ISSN 1039-3218

Water Column Trophodynamics in Port Phillip Bay

C. Crawford, G. Jenkins and G. Edgar
Victorian Institute of Marine Science
P.O. Box 138
Queenscliff, 3225. Australia

Technical Report No. 1

CSIRO Port Phillip Bay Environmental Study
21st Floor, 625 Little Collins Street
Melbourne, Victoria 3000.

August 1992

CONTENTS

EXECUTIVE SUMMARY

1) Studies over the past 20 years suggest that zooplankton abundances in Port Phillip Bay are quite low by world standards and are not indicative of significant nutrient enrichment. However, zooplankton abundance on a Bay-wide spatial scale has not been sampled since 1982.

2) Studies of water column trophic linkages have only been investigated for schyphomedusae, larval fish and cladocerans. Grazing/clearance rates have been estimated from field data for larval fish and schyphomedusae only. Larval fish and schyphomedusae were found to have minimal impact on zooplankton populations, however schyphomedusae may have a significant impact on abundances of fish eggs and larvae.

3) Laboratory experiments on grazing by the dominant calanoid copepod in Port Phillip Bay suggested a clearance time for the volume of the Bay of 25 d, similar to a literature derived estimate of 24 d for suspension feeding bivalves in the Bay. The estimate for the copepod was, however, probably conservative considering the small size of the phytoplankton cells used in the experiment. Estimates of clearance rates by clupeoid fish based on fishery catches and literature information suggests that copepod production may be rapidly consumed by this group.

4) The only field study of the impact of toxicants on zooplankton showed no trends in the spatial distribution of zooplankton communities which could be attributed to pollution sources. One laboratory study has been conducted on the acute toxicity of copper, cadmium and zinc to two species of calanoid copepod occurring in Port Phillip Bay.

5) Studies on zoobenthos have related mainly to distribution and abundance and, apart from an overall estimate of filtration rate by the suspension feeding molluscs extrapolated from literature values, no direct studies have been conducted on trophodynamics at the sediment-water interface. Similarly, although much information is available on residues of toxicants in benthic fauna of Port Phillip Bay, no direct research has been conducted on the trophic pathways leading to this accumulation.

6) A synthesis of trophodynamics of Port Phillip Bay utilising information from eutrophic areas overseas suggests that an increased input of nutrients to the Bay may lead to larger phytoplankton blooms when production is released from limitation by factors such as temperature and light. Blooms are likely to outstrip grazing, particularly if 'weed' phytoplankton species - which are poorly grazed - dominate. Significant areas of anoxia due to senescence and sinking of phytoplankton may also be expected. An increased role for the 'microbial loop' may result.

7) It is likely that suspension feeding benthic animals are siginificant grazers of plankton in Port Phillip Bay. Effects of increased nutrient input on trophodynamics in terms of the sediment-water column interface would be difficult to predict. However, it is envisaged that shading resulting from phytoplankton blooms and anoxia at the end of blooms would be detrimental to benthic communities.

8) Specific recommendations for future work on water column trophodynamics in relation to nutrients and toxicants are provided.

TERMS OF REFERENCE

To review the literature on water column trophodynamics of smaller, non-commercial organisms in Port Phillip Bay, particularly in relation to nutrients and toxicants. This may also include interaction with benthic fauna and processes at the sediment-water interface. Although specific information on commercial fish and shellfish, phytoplankton, seagrasses, and benthic algae is reviewed separately, some information on phytoplankton blooms and toxicants in benthic suspension feeders is included as a result of their close relationship with water column trophodynamics.

The general objectives for the review are:

1. To document the state of present knowledge of water column trophodynamics in Port Phillip Bay in relation to the objectives for the Project (as provided in the Project Summary), including the identification of extant databases and maps.

2. To identify, and where possible quantify, key physical, chemical or biological processes controlling the natural interactions of water column trophodynamics with nutrients and toxicants.

3. To identify the key processes and level of knowledge needed to predict the impact of a 50% increase in nutrients and/or toxicants on water column trophodynamics in Port Phillip Bay.

1.0 Current Knowledge on Water Column Trophodynamics

There is limited information available on food web interactions in the water column of Port Phillip Bay. Most research on water column trophodynamics in the Bay has been university based with much of the work carried out by postgraduate students; no major projects on water column trophodynamics have been conducted by other agencies. In addition, no studies were found specifically on the effects of nutrients or toxicants on the trophodynamics of Port Phillip Bay. To our knowledge there are no current studies of water column trophodynamics in Port Phillip Bay.

The vast majority of the information on water column fauna and flora consists of species composition and distribution, with only limited data or hypotheses on feeding and predator/prey relationships. Previous studies that provide relevant information are summarised below.

1.1 Zooplankton

The Phase One of the Environmental Study of Port Phillip Bay (1968-71) report provides results of preliminary studies of biological characteristics of the Bay (MMBW & FWD, 1973). Data were obtained on the species composition, abundance and distribution, and the standing crops of phytoplankton and zooplankton in the Bay. However, interpretation of the zoological data is restricted because of problems in the sampling strategy - in particular that three different sizes of mesh, ranging from 159 to 262 microns, were used to catch the plankton. Nevertheless the data indicate a strong correlation between phytoplankton and zooplankton abundances.

A mean total crustacean standing crop in the Bay of 3,700 individuals m^{-3} was calculated for 1969-70 (MMBW & FWD, 1973). This estimate is within the range of values generally encountered in other coastal waters, but is considerably less than those recorded from estuaries overseas. The chlorophyll *a* concentrations - used as an index of phytoplankton biomass - were also low by comparison with many estuaries and they correspond more closely with values obtained from oceanic waters around Australia. This suggests that zooplankton biomass is being limited by the availability of phytoplankton food. A winter peak in phytoplankton biomass followed the peak period of nutrient input into the Bay and preceded a zooplankton maximum. Maximum crustacean standing crops were recorded in late winter and early spring. There were four main groups of crustaceans present in the Bay - Copepoda (82%), Cladocera (13%), Malacostraca (5%), and Cirripedia (0.4%).

Arnott (1974) described the methods and results of the above zooplankton study in PPB in greater detail. He also included an examination of affinities between species and the establishment of four recurrent groups as a means to simplify characterization of environments and the detection of environmental changes. A discussion on the adaptive significance of diurnal vertical migration was also included.

Kimmerer and McKinnon (1985) provided further information on species composition, distribution and abundances of zooplankton in the Bay. They sampled the plankton using a 200 micron mesh net during a 13 month period in 1982/83 - a period which included 9 months of drought conditions. Kimmerer and McKinnon (1985) obtained similar results to MMBW & FWD (1973) and Arnott (1974) in that they observed low chlorophll values and zooplankton abundance relative to other temperate bays. They agreed with MMBW & FWD (1973) that the relatively low trophic status of Port Phillip Bay waters indicates a relatively low nutrient input per unit area.

Comparisons of the zooplankton of Port Phillip Bay with the adjacent marine embayment, Western Port, by Arnott (1974) and Kimmerer and McKinnon (1985) have shown that many of the species common in each bay are excluded or reduced in abundance in the other bay. In particular, both studies reported that Cladocera were absent from Western Port but abundant in Port Phillip Bay, and the copepod *Paracalanus indicus* - dominant in PPB - was greatly reduced in abundance in Western Port. Arnott (1974) and Kimmerer and McKinnon (1985) suggested that lower levels of turbidity and suspended detritus present in Port Phillip Bay may contribute to the differences between the bays because the detritus could be an important source of food for zooplankton in Western Port. Kimmerer and McKinnon (1985) also discussed other possible mechanisms causing the differences in zooplankton communities between the two bays and suggested that predator abundance may be an important contributory factor. They observed that Cladocera and *P. indicus* were more visible and slower swimming than *Acartia tranteri* - the most abundant species in Western Port - and suggested that fish predation may have a greater effect on the former species than the latter.

Later experiments (Kimmerer and McKinnon, 1989) showed that *P. indicus* could eat food of a smaller size and at a faster rate than *A. tranteri*. When fed labelled *Tetraselmis chui* in Western Port water, *P. indicus* had a clearance rate of ca. 10 ml copepod^{-1}d^{-1} compared with ca. 2 ml copepod^{-1}d^{-1} for *A. tranteri*. Analysis of plankton samples also revealed that phytoplankton in Western Port were generally smaller in size than those in Port Phillip Bay. Relatively large diatoms or dinoflagellates were always found in Port

Phillip Bay, whereas the numerically dominant species in Western Port were small flagellates and cryptomonads - mostly smaller than 5mm. Neither species of copepod had significant difficulty in collecting food from detrital-laden water from Western Port, and Kimmerer and McKinnon concluded that feeding patterns were not important in determining the distributions of the two species. Other experiments showed that predation by small, common planktivorous fishes was selective, with *P. indicus* being preyed upon about twice as much as *A. tranteri.* This was attributed to *P. indicus* being more visible and having a slower escape response than *A. tranteri*. Kimmerer and McKinnon (1989) suggested that visual predation in temperate marine bays and estuaries is more important in shallow than in deeper waters, resulting in the exclusion of species vulnerable to visual predators. This would apply regardless of the nutritive status of the water because the mechanism is more related to mean depth than any other feature of the bays.

Kimmerer and McKinnon (1985) observed that many of the zooplankton species in Port Phillip Bay showed seasonal patterns of abundance, with most occurring in highest numbers during summer. *A. tranteri* was most abundant in Port Phillip Bay in late winter-spring, the cladoceran *Evadne nordmanni* was common in winter and succeeded in summer by *Evadne tergestina* and *Podon polyphemoides*. The copepods *Gladioferens inermis* and *Tortanus barbatus* were also most abundant in summer, while *P. indicus* and *Oikopleura dioica* were common throughout the year.

