Und2 vs. D1	2.007	**0.031**			
Und2 vs. D2	2.807	**0.005**			
D1 vs. D2	1.792	0.065	ns		
Multivariate Dispersion (surveys combined)					
Location	%Disp		*t*	*P*	
Und1	36.6	Und1 vs. Und2	2.745	**0.008**	
Und2	26.3	Und1 vs. D1	3.645	**0.001**	
D1	22.3	Und1 vs. D2	4.048	**<0.001**	
D2	21.4	Und2 vs. D1	2.102	**0.050**	
		Und2 vs. D2	3.131	**0.003**	
		D1 vs. D2	0.505	0.635	ns

* Monte Carlo simulation used as number of unique permutations < 100.

Table 4: SIMPER analysis showing those taxa that collectively contribute 50% or more to dissimilarities between macrobenthic assemblages in dredged and undredged locations on two occasions in The Entrance, Tuggerah. Data were 4[th] root transformed for analysis but average abundances are shown untransformed.

Survey 1						
	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
	Undredged 1	Undredged 2				
Average dissimilarity = 87.84%						
Sabellidae	0.00	73.88	10.64	5.26	12.12	12.12
Oligochaeta	0.00	35.38	9.05	5.94	10.30	22.42
Spionidae	0.00	15.25	7.26	5.96	8.27	30.68
Capitellidae	0.00	8.38	6.30	5.44	7.17	37.85
Nematoda	0.57	22.13	5.86	2.17	6.67	44.52
Amphipoda	0.00	5.63	5.60	6.32	6.37	50.89
	Undredged 1	Dredged 1				
Average dissimilarity = 83.61%						
Nematoda	0.57	74.63	10.41	3.65	12.45	12.45
Amphipoda	0.00	4.75	6.86	3.30	8.20	20.65
Orbiniidae	0.00	4.13	6.54	4.16	7.82	28.47
Nereididae	0.00	4.50	6.51	4.64	7.78	36.25
Saccocirridae	7.71	0.00	6.37	1.81	7.61	43.86
Oligochaeta	0.00	5.75	5.38	1.58	6.43	50.29
	Undredged 1	Dredged 2				
Average dissimilarity = 81.63%						
Nematoda	0.57	136.13	11.73	4.05	14.37	14.37
Oligochaeta	0.00	13.08	6.97	3.60	8.54	22.92
Spionidae	0.00	5.33	6.00	4.79	7.35	30.26
Nereididae	0.00	3.63	5.58	5.06	6.83	37.10
Saccocirridae	7.71	0.00	5.52	2.02	6.76	43.86
Platyhelminthes	0.00	12.08	5.21	1.42	6.38	50.24
	Undredged 2	Dredged 1				
Average dissimilarity = 49.41%						
Sabellidae	73.88	2.00	6.07	2.20	11.93	11.93
Spionidae	15.25	0.88	3.76	1.84	7.39	19.32
Oligochaeta	35.38	5.75	3.30	1.45	6.49	25.81
Capitellidae	8.38	0.56	3.13	1.57	6.15	31.96
Orbiniidae	0.50	4.13	2.77	1.72	5.45	37.41
Nereididae	0.63	4.50	2.67	1.56	5.24	42.65
Hesionidae	6.00	0.75	2.60	1.50	5.10	47.76
Bivalvia	1.75	4.75	2.55	1.45	5.00	52.76
	Undredged 2	Dredged 2				
Average dissimilarity = 45.83%						
Sabellidae	73.88	1.25	4.88	3.10	10.29	10.29
Nematoda	22.13	136.13	3.39	1.89	7.15	17.44
Platyhelminthes	0.00	12.08	3.22	1.40	6.78	24.23
Hesionidae	6.00	0.00	3.11	2.25	6.55	30.78
Syllidae	1.25	9.58	2.59	1.38	5.46	36.24
Capitellidae	8.38	5.75	2.53	1.50	5.34	41.59
Nereididae	0.63	3.63	2.41	1.54	5.09	46.68
Opheliidae	3.63	0.00	2.14	1.13	4.52	51.20

continued...

Table 4: Continued.

Survey 2

	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
	Undredged 1	Undredged 2				
Average dissimilarity = 80.06%						
Sabellidae	0.00	56.63	8.19	8.41	10.23	10.23
Spionidae	0.00	37.88	7.65	8.48	9.55	19.78
Nematoda	1.13	77.38	6.75	2.73	8.43	28.20
Amphipoda	0.13	14.00	5.43	4.24	6.79	34.99
Oligochaeta	0.75	29.63	5.28	2.37	6.59	41.59
Tanaidacea	0.00	14.00	4.27	2.06	5.33	46.91
Capitellidae	0.00	7.00	3.47	1.52	4.34	51.25
	Undredged 1	Dredged 1				
Average dissimilarity = 75.66%						
Nematoda	1.13	44.38	7.23	2.44	9.55	9.55
Sabellidae	0.00	11.75	7.10	7.71	9.39	18.94
Amphipoda	0.13	11.00	6.55	4.16	8.65	27.59
Orbiniidae	0.13	7.75	6.05	3.86	8.00	35.59
Nemertea	8.75	0.38	5.32	1.96	7.03	42.61
Nereididae	0.25	4.63	4.66	2.35	6.17	48.78
Platyhelminthes	0.13	16.38	4.58	1.24	6.06	54.84
	Undredged 1	Dredged 2				
Average dissimilarity = 72.86%						
Platyhelminthes	0.13	471.38	11.13	2.37	15.27	15.27
Nematoda	1.13	344.38	9.68	4.39	13.29	28.56
Oligochaeta	8.88	69.75	6.16	2.44	8.46	37.01
Amphipoda	0.13	17.50	5.25	4.13	7.20	44.22
Sabellidae	0.00	9.63	4.97	7.09	6.82	51.04
	Undredged 2	Dredged 1				
Average dissimilarity = 42.86%						
Spionidae	37.88	3.13	3.72	1.92	8.95	8.95
Orbiniidae	0.63	7.75	2.89	1.98	6.97	15.93
Platyhelminthes	1.50	16.38	2.63	1.27	6.33	22.26
Opheliidae	3.88	0.13	2.22	1.53	5.36	27.62
Sabellidae	56.63	11.75	2.05	1.82	4.93	32.54
Thalassinidae	1.50	0.13	2.01	1.82	4.84	37.38
Tanaidacea	14.00	1.13	1.98	1.23	4.78	42.16
Capitellidae	7.00	0.88	1.98	1.36	4.76	46.92
Syllidae	1.13	9.50	1.91	1.34	4.60	51.52
	Undredged 2	Dredged 2				
Average dissimilarity = 41.52%						
Platyhelminthes	1.50	471.38	6.90	2.01	18.47	18.47
Nematoda	44.38	344.38	3.49	2.26	9.33	27.79
Nemertea	0.38	10.88	2.60	1.57	6.95	34.74
Oligochaeta	8.88	69.75	2.52	1.66	6.75	41.49
Copepoda	0.00	3.13	1.81	1.23	4.83	46.32
Spionidae	3.13	5.38	1.61	1.08	4.30	50.62

Table 5: Permutational Analysis of Variance and *post hoc* tests comparing numbers of macrobenthic taxa, total abundance and Shannon-Wiener diversity in dredged and undredged locations surveyed on two occasions in The Entrance, Tuggerah. Data transformations as indicated. Significant factors/contrasts in bold. ns = not significant ($p < 0.05$). R = redundant term due to significant interaction.

Source of Variation	df	SS	MS	*F*	*P*
No. of taxa (untransformed)					
Survey	1	37.8	37.8	8.187	0.051
Locations	3	978.1	326.0	15.710	**0.031**
Sites(Locations)	4	83.0	20.8	3.354	**0.015**
Survey x Locations	3	17.1	5.7	1.235	0.401
Survey x Sites(Locations)	4	18.4	4.6	0.745	0.548
Residual	47	290.9	6.2		
Total	62	1426.9			
Post hoc tests for Locations	*t*	*P**			
Und1 vs. Und2	82.830	**<0.001**			
Und1 vs. D1	3.159	0.091			
Und1 vs. D2	10.672	**0.010**			
Und2 vs. D1	1.735	0.229	ns		
Und2 vs. D2	1.994	0.176	ns		
D1 vs. D2	0.907	0.458	ns		

Source of Variation	df	SS	MS	*F*	*P*
Total Abundance (4th root transformed)					
Survey	1	5.1	5.1		R
Locations	3	49.8	16.6		R
Sites(Locations)	4	2.5	0.6		R
Survey x Locations	3	7.3	2.4	13.134	**0.016**
Survey x Sites(Locations)	4	0.7	0.2	0.847	0.503
Residual	47	10.3	0.2		
Total	62	75.6			
Post hoc tests for Survey x Location for pairs of the factor "Survey"					
Survey 1 vs. Survey 2	*t*	*P**			
Und1	0.823	0.694	ns		
Und2	0.339	0.390	ns		
D1	0.668	0.723	ns		
D2	0.336	0.079	ns		
Post hoc tests for Survey x Location for pairs of the factor "Location"					
Survey 1	*t*	*P**			
Und1 vs. Und2	4.524	**0.040**			
Und1 vs. D1	2.179	0.164	ns		
Und1 vs. D2	7.501	**0.017**			
Und2 vs. D1	0.861	0.486	ns		
Und2 vs. D2	0.395	0.722	ns		
D1 vs. D2	1.219	0.345	ns		

continued...

Table 5: Continued.

Post hoc tests for Survey x Location for pairs of the factor "Location"					
Survey 2					
Und1 vs. Und2	28.279	**0.001**			
Und1 vs. D1	4.354	**0.041**			
Und1 vs. D2	17.675	**0.004**			
Und2 vs. D1	2.920	0.099	ns		
Und2 vs. D2	8.252	**0.011**			
D1 vs. D2	7.195	**0.020**			

Source of Variation	df	SS	MS	*F*	*P*
Diversity H' (untransformed)					
Survey	1	0.432	0.432	3.361	0.154
Locations	3	4.604	1.535	26.596	**0.032**
Sites(Locations)	4	0.231	0.058	0.635	0.644
Survey x Locations	3	0.271	0.090	0.702	0.592
Survey x Sites(Locations)	4	0.514	0.128	1.414	0.241
Residual	47	4.270	0.091		
Total	62	10.212			
Post hoc tests for Locations	*t*	*P**			
Und1 vs. Und2	6.121	**0.024**			
Und1 vs. D1	3.820	0.063	ns		
Und1 vs. D2	0.032	0.977	ns		
Und2 vs. D1	2.306	0.152	ns		
Und2 vs. D2	16.086	**0.005**			
D1 vs. D2	6.401	**0.024**			

* Monte Carlo simulation used as number of unique permutations < 100.

Table 6: Correlations between macrobenthos and sediment characteristice in Undredged and Dredged locations in the first survey at The Entrance, Tuggerah. Significant correlations ($p \leq 0.05$) in bold. N = 32, critical $r^2 = 0.349$.

Dredged Locations	Median Grain Size	% Fines
Number of Taxa	0.328 ($p \leq 0.07$)	0.320 ($p \leq 0.07$)
Total Abundance	**0.502**	**-0.513**
Diversity (H')	**-0.556**	**0.561**

Undredged Locations	Median Grain Size	% Fines
Number of Taxa	0.322 ($p \leq 0.07$)	-0.289
Total Abundance	-0.215	-0.150
Diversity (H')	-0.310	-0.264

Table 7: Permutational Analysis of Variance and *post hoc* tests of macrobenthic assemblages in the mouths of four types of ICOLLs compared with those in dredged and undredged locations in the Entrance, Tuggerah (surveys combined). Significant factors/contrasts in bold. Data 4th root transformed. ns = not significant.

