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Recommended Monitoring Programs For Port Phillip Bay

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EXECUTIVE SUMMARY

The Port Phillip Bay Environmental Study resulted in a fairly complete understanding of the major ecological processes contributing to the health of the Bay. A suite of physical, chemical and ecological models were built summarising much of this understanding and formally combining a quantitative understanding of key processes into a predictive mathematical framework. A critical loading was identified beyond which irreversible change in the state of the Bay would be expected. The major results from the Study and an explanation of the model were published in the Final Report (Harris *et al*. 1996).

Now that the Study is complete and the Final Report is published there is a need for an ongoing monitoring program. This program will need to operate at a number of levels. The first level of monitoring is designed to monitor the health of the Bay and to provide a warning system in the event that unforeseen environmental changes occur. This part of the proposed monitoring program has immediate management implications and will provide the basis of an ongoing management program.

The second level of monitoring is designed to build on our understanding of the Bay processes, maintain historical records and provide data for future model runs which may be required to assess various management options. Throughout this report there are many references to areas where monitoring combined with further research can provide improved process understanding. These suggestions and those provided in the Final Report provide opportunities for Victorian Research Institutes to investigate.

It is suggested that government organisations should review their own monitoring programs in the light of these suggestions. A unified ongoing monitoring program may be more efficient.

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1. INTRODUCTION

The Port Phillip Bay Study (Harris *et al,*1996) disclosed not only the current environmental status of the Bay but also the biogeochemical processes which maintain that status. In general the Bay was found to be oligo- to mesotrophic with few toxicant problems other than high levels of certain toxicants adjacent to historic inputs. There is little or no evidence of trends in the Bay other than those related to rainfall variations and a probable decline in toxicant levels overall.

The trophic status of the Bay had long presented a puzzle to scientists. With known inputs of nitrogen and phosphorus compounds amounting to a moderate areal loading, it would normally be the case that the Bay would exhibit much higher levels of algal biomass and productivity than have been found in all surveys over the last 26 years. It was suspected that the almost oligotrophic state of the Bay was related to the very low levels of dissolved inorganic nitrogen (as ammonia and nitrate) since laboratory trials of enrichment showed enhanced algal growth only when such nutrients were added.

However, this begs the question of why Bay levels of inorganic nitrogen are so low, especially when phosphate levels reflect a balance between inputs and losses to Bass Strait and dissolved organic nitrogen levels appear to behave similarly.

Thanks to the Study it is now known that the low levels of inorganic nitrogen, and the consequent low levels of primary production in the Bay are due to losses of nitrogen through nitrification and denitrification processes in the sediments. These processes are greatly enhanced by active mixing and irrigation of the sediments by benthic invertebrates.

A numerical model built on the physical and biogeochemical processes elucidated during the Study predicts that the Bay would gradually tend to eutrophy if inorganic nitrogen inputs rose above present levels. This increase in algal growth would become evident at the margins of the Bay and spread throughout the Bay when inputs exceeded twice the present magnitude. At three times present inputs, the Bay would be so eutrophic that recovery would be problematical (Parslow and Murray, 1997).

This unfortunate outcome results from a positive feedback. As inputs rise, productivity rises, the organic load to the sediments increases and sediment oxygen demand exceeds the rate of supply from the water column. When this occurs, nitrification (and hence denitrification) ceases. Eventually all inorganic nitrogen generated from breakdown of organic matter in the water and on the surface of the sediment is recycled as ammonia and the levels of inorganic nitrogen in the Bay behave as phosphate does now. The Bay waters would turn green and the bottom sediments would produce toxic sulfides, driving out benthic invertebrates and the fish which feed on them. There is some evidence that Hobsons Bay would be in this state now were it not for flushing by water from the main Bay.

Preventing this dismal prospect depends upon maintaining low inputs of inorganic nitrogen to the Bay. This can be done by continuing the technological improvements in sewage treatment occurring at the Western Treatment Plant and by improving management in the catchments of the principal tributaries to the Bay, notably the Yarra River.