Fancett (1988a,b) also investigated the species composition and abundance of zooplankton in Port Phillip Bay. He studied two size classes of zooplankton - the microplankton (>50 mm) and mesoplankton (>150 mm) - at weekly intervals from December 1985 to December 1986 as part of his study on the feeding of scyphomedusae. The microzooplankton had a mean total abundance of 207,000 m^{-3} and was dominated by several main groups including tintinnids (39%), copepod nauplii (26%), bivalve larvae (16%) and rotifers (9%). There was no apparent seasonal influence on the abundance of microzooplankton. The mesozooplankton had a mean total abundance of 4,376 m^{-3} and was dominated by copepodids and adult copepods (58%), larvaceans (18%), bivalve larvae (9%) and cladocerans (5%). The mesozooplankton exhibited marked seasonality in abundance with many species having highest abundances over summer and lowest abundances during winter. Although the composition of the mesoplankton was similar to that found previously by Arnott (1974) and Kimmerer and McKinnon (1985), the mean abundance of mesozooplankton was higher, possibly because of the smaller mesh size net used or because of the higher level of primary production that was encountered. The mean abundance of the microzooplankton was low compared with other neritic waters, reflecting the low chlorophyll levels in the Bay.

The zooplankton community in areas of different water quality in Corio Bay was investigated quantitatively over 4 days in 1979 by Arnott *et al.* (unpublished manuscript). Four 1 km^2 areas were sampled, three in Corio Bay and a control in the Geelong Outer Harbour. Plankton were collected using a 200 mm mesh net and data for 12 environmental variables were recorded. The results indicated that the zooplankton communities of Corio Bay were not adversely affected by the water quality. Densities of zooplankton in Corio Bay were considerably higher than in the less polluted Geelong Outer Harbour, while species richness was similar in both regions. Densities in Corio Bay were also high compared with seasonal data reported by Arnott (1974). Because the direction of zooplankton density gradients within Corio Bay were inconsistent, and also because variations in community composition between areas were relatively small, it was evident that none of the areas investigated in the Bay were more unfavourable to zooplankton than any other.

Classification of data from Arnott *et al.* (unpublished manuscipt) revealed three station groups which reflected differences in density and relative abundance of widely distributed taxa rather than characteristic species. The Geelong Outer Harbour area was characterised by *A. tranteri* copepodids and adults and *G. inermis* adults. The southern Corio Bay representatives included the three cladocerans *P. polyphemoides*, *Podon intermedius* and *E. nordmanni,* copepods *P. indicus* and *Oithona brevicornis,* hydromedusae, and gastropod, echinoderm and ascidian larvae. The middle and northern Corio Bay areas were characterised by *Kelleria corioensis*, *G. inermis* copepodids, decapod larvae, scyphozoan medusae and fish eggs. Analysis of the data indicated the presence of an east-west environmental gradient between the Harbour and Bay, and a weaker north-south gradient within Corio Bay. The main spatial trends displayed by the environmental variables were therefore similar to those evident for the zooplankton. These results, however, were obtained over a very short sampling period and may not be representative of the zooplankton community structure over longer time scales.

Aspects of the feeding of scyphomedusae on icthyoplankton and other zooplankton in Port Phillip Bay were investigated by Fancett (1988a,b) and Fancett and Jenkins (1988). The percentage composition of the gut contents for the two most common scyphomedusae found in the Port Phillip Bay was: for *Pseudorhiza haeckeli* - fish eggs (41%), copepods (33%), larvaceans (8%), cladocerans (4%), crab zoea (4%) and decapod larvae(1%); and for *Cyanea capillata* - larvaceans (31%), cladocerans (29%), fish eggs (14%), copepods (11%), hydromedusae (9%), and ascidian tadpoles (3%). Scyphomedusae showed strong positive selection for fish eggs and yolk-sac larvae, and negative selection for other prey items including post yolk-sac fish larvae. Fancett (1988b) considered that positive selection for fish eggs and yolk-sac larvae may have related to the limited escape response of the prey, especially as few post yolk-sac larvae were eaten. Fancett and Jenkins (1988) found in laboratory experiments that the clearance rates of prey by *P. haeckeli* and *C. capillata* were independent of prey density and light conditions. However, *P. haeckeli* varied its clearance rate according to the prey offered whereas *C. capillata* showed no such variability. They combined information on clearance rates with the field studies of abundance and size distribution of scyphomedusae to determine the percentage of water cleared of fish eggs and yolk-sac larvae and copepods. They concluded that predation by scyphomedusae was not a major factor affecting zooplankton abundances in Port Phillip Bay with less than 0.4% of the Bays' total population of copepods and fish eggs consumed per day. However, localised impacts of predation by scyphomedusae was much greater with a maximum clearance of 1.6% of copepods and 2.4% of fish eggs and larvae per day by *C. capillata*, and 4.8% of copepods and 3.8% of fish eggs per day for *P. haeckeli.* Fancett and Jenkins (1988) calculated that this corresponded to *C. capillata* removing up to 19.6% and *P. haeckeli* up to 17.6% of fish eggs and larvae over their period of development. Thus scyphomedusae predation may be a significant source of mortality for fish eggs and yolk-sac larvae in localised areas. Fancett (1988a) speculated that mortality of copepods, particularly *A. tranteri*, is largely the result of filter feeding anchovies and pilchards in the Bay. Copepod mortality rates were highest during summer when populations of juvenile anchovies and pilchards were greatest.

The distribution and abundance of zooplankton in relation to environmental variables in Swan Bay was studied by Swadling (1984). She found that the taxonomic assemblage was more similar to that of Western Port than that of Port Phillip Bay. She suggested that the presence of eelgrass in Swan Bay and Western Port had a strong, although indirect, influence on the zooplankton assemblage.

As was noted above, marine cladocerans are an important component of the zooplankton in Port Phillip Bay but not in Western Port. Jagger (1985) studied the food of the cladoceran *P. intermedius* in Port Phillip Bay from feeding experiments and examination of faecal pellets using SEM. Jagger found that the most common food item identified in faecal pellets were large diatoms, mainly *Rhizosolenia* sp. This genus was also the dominant diatom in the environment at the time of sampling. Phytoplankton of various sizes were fed to *P. intermedius* but significant feeding only occurred on diatoms of the size of *Rhizosolenia*. Jagger *et al.* (1988) concluded that marine cladocerans are probably not resident in Western Port because the particle suspension consists mainly of detrital remains of seagrasses and small phytoplankton. Diatoms large enough to be ingested efficiently by *P. intermedius* make up only a small proportion of the total chlorophyll; thus suitable feeding conditions for *P. intermedius* may not occur there.

Information on the composition and distribution of ichthyoplankton in Port Phillip Bay has been provided by Jenkins (1986). His winter samplings showed multi-species patchiness of fish larvae and a positive correlation between larval abundances and volume of net zooplankton. Further studies (Jenkins, 1988) on the distribution of microplankton collected concurrently with larval flounders in the Werribee region of Port Phillip Bay showed some evidence of fine-scale patchiness of important prey for larval flounder, however observed abundances of microplankton were well below levels often thought necessary for significant survival of larval fish. Bivalve veligers were the most abundant component of the microzooplankton on all sampling dates, tintinnids were relatively abundant on two sampling occasions, copepod nauplii were common on only the last sampling and invertebrate eggs were very patchy in their distribution. Diatoms were significantly more abundant on all occasions than dinoflagellates.

A comparison of the diets, prey selection and predatory impact of co-occurring larvae of two flounders species, *Rhombosolea tapirina* and *Ammotretis rostratus*, in Port Phillip Bay showed that bivalve veligers, the most abundant zooplankter in the environment, were the dominant prey of small larvae of both species (Jenkins, 1987). When large larvae of both species were collected together the cladoceran *E. nordmanni* was the dominant prey of *R. tapirina* whilst paracalanid copepodids were the dominant food of *A. rostratus*. Comparisons of diets of flounder larvae with abundances of microplankton in the environment revealed strong selection for prey type as well as prey size. Jenkins (1987) estimated that flexion-stage *R. tapirina* would consume approximately 76 prey d^{-1} and concluded that, at the levels of larval fish and prey abundances observed, the flounder larvae in Port Phillip Bay would have negligible impact on prey populations.

McKinnon (1988) and McKinnon *et al.* (1992) studied length-frequency distributions and electrophoretic differences in a group of calanoid copepods (previously attributed to *A. tranteri)* in Port Phillip Bay and Western Port. Three morphs were found and described; small, [*Acartia* sp. (S)], medium, [*Acartia fancetti*], and large, [*Acartia* sp. (L)]. *A. fancetti* and *Acartia* sp. (S) were present in Port Phillip Bay. McKinnon *et al.* (1992) suggested that the larger size of *A. fancetti* in Port Phillip Bay compared with Western Port was probably due to differences in temperature and food.

1.2 Sediment - Water Interface

The macrobenthos of PPB has been well documented by Poore and co-authors over the last twenty years (Poore and Kudenov, 1976, 1977a,b; 1978a,b; Poore and Rainer, 1974, 1976, 1979; Poore *et al*., 1975). As Poore is concurrently writing a literature review on Port Phillip Bay benthos his data will not be extensively repeated in this review - only information of relevance to water column trophodynamics will be discussed.

The distribution and abundances of zoobenthos in Port Phillip Bay was studied as part of the Environmental Study of Port Phillip Bay, Phase One (MMBW & FWD, 1973). Poore and Rainer (1974) used this information in conjunction with other work to investigate the abundance, distribution of feeding types and patterns of diversity of molluscan fauna of the Bay, and to relate these to environmental variables such as depth and sediment type.

Six feeding types were distinguished among the 105 species collected. Infaunal suspension feeders dominated in marginal sandy substrates while surface deposit feeders dominated in the silt and clay sediments of the Central region and Corio Bay. Epifaunal suspension feeders, grazers, scavengers and predators were less abundant and were seldom dominant. Numbers of individuals and species, and diversity varied widely but were generally higher in marginal areas. Four areas of the Bay were recognised on the basis of faunal similarities and the distribution of species numbers, diversity and dominant feeding type: the Nepean sand banks, the deep water Central and Corio regions, marginal areas and the shallow seagrass sand flats.

Biomass values also varied substantially, but in general were highest in regions containing a substantial amount of seagrass and in areas close to major inputs to the Bay. Suspension feeders had the greatest biomass of any feeding type and their highest mean biomass was recorded in the Werribee region, followed by the Bellarine region and the Yarra region. Overall, suspension feeders constituted 89% of the total mollusc biomass, followed by deposit feeders (8.6%), carnivores and scavengers (1.3%) and grazers (1%).

