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Soft-bottom macrobenthos of Port Phillip Bay: a literature review

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CONTENTS

SUMMARY

Bay-wide and local surveys of the zoobenthos of soft-sediments in Port Phillip Bay over about the last 20 years have discovered:

1. Port Phillip Bay supports a diversity of benthic communities which are primarily correlated with the nature of the sediment. They range from species-poor communities on muddy environments to species-rich communities on sandy sediments.

2. There is no clear indication from the only quantitative bay-wide survey of an effect on benthic community structure of the effluent from the Werribee Treatment Complex (WTC).

3. Small-scale spatial and temporal variability in community indices and species densities is high and must be taken into account in designing future monitoring.

4. Benthos is exceptionally rich in species compared to similar ecosystems in other parts of the world and is characterised by extraordinary radiation of some families and genera.

5. Effluent from the WTC has a measurable effect on benthic community composition only within about 300 m of the drains and is the result of the combined influence of nutrients and fresh water. A lesser effect is suspected further offshore.

6. The fauna of the Yarra River is more depressed in terms of numbers of species than might be expected from sedimentary properties alone.

7. The fauna of Corio Bay and the Geelong Arm seems to have changed over the period of 20 years for which data are available, with suspected lower densities of macrobenthos and especially with the spread of at least two introduced species of molluscs and one of polychaete.

8. Benthic molluscs contribute a large fraction to the biomass of the bay-wide fauna and suspension feeding molluscs may process a significant fraction of primary planktonic production. Actual rates have not been measured.

9. In the immediate vicinity of the WTC drains epifloral microalgae process nutrients and probably contribute directly to deposit feeders which dominate there.

10. Knowledge of the nutrient pathways involving zoobenthos is based only on extrapolation from foreign literature. Some pathways have been suggested, few have been observed, and no rates have been measured.

11. Most of the important data describing zoobenthic communities is available only as computer print-out. Of the major studies only the 1969-1973 bay-wide survey data are available as an ASCII file and this needs updating in the light of modern taxonomic knowledge.

12. The report of Quinn and Keough (1991) on biological monitoring in Port Phillip Bay should be consulted for recommendations on future monitoring and research into processes.

13. Knowledge of the effects of toxicants on whole macrobenthic communities in Port Phillip Bay is negligible although their effects on individual species are well investigated. These have not been reviewed but Coller *et al.* (1991) and Phillips *et al.* (*in press*) prepared thorough summaries and reviews.

1.0 Introduction

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 during the 1970s.

Benthic communities are the assemblages of animals (rarely plants) living on or in the muddy and sandy environments of the sea-floor. The organisms which live there range in size from minute bacteria and protozoans to large colonial animals. The "macrobenthos" is usually thought of as comprising those animals retained on a 1-mm-mesh sieve; more recently 0.5 mm meshes have been used but in neither case are the smaller interstitial meiofaunal animals considered part of this community. There is of course a strong functional inter-relationship between the macrofauna and meiofauna but no studies on meiofauna have ever been undertaken in Port Phillip Bay.

The advantages of studying macrofauna are:

1. The animals are relatively non-mobile and are therefore useful for studying the local effects of pollutants;
2. Its response to perturbation at taxonomic levels higher than species has been better tested than any other component of the biota;
3. Quantitative sampling is easy and repeatable;
4. There is an extensive research literature on the effects of pollution, particularly organic enrichment, on macrobenthic communities, against which particular case-histories can be evaluated.

This combination of advantages has resulted in the soft-bottom macrobenthos being probably the most widely used component of the marine biota in environmental impact studies. But there are several disadvantages:

1. Sampling requires relatively large research ships to handle the gear needed and considerable ship-time is often required;
2. Sorting and identification of benthic material in the laboratory requires highly trained staff and substantial commitment of time;
3. In Australia, at least, the marine fauna is largely undescribed, is poorly documented in the literature, and is exceptionally diverse compared to faunas of other parts of the world. Also, the number of taxonomists with relevant skills is few;
4. The potential response time of macrobenthos to a pollution event is slow. Generation times are measured in years, so that although losses of species due to severe pollution may be immediate, the colonisation of new species in changed conditions is slow. Thus, the full establishment of a community characterising the new environmental conditions may take several years;
5. Macrobenthos experiments in mesocosms have been poorly developed because such experiments can rarely be run long enough for fully representative community changes to occur, and recruitment of species to mesocosm systems is a problem because of their planktonic larval stages;

6. Settlement and recruitment of spat from the plankton to the bottom are often erratic and as a result dramatic changes in the abundances of individual species may occur from year to year, resulting in natural temporal changes in community structure. Thus, the baseline against which anthropogenic effects are to be measured is inherently variable.

In spite of these disadvantages macrobenthic communities offer numerous opportunities for monitoring of change, measurement of processes, and for experimentation in the laboratory and field.

This review concentrates on macrobenthos as :

1. a tool for monitoring change (descriptions of community structure in sections 2 and 3); and
2. a processor of nutrients (identification of pathways and measurement of rates in section 4).

Historically, and in fact for practical purposes, research has concentrated on two scales: bay-wide studies and local studies, especially around the Werribee Treatment Complex (WTC).

I have not reviewed the effects of toxicants on benthic communities, mainly because these have been reviewed recently by others. Biological studies of toxicants (trace metals, organochlorines and hydrocarbons) in Port Phillip Bay have concentrated on a few single species (e.g., the mussel *Mytilus edulis*). No research on multispecies benthic communities has been carried out here. Smith *et al*. (1981) reported on concentrations of heavy metals in water, sediment and mussels in Corio Bay, one of the most contaminated environments in Port Phillip Bay. Although they discussed possible pathways along which toxicants reach the marine biota no measurements were made. Current knowledge has been summarised and reviewed by Richardson (1990), Coller *et al*. (1991) and Phillips *et al.* (in press) and their work need not be repeated.

Concluding remarks are given in sections 5 and 6. This review should be read in conjuction with Quinn and Keough's (1991) report to the EPA on biological monitoring in Port Phillip Bay. They review the available data briefly, discuss monitoring from a theoretical point of view, and offer suggestions about the directions of future research.

2.0 Bay-wide macrobenthos surveys

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 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 almost 70 years later.

2.1 Fisheries and Wildlife Department - National Museum of Victoria Study, 1957-1963

The aim of the first major systematic study was to record the distribution and where possible the density of macroflora and macrofauna. Samples were collected at 317 stations by diver or dredge and specimens were distributed to taxonomists for identification and reporting. 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 of the Bay's fauna. Twenty-two new species were described but some diverse taxa, notably the Crustacea, were not studied and others were only superficially dealt with.

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. These results have very little impact on today's need for knowledge about the influence of the WTC on Port Phillip Bay.

2.2 MMBW - FWD Study, Phase One, 1968-1973

A large-scale quantitative benthic survey was begun in 1969 to provide baseline biological data for the first wide-ranging environmental study of Port Phillip Bay. The general aims of that study and results from its first three years have been set out elsewhere (MMBW and FWD, 1973).

