
The Findings 1992-1996

Publication Number: ISSN 1324-7905

The 4 year, $12 million Port Phillip Bay Environmental Study was principally funded by Melbourne Water and managed by CSIRO.

For more information visit Melbourne Water's Internet site http://www.melbwater.vic.gov.au

MELBOURNE WATER

Front cover photographs

Rosebud Beach, Port Phillip Bay, Victoria

Yellow Zoanthids *Photographer: Peter Kinchington*

Seal on Portsea Beach *Photographer: Yanni Delaportas*

Larval Jellyfish *Photographer: Peter Kinchington*

FOREWORD

Port Phillip Bay is one of Victoria's most precious natural assets and a significant feature of the Australian coastline. It is the entrance to one of Australia's busiest ports and supports major commercial and recreational fishing activities. The Bay is the focus of a growing tourism industry and an important part of the life of many Victorians. With over three million people currently living around its shores, it is essential that the multiple uses of the Bay are properly managed and that the Bay is protected for the enjoyment of future generations.

CSIRO was commissioned by the Victorian government to design and manage a major environmental study of the Bay. The Port Phillip Bay Environmental Study is the most comprehensive and integrated environmental audit undertaken on a coastal ecosystem in Australia. The aims of the Study were to assess the health of the Bay, identify the factors having an environmental impact and determine how best to manage the Bay in the long term.

To achieve its objectives, CSIRO assembled a multi-disciplinary team of researchers from State and Commonwealth agencies, universities and private consultants. Twenty-nine research organisations were involved and over forty-seven major research tasks were completed by some of Australia's leading scientists. The Study was carried out in a spirit of collaboration and cooperation. Without it we would not have succeeded in drawing together all the various threads into a verified set of conclusions. Much of the data gathered will be used in a numerical model which will be used to predict and avert potential problems.

This document presents the key findings of the four year, $12 million Port Phillip Bay Environmental Study, which was completed in June 1996. Managed by CSIRO, and principally funded by Melbourne Water, the Study was supervised by a Management Committee chaired by the Department of Conservation and Natural Resources (now Department of Natural Resources and Environment). Also represented on the Committee were the Environment Protection Authority, Melbourne Water, Melbourne Parks and Waterways, and Port of Melbourne Authority.

CSIRO acknowledges the contributions made by the many individuals, research teams and organisations involved in the Study. Their work will play a significant part in the future preservation of the Bay.

CSIRO was pleased to accept the management of the Port Phillip Bay Environmental Study and looks forward to continuing to utilise its breadth of knowledge, expertise and management skills to assist with other equally important national issues and to help achieve a greater understanding of the complex and exciting world we live in.

Dr Malcolm McIntosh
Chief Executive CSIRO

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This plate shows the salinity (saltiness) of Port Phillip Bay waters, measured monthly over two years. The lighter blue areas in the northeast of the Bay show the reduction in salinity caused by freshwater flowing into the Bay from the Yarra and other rivers and creeks. The dark blue areas, from January1995 to March 1995, show the rise in salt content of the Bay due to drought. With so little freshwater inflow, the Bay fills with the salty water of Bass Strait which is brought in by the tides.

Plate 2
Water Temperature - Seasonal Variation

This plate shows the temperature of the water in Port Phillip Bay measured monthly from May 1993 to March 1995. Temperatures range from a winter minimum of around 10°C up to 22°C or more in summer. Temperature affects many biological processes in the Bay. In warmer months, animals and plants grow faster and bacteria are more active in the sediments. Many fish migrate into and out of the Bay to feed and breed in response to seasonal temperature changes.

Plate 3
Chlorophyll *a* - Seasonal Variation

This plate shows the changing chemical state of the Bay in response to varying input from the catchment. In the wet spring of 1993, increased river inflow brought in the plant nutrients ammonia, nitrite and nitrate, phosphate and silicate. This resulted in high algal growth in the northeast of the Bay as shown by the high chlorophyll *a* levels. In the dry period (January 1995), where there was little river inflow, nutrient inputs are significantly reduced, resulting in minimal algal growth and very clear water.

Plate 4
Phytoplankton Composition - Mean Seasonal Variation

Taken over a five year period (1990-1994), this plate shows the “typical” composition and concentration of phyto-plankton at different times of the year. There are six categories of these microscopic plants but the majority are diatoms. They are represented by the green sector. Most phytoplankton occur in the northeast of the Bay as a result of nutrient inputs from the Yarra River.

Modelling Predictions

The Port Phillip Bay Environmental Study has constructed a numerical model which divides the Bay into 59 “boxes”. The predictive model, one of very few in the world, will be used to manage nitrogen loadings to the Bay. The model predicts, approximately, the inputs from the catchment and the effects of climatic conditions. The first application of the model was to predict when the Bay might “go green” from too much nitrogen input. For example, the top line of maps shows the distribution of dissolved inorganic nitrogen (DIN) in typical summer (A) and winter (B) conditions and what would happen to the Bay at three times the current loading (C). The second line shows the distribution of phytoplankton (microscopic algae living in the water) in summer (D) and winter (E) and the effects of three times the present nutrient loading (F). The (D) and (E) distributions correspond to conditions observed over many years of surveys. As illustrated, while the Bay is coping well at current nutrient levels, it is at serious risk if nutrient levels are radically increased, and will be in a eutrophic state at three times the current nutrient loading.

BACKGROUND

Melbourne has been extremely fortunate that Port Phillip Bay, one of its major assets and most attractive features, has stayed in such good health. All around the world, the health of other bays and estuaries has suffered enormously through the growth of cities and urban areas around their coastlines.

To keep the Bay in good condition it is necessary to determine how the ecological system works as a whole.

Over the past four years, the Bay has been at the centre of one of Australia's most extensive research projects - the Port Phillip Bay Environmental Study (PPBES). The aims of the recently completed Study were to assess the health of the Bay, identify factors that are having an environmental impact and determine how to best manage the Bay in the long term.

Scientists measuring salinity

The $12 million Study, managed by CSIRO and principally funded by Melbourne Water, examined the ecology of the Bay, including the abundance of plant and animal life and how species interact, the level of inputs entering the Bay and how the ecosystem deals with them, and the physical systems affecting this process.

A major element of the project was the development of a mathematical model of the physical and ecological processes occurring in the Bay. This model, tested successfully against actual measurements and observations, will provide a powerful predictive tool for use in Bay management and future marine projects.

In bringing together all these components of research and model development, the Port Phillip Bay Environmental Study has been the most totally integrated project of its kind ever carried out in Australia.

THE STARTING POINT

The Port Phillip Bay Environmental Study (PPBES) was similar in its aims and objectives to a number of other coastal ecology studies around the world.

The Study was able to use the discoveries from these overseas studies, and to use large amounts of Bay data collected over many years. For example, water quality data (in the form of nutrient concentrations) has been collected since 1947.

Through new field work and modern data handling, the Study brought together a consolidated databank of historical and current information.

A critical factor in the planning, organisation and performance of the Study was the high level of marine research expertise available in Victoria. The contribution made by these experienced specialists and scientists has been invaluable to the Study's success.

MAJOR OUTCOMES OF THE PPBES

Assessing toxicant dangers

Toxicants coming into the Bay include heavy metals, pesticides and petrochemicals. The measurement of their input levels, and distribution in the Bay waters, sediments and organisms, have provided a more detailed picture of their place in the ecosystem.

Study results show the overall toxicant levels are continuing to decline, and that the toxicants entering the Bay are largely "locked up" in the sediments. Although levels need to be monitored, present concentrations are well below accepted warning or danger limits.

Balancing the nitrogen budget

Greater understanding of the nitrogen cycle in the Bay – previously a critical gap in the knowledge of the Bay ecosystem – was a major gain of the Study.

Researchers have described the major nitrogen pathways in the Bay and have quantified the major pools and fluxes. They have shown that, because of the rapid turnover of nitrogen in the populations of suspended micro-organisms and seafloor organisms, flushing is not an important process. The nitrogen that is put into the Bay stays in the Bay and is assimilated there.

Sediments have turned out to be the primary determinant of water quality in the Bay. They were the least understood, but subsequently most important component of the ecosystem. The research results in this area caused changes to be made to a number of tasks in the course of the Study. Researchers were able to close the nitrogen budget for the Bay and to bring to light the key role of seafloor organisms in determining the water quality.

Defining critical nutrient load

The Study has shown that the present nutrient load to the Bay, while not causing eutrophication, is having some measurable effects. Consequently a modest reduction in the present nutrient load, to safeguard the Bay against climate variability and heavy rainfall events, would be prudent.

The researchers have also been able to define the critical nutrient load (using mathematical modelling), beyond which irreversible damage to the Bay would occur.

Highlighting biodiversity

The Study Design placed considerable emphasis on nutrient and toxicant loads, however, researchers have now concluded that conservation of biodiversity in the Bay is equally important for sustainable management.

Not foreseen in the Study Design was the discovery that the introduction of a number of exotic or alien species of organisms into the Bay has already had an observable effect on its ecology.

Modelling the processes

Throughout the Study, CSIRO scientists constructed numerical models to express the observed processes in mathematical terms.

The development of the Port Phillip Bay Integrated Model has produced the first fully-integrated ecological model for a marine ecosystem in Australia.

Predictions generated by the model, using historical and current data, have closely matched actual observations. Researchers are now in a much better position to make predictions about future states of the Bay ecosystem and the results of possible management actions.