However, the prospect of a degraded Bay is so unacceptable that a constant watch on Bay status is essential as an early warning system. This Technical Report puts forward a suitable program.

It was stated above that there is not a significant toxicant problem in the Bay in that no deleterious levels of common toxicants have been found in the water, sediment and biota of the Bay. This is probably due to two factors. One is the almost total diversion of industrial and domestic waste waters from the Bay catchment to sewage treatment plants. The other is the tendency for most heavy metals or organic toxicants to be fairly insoluble in water, especially salt water, with the result that they become sequestered in the sediments of the Bay, particularly in the deep central basin. Whilst it is true that this is not total removal from the system in that deposit feeders may take up contaminated sediment, this is not reflected in present toxicant analyses on Bay biota (Fabris,1995).

However, since toxicant analytical methods on plant and animal tissues are well established and the public health consequences of seafood contamination are very serious, it is only common sense to maintain a precautionary watch.

2. OBJECTIVES.

In designing a monitoring program for a system as complex as Port Phillip Bay, we are faced with a wide choice of potential variables to measure, and time and space scales to resolve. At the same time, we must recognise that the funds available for a monitoring program will be limited. To be cost-effective, a monitoring program must be designed with fairly specific objectives in mind, and there must be agreement and commitment to these objectives by the responsible agencies.

The broad objectives of the program proposed here are:

To monitor the health of the Bay, provide warning of adverse changes in the Bay's biogeochemical cycles and ecosystem function, and provide basic information for ongoing management of the Bay.

Three more specific objectives are:

- To monitor key variables related to nutrient cycling, water and sediment quality, and critical biogeochemical processes, in a manner designed to detect changes which would provide early warning of major shifts in the Bay's trophic status and clues to the factors responsible.
- To provide a basic data set on Bay inputs and properties sufficient to maintain the integrated physical-biogeochemical model developed as part of the PPBES as a viable ongoing interpretative and management support tool.
- To monitor toxicant loads, distribution and accumulation in biota with sufficient resolution to detect any major changes in toxicant status, and allow a risk assessment to be conducted and updated at intervals of five years.

It should be noted that the PPBES, and this proposed monitoring program, focus on the fate and impact of nutrient and toxicant loads to the Bay. However, one cannot maintain an artificial separation between these and other aspects of the Bay's management. As we discuss later, invasions of exotic marine species may have the potential to shift biogeochemical cycles in the Bay. More generally, there will be many opportunities for beneficial interaction between the monitoring program proposed here, and other monitoring programs: for example, those designed to support management of commercial and recreational fisheries, or toxic algal blooms.

3. FIRST LEVEL MONITORING

3.1. Input Loads

A significant handicap to understanding natural processes in the Bay resulted from lack of satisfactory monitoring of inputs from the catchment. In fact the situation was little better than in Phase One, 1969-71 (MMBW/FWD,1973).

Only the output from WTP is continually and comprehensively measured. Monitoring of the Yarra and other rivers had been intermittent with very limited suites of analytes. Gauging of flows was more comprehensive so that the erratic nature of water input was well known with its concomitant of extremely irregular input loads. Furthermore, some isolated studies had in fact shown that actual loads followed a pattern well established elsewhere of high loads during the "first flush" of a rain event followed by decreasing concentrations and loads as the run-off and flow declined. However, such studies were rare and only served to emphasise that calculation of loads on short time scales comparable, say, to a tidal cycle or growth and decay times of an algal bloom led to at best grossly inaccurate estimates and at worst, mere artefacts, when such calculations are extrapolated from coarse scale measurements.

The limited suites of parameters measured also made it difficult or impossible to close budgets or effect a mass balance.