The aims of the benthic survey were essentially descriptive, to evaluate the diversity of the Bay's fauna in terms of the numbers and composition of species present and to compare it with that of similar areas elsewhere. Although many data were gathered and good records kept not all the aims were met. A preliminary paper documenting the methods and results was published (Poore *et al.*, 1975) and a more analytical study of the molluscs was completed (Poore and Rainer, 1974). In an unpublished analysis zoobenthic communities were defined from the relative abundances of species using hierarchical classificatory techniques with the aim of relating them to physical environmental features, in particular sediment type. Only exploratory results are available and are presented here for the first time.

A regular grid of 86 stations at 5 km intervals was established to cover the whole of the Bay. Five 0.1 m^2 samples were taken at one time from each station; collections were made irregularly over 3_ years. Benthic samples were collected by either Smith-McIntyre grab or (rarely) suction sampler. Samples were sieved wet through a graded series of sieves with 1-mm minimum aperture and material retained was stored in 5% formalin for later sorting and identification.

The abundances of all species found were recorded on system cards and on magnetic tape. All specimens were stored after identification and counting and are now housed in the Museum of Victoria.

Samples for analysis of sediment parameters were taken on separate occasions from those for biological analysis. Dry sieving and pipette analysis were used to estimate phi-classes between -2 ϕ and 9 ϕ and Folk's graphic parameters were calculated. Percentage carbon by dry weight of sediment was obtained (Poore *et al*., 1975).

Poore *et al*. (1975) listed the 687 species recognised from this survey (plus 29 from a small series of supplementary samples) and summarised the numbers of species in 39 major taxa. The survey differed from many others of large areas in that an attempt was made to identify every animal retained on the sieves. There were severe taxonononomic problems, the success of identification varying with taxonomic group. About 40% of all species have specific names, some of which were provisional (Table 1). This fraction varied from one taxonomic group to another, molluscs and echinoderms being much higher (more than 90% identified to species), while crustaceans (34%) and annelids (all but 2 are polychaetes)(25%) contained a much lower proportion of species to which specific names could be assigned (Table 1).

Table 1. State of identification of species of the Port Phillip Bay benthic fauna, February 1975. Some improvement in the percentages of peracarid crustaceans and polychaete crustaceans can be expected in the light of recent revisions and descriptions. Numbers in brackets are percentages of total species in that taxon identified to that taxonomic level.

Taxonomic level	Species	Genus	Family	Higher level	Number of species	% of fauna
Mollusca	95 (92)	8 (8)	1	1	105	15
Annelida	59 (25)	162 (69)	14 (6)	0	235	33
Crustacea	86 (34)	99 (40)	60 (24)	5 (2)	250	35
Echinodermata	18 (95)	1 (5)	0	0	19	3
Other taxa	32 (31)	11 (11)	25 (24)	36 (35)	104	15
TOTALS	290 (41)	281 (40)	100 (14)	42 (6)	713	100

In the molluscs and echinoderms the fraction without specific names is probably a real indication of the number of undescribed species but the other two major groups certainly contain many undescribed species. Much work is still required to make an accurate estimate of this fraction. Ninety-four per cent of the polychaete species could be placed in an existing genus but for Crustacea this fraction was 74%. This reflects real differences in taxonomic knowledge.

In spite of good reviews of polychaete genera 14 species (6%) were identified only to family level. This percentage was much higher in the Crustacea, especially in the lower taxa. The cumaceans, some isopods and most decapods are relatively well known due to the particular interests of a few early naturalists but others, some very rich in species (ostracodes, mysidaceans, tanaidaceans and most amphipod families), were poorly known in Australia at the time of the survey. Lower invertebrate taxa (Anthozoa, Platyhelminthes, Nematoda, Nemertina) were also virtually unknown. These were divided into species and named as well as possible in the time available.

Density ranged from 140 to 14 270 individuals m^{-2} with a mean of 3 410. Highest densities were generally near the shore and lowest values in the sandbank region near the Bay entrance but overall trends were masked by unexplained variation. Much of this was the result of patchiness in the most common species, bivalve *Theora lubrica* (this was referred to as *T. fragilis* in most earlier publications but is now believed to be this introduced species).

The number of species per 0.1 m^2-sample ranged from 7 to 111 (mean = 33.1) and per five samples from 26 to 197 (mean = 69.0). Highest values were at marginal stations, in particular on the north-west and south coasts, and lowest values in parts of the central basin of the Bay and on the sandbank near its entrance. These species densities are much higher than comparable figures for other coastal waters and reflects the general high species richness of marine communities of south-eastern Australia compared to similar environments in other parts of the world.

A notable feature of Port Phillip Bay (and generally of the Victorian marine environment) is the high level of within-genus species radiation. Some examples are *Birubius* and *Paradexamine* (Amphipoda) with numerous species, *Callianassa* (Decapoda) with five species, *Polydora* (Polychaeta) with 11 species, and numerous other polychaete genera with more than four species. Radiation in the shallow-water amphipod, cumacean and isopod faunas in this part of Australia is well documented and our results suggest that the phenomenon is not restricted to these groups. Since the survey was completed there has been considerable effort on the taxonomy of marine coastal invertebrates in south-eastern Australia, especially in peracarid crustaceans and in polychaetes, the results of which can be incorporated into this study.

The benthos of Port Phillip Bay is particularly diverse. Although density (in terms of numbers of individuals per unit area) was similar to that in other coastal zones the number of species involved was very high.

Although Port Phillip Bay is rich in species many occurred at few stations. Thirty per cent (206 species out of 687) occurred at only one of the 86 stations and a further 11% (77 species) at only two stations. Only 4.7% (32 species) occurred at more than half of the stations sampled, the most ubiquitous species (*Theora lubrica*) being present at 71 stations. The most widespread species are generally those of muddy sediments and the rarer ones from nearshore sandy sediments.

A preliminary hierarchical analysis of the results gives a general picture of benthic communities. This type of treatment is very standard for this sort of data-set but there are many options in choosing techniques. The data were treated as a matrix of 86 stations (replicates summed) x 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.

The result from only one classification is presented. A more appropriate treatment may be available now in modern packages such as PATN. Other multivariate techniques will also be valuable tools in the search for pattern in these data.

The hierarchical analysis is reduced here to nine station-groups (Figure 1):

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 station on the east coast.