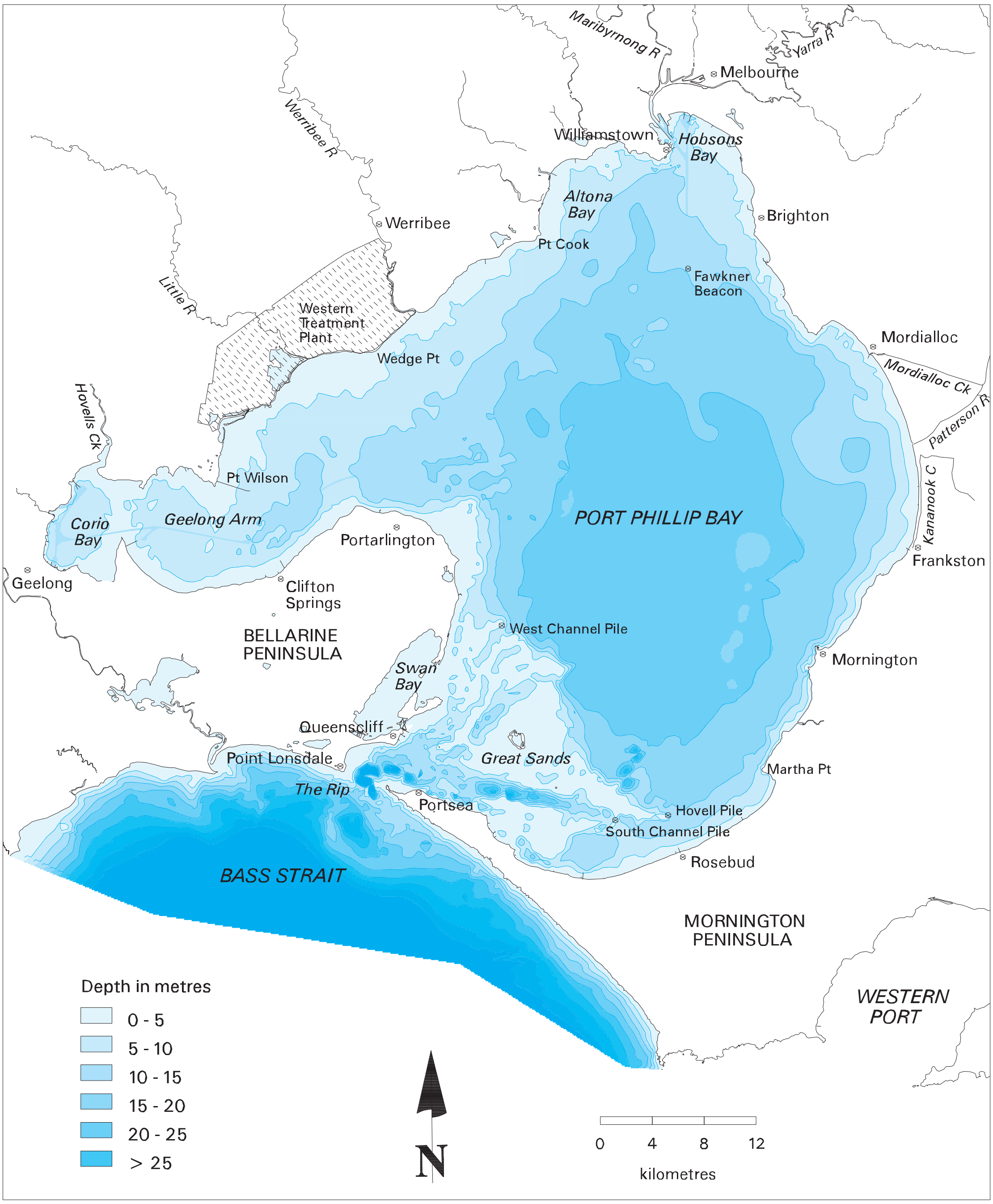


Figure 1
Locality map of Port Phillip Bay

ORIGINS OF THE BAY

Port Phillip Bay took on its present shape about 8,000 years ago. In the last glacial period, which ended about 18,000 years ago, sea level was about 130 metres lower than it is today. The Yarra, Werribee and Little Rivers, with Kororoit Creek, formed a delta that reached the sea between Cape Otway and King Island.

As the ice-caps receded the sea level rose, flooding the delta and the river valleys, forming what is now recognised as Port Phillip Bay. Wave action deposited sand to form the Nepean Peninsula, leaving only the present narrow entrance to the Bay at The Rip.

The whole bed of the Bay is covered with sand about one metre thick, with another metre of silt and mud in the deep central basin.

SIZE AND VOLUME

The Bay is very large in area, but also very shallow.

Length:	58 kilometres (Altona to Rye)
Width:	41 kilometres (Portarlington to Seaford)
Depth:	The greatest depth is 24 metres. Nearly half the Bay is less than 8 metres deep.
Volume:	25 cubic kilometres
Coastline:	264 kilometres
Total area:	1,950 square kilometres
Catchment area:	9,790 square kilometres
Population:	Over 3.2 million people live around the Bay.

WATERS OF THE BAY

Salt content

Port Phillip Bay is a marine system. Its waters have the same salt content as seawater, and all the animals and plants present are marine species. This is despite the barrier presented by the Great Sands at the southern entrance and continual input of fresh water by the Yarra River and other streams.

About 660 cubic kilometres of ocean water enter The Rip every year through tidal action, of which about 25 cubic kilometres (or less than 4%) mix with Bay waters. Freshwater input from all sources is about 2.9 cubic kilometres per year, while evaporation removes about 2.3 cubic kilometres of water each year.

This high ratio of salt water to freshwater input (over 40 times) ensures that, in the long term, the Bay waters have a salt content similar to Bass Strait.

Large seasonal variations in freshwater input contribute to seasonal variations in salinity. This “moving picture” is illustrated in Plate 1.

Water movement

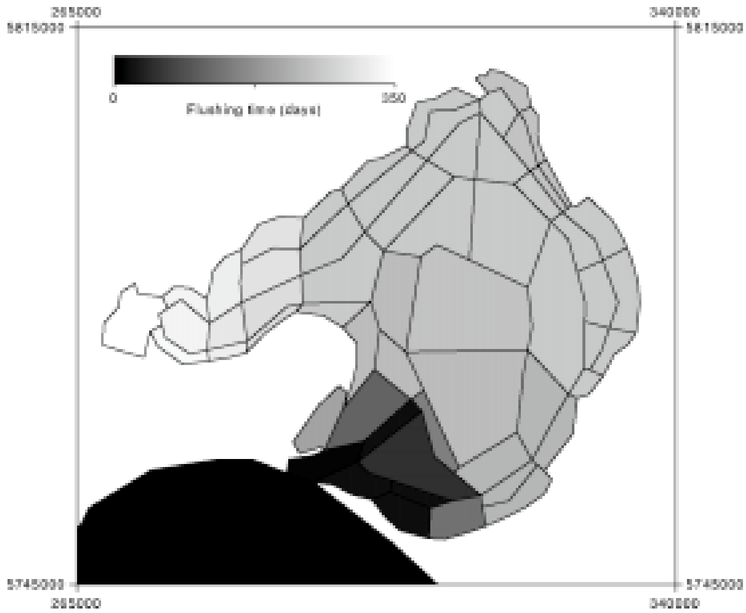
The Bay waters are in constant motion, being driven by three natural forces:

- *tidal movement*
- *the wind*
- *salinity and temperature gradients.*

Tidal movement is the predominant force. Twice a day, the ocean tides pour in through The Rip, raising the sea level by up to a metre at The Heads. As the water spreads out into the Bay, its velocity decreases and the rise in water level is reduced to about 0.6 metre.

Although the rise in Bay water level at each flood tide is due to the Bay waters being pushed north by the incoming Bass Strait waters, very little mixing occurs. The volume of the Bay is 25 cubic kilometres, and since this is about the volume of Bass Strait water that mixes with Bay water annually, the flushing time of the Bay is a year or more.

Figure 2
Flushing times for each box in the transport model with respect to Bass Strait



The transport model developed for the Bay divides the Bay into a pattern of discrete “boxes” or cells. Figure 2 uses this arrangement to illustrate the flushing (or total replacement) times for the various zones in the Bay.

The south of the Bay usually shows the influence of Bass Strait water, while the north of the Bay shows the influence from the Yarra River outflow and other fresh-water sources. The Geelong Arm and Corio Bay, because of their position off the main Bay, have even more limited circulation.

The wind is the second most important factor in water circulation. In fact, any net movement of Bay waters is almost entirely due to wind rather than the tides.

The wind has more effect on the shallow edges than the deeper centre, setting up circulation eddies if the wind is constant. Most of the time, however, the waters of the Bay move in rapidly changing patterns as the wind changes. Current measurements in the Bay show net movement of water varying from a few hundred metres per day to five kilometres per day, with deeper water moving in different directions to surface water. As Figure 3 indicates, the deeper currents can sometimes move at higher speeds than the surface currents.

These movements are important in transporting inputs from the catchment away from their source and dispersing them through the Bay.

Figure 3
Mean current measured for 17-18 May 1994.

Data from lower current meters are shown as grey arrows, upper meters are shown as black arrows. Arrow length is directly proportional to current speed. Mean wind velocity (measured at Hovell Pile) is also shown.

Salinity and temperature gradients are the third factor in water movement. Differences in salinity and temperature between locations occur frequently across the Bay and the Great Sands.

Temperatures may be higher or lower (depending on air temperature) at the edges of the Bay compared to the centre, since the shallow edges have a smaller heat capacity. Similarly, with Bass Strait being much deeper than the Bay, Bay waters are generally warmer than Bass Strait in summer and cooler in winter. Warmer water, being less dense, will flow over colder water.

In the Bay summer water temperatures can vary from winter temperatures by up to 12°C.

Salinity differences also lead to movement, with the less dense fresh water inputs from rivers and creeks tending to flow over the saline Bay water. The water movements caused by such density gradients in the Bay are of similar magnitudes to those produced by light winds.

Plates 1 and 2, in the centre section of this report, illustrate the seasonal variations in salinity and water temperature throughout the Bay. Differences between adjacent zones are the basis of the density gradients.

Mixing

Despite the existence of density gradients across the Bay, the Bay waters are usually well mixed and uniform with depth at any one place because of its shallowness.

Mixing takes place via several processes. Turbulence is one of these processes, occurring when less dense layers of water move horizontally over layers of higher density.

The wind and tidal water movements are different at the surface than at depth. A tumbling movement results, with surface waters exchanging with underlying waters. Also, when a surface current meets the coastline, some water diverges left and right, but some sinks and flows back in a reverse direction. This sets up further tumbling and mixing.

The most effective mixing occurs during strong winds when waves break. In violent storms the wave energy may even reach the bottom and stir up the sediments.

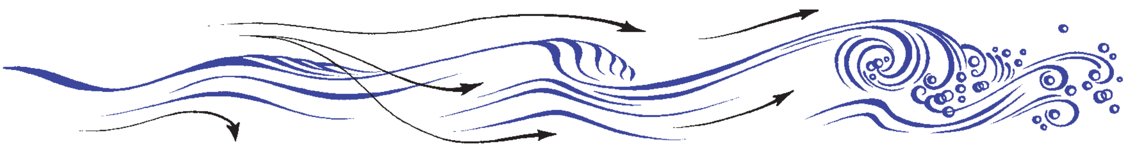
This effective mixing results in rapid dilution of inputs to the Bay.

Sedimentation

Suspended particulate matter in the form of silt, mud and organic debris enters the Bay from the rivers, creeks and drains. The total input of sediment has been estimated at 160,000 tonnes per year.

The sediments themselves are not static. Wave action at the shallow margins of the Bay winnows out finer, lighter material and transports it further offshore. Such material has, over time, gradually found its way to the deep central basin where wave action seldom disturbs it.

Chemical analysis of the bottom sediments shows that the central basin sediments contain most of the bacteria and organic remains, while the sediments at the Bay margin are mainly coarse sand.



Wind and wave action helps to disperse nutrients and keep the water and seabed full of oxygen.

LIFE IN THE BAY

Port Phillip Bay is home to thousands of species of marine flora and fauna. Many of the larger life forms are obvious and familiar – seaweeds, fish, dolphins, seals, crabs, shellfish, starfish and sea-urchins – but there is also a huge array of microscopic life.

Plant life

There are four main kinds of aquatic plants living in the Bay. These are

(i) phytoplankton,
(ii microphytobenthos
(iii) macroalgae
(iv) seagrasses.

