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# Phytoplankton Ecology of Port Phillip Bay, Victoria.

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## EXECUTIVE SUMMARY


- We have examined the available published and unpublished data relating to the phytoplankton ecology of Port Phillip Bay (PPB).

- The available literature specifically on the phytoplankton of the Bay is scarce and many of the studies that have been carried out relate to selected areas within PPB, thereby making it difficult to draw conclusions about the area as a whole.

- In other instances it is possible to make reasonable extrapolations from studies on other systems or with laboratory cultures. Such an example is afforded by the effects of toxicants on phytoplankton where there is a large literature worldwide but very little of it carried out with the phytoplankton of PPB.

- Port Phillip Bay, by comparison with many other embayments, does not currently suffer major problems of eutrophication or from excessive levels of toxicants.

- Nutrient levels in Port Phillip Bay are such that nitrogen is the nutrient limiting phytoplankton growth in most areas of the Bay. Any increase in nitrogen loading to the Bay is therefore likely to stimulate phytoplankton growth and disturb community structure and succession.

- There have been several occurrences of toxic algae in the Bay. This is of concern, but there is insufficient data to ascribe such events to any one factor or set of factors.

- The most complete data set relating to phytoplankton species composition and distribution is that currently being collected by the Marine Science Laboratories (MSL) at Queenscliff. However, this database is still in the process of analysis.

- There is a distinct lack of information regarding the primary productivity of Port Phillip Bay. Such information as is available is dated and relates to specific areas of the Bay. There is a concomitant paucity of data on physical data, such as underwater light fields, that are necessary to derive accurate models for overall primary productivity in the Bay.

- It is recommended that future studies build on the existing MSL data set for phytoplankton and nutrient distributions in the Bay. The sampling sites could be increased in number to improve spatial coverage of phytoplankton distribution. There should be concomitant measurements of primary productivity and relevant physical parameters. Estimates of phytoplankton biomass and species composition should be carried out on **all** samples.

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## INTRODUCTION

Phytoplankton are a basic component of marine ecosystems. As they are the base of the food chain they supply necessary dietary requirements for their predators via assimilation of important inorganic macro-nutrients such as carbon, nitrogen and phosphorous and a large range of micro-nutrients. These nutrients are subsequently cycled via other organisms during growth, reproduction, predation and death. The environmental and, for man, economic importance of these organisms is undisputed and well studied, though their ecology and ecophysiology are poorly understood. This review focuses on current knowledge of the ecology of phytoplankton in Port Phillip Bay, with particular emphasis on the requirements of the Port Phillip Bay Environmental Study (see CSIRO, 1992).

This document is divided into four chapters, each dealing with a distinct component of Port Phillip Bay phytoplankton. Each chapter has a short introduction, followed by a detailed analysis of current knowledge. Discussion of the implications of known and projected data will be given in chapter 4. The chapter titles are;

1. The Physical Environment
2. Phytoplankton
3. Ecophysiology
4. Conclusion and Discussion

A number of problems were encountered in the construction of this document, with the need to produce this review in a short period of time being the most important, though this was contributed to by the broadness of the topic, such that the information was located in many libraries and in a great variety of forms. We apologise to authors where information appears to have been neglected though time constraints in the production of this document did not allow us to procure all of the available references. As with all reviews a number of people assisted us in our efforts. Firstly our thanks to the staff at many libraries, particularly the Biomedical library at Monash University, for their help and advice. Secondly to the following people for their quick replies to requests for information, Dr. Neil Hickman, Dr. Graeme Arnott and Dr. Andrew Longmore from Marine Science Laboratories, Dr. David Hill from Melbourne University, Dr. Gustaaf Hallegraef from the University of Tasmania and Dr. Rick Royle from Monash University. We would also like to thank Mrs. Carol Logan for her invaluable help with the presentation of this report and for putting up with our constant unusual requests. Lastly to Dr. Peter Jernakoff and Dr. Tony Chiffings for the timely supply of the Port Phillip Bay Bibliographic Database.

### List of Abbreviations.

EPA Environment Protection Authority, Victoria
MSL Marine Science Laboratories, Queenscliff
PAR Photosynthetically Active Radiation
PPB Port Phillip Bay
Werribee Sewage-Treatment Farm and Werribee Farm are synonyms in this report.

**CHAPTER 1.**

# 1.0. Port Phillip Bay : The Physical Environment

## 1.1. Introduction

Phytoplankton growth and productivity is influenced by a range of physiochemical factors, predominant among which are temperature, light and nutrient levels. It is relevant, therefore, to briefly consider in this review the range of values for these parameters encountered in Port Phillip Bay.

## 1.2. Brief description

Port Phillip Bay (PPB) is located in south-eastern Australia in the state of Victoria. The Bay has an area of about 1950 $km^2$ with a single 3 km wide entrance to Bass Strait at its southern end (Fig. 1). The average depth of the Bay is 14 m, with a maximum of 22 m. The turn around time for the Bay's water contents is about 12 months (MMBW and FWD, 1973). The major freshwater inputs to the Bay are the Yarra/Maribyrnong and Werribee River systems, however the annual inflow from rivers and streams (about 5 % of the total Bay volume) is approximately equivalent to annual surface evaporation, therefore maintaining the salinity at normal sea-water concentrations. The exception to this is Corio Bay where annual evaporation exceeds annual freshwater input resulting in a slightly more saline environment (about 36 ppt.) (MMBW and FWD, 1973).

## 1.3. Salinity stratification

Salinity stratification is unusual throughout PPB, with the exception of areas affected by major freshwater inputs, particularly Hobsons Bay (MMBW and FWD, 1973; Grant and Gayler, 1982; EPA, 1983; Longmore *et al*, 1990). Occasional salinity stratification does occur within the Bay but is usually restricted to a stratum difference of 1-2 ppt (EPA, 1983; Longmore *et al*, 1990). Surface salinity in Hobsons Bay varies between 7 - 35 ppt. and is apparently related to total river flow (Grant and Gayler, 1982). The level of stratification for this wedge of water extending from the mouth of the Yarra/Maribyrnong Rivers varies considerably, from completely mixed, to highly stratified (Grant and Gayler, 1982).

## 1.4. Temperature

Water temperature in PPB fluctuates in parallel with air temperature, displaying annual cyclic variation. Minimum measured water temperatures are approximately 9$^{o}$C, whilst maximum water temperatures are approximately 20 to 25$^{o}$C, though occasionally higher. Concurrent variation across the Bay is minimal and usually in the order of ±1$^{o}$C (MMBW and FWD, 1973; Axelrad, 1978; Axelrad *et al*, 1979; Brown *et al*, 1980; Grant and Gayler, 1982; EPA, 1983; Mickelson and Bulthuis, 1985). Occasional temperature stratification has been observed within the Bay, though this is generally a localized occurrence (Grant and Gayler, 1982; Mickelson and Bulthuis, 1985).