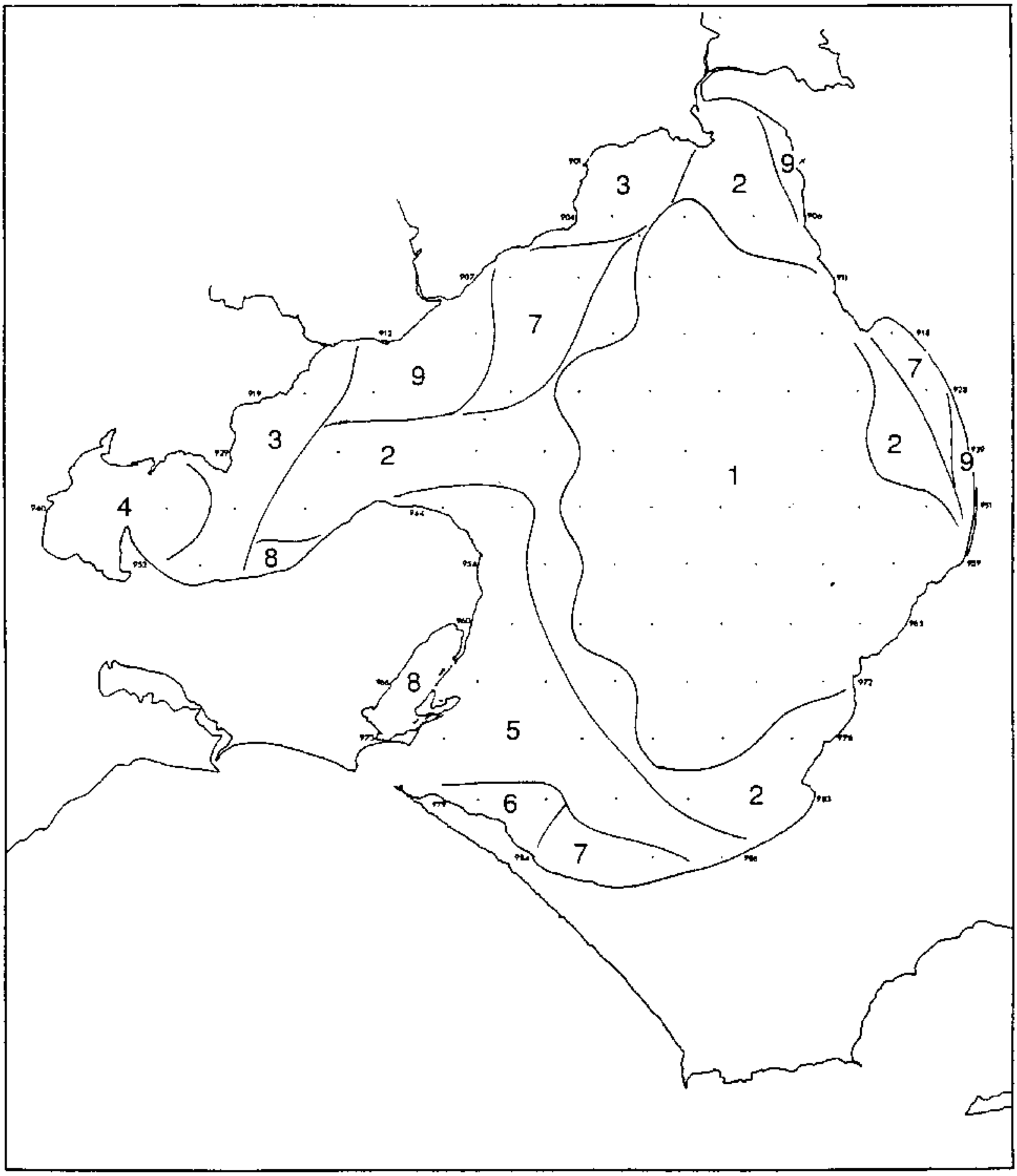

Figure 1. Benthic communities of Port Phillip Bay derived using hierarchical analysis of species densities of all macrofauna at 86 regularly spaced stations sampled between 1969 and 1673. Stations are grouped into nine groups, 1 to 9 (results of analyss of data published by Poore et al., 1975).

Groups 1-4 are more similar to each other than to the rest, 5-9 which are themselves related. Without going into detail it is clear that community patterns are closely correlated with the nature of the sediments and that the west coast of Port Phillip Bay, notably the region off the WTC, is more complex and diverse than other parts of the Bay.

Poore and Rainer (1974) took the data on molluscs from this survey (15% of the species but a much larger fraction of the biomass) and treated their distribution in detail. They recognised eight regions based on impressions of faunal composition and sediments (Figure 2). Biomass was determined for six feeding types: epifaunal suspension feeders, infaunal suspension feeders, surface deposit feeders, grazers, predators and scavengers. As expected, the distribution of molluscs within Port Phillip Bay can be related primarily to substrate and food supply characteristics. Some hydrological effects were apparent, while predation was thought to play a part in determining the distribution of a few species.

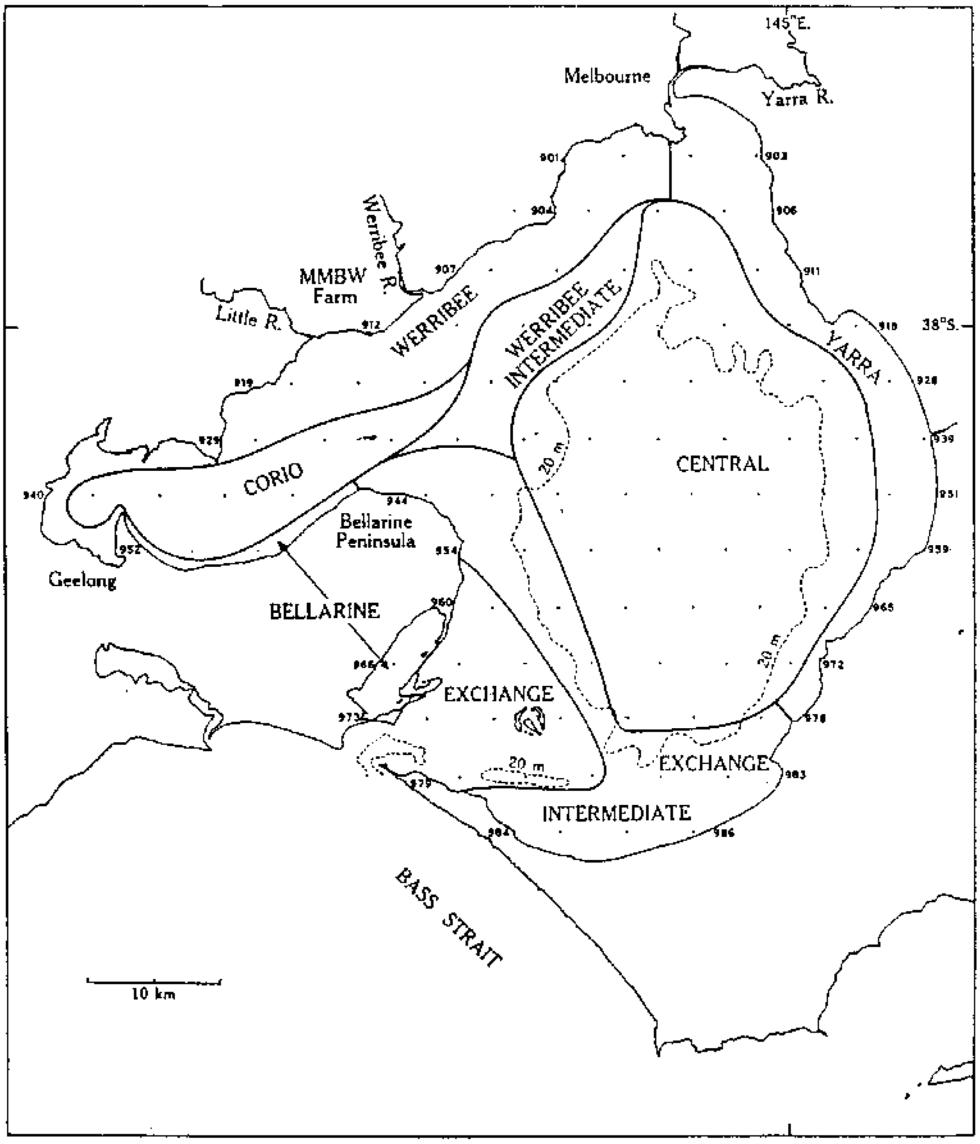

Figure 2. Regions of Port Phillip Bay derived intuitively from data on the distribution of molluscs (from Poore and Rainer, 1974).