The distribution of molluscs within Port Phillip Bay was related primarily to substrate and food supply characteristics, while purely hydrological effects were limited to nearshore areas. Substrate limitations were apparant for herbivorous species and some sessile bivalves requiring a hard substrate. Poore and Rainer (1974) estimated that Port Phillip Bay suspension feeders - the largest mollusc feeding group - had a collective wet weight of 3.93×10^{11}g which was equivalent to 2.16×10^{10}g dry tissue weight. Using data from the literature they applied an estimate of 2 litres $hr^{-1}g^{-1}$ for the average filtering rate of all suspension feeders to get a clearance rate of $4.32 \times 10^7 m^3 hr^{-1}$. This rate is roughly equivalent to filtering the subtidal volume of the Bay in just over 24 days. Poore and Rainer (1974) therefore concluded that the suspension feeders as a group are a major pathway for energy transfer to the rest of the zoobenthos, and this is reflected in the high densities of suspension feeders in the Werribee and Yarra regions.

1.3 Sewage Effluent

A number of studies have been conducted on the effects of effluent from the Werribee Treatment Complex (WTC) on the biota of the region. The WTC discharges secondary treated sewage effluent into Port Phillip Bay *via* five main drains.

A preliminary investigation of fish communities in the WTC outfall region was conducted by Brown and Negilski (1976). Their results were collected over a short period of time and without replication and so can only be considered as providing general information. They observed that the inshore area was utilized primarily by juvenile fish, particularly flounders (*Rhombosolea tapirina* and *Ammotretis rostratus*) and yellow-eye mullet (*Aldrichetta forsteri*), and was therefore an important nursery area. These three abundant inshore fish species fed almost exclusively on benthic invertebrates, especially amphipods, isopods and to a lesser extent polychaetes. These invertebrate groups are known to be very abundant in the region and Brown and Negilski (1976) thought the fish were probably opportunistic feeders showing no marked degree of preferential prey selectivity. Two deeper-water fish species whose gut contents were analysed showed significant resource partitioning with the sand flathead (*Platcephalus bassensis*) consuming a number of benthic crustacean groups in addition to polychaetes, bivalves, gastropods, and occasionally fish. The diet of the bluespot flathead (*Platycephalus caeruleopunctatus*) was primarily clupeiform fish (anchovies, *Engraulis australis*). Brown and Negilski (1976) found some evidence of effluents from the WTC affecting the fish community *via* behavioural and metabolic responses.

Poore and Kudenov (1977b) surveyed the distribution and abundance of macrofauna in the area around one of the main effluent drains from the WTC. Studies of the demersal fish fauna, sediment microbiology and planktonic primary productivity were also conducted. They found a high species richness in the fauna and that the fauna contained several euryhaline and opportunistic species. Estimates of biomass and production revealed that the biomass of suspension feeders was four times greater than that of deposit feeders, with production in both groups being equal. Bivalves were the most common suspension feeders and polychaetes the most common deposit feeders. Suspended particulate matter was considered essential for the maintenance of both suspension and deposit feeders. The community P:B ratio was estimated to be 2, which was considered to be indicative of a "healthy" temperate community. However, the overall P:B ratio was expected to be higher because the intertidal zone was not sampled.

The distribution of benthos around the drain outlet was patchy, but one station was clearly influenced by the outfall as it contained higher numbers of individual animals and a high proportion of scavengers and deposit feeders. These factors were significantly correlated with the high organic fraction, bacteria, and high interstitial concentrations of phosphorous, nitrites and ammonia. They concluded that the nearshore benthos of sandy sediments was modified by the discharge from the drain in a rather patchy fashion extending about 300m out from the drain.

Poore and Kudenov (1977b) considered the drains' disharge was likely to affect the macrofauna community structure - either directly or indirectly - by increasing dissolved nutrients, particulate organic matter and freshwater. Dissolved nutrients indirectly affect the benthos by stimulating primary production of phytoplankton and benthic diatoms which are exploited by deposit and suspension feeders. Particulate matter buffers the ecosystem against energy fluctuations derived from primary production. Freshwater directly influences the distribution and species composition of the macrobenthos by favouring euryhaline species.

The effect of treated sewage discharge from the WTC on the biota of Port Phillip Bay was examined by a team of scientists, each investigating different components of the ecosystem (Axelrad *et al.*, 1981). The WTC contributes more than half of the total nitrogen and phosphorous input to the Bay. Species composition, biomass and productivity at sites near the sewage farm were compared with those at control sites remote from the farm.

The results showed that the effects of the sewage effluent on the biota differed between the different trophic levels of the ecosystem. Rates of bacterial nitrification and denitrification were greatest in sediments closest to the sewage discharge point. Up to 15% of the inorganic nitrogen discharge may be lost *via* sequential nitrification-denitrification in a 4 km^2 area adjacent to the outfalls. Epibenthic microalgal biomass and productivity were found to be five times greater at Werribee than at a control station. These algae may have an important inpact on higher trophic levels of the food chain. The Werribee macrophyte community showed many of the features of similar communities in nutrient-rich environments. There was reduced species diversity, dominance of fast growing opportunistic species, loss of large, brown algal species and occurrence of occasional algal blooms as compared with communities in nutrient-poor areas of the Bay. Phytoplankton productivity decreased with increasing distance from sewage outfalls only during summer. Nitrogen was thought to be the nutrient critical to phytoplankton biomass production in the Bay, but light and/or temperature may limit productivity over much of the non-summer period. Bay-wide phytoplankton productivity was similar to that of non-eutrophic coastal marine waters.

A specific study of zooplankton was not undertaken; instead data was taken from the previous major environmental study of the Bay (MMWD & FWD, 1973) as described above. The low mean standing crop of zooplankton compared with other coastal marine systems indicates that Port Phillip Bay is not a highly eutrophic environment. Zooplankton densities in the high nutrient concentration waters of the Werribee zone were highly variable but were usually lower than elsewhere in the Bay. Crustacean species found at Werribee were also distributed throughout the Bay. The macrobenthos community was modified in a patchy manner near the sewage outfall, but the Werribee offshore macrofauna was typical of that occurring along the whole north-western coast of the Bay. During summer fish biomass at Werribee was equivalent to that found at stations remote from sewage outfalls although community composition differed. The nearshore fish community at Werribee was dominated by juveniles and small species, while older and larger fish were more abundant offshore.

Axelrad *et al.*, (1981) concluded that the sewage discharge affected benthic communities more than planktonic ones. They attributed this, at least in part, to the fact that the treated sewage was discharged to an area of the Bay where water depth did not exceed 5 m within 1 km of shore. Even so, the measurable impact of the discharge was limited to a few hundred meters around the outfalls. They also considered that nutrient discharge was only part of the explanation for the differences between animal communities at Werribee and those at nutrient-poor areas of the Bay. The planktonic, benthic and fish faunal communities in the Werribee area all contained several estuarine representatives, indicating that freshwater discharge alone may have caused some of the changes in the biota of the Werribee region.

The population and reproductive biology of the spionid polychaete *Boccardia proboscidea* in soft sediment sites along the foreshore of the WTC and on a rock platform at Gunnamatta Beach was studied by Petch (1989). All sites were situated near major discharges of secondarily-treated sewage effluent. Petch (1989) found that the distribution of *B. proboscidea* was essentially restricted to areas subjected to high organic input. This restricted distribution appeared to be because *B. proboscidea* was food limited. This species was dominant in areas close to sewage outfalls because of its tubiculous habit, a plastic life-history pattern and a unique larval biology, and because it did not suffer competition from more sensitive species. It was also found that size of the population of *B. proboscidea* surrounding an effluent outfall appeared to be related to the degree of organic pollution of the environment. Because large aggregations of *B. proboscidea* only occur in organically-polluted localities, Petch (1989) concluded that this species has a definite role as an indicator of organic pollution.

The ecology of the nereid polychaetes *Ceratonereis erythraeensis* and *Australonereis ehlersi* along intertidal and shallow subtidal sandflats offshore from the WTC was studied by Dorsey (1981). Both species were selective, surface deposit feeders feeding on micro-organisms such as bacteria, protozoans, diatoms and dinoflagellates associated with mineral grains, detritus and organic mineral aggregates. Food was thought not to be a limiting resource because of the high production of benthos in the region. *C. erythraeensis* appeared to be tolerant of stressful conditions as dense populations were found in areas continuously exposed to sewage effluents. *A. ehlersi*, however, was not found at the sewage drain and was found in mid-intertidal to subtidal depths.

1.4 Algal Blooms

An algal bloom of the diatom *Rhizosolenia chunii* is thought to have had toxic effects on shellfish in Port Phillip Bay in 1987 (Parry *et al*., 1989). Coincident with this bloom, mussels, flat oysters and scallops in the Bay developed a bitter taste that was so unpleasant and persistent that mussels became unmarketable for 7 months. High shellfish mortality 3-8 months after the bloom is thought to have been associated with the bloom.

The first bloom in Port Phillip Bay of algae toxic to humans was recorded in January 1988 when high concentrations of *Alexandrium catenella* were observed. Other species of toxic dinoflagellates have also been recorded in the Bay including *Dinophysis acuminata* and *Gymnodinium* cf. *nagasakiense*, and the toxic diatom *Nitzschia pungens* (Arnott, 1990a). These species can produce extremely potent toxins in some localities, although the reasons why the algae are toxic in some areas and not others are not generally known. Filter-feeding shellfish (e.g. mussels, scallops and oysters) feed on the algae and accumulate the toxins. These toxins do no apparent harm to shellfish, but consumption of contaminated shellfish by humans can result in various forms of shellfish poisoning, including paralytic shellfish poisoning (PSP), diarrhetic shellfish poisoning (DSP), and amnesic shellfish poisoning (ASP) In extreme cases such poisoning can cause death.

In 1988 *Alexandrium catenella* was concentrated in Hobsons Bay and nearby localities for about 10 weeks. Mussels from the infected area contained up to six times the permissible concentration of toxin, but toxins were not detected in scallops or whole tissue of two types of planktivorous fish - anchovies and pilchards (Arnott, 1990a). No cases of human poisoning by toxic algae have been diagnosed in Victoria. However, resting cysts of *A. catenella* have been found in the bottom sediments of northern Port Phillip Bay, and as *A. catenella* re-appeared in the Bay during the summers of 1988-89 and 1989-90, the potential for future toxic blooms remains high (Arnott, 1990a). In late 1991 a bloom of another potentially toxic diatom, *Nitzcchia pseudodelicatissima*, was recorded in the Bay. This species has produced domoic acid, resulting in ASP overseas, but testing of shellfish and planktivorous fish from Port Phillip Bay detected no domoic acid (Arnott, pers. comm.).