Source of variation	df	SS	MS	*F*	*P*
ICOLLs vs. Dredged locations in Tuggerah					
Lagoon Type	4	188770.0	47193.0	31.191	**0.002**
Sites(Lagoon Type)	5	7563.1	1512.6	0.978	0.477
Residual	270	417790.0	1547.4		
Total	279	614130.0			
Post hoc tests					
Lagoon Type vs. Tuggerah		*t*	*P**		
Naturally mainly closed		7.890	**<0.001**		
Naturally mainly open		7.646	**<0.001**		
Managed, mainly closed		4.866	**<0.001**		
Managed, mainly open		8.513	**<0.001**		

Source of variation	df	SS	MS	*F*	*P*
ICOLLs vs. Undredged locations in Tuggerah					
Lagoon Type	4	153990.0	38498.0	25.055	**0.002**
Sites(Lagoon Type)	5	7671.5	1534.3	0.900	0.613
Resdual	269	458680.0	1705.1		
Total	278	620530.0			
Post hoc tests					
Lagoon Type vs. Tuggerah		*t*	*P**		
Naturally mainly closed		6.0126	**<0.001**		
Naturally mainly open		5.9316	**<0.001**		
Managed, mainly closed		6.7413	**<0.001**		
Managed, mainly open		4.8827	**<0.001**		

* Monte Carlo simulation used as number of unique permutations < 100.

Table 8: SIMPER analysis showing those taxa that collectively contribute 50% or more to dissimilarities between macrobenthic assemblages in the mouths of four types of ICOLLs and those in dredged and undredged locations in the Entrance, Tuggerah (surveys combined). Data were 4th root transformed for analysis, but average abundances are shown untransformed.

ICOLLs vs. Dredged locations in Tuggerah						
Management Type	ICOLL Av.Abund	Tuggerah Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Naturally mainly closed						
Average dissimilarity = 87.53%						
Nematoda	0.05	149.88	14.11	4.77	16.12	16.12
Syllidae	0.00	10.61	7.46	3.22	8.52	24.64
Oligochaeta	22.84	24.36	7.34	2.08	8.39	33.03
Platyhelminthes	0.00	126.11	7.30	1.27	8.34	41.37
Amphipoda	0.25	8.66	5.98	1.86	6.84	48.21
Orbiniidae	0.27	3.96	5.28	1.76	6.04	54.24
Naturally mainly open						
Average dissimilarity = 88.68%						
Nematoda	53.39	149.88	13.88	3.36	15.65	15.65
Platyhelminthes	0.00	126.11	7.48	1.27	8.44	24.09
Syllidae	0.06	10.61	7.46	2.89	8.41	32.51
Oligochaeta	3.11	24.36	7.45	2.16	8.40	40.91
Nereididae	0.27	4.03	6.11	2.23	6.89	47.79
Amphipoda	5.00	8.66	5.64	1.65	6.36	54.15
Managed, mainly closed						
Average dissimilarity = 86.14%						
Nematoda	0.52	149.88	13.58	3.46	15.77	15.77
Platyhelminthes	0.00	126.11	7.29	1.26	8.47	24.24
Syllidae	0.34	10.61	6.78	2.28	7.87	32.11
Oligochaeta	1.13	24.36	6.74	1.82	7.82	39.93
Orbiniidae	0.70	3.96	5.70	1.88	6.62	46.55
Nereididae	0.16	4.03	5.67	1.98	6.58	53.13
Managed, mainly open						
Average dissimilarity = 63.27%						
Nematoda	6.46	149.88	10.26	2.69	16.22	16.22
Platyhelminthes	0.00	126.11	5.90	1.22	9.33	25.55
Oligochaeta	1.34	24.36	5.73	2.06	9.06	34.60
Sabellidae	1.09	6.16	3.75	1.43	5.92	40.52
Syllidae	5.55	10.61	3.66	1.28	5.79	46.31
Capitellidae	0.67	2.41	3.14	1.09	4.97	51.28

continued.

Tuggerah Entrance Dredging Study

Table 8: Continued.

ICOLLs vs. Undredged locations in Tuggerah						
Management Type	ICOLL Av.Abund	Tuggerah Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Naturally mainly closed						
Average dissimilarity = 91.84%						
Nemertea	0.39	4.06	9.16	1.09	9.98	9.98
Nematoda	0.05	26.11	8.97	0.91	9.76	19.74
Oligochaeta	22.84	16.97	7.42	1.11	8.08	27.82
Saccocirridae	0.00	2.29	6.36	0.69	6.93	34.75
Spionidae	17.00	13.71	5.84	0.93	6.36	41.11
Sabellidae	0.03	33.68	5.69	1.01	6.20	47.31
Syllidae	0.00	1.65	4.95	0.87	5.39	52.70
Naturally mainly open						
Average dissimilarity = 92.72%						
Nemertea	0.02	4.06	10.12	1.12	10.92	10.92
Nematoda	53.39	26.11	10.07	0.88	10.86	21.78
Saccocirridae	0.00	2.29	6.84	0.69	7.38	29.16
Oligochaeta	3.11	16.97	6.72	1.21	7.25	36.41
Sabellidae	0.03	33.68	5.80	0.99	6.25	42.66
Syllidae	0.06	1.65	5.25	0.84	5.67	48.32
Amphipoda	0.50	5.10	4.99	0.91	5.38	53.71
Managed, mainly closed						
Average dissimilarity = 89.59%						
Nemertea	0.36	4.06	9.17	1.04	10.24	10.24
Nematoda	0.52	26.11	8.94	0.85	9.98	20.22
Oligochaeta	1.13	16.97	6.52	1.21	7.27	27.49
Saccocirridae	0.00	2.29	6.48	0.68	7.24	34.73
Sabellidae	0.25	33.68	5.72	1.01	6.38	41.11
Amphipoda	1.14	5.10	5.29	0.83	5.90	47.01
Syllidae	0.34	1.65	5.14	0.81	5.74	52.75
Managed, mainly open						
Average dissimilarity = 78.29%						
Nematoda	0.52	26.11	6.16	1.37	7.87	7.87
Nemertea	0.36	4.06	5.77	1.11	7.37	15.23
Nereididae	0.16	0.39	5.63	1.06	7.19	22.42
Amphipoda	1.14	5.10	5.23	0.90	6.68	29.10
Sabellidae	0.25	33.68	4.93	1.15	6.29	35.40
Spionidae	1.89	13.71	4.85	1.25	6.19	41.59
Oligochaeta	1.13	16.97	4.81	1.23	6.15	47.74
Syllidae	0.34	1.65	4.32	0.94	5.52	53.25

Table 9: Permutational Analysis of Variance and *post hoc* tests comparing numbers of macrobenthic taxa, total abundance and Shannon-Wiener diversity in the mouths of four types of ICOLLs compared with those in dredged and undredged locations in the Entrance, Tuggerah (surveys combined). Data transformations as indicated. Significant factors/contrasts in bold. ns = not significant (p < 0.05).

Source of variation	df	SS	MS	*F*	*P*
No. of Taxa (Untransformed) ICOLLs vs. Dredged locations in Tuggerah					
Lagoon Type	4	3372.3	843.1	32.928	**0.008**
Sites(Lagoon Type)	5	129.1	25.8	3.346	**0.006**
Residual	270	2084.0	7.7		
Total	279	5585.4			
Post hoc tests for Sites(Lagoon Type) vs. Sites(Tuggerah)		*t*	*P**		
Naturally mainly closed		2.296	**0.026**		
Naturally mainly open		1.324	0.199	ns	
Managed, mainly closed		0.635	0.529	ns	
Managed, mainly open		1.218	0.235	ns	
Post hoc tests Management Type vs. Tuggerah					
Naturally mainly closed		6.860	**0.022**		
Naturally mainly open		8.272	**0.014**		
Managed, mainly closed		7.915	**0.015**		
Managed, mainly open		3.652	0.064	ns	

Source of variation	df	SS	MS	*F*	*P*
No. of Taxa (Untransformed) ICOLLs vs. Undredged locations in Tuggerah					
Lagoon Type	4	2268.1	567.0	46.480	**0.016**
Sites(Lagoon Type)	5	61.1	12.2	1.099	0.361
Residual	270	2989.0	11.1		
Total	279	5317.2			
Post hoc tests Management Type vs. Tuggerah		*t*	*P**		
Naturally mainly closed		8.689	**0.007**		
Naturally mainly open		15.738	**<0.001**		
Managed, mainly closed		16.227	**<0.001**		
Managed, mainly open		3.811	**0.030**		

Source of variation	df	SS	MS	*F*	*P*
Total Abundance (4th root transformed) ICOLLs vs. Dredged locations in Tuggerah					
Lagoon Type	4	210.8	52.71	70.328	**0.009**
Sites(Lagoon Type)	5	3.7	0.75	0.760	0.582
Residual	270	265.2	0.98		
Total	279	479.8			
Post hoc tests Management Type vs. Tuggerah		*t*	*P**		
Naturally mainly closed		13.675	**<0.001**		
Naturally mainly open		9.696	**0.004**		
Managed, mainly closed		19.399	**<0.001**		
Managed, mainly open		9.514	**0.004**		

continued...

Table 9: Continued.

Source of variation	df	SS	MS	*F*	*P*
Total Abundance (4th root transformed)					
ICOLLs vs. Undredged locations in Tuggerah					
Lagoon Type	4	34322.0	8580.5	31.909	**0.023**
Sites(Lagoon Type)	5	1340.4	268.1	0.811	0.574
Residual	270	88918.0	330.6		
Total	279	124640.0			
Post hoc tests					
Management Type vs. Tuggerah		*t*	*P**		
Naturally mainly closed		5.849	**0.003**		
Naturally mainly open		6.831	**0.001**		
Managed, mainly closed		12.783	**<0.001**		
Managed, mainly open		2.754	0.067	ns	

Source of variation	df	SS	MS	*F*	*P*
Diversity (Untransformed)					
ICOLLs vs. Dredged locations in Tuggerah					
Lagoon Type	4	32.2	8.04	17.360	**0.034**
Sites(Lagoon Type)	5	2.3	0.47	1.959	0.088
Residual	270	64.2	0.24		
Total	279	98.7			
Post hoc tests					
Management Type vs. Tuggerah		*t*	*P**		
Naturally mainly closed		3.448	0.071	ns	
Naturally mainly open		10.473	**0.003**		
Managed, mainly closed		13.445	**<0.001**		
Managed, mainly open		0.282	0.804	ns	

Source of variation	df	SS	MS	*F*	*P*
Diversity (Untransformed)					
ICOLLs vs. Undredged locations in Tuggerah					
Lagoon Type	4	35.1	8.78	19.039	**0.034**
Sites(Lagoon Type)	5	2.3	0.46	1.872	0.101
Residual	270	66.7	0.25		
Total	279	104.2			
Post hoc tests					
Management Type vs. Tuggerah		*t*	*P**		
Naturally mainly closed		3.972	0.055	ns	
Naturally mainly open		11.647	**0.001**		
Managed, mainly closed		15.037	**<0.001**		
Managed, mainly open		0.565	0.630	ns	

* Monte Carlo simulation used as number of unique permutations < 100.

Table 10: Permutational Analysis of Variance and *post hoc* tests comparing meiobenthic assemblages in dredged and undredged locations surveyed on two occasions in The Entrance, Tuggerah. Data were 4th root transformed. Significant factors/contrasts in bold. R = redundant term due to significant interaction.

Source of Variation	df	SS	MS	*F*	*P*
Survey	1	1719.5	1719.5		R
Locations	3	8451.6	2817.2		R
Sites(Locations)	4	884.14	221.04		R
Survey x Location	3	1588.8	529.6	3.732	**0.027**
Survey x Sites(Location)	4	567.67	141.92	0.501	0.954
Residual	48	13590	283.12		
Total	63	26801			

Post hoc tests for Survey x Location for pairs of the factor "Survey"

Survey 1 vs. Survey 2	*t*	*p*	
Und1	2.915	**0.026**	
Und2	1.000	0.754	ns
D1	1.240	0.348	ns
D2	2.352	0.065	ns

Post hoc tests for Survey x Location for pairs of the factor "Location"

Survey 1	*t*	*P**	
Und1 vs. Und2	6.232	**0.001**	
Und1 vs. D1	3.974	**0.003**	
Und1 vs. D2	3.596	**0.003**	
Und2 vs. D1	2.706	**0.019**	
Und2 vs. D2	2.542	**0.022**	
D1 vs. D2	0.281	0.982	ns
Survey 2			
Und1 vs. Und2	3.647	**0.002**	
Und1 vs. D1	2.703	**0.009**	
Und1 vs. D2	2.752	**0.008**	
Und2 vs. D1	4.707	**0.001**	
Und2 vs. D2	3.129	**0.005**	
D1 vs. D2	1.363	0.207	ns

Multivariate Dispersion (surveys combined)

Location	%Disp		*t*	*P*	
Und1	20.0	Und1 vs. Und2	1.518	0.179	ns
Und2	16.7	Und1 vs. D1	5.751	**<0.001**	
D1	11.3	Und1 vs. D2	2.699	**0.014**	
D2	15.6	Und2 vs. D1	2.717	**0.014**	
		Und2 vs. D2	0.543	0.642	ns
		D1 vs. D2	3.050	**0.009**	

* Monte Carlo simulation used as number of unique permutations < 100.

