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Changes in Port Phillip Bay Benthic Invertebrate Communities 1969 - 1995

Robin S. Wilson, Simon Heislers and Gary C.B. Poore
Museum of Victoria
71 Victoria Crescent
Abbotsford, Victoria 3067, Australia

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Port Phillip Bay Environmental Study
CSIRO Environmental Projects Office
Building 9, Forestry Site, Banks Street
Yarralumla, ACT, Australia

PO Box 225, Dickson, ACT 2602, Australia

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EXECUTIVE SUMMARY

An important element of change in benthic communities in Port Phillip Bay during the period 1969—1995 has been the increased importance of species that are common to a range of sediment types, and a relative reduction in numbers of species with more specific sediment preferences.

Family level identifications are adequate to resolve patterns in community structure due to sediment differences, but do not always resolve temporal change in community structure.

It may not be much more expensive to identify all species. If this is done a monitoring program would probably detect future introduced species.

These data show a trend towards suspension feeders (now 33%, used to be 23%) at the expense of deposit feeders (down from 71% to 55%). Individual abundances of Crustacea and Mollusca, the dominant phyla of 1969—1973, are down 75% and 80% respectively, while the total number of species within these phyla are down 20% and 32% respectively. The Annelida appeared as the most abundant phylum in 1994—1995.

The major source of spatial variation in Port Phillip Bay benthos is still the primary division between mud and sand sediments. All other variation is minor by comparison, including that due to interannual change, introduction of exotic species and scallop dredging.

Interannual change in Port Phillip Bay benthic communities exceeds seasonal change.

Pairwise comparisons of ecologically important species indicate that significant change has occurred during the gap in PPB sampling 1975—1991. Other interannual changes are often not statistically significant.

We recommend that an annual sampling intensity of about 30 grabs, spread across the strata sampled in 1994—1995, would be adequate for monitoring purposes.

Annual monitoring is recommended, otherwise it is likely that ecological change will be first detected during the course of other studies (as happened prior to the current CSIRO PPBES), and a monitoring program will be seen to have failed.

Ecologically significant monitoring depends on basic biological knowledge of key common species, knowledge that is presently unavailable. We recommend that studies at both post-graduate and post-doctoral level which aim to provide this vital information be funded and fostered.

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I. INTRODUCTION

1.1. Brief history of benthic research in Port Phillip Bay

Quantitative descriptions of soft-bottom macrobenthos are often an important part of studies of the effect of pollutants on marine communities. Historically, this has been the case in Port Phillip Bay where considerable information has been gathered, especially since the 1970s (Poore, 1992). Benthic communities are the assemblages of animals (rarely plants) living on or in the muddy and sandy environments of the sea-floor. The “macrobenthos” is usually thought of as comprising those animals retained on a 1-mm-mesh sieve.

The need for a survey of the biology of Port Phillip Bay was first recognised in 1888 when the Royal Society of Victoria elected a committee of scientists to begin work. Although it was intended that this be a systematic study, little other than a few taxonomic reports were written (Macpherson and Lynch, 1966). A real attempt at a Bay-wide look at the biological communities did not start until 70 years later.

The aim of the first major systematic study by the Fisheries and Wildlife Department and National Museum of Victoria between 1957 and 1963 was to record the distribution and where possible the density of macroflora and macrofauna. In 1966 and 1971 two volumes of the *Memoirs of the National Museum of Victoria* were devoted to papers on geology, geomorphology, bottom sediments, flora, and taxonomy of numerous groups of invertebrates. Although much new information was gathered, the study added little to the taxonomy or ecology of the Bay's fauna. A concluding paper (Black, 1971) described in very general terms the major benthic communities of the Bay; her results were based more on large infaunal species, such as molluscs, and epifauna than on the smaller and more abundant infauna. Nevertheless, the communities recognised were broadly accurate.

A large-scale quantitative benthic survey was begun in 1969 jointly by Melbourne and Metropolitan Board of Works and Fisheries and Wildlife to provide baseline biological data for the first wide-ranging environmental study of Port Phillip Bay (MMBW and FWD, 1973). The aims of this, the Phase One benthic survey, were essentially descriptive (Poore and Rainer, 1974; Poore *et al.*, 1975). During Phase Two, Poore and Rainer (1979) monitored the simplest of the Port Phillip Bay communities, that on muddy sediments. Lastly, in 1991—1992 the Victorian Fisheries Research Institute conducted a study of the effects of scallop dredging on benthic communities - the SDE study (Currie and Parry, 1996). An outcome of this research was information on benthic communities in a small area of the Bay.

The Port Phillip Bay Environmental Study started in 1992 (Phase Three) and included, among many other reviews and research tasks, a re-survey of benthic communities which is reported on here.

1.2. Objectives of this study

After a review of the literature on the benthos in Port Phillip Bay (Poore, 1992) and on the role of suspension-feeding and deposit-feeding benthic invertebrates in nutrient cycling (Wilson et al., *1993)* benthic sampling commenced in 1994 to:

1. re-survey the benthos of major habitats to detect Bay-wide change from conditions 20 years ago; and

2. measure scales of temporal variation required to develop a monitoring program for the benthic infauna of Port Phillip Bay.

This report briefly summarises the methods, data and conclusions of the earlier benthic surveys and presents new data on which a comparison can be based.

1.3. Data and methods

The analyses presented in this report are based on four benthic survey data-sets from Port Phillip Bay. This section describes how these data were collected, the taxonomic database linked to these data at the Museum of Victoria, and the manner in which biomass data were obtained. All databases are held at the Museum of Victoria and the Port Phillip Bay Environmental Projects Office, Canberra.

1.3.1. Sampling and sorting methods

Collection methods were the same in all surveys, each using Smith-McIntyre grabs deployed from 15—18 m research vessels. In the 1960s and 1970s navigation was by dead reckoning or horizontal triangulation. More recently, satellite navigation was used.

Samples were washed in the field over 1.0 mm sieves, fixed in 5% formalin and sorted in the laboratory under stereomicroscopes. All specimens were transferred to 70% alcohol after identification for storage in the Museum of Victoria collections where most are now registered.

1.3.2. Species identifications and the taxa database

All specimens were identified to nominal species using reference cards and voucher material in Phases One and Two (Poore et al., *1975).* This taxonomy was extended into the current PPBES and the SDE study and has now been standardised and represented by a single taxonomic database (‘*taxa*’) at the Museum of Victoria. This database contains unique species codes, full taxonomic details and some biological and trophic information for all species currently recognised from Port Phillip Bay benthic communities.

Some invertebrate groups identified to species level in PPBES Phase One and in the SDE study have not been identified to the same level as PPBES Phase Three samples, either because the taxonomy of the group is considered unreliable (Nemertea), or because the group is not retained predictably on 1.0 mm mesh (Nematoda, Foraminifera), or because presence of the group merely reflects the availability of suitable hard substrates in the sediment (Bryozoa, Hydrozoa, Porifera). These taxa have been excluded from all data sets.

Some taxonomically difficult families have probably not been identified consistently in all studies (e.g., Capitellidae, Syllidae, Paraonidae, Cirratulidae) and since re-identification of all material was not possible these taxa have been treated at family level in all analyses.

The data incorporated within this report, including counts of species in samples, are stored in another database called '*marine*' from which spreadsheets or matrices can be written for input into statistical programs.

1.3.3. Biomass and trophic classes

Biomass estimates are based on measurement of ash free dry weight (AFDW) taken from identical or analogous taxa in Phase Two. These estimates have been applied to modern abundances to estimate biomass. Because biomass estimates for many taxa are highly skewed by the presence of a few large individuals, median, minimum and maximum values rather than means and standard deviations are used throughout.

2. EARLIER SURVEYS

Each of the earlier surveys had its own objectives. These are briefly reviewed and the available data described.

2.1. Phase One study: 1969—1973

2.1.1. Objectives

Given the poor knowledge of marine invertebrates in southern Australia in the 1960s, the objectives of the Phase One study, which was largely descriptive, were to determine the effects of discharges into the Bay and to investigate appropriate parameters to be used to evaluate future quantitative changes, to provide a quantitative baseline against which to gauge future change, and to define the areas of the Bay most susceptible to human influence. The survey was done in sufficient detail to relate patterns of species distribution to other interacting biological and physicochemical characteristics.

Because this was the only quantitative survey of the benthos of all the Bay its results enabled a stratification for later work.

2.1.2. Methods and data

A regular grid of 86 stations at 5 km intervals was established to cover the whole of the Bay (Figure 1). Five 0.1 m^2 samples were taken at one time from each station; collections were made irregularly over 3_ years. The results take the form of a 3-dimensional matrix of 86 stations by 5 replicates by 687 species. Each cell is the number of individuals per sample.

2.1.3. Classification of stations

A hierarchical analysis of the results gave a general picture of benthic communities. The data were treated as a matrix of 86 stations (with replicates summed) by 687 species and classified hierarchically. A Bray-Curtis measure (using log density data) was used to measure similarity between stations and flexible sorting used to construct a tree describing relationships between them.