The Victorian Government Fisheries Division established a Victorian Shellfish Sanitation Program in 1987 to monitor levels of pathogens and harmful contaminants, including marine biotoxins, in shellfish. This program was designed to ensure that all shellfish from commercial aquaculture farms met the health standards of the USA Food and Drug Authority and thereby be certified safe for human consumption (Arnott, 1990b). In 1990-91 the comprehensive marine biotoxin surveillance project included frequent phytoplankton monitoring, routine mouse bioassay to determine toxin concentrations in mussels, and an early-warning information network. Fifteen stations were sampled every 2 weeks - with weekly sampling in summer if required - and each sample was quickly scanned for the presence of toxic algal species (Arnott, 1990a). This biotoxin surveillance program will have to be maintained for as long as the Government wishes to participate in the US-accredited shellfish sanitation program.

1.5 Toxicants

A few studies have been conducted on the concentrations of heavy metals in edible flesh from shellfish and finfish. Most of this work has been conducted from a human health point of view to determine whether levels of metals in fish flesh are below statutory levels set by the Health Commission of Victoria. Such studies relate to water column trophodynamics through the accumulation of heavy metals in the prey and predators of water column biota.

Fabris (1991) summarised the data available on contamination of shellfish in Port Phillip Bay by heavy metals (cadmium, copper, nickel, lead, zinc, arsenic, mercury, tributyltin), petroleum hydrocarbons, pesticides and polychlorinated biphenyls. He concluded that the data indicate that shellfish from the Bay are contaminated by many classes of chemicals with the extent of contamination depending on the locality. He compared recent data with data collected in the 1970s and noticed that in some areas of the Bay (e.g. Corio Bay) concentrations of some contaminants (e.g. cadmium and polychlorinated biphenyls) in shellfish had decreased, while concentrations of other contaminants such as petroleum hydrocarbons had remained unchanged. Concentrations of most of the contaminants are highest in shellfish from Corio and Hobsons Bays but, with the notable exception of cadmium and lead in shellfish from the Rippleside area of Corio Bay, the concentrations are now below the maximum concentrations permitted by Victorian health regulations.

Fabris (1991) concluded that there are major deficiencies in our knowledge of the status of contaminants in Port Phillip Bay. The majority of data for contaminants other than heavy metals are available from mussels only. Most of the data for metals and organic contaminants from molluscs are more than a decade old and much of the recent data is limited because it is species and site specific. There is less information available on current levels of organic and inorganic contaminants in shellfish from the Bay than there was a decade ago. Fabris (1991) recommended that monitoring programs using bio-indicator organisms, and including testing for organometallic compounds of tin, arsenic, polychlorinated biphenyls and chlorinated phenolic compounds, should be re-introduced.

The concentrations of mercury found in edible tissues of marine animals from Port Phillip Bay and other areas in south-eastern Australia were reported by Walker (1988). Five of the eleven species that he tested from PPB had mean concentrations of 0.39-0.63 $\mu g\ g^{-1}$; in the remaining six species they were 0.04-0.27 $\mu g\ g^{-1}$. Thus five species - snapper, ling, long-nose flathead, hammerhead shark and seven-gilled shark - had mercury levels close to or above the statutory limit of 0.5 $\mu g\ g^{-1}$ wet weight set by the Victorian Health Commission. Walker (1988) suggested that mercury in the diet accounts for a substantial amount of the mercury present in the fish. Thus the higher a species is in the food chain, and the more fish it consumes, the higher the mercury content in the flesh is likely to be.

Analysis of the mercury and cadmium concentrations of the commercial scallop, *Pecten fumatus*, showed that the results obtained were greatly affected by the type of tissue analysed, the locality and, to a lesser extent, the length of the scallops (Walker *et al*., 1982). The concentrations of mercury in three types of scallop tissue were well below the statutory limit. Concentrations of cadmium in edible tissues (adductor muscle and gonad) were below the Victorian statutory limit of 0.2 parts per million (ppm) (2.0 $\mu g\ g^{-1}$) wet weight, but inedible tissues (viscera) contained cadmium concentrations well above the limit (Walker *et al*., 1982). Mercury concentrations in blacklip abalone, *Notohaliotis* *ruber*, and blue mussel, *Mytilus edulis planulatus,* were also below the limit (Walker, 1982). Because mercury is the most toxic heavy metal for certain species of benthic algae and phytoplankton, mercury contamination has the potential to affect the food chain of Port Phillip Bay (Hall and MacDonald, 1986).

A study of cadmium levels in Port Phillip Bay mussels by Talbot *et al.* (1976) showed that mussels from 15 of 22 locations were heavily contaminated. The mud oyster, *Ostrea angasi*, accumulated this toxic metal more than mussels. However, preliminary tests of cadmium concentrations in the edible flesh of all commercially important species of fish from the Bay have shown mean concentrations lower than the existing statutory limit, except for the seven-gilled shark (Hall and MacDonald, 1986).

Other heavy metals present in Port Phillip Bay include zinc, copper and lead, but the mean concentrations of these metals in the edible flesh of fish species examined so far are within the existing statutory health limits for human consumption (Hall and MacDonald, 1986). However, the toxicity of these metals to the marine biota of the Bay are not well known, and the effects of continued contamination of the Bay with these metals cannot be predicted (Hall and MacDonald, 1986). Concentrations of copper and zinc in mussels have shown no apparent trends with time and have never exceeded the limits specified in the health regulations. Lead concentrations in mussels collected offshore are relatively low, but those collected in the intertidal zone are higher and are close to or above the statutory limit in the Corio Bay area. Tributyltin (TBT), an ingredient of anti-fouling paint, is known to be extremely toxic to marine organisms. The use of TBT in Victoria has been severely restricted by legislation since 1989. There are, however, very little data available on concentrations of TBT in shellfish in Port Phillip Bay (Fabris, 1991).

Heavy metals in shellfish, particularly *M. edulis planulatus*, have been studied on several occasions in Corio Bay because this area receives large quantities of industrial waste. Fabris *et al*. (1986) found that concentrations of manganese and zinc in mussels from Corio Bay were similar to those in mussels surveyed in 1976, but copper levels were relatively high at Rippleside Park due to the use of 'copper slag' at a nearby shipyard. Cadmium concentrations had decreased in all mussels except those from Rippleside Park. A study of mussel-dominated communities in Corio Bay by Holmes (1989) did not show a close correlation between community structure and detailed distribution of contaminants.

Heavy metal toxicity tests using organisms that occur in Port Phillip Bay have also been conducted. Coleman and Mann (1984) investigated the accumulation of cadmium and copper by *Mytilus edulis, Neotrigonia margaritacea* and *Notocallista diemenensis* to assess their suitability as biological indicators of pollution. *M. edulis* was considered to be the best indicator species for cadmium but was probably unsuitable for copper monitoring. The acute toxicity of copper, cadmium and zinc to three species of copepods - *Scutellidium* sp., *P. indicus* and *A. tranteri* - was examined by Arnott and Ahsanullah (1979). The latter two species, although collected from Western Port for these experiments, are important components of the zooplankton in Port Phillip Bay. Copper was found to be the most toxic metal, (LC_{50} Cu 0.18-0.2 mg l^{-1}), with cadmium more toxic than zinc for two of the species (LC_{50} Cd 0.66-1.37 mg l^{-1}; LC_{50} Zn 1.09-1.86 mg l^{-1}). Arnott and Ahsanullah (1979) discussed problems with applying LC_{50} data to existing water quality criteria and suggested that such a practice may produce unrealistic 'safe' concentrations for copper.

Petroleum hydrocarbons have contaminated all parts of Port Phillip Bay but are most prevalent in Corio and Hobsons Bays. However most of the data, with the notable exception of Corio Bay, are more than 10 years old. The data indicate that Port Phillip Bay as a whole is chronically contaminated by petroleum hydrocarbons, and that concentrations have remained virtually unchanged for the past 15 years (Hall and MacDonald, 1986; Fabris, 1991). Effects of hydrocarbon pollution on marine organisms include reduced growth of phytoplankton and marine plants, reduced reproductive success and tainting of filter feeding invertebrates (Hall and MacDonald, 1986).

Polychlorinated biphenyls (PCBs) were recorded at high levels in mussels from Port Phillip Bay more than 10 years ago, especially in Corio and Hobsons Bays. Recent data, although limited, do indicate large decreases in the concentrations of PCBs in mussels (Fabris, 1991). Hall and MacDonald (1986) consider that the ecological consequences of observed concentrations of PCBs in Port Phillip Bay cannot be predicted.

Known effects of toxicants in Port Phillip Bay have been reviewed by Coller *et al.* (1991) and Phillips *et al.* (in press). There have been no studies on the residual levels of toxicants in small, watercolumn fauna and little on pelagic fishes such as pilchards and anchovies. Furthermore the trophic pathways that lead to bioaccumulation in organisms such as benthic suspension feeders remain unstudied.

2.0 Synthesis of Port Phillip Bay Trophodynamics

2.1 Trophodynamics in the pelagic ecosystem

The relative importance of benthic and pelagic organisms to pelagic trophodynamic processes depends largely on water depth. Officer *et al.* (1982) suggested that benthic invertebrates play an important role in grazing phytoplankton in eutrophic areas 2 to 10 m deep. Because the average depth of Port Phillip Bay is 13.7 m (MMBW & FWD, 1973) both pelagic and benthic processes are likely to contribute substantially to water column trophodynamics.

Port Phillip Bay is very weakly estuarine and the zooplankton is dominated by euryhaline marine or open coastal species (Kimmerer and McKinnon, 1985). Effects of freshwater input on zooplankton species composition would be expected to be localised - probably seasonally - to areas of major freshwater input. Significant freshwater inflow may be expected to increase zooplankton production as a result of nutrient input. Water column stratification in the Bay is also minimal; limited to a warm surface layer of a few metres on calm summer days (Kimmerer and McKinnon, 1985; K. Black pers. comm.). The lack of stratification is presumably a major factor contributing to the relatively high densities of diatoms in Port Phillip Bay (Cushing 1989).

A further important physical factor affecting water column trophodynamics is mixing between the Bay and Bass Strait. Mixing appears to be minimal with a water residence time of approximately 180 d. This suggests that nutrients and toxicants will tend to be taken up in food chains within the Bay rather than mixed out of the system.