One considerable advance made during the Study was the development of numerical models of flows and loads in the Yarra and Patterson rivers and Mordialloc Creek based on historic gauging and monitoring and the application of hydrological theory. These are described in PPBES Technical Report No. 33 (Sokolov,1996). Such models have great potential for calculating inputs on a time scale commensurate with natural processes provided that representative sampling or monitoring is carried out. These models require continuously gauged flows, and regular sampling of nutrient and toxicant loads with temporal resolution sufficient to resolve periods of high and low flow. Sampling surveys targeting high runoff events are likely to improve model parameter estimates. The frequency of sampling required will depend on how often it is necessary to update the catchment parameters: that is, on the expected rate of change of catchment properties. More intensive sampling may be required after known changes to catchment management.

The review of nutrient, toxicant and sediment load data (NSR Environmental Consultants Pty Ltd, 1993) suggested that, after WTP, the Yarra, and the Patterson-Mordialloc system are accounted for, Kororoit Creek and Kananook Creek contribute approximately 65% of the remaining annual N and P loads. However, these estimates were based on data from the 1979-81 EPA survey, and may not be applicable 15 years later. Moreover, the estimates for most creeks and drains were based on a small number of samples, and catchment models were not fitted, so that the annual load estimates were highly uncertain. The Phase 1 study estimated loads from all catchments based on catchment properties (land use type and population), and did not predict such high loads from Kororoit and Kananook Creek. Both Phase 1 and Technical Report No. 12 agreed that the Werribee River catchment should represent a relatively small source, despite the very concentrated load from the Werribee Irrigation district. However, during the PPBES, estimates of loads during one runoff event from Werribee River, based on under way measurements off the mouth, in September 1993, exceeded the estimated annual loads from other studies.

While the available data suggest that catchments other than the Yarra system and Patterson-Mordialloc make a relatively small contribution to the total Bay-wide nutrient load, loads from these catchments may have important effects on local water quality on the north-west and east coasts. This is also true in Corio Bay where, although local loads appear to be relatively small, flushing is very weak.

One other deficiency in our knowledge of inputs to the Bay was the contribution from atmospheric fall-out, both wet and dry. Rough estimates were made for ammonia and nitrate loads based on rainfall analysis or extrapolation from overseas experience, but no satisfactory estimates of phosphorus or toxicant input could be made (Beer *et al*, 1992). The input of inorganic nitrogen to the Bay is undoubtedly significant. Even the crude estimates put the load at over 1000 tonnes per annum or 10 to 20 % of total nitrogen input. A limited measurement program is therefore also recommended for this source.

3.1.1. Recommended Input Monitoring Program

1. Western Treatment Plant.

The present monitoring program should be continued. A one-off scan for toxicants should also be conducted. Any chemical species showing significant levels should be added to the routine monitoring. Suggested candidates for the scan are :-

1. Organochlorine pesticides (a suite of all those in common use).
2. Total petroleum hydrocarbons
3. Total PAH's
4. Total phthalates
5. PCB's
6. Chlorinated phenols
7. Triazine herbicides
8. Organophosphorus pesticides
9. Dioxins and furans as TTE
10. Heavy metals including e.g. Cu, Zn, Cr, Pb, Hg, Cd

Analyses should separate dissolved and suspended fractions

2. The Yarra

The present "Streamwatch" program should continue. In addition, appropriately timed profiles should be collected in mid-stream below the Westgate Bridge at the site used in PPBES (Sokolov,1996).

Samples should be collected at surface, 1, 2, 4, 7 and 10 metre depth for analysis of:

a) Ammonia, nitrate, silicate, phosphate, organic phosphorus, organic nitrogen, total phosphorus, total nitrogen, organic carbon, total carbon and suspended solids.
b) Copper, zinc, chromium, nickel, cadmium and lead.
c) PAH's
d) An organochlorine pesticide

On each occasion a profile of salinity, temperature and dissolved oxygen should be taken.

3. Other Tributaries

We recommend that continuous gauging should be maintained on the principal creeks and drains, including Werribee River, Kororoit Creek and Kananook Creek, and a nutrient and toxicant sampling program sufficient to calibrate empirical catchment models be conducted.

Some of the monitoring should be adjusted to record storm events with multiple sampling over the storm hydrograph.