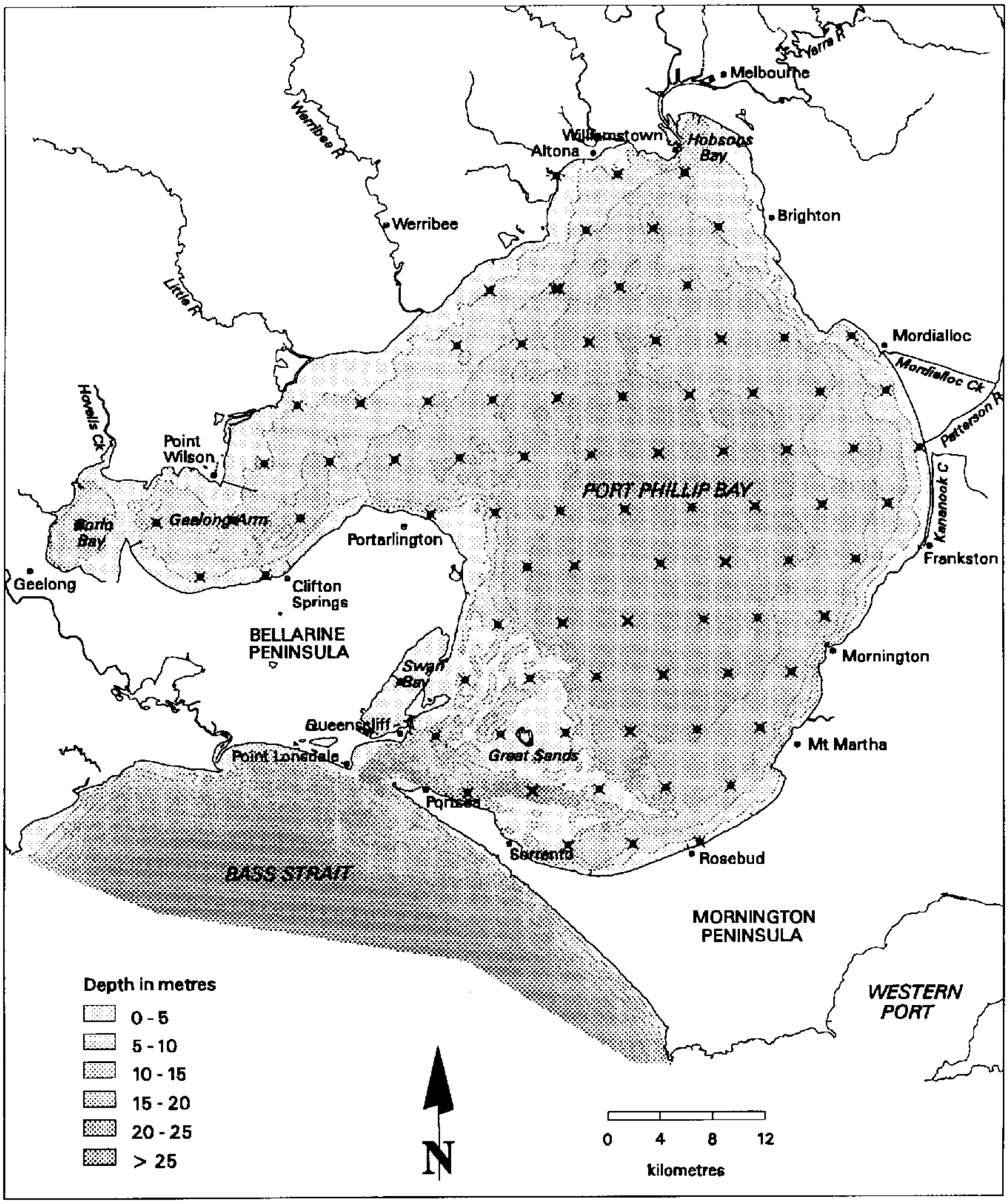

Figure 1: Map of Port Phillip Bay showing the 86 regularly spaced stations sampled between 1969 and 1973.

The hierarchical analysis is reduced here to nine station-groups (based on analysis of data published by Poore *et al*., 1975):

1. The central basin of muddy sediments at depths greater than 15 m (a region of low species richness);
2. Intermediate stations surrounding the central basin plus an area at the entrance to the Geelong Arm (a region of high species richness);
3. Corio Bay entrance, shallow water north of Point Wilson, plus the Altona region (a region of high species richness);
4. Corio Bay muddy environments (a region of low species richness);
5. Southern sands, shallow tidal coarse sands;
6. Region near entrance to Port Phillip Bay, coarse sands;
7. Offshore from Werribee region, Portarlington and other shallow environments (regions of very high species richness);
8. Swan Bay and Clifton Springs area, seagrass communities (very high species richness);
9. Shallow water off Werribee and similar stations on the east coast.

Groups 1—4 are more similar to each other than to the rest, 5—9 which are themselves related. Community patterns are closely correlated with the nature of the sediments. The west coast of Port Phillip Bay, notably the region off the WTC, is more complex and diverse than other parts of the Bay.

These results were corroborated by GNMDS (global non-metric multi-dimensional scaling) analysis of the same data by N.A. O'Connor (pers. Comm.). Regions 6 and 7 of the classification were the most different from the remainder in a 2-dimensional plot. The three stations of region 8 were also relatively isolated. Stations of the central basin (region 1) were tightly clustered and the remainder on sandy sediments (regions 2—5, 9) more loosely grouped. The result was best demonstrated by analysis of data at the species level but also demonstrated with genus- and family-level data.

2.2. Phase Two study: 1973—1975

2.2.1. Objectives

None of the surveys of the Phase One study took any account of temporal variability in community composition and structure. This shortcoming was redressed by Poore and Rainer (1979) who monitored the simplest of the Port Phillip Bay communities, that on muddy sediments. Repeated sampling over three years at three stations enabled comparison of community composition between areas of slightly different environmental regimes and levels of human influence. A second objective was to assess the relative importance of seasonal effects and year to year changes in the community (Poore and Rainer, 1979).

2.2.2. Methods and data

The three stations chosen for study were in similar environments in three different parts of Port Phillip Bay: in Corio Bay and in the centre of the Bay (both on predominantly silt-clay sediments, but differing in depth); and off Martha Point (on a sand-silt-clay sediment). Sampling was quarterly for three years and sample processing was the same as in earlier surveys. Abundances and biomass values were recorded from these samples (Poore and Rainer, 1979).

2.2.3. General results

The fauna totalled 249 species. Differences between stations were found in the mean numbers of individuals and species but not in diversity or evenness measures. The variation of community statistics with time was a more significant result. Seasonal variation was relatively unimportant compared to year to year differences. The available data on physicochemical variables did not explain this phenomenon; no one station appeared to be physically or chemically more variable than any other (Poore and Rainer, 1979).

2.3. Scallop dredging effects (SDE) study: 1991—1992

2.3.1 Objectives

In 1991—1992 the Victorian Fisheries Research Institute conducted a study of the effects of scallop dredging on benthic communities (Currie and Parry, 1996). The aim was to detect changes in densities of the most abundant benthic species and in overall community structure after experimental dredging.

2.3.2. Methods and data

Three locations in 12—15 m depth (off St Leonards, Portarlington and Dromana) were sampled intensively in an experimental design that employed dredged and control plots (Figure 2). Sampling methods were much as in the earlier surveys and species identifications were tied to Museum of Victoria collections.

3. PHASE THREE SURVEY, 1994—1995: DESIGN AND ANALYSES

The Phase Three study uses some of the data from earlier surveys and compares these with new information collected on the basis of a stratified sample design. Analysis of the Phase One data revealed three major zones closely correlated with sediment type: a central muddy basin at depths greater than about 15 m, a marginal sandy area around most of the Bay, and a zone in the southern part of the bay where sediments are well-sorted coarse sands and where the overlying water is exchanged with daily tides through the Heads. The southern area was not selected for re-survey because its fauna is more similar to that of Bass Strait than to the rest of the Bay and seemed a priori most isolated from changes in Port Phillip Bay. Three strata were selected for re-sampling (Figure 2):

1. the muddy basin and Corio Bay;
2. the eastern coast on sandy sediments; and
3. the western coast on sandy sediments (Figure 2).

This geographical division of sandy sediments was justified on the rationale that it may reveal local influences, i.e., the concentrated input of water and nutrients from the Werribee Treatment Centre on the west and the more diffuse inputs from smaller streams and drains on the east.

3.1.1. Data from previous surveys

Data from previous surveys was selected as follows:

PPBES Phase One: 45 grab samples selected at random from both sand strata, representing replicates 1—3 from each of all 15 “sand” stations; and 55 samples from the mud stratum, representing replicate 1 from each “mud” station, i.e. a total of 100 grab samples representing collections integrated over the period 1969—1973.

PPBES Phase Two: 180 grabs from mud stratum (the entire PPBES-2 data-set), representing 60 grabs per year for each of 1973, 1974, 1975.

SDE: 30 samples from the Dromana site (collected 19 and 30 Aug 1991), and 44 samples from the Portarlington site (11 Nov and 13 Dec 1991). SDE data from St Leonards were not used as this location is in the exchange zone. SDE data include both dredged and control samples.

Since PPBES-2 data were available only as pooled abundances from five samples, then with respect to multivariate analyses, Phase One, SDE and Phase Three data were also pooled across stations (within strata) to produce comparable summed abundances from groups of five grabs. In a few cases, four grabs were summed where multiples of five were not present.

All of the above data are tagged with the marker “ppbesa” on the Museum of Victoria *marine* database.

3.1.2. 1994—1995 sampling

During Phase Three 14 stations were located within each of the three strata (eastern sandy sediments, western sandy sediments, muddy central basin plus Corio Bay). Within each stratum, stations were depth stratified, 7 and 12 m depths each with seven stations in the shallower sandy zones, and 17 and 22 m depths each with seven stations in the deeper muddy zones. Two grab samples were taken at each station, but only a single grab has been sorted from most stations. Twenty-three of the 42 stations were placed at the location of Phase One stations. Five replicate grab samples were taken from each of the three muddy Phase Two stations of (Poore and Rainer, 1979) and at the Portarlington site of the Currie and Parry SDE study, thus repeating the sampling design of those studies.

In all, 58 samples were taken in October 1994 (24 “sand” and “36 “mud”); 60 in April 1995 (21 “sand” and 39 “mud”); and 50 in October 1995 (17 “sand” and 33 “mud”).