For much of the year phytoplankton production in Port Phillip Bay may be limited by light and/or temperature (Axelrad *et al.*, 1981). During summer months, when these factors are probably not limiting, nitrogen is the most likely limiting factor (Axelrad *et al.*, 1981). A further physical factor of possible significance to phytoplankton is turbidity. Increase in turbidity due to catchment erosion, mixing due to storms etc would be expected to depress phytoplankton and higher trophic level production in the pelagic food chain. If turbidity levels were reduced, phytoplankton production would correspondingly increase.

To date there is little strong evidence that eutrophication is affecting food chain trophodynamics in Port Phillip Bay although some indicators suggest that effects are beginning to appear (Saunders and Goudey, 1990). For example, algal blooms (Beckman, 1988; Parry *et al.*, 1989; Arnott 1990a) and areas of depressed dissolved oxygen levels (Longmore *et al.*, 1990) have been reported, although oxygen deficiency may be more related to stratification and benthic respiration than to senescence and sinking of bloom phytoplankton (Longmore, pers. comm.). It is, however, possible that Port Phillip Bay is showing early signs of nutrient enrichment in the pelagic environment.

Little information is available on the effect of toxicants on the pelagic ecosystem in Port Phillip Bay; or for that matter the effect of toxicants on zooplankton. The only work conducted on the effect of toxins in the Bay was a laboratory study investigating acute toxicity of metals to some Port Phillip Bay zooplankton (Arnott and Ahsanullah, 1979). Large increases in toxin input may lead to chronic effects such as depressed reproductive rate as well as direct mortality of sensitive phytoplankton and zooplankton species. This may ultimately lead to a change in species composition with corresponding effects on trophodynamics. Significant contamination of bivalves by toxicants in Port Phillip Bay suggests that some toxicants are being concentrated through the pelagic food chain. An investigation of toxicant levels in zooplankton and pelagic clupeoid fish is desirable.

Although there is recent evidence for increasing chlorophyll ***a*** levels localised near the WTC (Saunders and Goudey, 1990), chlorophyll ***a*** levels are not generally elevated by world standards (Axelrad *et al.*, 1981). Considering the large input of nutrients to Port Phillip Bay and the relatively low mixing rate with Bass Strait it appears that phytoplankton production may be efficiently grazed. Information on trophic relationships in Port Phillip Bay plankton (Figure 1) is only available for a few groups. Jenkins (1987) found that feeding by larval flounder had little impact on zooplankton abundances. Fancett and Jenkins (1988) also concluded that the level of predation on zooplankton by schyphomedusae was low but that predation on larval fish was significant. Jagger *et al.* (1988) examined grazing by the cladoceran *Podon intermedius* on phytoplankton in the Bay and found preferential ingestion of large diatoms, however, impact on diatom populations was not determined. Kimmerer and McKinnon (1989) found that the dominant calanoid in the Bay, *P. indicus,* had a higher clearance rate of the small flagellate *Tetraselmis chui* (ca. 10 ml copepod^{-1} d^{-1}) than did *A. tranteri* (ca. 2 ml copepod^{-1} d^{-1}). If the grazing rate of *P. indicus* is related to total holoplankton (> 150 μm) densities of 4000 m^{-3} (Fancett 1988a), then animals present in 1 m^3 would clear about 40 l d^{-1}, giving an approximate clearance time for the volume of the Bay of 25 d. Clearance rates by *P. indicus* for larger diatoms and dinoflagellates which may bloom in Port Phillip Bay would probably be much higher due to more efficient handling. To date there are no estimates of the grazing impact by zooplankton on larger phytoplankton or the impact of planktivorous clupeoids on phytoplankton and zooplankton in the laboratory, let alone any field based estimates for Port Phillip Bay.

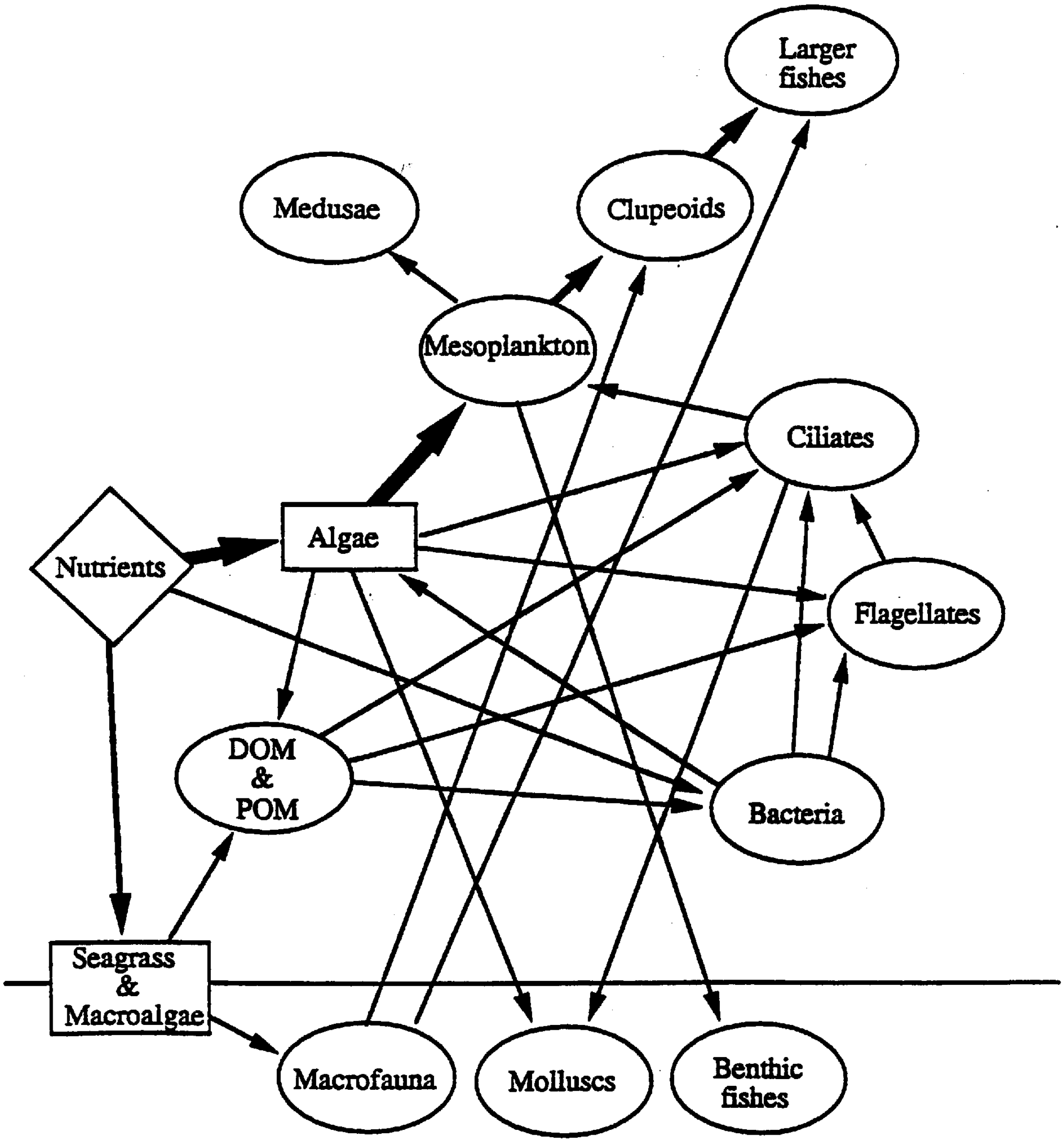

Figure 1. Major trophic linkages pertaining to the Port Phillip Bay water column. Interactions between benthic groups are not shown, nor is the return of faeces, exuviae, bodies etc. to benthic detritus.

The most important trophic pathway for phytoplankton production in the pelagic ecosystem is probably *via* zooplankton to pelagic clupeoids (Fancett, 1988a)(Figure 1). The pelagic uptake of carbon and nutrients may be highly important in Port Phillip Bay if commercial fish catches are taken as an indication. Recent catches of clupeoids (pilchards and anchovies) from Port Phllip Bay have ranged from 700 to 1400 tonnes compared to 500 to 600 tonnes for demersal fish (M. McDonald pers. comm.). It is expected that the difference between population sizes and catches of these two fish categories would be much greater for clupeoids because the clupeioid fishery is believed to be largely under-exploited whilst the demersal fishery is more fully exploited (M. McDonald pers. comm.).

If a total population of 5000 tonnes of clupeoids is assumed, with an average fish weight of 10 g, and the clearance rate of zooplankton for a 10 g fish is taken to be 3 litres min^{-1} (James and Findlay, 1989), then constant feeding would see the entire volume of the Bay (2.51×10^{10} m^3) grazed by clupeoids over a period of 10 days. This estimate does not consider diurnal feeding patterns, movements within and to and from the Bay and other factors. However the estimate is consistent with other studies which show that grazing by clupeoids may have a major impact on zooplankton. For example, Koslow (1981) estimated that clupeoids could consume 30% to 50% of zooplankton biomass in southern California. It appears possible therefore that large populations of clupeoids in Port Phillip Bay may graze most zooplankton production, and that only when zooplankton production increases sufficiently to outstrip this heavy grazing pressure will greater zooplankton biomass occur. A critical question is whether migration of pelagic fish from Port Phillip Bay leads to a major export of carbon and nutrients from the system.

The importance of the "microbial loop" (Azam *et al.,* 1983) in water column trophodynamics has not been investigated for Port Phillip Bay (Figure 1), although high numbers of tintinnids in the zooplankton indicates that the microbial loop is potentially of importance. It is likely that dissolved organic matter released when phytoplankton blooms senesce would be taken up by heterotrophic bacteria, which would in turn be consumed by heterotrophic flagellates and ciliates (Malone *et al*,. 1991). The ciliates would be large enough to be consumed by mesoplankton (Stoecker and McDowell Capuzzo, 1990).