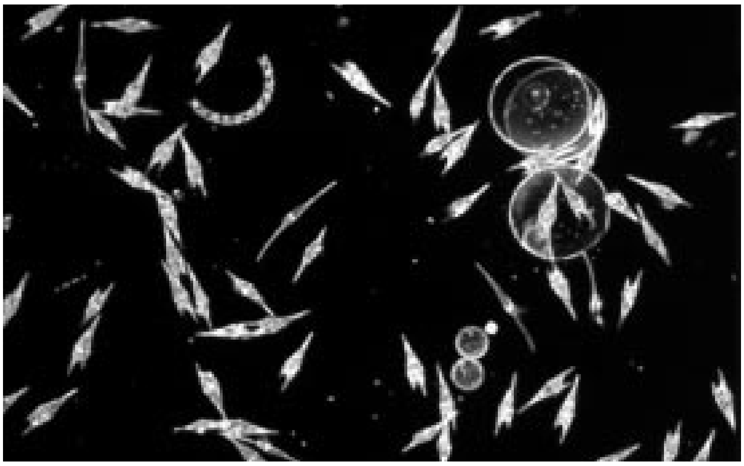
All four types of marine plants use light energy from the sun to transform carbon dioxide, water and elements such as nitrogen and phosphorous into organic matter and oxygen (the process called photosynthesis).

The phytoplankton

This is the general name for the many tiny single-celled algae that live in the water and are moved about by currents. The Bay contains more than 300 species of phytoplankton, ranging in size from a few thousandths to a few tenths of a millimetre across. The two main categories are *diatoms* and *dinoflagellates.*

Diatoms, recognised by their intricate silica skeletons, keep close to the surface and hence close to light. They are usually most numerous in summer, especially in the north-eastern part of the Bay.

Phytoplankton are so small that a single drop of water might contain thousands of individuals.
Photographer: G Hallegraeff, CSIRO



Dinoflagellates have two flagella, or threads, which can be used to steer them through the water, usually towards light. They have a more versatile lifestyle, some being able to live on organic matter dissolved in water, whilst others are carnivorous and eat smaller algae, bacteria and protozoa. They are most numerous in summer and autumn in the north of the Bay.

The microphytobenthos

This impressive name means “microscopic algae living on the seafloor”. They are also referred to as benthic algal mats because the algae grow over the surface of the sediment.

Almost all of the microphytobenthos consists of diatoms, although occasionally dinoflagellates, green algae and even some blue-green algae also occur. They are able to take advantage of the high nutrient (nitrogen and phosphorous) levels resulting from the decay of organic matter falling onto the Bay floor. They grow at about a quarter of the rate of phytoplankton.

There are dense mats in southern Corio Bay and off Clifton Springs, and moderately dense patches in the entrance to Geelong Arm, off Portarlington, and in the eastern part of the Bay.

The macroalgae

These are large, multi-celled algae generally known as “seaweeds”. Some of these grow on surfaces such as rocks, shells or even firm sand, and are kept in place by a structure called a rhizome or holdfast. Others, the drift algae, simply lie on the Bay floor and are moved around by water currents.

Over 60 species of green algae, nearly 100 species of brown algae and about 260 species of red algae have been recorded in the Bay.

Macroalgae obtain nutrients mainly by uptake from the water through their fronds and stems. All need

Old Wives in Bull Kelp (Pope's Eye)
Photographer: P Kinchington, Marine Science Services

light, so they can only grow where sufficient sunlight penetrates the water. The most dense stands occur in the shallower waters of the Bay, mainly between 4 and 8 metres depth.

Seagrasses

Seagrasses are marine flowering plants that can reproduce either by vegetative growth or from seed fertilised by pollen. They usually grow on sandy or muddy surfaces, depending on their rhizomes and roots for anchorage.

Seagrasses obtain some nutrients from the sediment through their roots, while the leaves take up nutrients directly from the water. The rhizome systems of sea-grasses are also important in stabilising the sediment and restricting its movement by wave action.

Seagrass beds are areas of high biological productivity and provide food and shelter for many marine animals. About 95% of the Bay's seagrasses occur in waters shallower than 5 metres, reflecting their reliance on access to sunlight.

Animal life

The breadth of animal life in the Bay ranges from microscopic single-celled organisms through to sharks, as well as marine mammals such as seals and dolphins.

Zooplankton

These are the small invertebrate (no backbone) animals living in the waters of the Bay. They range in size from microscopic single-celled protozoa (the most primitive animal life-form) only a few thousandths of a millimetre in diameter, up to shrimp-like creatures and fish larvae a few millimetres long.

The smallest creatures, or microzooplankton, consume bacteria, tiny particles of organic debris and the smallest algae. Of the larger zooplankton in the Bay (those bigger than 0.05 mm), most belong to a group called the crustaceans. This group includes all the invertebrates with armoured bodies and jointed legs (like crabs, prawns and lobsters).

Most zooplankton are filter feeders, that is, they are able to pump water through their mouth and over some sort of filter system, like bristles, which retains the algae and organic particles. Others use minute hairs, called cilia, to sweep particles along tentacles or grooves into their mouth.

It has been calculated that the free-swimming zooplankton alone probably filter the volume of the Bay about twice a month, and the benthic (seafloor) filter feeders are similarly active. Hence the whole volume of the Bay passes through the total invertebrate population on something like a weekly basis.

Zoobenthos

These are the invertebrate animals which live in or on the sediments. They vary in size from protozoa to quite large shellfish such as scallops. The population of these animals in the Bay is extremely rich and diverse. Even if only those larger than 1 mm are counted, there are about 700 species present, amounting to a live weight biomass of half a million tonnes.

The main groups of animals present are crustaceans (as in the zooplankton but larger), molluscs (shellfish like scallops and mussels) and the polychaeta (segmented marine worms). There are, however, representatives of most other invertebrate groups, such as sea-urchins and starfish, sea squirts, roundworms, flatworms, sponges, sea-spiders, bryozoans, sea anemones and corals.

These animals feed in three ways. Some are predators or hunters, eating other smaller animals. Others are filter feeders, like most of the zoo-plankton. Deposit feeders constitute the third group, eating the organic debris from dead plants and animals on the floor of the Bay.

The fish of the Bay

The first thorough trawl survey of the Bay fish was carried out during the last major environmental study of the Bay in 1969-71. Altogether, 63 species of fish were caught, of which the three flathead species were the most abundant (about 50% of the catch), followed by stingarees and spiny gurnard.

Similar surveys have been conducted in March of each year since 1990. A total of 84 species have been caught, with sand flathead still the most numerous, followed by globefish, eastern shovel-nose stingaree, sparsely spotted stingaree and spiny gurnard. Although there seems to be no obvious change in the total abundance of fish in the Bay, the relative abundance of various species has changed significantly since the 1969-71 survey, more than 20 years ago. Some of these changes reflect natural cycles.

These more recent surveys, however, suggest that the different fish species inhabit different depth zones in the Bay. Sand flathead are most abundant in deeper waters, whereas stingarees and globefish are more common in shallower waters. Snapper are most common at intermediate depths, from 12 to 17 metres.

The depth distribution of fish seems to be related to their diet. Most consume the invertebrate animals living on the bottom of the Bay, and these in turn are distributed by depth, mainly because of preference for different kinds of bed sediment (sand, silt or clay), which are also distributed by depth.

Marine mammals

A variety of marine mammals have frequented Port Phillip Bay over the years. The Bay has a healthy population of over 100 Bottlenose Dolphins, with other species being sighted occasionally.

Large whales, including Humpbacks, Southern Rights and Killer Whales have been sighted at various times, but do not form part of a permanent Bay population.

A number of seals have also taken up residence, making use of shipping buoys and beacons.

Over 100 dolphins live in Port Phillip Bay
Photographer:Yanni Delaportas

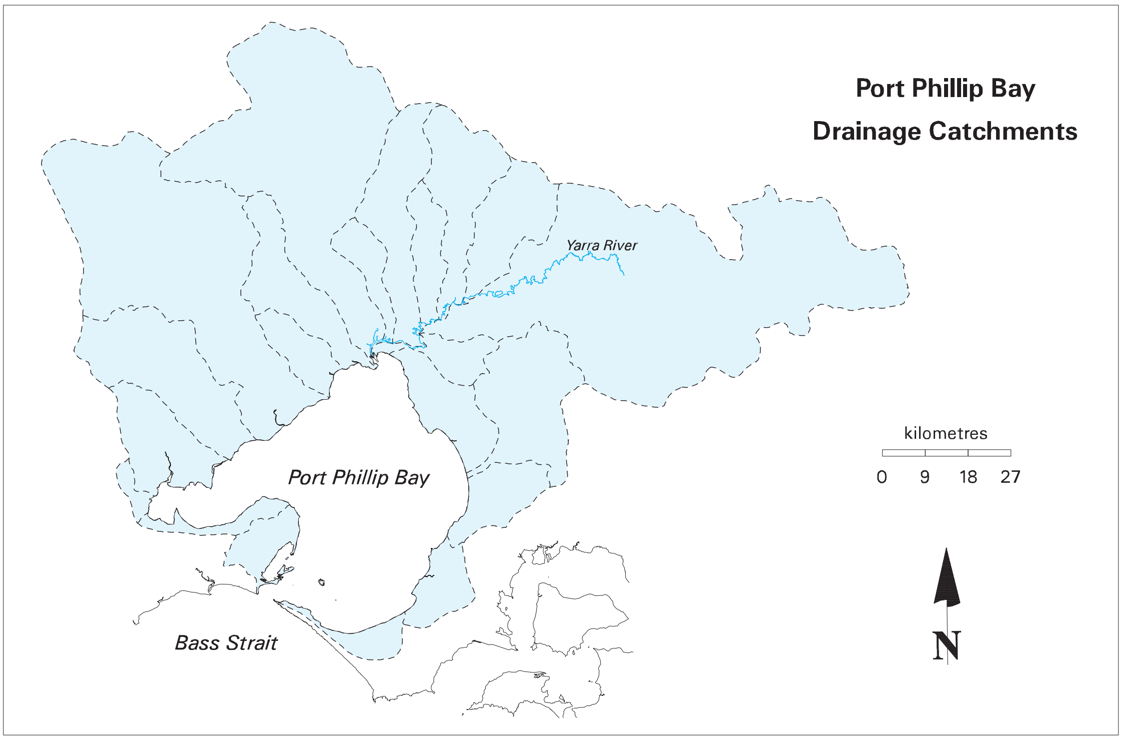


Figure 4
The Port Phillip Bay catchment covers nearly 10,000 square kilometres.

CATCHMENT AREA

The Port Phillip Bay catchment is Australia's most densely populated catchment and covers nearly 10,000 square kilometres. Figure 4 shows the extent of the catchment area.

RIVERS AND DRAINS

There are eight major creeks and rivers flowing into the Bay, and about 5,000 underground drains collecting run-off in the greater Melbourne area. These drains discharge either to creeks and rivers or directly through more than 300 outlets into the Bay.