Direct substrate limitations exist for herbivorous species that are more usually found grazing on macrophytes or hard substrates. Most chitons and lower gastropods found were limited to areas such as the Bellarine region and to sandy substrates either with a mixture of coarse shell or with large epifaunal molluscs. The small biomass of herbivorous molluscs (<1.0% of all molluscs) may be attributed primarily to the limited area of suitable substrate. Substrate limitations also existed for sessile bivalves such as the pteriid *Electroma georgiana*, usually occurring attached to algae, and the oyster *Ostrea angasi*, attached to shell or other hard substrate. Both species showed a highly irregular distribution that reflects the availability of suitable substrate. Few large motile species were found in the central region, an area of sediments with a high proportion of silt and clay, reflecting the difficulty of remaining in contact with the fine sediment. Species showing features presumably adaptive for life in fine sediments were the venerid *Callanaitis disjecta* and the cardiid *Fulvia tenuicostata*, both frequent in mixed sand-silt sediments on the edge of the central basin.

Although the hydrology of the Bay is basically similar to that of Bass Strait, periodic reduction in salinity occurs near the major inputs, and the fauna near them reflects this. *Notospisula trigonella*, for example, is characteristically found in areas around freshwater inputs.

The distribution and nature of the food supply superimposes large-scale patterns on sediment-related distribution. The principal inputs to the Bay are from the land, with most freshwater input in the northern half of the Bay from the WTC and the Yarra River. Both are substantial sources of nitrogen and phosphorus, chiefly in inorganic forms, and the Yarra also carries a high load of suspended material. Phytoplankton density as measured by chlorophyll *a* is highest in the areas adjacent to these inputs. Suspension feeders reliant on this food source form the largest mollusc feeding group.

Two other feeding groups, grazers and surface deposit feeders, have maximum biomass in the Bellarine region. This is probably a function of the extensive macrophyte beds, although the abundance of deposit feeders is aided by the absence of strong tidal current that would otherwise remove much of the detrital material. The absence of grazers, and the relative paucity of surface deposit feeders in grab samples from the Werribee region, may be related to the fact that much of the algae there is present as drift beds of filamentous red algae. In the absence of grazers the rate of breakdown of this material into detritus is low.

The role of predation and scavenging in determining mollusc distributions cannot be defined on the basis of mollusc distribution data only. Most predacious molluscs feed on a variety of invertebrates, while molluscs also are the prey of a number of other groups. Near Port Phillip heads, predators and scavengers formed nearly half of the total mollusc biomass. An important predator on molluscs is the common asteroid *Coscinasterias calamaria* which feeds extensively on bivalves, and probably has a controlling effect on these species. Extensive dredging has been carried out since the early 1960s for the scallop *Pecten alba*. Apart from the consequent reductions in the numbers of *P. alba*, the disturbance of the bottom and the relocation of mussels and oysters caught in the dredges has probably affected the distribution of some species. Current studies by G. Parry (Marine Science Laboratories) are investigating the effects of scallop dredging more directly.

The relationship between fauna and sediments, exemplified by the molluscs, was corroborated by the distribution of the five species of the ghost-shrimp genus *Callianassa* (Poore, 1975). The newly described species, *C. arenosa*, was found at low densities (maximum of 60 individuals m^{-2}) on sediments and depths of an intermediate nature - silty sand between about 13 and 19 m deep. Another new species, *C. limosa*, occurred at most stations in the Bay but was notably absent from the well-sorted sands near the Bay entrance. Highest densities were in the fine sediments of the central basin deeper than 15 m (maximum 1,152 individuals m^{-2}) and in the Geelong arm. The average density in the northern part of the basin where the substrate contained an appreciable proportion of silt and around its edges was somewhat higher than that in clay sediments in the southern deeper part of the basin. *C. ceramica* was confined to shallow water less than 10 m deep where the sediments are predominantly sand. These occurred on the shelf along the southern coast and at nearshore stations along the western coast. Density was always low, maximum recorded being 46 individuals m^{-2}. A fifth species, *C. australiensis*, also occurs intertidally in Port Phillip Bay. The species of *Callianassa* known from Port Phillip Bay rarely coexist except at a few stations of intermediate sediment type. In the central basin of the Bay *C. limosa* was one of the two dominant invertebrate species in a rather impoverished macrofauna, the other being the bivalve *Theora lubrica*. This species, therefore, must play an important part in the material and energy turnover of this extremely soft substrate.

The collections from this survey are now housed in the Museum of Victoria where many are registered as part of that institution's databases. Many of the specimens have become type material of new species. Some "species" will need to be reidentified in the light on new taxonomic work before comparative surveys are undertaken. The raw data (counts of individuals per replicate per station) are stored as ASCII files at Melbourne Water and the Museum.

2.3 A long-term study of macrobenthos of muddy environments

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. 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 much as in earlier surveys.

The fauna totalled 249 species of which 37% were polychaetes, 30% crustaceans and 14% molluscs. More than half (131 species) were deposit feeders and all numerically-important species and a major portion of the biomass belonged to this trophic group. In Corio Bay the numerically-dominant species were the bivalve *Theora lubrica*, the decapod *Callianassa limosa*, the bivalve *Electroma georgiana*, and the polychaetes *Nephtys inornata* and *Eupolymnia nebulosa*. In the centre of the bay *T. lubrica, C. limosa*, the amphipod *Byblis mildura*, the phoronid *Phoronis pallida, N. inornata* and the ophiuroid *Amphiura elandiformis* were common and off Mt Martha *T. lubrica, C. limosa, P. pallida*, the bivalve *Leionucula obliqua* and the polychaete *Myriochele* sp were the most abundant 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 physico-chemical variables did not explain this phenomenon; no one station appeared to be physically or chemically more variable than any other.

Differences between replicates contributed 14% of total variance in the numbers of individuals, but contribution to total variance in the number of species, diversity and evenness was 19 to 27%. This was probably due to small-scale disturbances or environmental heterogeneity.

Two species, *Theora lubrica* and *Callianassa limosa*, remained dominant over the period as they were six years earlier during the Phase One studies. The persistence of *Theora* and *Callianassa* as co-dominants can be taken to indicate that these two species did not unfavourably alter each other's environment over that period and may be dominant now in the centre of the bay, twenty years later. This may not be the case in Corio Bay (see below).

In summary, over the 3-year sampling period the benthos of silty-clay sediments in Port Phillip Bay showed irregular fluctuations in the density of the common species and in the identity of the minor species.

The only copy of these data is a computer print-out held by the Museum of Victoria.

3. Local specific studies

Benthic studies in smaller areas than those described above have been made in three areas of Port Phillip Bay: Werribee region, Corio Bay and the Yarra River. An experimental study of the effects of scallop dredging is also being undertaken in a wider region of the Bay. The Werribee studies are dealt with first, those covering the widest geographical region before the more localised studies.