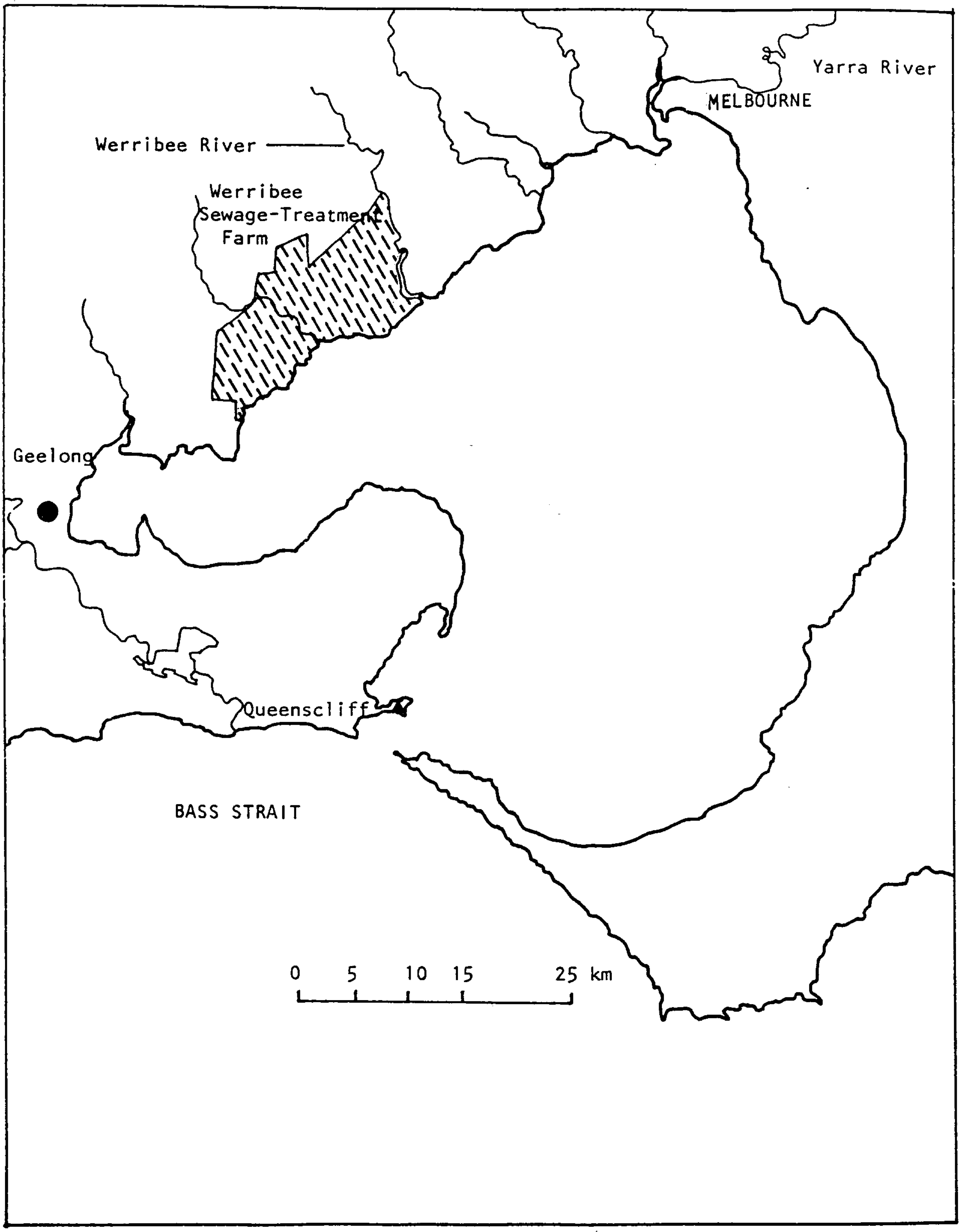


**Figure 1.** Port Phillip Bay

### 1.5. Light

The light regime of PPB varies considerably, following a yearly cycle. Sunshine and solar radiation are maximal in summer and minimal in winter months, with average values recorded at Werribee between 3.9 and 8.3 hours of sunshine, and between about 5.5 x $10^3$ MW hr $cm^{-2}$ and 22 x $10^3$ MW hr $cm^{-2}$ solar radiation (Brown *et al*, 1980). This would be expected to vary little across the Bay. Photosynthetically active radiation (PAR) is a component of solar radiation encompassing the range of 400 to 700 nm. Unfortunately, measurements of PAR in PPB appear to be extremely limited, with data readily available from only two studies. The annual pattern for PAR is the same as that for solar radiation, with levels between about 0.8 and 4.5 E $m^{-2}$ each month (Axelrad, 1978). Maximal surface PAR was about 1600 $\mu$E $m^{-2}$ $s^{-1}$ and 400 $\mu$E $m^{-2}$ $s^{-1}$ during summer and winter respectively, whilst at 3 m deep the corresponding figures are approximately 10% and 20% of surface PAR (Grant and Gayler, 1982). A complicating factor for PAR is the ability of some sewage discharge, from Werribee Farm, to selectively absorb blue light (Hickman and Axelrad, 1985). The importance of this will be discussed elsewhere.

Secchi disk data indicate that the Yarra/Maribyrnong River mouth is generally the most turbid area of the Bay and the major apparent source of turbidity (EPA, 1983; Longmore *et al*, 1990). Most central areas of PPB show little variation in secchi disk data and were generally >5.0 m and were thus fairly clear, while most other areas within the Bay range from 2 to 5 m (EPA, 1983; Longmore *et al*, 1990).

### 1.6. Nutrient Levels

Nutrients required for the growth of phytoplankton are a large and diverse group, comprising inorganic and organic components. The macro-nutrients required by microalgae are inorganic carbon, inorganic nitrogen and inorganic phosphorus, while the micro-nutrients, such as inorganic sulphur, various metals and vitamins are required in much smaller amounts. The fine details of the levels of these compounds in PPB and their interaction in the physical marine environment are not within the scope of this report and are detailed elsewhere. Summarized information is presented below.

#### *1.6.1. Inorganic Carbon*

Dissolved inorganic carbon (DIC), in aqueous medium, is composed of the following species; $CO_2$, $HCO_3^-$ and $CO_3^{2-}$. Even though the levels of DIC are not apparently recorded for PPB, the levels of DIC and the proportions of each species are related to pH, salinity and to a lesser degree temperature. Further details of these interactions can be found in Skirrow (1985). The waters of PPB have a pH range of 7.5 to 8.5 though usually in the range of 7.9 to 8.1 (Grant and Gayler, 1982; EPA, 1983; Longmore *et al*, 1990), a salinity of about 35 ppt and a temperature range of between 10 and 20$^o$C. This equates to an approximate DIC concentration of 2 mM when in equilibrium with air levels of $CO_2$.

### *1.6.2. Nitrogen*

Biologically active nitrogen is available to phytoplankton from two general sources, inorganic and organic nitrogen. The data regarding levels of each in PPB are presented in two separate sections. Of particular note are the extensive plumes often associated with the Werribee Sewage-Treatment Farm where higher than normal levels of total nitrogen (and phosphorus) are often measured (Longmore *et al*, 1990).

#### 1.6.2.1. Inorganic Nitrogen

Inorganic nitrogen ($N_{inorg}$) in water is composed of ammonia ($NH_3^+$), nitrate ($NO_3^-$) and nitrite ($NO_2^-$). The levels of these compounds have been well studied in PPB. The major source of $N_{inorg}$ to PPB is the Werribee Sewage-Treatment Farm, which contributes about 50% of the total Nitrogen to the Bay (MMBW and FWD, 1973). Other major sources of $N_{inorg}$ are the Yarra/Maribyrnong River system, Werribee River and Patterson River, though their loads of $N_{inorg}$ to PPB vary considerably (Longmore *et al*, 1990). One problem encountered with attempting to collate this data was the inconsistency in the units used to express $N_{inorg}$ concentration. The types of units used disallowed the quick comparison of some data sets. Added to this was the unclear presentation of the actual units of $N_{inorg}$ used in the 1990 EPA report (Longmore *et al*, 1990). Re-analysis of this data is not within the scope of this review. This data is summarized in Table 1. Elevated levels of $N_{inorg}$ exist around the sources of input with plumes extending into the Bay (Longmore *et al*, 1990). The centre of the Bay has close to background levels of $N_{inorg}$, indicating that dispersal/diffusion, denitrification, sedimentation and/or assimilation by phytoplankton of $N_{inorg}$ has occurred by the time input has reached these sites (Axelrad *et al*, 1981).

#### 1.6.2.2. Organic nitrogen

Organic nitrogen ($N_{org}$) compounds arise from the breakdown of once living material, and is thus present as a large range of compounds. The greatest source of $N_{org}$ is from Werribee Farm (MMBW and FWD, 1973), with other major inputs from the Yarra/Marribyrnong River system, Werribee and occasionally Patterson River. The Kjeldahl nitrogen assay is the most commonly used method for the determination of $N_{org}$, though care must be exercised in ensuring that the ammonium, which is also measured by this method, is corrected for. The data presented here is uncorrected Kjeldahl nitrogen. Most areas in PPB have Kjeldahl nitrogen of between 0.1 and 0.25 mg/l (7 to 18 µM) with elevated levels up to 47 µM (EPA, 1983; Longmore *et al*, 1990). Both Hobsons Bay and Corio Bay have higher than central PPB levels of Kjeldahl nitrogen (MMBW and FWD, 1973; EPA, 1983; Longmore et al, 1990). Current EPA data (EPA, 1990) for the fixed site monitoring program is only available as total nitrogen, though the spatial and temporal patterns of nitrogen distribution in PPB are the same as recorded in previous reports.

| Units | $N_{inorg}$ | $NH_3$ | $NO_3$ | $NO_2$ | $NO_x$ | $PO_4$ ($P_{inorg}$) | Reference |
|---|---|---|---|---|---|---|---|
| **Coast off Werribee Sewage-Treatment Farm** | | | | | | | |
| μM | <0.31->27.4 | <.01-17.9 | - | <.1->1.5 | <.2->6.0 | 2.7-5.7 | Longmore et al 1990 |
| μg-at/l N / P | - | 0.3-15.8 | - | - | 0.1-3.9 | 2.28-5.19 | Axelrad et al 1981 |
| μg-at/l N / P | - | <.71-7.1 | <.36-1.8 | .07-0.7 | - | 2.26-4.52 | EPA 1983 |
| μg/l | - | <10-100 | <5-25 | <1-10 | <10-35 | 70-140 | |
| μg-at/l N / P | - | 0-2.14 | - | - | - | 0.21 | MMBW & FWD 1973 |
| mg/l * | - | 0-30 | - | - | - | 6.5 | |
| μg-at/l N / P | - | 0.1-7.1 | 0-2.8 | .02-1.04 | - | - | Fisher and Cowdell 1982 |
| μg-at/l N / P | 3.1-33.4 | - | - | - | - | 3.66-7.88 | Axelrad et al 1979 |
| **Yarra Mouth** | | | | | | | |
| μg/l | - | 10-30 | 5-40 | 1-6 | 10-45 | 70-120 | EPA 1983 |
| μM | - | .44-1.74 | - | <0.3 | ≈3-≈17 | 2.4-3.4 | Longmore et al 1990 |
| **Central Port Phillip Bay** | | | | | | | |
| μM | - | <.01-.54 | - | <0.1 | <0.2 | <2 | Longmore et al 1990 |
| mg/l * | - | .04 | - | - | - | .2 | MMBW & FWD 1973 |
| μg-at/l N / P | 0.2-0.6 | - | - | - | 0-0.1 | 1.54-2.00 | Axelrad et al 1981 |
| mg/l | - | <0.01 | <0.05 | <0.02 | <0.01 | 0.05-0.07 | EPA 1983 |
| μg-at/l N / P | 0.1-0.4 | - | - | - | - | 0.9-2.16 | Axelrad et al 1979 |
| μg-at/l N / P | - | - | - | - | - | (6.8-7.4) | Smith and Longmore 1980 |
| **Bass Strait** | | | | | | | |
| μg-at/l N / P | - | 0.1 | 0-0.1 | 0-0.01 | - | - | Fisher and Cowdell 1982 |
| μg-at/l N / P | - | - | - | - | - | (4.5-6.9) | Smith and Longmore 1980 |

**Table 1.** Data from Port Phillip Bay regarding Phosphorus and Nitrogen levels. (* denotes data that was taken verbatim but may actually be μg/l)

*1.6.3. Phosphorus*

Phosphorus (P) is similar to nitrogen in both the species available and the spatial/temporal distribution in PPB. The major component of total phosphorus ($P_{tot}$) in PPB, and most other marine waters, is phosphate (also known as orthophosphate, $PO_4^{3-}$). In PPB, up to 90% of $P_{tot}$ can be $PO_4^{3-}$ (Smith and Longmore, 1980). The major source of P to PPB is Werribee Farm, which contributes approximately 60% of $P_{tot}$ to PPB (MMBW and FWD, 1973). The other major sources of P to PPB are the same as for nitrogen (Longmore *et al*, 1990). The problems associated with comparing $N_{inorg}$ data are similar to those for inorganic phosphorous ($P_{inorg}$) data and thus levels of $P_{inorg}$ are also summarised in Table 1. As with nitrogen, the centre of the Bay has the lowest levels of $P_{inorg}$, whilst the area off Werribee Farm has the highest recorded levels. Hobsons Bay and Corio Bay have elevated $P_{inorg}$ levels, with occasional high levels recorded off Patterson River. The absolute levels recorded vary considerably over time for all areas (Longmore *et al*, 1990).