The largest single source is the Yarra River, because of its large catchment (4,000 square kilometres) of which 55% is affected by urban or agricultural development. The second largest input volume is contributed by the treated effluent from the Western Treatment Plant at Werribee.

INPUTS

The table on the following page details the average annual inputs of various substances to Port Phillip Bay from the Yarra River, all other creeks, rivers and drains, and the Western Treatment Plant (WTP).

Average annual inputs of substances into the Bay

	Yarra	All Others	WTP
Flow (megalitres/year)	486,000	273,000	167,000
	tonnes/year	tonnes/year	tonnes/year
Total phosphorous	114	374	1,300
Total nitrogen	1,050	1,640	3,400
Suspended matter	150,000	-	6,600
Salt	38,800	14,000	201,000
Surfactants	52	54	36
Lead	19	11	1
Mercury	0.04	0.04	0.02
Zinc	63	58	5
Cadmium	0.17	0.14	0.02
Copper	6.6	8	1.8
Chromium	7.8	4.8	2
Arsenic	1.4	0.9	-
Nickel	6.3	2.9	4

STATE OF THE BAY - AN OVERVIEW

The Study has revealed that, despite a population of over 3 million people living around its shores, the Bay is generally cleaner and healthier than other bays around the world near large cities.

It has shown the Bay to be a dynamic and self-sustaining ecosystem which is habitat to over 1000 species of plants and animals.

It has identified that the key to the Bay's good health lies in the diversity of its plant and animal life and how they interact.

It has shown that, unlike many other bays, Port Phillip Bay does not suffer from oxygen depletion caused by excessive nutrient levels (eutrophication) and it has determined that toxicant levels are not a current threat to the Bay.

These are the key findings distilled from the 45 Technical Reports generated from the Study which provide the scientific data to accurately describe the present state of the Bay.

TOXICANT LOADING

The toxicology work has shown that there has been a long-term decline in the levels of most toxicants in the Bay. This is probably due to the implementation of stronger environmental regulations and controls, and diversion of industrial liquid waste to the sewerage system.

Before this diversion, industrial liquid waste was often partially treated and then directed into stormwater drainage systems or aquifers.

Toxicants originating from freshwater inputs drop out rapidly on entering the seawater, and so are restricted largely to the mouths of creeks and drains. Although there does not appear to be a toxicant problem in the Bay, ongoing monitoring is required.

More detail on the processes involving toxicants is presented in the later section entitled *A closer look at toxicants*.

NUTRIENT LOADING

Comparison of the concentrations of nutrients and chlorophyll in the waters of the Bay with other estuaries and embayments near major cities shows that water quality is good and that there is a relative scarcity of inorganic nitrogen compounds in the water of the Bay.

Port Phillip Bay differs from well-studied systems like Chesapeake Bay (on the east coast of the USA). The algal biomass in the Bay is strongly controlled by nitrogen at all times rather than being intermittently nitrogen-limited and phosphorous-limited.

Nitrogen to phosphorous ratios are very low by world standards, and chlorophyll levels (a measure of the algae present) are low to moderate compared with the more highly affected temperate estuaries in Europe and North America. The following table shows typical chlorophyll levels from a number of sites around the world. Port Phillip Bay falls very near the bottom of the range. Despite increasing population around the Bay, there has been no indication of any increase in nitrogen or chlorophyll concentrations in the water over the last decade.

However, there are seasonal variations in the concentrations because the freshwater input volume varies with rainfall. The highest input of freshwater (and nutrients) from the Yarra River occurs after summer storms. Nutrient input from the Western Treatment Plant is comparatively constant, but it reaches a peak during the winter when temperatures are low and biological activity is reduced.

The seasonal variations, as measured by chlorophyll *a* concentrations, are illustrated in Plate 3 in the centre section of this report. Nutrient variations may also have some bearing on the seasonal composition of the phytoplankton population, illustrated in Plate 4.

A comparison of typical chlorophyll levels from sites around the world

Site	Chlorophyll *a* (mg/m3)
Stockholm Archipelago (Sweden)	Up to 60
Portsmouth Harbour (UK)	Up to 96
Swanpool (UK)	5-540
Northern Adriatic (Italy)	Up to 13
Ebrie Lagoon (Ivory Coast)	Up to 56
New York Bight (USA)	45-80
Chesapeake Bay (USA)	3-33
Potomac Estuary (USA)	25-125
James River (USA)	50-100
Dickinson Bayou (USA)	120-500
Portage Inlet (Canada)	2-20
Kaneohe Bay (Hawaii)	0.2-5
Tokyo Bay (Japan)	Up to 60
Cockburn Sound (WA)	Up to 100
Port Phillip Bay (Vic)	1-20

SEDIMENTARY PROCESSES

A set of important, and previously unsuspected, processes in the sediments has been revealed in the way in which the Bay assimilates the nutrient load. These processes are described in the later section entitled *Life on the bottom.*

A major factor influencing the benthic (seafloor) processes is that oxygen concentrations at the surface of the sediments never fall to zero in the Bay proper. In fact, the lowest recorded oxygen concentration in bottom waters was more than 60% saturation. The oxygen levels in the water column and the sediments are crucial in maintaining the Bay's healthy state.

The Study demonstrated lower ammonia fluxes than expected between sediments and seawater, and high rates of denitrification (the conversion of nitrogen compounds to nitrogen gas) in the surface sediments.

PLANTS AND ANIMALS

Light penetration and water clarity in the Bay is good. Algal biomass is low except in one or two places around the margins, seagrasses are present, and the seafloor community is dominated by a rich diversity of deposit feeders.

Similarly, the fish population is large and diverse, and there is an abundance of birds. Dolphins are numerous, too, especially in the south.

The changes in the fish population have been irregular and sometimes difficult to interpret. It would seem that the total number of species has remained the same (with the addition of a few exotics) but the relative abundance of species has changed.

There is also some evidence of similar changes in the benthic invertebrates with a slight increase in the proportion of filter feeders over deposit feeders. It is true that there have been recent increases in the population of exotic suspension feeders and there are beds of red drift algae around the Bay. These are often signs of the early stages of nutrient enrichment. However, anecdotal and some documented evidence suggests that drift algae have always been present. We have not seen a marked increase in polychaete (marine worm) populations characteristic of eutrophication (the undesirable condition resulting from the excess of nutrient and the deficiency of oxygen).

The *Sabella* (European fan-worm) encroachment is characteristic of exotic species exploiting a new environment rather than a response to eutrophication. The Bay is certainly nowhere near the critical nutient load and there is no evidence of long-term deterioration in benthic communities.

The biggest threat to the Bay in future, however, may well be the introduction of exotic organisms which can change the way the entire Bay functions by competing with local species for food, habitat and oxygen.

Further research is required to determine the long-term effect of these introduced organisms on the Bay and other coastal waters around Australia.

European fan-worm
Photographer: CSIRO

LEVELS ACCEPTABLE AND FALLING

The Study indicates that toxicants are not at present a threat to the Bay. Overall, toxicant concentrations rarely exceed guideline values and most are decreasing with time.

This is not to say that toxicant loads should not continue to be controlled and eliminated wherever possible. Measurements of toxicant concentrations (both organic and inorganic) have been made in the water, sediments and biota and, with the exception of a few samples from the mouths of creeks and drains and within Corio Bay, are all at or below guideline levels.

SEAFOOD SAFE

There is no indication of the accumulation of toxicants in the tissues of valued species such as molluscs and fish. Few physically-affected organisms have ever been found (for example, displaying lesions). Toxicant levels appear to be declining as a result of stricter effluent controls and the diversion of liquid industrial wastes to the sewerage system.

Studies of low-level, chronic effects of toxicants have not been done, but any assessment based on the present information would not indicate an acute problem.

The table below details the results of toxicant analyses performed on flathead fish from the Bay and compares the results with the guidelines set by the National Health and Medical Research Council.

HISTORICAL DATA

The first toxicants investigations took place in the 1970s and were initially concerned with mercury because of the Minamata incident. (Minamata is a small Japanese fishing village which had its bay and fish stock poisoned by a nearby industrial complex.) Later, other toxicants were added as their effects became known. Results in the 1970s did give cause for concern. Mercury levels were found to be high in several species of fish taken from the Bay.

In certain localities, particularly Corio Bay, cadmium presented a concern. Furthermore, the earliest measures of some organic toxicants such as DDT and PCBs showed widespread low-level contamination of the Bay waters, sediments and biota with areas of high-level contamination in Corio Bay and Hobsons Bay.

HEAVY METALS IN FLATHEAD TISSUE FROM PORT PHILLIP BAY MG/KG WET WEIGHT

Site	Chromium	Cadmium	Nickel	Lead	Copper	Zinc	Mercury
Hobsons Bay	U/D	U/D	U/D	U/D	0.3	4.6	0.02
Corio Bay	U/D	U/D	U/D	U/D	0.4	5.5	0.10
Werribee	U/D	U/D	U/D	U/D	0.2	6.8	0.30
Mordialloc	U/D	U/D	U/D	U/D	0.7	4.8	0.09
St. Leonards	U/D	U/D	U/D	U/D	0.3	3.8	0.11
Southern Bay	U/D	U/D	U/D	U/D	0.2	4.4	0.12
NH&MRC	_	0.2	_	2.5	70.0	150.0	0.50

U/D signifies below the detectable level (0.1 mg/kg).
NH&MRC signifies National Health and Medical Research Council Guidelines.
Analyses performed by Australian Government Analytical Laboratories.

When the Study began in 1992, the information available on toxicant distribution in the Bay waters was abundant, but scattered in time and place of collection.

Most toxic (or harmful) metals, and a fairly representative range of organic toxicants, had been measured in either Bay waters, the sediments or edible seafoods.

DISPERSAL AND IMMOBILISATION

Many heavy metals and organic toxicants are not very soluble in water. They tend to adsorb onto any surface presented (for example, becoming tightly attached to the surface of clay particles). In sewage this will be the solids, and in rivers and drains the sediment arising from erosion. Hence, in sewage treatment plants, most metal and organic toxicants finish up in sludge. Whilst this does not get rid of toxicants it does at least immobilise them.

On the other hand, river and drain outflows into sea-water drop their sediment load to the bottom as the flow slows down and salt content rises. Furthermore, many toxicants are even less soluble in seawater than in freshwater so that they also fall to the bottom.

Figure 5 illustrates the dropping out of toxicants, showing the decrease in the concentrations of soluble and insoluble zinc compounds with increasing distance from the mouth of the Yarra River.

Of course, this is not the end of the story. Some small proportion of toxicants remain in solution in the water, and animals inhabiting the seafloor burrow into the sediments. Hence there is still the possibility of marine life, including edible seafoods, taking up toxicants.

Although this contamination pathway is a possibility, the Study has demonstrated that no serious problem exists.