3.1 Subtidal benthic fauna offshore from the Werribee region

The subtidal benthic faunal community has been studied by the MMBW but only unpublished simple analyses of considerable data are available. Three replicate samples of sediment infauna were taken at 20 sites, on 14 occasions, nearshore and offshore from the coast of the WTC between 1983 and 1984. Not all sites were sampled on all occasions (Brown and Davies, 1991).

Numerous species were identified and counted. The dominant fauna at the 15E and 145W outfalls were tubicolous, deposit/suspension feeding polychaetes including *Boccardia proboscidea*, *Malacoceros tripartitus* and *Heteromastus filiformis*, while at the mouths of the Werribee and Little Rivers capitellids (mainly *Capitella* sp.) and oligochaetes were most numerous. All these species, except *Heteromastus*, were either absent or rare at sites distant from the drains. *Capitella* and *Heteromastus* are both subsurface deposit feeders which ingest organic material from the sediments and are opportunistic species. *Boccardia* and *Malacoceros* are both surface deposit feeders. Very high densities of *B. proboscidea* are indicative of organic enrichment and this worm has been recorded near several sewage effluent outfalls in both Victoria and California although it is also infrequently recorded in low densities from non-enriched areas. The tube-dwelling spionid and capitellid species abundant at the river and outfall sites may reproduce by brooding offspring, thus allowing juveniles to quickly colonise available substrate when conditions are suitable.

At sites nearshore to the outfalls, deposit feeding polychaetes including *Magelona dakini*, *Pseudopolydora paucibranchiata*, *Eunice australis* and *Polydora protuberata*, deposit feeding amphipods including *Brolgus tattersalli* and the filter-feeding bivalves *Mysella donaciformis* and *Katelysia rhytiphora* were common. More distant from the outfalls, tube-dwelling deposit feeding polychaetes were not abundant, presumably because there is insufficient organic material to support large populations. Common species included the polychaetes *Magelona dakini*, *Schistomeringos loveni*, the filter-feeding bivalve *Hiatella australis* and the brittle-star *Amphiura elandiformis.* These sites were predominantly sandy silt or silty sand, often with a high proportion of shell grit. At sites in the Geelong Arm, furthest from the outfalls, common species were the bivalves *Tellina deltoidalis*, *Hiatella australis* and *Chioneryx cardioides*, the predatory worm *Nephtys inornata*, the tube-dwelling worm *Terebellides stroemii* and the brittle-star *Amphiura elandiformis.*

The 1983-1984 study confirmed the findings of earlier work (summarised below) that the impact of effluent from the WTC on benthic macroinvertebrates was greatest right at the discharge points and a zone of lesser impact was definable in the surrounding nearshore waters between Wedge Point in the north-east and Point Wilson in the south-west. Known effluent mixing characteristics and dispersion patterns identify this area, particularly between Wedge Point and Beacon Point, as the primary mixing zone of the effluent with Bay waters.

The material is now in the Museum of Victoria but there is no correlation between the cataloguing system used for these identifications and those of earlier studies. It has yet to be incorporated into the collections. Data from this survey are at Melbourne Water and the Museum and would lend themselves to more detailed analysis than has so far been attempted.

3.2 Benthos around the WTC 145W outfall

An intensive study of the biota near the 145W outfall of the WTC was undertaken in 1976 (Poore and Kudenov, 1978a) and the distribution of species correlated with several environmental factors. Invertebrate samples were taken at 36 stations on a radiating pattern within a 2-km radius and treated as in earlier studies. Samples were taken for nutrient analysis from the water column and interstitial water. Sediments nearshore were more sandy and uniform than offshore and a rich fauna was found including several euryhaline and opportunistic species. In all 246 species - 37% crustaceans, 36% polychaetes and 11% molluscs - were recorded. Of these, 55% were deposit feeders (mostly crustaceans and polychaetes), 25% predators (polychaetes and nemerteans), 14% suspensions feeders (crustaceans and bivalves) and 6% scavengers (crustaceans and gastropods).

The numerically dominant species were the bivalve *Notospisula trigonella*, oligochaete spp., the mysid *Gastrosaccus dakini*, amphipods of the genera *Corophium, Exoediceros, Tethygeneia* and *Limnoporeia*, and the polychaetes *Australonereis ehlersi, Boccardiella limnicola, Polydora socialis, Pseudopolydora paucibranchiata, Nephtys australiensis, Mediomastus* sp.*, Heteromastus* sp. and *Scolopolos cylindrifer*.

Classification of the stations revealed two stations groups, an inshore group at sites less than 1 m deep and an offshore group. Numbers of individuals were similar in both groups but the numbers of species and species diversity were significantly higher in the offshore group.

Correlations with common environmental variables were identified for 24 of the 49 common species recorded. *Euphilomedes, Dimorphostylis cottoni* and *Paraphoxus* (now known as species of other phoxocephalid genera) were positively correlated with depth and *Gammaropsis*, oligochaetes and *Exoediceros* were negatively correlated but it is probable that some associated sediment parameter was more likely to be the causative agent. Many of the species abundant in the nearshore areas were positively correlated with phosphate which may indicate their dependence on organic material. These species included the polychaetes *Polydora, Scoloplos, Prionospio* and *Cirratulus*, amphipods *Tethygeneia* and *Corophium* and oligochaetes. Ten other species were correlated with some feature of grain size.

The study found considerable heterogeneity and patchiness of the environment around the 145W outfall and that this area probably was influenced significantly by sediment transport by the prevailing onshore wind. It was concluded that the nearshore benthos of sandy sediments was modified by the discharge from the outfall in a rather patchy fashion extending about 300 m out from the end of the outfall. The longshore impact of the discharge was not quantified. The effect of the Werribee discharge on the macrofauna was much less severe than most reported in the literature. All stations had a rich fauna and the major effect of the drain was an increase in the numbers of deposit feeding estuarine polychaetes and amphipods. These animals all occur widely in the Bay although generally in much lower densities elsewhere.

The results of this survey were subjected to further analysis, canonical correlation analysis, by Poore and Mobley (1980). This analysis confirmed the earlier results.

Few collections of animals from this survey were kept and the only copy of the data is a computer print-out held by the Museum of Victoria.

3.3 Ecology of the polychaetes <u>Ceratonereis</u> <u>aequisetis</u> *and* <u>Australonereis</u> <u>ehlersi</u>

The ecology of two intertidal and subtidal polychaete species was studied offshore near Little River and the 145W outfall of the WTC along a 3-km stretch of coast between February 1976 and April 1977 (Dorsey, 1981). Three replicate core samples were taken monthly at each of 24 stations. Both *Ceratonereis aequisetis* (as *C. erythraeensis*) and *Australonereis ehlersi* were abundant but had different distributions. *Ceratonereis* occurred intertidally on muddy sands with very dense aggregations at the 145W outfall (mean densities up to 14 000 individuals m^{-2}) and in an area south-west of the Little River. *Australonereis* was collected only rarely at the outfall but was abundant in intertidal and subtidal areas on well-sorted, fine sand away from the outfall. Mean densities reached up to 3 000 individuals m^{-2} during periods of recruitment.