*1.6.4. Silicate*

Though not incorporated into organic matter, silicate is necessary for growth of some major groups of phytoplankton. Principally, diatoms have an important requirement for silicate as their 'outer shell' (frustule) is composed of silica (Bold and Wynne, 1978). The major source of silicate to PPB is the Yarra/Maribyrnong River system (EPA, 1983; Longmore *et al*, 1990). Concentrations in the Bay vary seasonally (Longmore *et al*, 1990), with concentrations ranging from 0.1 to 8.0 µM (Longmore *et al*, 1990) and 0 to <0.25 mg/l (EPA, 1983) being recorded from most areas in PPB. Levels at the mouth of the Yarra River have been recorded as >9 µM (Longmore *et al*, 1990) and between 0.1 and 0.45 mg/l (3 and 16 µM Si)(EPA, 1983).

*1.6.5. Other nutrients*

The list of micronutrients required for phytoplankton growth includes various metals (Fe, Mn, Cu, Zn, Mo), bromine, iodine and a number of vitamins (Dring, 1982). The absolute requirements of microalgae for these compounds is extremely low and difficult to demonstrate (Dring, 1982). The levels of iodine, bromine and vitamins in the waters of PPB are not readily available from the literature, though it is expected that these should not be below those present in normal sea-water, and possibly exist at higher levels in PPB. A number of the above metals, particularly zinc and copper are toxic to phytoplankton at elevated concentrations (Fisher, 1979). The concentrations of metals will be dealt with in the next section of this report.

## 1.7. Toxicants

Toxicants, for the purpose of this review, are various toxic heavy metals and organic compounds which occur at levels above normal background as a result of man's activities. Located on the shores of PPB are two major urban/industrial centres, Melbourne (population 3,022,157 Australian Bureau of Statistics (ABS) 1991 census) and Geelong, as well as a number of other smaller townships. Both Melbourne and Geelong have heavy concentrations of various industries as well as deep-water harbours. Most waste-waters from these industries finally become part of the input to PPB waters, though the output of toxicants is strictly controlled. The sources of various toxicants found in PPB is dealt with elsewhere and is of little importance to this review. This section on toxicants is divided into two parts, metals and organic toxicants, with levels of specific toxicants being dealt with separately.

### *1.7.1. Metals*

Heavy metals in the marine environment behave in complex ways. Several different ions as well as forms chelated with organic and inorganic compounds may be present (Fisher, 1979; Smith *et al*, 1981; Dring, 1982; Jones *et al*, 1987). The forms bound to particulate matter may be biologically unavailable, making the assessment of biologically active metal levels problematic (Fisher, 1979; Smith *et al*, 1981). Added to this are the complicated interactions between metals, possibly resulting in synergistic toxic effects (Smith *et al*, 1981). Concentrations of toxic metals in PPB are presented below.

#### 1.7.1.1. Arsenic (As)

Though not a true metal, arsenic levels will be treated in this section. EPA water quality data (EPA, 1983; EPA, 1990; Longmore *et al*, 1990) indicate that As contamination in PPB is not a problem. All recorded levels of As were well below the SEPP objective (<10 $\mu g\ l^{-1}$). The highest recorded concentration was 4.4 $\mu g\ l^{-1}$ (EPA, 1990) with most values between 1.5 and 3 $\mu g\ l^{-1}$. This is not much greater than the recorded levels for unpolluted sea-water (1-2 $\mu g\ l^{-1}$, Longmore *et al*, 1990).

#### 1.7.1.2. Cadmium (Cd)

Levels of cadmium are well studied in marine systems, as Cd can be concentrated by economically important species, e.g. the mussel *Mytilus edulis,* to toxic levels. EPA water quality data (EPA, 1983, 1990; Longmore *et al*, 1990) show that the waters of PPB currently have generally low levels of Cd which are almost always within the SEPP objective (<3 $\mu g\ l^{-1}$). The highest concentrations of Cd are most often recorded from Corio Bay (EPA, 1983 1990; Longmore *et al*, 1990). This is probably due to the slow release of Cd from contaminated sediments in Corio Bay, resulting from the discharge of waste containing Cd-based paint pigments (Smith *et al*, 1981; Longmore *et al*, 1990). This discharge was halted in 1974 (Longmore *et al*, 1990), though elevated levels of Cd are still to be found in certain Corio Bay sediments (EPA, 1981; Smith *et al*, 1981; Longmore *et al*, 1990). The slow release of Cd from these sediments into PPB is expected to continue for some time (Longmore *et al*, 1990; Smith et al, 1981; EPA, 1981).

#### 1.7.1.3. Chromium (Cr)

Chromium levels in the two more recent EPA reports (EPA, 1990; Longmore *et al*, 1990) were always below the SEPP objectives of <10 $\mu g\ l^{-1}$, whilst only two sites recorded concentrations above the SEPP objective between June 1980 and May 1982 (EPA, 1983).

#### 1.7.1.4. Copper (Cu)

Copper is an important biologically active metal, with low requirement levels for growth of microalgae as well as species specific toxicity levels (Fisher, 1979). Copper concentrations recorded in PPB varied considerably with more recent EPA studies (EPA, 1990; Longmore *et al*, 1990) recording levels below 3.5 μg $l^{-1}$ (SEPP objective <5 μg $l^{-1}$) and Smith *et al* (1981), sampling specifically in Corio Bay, recording levels up to 25 μg $l^{-1}$. Most samples (75%) tested by Smith *et al* (1981) were below 5 μg $l^{-1}$ with 6 of the 32 samples being between 5 and 10 μg $l^{-1}$ and 2 samples above 10 μg $l^{-1}$. The disparity between the two data sets is possibly related to the intensity and randomness of the sampling regime employed by Smith *et al* (1981) which allowed detection of localized (and possibly transitory) elevated concentrations of Cu.

#### 1.7.1.5. Lead (Pb)

As with cadmium, levels of lead (Pb) are well studied in the marine environment. Pb is another metal that can be concentrated by commercially important fish and shellfish to toxic concentrations. In PPB the SEPP objective for lead is <10 μg $l^{-1}$. Almost all of the samples reported from PPB had Pb concentrations below 10 μg $l^{-1}$ (Smith et al, 1981; EPA, 1983; Talbot, 1987; EPA, 1990; Longmore *et al*, 1990) except for a few records in older studies, with 1 sample in Corio Bay (Smith *et al,* 1981) and a small number of samples in the 1980-1982 EPA study (EPA, 1983).

#### 1.7.1.6. Mercury (Hg)

Mercury is another metal which can be concentrated to toxic levels within the food chain. The SEPP objective for Hg in PPB is <0.1 μg $l^{-1}$. In the 1980-1982 EPA study (EPA, 1983), a number of sites registered levels of Hg above the SEPP objective. These levels have subsequently dropped significantly and levels of Hg, with the exception of some problems in 1987 (EPA, 1990), have been generally below or close to the limit of detection (EPA, 1990; Longmore *et al*, 1990).

#### 1.7.1.7. Nickel (Ni)

The SEPP objective for nickel levels is <20 μg $l^{-1}$. EPA water quality data for PPB have usually recorded Ni levels below 5 μg $l^{-1}$ (EPA, 1983, 1990; Longmore *et al*, 1990).

#### 1.7.1.8. Zinc (Zn)

As with copper, zinc is required by phytoplankton at low concentrations for growth, but has higher species specific toxicity levels. Generally levels of Zn in PPB have been recorded to be below the SEPP objective (<20 μg $l^{-1}$). Occasional elevated zinc levels have been reported, with concentrations up to 48 μg $l^{-1}$, though this appears to be a temporary state (EPA, 1990). Elevated levels recorded in 1985-1986 were thought to be a result of sample contamination (Longmore *et al*, 1990).

*1.7.2. Organic Toxicants*

The majority of organic toxicants do not occur naturally in marine environments, and it is only the influence of man that has allowed their introduction into oceanic and coastal waters (Fisher, 1979). The two major types of organic toxicants are petroleum hydrocarbons and chlorinated hydrocarbons (such as DDT, dieldrin and PCB's), both of which are highly biologically active (Fisher, 1979). Information regarding the levels of organic toxicants in PPB waters are difficult to obtain, with most studies concentrating on levels of these compounds in sediments. A review of current information regarding toxicants in PPB is being conducted concurrently with this report and more detailed information will be available from that source (see Task T2, CSIRO, 1992). Concentrations >0.2 $\mu g\ l^{-1}$, for total hydrocarbons in marine waters, generally indicate contamination (Burns and Smith, 1980). High levels of total hydrocarbons, up to 22 $\mu g\ l^{-1}$, have been found in PPB (Burns and Smith, 1980; Talbot, 1987), with the highest concentrations being recorded in Hobsons Bay and Corio Bay. Hydrocarbon levels in the water column are usually highest close to the source of input, with concentrations decreasing with distance from input area. Adsorbtion of hydrocarbons to particulate matter followed by sedimentation appears to be the major cause of hydrocarbon removal from PPB waters (Burns and Smith, 1980).

### 1.8. Concluding Remarks

The material presented in this chapter has been summarized from a number of sources, and is thus only a brief picture of the physical environment of PPB. More detailed information is available from the material cited. The Environment Protection Authority (EPA) of Victoria, in conjunction with the Marine Science Laboratories (Queenscliff), currently conducts a fixed site monitoring program (started in 1984) for the waters of PPB and is possibly the best source for current physical data regarding the waters of PPB.