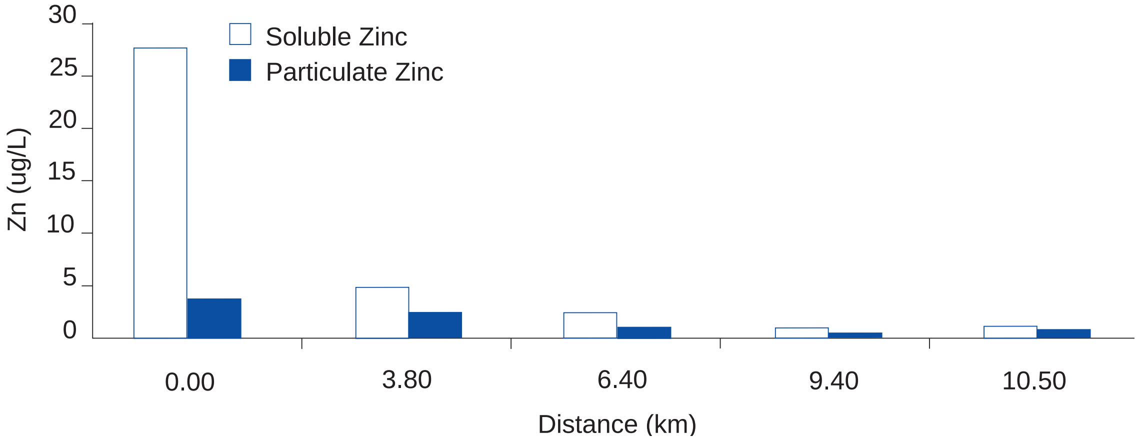


Figure 5
Concentration changes of dissolved and particulate zinc species in the Yarra River and Hobsons Bay with distance downstream from the Westgate Bridge.

PROGRESS IN REDUCING TOXICANTS

The big advance of the last two decades has been the gradual diversion of industrial liquid wastes to the sewer. Limits or sanctions can also be imposed on key noxious constituents, obliging the waste generator to treat plant effluent.

Levels of toxicants in Bay waters have generally declined over the last decade. Figure 6 illustrates this for the case of cadmium.

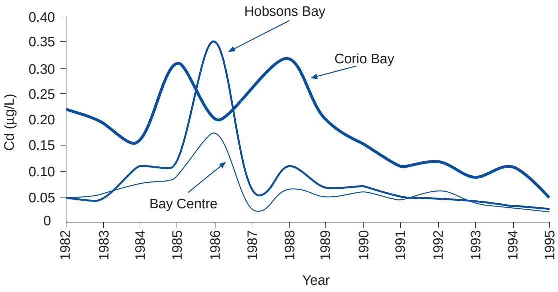


Figure 6
Changes in total cadmium concentration in waters from Hobsons Bay, Corio Bay and the Bay centre. (1982-1995)

Similarly, toxicant levels in the Bay sediments are generally well below dangerous levels. Figure 7 shows, for example, that total lead content in Bay sediments is below probable effect levels except for Corio Bay (Site 2). A similar pattern emerged for the large suite of organic toxicants monitored. (Site 23 is in the Yarra River and Site 32 in Kananook Creek).

In 1994, as part of the PPBES, when large samples of flathead, mussels and seaweed were collected from six sites around the Bay and analysed for seven heavy metals, all metal levels were below maximum permitted concentrations.

Of the five classes of organic toxicant measured, only petroleum hydrocarbons were detectable. This is not surprising considering the volume of commercial and recreational boat traffic on the Bay and residues from road traffic surrounding the Bay.

In conclusion, the Study shows that the only areas of concern are the mouths of creeks and drains and the western side of Corio Bay. These are historic "hotspots" likely to decline with time.

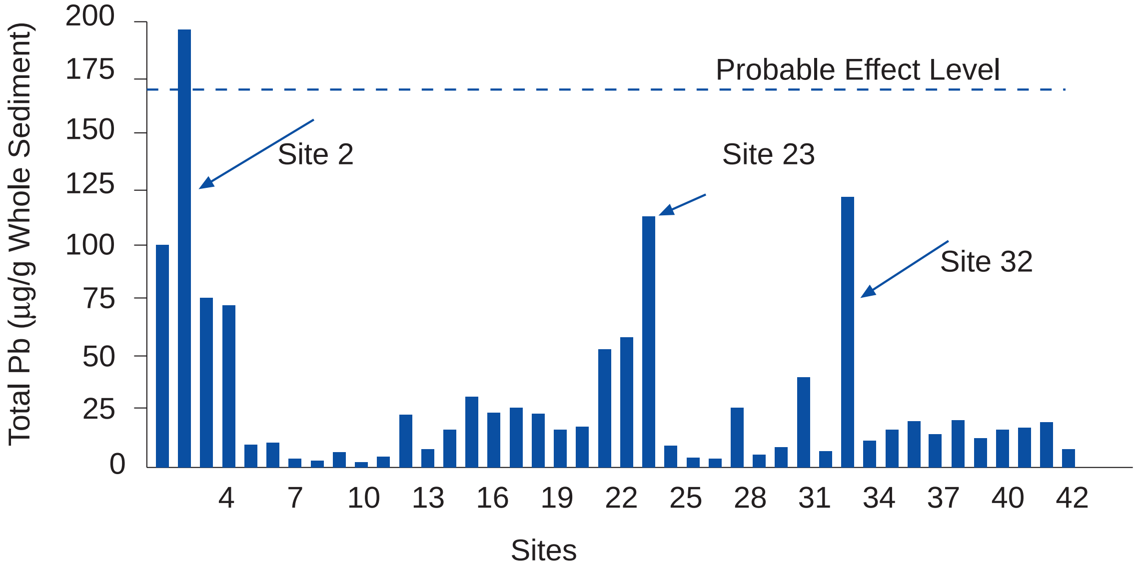


Figure 7
Concentrations of total lead in sediment from 42 Bay sites. Concentrations above the horizontal line may cause adverse biological effects.

THE NUTRIENT SYSTEM

BASIC NUTRIENT CYCLE

All aquatic ecosystems depend upon the cycling of the basic elements – carbon, nitrogen and phosphorous, together with several trace elements required for the synthesis of essential metabolic compounds. (For example, chlorophyll production requires magnesium.)

These basic elements are converted into plant tissue by the process of photosynthesis (where plants use light energy to transform carbon dioxide and water into organic matter and oxygen). This process is carried out in aquatic ecosystems by single-celled microalgae, the multicellular macroalgae (seaweeds) and flowering plants such as seagrass.

This plant tissue is consumed by animals, with some return of elements to the water through excretion and respiration. These herbivorous animals (mainly invertebrates) are in turn consumed by larger animals, and so on up through the food chain to fish, birds and dolphins, with continual loss of basic elements back to the water.

LOSSES FROM THE CYCLE

This would seem to form a closed cycle, but in fact elements are lost from the system through material sinking to the bottom.

Filter feeding animals excrete nitrogen and phosphorous compounds back into the water to be recycled by the microalgae, but they also defecate solid pellets. Other animals, like the crustacea, shed their “skins”. Some microalgae also escape grazing and fall to the bottom as they age and die.

Some of this organic material on the bottom is consumed by invertebrate animals (deposit feeders) or broken down by bacteria, and this is especially important in Port Phillip Bay. However, all bottom sediments contain some refractory organic material which cannot be recycled and which represents a loss to the system.

This loss of material is made up by on-going inputs from the Bay catchment, with nutrients being transported into the Bay via the rivers, creeks, drains and treated sewage effluent. The richness of living forms in the Bay depends on the magnitude of this input.

If the continuing nutrient input is small, the ecosystem will remain well balanced with a diversity of plants and animals.

If the input is very large, there is the danger that a state of “eutrophication” will develop. There is always a risk of eutrophy in enclosed, shallow water bodies like Port Phillip Bay, which have limited exchange with the ocean and large inputs of nutrients from a densely populated catchment.

This means that the plant population becomes very large and dominated by a few species. The water becomes cloudy so that seagrasses die from lack of light.

The consumption of oxygen in the decay of this excessive plant matter, plus the respiration of animals, then exceeds the supply of oxygen from the atmosphere to the water. The oxygen content of the water decreases so that only a few species of hardy animals survive and all the bottom living animals die.

Only the bacteria which can live on dead organic matter survive. These “anaerobic” bacteria use carbon, sulphur and nitrogen compounds instead of oxygen to produce energy. The by-products of these forms of anaerobic metabolism are methane (marsh gas), hydrogen sulphide (rotten egg gas) and ammonia. These gases are all toxic to higher life forms.

Eutrophication of the Bay would produce a revolting, poisonous stench. The water would go green and chemical precipitates would turn sediments black.

IS THE BAY SYSTEM LIKELY TO COLLAPSE?

The inputs of the nutrient elements nitrogen and phosphorous from the catchment to Port Phillip Bay appear, at first sight, to be large. Taking the critical or limiting element nitrogen for example, the total annual input from rivers, creeks, drains, sewage effluent and the atmosphere varies from about 6000 tonnes in a dry year like 1994 to about 8000 tonnes in a wet year like 1993.

However, taking the size of the Bay into account, this input corresponds to a loading of only three to four grams of nitrogen per square metre of water surface per year. By contrast, Tokyo Harbour receives 90 and Narragansett Bay (Rhode Island) in the USA receives 460 grams per square metre per year.

Even so, such an input should be sufficient to produce moderate levels of nitrogen compounds and microalgae in Bay waters. Instead, the levels of such indicators in the Bay are very low and have not increased since the earliest chemical surveys in the late 1940s and early 1950s. In fact, Figure 8 shows that, if anything, nitrate-nitrogen levels in the Bay may actually have declined.

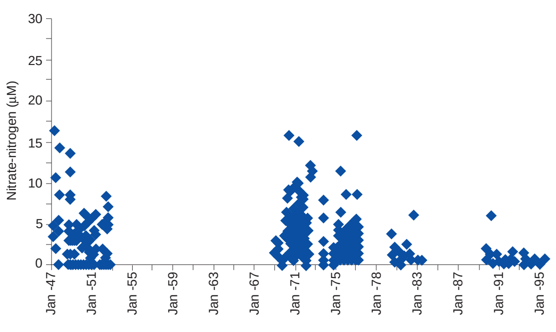


Figure 8
Nitrate-nitrogen concentrations from sites within the central area of the Bay.

PPBES Database Sources:
1. 1947-1952, Rochford, site 5
2. 1968-1976, Phase 1, central sites
3. 1975-1977, EPA, random central sites
4. 1980-1984, EPA, random central sites
5. 1989-1992, EPA, site 1229
6. 1993-1995, VFRI, site MW2 & N3

A similar picture emerges from examination of the total content of nitrogen and phosphorous compounds in the Bay at three intervals over 25 years. The table below shows these pool sizes in tonnes.