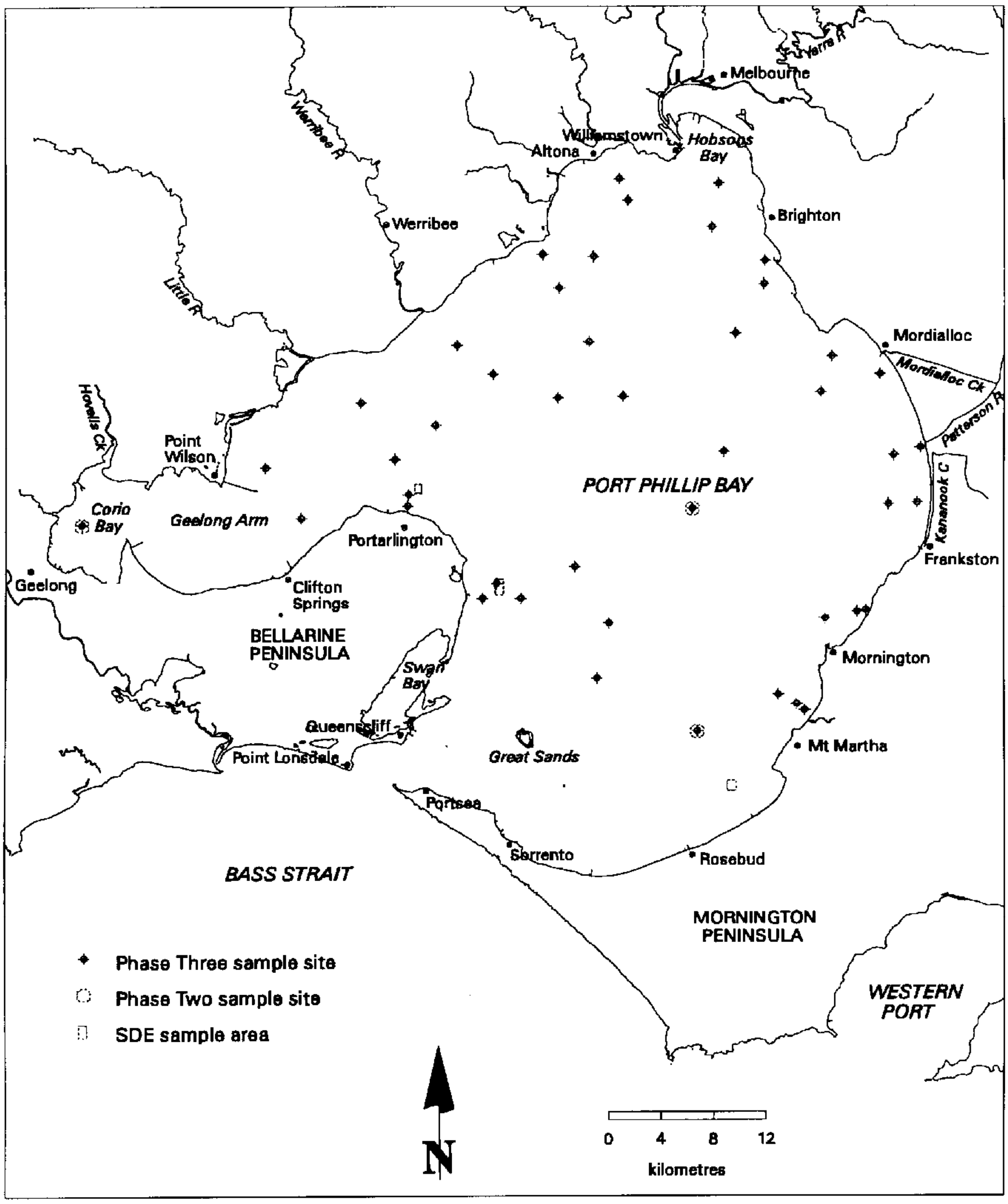

Figure 2: Map of Port Phillip Bay showing sites sampled during Phase Three (mud, eastern sand, western sand), the three muddy stations sampled during Phase Two, and the three areas intensively sampled during the SDE study.

4. SPATIAL AND TEMPORAL PATTERNS IN PORT PHILLIP BAY BENTHOS

4.1. Changes in community structure

4.1.1. Statistical analyses

The results and subsequent discussion pertaining to trophic structure and spatial distribution were based upon analysis of variance (ANOVA) within and between Phase One and Phase Three data. Data from Phase Two and SDE were not included because they were collected from a relatively limited number of stations confined to localised areas, and were not seen to satisfactorily represent the greater benthic communities of Port Phillip Bay within which they occurred, or at least to the same extent as the data collected from the numerous, ‘randomly’ and widely distributed stations in Phases One and Three. Most of the data required log transformation prior to analysis. Where appropriated, *Post hoc* comparison of means (Tukey honest significant difference test for unequal sample sizes) were performed to identify those groups contributing to significant variation.

4.1.2. Trophic structure

A detailed description of benthic community data from Phase One has been provided by (Wilson *et al*., 1993*)*.

Since 1969—1973, the density of animals within the benthos of Port Phillip Bay has decreased significantly from a mean of 3372 individuals m^{-2} , to 1029 individuals m^{-2} during 1994—1995 (ANOVA: df=1, MS=72.968, P=0.000). Individual densities broken down by phyla and by feeding type are detailed in figure 3. A similar significant pattern of decline over this period was observed in terms of species diversity (ANOVA: df=3, MS=2164.818, P=0.000) where an average of 31 species were identified per sample during 1969—1972, compared with an average of 22 species per sample in 1994—1995. The total number of species recorded Baywide has dropped from 282 species in 1969—1973, to 239 species in 1994—1995. Mean numbers of species per sample and total numbers of species, broken down by phylum and feeding type, are detailed in figures 4 and 5 respectively.

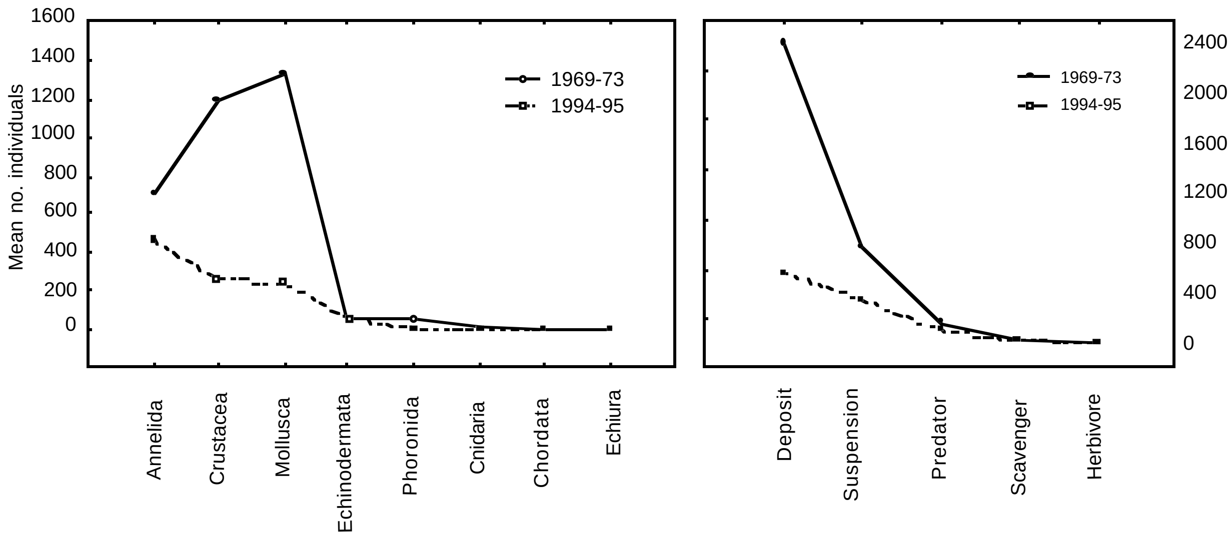

Figure 3: Mean numbers of benthic animals identified per m^2 during Phase One (1969—1973) and Phase Three (1994—1995) of the Port Phillip Bay Environmental Surveys, broken down by Phyla, and by Feeding Type.

In terms of taxonomic representation, more than 98% of all animals sampled and of all species identified during 1969—1973 and 1984—1985 belonged to one of the following phyla: Annelida, Echinodermata, Crustacea and Mollusca. A significant decline was observed in both the mean number of species per sample (ANOVA: *Post hoc* test, $P<0.001$), and mean number of individuals m^{-2} (ANOVA: *Post hoc* test, $P<0.001$), within the phyla Crustacea and Mollusca since 1969—1973. There was not a significant change in the mean number of individuals, or species, within either the Annelida or Echinodermata.

The Crustacea and Mollusca accounted for 75% of all benthic animals in 1969—1973 in roughly equal proportions, and were the most abundant benthic taxa in this regard. However, densities of Crustacea and Mollusca were respectively 75% and 80% lower in 1994—1995 than in 1969—1973, and resulted in all other phyla becoming relatively more abundant within the benthos without exhibiting significant changes in absolute terms. The Annelida were the most abundant taxa in 1994—1995 accounting for 45% of all benthic animals (compared with 21% in 1969—1973), with the Crustacea and Mollusca accounting for a further 49%, again in roughly equal proportions.

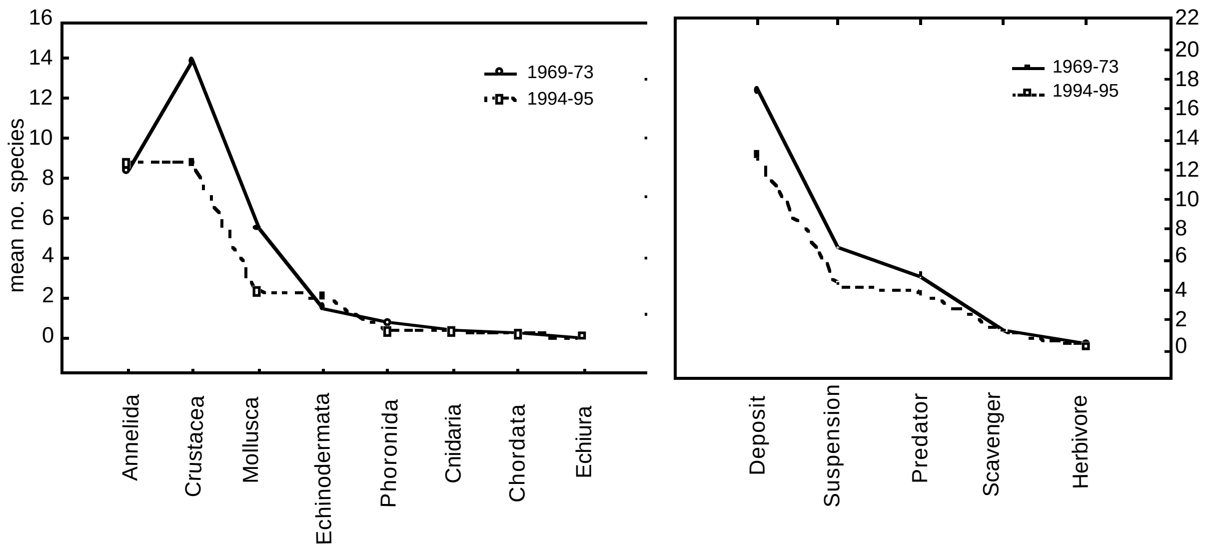

Figure 4: Mean numbers of benthic species identified per grab sample during Phase One (1969—1973) and Phase Three (1994—1995) of the Port Phillip Bay Environmental Surveys, broken down by Phyla, and by Feeding Type.