# CHAPTER 2

## 2.0. Phytoplankton

This chapter will deal with current knowledge of phytoplankton species composition, distribution (spatial and temporal as determined by cell numbers and chlorophyll *a*) and the occurrence of algal blooms (toxic and non-toxic) within PPB.

### 2.1. Species composition

Most groups of phytoplankton are represented in PPB, though the dominant group is usually diatoms, followed by cryptophytes and dinoflagellates (MMBW and FWD, 1973). A current list of microalgae found in PPB from the MSL phytoplankton monitoring program 1987-1992 is included (Appendix 1. see Chapter 4 for details of this program). A number of microalgal species that have been previously recorded in PPB are not currently on this list, possibly due to low abundance, though they may be recorded by this program in the future.

### 2.2. Spatial and Temporal Distribution

The general trend of succession in Australian coastal phytoplankton communities is for a spring bloom of diatoms to be followed in summer by coccolithophorids, microflagellates and dinoflagellates. Late summer/autumn often sees a second diatom bloom and occasionally short increases in cryptomonads and silicoflagellates before the population settles to a winter minimum (Jeffrey and Hallegraeff, 1990). However, published reports concerning the overall spatial and temporal distribution of phytoplankton in PPB are almost nonexistent, though limited data is available from 1968-1971 (MMBW and FWD, 1973). The best existing database of phytoplankton distributions is that collected by MSL, Queenscliff. This represents the most thorough, complete data set currently (and historically) available. However, analysis of this data set is still being carried out (G. Arnott, personal communication) and it is therefore not yet possible to describe the trends in phytoplankton distribution that might be evident from that study. It is apparent that although the best available, the MSL data set does not include information on nanno- and pico-planktonic microalgal abundance. These organisms are major contributors to the productivity of marine ecosystems (Jeffrey and Hallegraeff, 1990)

Whilst data on spatial and temporal distribution in phytoplankton numbers and species composition is not yet available, these would be reflected, in broad terms at least, in chlorophyll *a* distributions (see below).

### 2.3. Chlorophyll *a*

Chlorophyll *a* (chl *a*), a photosynthetic pigment possessed by all phytoplankton, is a commonly used parameter for phytoplankton density. The EPA fixed site monitoring program, as well as previous EPA PPB water quality programs, measures chl *a* in PPB. The use of chl *a* as a measure of phytoplankton populations is far from precise and is problematic in interpretation. Two major problems are:

1 : The inability of this method to differentiate easily between algal groups, let alone species,

2 : The lack of correlation this method has with absolute cell densities given the vastly different cell:chlorophyll ratios of different species, and the effect of temperature and irradiance on cell:chlorophyll ratios within species (Wood and Beardall, in preparation).

However, given these problems, general trends can still be elucidated from the collection of chl *a* data, particularly with reference to eutrophication. A brief survey of recent data (since 1980: EPA, 1983, 1990; Longmore *et al*, 1990) shows that the highest levels of chl *a* are usually encountered off Werribee Farm, in Hobsons Bay, in Corio Bay and off Patterson River. These elevated concentrations of chl *a* coincide with elevated nutrient levels, though occasional records of higher than average chl *a* in Swan Bay (EPA, 1983; Longmore *et al*, 1990) do not accord with this general relationship. The highest levels of chl *a* relate to seasonal productivity and structure of these communities is not known. An analysis of trends in chl *a* data collected in PPB between 1970 and 1986, by Saunders and Goudey (1990), displays the following. The area off Werribee Farm had a general increase in chl *a* content of about 6.3% per year. Corio Bay has shown a downward trend of between 3 and 9% per year depending upon the segment of Corio Bay investigated, as has Hobsons Bay. No apparent change has occurred in chl *a* levels in the centre of the Bay over the same period.

### 2.4. Phytoplankton Blooms

Rapid increases in phytoplankton cell numbers, usually of a single species, is called a bloom. Blooms are a natural occurrence, though the increase in nutrient levels as a result of human activity may have increased the frequency, intensity and length of these events (Hallegraeff and Bolch, 1991). In PPB, the surveillance of phytoplankton populations is important as an 'early warning' system for algal blooms, particularly with respect to toxic species (Arnott, 1990). Blooms of non-toxic phytoplankton are apparently not a problem in PPB, and records of their occurrences are not readily available (if at all). Massive fish kills have been associated with non-toxic microalgal blooms in various marine systems (Bulthuis and Cowdell, 1982), mainly as a result of depleted oxygen in marine waters (anoxia). No reports of fish kills in PPB have been associated with anoxia caused by phytoplankton blooms.

Toxic phytoplankton blooms can have dramatic consequences, particularly from a public health aspect, as shellfish can accumulate microalgal toxins to levels that are potentially lethal to humans. Deaths from microalgal related shellfish poisoning have been reported in Europe, North America, Japan (Hallegraeff *et al,* 1988a) and Canada (Arnott, in press). Associated with these deaths is a large number of non-lethal poisonings. Non-lethal poisonings associated with toxic phytoplankton blooms have been recorded in Tasmania (Hallegraeff *et al*, 1988b). A number of different toxic and potentially toxic phytoplankton species have been recorded from PPB waters (Table 2.). It is not known whether these species are endemic or if they have been introduced, though it has been suggested that ships ballast may be an important point of introduction for viable toxic algae (Hallegraeff *et al*, 1988b, 1991; Hallegraeff and Bolch, 1991; Department of Conservation and Environment, 1991). The toxins produced vary between and within species (Hallegraeff *et al*, 1991) and the effects can be separated into a number of different toxin types (Table 3). The first record of a toxic microalgal species in PPB was the dinoflagellate *Alexandrium catenella* in 1986. Since that time three shellfish toxicity alerts with respect to *A. catenella* have been issued for areas of PPB. These were in 1988, 1991 (Department of Conservation and Environment, 1991) and 1992 (G. Hallegraeff, personal communication). A bloom of the toxic diatom species *Nitzschia pseudodelicitissima* was recorded in PPB in mid-November 1991 and a public health alert issued. No toxins were detected for this bloom, though monitoring of *N. pseudodelicitissima* continues. Other toxic species recorded from PPB are *Gymnodinium mikimotoi* and *G. pulchellum,* both of which are known to cause fish-kills (G. Hallegraeff, personal communication), and *Rhizosolenia cf. chunii,* which was associated with bitter tasting mussels in PPB after a massive bloom in August/September 1987 (Parry *et al*, 1989). Monitoring of the Bay for toxic microalgae is currently conducted by MSL (since 1987) with the assistance of the University of Melbourne Botany Department (for algal identification). Blooms have been ascribed to a number of possible causes, including changes in salinity, light regime and nutrient levels. There is no conclusive evidence to favour any one of the varying theories, thus making the prediction of bloom occurrences difficult.

| Species | First Record | Recorded Blooms | Toxin Type | Reference |
|---|---|---|---|---|
| **Dinoflagellates** | | | | |
| *Alexandrium catanella* | 1986 | 3(1988, 1991,1992) | PSP | Hallegraeff et al 1988 |
| *Gymnodinium mikimotoi* | N/A | | N/A | G.Hallegraeff |
| *G. pulchellum* | N/A | | N/A | pers. comm. |
| **Diatoms** | | | | |
| *Nitzschiella pseudodelicatissima* | 1991 | 1 (1991) | ASP | G.Arnott (in press) |
| *Rhizosolenia cf. chunii* | 1987 | 1 (1987) | Unknown | Parry et al 1989 |

**Table 2.** Species of toxic phytoplankton recorded from Port Phillip Bay, including; first record, recorded blooms and toxin type (N/A information not available).

| Toxin Type | Effects |
|---|---|
| ASP (Amnesic shellfish poisoning) | Vomiting, loss of balance, amnesia, death. |
| DSP (Diarrhetic shellfish poisoning) | Severe bouts of diarrhoea |
| PSP (Paralytic shellfish poisoning) | Headaches, nausea, vomiting, diarrhoea, muscular paralysis, respiratory paralysis causing death. |

**Table 3.** Phytoplankton toxin type and clinical symptoms.

**CHAPTER 3**

## 3.0. Ecophysiology

The response of phytoplankton to environmental conditions is of primary importance when attempting to understand their ecology. Laboratory studies of phytoplankton physiology, biochemistry and molecular biology are extensive, though translating laboratory results to the field is fraught with difficulties (see Fisher, 1979 for some examples). However, general trends may be cautiously implied from these data. This chapter will deal mostly with studies conducted in PPB and as such will not attempt to review current knowledge regarding phytoplankton ecophysiology in general (an enormous, if not impossible, task). This chapter is divided into four sections, each distinct in the type of component surveyed with regard to the phytoplankton environment, though it would be a mistake to neglect the inter-relatedness of all these factors in their influence on microalgae. The sections are :

1. Effects of Physical factors
2. Effects of Nutrients
3. Effects of Toxicants
4. Productivity

### 3.1. Physical factors

Salinity, temperature and light are the three main physical factors affecting phytoplankton in PPB and their levels in this area have been summarized in Chapter 1. The seasonal variations of light and temperature are particularly important, though the influence of man on these factors in PPB is minimal.

#### *3.1.1. Salinity*

Overall, phytoplankton have a fairly stable salinity environment in PPB. Generally, no effect is expected on phytoplankton ecophysiology from the salinity environment in PPB, with the possible exception of localized stratification. Stratification has been implicated as a factor in the initiation of phytoplankton blooms (Parry *et al*, 1989), though this is unconfirmed. The effects on phytoplankton of minor salinity stratification found in PPB are unknown but are expected to be minimal.