Levels of nitrogen and phosphorous compounds in the Bay at intervals over 25 years

Substance	1969-70	1980-84	1993-95
Ammonia-nitrogen	360	140	163
Nitrate-nitrogen	123	91	90
Organic nitrogen	7822	3934	2772
Phosphate-phosphorous	1891	1473	1460
Chlorophyll *a*	33	24	21

It can be seen that the total Bay content of both ammonia-nitrogen and nitrate-nitrogen decreased between 1969-70 and 1980-84 and then remained constant. The same applies to phosphorous. The change in chlorophyll a content, which is a measure of micro-algae in the water, reflects the change in nitrogen and phosphorous, there being less nutrient elements for the microalgae to grow.

CURRENT NUTRIENT INPUT LEVELS

It is likely that the fall in nitrogen and phosphorous partly reflects the diversion of nearly half of Melbourne's sewage to the new treatment plant at Carrum in 1975, and the increasing efficiency of nutrient removal in the Western Treatment Plant (WTP) at Werribee since then. Depending on seasonal impact the present input of nitrogen from the WTP is about 3000-4000 tonnes a year, decreasing as technology improves.

Research during the Study revealed that the treated effluent from the WTP has a minimal impact on the Bay and that treated effluent can only be detected to about 500 metres from the outlets.

The input of nitrogen and phosphorous from the Bay catchment as a whole is likely to have increased over the years with spreading urbanisation, but it is difficult to discern any trend because of poor historical records and wide variation in climate. For example, in the dry year 1994 only about 1900 tonnes of nitrogen compounds are estimated to have entered the Bay through all rivers, creeks and drains. In the previous wet year, 1993, about 3600 tonnes of nitrogen entered the Bay by these routes.

FORMS OF NITROGEN INPUT

The forms of nitrogen entering the Bay are either inorganic, that is, ammonia and nitrate, or organic. The latter form is an unknown complex mixture of materials derived from the breakdown of terrestrial vegetation, either directly or via eroded soil.

Aerial view of Paterson River outflow. Run-off from the catchment enters the Bay from rivers, creeks and drains.

The proportions of the three nitrogen forms vary with source but overall are roughly similar. However, as the previous table shows, in the Bay itself well over 90% of the nitrogen present is in organic form. Most of the inorganic nitrogen has disappeared. This is the reason for the low levels of ammonia and nitrate in the Bay and the low levels of microalgae.

As to the latter, chlorophyll *a* pigment in Port Phillip Bay is commonly present at about one or two micrograms in a litre of water, with occasional short-lived rises to ten. By contrast, chlorophyll *a* levels in similar water bodies elsewhere range up to 50 micrograms, with some reaching 100.

WHERE HAS THE NITROGEN GONE?

Looking at the nutrient input levels in comparison with other bays and estuaries, higher observed levels of nitrogen compounds should be expected. Likewise, chlorophyll *a* levels should be higher than they are.

What happens to the missing nitrogen?

This question had been asked after earlier studies, when it became obvious that the figures did not balance. It was not until the Port Phillip Bay Environmental Study was undertaken that the problem was resolved. The integrated nature of the project and the use of sampling and measuring technology not available to earlier researchers, illuminated the nature of the processes.

The Study has identified and described the seafloor processes involved, and has highlighted the important role played by the seafloor organisms in taking up and recycling the nitrogen released from the sediments by decomposition.

THE SEAFLOOR CYCLE

Nutrient elements are taken up by the phytoplankton (microalgae) and other plants which are in turn consumed by zooplankton (tiny invertebrates).

Some nutrients are recycled, but most fall to the Bay floor as faecal residues or dead algal cells. There they are eaten by bottom-living invertebrates (deposit feeders) or decomposed by bacteria. Either way, the basic elements are converted back to their original inorganic forms of carbon dioxide, ammonia, nitrate, phosphate and silicate.

In many water bodies, these inorganic forms would diffuse upwards into the water and be recycled. In Port Phillip Bay this only happens to a limited extent because of two factors unique to the Bay.

Penetration of light

The shallowness and clarity of the Bay allows some sunlight to reach the Bay floor. This enables particular microalgae mats (microphytobenthos, shown as MPB in Figure 9) to flourish on and in the sediment.

These algal mats intercept the inorganic forms of nutrients in the sediments before they enter the Bay waters, and use them for growth. The MPB are then eaten and excreted by the bottom invertebrates, so that most of the nutrients are "by-passed" back into the sediments.

Oxygenation of the sediments

At the same time, because the bottom sediments are mixed up and oxygenated by some of the several hundred species of invertebrates living there – even to a depth of 50 centimetres – the ammonia and nitrate formed are rapidly mixed radially within the sediment.

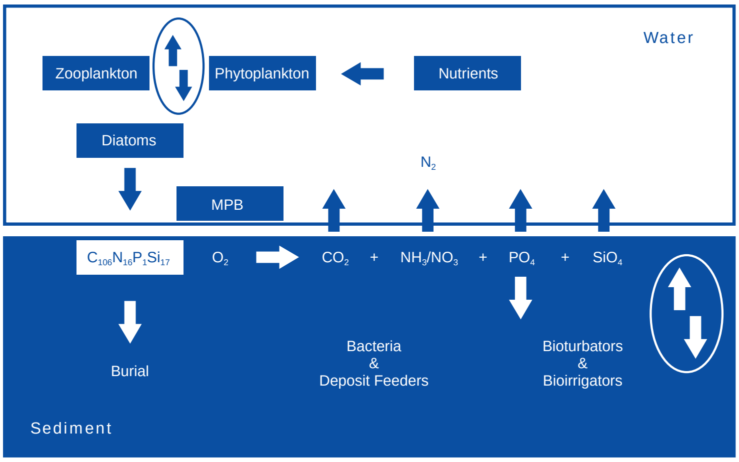
Where ammonia reaches an oxygenated zone, certain bacteria oxidise it to nitrate. Some nitrate will diffuse into zones of low oxygen where other bacteria convert the nitrate to inactive nitrogen gas. This process is called denitrification. The nitrogen gas diffuses up into the water and eventually back to the atmosphere. About half the inorganic nitrogen formed in and on the sediments is converted in this way.

BALANCING THE NITROGEN BUDGET

The amount of nitrogen removed from the ecosystem by these processes is equal to about 80-90% of the nitrogen input to the Bay. The nitrogen cycle in the Bay is therefore almost entirely balanced by this process, with 10 to 20% of input being exported to Bass Strait or buried in the sediments in refractory forms.

Even though phosphorous levels are higher than nitrogen levels, the processes in play ensure that nitrogen levels are the limiting factor in the growth of algal populations in the Bay.

Figure 9
A process description for nutrient dynamics in Port Phillip Bay.



An artists impression of nutrient cycling in the Bay. Plants absorb nutrients. Marine animals graze on the plants and recycle the nutrients. Animals on the seafloor burrow through sediments in search of food and, in doing so, irrigate the seabed with vital oxygen.

THE NEED TO PREDICT

All previous studies of the Bay, going back to 1947, have been essentially descriptive, that is, they told us the state of the Bay without any way of understanding how it reached that state. Nor could such studies give any prediction of the effect of changes in catchment input or Bay geometry.

In order to develop such predictive abilities it is necessary to measure the rates at which natural processes operate in the Bay.

From the very beginning, all the Port Phillip Bay Environmental Study research tasks were designed to not only monitor the chemical, physical and biological state of the Bay over two or three years, but to also measure the rate of change in response to season, year and inputs. Most tasks also allowed a comparison with historic data to assess the extent of changes (if any) over periods varying from five to fifty years.

DEVELOPMENT OF THE MODELS

Parallel with the field tasks, CSIRO scientists were also constructing three numerical models which express, in mathematical terms, the processes observed.

Hydrodynamic model

The basic construct is a three-dimensional hydrodynamic model which is able to predict, for any given wind direction and speed, tide state, freshwater input and density structure, the magnitude and direction of water movements in the Bay.

Transport model

Building on this hydrodynamic base, a transport model was constructed which translates water movement into the flux or transport of dissolved and suspended materials around the Bay.

For instance, the pathways and rate of mixing of the Yarra River plume for any given flow can be described.

Biological effect model

With such a knowledge of the flow and flux rates, it became possible to build a third tier in the models which describes the effects of these rates on the algae and small invertebrate populations of the Bay.

It is theoretically possible to take this third stage up to larger invertebrates and fish, but the uncertainties and complexities of food webs increase with nutrient levels and predictions of outcome become increasingly approximate.

Since knowledge of algal growth and grazing rates were fairly well known through the Study research tasks, it was decided to keep the ecological model to these simpler levels. After all, the first concerns would arise if the Bay were to “go green”. Hence prediction of which nutrient loads would be likely to start a slide into eutrophication is the first consideration.

Computers are used to monitor Bay processes

COMPLEXITIES INVOLVED

Construction of such an integrated model is not a simple task. In the first place, widely different time scales are involved. In the physical arena there may be processes operating over a few hours (the tides), several hours or days (weather), months (seasonal effects) or even years (climate).

Similarly, chemical processes such as the fate of metal or organic toxicants vary widely in rate and complexity, and also introduce spatial variability. For example, the distribution of zinc when it enters the Bay depends not just on water movements but also precipitation to the bottom.

Further, the biological arena encompasses micro-organisms such as bacteria and algae which have growth rates measured in hours or days, smaller invertebrates which may have life-cycles of weeks or months, and larger invertebrates with life-spans of years.

HOW THE MODEL WORKS

The integrated model consists of a set of equations which prescribe the local changes in the variables, on time scales of hours to days, and the exchanges among adjacent spatial cells.

Through an intensive numerical exercise, the model integrates these local effects to predict the response of the entire Bay to changes in catchment management on time scales of years.

VERIFYING THE PREDICTIONS

The assumptions and parameter values in the underlying equations are checked by comparing the model predictions with observations. The field program in the Study provides a comprehensive and unprecedented data set for this purpose.

To the extent that the underlying processes are correctly represented, the model can be used to predict the response of the Bay to nutrient loadings outside the range of historical experience.

So far, the integrated model deals only with the nutrient cycle. A toxicant model is being developed.

The model has been calibrated to match the observed annual nitrogen budget, and predicts spatial and seasonal distributions of nutrients and phytoplankton which match observed distributions reasonably well. Analysis and calibration of the model is proceeding.

PREDICTION OF CRITICAL LOAD

The model predicts that the Bay has a high risk of becoming eutrophic at two to three times current nitrogen loadings, and thereby defines an assimilative capacity (or critical load) for the Bay which agrees with empirical results from North American estuaries.

The assimilative capacity predicted by the model depends heavily on the understanding of sediment processes and nutrient fluxes obtained during the Study. When the nutrient loading to the model is increased gradually, the predicted condition of the Bay changes little at first, but deteriorates rapidly as the assimilative capacity is approached.

Plate 4 (modelling predictions, in the centre section of this report) illustrates predictions produced by the integrated model. Predictions are generated for summer (A) and winter (B) distributions of dissolved inorganic nitrogen (DIN), and summer (D) and winter (E) distributions of phyto-plankton. These are in close agreement with the currently observed distributions. Parts (C) and (F) are distribution predictions for DIN and phytoplankton respectively, arising from nitrogen loading increasing to three times its current level.