Table 11: SIMPER analysis showing those taxa that contribute individually 5% or more to dissimilarities between meiobenthic assemblages in dredged and undredged locations on two occasions in The Entrance, Tuggerah. Data were 4th root transformed for analysis, but average abundances are shown untransformed.

Survey 1

	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
	Undredged 1	Undredged 2				
Average dissimilarity = 36.36%						
Nematoda	485.80	185.82	5.41	1.35	14.88	14.88
Oligochaeta	0.32	4.32	4.72	1.91	12.97	27.85
Polychaeta	0.75	7.89	4.68	1.71	12.86	40.72
Halacaridae	1.61	0.00	3.66	1.61	10.06	50.78
Harpacticoida	58.58	25.67	3.44	0.84	9.46	60.24
Ostracoda	1.18	5.75	3.29	1.22	9.05	69.29
Platyhelminthes	1.93	11.85	3.13	1.34	8.60	77.89
Copepoda	0.64	0.11	1.92	0.83	5.27	83.17
	Undredged 1	Dredged 1				
Average dissimilarity = 33.92%						
Ostracoda	1.18	31.06	5.31	2.15	15.67	15.67
Platyhelminthes	1.93	49.05	4.96	2.20	14.62	30.29
Polychaeta	0.75	7.60	3.63	1.63	10.71	41.00
Oligochaeta	0.32	2.18	3.34	1.85	9.84	50.84
Halacaridae	1.61	0.00	3.00	1.62	8.86	59.70
Foraminifera	0.43	3.18	2.84	1.16	8.37	68.07
Mollusca	0.43	2.50	2.64	1.36	7.79	75.86
Nematoda	485.80	528.54	2.19	1.23	6.45	82.31
Amphipoda	0.00	0.64	1.86	0.96	5.49	87.80
	Undredged 1	Dredged 2				
Average dissimilarity = 33.80%						
Ostracoda	1.18	34.91	5.53	1.92	16.37	16.37
Platyhelminthes	1.93	19.49	3.80	1.88	11.24	27.61
Oligochaeta	0.32	3.78	3.78	1.84	11.19	38.80
Halacaridae	1.61	0.00	3.13	1.63	9.26	48.06
Polychaeta	0.75	4.18	3.02	1.34	8.94	57.01
Foraminifera	0.43	3.86	2.68	0.99	7.94	64.94
Nematoda	485.80	466.35	2.61	1.38	7.73	72.67
Harpacticoida	58.58	94.85	2.38	1.41	7.04	79.72
Mollusca	0.43	1.14	2.19	1.10	6.47	86.18
Copepoda	0.64	0.32	1.78	0.90	5.27	91.45
	Undredged 2	Dredged 1				
Average dissimilarity = 27.66%						
Nematoda	185.82	528.54	4.49	1.44	16.22	16.22
Ostracoda	5.75	31.06	4.16	1.52	15.05	31.28
Mollusca	0.11	2.50	2.97	1.52	10.73	42.01
Harpacticoida	25.67	58.48	2.84	0.93	10.28	52.29
Foraminifera	0.11	3.18	2.74	1.17	9.89	62.17
Platyhelminthes	11.85	49.05	2.65	1.56	9.60	71.77
Amphipoda	0.54	0.64	1.89	1.05	6.84	78.61
Oligochaeta	4.32	2.18	1.85	1.15	6.69	85.30

continued...

Table 11: Continued.

Survey 1	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
	Undredged 2	Dredged 2				
Average dissimilarity = 28.83%						
Ostracoda	5.75	34.91	4.39	1.45	15.23	15.23
Nematoda	185.82	466.35	4.32	1.35	15.00	30.23
Harpacticoida	25.67	94.85	3.58	0.99	12.41	42.64
Foraminifera	0.11	3.86	2.58	1.00	8.93	51.57
Platyhelminthes	11.85	19.49	2.14	1.14	7.42	58.99
Mollusca	0.11	1.14	2.13	1.00	7.39	66.38
Oligochaeta	4.32	3.78	2.05	1.19	7.09	73.47
Amphipoda	0.54	0.61	1.78	0.91	6.17	79.65
Polychaeta	7.89	4.18	1.76	1.07	6.11	85.76

Survey 1						
	Undredged 1	Undredged 2				
Average dissimilarity = 31.25%						
Nematoda	817.39	184.43	4.87	1.02	15.58	15.58
Polychaeta	2.36	30.42	4.69	2.30	15.00	30.59
Oligochaeta	1.50	7.50	4.12	1.65	13.18	43.77
Foraminifera	2.46	0.82	3.00	1.44	9.59	53.36
Ostracoda	5.89	5.57	2.63	1.15	8.42	61.78
Platyhelminthes	7.82	8.32	2.01	0.98	6.44	68.23
Copepoda	0.11	0.68	1.91	0.99	6.11	74.34
Harpacticoida	29.99	24.28	1.62	1.41	5.19	79.53
Mollusca	0.32	0.86	1.62	0.86	5.17	84.70
	Undredged 1	Dredged 1				
Average dissimilarity = 26.69%						
Platyhelminthes	7.82	0.86	4.29	2.09	16.09	16.09
Nematoda	817.39	545.46	3.66	1.27	13.70	29.79
Oligochaeta	1.50	6.85	3.42	1.69	12.83	42.62
Polychaeta	2.36	15.10	3.03	1.69	11.34	53.96
Ostracoda	5.89	13.71	2.64	1.18	9.91	63.87
Copepoda	0.11	0.86	1.78	1.01	6.66	70.53
Harpacticoida	29.99	27.42	1.65	1.36	6.19	76.72
Amphipoda	0.32	0.54	1.47	0.83	5.51	82.23
Foraminifera	2.46	4.07	1.44	1.02	5.41	87.64
Mollusca	0.32	0.32	1.43	0.93	5.37	93.01
	Undredged 1	Dredged 2				
Average dissimilarity = 30.88%						
Platyhelminthes	7.82	185.55	5.87	2.52	19.02	19.02
Nematoda	817.39	493.70	3.73	1.20	12.07	31.09
Oligochaeta	1.50	6.53	3.33	1.64	10.79	41.88
Ostracoda	5.89	16.89	2.79	1.23	9.05	50.93
Polychaeta	2.36	13.14	2.70	1.53	8.74	59.67
Harpacticoida	29.99	94.11	2.60	1.42	8.43	68.10
Foraminifera	2.46	2.57	2.12	1.24	6.87	74.97
Copepoda	0.11	1.07	1.74	1.02	5.64	80.61
Amphipoda	0.32	0.64	1.68	1.02	5.45	86.07
Decapoda	0.00	0.43	1.65	1.04	5.33	91.40

continued...

Table 11: Continued.

Survey 2	Av.Abund	Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
	Undredged 2	Dredged 1				
Average dissimilarity = 24.00%						
Platyhelminthes	8.32	0.86	4.71	1.63	19.61	19.61
Nematoda	184.43	545.46	4.60	1.87	19.17	38.77
Foraminifera	0.82	4.07	3.05	1.65	12.71	51.49
Ostracoda	5.57	13.71	1.90	1.14	7.93	59.42
Copepoda	0.68	0.86	1.82	1.10	7.59	67.01
Amphipoda	0.61	0.54	1.59	0.91	6.61	73.62
Harpacticoida	24.28	24.42	1.43	1.65	5.95	79.57
Mollusca	0.86	0.32	1.42	0.86	5.92	85.48
	Undredged 2	Dredged 2				
Average dissimilarity = 26.52%						
Platyhelminthes	8.32	185.55	6.27	2.13	23.63	23.63
Nematoda	184.43	493.70	4.11	1.66	15.49	39.12
Harpacticoida	24.28	94.11	2.64	1.44	9.96	49.08
Foraminifera	0.82	2.57	2.33	1.18	8.78	57.86
Ostracoda	5.57	16.89	2.06	1.22	7.77	65.63
Copepoda	0.68	1.07	1.81	1.11	6.83	72.47
Amphipoda	0.61	0.64	1.70	1.05	6.41	78.87
Decapoda	0.21	0.43	1.49	1.01	5.63	84.50

Table 12: Permutational Analysis of Variance and *post hoc* tests comparing numbers of meiobenthic taxa, total abundance and Shannon-Wiener diversity in dredged and undredged locations surveyed on two occasions in The Entrance, Tuggerah. Data transformations as indicated.

Source of Variation	df	SS	MS	*F*	*P*
No. of taxa (untransformed)					
Survey	1	8.266	8.266	13.564	**0.021**
Locations	3	35.922	11.974	10.218	**0.025**
Sites(Locations)	4	4.688	1.172	0.889	0.472
Survey x Location	3	2.172	0.724	1.188	0.425
Survey x Sites(Location)	4	2.438	0.609	0.462	0.761
Residual	48	63.250	1.318		
Total	63	116.730			
Post hoc tests for Surveys	*t*	*P**			
Und1 vs. Und1	0.174	0.068	ns		
Und2 vs. Und2	0.162	0.205	ns		
D1 vs. D1	1.000	0.870	ns		
D2 vs. D2	0.328	0.259	ns		
Post hoc tests for Locations	*t*	*P**			
Und1 vs. Und2	2.200	0.161	ns		
Und1 vs. D1	9.487	**0.012**			
Und1 vs. D2	3.414	0.080	ns		
Und2 vs. D1	4.608	**0.046**			
Und2 vs. D2	1.861	0.208	ns		
D1 vs. D2	0.566	0.635	ns		

Source of Variation	df	SS	MS	*F*	*P*
Total Abundance (4^{th} root transformed)					
Survey	1	0.323	0.323	5.745	0.069
Locations	3	2.648	0.883	25.979	**0.007**
Sites(Locations)	4	0.136	0.034	0.518	0.719
Survey x Location	3	0.161	0.054	0.955	0.481
Survey x Sites(Location)	4	0.225	0.056	0.857	0.496
Residual	48	3.149	0.066		
Total	63	6.642			
Post hoc tests for Locations	*t*	*P**			
Und1 vs. Und2	3.320	0.054	ns		
Und1 vs. D1	3.260	0.083	ns		
Und1 vs. D2	4.987	**0.040**			
Und2 vs. D1	3.253	0.082	ns		
Und2 vs. D2	8.811	**0.013**			
D1 vs. D2	4.455	0.051	ns		

Source of Variation	df	SS	MS	*F*	*P*
Diversity H' (untransformed)					
Survey	1	0.233	0.233	0.546	0.496
Locations	3	17.223	5.741	6.611	0.091
Sites(Locations)	4	3.474	0.868	1.400	0.253
Survey x Location	3	0.291	0.097	0.227	0.867
Survey x Sites(Location)	4	1.708	0.427	0.689	0.618
Residual	48	29.770	0.620		
Total	63	52.699			

* Monte Carlo simulation used as number of unique permutations < 100.

Table 13: Correlations between meiobenthos and sediment characteristice in Undredged and Dredged locations in The Entrance, Tuggerah.

Dredged Locations		
	Median Grain Size	% Fines
Number of Taxa	-0.134	0.137
Total Abundance	0.076	-0.082
Diversity (H')	**0.404**	**-0.413**
Undredged Locations		
	Median Grain Size	% Fines
Number of Taxa	0.113	0.016
Total Abundance	0.093	0.010
Diversity (H')	-0.334	-0.258

Table 14: Permutational Analysis of Variance and *post hoc* tests of meiobenthic assemblages in the mouths of four types of ICOLLs compared with those in dredged and undredged locations in the Entrance, Tuggerah (surveys combined). Data were 4th root transformed. Significant factors/contrasts in bold. ns = not significant.