4. Atmospheric Fall-out

Analyses should be conducted on rainwater collected as close to the Bay edge as possible. In fact a wet-dry fall-out gauge could be incorporated on the automated weather station described in Section 4.1. The analyses should include at least nitrate and ammonia on a monthly or similar basis, and a preliminary screening for lead and total organic carbon.

3.2 Chemical Indicators In The Bay

3.2.1 Nutrients

With respect to nutrients and eutrophication, monitoring of water column and sediment variables can potentially serve two purposes: to provide a quantitative measure of changes in water and sediment quality in the Bay, and to indicate the status of the biogeochemical processes which determine water quality. The standard water quality indicators are phytoplankton biomass (chlorophyll *a*), dissolved oxygen, dissolved inorganic nutrients (ammonia, nitrate, phosphate and silicate), total N and P, and light attenuation.

The Study found that phosphate is present in excess in Port Phillip Bay, and that nitrogen is the key limiting nutrient. However, silicate undergoes large biologically driven fluctuations in the Bay, and may be important in controlling phytoplankton composition.

The surveys carried out during the Study provided a very comprehensive picture of the spatial and temporal patterns in water quality variables in the Bay, with important implications for long-term monitoring. In terms of water quality, the Bay can be divided into a number of zones. The Bay Centre comprises the area deeper than 15 m, and represents about 80% of the volume of the Bay. It is characterised by weak spatial gradients, although these are stronger in the north and west. Chlorophyll and DIN levels are generally low, but show significant seasonal and interannual changes. The Great Sands represent a zone of mixing between Bass Strait water and Bay water. This zone has strong spatial gradients of those properties such as phosphate and silicate which are elevated in the Bay Centre compared with Bass Strait. Temporal variation in this zone may be dominated by tidal flow and mixing: seasonal and interannual variation are less important.

The area around the Bay edge sees most of the impact of current nutrient loads on water quality. The zone along the eastern shore is relatively narrow, and appears to exchange rapidly with the Bay Centre, so that water quality there is rather similar to that in the Bay Centre. The zone in the north-east is under the influence of the Yarra, and typically shows very strong spatial patchiness and gradients away from the Yarra mouth. Hobsons Bay has the highest observed chlorophyll concentrations in the Bay, and moderate ammonia concentrations. This region also shows strong temporal fluctuations in response to Yarra runoff events.

The zone off Werribee sees the highest ammonia and phosphate loads, and contains the highest ammonia concentrations. It also shows strong spatial patchiness and gradients away from the outfalls. The seasonal cycle is more regular, because of the winter ammonia discharge from Werribee.

The southwest and Corio Bay behave rather similarly to the Werribee region, with weaker chlorophyll and ammonia maxima due to dilution. The area of the north shows moderate to high chlorophyll concentrations, and strong temporal and spatial gradients. It appears to come under the influence of both WTP and the Yarra, depending on wind and Bay circulation. It may also be subject to highly intermittent loads from Werribee River and Kororoit Creek.

The Bay Centre represents a majority of both the volume and surface area inside the Great Sands, and its water quality is clearly an important index of the overall state of the Bay. It also has relatively weak spatial and temporal fluctuations compared with the coastal zones, and therefore provides an environment in which it may be easier to detect change. The interannual change from dry 1993/94 to wet 1994/95 in chlorophyll and ammonia concentrations was quite striking in this zone.

On the other hand, current and likely future concerns about water quality are focused on the coastal zones close to the major point sources, particularly in Hobsons Bay and off Werribee. The difficulty here is that change must be detected against a background of high spatial and temporal variability, and this requires a large number of statistically independent samples.

The same arguments apply to detecting change in key biogeochemical processes. Bay Centre sediments show the highest denitrification efficiencies, and are responsible for the removal of a majority of the nitrogen load to the Bay. On the other hand, coastal sediments are subject to higher sediment fluxes per unit area, show lower denitrification efficiencies, and are most vulnerable to changes which could reduce denitrification efficiency (including invasions of exotic species).