#### *3.1.2. Temperature*

Temperature plays a major role in phytoplankton growth and physiology, and this has been well documented in the literature. The variations in temperature in PPB are great enough to play a significant role in determining species composition and succession, as has been demonstrated in other marine systems (e.g. Goldman and Mann, 1980). Numerous studies have demonstrated varying growth responses of different microalgae to temperature (e.g. Goldman, 1977; Wood and Beardall, in preparation), and this may be a factor in initiating algal blooms. The effect of temperature on photosynthesis is also well documented (see Davison, 1991 for review) and this will be dealt with under productivity. As previously mentioned in Chapter 2, the cell:chlorophyll *a* ratio is influenced by temperature and could be a factor in interpreting seasonal chl *a* changes.

### *3.1.3. Light*

Light is essential for photosynthesis and thus the level and quality of light is of vast importance. Some species of phytoplankton will migrate in the water column in response to light levels (e.g. Sournia, 1982; Kahn and Swift, 1978) and this plays an important role in determining overall primary productivity and the distribution of pelagic herbivores. Nutrient availability also affects bouyancy of phytoplankton. In winter, light may be a limiting factor in PPB (Grant and Gayler, 1982). Water quality also plays a role in light attenuation. Highly turbid waters would be expected to quickly reduce the depth at which light levels could support photosynthesis. Off Werribee Farm, this is compounded by the presence of lignin in the sewage discharge, which absorbs blue light (Hickman and Axelrad, 1985). Blue light is an important component of PAR for phytoplankton (Dring, 1982). The effects of lowered blue light levels in PPB will be discussed in section 3.4. Furthermore, different phytoplankton species have characteristic light requirements and the availability of light can readily control successional phenomena (Richardson *et al*, 1983).

## 3.2. Nutrients

The range of effects resulting from changes in nutrient levels is well recorded and studied in laboratory cultures of microalgae. Particular interest has been focused on the roles of carbon (C), nitrogen (N) and phosphorus (P), as they are by far the major nutrients required by phytoplankton (Dring, 1982). Other nutrients can limit phytoplankton growth in certain circumstances (eg iron, Glover 1977, 1978). Most studies on phytoplankton ecophysiology in PPB relate to the macronutrients N and P.

### *3.2.1. Inorganic carbon*

The levels of inorganic carbon present in PPB (see section 1.6.1.) are expected to be typical of marine systems at about 2 mM and should not be limiting for phytoplankton growth and photosynthesis (Beardall, 1989).

### *3.2.2. Nitrogen and Phosphorus*

Nitrogen and phosphorus loading to PPB has dramatically increased since settlement of its shores (MMBW and FWD, 1973). The studies of N and P in PPB, in relation to phytoplankton, have been conducted in an attempt to understand and possibly predict eutrophication of the Bay's waters. Eutrophication can result from excessive nutrient loading (Table 4), with disastrous consequences for many marine organisms and commercial fisheries (see Bulthuis and Cowdell, 1982 for review). Generally levels of N and P in PPB are lower than those recorded for eutrophied systems (Table 1). Axelrad *et al* (1981) suggest that N is the limiting nutrient in PPB and this is generally confirmed by assessing nutrient levels in Table 1 and comparing these to the Redfield ratio of C : N : P = 106 : 16 : 1 for phytoplankton cells. N : P ratios in PPB range from approximately 0.2 : 1 in the central bay region, to >4 : 1 off Werribee. Bass Strait waters show a ratio of 0.93 : 1. Since N : P is required by phytoplankton cells in the ratio of 16 : 1, clearly most PPB waters have levels of N relative to P that are lower than is required to sustain extensive growth.

| Eutrophic Ecosystems | Chlorophyll (µg/ℓ) | Nitrogen (µM) | Phosphorus (µM) |
|---|---|---|---|
| Stockholm Archipelago | ⩽60 | | 20–170 ($PO_4^{3-}$) |
| Portsmouth Harbour | ⩽96 | 0.3–45 ($NO_3^-$), 3–48 ($NH_4^+$) | 0.7–4 ($PO_4^{3-}$) |
| Swanpool | 5–540 | 1.2–860 ($NO_3^-$+$NH_4^+$) | 0.06–63 ($PO_4^{3-}$) |
| Lake Maryût | | | ⩽32 ($PO_4^{3-}$) |
| Saronikos Gulf | | 0.5–45.7 ($NO_2^-$+$NO_3^-$+$NH_4^+$) | 0.1–14.5 ($PO_4^{3-}$) |
| Northern Adriatic Sea | ⩽13 | | |
| Ebrie Lagoon | ⩽53 | 0.98–50.1 ($NO_2^-$+$NO_3^-$+$NH_4^+$) | 0.11–2.1 ($PO_4^{3-}$) |
| Harrington Sound | | 3.0 ($NO_2^-$+$NO_3^-$+$NH_4^+$) | 0.03 ($PO_4^{3-}$) |
| Boston Harbor | | 1.4–51.4 ($NH_4^+$) | 0.5–3.5 ($PO_4^{3-}$) |
| Moriches Bay | | | 5–15 ($PO_4^{3-}$) |
| New York Bight Apex | 45–80 | 6.7–96 ($NO_3^-$), 2–28 ($NH_4^+$) | 1–4.8 ($PO_4^{3-}$) |
| Chesapeake Bay | 3.3–33 | 0.4–105 ($NO_2^-$+$NO_3^-$) | 1–2 (Total P) |
| Potomac Estuary | 25–125 | 10.7–228.6 ($NO_2^-$+$NO_3^-$+$NH_4^+$) | 2.6–38.7 (Total P) |
| James River | 50–100 | ⩽231 ($NO_3^-$) | 12.6 ($PO_4^{3-}$) |

**Table 4.** A summary of selected eutrophic systems (from Bulthuis and Cowdell, 1982)

**Table 4.** continued

| | | | |
|---|---|---|---|
| Chowan River | | $\leq 50$ ($NO_3^-$), $\leq 50$ ($NH_4^+$), $\leq 71$ (D.O.N.) | |
| Dickinson Bayou Estuary | 120-500 | | 5.8-17.7 (Total P) |
| Portage Inlet | 2-20 | 0-28 ($NO_3^-$), 1.5-4 ($NH_4^+$) | 2-7 ($PO_4^{3-}$) |
| Kaneohe Bay | 0.24-5.3 | 1.6-4.6 ($NO_2^-$+$NO_3^-$+$NH_4^+$) | 0.1-4 ($PO_4^{3-}$) |
| Tokyo Bay | $\leq 60$ | | |
| Seto Inland Sea | | | 0.9-1.1 (Partic. P) |
| Orielton Lagoon | | 7-57 ($NO_2^-$+$NO_3^-$), 14-360 ($NH_4^+$) | |
| Cockburn Sound | $\leq 100$ | <1-255 ($NO_2^-$+$NO_3^-$+$NH_4^+$) | 1.3-20.6 (Total P) |
| Peel-Harvey Estuary | | 69 (Total N) | 1.6 (Total P) |

Consequently, an increased N loading in the Bay is likely to stimulate phytoplankton growth (particularly when factors such as light and temperature are not limiting). Increasing the phosphate levels in PPB will generally not have an effect unless local N levels are low, or a concomitant increase in N occurs. Thus an increase in N loading to PPB will have far greater impact on phytoplankton biomass than increases in P. The exception is in Hobsons Bay and the mouth of the Yarra River, where P has been suggested to be the limiting nutrient (Grant and Gayler, 1982). The consequences of increasing the P loading in these areas is expected to be the same as those for N.

Fisher and Cowdell (1982) demonstrated that clones of four diatom species isolated from PPB were able to utilize dissolved organic nitrogen sources for growth. The diatoms incorporated N from these compounds as efficiently as they incorporated inorganic N.
Interestingly, Romeo and Fisher (1982), using three diatom species (clones of which were isolated from PPB and Western Port), demonstrated adaptation of the PPB clones to elevated levels of N. These adaptations were manifested in slightly larger cell sizes and higher growth rates. The adaptation of growth rate to elevated nutrient levels would facilitate algal blooms and have important ramifications in eutrophic systems. Increased N and/or P loading could allow the rapid growth of adapted species to eutrophic levels, resulting in algal community changes (Fisher, 1979; Bulthuis and Cowdell, 1982). The implications of altered N : P ratios for species composition is, however, poorly understood.

#### *3.2.3. Silicate*

The level of silicate required for phytoplankton growth is not normally expected to be limiting in PPB, though 'loss of silicate' from the water column is often due to localized uptake of this element by microalgae during growth (Dring, 1982). Biological depletion of silicate by diatoms will lead to this group being replaced by other species and is a normal successional phenomenon.

#### *3.2.4. Micronutrients*

The recorded levels of micronutrients required for microalgal growth in PPB are also not expected to be limiting (see Dring, 1982 for review) and in some cases may actually be toxic. This case will be discussed in the next section.

### 3.3. Toxicants

Toxicants have been the focus of many laboratory investigations (O'Brien and Dixon, 1976; Fisher, 1979; Murphy and Belastock, 1980; Fisher and Jones, 1981), and with the increasing sophistication in analytical techniques and equipment, new and novel approaches to detecting the effects of toxic compounds on microalgae have been possible (eg. Jones *et al*, 1987). The toxicants, and their levels in PPB, that will be discussed in this section, have been summarized in Chapter 1.

### *3.3.1. Metals*

The effects of heavy metals on phytoplankton are important for a number of reasons. The public health aspect needs to be addressed, as various filter feeding and other organisms higher in the food chain can concentrate heavy metals to levels toxic to humans. As phytoplankton are the base of many food chains, their ability to assimilate heavy metals is thus extremely important. Also, filter feeding organisms rely on phytoplankton for various dietary components. Any change in phytoplankton biomass, species composition and levels of dietary components will affect organisms at higher trophic levels. In this section, details of the effects of heavy metals will not be discussed and are reviewed by Fisher (1979) the effects of heavy metals on phytoplankton are summarised in Table 5. The material presented below will concentrate on studies conducted in PPB.

#### 3.3.1.1. Arsenic

No studies on the effects of arsenic on phytoplankton in PPB could be uncovered.