Source of variation	df	SS	MS	*F*	*P*
ICOLLs vs. Dredged locations in Tuggerah					
Lagoon	4	31041	7760.3	13.885	**0.028**
Sites(Lagoon)	5	2806.1	561.23	1.128	0.308
Residual	270	134350.0	497.59		
Total	279	168200.0			
Post hoc tests	*t*	*P**			
Lagoon Type vs. Tuggerah					
Naturally mainly closed	5.594	**<0.001**			
Naturally mainly open	6.231	**0.001**			
Managed, mainly closed	8.670	**<0.001**			
Managed, mainly open	5.780	**<0.001**			

Source of variation	df	SS	MS	*F*	*P*
ICOLLs vs. Undredged locations in Tuggerah					
Lagoon	4	20765	5191.3	10.146	**0.028**
Sites(Lagoon)	5	2553.9	510.78	0.956	0.533
Residual	270	144260.0	534.28		
Total	279	167570.0			
Post hoc tests	*t*	*P**			
Lagoon Type vs. Tuggerah					
Naturally mainly closed	4.355	**0.001**			
Naturally mainly open	1.622	0.127	ns		
Managed, mainly closed	8.775	**<0.001**			
Managed, mainly open	4.758	**<0.001**			

* Monte Carlo simulation used as number of unique permutations < 100.

Table 15: SIMPER analysis showing those taxa that contribute individually 5% or more to dissimilarities between meiobenthic assemblages in the mouths of four types of ICOLLs and those in dredged and undredged locations in The Entrance, Tuggerah. Data were 4th root transformed for analysis but average abundances are shown untransformed.

ICOLLs vs. Dredged locations in Tuggerah						
Management Type	ICOLL Av.Abund	Tuggerah Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Naturally mainly closed						
Average Dissimilarity 41.77%						
Ostracoda	0.00	24.14	7.73	4.71	18.51	18.51
Nematoda	*169.32*	*508.51*	*5.23*	*1.43*	*12.53*	*31.04*
Polychaeta	28.08	10.00	5.16	2.01	12.36	43.41
Platyhelminthes	71.62	85.13	4.47	1.20	10.69	54.10
Oligochaeta	3.59	4.84	4.45	2.24	10.66	64.76
Harpacticoida	124.80	68.71	3.99	1.20	9.56	74.31
Foraminifera	0.10	3.42	3.45	1.35	8.26	82.58
Naturally mainly open						
Average Dissimilarity 35.73%						
Ostracoda	0.00	24.14	7.37	5.02	20.63	20.63
Polychaeta	2.34	10.00	4.65	1.87	13.00	33.63
Oligochaeta	11.16	4.84	4.18	2.02	11.70	45.33
Nematoda	240.74	508.51	3.82	1.45	10.70	56.03
Harpacticoida	203.37	68.71	3.65	1.35	10.21	66.23
Foraminifera	0.14	3.42	3.29	1.36	9.22	75.45
Platyhelminthes	62.91	85.13	2.90	1.29	8.10	83.55
Mollusca	0.09	1.02	1.79	0.85	5.01	88.57
Managed, mainly closed						
Average Dissimilarity 40.39%						
Ostracoda	0.05	24.14	7.46	4.39	18.47	18.47
Polychaeta	1.27	10.00	5.28	2.46	13.07	31.54
Nematoda	199.12	508.51	4.94	1.48	12.22	43.76
Harpacticoida	262.97	68.71	4.70	1.19	11.64	55.40
Oligochaeta	24.39	4.84	4.22	1.83	10.46	65.86
Platyhelminthes	72.91	85.13	3.90	1.18	9.66	75.52
Foraminifera	0.14	3.42	3.36	1.35	8.32	83.84
Managed, mainly open						
Average Dissimilarity 37.54%						
Ostracoda	2.31	24.14	6.86	2.75	18.26	18.26
Nematoda	251.72	508.51	5.33	1.46	14.19	32.45
Platyhelminthes	76.34	85.13	4.04	1.18	10.77	43.22
Oligochaeta	4.73	4.84	3.78	1.75	10.07	53.29
Harpacticoida	118.04	68.71	3.76	1.14	10.02	63.31
Polychaeta	7.16	10.00	3.42	1.29	9.12	72.43
Foraminifera	0.08	3.42	3.32	1.35	8.84	81.27

continued...

Table 15: Continued.

ICOLLs vs. Undredged locations in Tuggerah						
Management Type	ICOLL	Tuggerah				
Naturally mainly closed						
Average Dissimilarity 37.54%						
Polychaeta	28.08	10.35	5.80	1.51	14.81	14.81
Nematoda	169.32	418.36	5.24	1.10	13.39	28.20
Platyhelminthes	71.62	7.48	5.07	1.41	12.96	41.15
Harpacticoida	124.80	34.63	4.94	1.18	12.60	53.76
Ostracoda	0.00	4.60	4.75	1.54	12.13	65.89
Oligochaeta	3.59	3.41	4.05	1.19	10.34	76.23
Copepoda	2.72	0.38	2.01	0.64	5.14	81.36
Naturally mainly open						
Average Dissimilarity 35.62%						
Harpacticoida	203.37	34.63	5.38	1.40	15.11	15.11
Polychaeta	2.34	10.35	4.99	1.47	14.00	29.11
Platyhelminthes	62.91	7.48	4.96	1.53	13.92	43.03
Ostracoda	0.00	4.60	4.48	1.55	12.58	55.62
Nematoda	240.74	418.36	4.25	1.16	11.92	67.54
Oligochaeta	11.16	3.41	4.09	1.20	11.48	79.02
Foraminifera	0.08	0.95	1.81	0.75	5.08	84.10
Managed, mainly closed						
Average Dissimilarity 39.75%						
Harpacticoida	262.97	34.63	5.79	1.12	14.56	14.56
Platyhelminthes	72.91	7.48	5.74	1.67	14.43	28.99
Polychaeta	1.27	10.35	5.44	1.58	13.68	42.67
Nematoda	199.12	418.36	5.05	1.18	12.71	55.39
Oligochaeta	24.39	3.41	4.85	1.25	12.20	67.59
Ostracoda	0.00	4.60	4.57	1.53	11.50	79.08
Managed, mainly open						
Average Dissimilarity 37.41%						
Nematoda	251.72	418.36	5.54	1.18	14.80	14.80
Platyhelminthes	76.34	7.48	5.47	1.59	14.63	29.44
Harpacticoida	118.04	34.63	4.86	1.17	12.98	42.42
Ostracoda	2.31	4.60	4.51	1.48	12.04	54.46
Polychaeta	7.16	10.35	4.30	1.29	11.49	65.95
Oligochaeta	4.73	3.41	3.82	1.17	10.21	76.16
Copepoda	8.39	0.38	1.92	0.63	5.13	81.29

Table 16: Permutational Analysis of Variance and *post hoc* tests comparing numbers of meiobenthic taxa, total abundance and Shannon-Wiener diversity in the mouths of four types of ICOLLs compared with those in dredged and undredged locations in the Entrance, Tuggerah (surveys combined). Data transformations as indicated. Significant factors/contrasts in bold. ns = not significant (p < 0.05).

Source of variation	df	SS	MS	*F*	*P*
No. of Taxa (Untransformed)					
ICOLLs vs. Dredged locations in Tuggerah					
Lagoon Type	4	545.34	136.330	142.290	**0.021**
Sites(Lagoon Type)	5	4.8224	0.964	1.218	0.308
Residual	270	213.75	0.792		
Total	279	763.91			
Post hoc tests	*t*	*P**			
Lagoon Type vs. Tuggerah					
Naturally mainly closed	*20.285*	***0.001***			
Naturally mainly open	14.400	**0.004**			
Managed, mainly closed	16.637	**0.004**			
Managed, mainly open	*18.546*	***<0.001***			

Source of variation	df	SS	MS	*F*	*P*
Total Abundance (4th root transformed)					
ICOLLs vs. Dredged locations in Tuggerah					
Lagoon Type	4	0.7482	0.187	10.698	**0.015**
Sites(Lagoon Type)	5	7.98E-02	0.016	0.277	0.928
Residual	270	15.542	0.058		
Total	279	16.37			
Post hoc tests	*t*	*P**			
Lagoon Type vs. Tuggerah					
Naturally mainly closed	0.703	0.509	ns		
Naturally mainly open	9.711	**0.010**			
Managed, mainly closed	1.110	0.346	ns		
Managed, mainly open	4.687	**<0.001**			

Source of variation	df	SS	MS	*F*	*P*
Diversity H' (Untransformed)					
ICOLLs vs. Dredged locations in Tuggerah					
Lagoon Type	4	21.635	5.409	3.922	0.121
Sites(Lagoon Type)	5	6.9561	1.391	1.307	0.270
Residual	270	287.43	1.065		
Total	279	316.02			

continued...

Table 16: Continued.

Source of variation	df	SS	MS	*F*	*P*
No. of Taxa (Untransformed)					
ICOLLs vs. Undredged locations in Tuggerah					
Lagoon Type	4	256.65	64.163	73.637	**0.021**
Sites(Lagoon Type)	5	4.3537	0.871	0.981	0.426
Residual	270	239.57	0.887		
Total	279	500.57			
Post hoc tests	*t*	*P**			
Lagoon Type vs. Tuggerah					
Naturally mainly closed	15.349	**0.002**			
Naturally mainly open	10.738	**0.009**			
Managed, mainly closed	12.106	**0.002**			
Managed, mainly open	12.838	**<0.001**			

Source of variation	df	SS	MS	*F*	*P*
Total Abundance (4th root transformed)					
ICOLLs vs. Undredged locations in Tuggerah					
Lagoon Type	4	1.243	0.311	12.717	**0.004**
Sites(Lagoon Type)	5	0.113	0.023	0.319	0.899
Residual	270	19.164	0.071		
Total	279	20.520			
Post hoc tests	*t*	*P**			
Lagoon Type vs. Tuggerah					
Naturally mainly closed	1.546	0.205	ns		
Naturally mainly open	4.425	0.051	ns		
Managed, mainly closed	2.759	0.057	ns		
Managed, mainly open	5.274	**0.001**			

Source of variation	df	SS	MS	*F*	*P*
Diversity H' (untransforrmed)					
ICOLLs vs. Undredged locations in Tuggerah					
Lagoon Type	4	4.424	1.106	0.686	0.627
Sites(Lagoon Type)	5	8.148	1.630	1.417	0.215
Residual	270	310.580	1.150		
Total	279	323.150			

* Monte Carlo simulation used as number of unique permutations < 100.

9 Figures

Figure 1: Aerial photograph showing the positions of the sampling locations at The Entrance, Tuggerah.

Figure 2: Median grain size and percent fines at dredged and undredged locations at The Entrance, Tuggerah.

Figure 3: Median grain size and percent fines in sediment from dredged and undredged locations in The Entrance, Tuggerah compared with that in the mouths of four types of ICOLLs in New South Wales.

Figure 4: nMDS of macrobenthic assemblages in dredged and undredged locations on two occasions in The Entrance, Tuggerah.

Figure 5: Number of Taxa, Total Abundance and Shannon-Wiener Diversity (H') of macrobenthos in dredged and undredged locations in The Entrance, Tuggerah.

Figure 6: nMDS of macrobenthic assemblages in the mouths of four types of ICOLLs compared with those in dredged and undredged locations in The Entrance, Tuggerah.

Figure 7: Number of Taxa, Total Abundance and Shannon-Wiener Diversity (H') of macrobenthos in the mouths of four types of ICOLLs compared with dredged and undredged locations in The Entrance, Tuggerah.

Figure 8: nMDS of meiobenthic assemblages in dredged and undredged locations in The Entrance, Tuggerah.

Figure 9: Number of Taxa, Total Abundance and Shannon-Wiener Diversity (H') of meiobenthos in dredged and undredged locations in The Entrance, Tuggerah.

Figure 10: nMDS of meiobenthic assemblages in the mouths of eight ICOLLs compared with those in dredged and undredged locations in The Entrance, Tuggerah.