Both worms are selective deposit feeders. *Ceratonereis* ingested a wider range of grain sizes (medium sand to silt and clay) than *Australonereis* (mainly silt and clay). *Ceratonereis* also preyed or scavenged on dead or living animals. *Australonereis* consumed only fine sediments, probably as a tubicolous suspension feeder. Both species fed on micro-organisms (eg. bacteria, protozoans, diatoms and dinoflagellates) associated with mineral grains, detritus and organic mineral aggregates. Production by this microbiota was greater than at similar sand habitats in the Bay, therefore food was probably not a limiting resource for the worms. Both species are tubicolous, live about 1-1.5 years, grow rapidly, reproduce from spring to autumn and probably die after spawning. *Ceratonereis* broods its young in tubes and juveniles emerge after 4-6 weeks of incubation. *Australonereis* produces free swimming larvae.

3.4 Intertidal fauna adjacent to Werribee

The intertidal fauna at Werribee was described as an opportunistic assemblage by Dorsey (1982). He sampled five sites between the 145W outfall and the Lake Borrie outfall. Four replicates were taken at each site with a 16 cm long corer (area 0.008 m^2) and washed through a 0.5 mm sieve. Very dense infaunal assemblages dominated by polychaetes were discovered.

The most numerous polychaetes were *Capitella capitata, Boccardia proboscidea, B. chilensis, Ceratonereis aequisetis* and *Desdemona* sp. Corophioid amphipods and bivalve molluscs were also common. Amphipods were represented by species of *Paracorophium, Corophium* and *Podoceropsis*; most bivalves were *Kellia* sp. Greatest faunal desities of more than 300 000 individuals m^{-2} peaked in the summer at the outfalls and densities of 100 000 to 300 000 m^{-2} occurred between these sites. Deposit feeders, suspension feeders and deposit/suspension feeders accounted for 83% of species and 99.8% of individuals, mainly tubicolous polychaetes such as *B. proboscidea*. The tubicolous polychaetes and amphipods were more abundant at the outfalls than elsewhere.

Dorsey (1982) partitioned the intertidal fauna into feeding types and compared his results with those of Poore and Kudenov (1978a) from offshore. Although there were far fewer species located intertidally (28 vs 246), the ratios of feeding types were similar. Thus, the deposit and/or suspension feeders were dominant both intertidally and subtidally in the vicinity of the WTC discharges.

3.5 The ecology of Boccardia proboscidea

The ecology of *Boccardia proboscidea* - a species often occurring in areas of high organic inputs - was investigated at four WTC outfalls from January 1984 to March 1985 (Petch, 1989). *B. proboscidea* is unknown from other areas in Port Phillip Bay but does occur near the Boags Rocks outfall in Bass Strait. Four replicate samples were taken each month with a 30 cm long corer of 0.0043 m^2 area and washed through a 0.5-mm-mesh sieve. The sampling sites ranged in distance from 5 to 800 m from the nearest outfall and covered the known range of the species at that locality. Petch (1989) concluded that the worms fed on organic matter settling out of the effluent and on epibenthic microalgae (Axelrad *et al.*, 1981). Density fluctuations and reproductive effort were influenced by food availability and season. The worms produce both planktonic larvae (with wide dispersal ability) and brooded juveniles with very short planktonic lives (which settle very close to the parent). It is likely that *B. proboscidea* is an introduced species and has been transported to Port Phillip Bay by shipping.

3.6 The fauna of the Yarra River and Hobsons Bay

Several reports on the benthic communities of the Hobsons Bay region, notably Watson (1972, 1973) and others for the PMA by the same author, contain data on the communities in the region. Their objectives were generally quite restricted and did not allow very detailed descriptions of the benthos. In the most wide-ranging study observations were made by divers at 34 stations in Hobsons Bay (Watson, 1972). Numerous species from several taxa were listed and the dominance of the bivalves *Notospisula trigonella* and *Theora lubrica* noted. Watson (1973) reported negligible long-term effects on large infaunal and epifaunal species from the laying of a submarine pipeline across Hobsons Bay.

The first quantitative survey, incorporating both spatial and temporal variability, was reported by Poore and Kudenov (1978b). Samples were taken by grab sampler and treated in much the same way as in other surveys by these authors. A total of 248 species were recorded from this survey: 152 species were found in the Yarra River and muddy Hobsons Bay stations and 178 species at sandy Hobsons Bay stations. Approximately 41% were polychaetes, 33% crustaceans and 12% molluscs; the proportions are similar to those in other surveys in Port Phillip Bay (Poore *et al*., 1975; Poore and Kudenov, 1978a).

The fauna has a high degree of speciation within genera and families, as is typically found in Port Phillip Bay. For example, there were three species of the crab genus *Halicarcinus*, 15 species of phoxocephalid amphipods, and five species of *Polydora* and three of *Prionospio* from the polychaete family Spionidae. In most cases ecological separation of the species was observed.

The fauna contained some estuarine species, but even in the river several marine species from the central basin of Port Phillip Bay were represented. Estuarine species included: *Notospisula trigonella* (Bivalvia); *Capitella capitata*, *Lumbrineris* sp., *Malacoceros* sp., *Nephtys australiensis*, *Polydora* species, *Prionospio* species (Polychaeta); Oligochaeta; *Corophium* sp., *Gammaropsis* sp., *Limnoporeia* sp., *Tethygeneia* sp. (Amphipoda); *Halicarcinus australis*, *Philyra undecimspinosa* (Brachyura); *Styela clava* (Ascidiacea).

The muddy sediment faunas of the Yarra River and the central Port Phillip Bay basin are dominated by *T. lubrica* (Poore and Rainer, 1974). This is a deposit feeding tellinacean and is probably more successful in sediments rich in organic matter. Factors contributing to its high river densities may be increased food supply and reduced interspecific competition. Co-existing species which normally inhabit and central Port Phillip Bay basin (*Callianassa limosa*, *Nephtys inornata*, *Byblis mildura*, and *Phoronis pallida*) do not occur in the Yarra River.

Few collections of animals from this survey were kept and the only copy of the data is a computer print-out held by the Museum of Victoria.

3.7 Benthos of Geelong Arm and Corio Bay

The fauna of the Geelong Arm and Corio Bay were first described as part of large studies: the general bay-wide study of Poore *et al*. (1975) and as one of the seasonally sampled stations of Poore and Rainer (1979). At least one private consultants' report also deals superfically with the benthos of the region but provides little of value for the general Port Phillip Bay study.

A more specifically directed study was made by Coleman (unpublished manuscript) who investigated the possibility that known high concentrations of heavy metals and hydrocarbons in sediments in Corio Bay influenced benthic community structure. Benthos were sampled in 1987 from 60 stations in 12 strata using replicate 0.1 m^2 samples. A fauna of 172 species, almost the same number reported by Poore and Rainer (1979), was found: 45% polychaetes, 27% crustaceans and 17% molluscs. Few species were very common; *Theora lubrica* and *Tharyx* sp. were the only species represented by more than 10% of the total individuals. Densities of animals ranged from 175 to 420 individuals m^{-2}, much lower than recorded in previous studies in the same area. No explanation could be given for this. Concentrations of toxicants in the sediments were considered below levels demonstrated to be toxic in other systems and their effect in Corio Bay was not measurable. Data from this study are held by the Marine Science Laboratories (MSL) and await final analysis and reporting.