While phytoplankton production and grazing are probably well balanced in Port Phillip Bay over the long-term, phytoplankton production may exceed grazing in localised areas at certain times, possibly resulting in bloom conditions. Experiences in other coastal systems suggest that increased nutrient input would eventually lead to more frequent phytoplankton blooms in Port Phillip Bay given suitable conditions of light and temperature. Under normal circumstances this increase in primary production would be expected to lead to biomass increases at higher trophic levels. However, associated with increased phytoplankton production there may be a change in phytoplankton species composition from 'desirable' groups such as diatoms to species which are poorly grazed by zooplankton and benthos such as the flagellate *Phaeocystis* (Beukema and Cadée. 1991; Hansen and van Boekel, 1991). Such 'undesirable' species would tend to sink after blooming leading to anoxia in the sediment from their decomposition. Secondary effects of blooms such as shading and toxin production may also be detrimental to the 'normal' food chain dynamics which determine palatability and production of - for example - commercial fish species.

At present there is negligible information available which can be used to predict the effects of a 50% increase in nutrients and toxicants on the water column trophodynamics of Port Phillip Bay. Any such predictions require a knowledge of the factors limiting phytoplankton growth and production. It also requires knowledge of the nature of any change in phytoplankton species composition associated with elevated nutrient inputs. Assuming that nutrient limitation occurs during summer (Axelrad *et al*., 1981), then increases in nutrients should lead to predictable long-term increases in phytoplankton production over summer periods. Given a growth rate for planktonic copepods of about 0.1 d^{-1} (Kimmerer and McKinnon, 1987), a measurable increase in mesoplankton would also probably occur over the long-term related to seasonal phytoplankton production.

An approach to predicting the effect of an increase in nutrient input on plankton dynamics could be as follows:

(1 Relate the predicted amount of phytoplankton available over the nutrient limited period to estimates of clearance rates of component grazers (i.e. zooplankton, clupeoids) determined from laboratory experiments and field sampling.

(2) Model excess phytoplankton production in terms of an increased role of the microbial loop (van Boekel *et al.*, 1992), together with increased bacterial decomposition at the sediment-water interface (Malone *et al.*, 1991).

(3) Determine the increase in biomass of grazers and higher trophic levels from consideration of growth efficiencies and population dynamics.

Predicted increases in higher trophic levels resulting from increased phytoplankton production may not occur owing to changes in phytoplankton species composition. Mesocosm experiments could be used to try and simulate conditions of increased nutrients and subsequent shifts in phytoplankton species composition.

The consequences of increased toxicant concentrations on water column trophodynamics should be most apparent as an accumulation of toxicants in higher trophic level consumers such as bivalves and pelagic fishes (Coleman *et al.*, 1991). The effect of increasing toxicants is most predictable for bivalves on the basis of present knowledge. The influence of toxicants on zooplankton and clupeoids is very poorly known and clearly warrants investigation.

3.0 Planktonic-benthic coupling

3.1 Planktonic input into benthic processes

The composition, density and flux of planktonic organisms all greatly affect benthic community structure in shallow coastal waters (Doering *et al*., 1989) including Port Phillip Bay. Planktonic plants and animals are directly captured and ingested by suspension feeding benthic animals; they also contribute to the rain of particulate material which provides the food resource of benthic deposit feeders During planktonic algal blooms light in the water column may be attenuated, thereby reducing the production of the phytobenthos. The three trophic bases of the benthos - suspended material, detritus and benthic algae - are thus all affected by water column processes.

Linkages between plankton and benthos can be qualitatively described for Port Phillip Bay, however the size of these linkages cannot be estimated with any degree of accuracy on the basis of present knowledge. Water column processes exert greatest influence on planktivorous animals such as bivalves, sponges, ascidians and anthozoans. Suspension feeding bivalves - particularly scallops, oysters, mussels and cockles - form the domininant benthic functional group in all major areas of the Bay other than the deep central section where deposit feeding molluscs predominate (Poore and Rainer, 1974). Because food supply is considered to be directly responsible for mollusc distribution patterns (Poore and Rainer, 1974), a reduction in the supply of phytoplankton such as would accompany an increase in turbidity would probably cause a decrease in numbers of suspension feeders.

Planktonic copepods provide an important food source for epibenthic fishes in localised areas of Port Phillip Bay, primarily in locations with dense beds of seagrasses such as Swan Bay. The major planktivorous fishes in seagrass habitats are the syngnathids *Stigmatopora nigra* and *Stigmatopora argus*, the hardyheads *Atherinasoma presbyteroides*, *Atherinasoma microstoma* and *Kestratherina brevirostris*, and the apogonid *Siphamia cephalotes*. While these fishes can also feed on benthic as well as planktonic invertebrates, population numbers would be expected to decline in association with any decline in mesoplankton populations.

In addition to *in situ* autotrophic production and the deposition of material of terrigenous and resuspended benthic origin, the faeces, exuviae and bodies of planktonic organisms provide the organic input into the benthic detrital food web. In contrast to the overseas situation (e.g. Grebmeier *et al*., 1989, 1990) very little work has been done in Australian coastal waters on the relative input of detritus from planktonic versus benthic sources, and no such studies have been conducted in Port Phillip Bay. The only temperate estuary in Australia where relevant work has been done is the Peel-Harvey system where benthic take up of zooplankton fecal material was found to be an important pathway (A. McComb, pers. comm.). Because of the locally-variable contribution of planktonic inputs to the total detrital pool at sites worldwide and the lack of a predictable response of benthos to nutrient enrichment in mesocosms (Widbom and Elmgren, 1988), it is not possible to accurately speculate on the consequences of changes in nutrient inputs to deposit feeding assemblages in the Bay.

The production of grazing benthic invertebrates, including molluscs, amphipods, isopods and polychaetes, appears to be directly related to levels of light (Edgar, 1991). Any reduction in light quality in Port Phillip Bay - either directly from suspended material input or indirectly from phytoplankton blooms - will presumably negatively affect populations of benthic invertebrate grazers. These populations notably provide the primary food source of commercially and recreationally valuable fishes in the Bay (e.g. whiting and snapper).

3.2 Benthic input into planktonic processes

Whether phytoplankton availability or predation by fishes and large invertebrates regulates the total population size of zooplankton (i.e. bottom-up versus top-down processes) remains a contentious issue in ecology (McQueen *et al*., 1989). Most relevant studies have been conducted on the simplified food webs in freshwater habitats (e.g. Hanazato and Yasuno, 1989) and the processes observed extrapolated to the marine situation. It is nevertheless clear that grazers and predators can substantially affect populations of particular food species (e.g. Horsted *et al.*, 1988; Kimmerer & McKinnon, 1989), and cause localised depletion of prey (Riemann *et al,* 1988).

In Port Phillip Bay the impact of benthic organisms on planktonic species is likely to prove substantial. Poore and Rainer (1974) estimated that suspension feeding bivalves filter the equivalent of the volume of the Bay every 24 days. When coupled with the ingestion rates of other filter feeding animals such as sea pens, gorgonians, sponges and ascidians it appears likely that benthic organisms may exert considerable influence on the dynamics of phytoplankton species. Because the water column in Port Phillip Bay is typically well mixed it is reasonable to use the entire volume of the Bay for this calculation. It is likely that such influence by benthic organisms would be greatest in shallow water habitats (Officer *et al*., 1982).

Shallow water areas also characteristically contain large populations of planktivorous fishes - especially in seagrass-dominated areas. Populations of the pipefish *Stimatopora* spp. occur in densities of about 5 m^{-2} in Swan Bay (G. Jenkins, unpublished data). Assuming that each fish consumes 3% of its body weight per day, the mean weight of ingested copepods is 8 µg AFDW, the mean body weight of *Stigmatopora* is 50 mg AFDW and 55% of their diet consists of calanoid copepods (G. Edgar, all unpublished data from Western Port), then the population would consume about 500 calanoids m^{-2} d^{-1}. Given a mean water column depth in Swan Bay of 1.5 m and a mean density of calanoids of 4,000 m^{-2} (Fancett, 1988a), pipefish are estimated to ingest about 8% of the total copepod population each day. While this estimate should be treated with caution because of large possible errors involved in its' calculation, the estimate shows that syngnathids have a potentially large impact on calanoid populations in Swan Bay and presumably also in other shallow water habitats in Port Phillip Bay. Any change in the density of seagrasses would be expected have flow on effects to copepod dynamics.

Poore and Rainer's (1974) results suggest that commercial bivalve fishing and farming may have an impact on planktonic species. However, recent surveys of scallop densities (G. Parry, pers. comm.) indicate that the total weight of scallops in Port Phillip Bay is presently about 10% of the total weight of molluscs used in Poore and Rainers (1974) calculations. This suggests that fluctuations in scallop density resulting from commercial harvesting activities would have little influence on plankton populations. Commercial mussel dredging catch statistics (G. Parry pers. comm.) show a total weight of dredged mussels equivalent to 0.5 % of the total weight of molluscs in the Bay. The overall impact would therefore seem very low, although dense concentrations in wild mussel beds and commercial farms would be expected to have important localised effects (Fréchette and Bourget, 1985). The activity of bivalve dredging may have indirect influences on bivalve feeding by disturbing habitat and resuspending sediment which would affect feeding efficiency (Bricelj and Malouf, 1984; Bricelj *et al*., 1984).

Benthic organisms exert both positive and negative influences on the pelagic food web. Mysids, which occur in very high (yet to be quantified) densities in Port Phillip Bay, form a major linkage between the detrital benthic food web and pelagic fishes. The meroplanktonic larvae of decapods, particularly *Callianassa* spp. in unvegetated habitats and *Macrobrachium intermedium* in seagrass and macroalgal beds, also constitute a major resource for planktivorous pelagic fishes. The contribution of meroplankton to the planktonic food web has yet to be quantified for Port Phillip Bay, however in Western Port decapod larvae comprise about 50% of the diet of clupeoids during summer months.

Moreover, many benthic meiofaunal and macrofaunal species enter the water column in large numbers at night, particularly crustaceans and polychaetes. These 'demersal zooplankton' (or 'tychoplankton') provide a major fraction of the diet of nocturnally-feeding, planktivorous pelagic fishes (Robertson and Howard, 1978).