Figure 11: Number of Taxa, Total Abundance and Shannon-Wiener Diversity (H') of meiobenthos in the mouths of four types of ICOLLs compared with dredged and undredged locations in The Entrance, Tuggerah.

Figure 1: Aerial photograph showing the positions of the sampling locations at The Entrance, Tuggerah. Und = undredged, D = dredged.

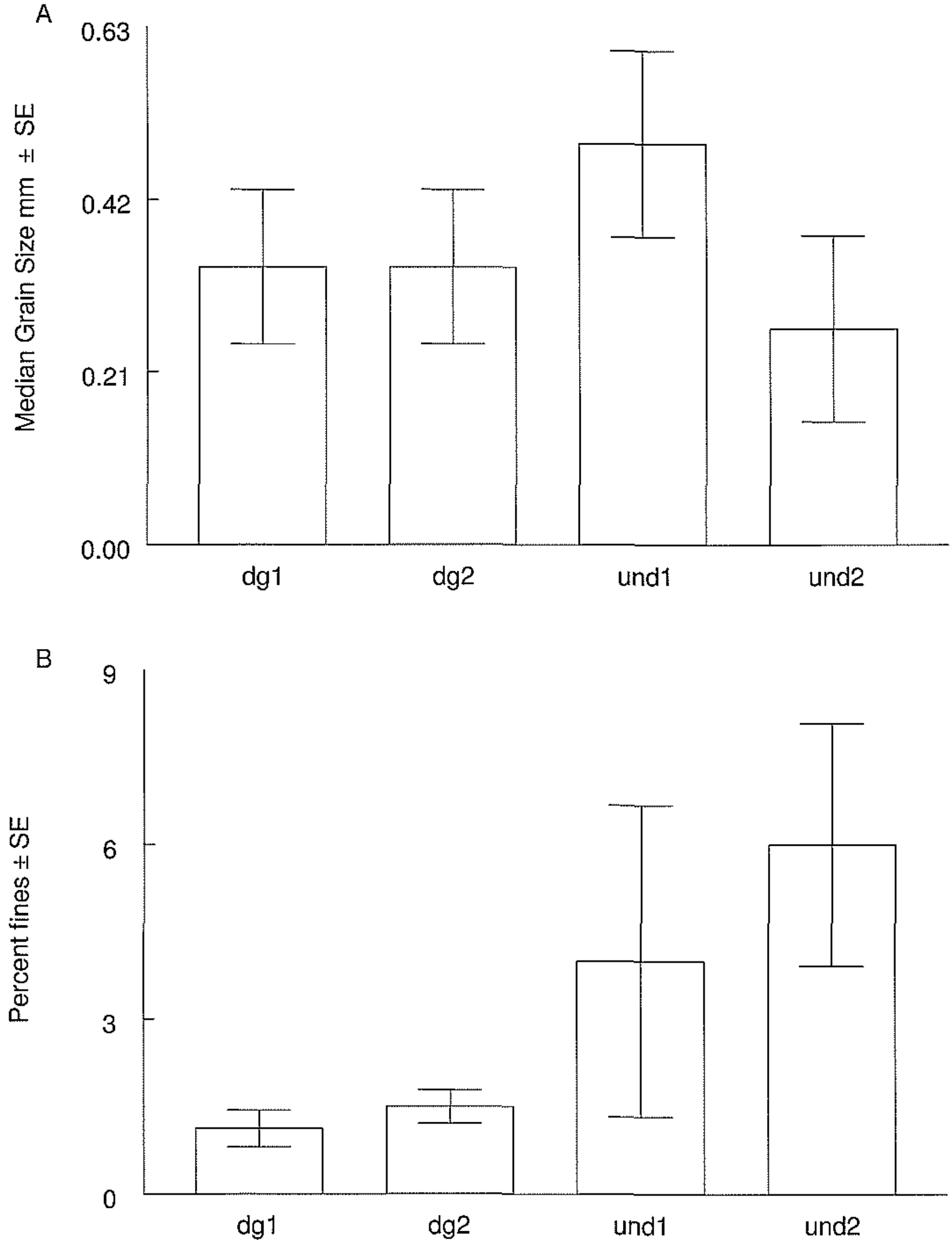

Figure 2: A) Median grain size and B) Percent fine sediment (< 0.063 mm) at dredged and undredged sites at The Entrance, Tuggerah. N = 4.

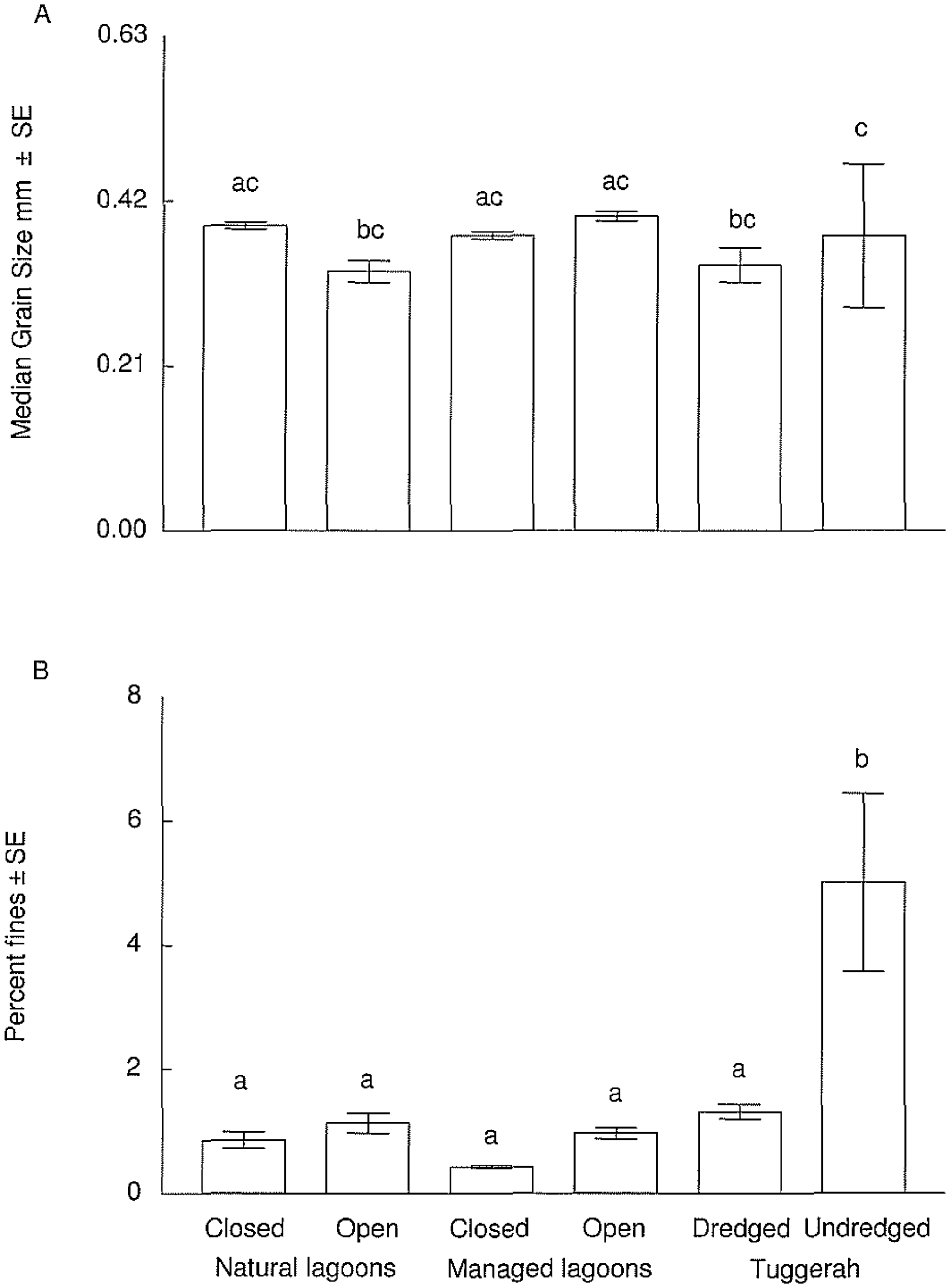

Figure 3: A) Median grain size and B) Percent fine material (< 0.063 mm) in sediment from the mouths of four types of ICOLLs in New South Wales compared to dredged (Td) and control (Tc) locations in The Entrance, Tuggerah. N = 4. Letters indicate significant differences (ANOVA, $p < 0.05$).

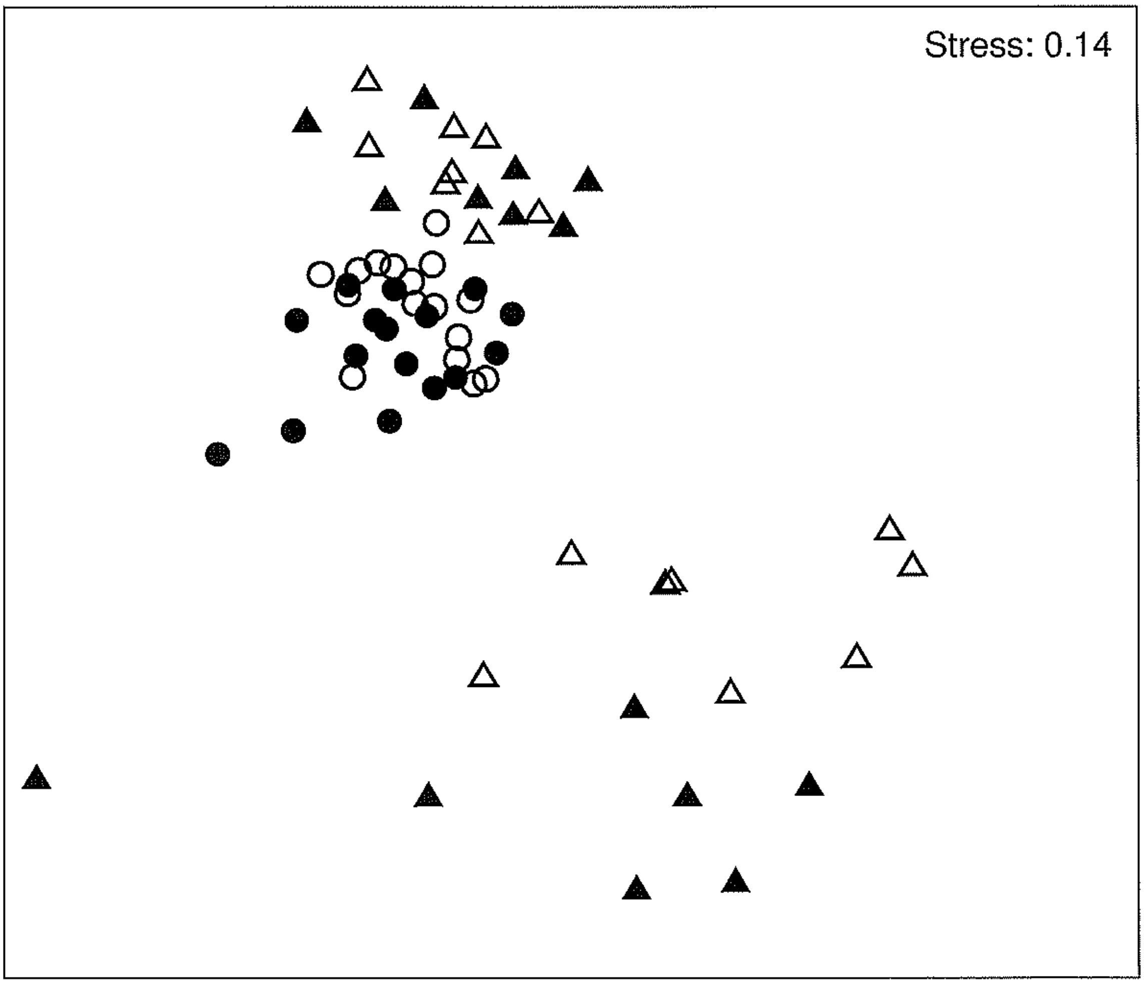

Figure 4: nMDS of macrobenthic assemblages in dredged (circles) and undredged (triangles) locations on two occasions in The Entrance, Tuggerah. Survey 1 - solid symbols, Survey 2 - open symbols.