A cost-effective solution to the problem of resolving or at least averaging over spatial and temporal variation, especially in coastal waters, appears to lie with the use of moored automated monitoring systems at selected locations in the Bay. This recommendation is based on an assessment that much of the observed local spatial variation is associated with patchiness on scales of hundreds of metres to kilometres which is likely to be advected past a moored sensor as a result of tidal or wind-driven flow. At the same time, there are undoubtedly changes in chlorophyll or nutrient levels within zones on time scales of days to weeks, due to runoff events and biological processes. Continuous moored sensors will capture much more of this variability than spatial surveys at monthly intervals.

Relatively low-cost automated systems are available now to monitor temperature, salinity, dissolved oxygen, chlorophyll fluorescence, underwater light levels and turbidity. Temperature and salinity sensors can provide information on runoff, flushing and vertical stratification. Chlorophyll fluorescence, with adequate calibration, can monitor phytoplankton biomass. Light attenuation in the water column is important for phytoplankton production, and critical for benthic flora, especially microphytobenthos which appear to play an important role in sediment biogeochemistry. PAR sensors at the bottom and near surface would provide data on both attenuation and bottom irradiance. Turbidity sensors would provide information about changes in processes driving suspended sediment concentrations.

Measurement of oxygen on a continuous basis was successfully achieved, over a period of three years, in the past and showed that sediment oxygen demand can produce oxygen saturation levels as low as 70% at the bottom during thermal or haline stratification (Mickelson, 1990). Instrumentation has advanced since then and it would be quite feasible to locate a vertical chain of oxygen sensors with data logging attachments at one or more locations in the Bay. These sensors could include probes for salinity and temperature measurement and eventually the other parameters mentioned above.

A more comprehensive approach such as under way sampling surveys (Longmore *et al*, 1996), involves an order of magnitude increase in costs and would need to be justified for its value in updating the integrated numerical model of the Bay, itself a continuing expense. Such a procedure would certainly be appropriate if large increases in nutrient input were likely, but there are presently no indications of this.

It is also difficult to imagine physical alterations of the Bay of sufficient magnitude to require rethinking of the basic structure of the model. Hence large-scale intensive surveys are probably better considered under research needs and these are dealt with later in this document.

The fortnightly water quality sampling program maintained by MAFRI since 1990 (Magro *et al,* 1996, Longmore *et al*, 1996) should continue as those sites represent an important long-term data set for phytoplankton composition and toxic algae as well as water quality variables. In addition to the original coastal sites, and a site in the Bay Centre (preferably coinciding with the moored assembly) the PPBES site at the Heads should be maintained to provide a Bass Strait boundary condition.

3.2.2.Toxicants

Toxicant indicators are a different question again. As mentioned above, toxicant levels in the Bay waters, sediments and biota are generally low although the Bay cannot be described as pristine. It should be sufficient to monitor selected organisms for a suite of toxicants to both protect human health and check whether toxicants are moving through the Bay ecosystem.

Since there is a large historic data base on several taxa, trends should be discernible if they occur. The organisms to be tested should be those on which most historic data has been obtained. Mussels and flathead fish are the first candidates. These have the additional advantage of being indicators of human health hazard.

A more profound consideration is that of sub-lethal effects of toxicants on Bay flora and/or fauna. None have so far been demonstrated but this reflects the paucity of investigation rather than a sure knowledge. Toxicology is a complex field still in the research arena except for empirical assays, but there are several techniques based on physiological processes which enable detection of chronic sub-lethal effects. This matter is dealt with later.

3.2.3 Recommended Chemical Monitoring Program

5. Fixed Station Sampling

The fortnightly water quality and phytoplankton composition and toxic algae sampling programs maintained by MAFRI since 1990 should continue in a similar manner. In addition to the original coastal sites, and the mooring site in the Bay Centre, the PPBES site at the Heads (flood & ebb) should be maintained to provide a Bass Strait boundary condition.