THE NEXT STEPS

The Port Phillip Bay Environmental Study has revealed that the Bay is currently in good condition. The challenge is to keep it that way.

Increasing population, urban growth, shipping and recreational use all place pressure on the Bay's natural systems. By good fortune, our use of the Bay and its catchment over the years has not destroyed the Bay's ecosystem. The processes at work in the Bay have been able to cope with the increasing demands placed on them by human activity, but there are limits to how far the system can be pushed.

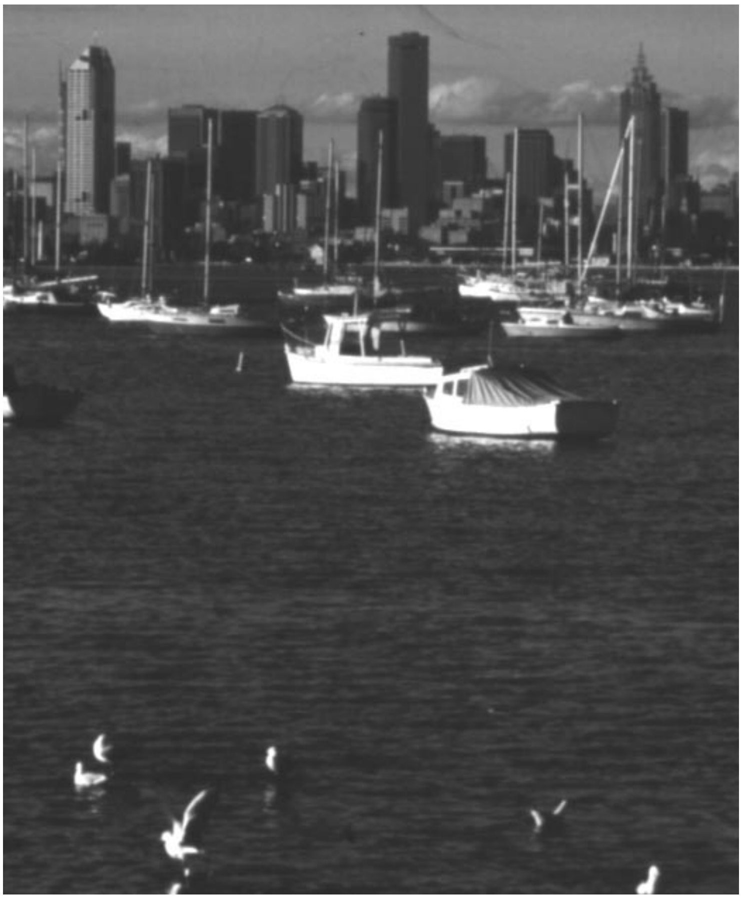
The Study has provided vital information on how the Bay works and what the limits are. This information, together with on-going research, provides the scientific framework to develop management programs to protect and care for the Bay in the long term.

The Integrated Model developed for the Bay during this Study will be used to predict the effects of continuing urban development around the Bay. The model will then be used to assess the effectiveness of proposed schemes for protection and conservation of the Bay environment.

The success of this Study will serve as a great encouragement to the design and performance of other studies in Australia and around the world. The discoveries made and information gathered will be applied in other projects so that further progress can be made.

To assist in the formulation of management and conservation programs, the researchers involved in the Study have produced 16 recommendations. If these recommendations are accepted and acted upon, there is a very good chance of maintaining Port Phillip Bay in a healthy state.

The study has revealed the bay is currently in good condition. The challenge is to keep it that way.



RECOMMENDATIONS

TOXICANTS

Recommendation 1

Although toxicants are at low levels in the Bay at present, inputs should continue to be managed and ideally reduced. As a precaution one should monitor toxicants in valued ecosystem components every five years.

Recommendation 2

Although the impact of toxicants is largely restricted to the mouths of creeks and drains, these are areas of human contact. It would seem wise to develop local catchment management strategies to reduce toxicant inputs to these waterways.

Recommendation 3

Investigate the possibility of long-term chronic effects of low level toxicants on the biota of the Bay.

ECOLOGY

Recommendation 4

The benthos are a vitally important component of the Bay ecosystem. To protect the biodiversity of the benthos and its key role in ecosystem function, habitat destruction must be reduced to a minimum. The effects of fishing, dredging and coastal engineering on seagrasses and the benthos must be minimised and should be closely monitored. The disposal of dredged spoil must be confined to as small an area as possible.

Recommendation 5

There is insufficient historical monitoring data to fully document any variability of seagrass beds and reefs over the years. Changes in the extent of seagrass beds and the condition of reefs must be closely monitored on a regular basis. Community involvement in these activities should be encouraged by the use of volunteer naturalists.

Recommendation 6

Protection and conservation of the Bay ecosystem and its habitats are essential for the sustainable health of the Bay. Wherever practicable habitat restoration should be attempted, like the establishment of artificial reefs. Community adoption of and involvement in these programs is desirable.

Recommendation 7

The introduction and spread of exotic species is a major issue for the sustainable use of the Bay. We endorse moves at National and State levels to control such introductions. In conjunction with these programs, steps should be taken to minimise further introductions to the Bay. Monitoring around port areas needs to be initiated and maintained. The role and function of exotic species in the overall ecology of the Bay must be assessed.

Recommendation 8

To protect valued resources, commercial and recreational fishing should be managed so as to ensure continued sustainable exploitation. Fish habitats must be protected and where possible restored. To conserve the resources of the Bay, management agencies should consider the establishment of protected areas.

NUTRIENTS

Recommendation 9

To ensure the sustainable health of the Bay for future generations (and allow for climate variability) a target reduction in overall load of 1,000 tonnes of nitrogen per year should be adopted. This target is consistent with ongoing stability and protection of the Bay ecosystem.

Recommendation 10

The impact of storm loads and urban runoff in the Yarra River and the major creeks and drains must be reduced. Control of storm loads is more important than control of nutrient loads during base flow conditions. Wherever possible Total Suspended Solids and N loads to the Bay from these sources should be reduced by catchment remediation and reduction in storm overflows. Strategies to reduce N loads to the Bay should give this recommendation highest priority.

Recommendation 11

Improve the denitrification efficiency of the WTP where practicable. This is especially important in winter when denitrification efficiencies in the WTP are low. If denitrification efficiencies in winter could be increased to a similar level to those in summer then ammonia loads from the WTP could be decreased significantly. Cost effective ways to achieve this should be investigated.

Recommendation 12

A clear distinction must be made between environmental quality around the edges of the Bay and the overall health of the entire system. Local impacts around the mouths of creeks and drains are higher than in the centre of the Bay. In addition to catchment remediation, good planning and sensitive foreshore development is essential. It is important to protect the aesthetic and conservation values of the coastal and intertidal zone by a combination of public education, litter control, beach restoration and minimisation of physical impacts.

Recommendation 13

An ongoing monitoring program should be established. The monitoring program should be designed to monitor the ongoing health of the Bay, to provide early warning of unforeseen impacts (e.g. climate variability and exotic species) and to measure performance on a year to year basis and ensure compliance with these targets. It should include water quality. Loading targets for the Bay should be agreed and a timeline set for achievements of these goals. This is the responsibility of Government. Sediment fluxes, benthic biodiversity and other sensitive indicators of Bay function should be monitored to ensure compliance with management goals and sustainable ecosystem health.

GENERAL

Recommendation 14

The integrated model and its predictive capabilities should be used on an ongoing basis to assess trends in the data and monitor performance in improving the trophic state of the Bay (this will be a massive ecosystem experiment - good performance criteria will be needed). Publicly report the annual performance and implement the necessary changes in terms of changes in management policies and water quality criteria.

Recommendation 15

If the reduction in N loads is achieved, SEPP chlorophyll criteria may be reset.

Recommendation 16

The Bay and its catchments 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 cycle so that long term sustainable management of the Bay becomes possible.

GLOSSARY

Algae: A large group of non-flowering plants, many microscopic, containing chlorophyll. Most algae are aquatic.

Ammonia (ammonium): Compound consisting of a single nitrogen atom coupled with three or four hydrogen atoms. It is a nitrogen source for algae.

Bacteria: A large group of single cell or filament-like microscopic organisms lacking chlorophyll a and well defined cell nuclei. Cells multiply by simple fission.

Benthic: Belonging to the sea floor.

Benthos: Organisms living on or in association with the sea floor.

Bioaccumulation: The concentration of substances (especially toxicants) in the tissues of plants and animals.

Biochemical: Chemical reactions occurring in living organisms.

Biodiversity: Measure of the number of species inhabiting a given area.

Biomass: The living weight of animal or plant populations or communities.

Biota: All living organisms of a region.

Bivalve: A type of mollusc possessing a hinged two-valve shell (e.g. scallops and mussels).

Bloom: Microalgae occurring in dense numbers in a water body.

Catchment: The area of land from which run-off from rain enters a waterway.

Chlorophyll: The green pigments of plants which capture and use the energy from the sun to drive the photosynthesis process.

Chronic: Over a long time. Opposite of "acute".

Contaminant:
A substance out of place (also pollutants).

Crustacean: An animal living in water which has jointed limbs and a hard outer surface (e.g crabs).

Cycling/recycling: The movement of an element (like nitrogen) through various forms, living and non-living back to its starting form.

Denitrification: The conversion of bound nitrogen to elemental (gaseous) form.

Deposit feeder: An animal which eats organic matter on or in the sea bed.

Diatom: A variety of microalgae which have siliceous skeletons.

Ecology: The relationship of living things to their environment.

Ecosystem: A community of plants or animals or both.

Eddy: A rotating or whirling movement of air or water.

Effluent: An outflow, usually sewage or wastewater.

Estuary: The zone where a river mixes with the sea.

Eutrophic: Having an unnaturally high content of algae due to excess nutrients.

Fauna: All kinds of animals.

Flagellate: A single-celled organism with a whip-like appendage used for locomotion.

Filter feeder: An animal which gains its food by filtering organic particles from water.

Flora: All kinds of plants.

Flushing: The rate at which a lake or bay exchanges its water content.

Flux: Flow of material.

Food chain: The sequence of consumption of plants by animals and those animals by other animals.

Food web: A complex of food chains.

Grazing: The eating of plants by animals.

Habitat: The place where a plant or animal lives.

Heavy metals: A general term for cadmium, chromium, copper, iron, mercury, nickel, manganese, lead, zinc, arsenic and selenium.

Hydrocarbons: Compounds of hydrogen and carbon such as petroleum.

Hydrodynamic: Related to movement of water.

Ice Age: Those stages in geological time when temperatures on earth fell so low that the polar ice-caps expanded, glaciers formed in river valleys and sea level fell. Also called glacial periods or epochs.

Inputs: Substances entering a water-body.

Invertebrate: Animals without backbones.