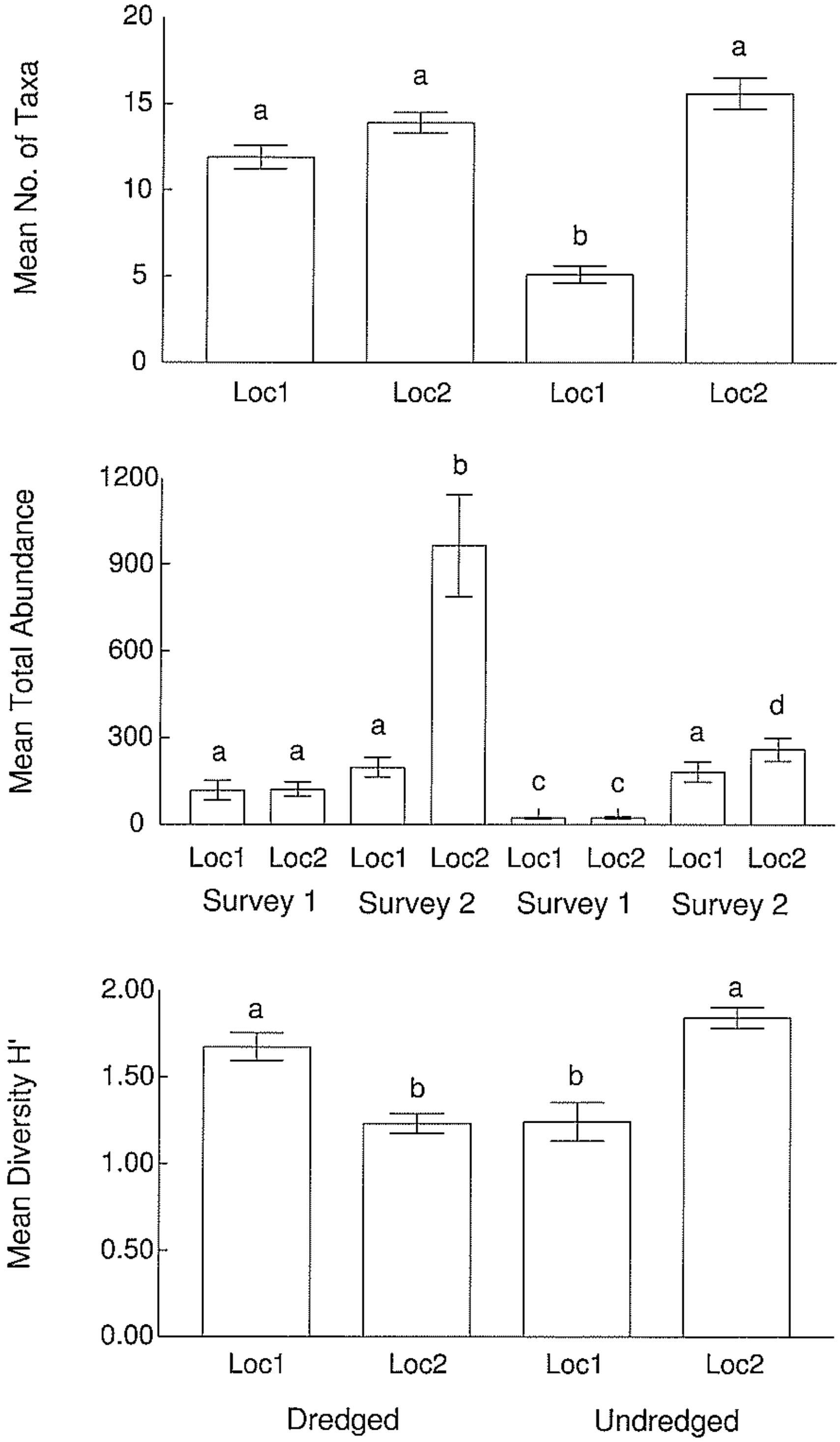

Figure 5: Mean Number of Taxa, Total Abundance and Shannon-Wiener Diversity (H') (± SE) of macrobenthos in dredged and undredged locations in The Entrance, Tuggerah (surveys combined for number of taxa and diversity). Letters indicate significant differences (ANOVA: $p \leq 0.05$). N = 16 (N = 8 for Total Abundance).

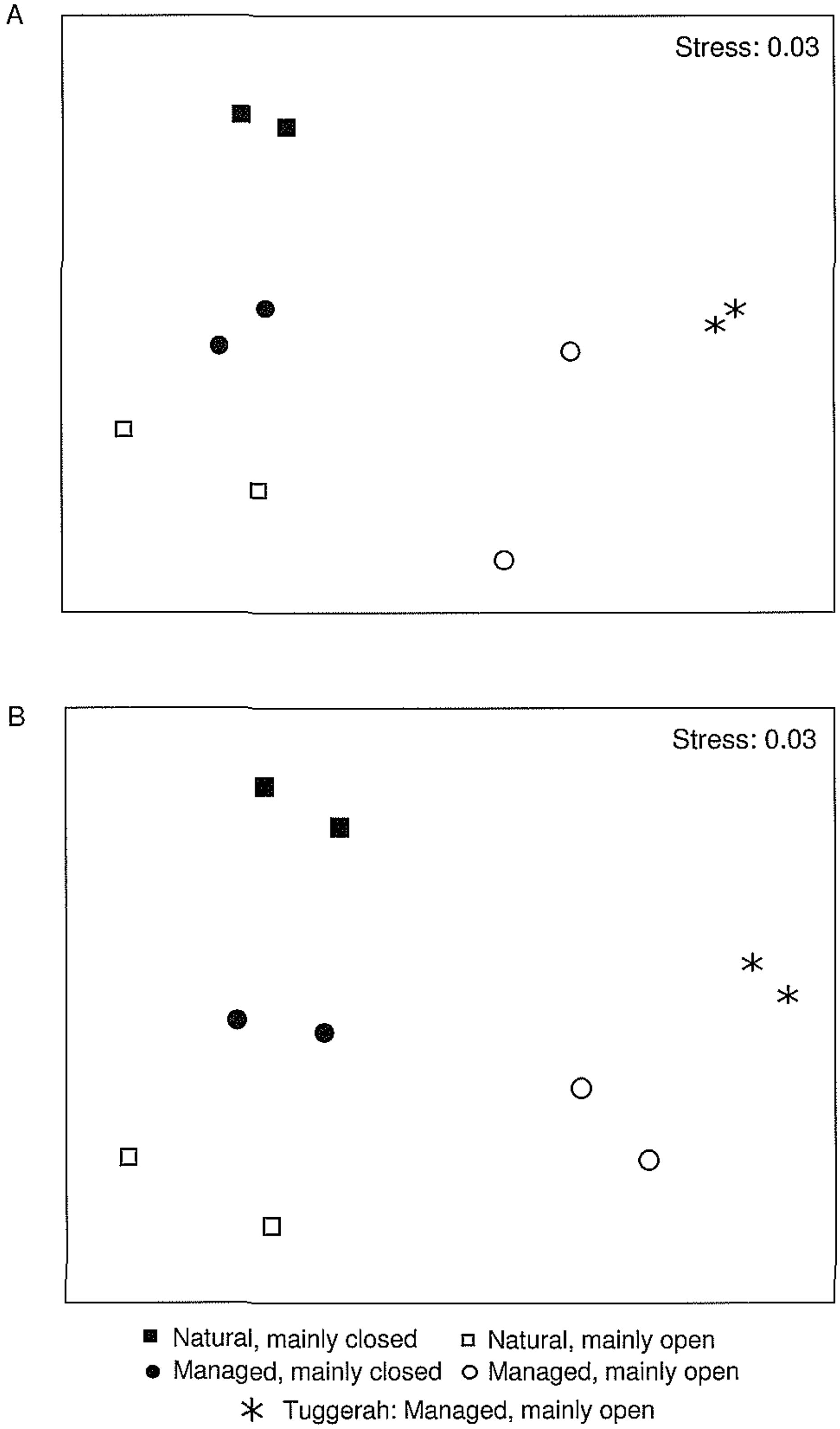

Figure 6: nMDS based on centroids of macrobenthic assemblages in the mouths of four types of ICOLLs compared with those in A) Dredged and B) Undredged locations in The Entrance, Tuggerah (surveys combined).

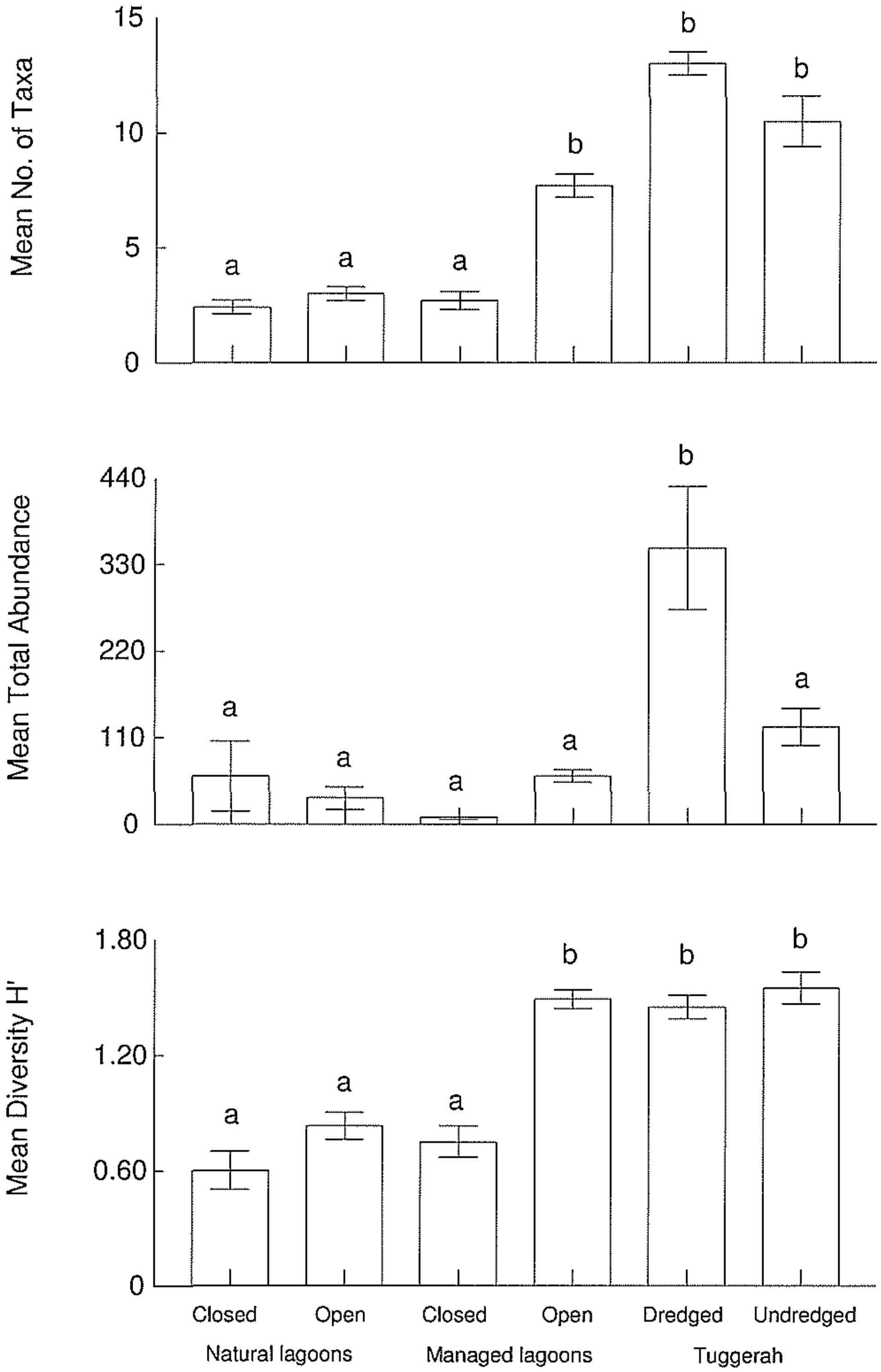

Figure 7: Mean Number of Taxa, Total Abundance and Shannon-Wiener Diversity (H') (±SE) of macrobenthos in the mouths of four types of ICOLLs compared with dredged and undredged locations in The Entrance, Tuggerah (surveys combined). Letters indicate significant differences (ANOVA: $p \leq 0.05$). N = 64 for natural lagoons, 56 for managed lagoons and 32 for Tuggerah.