6. Continuous Monitoring

It is recommended that a chain of monitors be installed at three locations in the Bay. Station one would be in the deep centre basin, station two in Hobsons Bay and station three in Corio Bay. The stations would include sensors for oxygen, salinity, temperature, chlorophyll fluorescence and PAR, extending to other parameters as and when suitable sensors are developed. Two other locations that should be considered for stations are Werribee and Sandringham. When the stations are serviced, chlorophyll a and nutrients should be measured in samples collected at the site.

7. Bioaccumulation Program

Common mussel (Mytilus educes planulatus Lamarck) and sand flathead (Platycephalus bassensis) should continue to be tested annually for the following toxicants:

1. Organochlorine pesticides (a suite of all those in common use).
2. Total petroleum hydrocarbons
3. Total PAH’s
4. Total phthalates
5. PCB’s
6. Chlorinated phenols
7. Triazine herbicides
8. Organophosphorus pesticides
9. Dioxins and furans as TTE
10. Heavy metals including e.g. Cu, Zn, Cr, Pb, Hg, Cd

Specimens should be collected from the key areas of Corio Bay, Geelong Arm, Werribee, Hobsons Bay, Mordialloc and the Southern Bay.

3.3. Biological Indicators In The Bay

The existing nutrient loads to the Bay, while not sufficient to turn the Bay eutrophic, are sufficient to produce moderate algal blooms in coastal areas. These blooms have at times consisted of nuisance or toxic species, and there is no reason to expect this situation to change in the future. The current programs to monitor phytoplankton composition in the Bay in order to guard against shellfish poisoning should continue.

Reference has already been made to the threat of eutrophication in the Bay. The other threat is that of disturbance of the ecosystem through biological factors. Of these the most pressing is the advent of exotic organisms. PPBES Technical Reports (Bird *et al* 1996, Officer *et al* 1996 and Wilson *et al* 1996) draw attention to significant changes in the benthic invertebrate population of the Bay over two decades. One such change is an increase in the proportion of suspension feeders over deposit feeders. Another is a dramatic decline in the numbers of ghost shrimp which are known to be active irrigators and mixers of the bottom sediments. Both changes could affect denitrification. There have also been changes in the absolute and relative abundance of several fish species in the Bay (Parry *et al,* 1995).

Concurrent with these changes several exotic species have invaded the Bay, not only benthic invertebrates but also several plant species. One particular alien organism, the sabellid fanworm (*Sabella spallanzanii)* has colonised the Geelong Arm and is reported spreading further into the Bay. The fanworm is a filter feeder and has the potential to both starve out and physically displace important deposit feeders which presently irrigate the bottom sediments. The fanworm is apparently inedible so that large tracts of the bottom are denied to fish and other carnivores as feeding grounds.

It is of course possible to limit or stop the further introduction of exotic organisms by quarantine measures. However we cannot as yet consider control of those already here both because they are now too widespread for physical removal and because we know too little of their autecology to suggest biological control measures.

In this situation it is vital to maintain a watching brief. We need to know whether the pests are still spreading, reaching equilibrium or declining. Parallels could be drawn here with the crown-of-thorns starfish or European carp. It may even turn out that some pests reach a point where physical intervention becomes possible.

A first approach to monitoring the condition of the benthic community could be the maintenance of the annual trawl fish survey with limited sampling of the bottom. This would give an integrated picture of fish and diet abundance and speciation with their relation to the total zoobenthic community, at the same time offering logistic savings.

8. Fauna Surveys

It is recommended that the standard MAFRI trawl survey of 22 sites in autumn each year be continued. As part of this survey, five Smith-MacIntyre grabs be taken at each of the 22 trawl sites for analysis of the fauna present. Identification should be to family level in general but to species level for the following organisms : -

1. Corbula cf. gibba
2. Echinocardium cordatum
3. Neochallichirus limosus
4. Dimorphostylis cottoni
5. Pyromaia tuberculata
6. Byblis mildura
7. Lumbrineris sp. MoV322
8. Euchone sp. MoV1755
9. Leitoscoloplos bifurcatus
10. Teora lubrica
11. Sabella spallanzanii and
12. Dittosa undecimspinosa.