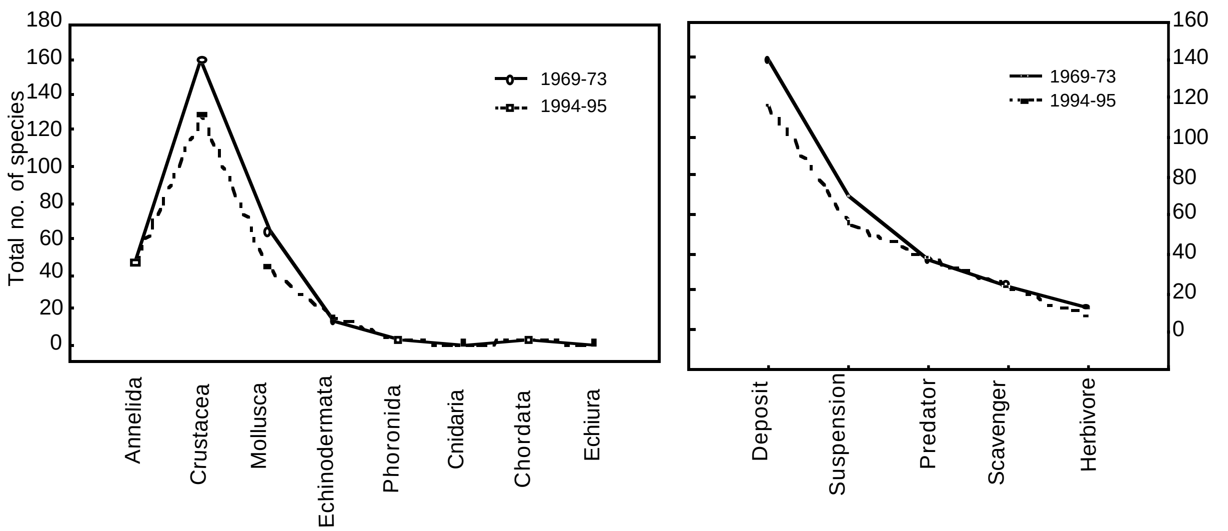

Figure 5: The total number of benthic species recorded during Phase One (1969—1973) and Phase Three (1994—1995) of the Port Phillip Bay Environmental Surveys, broken down by Phyla, and by Feeding Type.

Per sample, the Crustacea and Annelida were the most diverse phyla in 1969—1973, respectively accounting for 46% and 27% of the mean number of species. They were also the most diverse phyla in 1994—1995, although there was on average 38% fewer species of Crustacea per sample than in 1969—1973. Because the mean number of annelid species did not significantly differ between 1969-73 and 1994—1995, these two phyla were equally as diverse in 1994—1995, each accounting for 39% of the mean number of species per sample. The Mollusca were considerably less diverse in 1994—1995 accounting for 10% of the mean number of species per sample, where they previously (1969—1973) accounted for 18% of the mean number of species per sample.

In spite of a significant decline in the total number of species of Crustacea and Mollusca recorded Baywide, and little or no change in the total number of species of all other phyla, the relative abundances of each phyla measured in this regard has changed little between 1969—1973 and 1994—1995. There were clearly more species of Crustacea than any other phyla, and they accounted for 56% of the total number of species recorded in 1994—1995. The Annelida and Mollusca were the next most diverse phyla accounting for an additional 37% of species (in 1994—1995) in roughly equal proportions.

In terms of feeding mode, more than 94% of all species and more than 99% of all animals sampled during 1969—1973 and 1994—1995 were associated with one of the following groups: deposit feeder, suspension feeder, Predator and Scavenger. A significant decline was identified in the mean number of species per sample (ANOVA: *Post hoc* test, $P<0.001$) within the deposit and suspension feeders, and in the mean number of individuals m^{-2} (ANOVA: *Post hoc* test, $P<0.001$) within the deposit feeders, since 1969—1973. There was not a significant change in the mean number of individuals, or species, within either the Predators or Scavengers since 1969—1973.

Deposit and suspension feeders accounted for 94% of all benthic animals in 1969—1973 and although mean numbers of individuals m^{-2} for these two groups were respectively 61% and 25% lower in 1994—1995, these feeding groups remained predominant accounting for 88% of the mean numbers of individuals m^{-2} in 1994—1995. With respect to one another, deposit feeders were most abundant accounting for 71% and 55% of the benthos in 1969—1973 and 1994—1995 respectively. However, the decline in the abundance of deposit feeders was much greater than for the suspension feeders and as a result the suspension feeders made up a greater proportion of the benthos in 1994—1995 (33%) than they did in 1969—1973 (23%).

Although mean numbers per sample, and total numbers of deposit and suspension feeding species were significantly lower in 1994—1995 than in 1969—1973, these results did not translate into marked changes in the relative abundances of each group, indicating that species loss was relatively uniform across all groups. The deposit feeders were the most diverse, accounting for 58% of the mean number of species per sample, and 49% of the total number of species recorded in 1994—1995. Suspension feeders were the second most diverse group, accounting for 22% of the mean number of species per sample, and 24% of the total number of species in 1994—1995.

4.1.3. Spatial distribution

Decline in the total number of recorded species was confined only to the western sandy community where 180 species were recorded in 1994—1995, compared with 236 species in 1969—1973. Conversely there was an increase in the total number of species recorded within the eastern sandy community where 148 species were recorded in 1994—1995, compared with 118 species in 1969—1973. There was practically no change in the number of species recorded from the central muddy community, with a total of 167 recorded species in 1994—1995, 2 more than in 1969—1973.

In terms of species composition, the central muddy, eastern and western sandy communities were relatively more homogenous in 1994—1995 than in 1969—1973. Each community exhibited a greater number and proportion of species common to any other in 1994—1995 compared to 1969—1973 (Table 1). The total number of species common to all three communities increased from 77 species (from a total of 282 species) in 1969—1973 to 97 species (from a total of 239 species) in 1994—1995.

Considering the conclusion drawn from multivariate analysis (see section 4.2) that sediment type (*i.e*. sand versus mud) is the main factor influencing community composition, it is interesting to note that the central muddy and western sandy communities have more species in common than the western and eastern sandy communities. This apparent disparity is due to the fact that similarity as measured in the multivariate analysis is influenced by the relative abundance of all species present within a sample, with common species making a greater contribution to similarity than rare species. Data such as those presented above, which are counts of the absolute number of species common to different communities does not take into account the relative abundances.

Table 1: Absolute and relative numbers of species common among communities during phase-1 (1969—1973) and phase-3 (1994—1995) of the Port Phillip Bay Environmental Survey. Proportions appear in brackets and are expressed as a fraction of the number of species common to each respective combination of communities divided by the total number of species identified from those communities.

Communities:	1969-1973	1994-1995
Central Mud and Western Sand	128 (0.47)	130 (0.60)
Eastern Sand and Western Sand	105 (0.42)	114 (0.53)
Central Mud and Eastern Sand	80 (0.39)	106 (0.43)
All communities	77 (0.27)	97 (0.41)

Significantly lower mean numbers of animals m^{-2} were recorded within each community (ANOVA: *Post hoc* test, $P<0.01$) in 1994—1995 compared to 1969—1973. There was also an observed decline in the mean numbers of species per sample within each of the central muddy, eastern and western sandy communities in 1994—1995, though significant only within the western sandy community (ANOVA: *Post hoc* test, $P<0.001$).

Regardless of such temporal changes, western sandy sediments supported greater densities of animals than the central muddy sediments, which respectively carried a greater density of animals than the eastern sandy sediments. The only statistically significa*hoc* nt (ANOVA: *Post* test, $P<0.05$) difference detected between any of the communities however, was for western sandy and central muddy communities during 1994—1995. In addition, western sandy sediments supported significantly greater mean numbers of species per sample (ANOVA: *Post hoc* test, $P<0.001$) than either of the other two communities, and though not statistically significant, eastern sandy sediments supported a greater mean number of species per sample than the central muddy sediments.

4.1.4. Dominant species

As has already been noted, the Port Phillip Bay macrobenthos has experienced significant change since 1969—1973. Only three of the ten most abundant species from 1969—1973 ranked among the top ten in 1994—1995 (Tables 2, 3). Two of the six most abundant species (*not* including *Sabella spallanzanii*) are or may be introductions from elsewhere in the world.

Table 2: Ten numerically dominant benthic species collected during 1969—1973. Introduced species are marked *

Semelidae *Theora lubrica* (Gould, 1861) [Mollusca]*
Callianassidae *Neocallichirus limosus* (Poore, 1975) [Crustacea]
Mactridae *Notospisula trigonella* [Mollusca]
Diastylidae *Dimorphostylis cottoni* Hale, 1936 [Crustacea]
Corophiidae *Rhinoecetes* sp. MoV 1302 [Crustacea]
Philomedidae *Euphilomedes* sp. MoV 18 [Crustacea]
Phoronidae *Phoronis pallida* (Schneider, 1862) [Phoronida]
Lumbrineridae *Lumbrineris* sp. MoV 322 [Polychaeta]
Veneridae *Chioneryx cardioides* (Lamarck, 1818) [Mollusca]
Nuculidae *Nuculoma obliqua* Lamarck, 1819 [Mollusca]

Table 3: Ten numerically dominant benthic species collected during 1994—1995. Introduced species are marked *

Corbulidae *Corbula* cf. *gibba* (Olivi, 1792) [Mollusca]*
Lumbrineridae *Lumbrineris* sp. MoV 322 [Polychaeta]
Semelidae *Theora lubrica* (Gould, 1861) [Mollusca]*
Diastylidae *Dimorphostylis cottoni* Hale, 1936 [Crustacea]
Nephtyidae *Nephtys inornata* Rainer and Hutchings, 1977 [Polychaeta]
Sabellidae *Euchone* sp. MoV1755 [Polychaeta]
Orbiniidae *Leitoscoloplos bifurcatus* (Hartman, 1957) [Polychaeta]
Magelonidae *Magelona* cf. *dakini* Jones, 1978 [Polychaeta]
Ampeliscidae *Byblis mildura* Lowry and Poore, 1985 [Crustacea]
Chaetopteridae *Phyllochaetopterus* sp. MoV640 [Polychaeta]

The species, *Sabella spallanzanii* (and perhaps also *Euchone* sp. MoV1755) ,both sabellid polychaetes, and *Corbula* cf. *gibba* (a bivalve mollusc) are suspension feeders, and there is concern that the high abundances of these species may be responsible for changing Port Phillip Bay from a system in which the activities of deposit-feeders determined nutrient fluxes and water quality to a system dominated by the dynamics of suspension feeders and phytoplankton. This would be so if, as has been suggested by P. Jernakoff (pers. comm.), deposit feeders promote loss of nitrogen from the system through nitrification and denitrification, while suspension feeders may instead promote phytoplankton growth by raising ammonia levels in the water column and displacing deposit feeders.

4.1.5. Species recruitment curves

After a sampling effort in excess of 1,000 Smith-McIntyre grab samples spanning 25 years in Port Phillip Bay, species continue to be recruited to the known Port Phillip Bay fauna (Figure 6). At the conclusion of Phase Two (1975) the species accumulation curve levels off. Sampling during the SDE study (1991—1992) added eight species new to PPBES samples, and Phase Three (1994—1995) revealed a further 35 (Table 4). These new records include ecologically significant species such as the two species of the sabellid genus *Euchone* and introduced species such as *Corbula* cf. *gibba*. Most of these common animals were first noticed in the SDE study (Table 4). The new records also include new records of individually unremarkable species already known from the region outside Port Phillip Bay. It is not surprising to find many such species eventually collected from Port Phillip Bay benthos, and most (not tabulated) are recorded only once. The fact that so many of these new records occur only once in PPBES research indicates that an increase in taxonomic knowledge or care in 1994—1995 may at least partially explain the new rise in the curve in Figure 6.