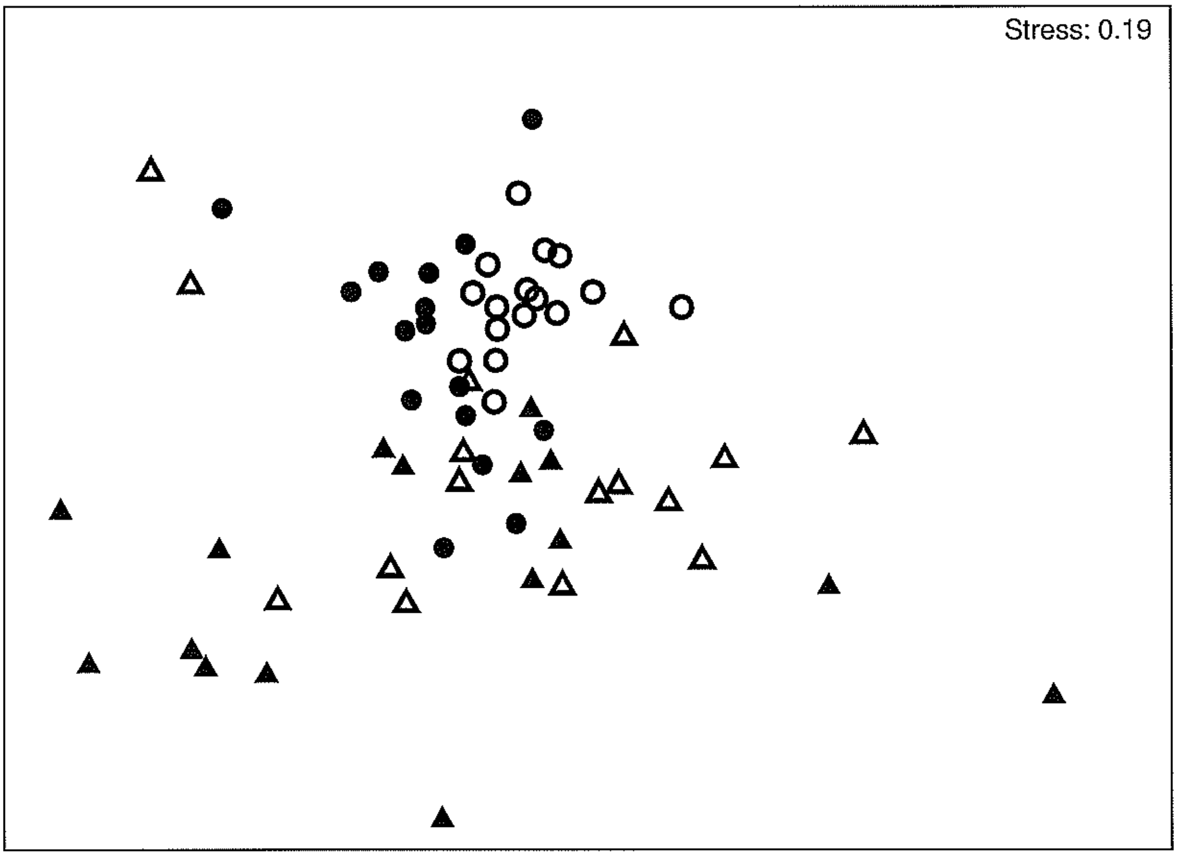

Figure 8: nMDS of meiobenthic assemblages in dredged (circles) and undredged (triangles) locations on two occasions in The Entrance, Tuggerah. Survey 1 - solid symbols, Survey 2 - open symbols.

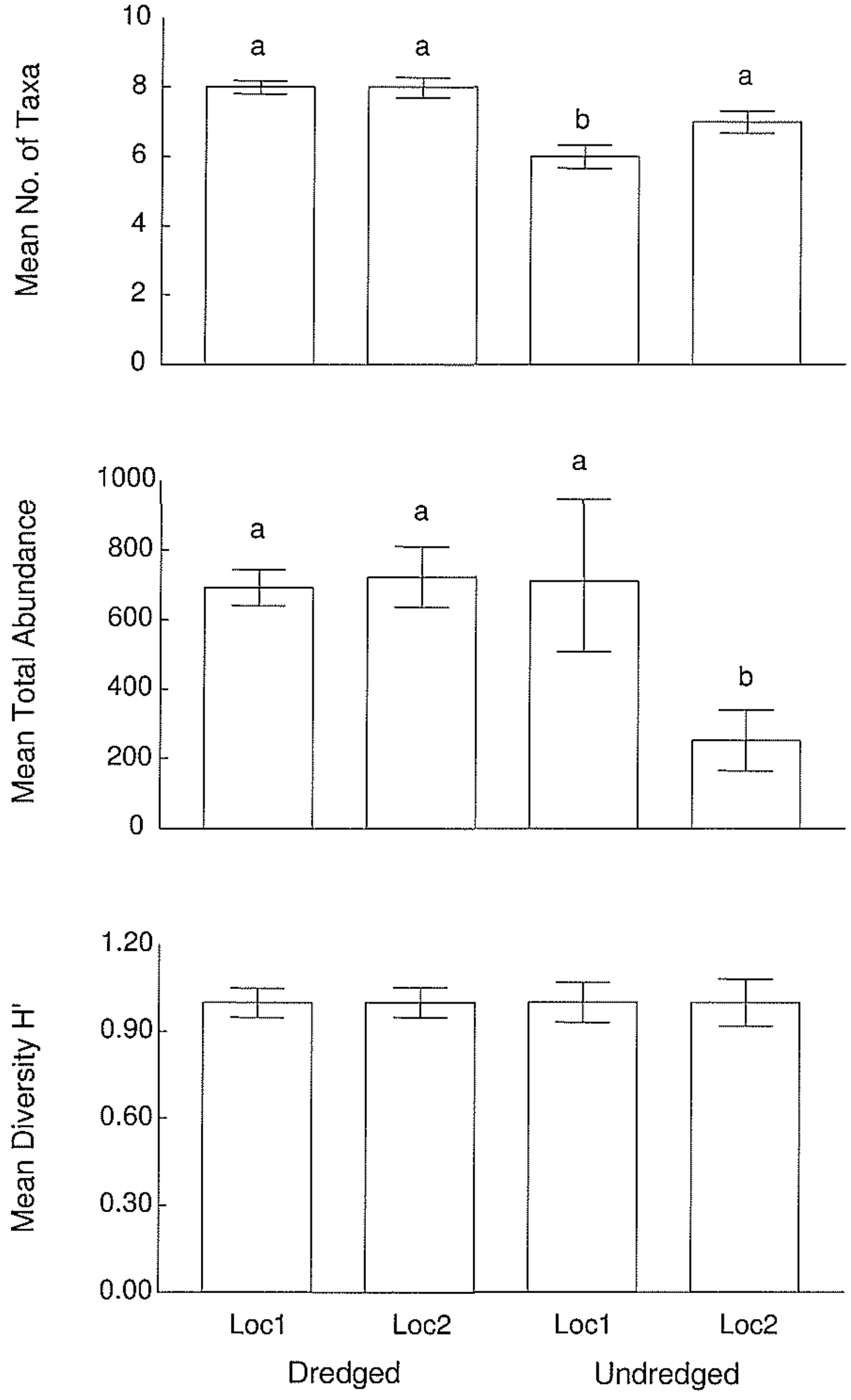

Figure 9: Mean Number of Taxa, Total Abundance and Shannon-Wiener Diversity (H') (±SE) of meiobenthos in dredged and undredged locations in The Entrance, Tuggerah (surveys combined). Letters indicate significant differences (ANOVA: $p \leq 0.05$). N = 16.

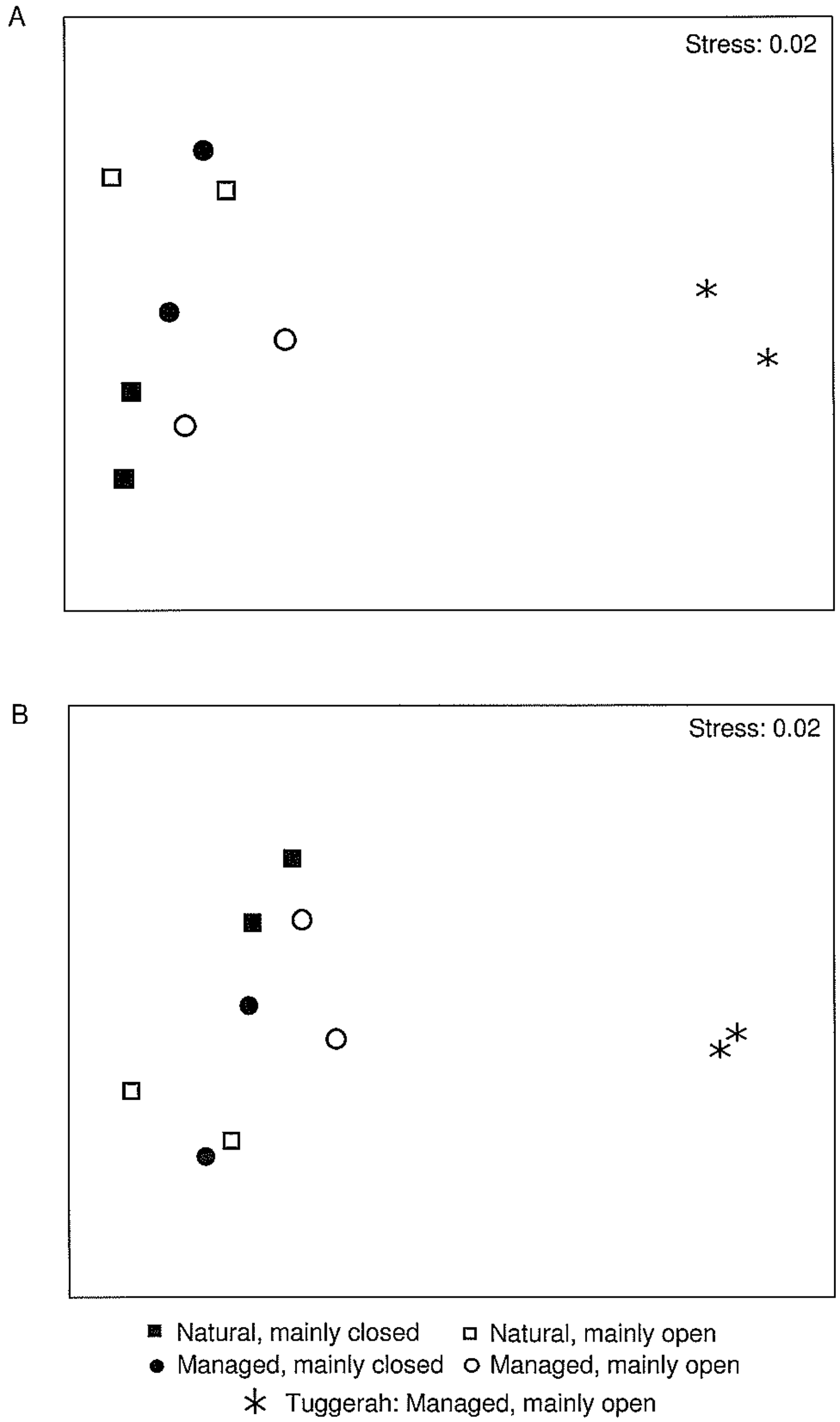

Figure 10: nMDS based on centroids of meiobenthic assemblages in the mouths of eight ICOLLs compared with those in A) Dredged and B) Undredged locations in The Entrance, Tuggerah (surveys combined).