9. Phytoplankton Surveys

The phytoplankton composition and toxic algae sampling programs maintained by MAFRI since 1990 should continue in a similar manner (see Box 5).

4. SECOND LEVEL MONITORING

Whilst the first level monitoring program would suffice to provide some warning of deterioration in the condition of the Bay it would not explain any changes observed nor separate anthropogenic effects from climatic trends or natural cycles. The Study elucidated the key biogeochemical processes in the Bay but also disclosed several gaps in understanding and deficiencies in our knowledge. Hence there is an argument for continued research on the Bay on directed lines.

4.1. Climatic Trends

Dramatic changes in the status of the Bay were observed from 1990 to 1995 apparently in response to fluctuations in rainfall (and thus changes to input loads).These changes varied in both magnitude and spatial extent. The CSIRO Integrated Model of the Bay can predict in broad terms such changes but will require continual validation if the effects of input change in the future is to be accurately forecast. Hence some form of Bay-wide monitoring is desirable. The Study showed that under-way measurement of individual parameters can be converted by GIS surface generation software into statistically sound Bay wide distribution maps (Longmore *et al* 1996, Shao and Fox 1996). These generated surfaces provide the opportunity to calculate nutrient pools sizes Bay wide or for identified zones.

It is therefore suggested that a semi-annual (summer-winter) survey be conducted each year with under-way measurement of salinity, temperature, dissolved oxygen, chlorophyll and the standard suite of nutrients. The cruise track should provide even coverage of the Bay surface. The results can be integrated with the continuous measurements by sensor recommended earlier in this report.

It would be advantageous if some physical measurements could be made on a continuous basis, in particular PAR, air temperature and wind. Vertical profiles of PAR could be taken when the moored array is serviced and correlated with a surface sensor in continuous mode.

10. Under way Sampling

Two Bay-wide under way surveys should be conducted each year. Measurements would include: salinity, temperature, dissolved oxygen, chlorophyll and the standard suite of nutrients.

11. Continuous Physical Measurements

Light levels, air temperature and wind should be measured on a continuous basis. A light recorder, anemometer and thermometer should be installed in an automatic weather station placed on some existing structure in the Bay.

4.2. The Nitrogen Cycle in the Bay

Two aspects of this topic need further elucidation.

Firstly, the Study made clear that micro-algal growth and grazing are closely coupled so that primary production in the water column is rapidly recycled or transferred to the bottom. The limited grazing task possible in the Study gave the first quantitative description of this relationship but at the same time warned that a large and significant component of the grazing population was probably lost in the experimental procedure. Similarly the role and fate of dissolved organic nitrogen needs elucidation. Nitrogen isotope techniques may be a better approach to tracing nitrogen pathways in the water column and to the sediments.

The second aspect relates to the nitrification/denitrification process in the Bay sediments and its interconnection with benthic microalgae or microphytobenthos. The chamber work during the Study demonstrated unequivocally that this area was critical to maintaining the oligo-mesotrophic status of the Bay. Ancillary factors are the effective sequestration rate of nitrogen and phosphorus compounds in the sediment and bioturbation-irrigation. A better understanding of this system in a holistic sense could explain why, for example, some areas of the Bay - notably Hobsons Bay - do not denitrify, and whether other areas of the Bay are vulnerable to loss of this vital process.

Both the above topics require sophisticated scientific skills, but these are available in Victoria. It would also be more productive and logistically economical if the work were carried out on a team basis as occurred during the Study.

Because the work is so sophisticated it is difficult to specify exactly the procedures to be followed as with monitoring. However, some general indication of research lines can be indicated : -

12. The Nitrogen Cycle

By appropriate experimental techniques examine the rates and pathways of nitrogen transformations in the water column. Assess the proportion of nitrogen recycled as opposed to loss to the sediment.

By means of chambers and sediment cores elucidate nitrogen and phosphorus pathways in the sediment and between sediment and water. Investigate the effect of microphytobenthos and benthic fauna on these pathways. Quantify relationships between sediment oxygen demand, organic load, oxygen supply and nitrification/denitrification

4.3. The Ecology of the Bay

The monitoring recommended for benthic fauna is probably adequate to document changes in this compartment, although improved taxonomic knowledge will always be required.