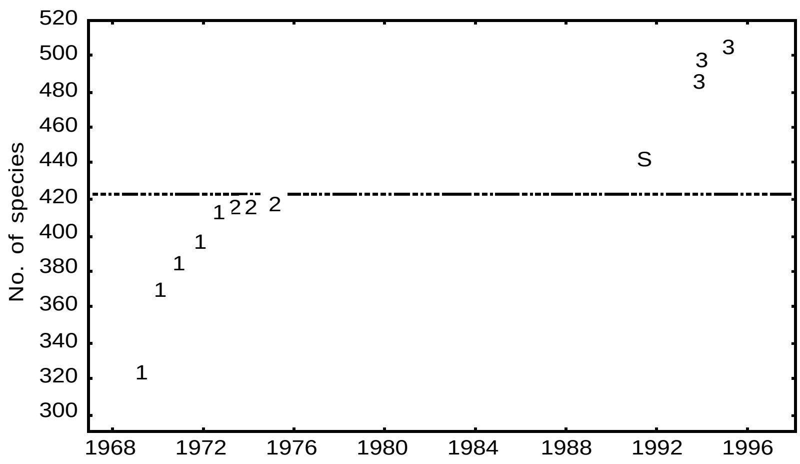

Figure 6: **Cumulative number of species taken over time in more than 1000 grab samples. Phases One, Two and Three are numbered 1, 2, 3 and SDE samples, S.**

Table 4: **Taxa first reported from Port Phillip Bay during the SDE (1991—1992) and the most common of 35 first collected during Phase Three (1994—1995) surveys (ranked by abundance)**

No. of Records	Family *Genus species*
	1991—1992
337	Corbulidae *Corbula* cf. *gibba* (Olivi, 1792)
330	Paranthuridae *Bullowanthura pambula* Poore, 1978
237	Sabellidae *Euchone* sp. MoV1755
84	Haminoeidae *Liloa brevis* (Quoy and Gaimard, 1833)
16	Anthuridae *Haliophasma cribense* Poore, 1975
16	Hiatellidae *Hiatella australis* (Lamarck, 1818)
72	Melitidae *Dulichiella australis* (Haswell, 1879)
5	Veneridae *Venerupis anomala* (Lamarck, 1818)
	1994—1995
22	Majidae *Pyromaia tuberculata* (Lockington, 1877)
10	Goneplacidae *Hexapus granuliferus* Campbell and Stephenson, 1970
9	Aeolidiidae Unknown sp.
4	Sabellidae *Sabella spallanzannii* (Gmelin, 1791)

4.1.6. Summary

In summary, since the environmental survey of 1969—1973, the benthic fauna of Port Phillip Bay has been subject to significant change. Compared to 1969—1973, the Bay as a whole has become relatively more homogenous in terms of community structure. There has been a 70% decline in the total number of animals recorded per unit area, and a 15% decline in the total number of species recorded. The most significant losses have occurred within the Crustacea and Mollusca, polychaete abundances being relatively unchanged. The major trophic groups, deposit and suspension feeders, have also changed, with a shift away from benthic communities dominated by deposit feeding crustaceans and molluscs (in 1969—1973), toward communities dominated by annelids and within which the role of deposit feeders is greatly diminished (in 1994—1995).

Although these significant changes in benthic community structure in Port Phillip Bay are coincident with the introduction of several exotic species of invertebrates, there is no evidence of a causal relationship and these changes may be within the limits of natural variability. Quantitative data describing Port Phillip Bay benthos are still very uneven, with long periods where no sampling took place. However, what data there are suggest that high levels of annual variation are normal. For example, during the Phase Two survey, individual abundances for the years 1973, 1974 and 1975 were respectively 1199, 745 and 1968 animals m^{-2}, These numbers represent an order of change over 3 years which is almost as large as that observed over the 21 years between Phase 1 and Phase 3.

Annual long term monitoring of the benthos of Port Phillip Bay is urgently required, and would provide a more continuous and long term database and better estimates of variability on annual and longer time scales.

4.2. Factors influencing community structure

4.2.1. Statistical analyses

Multivariate statistical techniques are commonly used for the purpose of reducing a large number of variables (e.g. species) down to a small number of factors explaining most of the variation within these variables, which may then be easily interpreted when graphically represented in two (or more) dimensions. Data were analysed with PATN software, using detrended correspondence analysis (DCA) based on Bray Curtis dissimilarity measures (Belbin, 1993). In some cases, semi-strict hybrid multi-dimensional scaling (SSH) was performed upon the data in addition to DCA for the purpose of verifying the results gained from DCA. All multivariate analyses reported here are based on untransformed abundances. Most raw abundances vary by less than two orders of magnitude, and analyses based on log-transformed and presence/absence data produced very similar results.

4.2.2. Bay-wide community patterns

DCA plots of vector 2 and vector 3 vs vector 1 are presented with data points labelled with sediment stratum code, m for mud and s for sand (Figures 7 and 8). The principal axis of variation clearly separates mud and sand but not the eastern and western sand strata. The same axis also separates samples from Phases One and Two combined (low and high scores) from those taken during the SDE study and Phase Three (intermediate scores). Vectors 2 and 3 show .some separation of sampling occasions, with Phase One samples on mud scoring lower on these axes than Phase Two samples. These first three axes account for most of the variation in these data; eigenvalues are 0.69, 0.38 and 0.23 respectively.

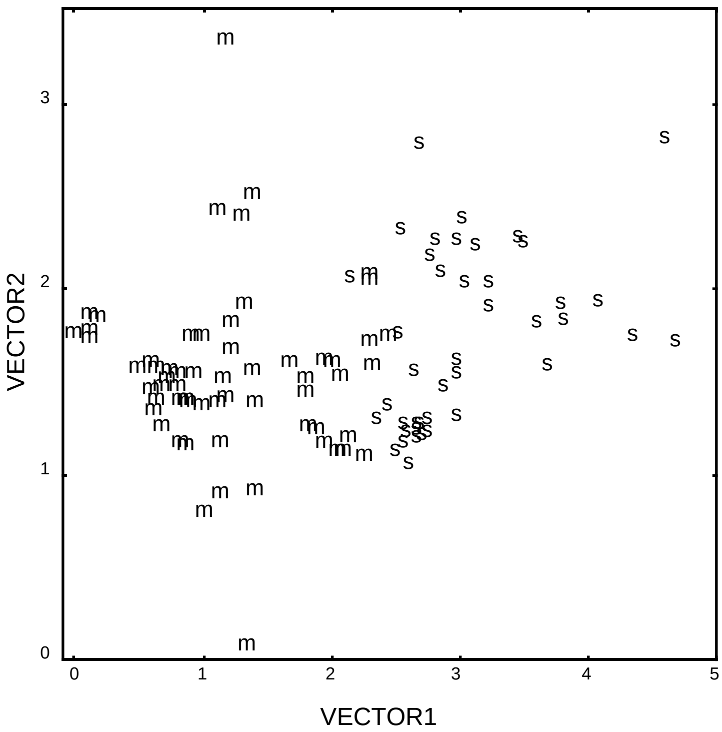

Figure 7: **DCA plot of vector 1 against vector 2 of all benthic data labelled m for mud and s for sand strata. Samples from Phases One and Two and from the SDE study are enclosed. No Phase Two samples were taken on sand.**

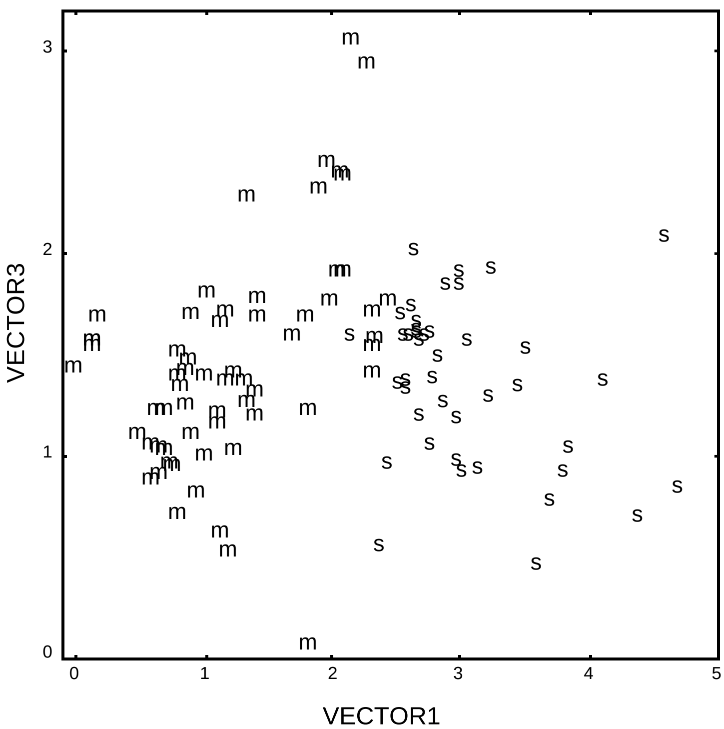

Figure 8: **DCA plot of vector 1 against vector 3 of all benthic data labelled m for mud and s for sand strata. Samples from Phases One and Two and from the SDE study are enclosed. No Phase Two samples were taken on sand.**

Figure 9 reinforces the view that there was no separation of eastern and western sand stations, a finding of the Phase One analysis.

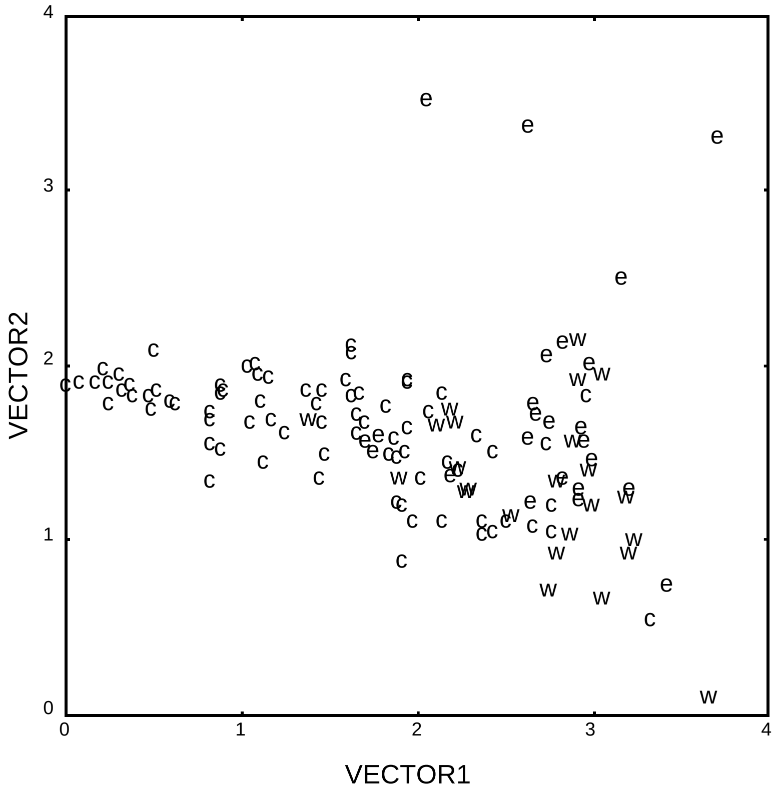

Figure 9: DCA plot of vector 1 against vector 2 of benthic data from Phase Three. Samples are labelled c for central mud stratum and e and w for eastern and western sand strata.