More recently (February 1992) 24 sites at six points along the Arm were sampled by Carey and Watson (1992). Several species of epibenthos were identified, typical of similar habitats in the rest of Port Phillip Bay. The seagrass *Halophila australis*, the alga *Caulerpa remotifolia*, sponges, the ascidians *Pyura stolonifera* and *Sycozoa pedunculata*, echinoderms *Stichopus mollis*, *Tosia australis* and *Patiriella brevispina*, bivalves *Pecten alba* and *Electroma georgiana* and the hydroid *Obelia australis* were observed. Notable was a large and abundant colonial polychaete tentatively identified as an introduced species, *Sabella spallanzanii*, which was most common in the outer harbour of Corio Bay. This species was not recorded prior to the early 1980s.

Polychaetes, crustaceans and molluscs dominated the infauna (samples sieved through 710 μm mesh) representing 44, 37 and 12% respectively of the total individuals and similar fractions of numbers of species. The dominant species recorded were much the same as in earlier studies but a remarkable absence from the list of most common was the decapod *Callianassa limosa* which had previously dominated the muddy environments of this region. An introduced infaunal bivalve, *Musculista senhousia*, was common at one site and was recorded in Victoria for the first time in this study. Differences in sampling method and sieve mesh size made interpretaton of further discrepancies between this and earlier studies impossible.

Data and collections are held by Marine Science and Ecology P/L.

3.8 Effects of scallop dredging on benthos

Parry and Currie (1992) have prepared an interim report on the effects of experimental scallop dredging on infaunal, epifaunal and fish community structure at three areas in the south of Port Phillip Bay. Data available now are inadequate to determine how seriously changes should be viewed. The proportions of major taxa have changed as a result of dredging but are difficult to detect and explain. Deaths of large crabs, *Leptomithrax gaimardii*, and of sabellid polychaetes, were observed by divers. This work is continuing and it is suspected that effects are rather subtle and might be explained only with an understanding of the natural history of some of the important species, e.g., *Callianassa* spp. which inflence the sedimentary bedform. Data are held by MSL.

4.0 Benthic processes

Specific knowledge of benthic processes, the interaction between nutrients and the benthic macrofauna, in Port Phillip Bay are negligible and must be inferred from the general literature. No laboratory or field experiments have been done. A review of the general literature is beyond the scope of this project.

In many of the descriptive studies described above biomass was measured and assigned to feeding classes. Assignments were on the basis of data from the literature rather than direct observations. The diets of some Port Phillip Bay fishes have been researched as part of fisheries programs by MSL scientists and by students. Many demersal fishes feed on benthic invertebrates and play an important role in the cycling of nutrients out of sediments (see for example the review for the Werribee region by Axelrad *et al*., 1981). But these data have not been reviewed because they are so slight and are being covered in other reviews.

No data on biomass or processes involving benthic invertebrates are stored electronically but MSL may have data on fish diets.

An assessment of current knowledge, most of which is rather speculative, is on two scales: Bay-wide processes and those occurring near the WTC.

4.1 Bay-wide nutrient processes

The fate of nutrients in the water mass, specifically the relative importance of pathways through phytoplankton, detritus and zooplankton, eventually leading to the sediments has never been investigated. Poore and Rainer (1974) used their data on the distribution and density of mollusc biomass to make some elementary calculations on rates of processes. These have never been tested. Suspension feeders form the largest mollusc feeding group with an estimated biomass of 3.93×10^{11} g wet weight Bay-wide. This is equivalent to 2.16×10^{10} g dry tissue weight. Applying a long-term filtering rate of 2 litres hr^{-1} g^{-1} dry tissue weight for all suspension feeders (based on figures in the literature), a clearance of 4.32×10^7 m^3 hr^{-1}, roughly equivalent to filtering the subtidal volume of Port Phillip Bay (2.51×10^{10} m^3) in just over 24 days, was estimated. The distribution of suspension feeder biomass accords with the importance of this group as a major pathway of energy transfer to the rest of the zoobenthos. High densities of suspension feeders were found in the Werribee and Yarra regions, while lowest densities were recorded from the region near the Heads. The relative importance of phytoplankton and suspended detritus as food for suspension feeders is difficult to determine. However, the extensive areas of sea-grass in the Bellarine region and drift algae in the Werribee region probably constitute an important source for the organic detritus present. There is considerable evidence in the literature that organic detritus derived from plant material cannot be utilized directly by the benthos but the high biomass of suspension feeders in both areas suggests that some of the associated microfauna and microflora is locally available.

The central basin of Port Phillip Bay is a sedimentary sink and it is possible that it may be a nutrient sink as well. However, pathways leading to it have not been explored.

4.2 Epibenthic microalgae at Werribee

Although not strictly within the scope of this review it is relevant to discuss the results of a small study of epibenthic microalgal productivity (Axelrad *et al.*, 1981). Biomass and productivity were determined for shallow-water (2 m) stations, one offshore of the Werribee sewage discharge and another (St Leonards) remote from significant nutrient discharge. Epibenthic microalgal productivity was determined by a C^{14} method in the laboratory for cores of sediment taken from the field. Biomass was determined by a fluorescence method. Salinity and nutrient concentrations of waters immediately overlying the sediments were also determined. Sampling was repeated at six-weekly intervals over one year (1977-1978).

Salinity did not differ between the two sampling sites but concentrations of nutrients, particularly of nitrogen, were much higher in water overlying sediments at Werribee than at St Leonards. Mean chlorophyll *a* concentration in the surface centimetre of sediment showed little seasonality but was significantly greater at Werribee than at St Leonards. Productivity was greatest in summer at both stations with that at Werribee being significantly greater than that at St Leonards all year. Annual productivity calculated by intergrating daily productivity values over the year was five times greater at Werribee than at St Leonards.

It is clear that the nutrient discharge from the WTC results in elevated epibenthic microalgal biomass and productivity, increasing each about five-fold relative to the control area. The value of 236 ± 19 g C m^{-2} yr^{-1} obtained for epibenthic microalgal productivity at Werribee was the highest reported at the time for shallow-water marine environments. These algae must therefore have an important impact on higher trophic levels of the food chain.

4.3 Productivity estimates of zoobenthos at Werribee

Biomass was measured for all the infaunal samples taken by Poore and Kudenov (1978a). Five feeding types: grazers, deposit feeders, filter feeders, predators, and scavengers, were recognised (Poore and Kudenov, 1976). Total biomass (ash-free dry weight) ranged from 2.6 to 300 g m^{-2} (mean = 44 g m^{-2}) but there was little correlation between biomass of individual feeding types and distance from the outfall. The fauna was dominated by suspension feeding bivalve molluscs (73%). Of these *Notospisula trigonella* was dominant inshore and *Katelysia rhytiphora* was dominant offshore.

Using production:biomass ratios from the literature trophic relationships were presented graphically as a notional food web. Although the biomass of suspension feeders was four times that of deposit feeders, the ratio of their productivities was more equal. These results are very preliminary and more sophisticated treatments of the data would be possible now.