4.0 Recommendations for Future Work on Water Column Trophodynamics

1) Collect zooplankton biomass data for comparison with historical data and to serve as a baseline for future sampling.
2) Determine - by means of a series of laboratory studies - the impact of grazing by major zooplankton species on larger phytoplankton.
3) Obtain field based estimates of zooplankton grazing rates on phytoplankton.
4) Determine the prey selectivity and grazing impact of clupeoid fishes on phytoplankton and zooplankton.
5) Determine abundances and movement patterns of clupeoid fishes in Port Phillip Bay.
6) Investigate the production of planktonic bacteria, microflagellates and protozoa in Port Phillip Bay in order to determine the importance of the microbial loop.
7) Conduct mesocosm experiments to assess the impact of eutrophication on phytoplankton abundance and composition in the presence and absence of grazers such as zooplankton, bivalves and planktivorous fish.
8) Conduct experiments on chronic and lethal affects of toxicants on zooplankton in Port Phillip Bay.
9) Measure present levels of toxicant residue in zooplankton and pelagic fish.
10) Determine trophic pathways for toxicants accumulated by organisms such as benthic suspension feeders.
11) Determine the relative input of detritus from planktonic versus benthic sources in the benthic food web.

5.0 Acknowledgements

We wish to thank G. Arnott, G. Parry, M. McDonald, N. Hickman, A. Longmore, S. Palmer and G. Nicholson (Marine Science Laboratories), G. Poore (Museum of Victoria), J. Beardall and M. Wheatley (Monash University), and D. Ball, K. Black and M. Holloway (VIMS) for advice and assistance in preparing this review.

6.0 Bibliography

Arnott, G.H., (1974). Studies on the zooplankton of Port Phillip Bay and adjacent waters with special reference to copepoda. Ph.D Thesis, Monash University.

Arnott, G.H., (1990a). Surveillance of toxic marine algae and biotoxins in shellfish in Port Phillip Bay. Internal Report No.187, Marine Science Laboratories, Department of Conservation and Environment, Victoria.

Arnott, G.H., (1990b). Port Phillip Bay shellfish sanitation program 1. Introduction and overview. Technical Report No. 75, Marine Science Laboratories, Department of Conservation and Environment, Victoria.

Arnott, G.H. and J.D. Ahsanullah, (1979). Acute toxicity of copper, cadmium and zinc to three species of marine copepod. *Aust. J. Mar. Freshwater Res*., **30:** 63-71.

Arnott, G.H., M.C. Mobley and G.C.B. Poore, (unpublished). Zooplankton community composition from different water quality areas in Corio Bay, Victoria, Australia. Unpublished manuscript.

Axelrad, D.M., G.C.B. Poore, G.H. Arnott, J. Bauld, V. Brown,V, R.R.C. Edwards and N.J. Hickman, (1981). The effects of treated sewage discharge on the biota of Port Phillip Bay, Victoria, Australia. In. *Proceedings of the First International Symposium on Nutrient Enrichment of Estuaries* (eds. B.J. Neilson and L.E. Cronin), Humana Press, New Jersey. pp 279-306.

Azam, F., T. Fenchel, J.G. Field, J.S. Gray, L.A. Meyer-Reil, and F. Thingstad, (1983) The ecological role of water-column microbes in the sea. *Mar. Ecol. Prog. Ser.,* **10**: 257-263.

Beckman, R., (1988). Blooms and gloom. *Ecos*, **57**: 2-33.

Beukema, J.J. and G.C. Cadée, (1991). Growth rates of the bivalve *Macoma balthica* in the Wadden Sea during a period of eutrophication: relationships with concentrations of pelagic diatoms and flagellates. *Mar. Ecol. Prog. Ser.*, **68**: 249-256.

Bricelj, V.M. and R.E. Malouf, (1984). Influence of algal and suspended sediment concentrations on the feeding physiology of the hard clam *Mercenaria mercenaria*. *Mar. Biol.*, **84**: 155-165.

Bricelj, V.M., R.E. Malouf and C. de Quillfeldt, (1984). Growth of juvenile*Mercenaria mercenaria* and the effect of resuspended bottom sediments. *Mar. Biol.*, **84**: 167-173.

Brown, I.W. and D.S. Negilski, (1976). An exploratory investigation to assess the nature and importance of fish communities in the Werribee sewage treatment farm outfall region. Environmental Studies Series Report No. 47, Marine Pollution Studies Group, Ministry for Conservation, Melbourne.

Coleman, N and T.F. Mann, (1984). The accumulation of cadmium and copper by *Mytilus edulis* L., *Neotrigonia margaritacea* (Lam.) and *Notocallista diemenensis* (Hanley). Technical Report No. 36, Marine Science Laboratories, Department of Conservation, Forests and Lands, Victoria..

Coller, B.W., A. Lindsay and M.I. Coller, (1991). Toxicants in Port Phillip Bay. Consultants report to Environmental Services Section, Melbourne and Metropolitan Board of Works. Part 1: Toxicants in Port Phillip Bay: Distribution, effects and sources - integrated report. Part 2: Summaries of previous reports on toxicants in Port Phillip Bay. Part 3: Summaries of previous reports with reference to toxicants in marine environments. [internal unpublished report in three volumes].

Colman, R., D. Gwyther, M. Keough, G. Quinn and J. Smith, (1991). Assessment of indicators, data and environmental monitoring programs for Victorian coastal and marine environments. Report to the Commissioner for the Environment. Victorian Institute of Marine Sciences, Melbourne. 109 pp.

Cushing, D.H., (1989). A difference in structure between ecosystems in strongly stratified waters and those that are only weakly stratified. *J. Plankton Res.*, **11**: 1-13.

Doering, P.H., C.A. Oviatt, L.L. Beatty, V.F. Banzon, R. Rice, S.P. Kelly, B.K. Sullivan and J.B. Frithsen, (1989). Structure and function in a model coastal ecosystem: silicon, the benthos and eutrophication. *Mar. Ecol. Prog. Ser.*, **52**: 287-299.

Dorsey, J.H., (1981). The ecology of *Australoneris ehlersi* (Augener 1913) and *Ceratonereis erythraeensis* Fauvel, 1919 (Polychaeta, nereidae) living offshore from the Werribee sewage treatment farm, Port Phillip Bay, Victoria, Australia. Ph.D. Thesis, Dept. of Zoology, University of Melbourne. 228 p.

Edgar, G.J., (1991). Distribution patterns of mobile epifauna associated with rope fibre habitats within the Bathurst Harbour estuary, south-western Tasmania. *Estuar. Coast. Shelf Sci*., **33**: 589-604.

Fabris, G.J. (1991): Summary of data on contamination of shellfish in Port Phillip Bay by heavy metals, petroleum hydrocarbons, pesticides and polychlorinated biphenyls. Internal Report No.191, Marine Science Laboratories, Department of Conservation and Environment, Victoria.

Fabris, J.G., C.F. Gibbs and P. Brown, (1986). Cadmium and other heavy metals in mussels (*Mytilus edulis planulatus* L.) from Corio Bay, Victoria. Technical Report No. 49, Marine Science Laboratories, Department of Conservation, Forests and Lands, Victoria.

Fancett, M.S., (1988a). The impact of predation by Scyphomedusae upon the abundance and species composition of the zooplankton of Port Phillip Bay, Victoria. Ph.D Thesis, Zoology Department, University of Melbourne.

Fancett, M.S., (1988b). Diet and prey selectivity of scyphomedusae from Port Phillip Bay, Australia. *Mar. Biol.*, **98**: 503-509.

Fancett, M.S. and G.P. Jenkins, (1988). Predatory impact of scyphomedusae on ichthyoplankton and other zooplankton in Port Phillip Bay. *J. Exp. Mar. Biol. Ecol*., **116**: 63-77.

Fréchette, M and E. Bourget, (1985). Energy flow between pelagic and benthic: factors controlling particulate organic matter available to an intertidal mussel bed. *Can. J. Fish. Aquat. Sci*., **42**: 1158-1165.

Grebmeier, J.M., C.P. McRoy and H.M. Feder, (1988). Pelagic-benthic coupling on the shelf of the northern Bering and Chukchi Seas. I. Food supply source and benthic biomass. *Mar. Ecol. Prog. Ser.*, **48**: 57-67.

Grebmeier, J.M., H.M. Feder and C.P. McRoy, (1989). Pelagic-benthic coupling on the shelf of the northern Bering and Chukchi Seas. II. Benthic community structure. *Mar. Ecol. Prog. Ser.*, **51**: 253-268.

Hall, D.N. and C.M. Macdonald, (1986). Commercial fishery situation report: net and line fisheries of Port Phillip Bay, Victoria, 1914-1984. Marine Fisheries Report No.10, Fisheries Division, Department of Conservation, Forests and Lands, Victoria.

Hanazato, T and M. Yasuno, (1989). Zooplankton community structure driven by vertebrate and invertebrate predators. *Oecologia*, **81**: 450-458.

Hansen, F.C. and W.H.M. van Boekel, (1991). Grazing pressure of the calanoid copepod *Temora longicornis* on a *Phaeocystis* dominated spring bloom in a Dutch tidal inlet. *Mar. Ecol. Prog. Ser.*, **78**: 123-129.

Holmes, N.J., (1989). Mussel-dominated communities along an environmental gradient in Corio Bay, Victoria. Technical Report No. 69, Marine Science Laboratories, Department of Conservation, Forests and Lands, Victoria.

Horsted, S.J., T.G. Nielsen, B. Riemann, J. Pock-Steen and P.K. Bjørnsen, (1988). Regulation of zooplankton by suspension-feeding bivalves and fish in estuarine enclosures. *Mar. Ecol. Prog. Ser.*, **48**: 217-224.

Jagger, R., (1985). The feeding ecology of the marine cladoceran *Podon intermedius* (Liljeborg) in Port Phillip Bay. B.Sc. (Honours) Thesis, Zoology Department, University of Melbourne.

Jagger, R.A., W.J. Kimmerer and G.P. Jenkins, (1988). Food of the cladoceran *Podon intermedius* in a marine embayment. *Mar. Ecol. Prog. Ser.*, **43**: 245-250.

James, A.G. and K.P. Findlay, (1989). Effect of particle size and concentration on feeding behaviour, selectivity and rates of food ingestion by the Cape anchovy *Engraulis capensis*. *Mar. Ecol. Prog. Ser.*, **50**: 275-294.

Jenkins, G.P., (1986). Composition, seasonality and distribution of ichthyoplankton in Port Phillip Bay, Victoria. *Aust. J. Mar. Freshwater Res.*, **37**: 507-20.

Jenkins, G.P., (1987). Comparative diets, prey selection, and predatory impact of co-occurring larvae of two flounder species. *J. Exp. Mar. Biol. Ecol.*, **110**: 147-170.