4.2.3. Importance of introduced species

An important element of change in benthic communities in Port Phillip Bay during the period 1969—1995 has been the increased importance of species that are common on a range of sediment types, and a relative reduction in numbers of species with more specific sediment preferences.

Among the greater number of species now occurring on both sand and mud sediments are the new or introduced species *Corbula* cf. *gibba* (whose abundances are distributed across mud and sand sediments in the ratio 1.63:1) and *Euchone* sp. MoV1755 (2.57:1). To determine the effect of these two species on the patterns of community structure, the DCA analysis was repeated on a data set with these two deleted. These results are little different from those derived from the complete data set, and indicate that the new taxa are not having a significant direct effect on the overall patterns in community structure (Figure 10).

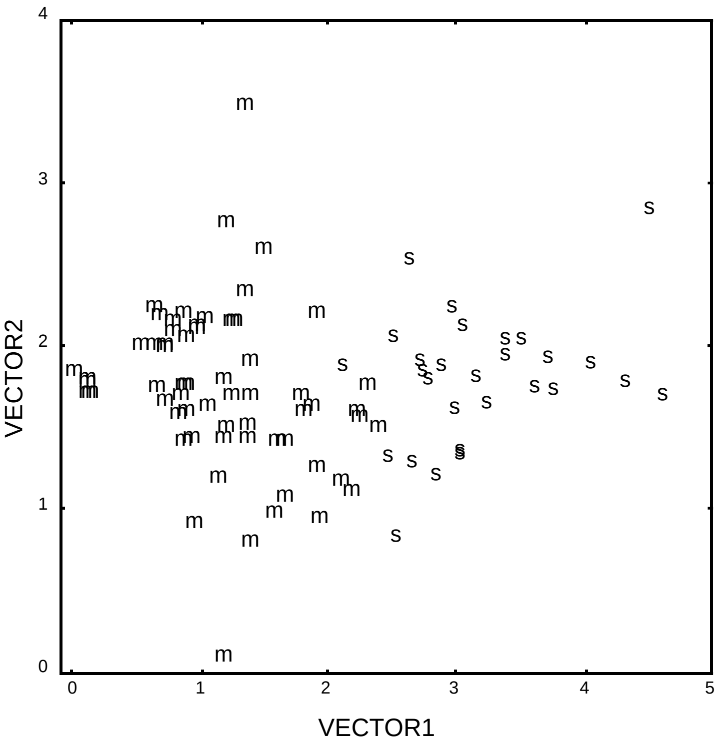

Figure 10: **DCA plot of vector 1 against vector 2 of all benthic species from Phase Three, excluding the new or introduced species, *Corbula* cf. *gibba* and *Euchone* sp. MoV1755. Samples are labelled m for mud and s for sand strata.**

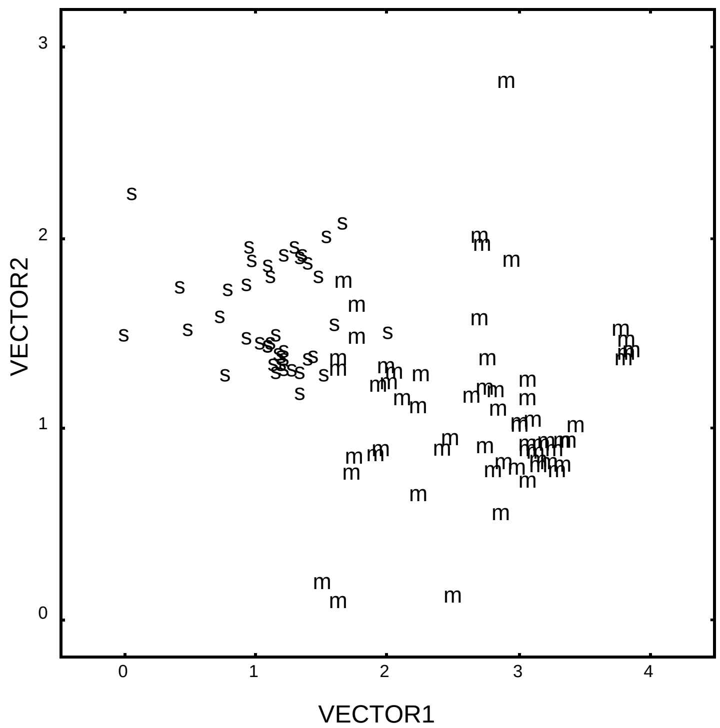

Figure 11: **DCA plot of vector 1 against vector 2 of all benthic data reduced to family level and labelled m for mud and s for sand strata.**

4.2.4. Changes in family composition

Restricting taxonomic identification to family level reduced the number of taxa in the data set from 362 species to 179 families. Analysis of families with DCA showed a pattern similar to that obtained from species level data, *i.e.* mud and sand communities were discriminated equally as clearly(Figure 11).

4.2.5. Summary

The major source of spatial variation in community structure of Port Phillip Bay benthos is still the primary division between mud and sand sediments with all other sources being minor in comparison, including that due to season, interannual change, introduction of exotic species and scallop dredging. Additional spatial variation within sand and mud strata was not detected within either analyses of Phase One data (Poore, 1992), or Phase Three (1994—1995) data (Figure 9).

One implication of the multivariate analyses (which are based on relative abundances) is that a distinction between benthic communities occurring within eastern and western sandy sediments cannot be made. However, univariate comparisons (which are based on absolute abundances) suggest that eastern and western sandy communities can be distinguished. Additional factors, such as the historical spread of at least one introduced species (*Sabella spallanzanii)* from the west, also suggests that eastern and western sandy communities should be retained as separate strata in future monitoring studies

The multivariate analyses summarise temporal change in community structure (Figures 7 and 8). On both mud and sand sediments, samples from the separate years can be differentiated on vectors 1 and 3. However, neither vector can be correlated with time because of the strong interaction with sediment type. Poore and Rainer (1979) first reported that interannual change, over only three years, in Port Phillip Bay exceeds seasonal change. These data support and extend that generalisation, indicating that variation measured over 5 months (SDE) or 3 years (Phase Two) is less than variation over a longer period. Seasonality was only a minor contributor to variation in Phase Three.

5. DISCUSSION

5.1. Monitoring

5.1.1. Selecting species for monitoring

Although family level identifications are sufficient to monitor Bay-wide changes in community and trophic structure, numerous species need to be monitored for one ecological reason or another. Doing this (identifying and counting significant species) may not be much less expensive than identification of all species. If this were not done a monitoring program would probably not detect future introduced species, for example, and would have failed. Criteria for selection of ecologically significant species for monitoring are:

Taxa characteristic of major groups in multivariate analyses. – A 2-way table of common species by stations from a hierarchical classification was used to identify taxa characteristic of the major groupings from the multivariate analyses. *Polyonyx transversus, Montacuta semiradiata*, *Chaetopterus* sp. MoV1718, *Birubius mayamayi*, *Phoronis pallida* and *Owenia* sp. MoV260 are characteristic of Phase One. *Bullowanthura pambula*, *Corbula* cf. *gibba* and *Kalliapseudes* sp. MoV104 are characteristic of the SDE and Phase Three.

Common species. – See Tables 2 and 3.

Principal suspension feeders. – *Corbula* cf. *gibba, Theora lubrica, Dimorphostylis cottoni* and *Euchone* sp. MoV1755.

Principal deposit feeders. – *Lumbrineris* sp. MoV322, *Leitoscoloplos bifurcatus, Echinocardium cordatum* (based on large biomass), *Neocallichirus limosus* and *Euchone* sp. MoV1755. Callianassid crustaceans, especially *Neocallichirus limosus*, are also significant because of their considerable bioturbation activity (Bird *et al*., 1996).

Principal fish prey species. – The most frequently occurring in 12 commonly trawled demersal fishes include several crabs among the list (Parry *et al., 1995): Dittosa undecimspinosa, Halicarcinus rostratus, Nectocarcinus integrifrons, Philyxia intermedia, Byblis mildura, Macrobrachium intermedium, Philine angasi* and *Diplocirrus* sp.

Introduced species. – Taxonomic review of the status of species new to Port Phillip Bay is not complete, but the following are confirmed or suspected of being introductions to Port Phillip Bay: *Corbula* cf. *gibba, Theora lubrica, Pyromaia tuberculata, Sabella spallanzanii*.

Our preliminary recommendations for monitoring taxa are based on taxa which occur at least twice in the above categories of potential ecological importance (Table 5).

Figures 12 to 14 illustrate changing abundances of 8 species of special interest for monitoring studies. These maps show *Euchone* sp. MoV 1755 and two introduced species, *Pyromaia tuberculata* and *Corbula gibba* to be more abundant in Phase 3. Distributions of *Euchone* sp. MoV 1755 and *Euchone* sp. MoV 1802 are presented in Figure 14, to emphasise the fact that of these two sabellid worm species, only *Euchone* sp. MoV 1755 is apparently new to Port Phillip Bay. According to Phase 1 written records, *Euchone* sp. MoV 1802 was apparently present in Phase 1 (1969—1973). Taxonomic research into the identity of these two species is continuing at the Museum of Victoria (M.MacArthur, pers. comm.).

Important bioturbators in Phase 1, including the two callianassids *Neocallichirus limosus* and *Biffarius arenosus,* show marked reductions. However, these maps need to be interpreted cautiously due to the different distribution of sampling stations between Phase 1 and 3. In particular, sampling of muddy sediments (which comprise 70% of the area of the Bay) was much less intense in Phase 3, so the maps in Figures 12 to 14 indicate greater reductions in muddy sediment animals than is actually the case. The results of Analysis of Variance comparing the variation in abundances of the species marked as potential monitoring targets (Table 5) and for which there were suitable data are presented in Table 6.