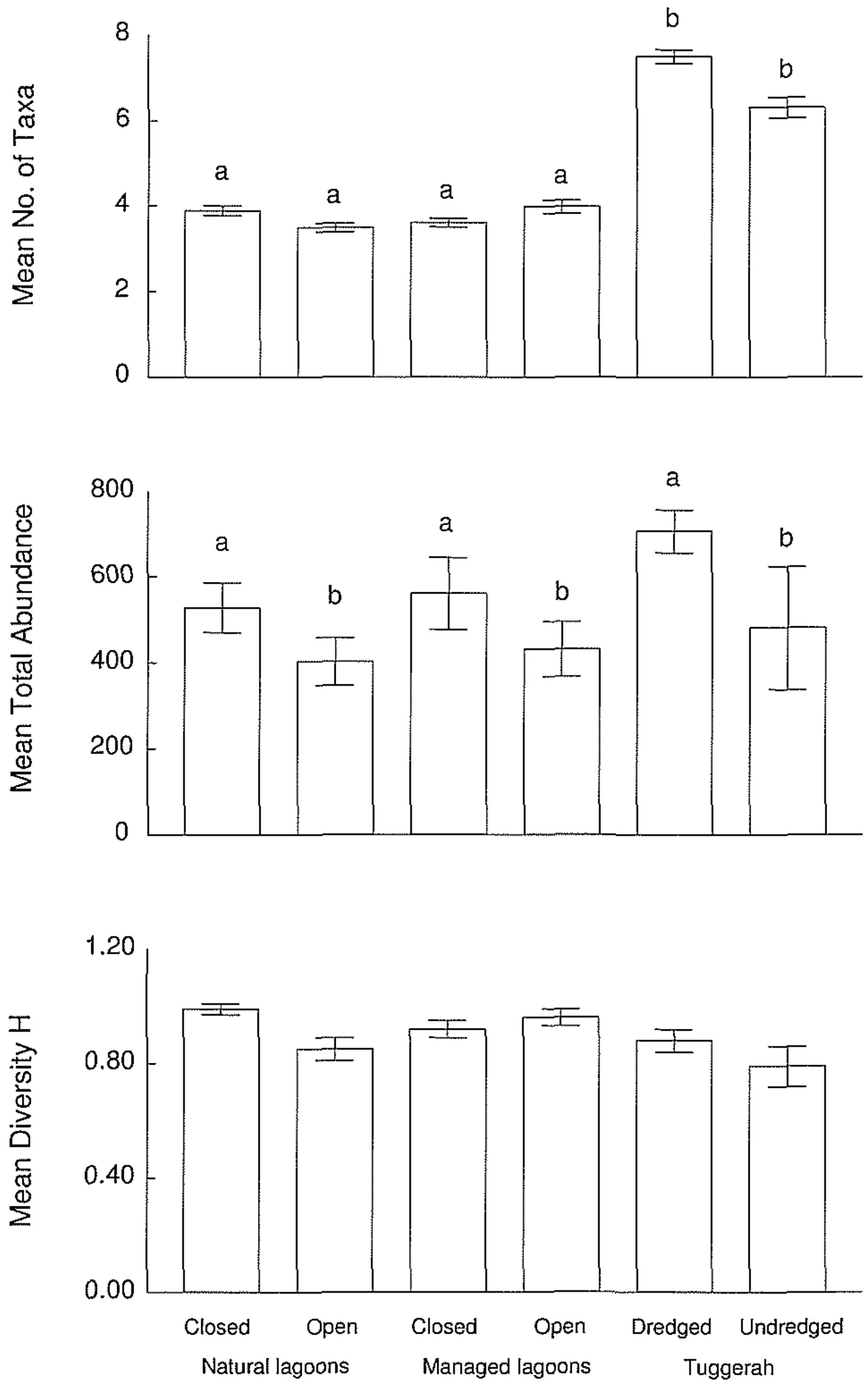

Figure 11: Mean Number of Taxa, Total Abundance and Shannon-Wiener Diversity (H') (±SE) of meiobenthos in the mouths of four types of ICOLLs compared with dredged and undredged locations in The Entrance, Tuggerah (surveys combined). Letters indicate significant differences (ANOVA: $p \leq 0.05$). N = 64 for natural lagoons, 56 for managed lagoons and 32 for Tuggerah.

10 Appendices

Appendix 1: GPS positions and depths of the sampling sites at The Entrance, Tuggerah.

Appendix 2: Particle size analysis of sediments from dredged and undredged locations in The Entrance, Tuggerah.

Appendix 3: Abundance and composition of macrobenthos in samples taken from dredged and undredged locations in The Entrance, Tuggerah.

Appendix 4: Abundance and composition of meiobenthos in samples taken from dredged and undredged locations in The Entrance, Tuggerah.

Appendix 1: GPS positions and depths for the sampling sites at The Entrance, Tuggerah.

Treatment	Site	Easting	Northing	Depth (m)
Dredged 1	1	0360550	6310812	1.9
Dredged 1	2	0360556	6310770	1.9
Dredged 2	1	0360619	6310089	1.9
Dredged 2	2	0360640	6310044	1.8
Undredged 1	1	0360552	6309615	1.0
Undredged 1	2	0360564	6309566	1.4
Undredged 2	1	0359965	6310614	1.5
Undredged 2	2	0359949	6310669	1.4

Appendix 2: Summary of sediment characteristics in dredged and undredged locations in The Entrance, Tuggerah. Particle size analysis undertaken by ALS Environmental.

	Locations			
	Undredged		Dredged	
	Und 1	Und 2	Dg1	Dg2
Median grain size (mm)	0.49	0.26	0.34	0.34
% Fines	4.00	6.00	1.13	1.50

Appendix 3: Summary of abundances of macrobenthos in dredged and undredged locations surveyed on two occasions in The Entrance, Tuggerah.

	Survey 1				Survey 2			
	Undredged		Dredged		Undredged		Dredged	
Taxon	Und 1	Und 2	Dg1	Dg2	Und 1	Und 2	Dg1	Dg2
Ampharetidae	0.1	0.0	0.0	0.1	0.0	0.0	0.0	0.0
Capitellidae	5.6	3.5	0.3	6.4	5.3	1.8	0.6	2.4
Chaetopteridae	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0
Cirratulidae	0.0	0.0	0.1	0.0	0.1	0.1	0.0	0.1
Dorvilleidae	1.3	2.0	1.8	0.9	0.9	3.1	0.4	1.8
Flabelligeridae	0.0	0.1	0.0	0.0	0.0	0.0	0.1	0.1
Glyceridae	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0
Hesionidae	3.3	3.1	0.6	0.1	0.0	1.8	0.0	0.3
Lumbrineridae	0.1	0.0	0.0	0.0	0.5	0.9	0.0	0.0
Magelonidae	0.0	0.0	0.1	0.3	0.3	0.0	0.0	0.0
Nephtyidae	0.1	0.0	0.3	0.5	0.3	0.0	0.1	0.0
Nereididae	0.4	0.3	3.5	4.6	0.6	0.3	5.1	2.9
Oenonidae	0.1	0.4	0.0	0.0	0.0	1.3	0.0	0.1
Opheliidae	1.1	2.6	0.1	0.0	1.1	2.8	0.1	0.0
Orbiniidae	0.4	0.1	2.1	2.7	0.1	0.6	4.9	6.1
Oweniidae	0.0	0.1	0.0	0.0	0.0	0.3	0.0	0.1
Phyllodocidae	0.1	0.0	0.0	0.0	0.0	0.1	0.0	0.0
Pilargidae	0.0	0.0	0.0	0.0	0.9	0.9	0.0	0.0
Pisionidae	1.1	1.8	0.0	0.0	0.0	0.0	0.0	0.0
Sabellidae	24.7	52.3	0.3	3.0	19.8	36.9	7.9	13.5
Sacrocirridae	0.6	6.3	0.0	0.0	0.6	1.5	0.4	0.3
Serpulidae	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0
Sigalionidae	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0
Spionidae	6.9	9.3	2.4	3.8	19.1	18.8	4.4	4.1
Syllidae	1.1	1.3	7.5	9.3	1.3	2.9	9.8	15.9
Mysidae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Aoridae	0.3	0.0	0.0	0.0	1.6	2.4	0.0	0.3
Corophiidae	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.4
Oedicerotidae	2.7	2.9	3.1	3.0	4.4	5.6	9.1	18.8
Cirolanidae	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0
Leptocheliidae	0.1	0.0	0.0	0.3	10.9	2.4	1.3	1.6
Diastylidae	0.0	0.0	0.0	0.0	0.5	0.3	0.0	0.0
Penaeidae	0.0	0.1	0.0	0.3	0.0	0.1	0.0	0.0
Callianassidae	0.9	0.1	0.4	0.0	0.6	0.9	0.4	0.3
Diogenidae	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0
Hymenosomatidae	0.0	0.0	0.0	0.0	0.1	0.0	0.1	0.0
Copepoda	0.1	0.8	0.3	0.8	1.3	0.1	1.5	1.6
Cypridinidae	0.0	0.0	0.3	0.1	0.0	0.0	0.9	0.9
Laevidentaliidae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Nassariidae	0.6	0.5	0.0	0.0	0.0	0.3	0.0	0.0
Haminoeidae	0.0	0.0	0.0	0.0	0.1	0.0	0.3	0.4
Philinidae	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0
Galeommatidae	1.3	0.4	1.9	3.1	1.3	0.0	0.8	0.1
Leptonidae	1.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Lucinidae	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0
Mactridae	0.1	0.0	0.0	0.1	0.0	0.0	0.0	0.0
Myochamidae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Nuculanidae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Veneridae	0.3	0.0	0.3	0.0	0.0	0.4	0.0	0.0
Echinoidea	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0

continued...

Appendix 3: Continued.

	Survey 1				Survey 2			
	Undredged		Dredged		Undredged		Dredged	
Taxon	Und 1	Und 2	Dg1	Dg2	Und 1	Und 2	Dg1	Dg2
Nematoda	7.1	16.4	78.3	132.5	55.6	22.9	228.6	160.1
Nemertea	2.1	3.1	2.0	3.5	6.6	4.1	1.6	9.6
Oligochaeta	17.3	20.3	13.0	5.8	10.4	20.0	41.8	36.9
Phoronida	0.1	0.1	0.0	0.0	1.5	0.3	0.0	0.0
Platyhelminthes	0.0	0.0	9.9	6.8	1.3	0.4	252.1	235.6
Anthozoa	0.1	0.9	0.1	0.0	0.1	0.0	0.0	0.1
Bryozoa	0.1	0.0	0.0	0.2	0.0	0.0	0.0	0.0

Appendix 4: Summary of abundances of meiobenthos in dredged and undredged locations surveyed on two occasions in The Entrance, Tuggerah.

	Survey 1				Survey 2			
	Undredged		Dredged		Undredged		Dredged	
Taxon	Und 1	Und 2	Dg1	Dg2	Und 1	Und 2	Dg1	Dg2
Nematoda	486	186	529	466	817	184	545	494
Harpacticoida	59	26	58	95	30	24	27	94
Copepoda	1	0	0	0	0	1	1	1
Platyhelminthes	2	12	49	19	8	8	86	186
Oligochaeta	0	4	2	4	1	7	7	7
Ostracoda	1	6	31	35	6	6	14	17
Polychaeta	1	8	8	4	2	30	15	13
Amphipoda	0	1	1	1	0	1	1	1
Tanaidicea	0	0	0	0	0	0	0	0
Cumacea	0	0	0	0	0	0	0	0
Kinorhyncha	0	0	0	0	0	0	0	0
Priapulids	0	0	0	0	0	0	0	0
Halacaridae	2	0	0	0	0	0	0	0
Mystacocarida	0	0	0	0	0	0	0	0
Tardigrada	0	0	0	0	0	0	0	0
Foraminifera	0	0	3	4	2	1	4	3
Gastrotricha	0	0	0	0	0	0	0	0
Echiurida	0	0	0	0	0	0	0	0
Syncarida	0	0	0	1	0	0	0	0
Decapoda	0	0	0	0	1	0	0	0
Mollusca	0	0	2	1	0	1	0	0