#### 3.3.1.2 Cadmium

The effects and effective levels of Cd on phytoplankton are reviewed by Fisher (1979) and Smith *et al* (1981). Jones *et al* (1987) investigated the effects of Cd on the fatty acid composition of the diatom *Asterionella glacialis* isolated from PPB. The results of this study indicate that the composition of essential fatty acids, required by higher trophic organisms, was altered. How this affects these organisms is not known, though a decrease in the nutritional value of phytoplankton is obviously important. It must be noted that the concentrations of Cd used in this study were 6.0 and 2.0 μM, whilst cadmium levels in PPB are usually below about 0.025 μM (3 μg $l^{-1}$). The effects of these levels of Cd on phytoplankton are unknown. Unpublished data by Fisher has been reported (Fisher, 1979), though the extent of this study is unknown.

#### 3.3.1.3. Chromium

No studies of the effects of chromium on phytoplankton in PPB could be found.

#### 3.3.1.4. Copper

The effects and effective levels of copper are reviewed by Fisher (1979) and Smith *et al* (1981). No studies on the effect of ambient levels of Cu on phytoplankton in PPB could be found, though reference to unpublished data by Fisher is made by Fisher (1979). The extent of this study is unknown.

#### 3.3.1.5. Lead

As with Cd and Cu, lead is reviewed by Fisher (1979) and Smith *et al* (1981). No studies on the effects of ambient Pb levels on phytoplankton in PPB could be found.

| TOXICANT | GROWTH INHIBITION | STIMULATORY AT LOW CONCN. | SPECIES SENSITIVITY | COMMENTS |
|---|---|---|---|---|
| <u>Hydrocarbons</u> | | | | |
| PCBs | + + + (0.1-10$\mu$gl$^{-1}$) | no | d > g > c | Estuarine organisms often more resistant than oceanic isolates. Stressed cells more sensitive |
| DDT, dieldrin etc. | + + (1-10$\mu$gl$^{-1}$) | no | " | |
| Aromatic hydrocarbons | + (50- > 100 $\mu$gl$^{-1}$) | in some cases | d > $\mu$flagellates | More volatile aromatic hydrocarbons (e.g. benzene, napthalene) are the most toxic. |
| <u>Heavy Metals</u> | | | | |
| Hg | + + + + + (0.2-0.6$\mu$gl$^{-1}$) | no | d > g > c | Organo-Hg compounds more toxic than free metal. Sub-lethal concentrations affect nutritional quality of algae. |
| Cu | + + + + ($\approx$ 3$\mu$gl$^{-1}$) | yes | " | Toxicity reduced by high levels of organics as chelating agent |
| Zn | + + + ($\geq$ 25$\mu$gl$^{-1}$) | yes | " | Acclimation of phytoplankton to high Zn loading has been recorded. Readily chelated by organic compounds in water. |
| Cd | + +($\geq$ 25$\mu$gl$^{-1}$) | no | " | Sub-lethal concentrations affect nutritional quality of algae. Not readily chelated in seawater |
| Pb | + ($\geq$ 1000$\mu$gl$^{-1}$) | no | " | |

**Table 5.** Summary of effects of major toxicants found in PPB on phytoplancton. (d= diatoms; g= green algae; c= cyanobacteria). Information extracted from Fisher (1979) and reference cited therein.

3.3.1.6. Mercury

The effects of mercury are also reviewed by Fisher (1979). Jones *et al* (1987) also investigated the effect of an organomercurial complex, which is reportedly more toxic than ionic Hg, on *Asterionella glacialis* fatty acid composition. This mercury-complex elicited similar effects to those noted for Cd, and the conclusions drawn regarding the effects on grazing herbivores would be similar. Again it should be noted that the mercury concentrations used by Jones *et al* (1987) were 0.2 and 0.6 μM, which are far higher than the usual PPB mercury concentrations of <0.5 nM (0.0005 μM). The effects of these lower levels of Hg on phytoplankton in PPB is unknown.

3.3.1.7. Nickel

No studies of the effects of nickel on phytoplankton in PPB could be found.

3.3.1.8. Zinc

The effects and effective levels of zinc are reviewed by Fisher (1979) and Smith *et al* (1981). No studies on the effect of Zn on phytoplankton in PPB could be found, though reference to unpublished data by Fisher is made by Fisher (1979). The extent of this study is unknown.

*3.3.2. Organic toxicants*

The effects of organic toxicants on phytoplankton are reviewed Fisher (1979) and O'Brien and Dixon (1976). The major effects are summarized in Table 5. No studies on the effects of hydrocarbons on phytoplankton in PPB could be found. Interpolation of research from other systems to PPB is microalgal responses would be possible if a detailed analysis of organic toxicant species and levels was available.

## 3.4. Productivity

One of the important aspects of phytoplankton communities is their role as primary producers, and this is related to their photosynthetic capacity. The level of microalgal productivity is important for a number of reasons, particularly;

1) The level of productivity is very important in determining the biomass higher in the food chain and

2) changes in productivity can be used to monitor water quality, and can indicate the presence of toxins not routinely measured.

Many environmental factors influence productivity, most notably temperature, light, nutrient levels and toxicants. As previously mentioned, algal photosynthesis is highly influenced by temperature (Davison, 1991). Grant and Gayler (1982) studied phytoplankton productivity in Hobsons Bay in an attempt to assess the possible effects of heated effluent from the Newport D power station. An annual cycle for productivity was observed, with low productivity in winter (<2 mg C $m^{-3}$ $hr^{-1}$ fixed) and high productivity (up to 10 mg C $m^{-3}$ $hr^{-1}$ fixed) in summer. Intense, short-term blooms, with a duration of less than a week, had measured productivities of

>200 mg C $m^{-3}$ $hr^{-1}$ fixed. These blooms appear to be a normal feature of Hobsons Bay (Grant and Gayler, 1982). This study also investigated the effects of temperature on photosynthesis. Data obtained demonstrated a species specific temperature above which productivity would greatly increase, suggesting that an increase in water temperature to between 25 and 27°C would increase local productivity greatly.

Axelrad *et al* (1979 and 1981) investigated the effect of treated sewage discharge on primary productivity, with particular emphasis on the nutrient enriched waters off the Werribee sewage-treatment Farm. As with the study by Grant and Gayler (1982), seasonal productivity changes were observed, with low levels in winter and high levels in summer. Axelrad *et al* (1979) found that productivity in the enriched waters 200 m off the coast of Werribee Farm ranged between 1 and 8.2 mg C $m^{-3}$ $hr^{-1}$ fixed, whilst in relatively oligotrophic waters off the coast near Queenscliff, productivity ranged between 0.67 and 3.9 mg C $m^{-3}$ $hr^{-1}$ fixed. For 6 out of 9 sampling times, productivity in enriched waters was significantly greater than in waters unaffected by discharge. The same pattern was observed by Axelrad *et al* (1981). In this study, three sites, with distances from Werribee farm of 2, 5 and 30 km, were surveyed for phytoplankton productivity. Corresponding productivity ranged from 0.54 to 16.53, from 0.42 to 8.32, and from 0.03 to 7.38 mg C $m^{-3}$ $hr^{-1}$ fixed, with annual productivities of 73, 43 and 33 g C $m^{-2}$ $yr^{-1}$ fixed, for stations at 2, 5 and 30 km respectively. Higher productivity in these two studies correspond to elevated nutrient levels although productivity values are not particularly high when compared to other coastal systems (Beardall *et al,* unpublished data; Clayton and King, 1990; Harris *et al* 1987). Axelrad *et al* (1981) suggest that winter productivity is limited by light and temperature, whilst summer productivity is nutrient limited. This observation was also made by Grant and Gayler (1982). From this data it was also apparent that productivity was lower at a station 200 m off the coast from Werribee Farm than at the station 2 km off the coast. Hickman and Axelrad (1985) suggest that lignin in the sewage discharge from Werribee Farm may be responsible for this observation. Lignin selectively absorbs blue light (Hickman and Axelrad, 1985). Experiments conducted by Hickman and Axelrad (1985) demonstrate that there is a significant reduction in productivity as a result of selective attenuation of blue-light, and that this is a species specific phenomenon. It was suggested that removal of lignin from Werribee Farm sewage discharge would increase phytoplankton productivity, in the waters directly off the Werribee Farm coast, by a factor of 2 to 3. The authors of this report also suggest that removal of lignin from the discharge could lead to eutrophication of these waters.

### 3.5. Concluding Remarks

Each of the environmental components mentioned above was treated separately for clarity. However it must be noted that the inter-relationships between all of these components are complex and difficult to unravel from the studies conducted. This is certainly the case, for example, for the Complex Effluent testing program, run by MSL in conjunction with the EPA, in which complex industrial effluents were tested for their effects on the growth of a common local diatom *Skeletonema costatum* (Holmes and Gibbs, 1985). The results demonstrated various levels of toxicity of these effluents. The number of components present in many of these effluents makes analysis of the toxic components difficult (as mentioned above) though measurement of general toxicity with these methods is possible.

## <u>CHAPTER 4</u>

### 4.0. Conclusion

This chapter is divided into four sections.

1. Synopsis of Current Knowledge
2. Effects of Increasing Nutrients/Toxicants
3. Available Databases
4. Recommendations

### 4.1. Synopsis of Current Knowledge.

As a coastal embayment, with large population centres and concentrated industries on its shores, PPB can be considered fairly unpolluted when compared to other similar systems (Table 4.). Physical and chemical factors within the Bay, which affect phytoplankton, are generally within acceptable levels (see SEPP objectives, Victorian Government, 1975). Some areas within the Bay, though, have elevated levels of nutrients and/or toxicants, turbidity problems or localized temperature fluctuations resulting from the influence of man. The continued monitoring of these and other Bay areas is, therefore, of utmost importance for future environmental and recreational activities in PPB.