The greatest gap in knowledge in this field is the interaction between native and exotic organisms. This has repercussions on the trophic relationships of fish in the Bay with its potential impact on public awareness. Of more fundamental importance is the potential disturbance of native in-fauna whose burrowing and irrigating activity enhances the nitrification process, and displacement of deposit feeders by filter feeders.

There is a Commonwealth Government program on the biology of imported marine pests but of necessity this is spread rather thinly nationwide. It would be of value to study the autecology of the principal "invaders" in Port Phillip Bay so that predictions may be made of their probable colonising success and perhaps even indicate viable control measures. A watching brief should be maintained in the shallow periphery of the Bay to monitor the spread of these organisms.

In the first instance the fanworm *Sabella spallanzanii* should be studied since this appears to present the greatest threat to the ecological balance of the Bay.

Notwithstanding the benthic faunal monitoring, there would be value in thoroughly surveying the benthic fauna at longer intervals. The pattern followed should be that of the PPBES task in this category (Wilson *et al*, 1996).

A neglected but important ecological compartment in the Bay is represented by the seagrass beds. These were mapped through aerial photographs until the early 1980's showing uneven patterns of extension and retreat in different parts of the Bay, but they have not been surveyed since then. Given their role of habitat provision for numerous marine fauna, especially fish, and their principal occurrence in the Geelong Arm which is to bear the greatest known anthropogenic impact in the next few years, a five yearly survey program would seem mandatory including some physiology. It may be of relevance here to point out that in Cockburn Sound (WA) dead seagrass beds have provided habitat for prolific growth of *Sabella spallanzanii*.

The two remaining biological compartments of the Bay ecosystem are the macroalgae and microphytobenthos. The microphytobenthos are now known to play a significant role in nutrient cycling between the sediments and the water column and this aspect has been mentioned above. There is probably a case for periodic surveys of microphytobenthos in the Bay to extend our knowledge of its distribution and activity and detect any significant shifts in distribution or abundance.

Macroalgae present a practical problem in that the numerous taxa display marked seasonal growth patterns. It is probably unrealistic to attempt to comprehensively map macroalgal distribution with a goal of determining secular changes. It would be more profitable to resurvey those areas off Werribee which have been most studied in the past (Chidgey and Edmunds, 1996). This should be done at five year intervals as for benthic fauna.

The five ecological components could conveniently be monitored on a five year rolling program dealing with one component each year. Some of these activities may provide the opportunity to involve local community groups or diving clubs.

13. Ecological Monitoring

Conduct comprehensive surveys of seagrasses, microphytobenthos, macroalgae, zoobenthos and introduced organisms in the Bay at five year intervals.

4.4. Toxicology

A program of assessment of sub-lethal toxicant effects on Bay fauna should be carried out. Candidate species should be edible fish and shellfish in the first instance, followed by other key fauna looking for anatomical, biochemical and physiological indicators of environmental stress induced by toxicants.

Every five years a risk analysis should be conducted based on the measured levels of toxicants in fauna and the assay responses disclosed by the above program.

5. IMPLEMENTATION OF MONITORING

Whilst there is adequate expertise in Victoria to carry out the program outlined above, it is not yet clear whose responsibility it is to commission the work. The State Government obviously must decide this.

However it is suggested that some form of consultative committee would be useful in collating departmental requirements, avoiding duplication and optimising use of human and equipment resources.

Finally, it is important to re-emphasise here the General Recommendation 3 on page 219 of the PPBES Final Report : -

> "The Bay and its catchment must be seen as an integrated whole. An integrated catchment management strategy is required. In any sustainable future, environmental science must support the development of future regional water management strategies and must underpin the reconciliation of economic, social and environmental imperatives. Models of the Bay must be integrated into catchment models and models of the entire water system so that long-term sustainable management of the Bay becomes possible."

6. REFERENCES

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