Jenkins, G.P., (1988). Micro- and fine-scale distribution of microplankton in the feeding environment of larval flounder. *Mar. Ecol. Prog. Ser.*, **43**: 233-244.

Kimmerer, W.J. and A.D. McKinnon, (1985). A comparative study of zooplankton in two adjacent embayments, Port Phillip and Westernport Bays, Australia. *Estuar. Coast. Mar. Sci.*, **21**: 145-159.

Kimmerer, W.J. and A.D. McKinnon, (1987). Growth, mortality, and secondary production of the copepod *Acartia tranteri* in Westernport Bay, Australia. *Limnol. Oceanogr.*, **32**: 14-28.

Kimmerer, W.J. and A.D. McKinnon, (1989): Zooplankton in a marine bay. III. Evidence for influence of vertebrate predation on distributions of two common copepods. *Mar. Ecol. Prog. Ser.*, **53**: 21-35.

Koslow, J.A., (1981). Feeding selectivity of schools of northern anchovy, *Engraulis mordax*, in the southern California Bight. *Fish. Bull. U.S.*, **79**: 131-142.

Longmore, A.R. R.A. Cowdell and C.F. Gibbs, (1990). Monitoring Port Phillip Bay water quality 1985-86. Scientific Report Series No. 89/003, Environment Protection Authority of Victoria.

McKinnon, A.D., (1988). The genus *Acartia* (Copepoda: Calanoida) in Port Phillip Bay, Western Port and the adjacent waters of Bass Strait. M.Sc. Thesis, Zoology Department, University of Melbourne.

McKinnon, A.D., W.J. Kimmerer and J.A.H. Benzie, (1992). Sympatric sibling species within the genus Acartia (Copepoda: Calanoida): A case study from Westernport and Port Phillip Bays, Australia. *J. Crust. Biol.*, **12**: 239-259.

McQueen, D.J., M.R.S. Johannes, J.R. Post, T.J. Stewart and D.R.S. Lean, (1989). Bottom-up and top-down impacts on freshwater pelagic community structure. *Ecol.*, **59**: 289-309.

Malone, T.C., H.W. Ducklow, E.R. Peele and S.E. Pike, (1991). Picoplankton carbon flux in Chesapeake Bay. *Mar. Ecol. Prog. Ser.*, **78**: 11-22.

MMBW & FWD (Melbourne and Metroploitan Board of Works and Fisheries and Wildlife Division), (1973). *Environmental Study of Port Phillip Bay: Report on Phase One 1968-71*. Melbourne and Metropolitan Board of Works, Melbourne.

Officer, C.B., T.J. Smayda and R. Mann, (1982). Benthic filter feeding: a natural eutrophication control. *Mar. Ecol. Prog. Ser.*, **9**: 203-210.

Parry, G.D., J.S. Langdon and J.M. Huisman, (1989). Toxic effects of a bloom of the diatom *Rhizosolenia chunii* on shellfish in Port Phillip Bay, southeastern Australia. *Mar. Biol.*, **102**: 25-41.

Petch, D.A., (1989). Variation in the spionid polychaete *Boccardia proboscidea* (Hartman 1940). Ph.D Thesis, Zoology Department, University of Melbourne.

Phillips, D.J.H., B.J. Richardson, A.P. Murray and G.J. Fabris, (in press). Trace metals, organochlorines and hydrocarbons in Port Phillip Bay, Victoria: an historical review. *Mar. Poll. Bull.*

Poore, G.C.B. and J.D. Kudenov, (1976). The benthic environment and fauna around a Werribee sewage treatment farm drain. Environmental Studies Series Report No.118, Ministry for Conservation, Victoria. 37 pp.

Poore, G.C.B. and J.D. Kudenov, (1977a). Port Phillip Bay Environmental Study - benthos of the Port of Melbourne, the Yarra River and Hobsons Bay. Final Report of Project P503, Marine Pollution Studies Group, Ministry for Conservation, Victoria.

Poore, G.C.B. and J.D. Kudenov, (1977b). The benthic environment and fauna around a Werribee Sewage-treatment farm drain. Report to the Port Phillip Regional Environmental Study, Ministry for Conservation, Victoria.

Poore, G.C.B. and J.D. Kudenov, (1978a). Benthos around an outfall of the Werribee sewage-treatment farm, Port Phillip Bay, Victoria. *Aust. J. Mar. Freshwater Res.*, **29**: 157-167.

Poore, G.C.B. and J.D. Kudenov, (1978b). Benthos of the Port of Melbourne: The Yarra River and Hobsons Bay, Victoria. *Aust. J. Mar. Freshwater Res.*, **29**: 141-155.

Poore, G.C.B. and S. Rainer, (1974). Distribution and abundance of soft-bottom molluscs in Port Phillip Bay, Victoria, Australia. *Aust. J. Mar. Freshwater Res.*, **25**: 371-411.

Poore, G.C.B. and S.F. Rainer, (1976). A three year study of the zoobenthos of muddy environments in Port Phillip Bay, Victoria. *Aust. Mar. Sci. Bull.*, **55**: 7.

Poore, G.C.B. and S.F. Rainer, (1979). A three-year study of benthos of muddy environments in Port Phillip Bay, Victoria. *Estuar. Coast. Mar. Sci.*, **9**: 477-497.

Poore, G.C.B., S.F. Rainer, R.B., Spies and E Ward, (1975). The zoobenthos program in Port Phillip Bay: 1969-73. Fisheries and Wildlife Paper No.7. Environmental Studies Section, Ministry for Conservation, Victoria.

Riemann, B., T.G. Nielsen, S.J. Horsted, P.K. Bjørnsen and J. Pock-Steen, (1988). Regulation of phytoplankton biomass in estuarine enclosures. *Mar. Ecol. Prog. Ser.*, **48**: 205-215.

Robertson, A.I. and R.K. Howard, (1978). Diel trophic interactions between vertically migrating zooplankton and their fish predators in an eelgrass community. *Mar. Biol.*, **48**: 207-213.

Saunders, J. and R. Goudey, (1990). Trends in Port Phillip Bay chlorophyll - data 1970-86. Science Report Series No 90/013, Environment Protection Authority, Melbourne.

Stoecker, D.K. and J. McDowell Capuzzo, (1990). Predation on Protozoa: its importance to zooplankton. *J. Plankton Res.*, **12**: 891-908.

Swadling, K., (1984). Ecological studies on the zooplankton of a shallow marine embayment (Swan Bay). B.Sc.(Honours) Thesis, Monash University.

Talbot, V.W., R.J. Magee and M. Hussain, (1976). Cadmium in Port Phillip Bay mussels. *Mar. Pollut. Bull.*, **7**: 84-86.

van Boekel, W.H.M., F.C. Hansen, R. Riegman and R.P.M. Bak, (1992). Lysis-induced decline of a *Phaeocystis* spring bloom and coupling with the microbial foodweb. *Mar. Ecol. Prog. Ser.*, **81**: 269-276.

Walker, T.I., (1982). Effect of length and locality on the mercury content of blacklip abalone *Notohaliotis ruber*, (Leach), blue mussel *Mytilus edulis planulatus* (Lamarck), sand flathead *Platycephalus bassensis* (Cuvier and Valenciennes), and long-nosed flathead, *Platycephalus cairuleopunctatus* (McCulloch), from Port Phillip Bay, Victoria. *Aust. J. Mar. Freshwater Res.*, **33**: 553-560.

Walker, T.I., (1988). Mercury concentrations in edible tissues of elasmobranchs, teleosts, crustaceans and molluscs from south-eastern Australian waters. *Aust. J. Mar. Freshwater Res*., **39**: 39-49.

Walker, T.I., J.W. Glover and D.G.M. Powell, (1982). Effects of length, locality and tissue type on mercury and cadmium content of the commercial scallop, *Pecton alba* Tate, from Port Phillip Bay, Victoria. *Aust. J. Mar. Freshwat. Res.*, **33**: 547-552.

Widborn, B. and R. Elmgren, (1988). Response of benthic meiofauna to nutrient enrichment of experimental marine ecosystems. *Mar. Ecol. Prog. Ser.*, **42**: 257-268.

Table 1 Synopsis of specific information on water column trophodynamics in Port Phillip Bay

Reference	Description	Data	Comment
MMBW&FWD, 1973 Arnott, 1974	Distribution and abundance of zooplankton in PPB	ASCII files with MW Files with MSL	First major study of zooplankton distribution and abundance.
Poore and Rainer 1974	Distribution and abundance of soft bottom molluscs in PPB	Ascii files with MW and MoV (lost?)	Contains estimate of mollusc grazing impact based on biomass and literature
Arnott and Ahsanullah, 1979	Laboratory study on acute toxicity of copper, cadmium and zinc on copepods occurring in PPB	Held at MSL	Only laboratory toxicity study for zooplankton in PPB
Anott et al. (unpublished man.)	Multivariate analysis of zooplankton communities in Corio Bay	Held at MSL	Only field study on zooplankton considering influence of toxicants
Swadling, 1984	Composition of zoolpankton in Swan Bay	Held by author	Eight month study in Swan Bay, zooplankton similar to Westernport
Kimmerer and McKinnon, 1985	Comparison of zooplankton distribution and	Held by author*	Zooplankton distribution and abundance in drought year
Jenkins 1987,1988	Field data on diet and feeding rate of flounder larvae in relation to plankton distribution	Held by author*	Reasonably detailed field data suggesting little impact on prey
Fancett 1988a,b	Abundances of zooplankton in relation to diet composition of schyphomedusae	Held by author*	Detailed study of trophic importance of this group
Fancett and Jenkins 1988	Laboratory determined clearance rates of schyphomedusae in relation to field data	Held by author*	Reasonably detailed data on grazing impact of this group.
Jagger 1985, Jagger et al. 1988	Laboratory and field study of diet of a cladoceran diatoms	Held by author*	Interesting results documenting diet of this abundant group
Kimmerer and McKinnon 1989	Aspects of ecology including feeding of copepods to explain differing dominance patterns in Westernport and PPB	Held by Author*	Only laboratory estimate of copepod grazing rates from PPB. Conservative due to small phytoplankton used.
McKinnon 1988, et al. 1992	Morpometric and electrophoretic study of copepod Acartia in PPB and WP	Held by Author*	Shows two species of *Acartia* present in PPB rather than one

* address held at VIMS