Current spatial and temporal phytoplankton distributions in the Bay follows complex patterns and are dependent on factors such as water temperature, light availability, nutrient availability and predation pressure. Some components of these factors follow annual seasonal patterns, while others fluctuate more randomly (though patterns of input of waste into PPB from Werribee Farm are highly controlled in occurrence). General patterns of phytoplankton distribution can be summized from chl *a* data, though problems in interpretation exist (Chapter 2). Research into remote sensing for chl *a* is continuing and if the problems associated with this can be reduced, more complete chl *a* distributions (spatial and temporal) in PPB will be possible.

As can be seen from this review, there is a general paucity of knowledge regarding the ecology of phytoplankton in PPB. Only recently have phytoplankton community monitoring programs been used as a tool to assess phytoplankton in PPB, and even these programs are not complete in their coverage of general Bay areas, nor do they include the smaller but often extremely important microalgae. The monitoring of phytoplankton blooms appears to be restricted to toxic-species. Data regarding the occurrence of all blooms in PPB is important, as knowledge on the mechanisms of bloom occurrence can be gained, allowing the more accurate future prediction of both toxic and non-toxic blooms.

It is apparent that knowledge of the ecophysiology of PPB phytoplankton specifically is almost non-existent (Chapter 3) and our present understanding is based almost entirely on interpolation from other systems. More information in this area is required. A current survey of literature regarding the effects on phytoplankton of the various toxins recorded in PPB would be an important first step as much research has been focused on this aspect of microalgal physiology and biochemistry. This base of information would allow a more thorough examination of the research needed and would establish a base of information on the general effects of toxicants on algae. The effects of the PPB nutrient regime on phytoplankton is also poorly understood. Inferences can be drawn from information relating to other marine systems, though the uniqueness of the PPB system does require its own baseline of research. Of particular concern is the lack of knowledge regarding the primary productivity of PPB waters. The only studies conducted have been very isolated in spatial scope and for only short periods. A more long-term and expansive study is needed, and along with phytoplankton community information would be a powerful database, useful not only in monitoring the Bay, but in combination with information on zooplankton and other trophic groups, would allow a better understanding of the energetics of the Bay and the ecology of our fisheries. A summary of references regarding phytoplankton ecology in PPB is presented in Table 6.

### 4.2. Effects of Increased Nutrient/Toxicant levels

The effects on phytoplankton of an increase in nutrient levels in PPB by 50% is hard to predict conclusively, given the paucity of knowledge of the ecophysiology of PPB phytoplankton, but could have disastrous consequences, particularly regarding community structure and eutrophication problems. It has already been pointed out that increasing the nitrogen loading to PPB could potentially stimulate phytoplankton growth and productivity in the Bay (refer Section 2.4). A number of areas in PPB already experience blooms of toxic and non-toxic phytoplankton and a rise in the nutrient load to PPB will most likely increase the number, intensity, extent and length of bloom events. This would adversely effect commercial and recreational shellfish fisheries, if increasing toxic blooms occurred, while eutrophication resulting from non-toxic blooms can cause fish kills (via anoxia) and are aesthetically unpleasant (a problem for recreational Bay users and tourism). No current eutrophication is evident in PPB and with the present levels of nutrients, should remain as such. Increasing toxicant input into PPB is also undesirable. Heavy metals, though at levels that may not apparently strongly affect phytoplankton, are assimilated by phytoplankton and thus passed into the food chain where they are concentrated by shellfish and fish. This would lead to an increase in public health risk from consumption of fish and shellfish from PPB, this would also affect commercial fisheries. The same is true for organic toxicants and thus increasing their levels is undesirable.

### 4.3. Databases

A number of databases are currently available and relevant to phytoplankton in PPB, These are :

The EPA fixed site monitoring program
The MSL phytoplankton monitoring program

The EPA fixed site monitoring program currently covers 3 sites in PPB (Fig. 2). Measurements are taken of the following parameters; pH, dissolved oxygen (% saturation and mg $l^{-1}$), secchi disk data, total N, total P, chl *a*, suspended solids, metals (As, Cd, Cr, Cu, Hg, Ni, Pb and Zn) (EPA, 1990).

The MSL phytoplankton monitoring program currently covers fifteen sampling stations and started on 21 March 1990. The stations and sampling regime are as follows:

Shellfish growing areas; Grassy Point (Portarlington) (S), Clifton Springs (T), "Arthur the Great" (Avalon) (S), Beaumaris (T), Wolley Reef (Frankston) (T), Balcombe Bay (Mornington) (S), Dromana (S) and Blairgowrie (T).

Early warning areas; Werribee (T), Altona (S), Williamstown (T), Port Melbourne (S), St. Kilda (S) and Sandringham (T) as well as an early detection station at Corio Quay (Corio Bay) (S).

The sampling regimes are:

T Chl *a* at intervals of 1m depth, a profile of salinity, temperature, dissolved oxygen and light attenuation, as well as an integrated water sample for nutrient analysis (with the exception of the Beaumaris station). Phytoplankton species and abundances for all species are recorded.

S Surface water measurements of chl *a*, salinity, temperature and dissolved oxygen (this is done at the Beaumaris station) and a surface water sample for nutrient analysis is taken at St. Kilda. If toxic or potentially toxic species are noted at these sites, an estimation of their abundance is made.

### 4.4. Recommendations

Though the above programs supply information relevant to phytoplankton in PPB, a number of shortcomings are evident.

The sites for phytoplankton monitoring should be expanded (Fig. 2), as this would be important for gaining a more comprehensive picture of phytoplankton distribution in space and time.

Measurements of phytoplankton productivity must be made, and conducting this in coordination with phytoplankton monitoring and nutrient analysis would supply the most comprehensive information. Cogniscance must be made of the potential role of nanno- and pico- plankton in the ecology of PPB. Added to this, measurements of PAR through the water column should be made. Conversion of all stations to a T type monitoring regime should be considered. This could be conducted as a component of both the EPA and MSL programs. These data would allow vastly more accurate modelling of PPB phytoplankton ecology and their role in PPB food chain energetics.

Assessment of the fractions of dissolved organic carbon present in PPB waters would be advantageous, particularly as vastly different toxicity levels (gram for gram) exist for different organic compounds. This would allow a more accurate assessment of the levels of toxicity of PPB waters to their phytoplankton communities. This could be included as a component of the EPA fixed site monitoring program.