Table 5: Annotated list of potential monitoring targets in Port Phillip Bay.

Taxon	comments
Corbula cf. *gibba*	dominant suspension feeder; probable exotic introduction; characteristic of Phase Three and SDE; globefish prey species
Echinocardium cordatum	dominant deposit feeder; globefish prey species
Neocallichirus limosus	dominant deposit feeder; significant bioturbator
Dimorphostylis cottoni	dominant suspension feeder; spiny gurnard prey species
Pyromaia tuberculata	exotic introduced species; elephant shark prey species
Byblis mildura	dominant suspension feeder; prey species of red mullet, spiny gurnard, eagle ray, sparsely spotted stingaree
Lumbrineris sp. MoV322	dominant deposit feeder; prey species of eastern shovel nosed ray
Euchone sp. MoV1755	dominant suspension feeder; characteristic of Phase Three and SDE; possible recent introduction but not an exotic species
Leitoscoloplos bifurcatus	dominant deposit feeder; prey of eastern shovel nosed ray
Theora lubrica	dominant suspension feeder; exotic introduction
*Sabella spallanzanii**	dominant suspension feeder; exotic introduction
*Dittosa undecimspinosa**	important prey species of seven species of fish

* These species occur rarely in Smith McIntyre Grab samples and thus have few quantitative historical data available for comparative studies. A different sampling technique would be required to monitor these species.

Table 6: ANOVA results comparing the variation in abundance of potential monitoring target species between Phase 1 (1969-1973) and Phase 3 (1993-1995). Taxa marked with an asterisk indicates those species identified only during the Phase 3 survey, i.e. recent (confirmed and/or suspected) introductions.

Taxon	df	MS	P	Period of greatest relative abundance
Byblis mildura	1, 113	2.568	0.084	no significant change
Corbula cf. gibba *				1993-1995
Dimorphostylis cottoni	1, 138	21.153	0.003	1969-1973
Echinocardium cordatum	1, 109	30.768	0.000	1969-1973
Euchone sp. MoV1755 *				1993-1995
Lumbrineris sp. MoV322	1, 158	10.191	0.017	1993-1995
Leitoscoloplos bifurcatus	1, 105	11.873	0.000	1993-1995
Neocallichirus limosus	1, 125	137.161	0.000	1969-1973
Pyromaia tuberculata *				1993-1995
Theora Lubrica	1, 149	82.130	0.000	1969-1973

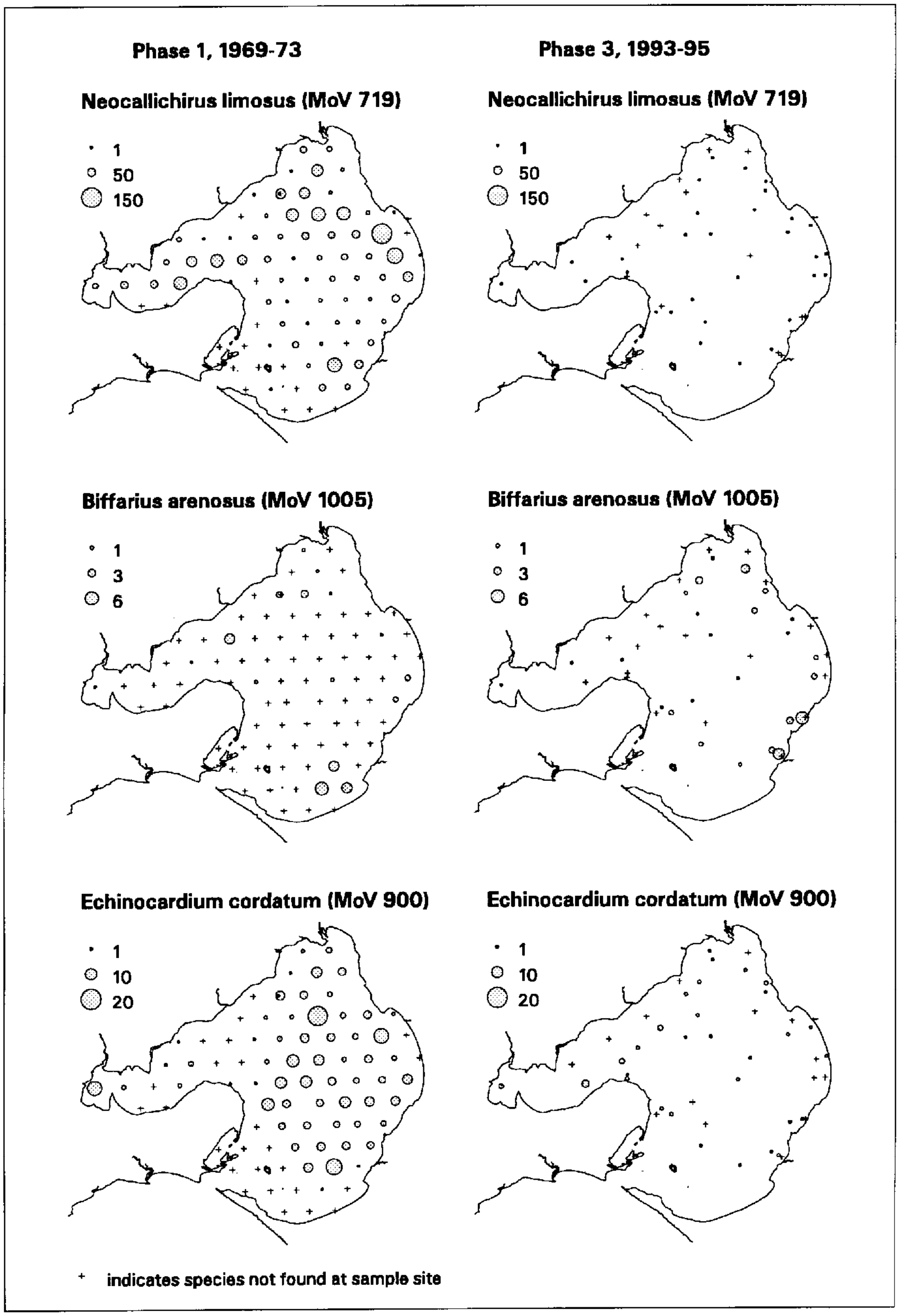

Figure 12: Change in frequency of occurence of *Neocallichirus limosus, Biffarius arenosus* and *Echinocardium cordatum* in Port Phillip Bay between 1969-1995; three dominant deposit and bioturbating species identified during the Port Phillip Bay Environmental Survey. Given values reflect individual densities (per 0.1 m^2).

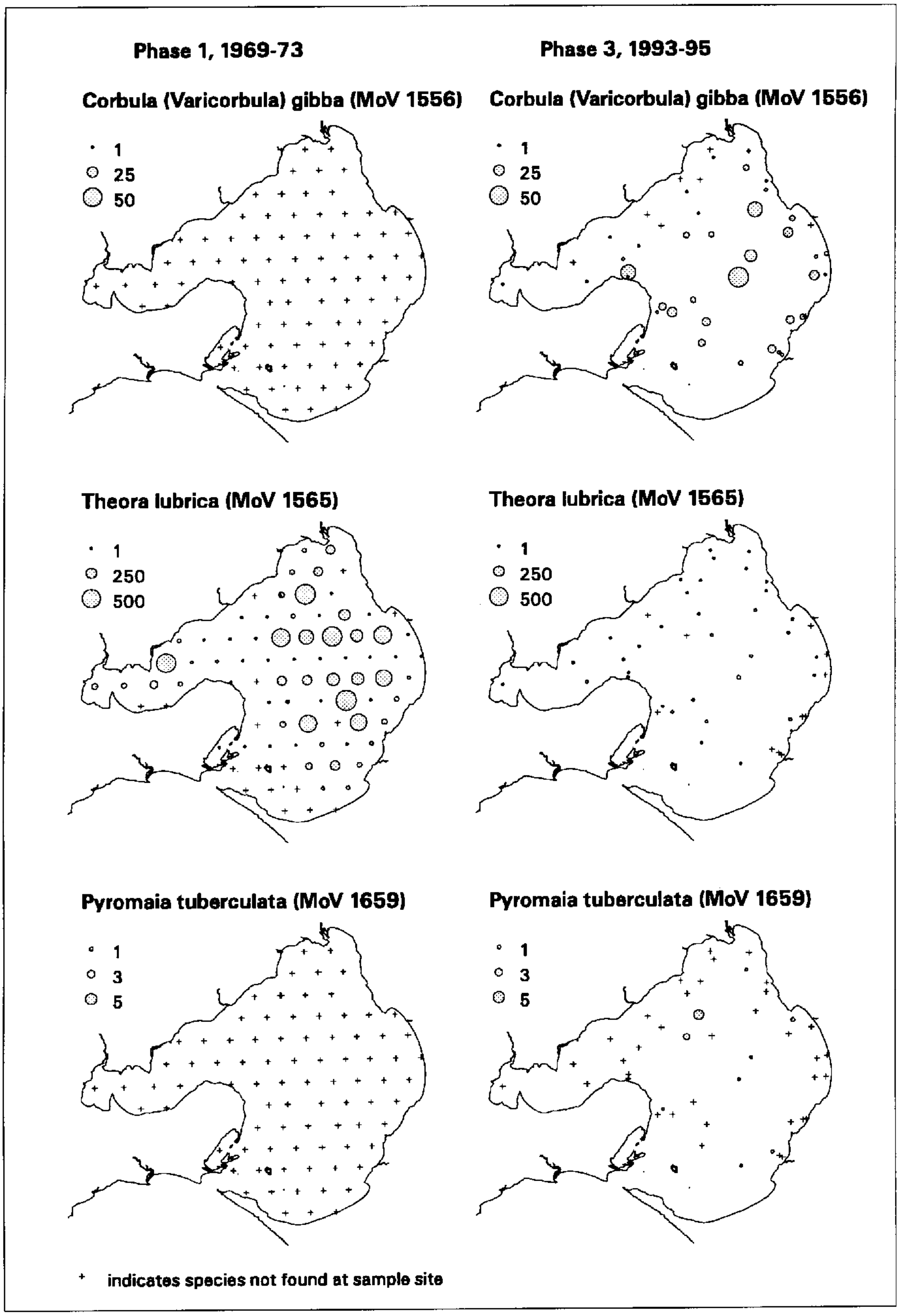

Figure 13: Change in frequency of occurence of *Corbula (Varicorbula) gibba, Theora lubrica* and *Pyromaia tuberculata* in Port Phillip Bay between 1969-1995; three (recently) introduced species identified during the Port Phillip Bay Environmental Survey. Given values reflect individual densities (per 0.1 m^2).