The fate of nutrients via a predatory pathway was described by Dorsey (1981). The polychaete *Ceratonereis aequisetis* is a major prey item of the red-necked stint *Calidris ruficolllis*, sharp-tailed sandpiper *C. acuminata* and curlew sandpiper *C. ferruginea* which also feed on several amphipods abundant in the area. These waders may play a role in limiting worm population sizes in the intertidal areas. Both worm species are known to feed at the surface of the substratum and are taken in preference to other available species. This pathway was not quantified.

Although potential pathways for nutrients to and from the benthos were identified by these authors no actual measurements of rates were made. Such data as were collected are no longer available.

4.4 Nutrient pathways at Werribee

While the impact of the discharge from the WTC on plankton communities was small it appears that benthic communities were significantly modified. This is due in part to the fact that nutrients are discharged to an area of the Bay where water depth does not exceed 5 m within 5 km of shore. Epibenthic microalgal productivity and biomass were much higher here than in areas remote from the discharge (see 4.2 above). This high level of primary production enabled development of a rich zoobenthic community in the nearshore Werribee region which in turn provides for feeding by small fishes. The epibenthic microalgae to zoobenthos to predators is the major pathway for nutrients reaching the biota in the Werribee region but the fraction of nutrients handled in this way is not known. The process has not been sufficiently quantified to allow any estimate of the effects of changes in the rate of nutrient input.

It appears that the importance of this pathway (epiflora to sediment deposit feeders) was not appreciated during the earlier work of Poore and Kudenov (1976; see 4.3 above).

However, nutrients are only part of the explanation for differences between communities in this area and elswhere. The fauna at all trophic levels contains several estuarine species and it is probable that the freshwater discharge alone is responsible. Changes in the concentration of nutrients will have a probable effect on community structure comparable to that of changes in absolute rates of discharge.

5.0 Conclusions: Benthic monitoring

The descriptions of the benthic infauna of Port Phillip Bay made in the 1970s are very detailed, perhaps more detailed than those of any other similar marine ecosystem. These descriptions comprise bay-wide components and finer-scale studies in areas of special interest. The data collected and the level of documentation are well preserved and so provide a benchmark against which to measure change over the last 15-20 years and from which it may be possible to predict future changes. This is possible in few other ecosystems. The benchmark does have its drawbacks:

1. It is not a description of the Bay as it was before European settlement. For example, species introductions have been recorded and some species have become abundant: the bivalve *Theora lubrica*, now the most abundant macrobenthic animal in Port Phillip Bay; the polychaete *Boccardia proboscidea*, now dominating the fauna of the shallow water environment very close to the drains at Werribee; and the polychaete tentatively identified as *Sabella spallanzanii*, now carpeting Corio Bay.

2. Taxonomic knowledge has improved significantly over the last 20 years, notably of peracarid crustaceans and polychaetes. Databases need to be updated and some re-sorting of museum reference collections will be needed before comparative work is started.

3. The benchmark has only a small temporal component. Seasonal and year-to-year variance is considerable in many community statistics.

4. All studies are of macrobenthos (> 1 mm) and so miss smaller species and life stages which play important roles in nutrient processing.

Nevertheless, modern statistical techniques incorporating parametric and non-parametric methods with mapping now exist to analyse existing data and to design optimal comparative surveys.

The value of zoobenthic community structure as a means of monitoring change in Port Phillip Bay has been demonstrated, especially in the Werribee region and in Corio Bay. In the former, change resulting from the WTC has been demonstrated by comparison with other areas otherwise expected to be similar; in the latter case, descriptions of the communities over a period of 20 years has revealed change. Such is the nature and scale of these changes that an attempt to search for change on a large bay-wide scale is warranted.

Quinn and Keough (1991) have made recommendations on data reviews and mathematical methods which might be appropriate for future monitoring. I concur with their views.

6.0 Conclusions: Nutrient-related processes

Benthic communities are major processors of materials in all marine ecosystems and there is no reason to believe that Port Phillip Bay is any different. Few serious attempts have been made to identify the pathways by which nutrients from the WTC reach and leave benthic communities. It is not known, for example:

1. What are the main forms in which the nutrients reach the benthos? Options include particulate material, phytoplankton, zooplankton, zooplankton faeces, detritus from other sources; these are not exclusive.

2. Is the benthos a nutrient sink and, if so, where?

3. What size classes, taxa and feeding guilds are most important in all phases of the nutrient pathways?

The answers to these questions will vary spatially and temporally. For example, it is suspected that epifloral productivity is a major source of food for benthic animals close to the WTC but is unlikely elsewhere. It is possible that the large central basin of the Bay is a sink for nutrients as it is for sediments. It is recommended that process-related measurements be undertaken on appropriate spatial and temporal scales.

Quinn and Keough (1991) have suggested the sorts of laboratory and field experiments with benthic communities that would be appropriate to further understand nutrient processes in Port Phillip Bay.

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Synopsis of information on macrobenthic communities of Port Phillip Bay

Reference	Description	Data	Comment
Memoirs of the National Museum of Victoria 1966, 1971	Geology, geomorphology, taxonomy and general description of communities	Some collections and archives in MoV	Limited value for the Port Phillip BayES
MMBW and FWD, 1975 Poore et al., 1975	Data on the distribution and abundance of over 700 benthic species at 86 station bay-wide	ASCII files with MW and MoV	Essential description of the communities of the bay in 1969-1973; very little analysis
Poore and Rainer, 1974	Distribution of numbers and biomass of feeding types of molluscs bay-wide	ditto, except biomass data seems lost	Description of mollusc distribution
Poore, 1975	Description of new species of callianassid shrimps with distributions correlated with sediments	ditto	
Poore and Rainer, 1979	Analysis of trends in benthic community structure and numbers of abundant species at muddy environments over 3 years	computer print-out with MoV	only long-term study on muddy sediments
Brown and Davies, 1991	Summary description of draft internal MW report on benthic communities (20 sites sampled for 2 years) offshore from Werribee (as part of review of environmental quality of north-western Port Phillip Bay)	ASCII files with MW and MoV	good data but only partly analysed
Poore and Kudenov, 1976, 1978a Poore and Mobeley, 1980	Description of fauna within a 2-km radius of 145W drain at WTC	computer print-out with MoV	good data thoroughly analysed; with the MW survey provides a baseline against which to measure change
Dorsey, 1981	Ecology of two polychaete species near WTC	probably lost	
Dorsey, 1982	Description of intertidal fauna near WTC	probably lost	
Petch, 1989	Ecology of polychaete *Boccardia proboscidea*	probably lost	

Synopsis of information on macrobenthic communities of Port Phillip Bay (continued)

Reference	Description	Data	Comment
Watson, 1972, 1973	General descriptions of benthic communities in Hobsons Bay	with Marine Science and Ecology Ltd	of little value to PPBES
Poore and Kudenov, 1978b	Description of benthic fauna of Yarra River and Hobsons Bay	computer print-out with MoV	
Coleman, ms.	Description of the benthos of Corio Bay in 1987	files with MSL	one-off description
Parry and Currie, 1992	Work in progress on the effects of scallop dredging on infauna and epifauna in areas of southern Port Phillip Bay	files with MSL	
Carey and Watson, 1992	Description of benthos at 6 points in Geelong Arm	data with MSE	
Axelrad et al., 1981	General review of Werribee ecosystem: description of communities and indication of important processes	data probably lost	Good description of important components and nutrient pathways in the immediate region of WTC