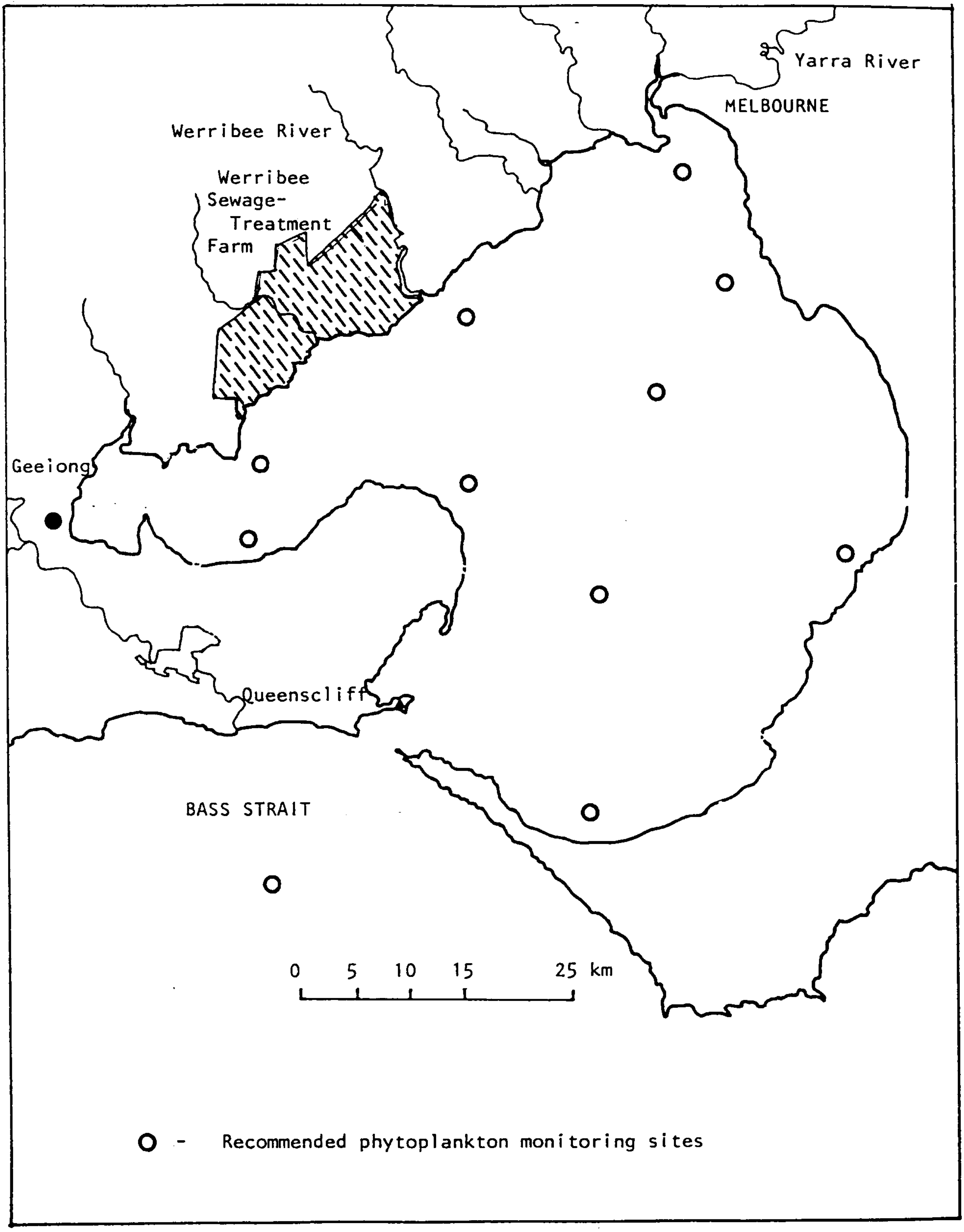


**Figure.2** Recommended phytoplankton monitoring sites. (see text for details)

| Reference | Title | Comments |
| --- | --- | --- |
| Arnott,GH, 1990 | Surveillance of toxic marine algae and biotoxins in shellfish in Port Phillip Bay, | Important. Details the phytoplankton monitoring scheme in PPB. |
| Arnott,GH, inpress | Bloom of a non-toxic strain of the alga *Nitzschia pseudodelicatissima* in Port Phillip Bay. | Important reference. Monitoring of possibly toxic phytoplankton bloom Details species and possible toxins. |
| Axelrad,DM, 1978 | Effect of the Werribee Sewage Treatment Farm Discharge on Phytoplankton Productivity, Biomass and Nutrients in Port Phillip Bay. | Important reference. One of the few phytoplankton productivity studies conducted in PPB, limited in scope though. |
| Axelrad,DM et al, 1979 | Microalgal productivity as affected by treated sewage discharge to Port Phillip Bay, | Important paper as it is one of few productivity studies in PPB, though limited in scope. |
| Axelrad,DM et al, 1981 | The effects of treated sewage discharge on the biota of Port Phillip Bay, Victoria, Australia. | Important PPB phytoplankton productivity paper, limited in scope |
| Brown,VB et al, 1980 | The effects of sewage effluent on the macrophytes off Werribee, Port Phillip Bay. | Useful for PPB physio-chemical information, otherwise of little use for the PPB phytoplankton study |

**Table 6.** Tabulated synopsis of current and past research on phytoplankton in PPB.

| | | |
|---|---|---|
| Bulthuis,DA; Cowdell,RA, 1982 | An annotated bibliography of eutrophic marine ecosystems. | Not related to PPB. A base of information regarding eutrophic systems that may be relevant to PPB. |
| Burns,KA; Smith,JL, 1980 | Hydrocarbons in Victorian Coastal Waters, Details hydrocarbon levels in PPB. | Relevant to PPB phytoplankton study. |
| Environment Protection Authority, 1981 | Heavy metals in the sediments of Port Phillip Bay and input streams | Of little use to the PPB phytoplankton study. |
| Environment Protection Authority, 1983 | Port Phillip Bay water quality, June 1980 - May 1982. | Highly important data. Contains levels of nutrients, toxicants and chl *a* as well as physical data. Important for PPB phytoplankton study. |
| Environment Protection Authority, 1990 | Port Phillip Bay 1988 Yearly Report (Water Quality Data WQD 90/009) | Highly important data. Contains levels of nutrients, toxicants and chl *a* as well as physical data. Important for PPB phytoplankton study. |
| Fisher,NS, 1979 | A review of marine pollution in Australia as it relates to the phytoplankton. | Important review of information in relation to Australian systems, relevant to PPB. |
| Fisher,NS; Cowdell,RA, 1982 | Growth of marine planktonic diatoms on inorganic and organic nitrogen. | One of few papers on nutrient physiology of PPB phytoplankton. Useful. |

**Table 6.** continued.

| | | |
|---|---|---|
| Grant,BR; Gayler,KR, 1982 | Phytoplankton productivity study Chap. 6 - Supplementary Papers. In: The Heated Effluent Study - Final Report. | Important reference. One of the few phytoplankton productivity studies. Limited to Hobsons Bay, but contains detailed information on local physio-chemical characteristics and chl *a* distributions. |
| Hallegraeff,G et al, 1988 | Ballast water a danger to aquaculture. | Important paper for PPB, particularly regarding methods for reducing the import of toxic-phytoplankton. |
| Hallegraeff,GM, 1984 | Species of the diatom genus *Thalassiosira* in Australian waters | Taxonomic study, of limited importance to PPB study. |
| Hallegraeff,GM; Bolch,CJ, 1991 | Transport of toxic dinoflagellate cysts via ships' ballast water. | Important paper for PPB, particularly regarding methods for reducing the import of toxic-phytoplankton. |

**Table 6.** continued.

| | | |
|---|---|---|
| Hallegraeff,GM et al, 1991 | Species of the toxigenic dinoflagellate genus *Alexandrium* in southeastern Australian Waters | Highly important. reference. Details the distribution and species of an important toxic dinoflagellate genera in PPB. Highly relevant to PPB phytoplankton study |
| Hallegraeff,GM et al, 1988a | Three esturine Australian dinoflagellates that can produce paralytic shellfish toxins. | Important reference on toxic-phytoplankton. Notes first record of species. Highly relevant to PPB study. |
| Hickman,NJ; Axelrad,DM, 1985 | The effect of a coloured waste stain on marine phytoplankton productivity. | Highly important paper. Details some effects a sewage discharge component on phytoplankton productivity in a small area of PPB. |
| Hill,DRA, 1991 | *Chroomonas* and other blue-green Cryptomonads | Taxonomic study, of limited importance to PPB study. |
| Hill,DRA, 1991 | A revised circumscription of *Cryptomonas* (Cryptophyceae) based on examination of Australian strains. | Taxonomic study, of limited importance to PPB study. |
| Hill,DRA; Wetherbee,R, 1988 | The structure and taxonomy of *Rhinomonas pauca* gen. et sp | Taxonomic study, of limited importance to PPB study. |

**Table 6.** continued.

| | | |
|---|---|---|
| Hill,DRA; Wetherbee,R, 1989 | A reappraisal of the genus *Rhodomonas* (Cryptophyceae) | Taxonomic study, of limited importance to PPB study. |
| Holmes,NJ; Gibbs,CF, 1985 | Complex effluent testing program, EO1, final report. | Useful reference, particularly as a basis for further studies on synergystic effects of toxins. |
| Huisman,JM, 1989 | The genus *Ceratium* (Dinophyceae) in Bass Strait and adjoining waters, Southern Australia | One of a number of taxonomic studies, limited in use. |
| Jeffrey,SW; Hallegraeff,GM, 1990 | Phytoplankton ecology of Australasian waters. | Review of phytoplankton ecology. Relevant to PPB, though not highly useful. |
| Jones,GJ et al, 1987 | The effect of mercury and cadmium on the fatty acid and sterol composition of the marine diatom *Asterionella glacialis* | Important reference. Rare study of metal effects on a phytoplankton species isolated from PPB, though metal levels in this study are much higher than those found in PPB. |
| Longmore,A et al, 1990 | Monitoring of Water quality in Port Phillip Bay, 1985-1986. (SRS 89/003.) | Highly important data. Contains levels of nutrients, toxicants and chl *a* as well as physical data. Important for PPB phytoplankton study. |

**Table 6.** continued.

| | | |
|---|---|---|
| McFadden,GI et al, 1986 | A study of the genus *Pyramimonas* (Prasinophyceae) from south-eastern Australia | One of a number of taxonomic studies, limited in use. |
| McFadden,GI et al, 1987 | Electron microscopic observations on *Pyramimonas olivaceae* N.Carter (Prasinophyceae, Chlorophyta) | One of a number of taxonomic studies, limited in use. |
| Mickelson,MJ; Bulthuis,DA, 1985 | Dissolved oxygen in bottom waters of Port Phillip Bay in March 1982 | Of little importance to PPB phytoplankton ecology. |
| MMBW and FWD, 1973 | Environmental study of Port Phillip Bay : Report on phase one 1968-71. | Highly important historical doccument. The baseline used for later EPA and MSL studies. Contains physio-chemical data, some species information (quite limited) and nutrient response information for some species present. |
| Moestrup,O; Hill,DRA, 1991 | Studies on the genus Pyramimonas from Australia and European Water Including the Description of *P propulsa* sp nov and *P mitra* sp nov, | Taxonomic study, of limited importance to PPB study. |
| Parry,GD et al, 1989 | Toxic effects of a bloom of the diatom Rhizosolenia chunii on shellfish in Port Phillip Bay, southeastern Australia. | Details a link between a phytoplankton bloom and shellfish toxicity. Important for PPB phytoplankton study. |

**Table 6.** continued.

| | | |
|---|---|---|
| Romeo,AJ; Fisher,NS, 1982 | Intraspecific comparison of nitrate uptake in three marine diatoms. | One of the few studies regarding phytoplankton nutrient physiology in PPB, useful, though limited in scope |
| Saunders,J; Goudey,R, 1990 | Trends in Port Phillip Bay chlorophyll-a data, 1970-1986. | Important analysis of disperse data sets of chl a distributions and concentrations. Accomplished a difficult analysis, and indicates trends in the data over the 1970-1986 period. |
| Smith,DJ et al, 1981 | Distribution and significance of copper, lead, zinc and cadmium in the Corio Bay ecosystem. | Detailed metal concentrations in Corio Bay, contains a basic review of the effects of metals on phytoplankton. |
| Smith,JD; Longmore,AR, 1980 | Phosphate distribution in Bass Strait and south-eastern Australian coastal waters. | Important reference. Gives a comparative view of P levels in Bass strait and in PPB. Demonstrates that PPB is indeed P enriched environment. Highly relevant to PPB phytoplankton study. |
| von Stosch,HA, 1985 | Some marine diatoms from the Australian region especially from Port Phillip Bay and Tropical North-eastern Australia | Taxonomic study, of limited importance to PPB study. |

**Table 6.** continued.

| | | |
|---|---|---|
| von Stosch,HA, 1986 | Some marine diatoms from the Australian Region, especially from Port Phillip Bay and tropical North-eastern Australia. II Survey of the Genus Palmeria and of the Family Lithodesmiaceae including the New Genus Lithodesmioides. | Taxonomic study, of limited importance to PPB study. |
| Talbot,VW, 1987 | Relationship between lead concentrations in seawater and in the mussel Mytilus edulis : A water-quality criterion. | Useful only as a source of metal concentrations |
| Victorian Government, 1975 | State environment protection policy (The waters of Port Phillip Bay) | Original water quality specifications for PPB (SEPP objectives). |

**Table 6.** continued

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