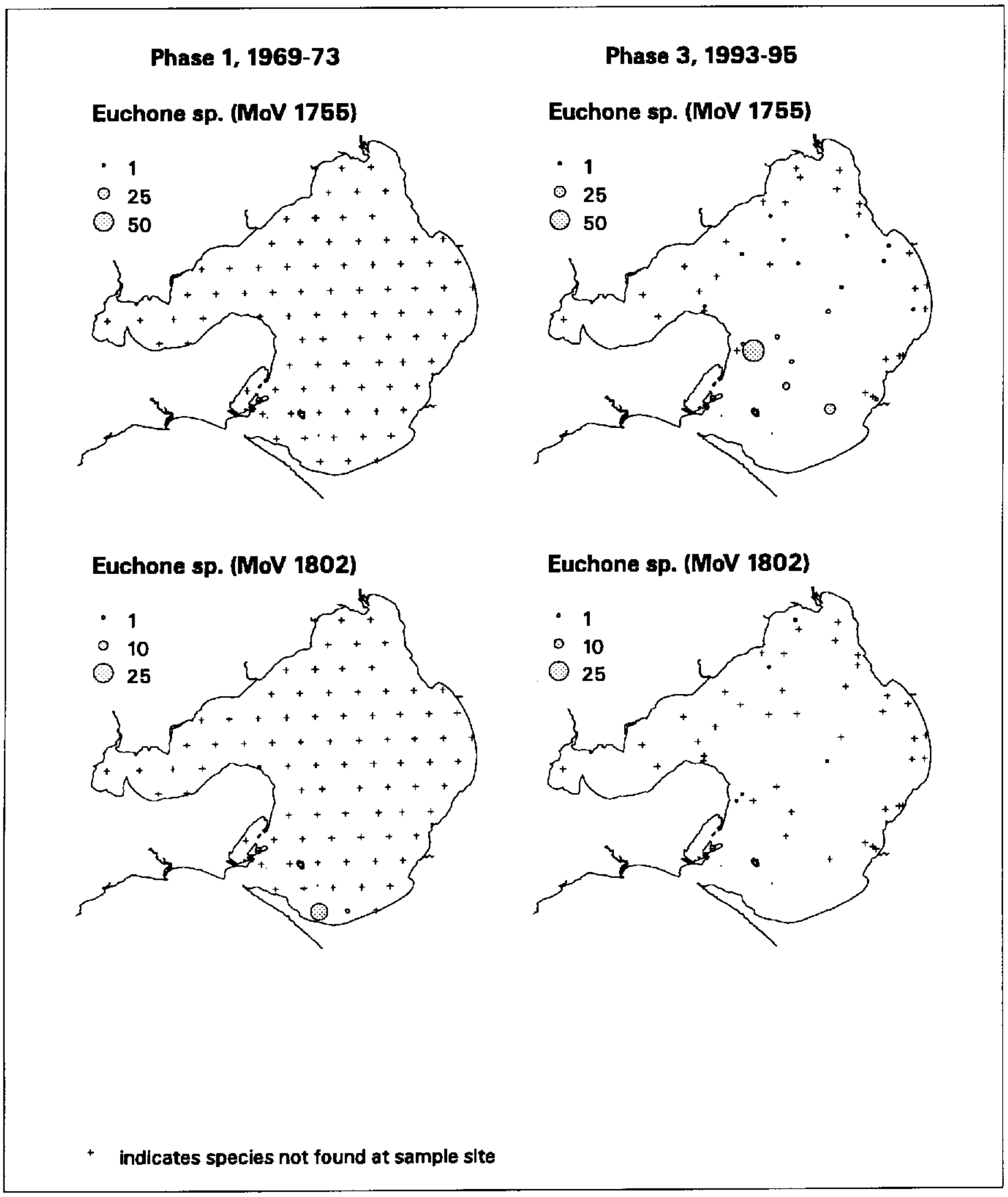

Figure 14: Change in frequency of occurence of *Euchone* spp. in Port Phillip Bay between 1969-1995. See text for discussion of these taxa. Given values reflect individual densities (per 0.1 m^2).

5.1.2. Intensity of sampling to detect changes in density of important species

Figure 15 presents the results of power analyses performed upon ANOVA's measuring the variance in individual abundances of potential monitoring target species in Port Phillip Bay (Table 6) from 1969 to 1995. Only those species within which significant change was detected over this period are figured.

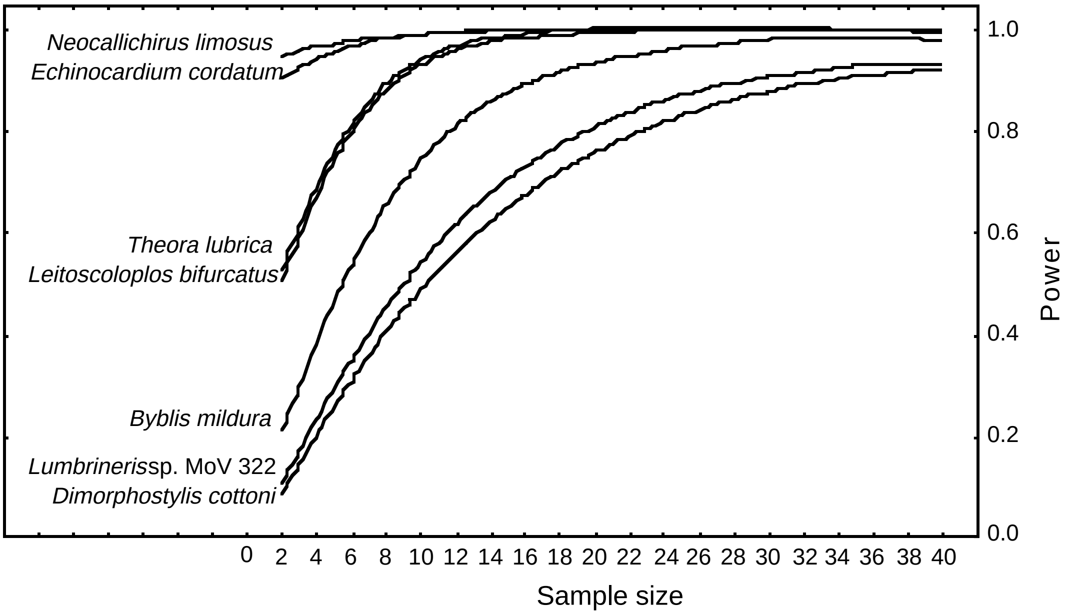

Figure 15: Plot of Power versus sample size of ANOVA's measuring the variance in individual abundances of potential monitoring target species in Port Phillip Bay from 1969 to 1995.

These results suggest that, for the target species tested, a sample of size of at least 22 grabs per sampling occasion would be necessary to provide a dataset sensitive enough to detect a significant change in individual abundance where a change had actually occurred (*i.e.* at least 80% of the time). Given that no single species is distributed uniformly across the Bay, it would be necessary to take grabs from between 30 and 40 stations around the bay in order to be relatively confident of attaining sample sizes of this order for the more widely distributed and abundant benthic species. This is approximately the sampling effort achieved in each of the 6-monthly Phase Three field trips (1994—1995). We recommend that an annual sampling intensity of about 30 grabs, spread across the strata sampled in 1994—1995, would be adequate for monitoring purposes. It would be a useful precaution to double this sampling effort, i.e. to take two grabs per station, but to sort and analyse data from only 1 grab per station unless the need arose to achieve a better estimate of ecological change. This was the strategy chosen for Phase Three.

5.1.3. Monitoring – Where?

The stratification of sampling used in Phase Three, i.e. discriminating between central muddy, eastern and western sandy communities, should be followed to make use of the existing data and analyses in future monitoring. Stations could be moved if necessary within these strata, for example to ensure that possible point source impacts are monitored (in which case additional replicates would be required at these locations), or to include stations used by fisheries or water chemistry studies.

5.1.4. Monitoring – When?

Data critical to the question of how frequently to monitor benthic communities have not been collected. This is because of the lack of sampling during the period 1975—1991 when the most significant levels of community change occurred. The data from Phase Two (which showed seasonal variation to be less than interannual variation) and Phase Three (with only two spring and one autumn samples, and only slight evidence of seasonal variation), suggest that annual sampling is sufficient. A sampling frequency of less than once per year would run the risk of a significant delay in detecting any future change in Port Phillip benthic communities. If monitoring of benthic communities were to be less frequent than annual, it is likely that ecological change will be first detected during the course of other research (as happened prior to the current re-survey) and a monitoring program will be seen to have failed.

6. RECOMMENDATIONS

6.1. Impact of *Sabella spallanzanii* on benthic communities

Because *Sabella spallanzanii* is a large species infrequently caught in Smith-McIntyre grab samples, we have no reliable data from this study on the extent of its distribution. Similarly, our data are not suitable for investigation of the possible effects of *Sabella spallanzanii* on the remainder of the benthic community. We recommend that the distribution of the species be monitored on a regular basis, especially over the next few years while it is spreading and that information be gathered on the means of its spread, its reproductive rate, and feeding.

6.2. Significance of shift towards suspension feeders

There appears to be a significant shift towards suspension feeders at the expense of deposit feeding invertebrates. The significance of such an ecological shift for development of a useful integrated model or for monitoring ecologically significant change will depend on basic biological knowledge of key common species. This knowledge is still unavailable for virtually all Port Phillip Bay taxa. For example, is the common sabellid worm, *Euchone* sp. MoV1755 (notionally a suspension feeder), perhaps just feeding on resuspended detritus? If so, perhaps the trophic status of the benthos is not changing as significantly as these results suggest. We recommend that such studies at both post-graduate and post-doctoral level that aim to collect this vital information be funded and fostered.

6.3. Bioturbation

Bioturbation, or the mixing of sediment by burrowing organisms, can affect chemical, biological and physical properties of benthic sediments (Bird, 1994). The effect of changes in community structure of macrobenthic populations within Port Phillip Bay, with respect to bioturbation and nutrient cycling, are discussed in detail in (Bird *et al*., 1996*).*

The most serious consequence of the changes detailed within this report with respect to bioturbation relate to the decline in abundance of deposit-feeders, and the resultant shift toward suspension-feeders. In contrast to deposit feeders, suspension-feeders rarely establish extensive burrow systems. A shift toward suspension-feeders at the expense of deposit-feeders will result in a decrease in burrow surface area, microbial production (which is enhanced in burrowed sediments), and the rate at which sediments are mixed. These changes may, in turn, be of detriment to the chemical dynamics the Bay (Bird *et al*., 1996).

7. ACKNOWLEDGEMENTS

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