Macroinvertebrates: The larger invertebrate animals (i.e. macroscopic).

Macrophyte (macroalga): A seaweed.

Metabolism: The build up and breakdown of living matter.

Microalgae: Single-celled plants. Generally less than 1/10th millimetre in length or diameter, usually much smaller.
Microphytobenthos (MPB): Single-celled algae which live in and on the sea floor. They are mostly diatoms.
Microzooplankton: The smallest zooplankton, those less than 0.05 of a millimetre in size.
Mixing processes: The ways in which water bodies mix e.g. shearing, wave action or wind stirring.
Model: A mathematical expression of a natural system.
Mollusc: An invertebrate animal with a shell (e.g. mussel).
Monitoring: Continuous measurement.
Nanoplankton: Those micro-algae between 2 and 20 thousandths of a millimetre in size.
NH&MRC: National Health and Medical Research Council.
Nitrate: The NO3 anion.
Nitrification: Formation of nitrate from reduced forms of nitrogen, such as nitrite and ammonia.
Nitrite: The NO2 anion.
Nutrients: Substances required for the growth of plants (like fertiliser).
Organism: A living entity of any size, plant or animal.
Particulates: Particles suspended in water.
Photosynthesis: The transformation of carbon dioxide and water to organic matter and oxygen by means of light energy.
Phytoplankton: Microalgae which live in the water column.
Plume: In oceanography a term applied to a recognisable outflow into a receiving water body (e.g. Yarra plume in the Bay).
Pollutant: A substance in excess or not belonging.
Polychaete: General term for a class of segmented worms with several seta (bristles) per segment. Very widespread in the marine environment.
PPBES: Port Phillip Bay Environmental Study.
Producer: An organism which can create living matter out of inorganic or inanimate matter.
Productivity: The magnitude of a producer’s activity.
Refractory: Resisting decomposition.
Residence time: The nominal time spent by a substance in a water body subject to tidal exchange or river flushing.
Respiration: The taking up of oxygen to decompose organic matter.
Salinity: The salt content of seawater.
Sea level: Some agreed mark from which tidal and other excursions can be measured. Also applied loosely to the sea surface.
Seagrass: A group of flowering plants which live rooted in the sea floor.
Sediment: Any solid material which sinks to the bottom.
SEPP: State Environment Protection Policy.
Sewage: Strictly speaking household waste but loosely applied to any waste sent to a treatment plant.
Stormwater: Run-off during storms.
Suspended matter: See particulates.
Suspension feeder: An animal which lives by filtering particles from the water.
Terrestrial: Of the land.
Tides: The movements of water in the ocean in response to gravitational pull of the moon and sun. As the earth turns the tides perform a daily cycle. Because the moon revolves around the earth the tides also undergo a lunar monthly cycle. The revolving of the earth around the sun imposes an annual cycle. All show up as high and low water levels.
Toxic: Poisonous.
Toxicant: A poison.
Trophic: Related to food chains and food webs.
Vertebrates: Animals with backbones.
WTP: Western Treatment Plant (Werribee).
Zoobenthos: Animals living on the sea floor.
Zooplankton: Small animals living in the water column, usually drifting with the water.

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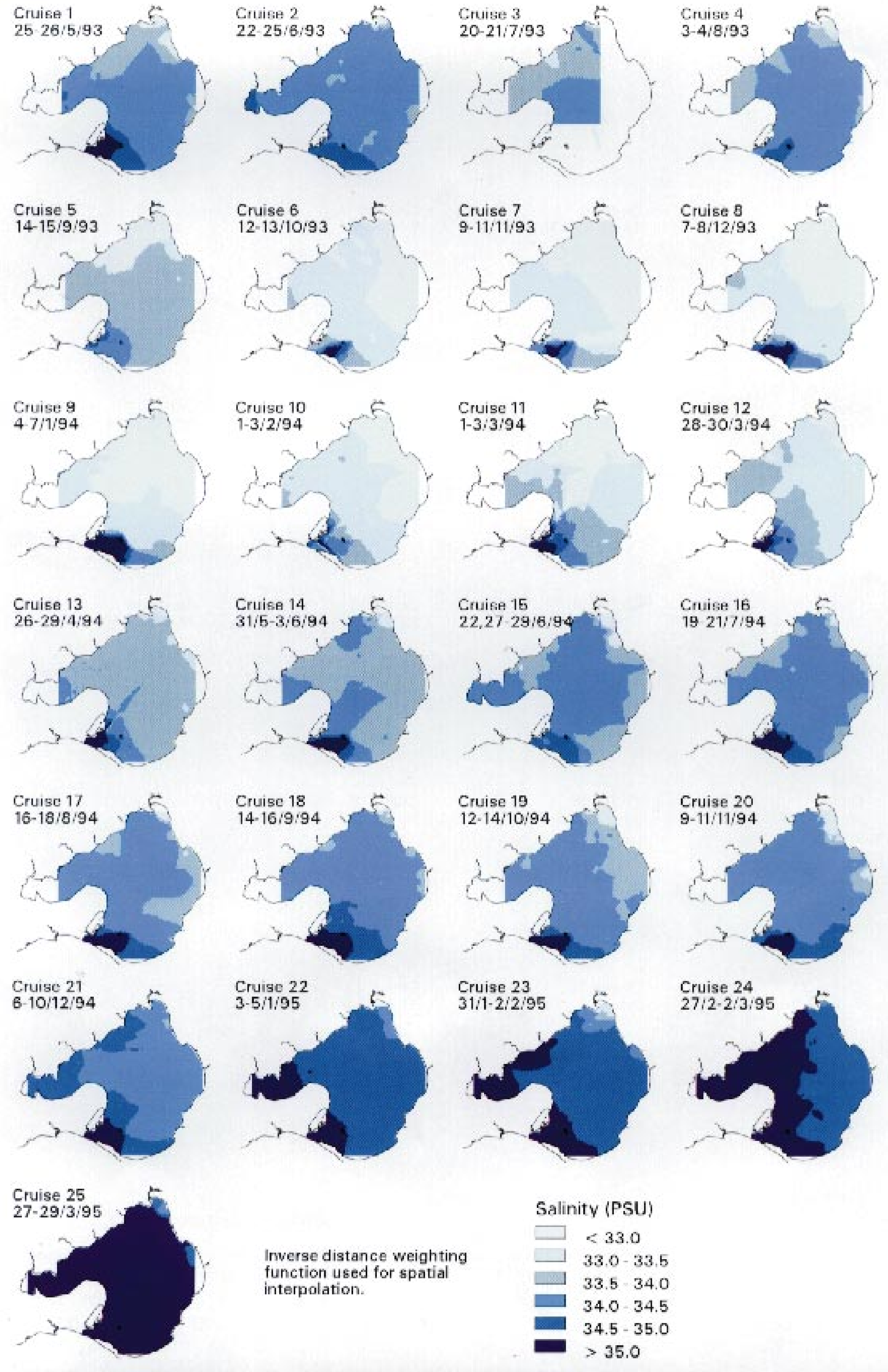


Plate 1
Salinity - seasonal variation

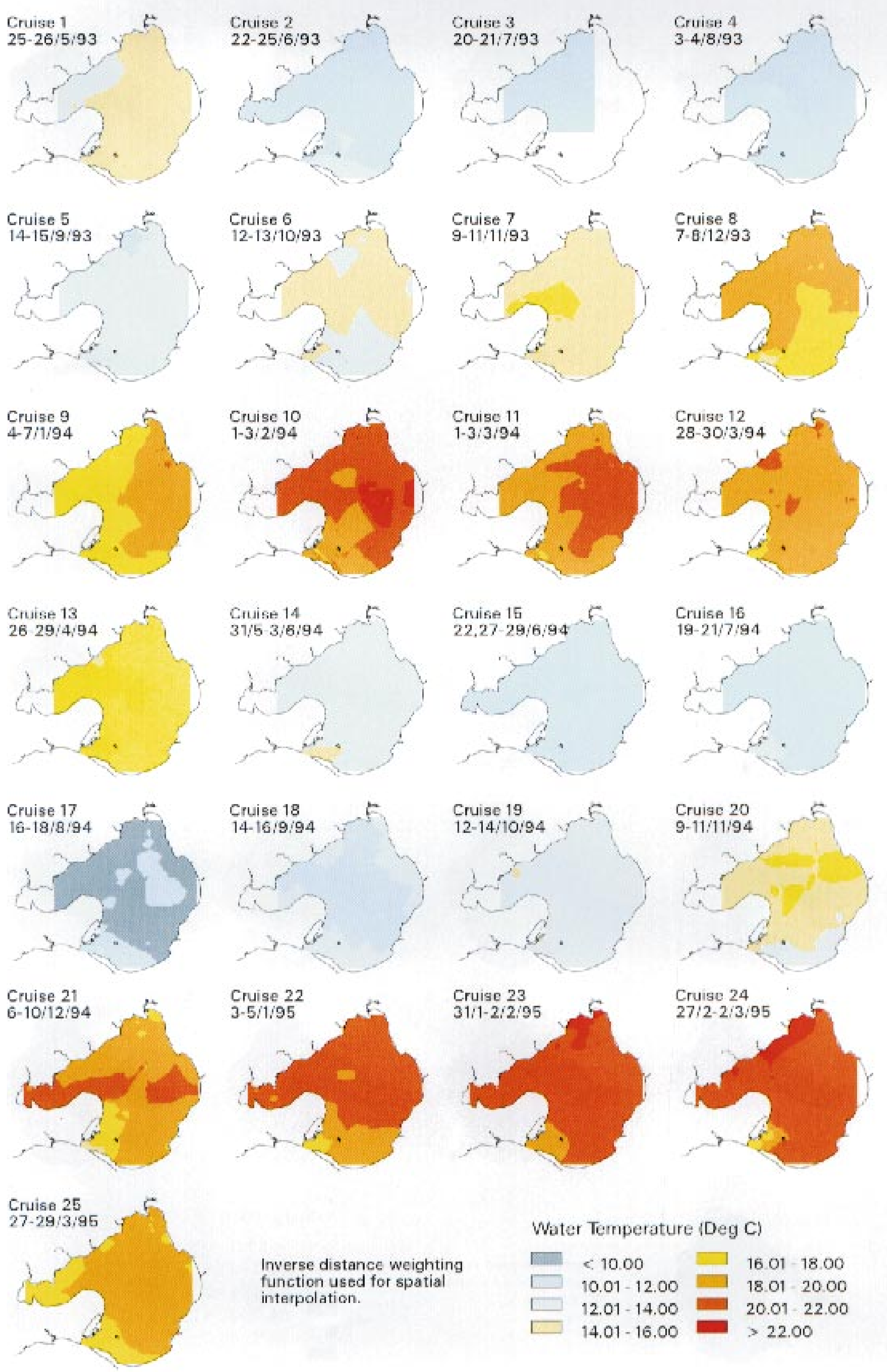


Plate 2
Water Temperature - seasonal variation

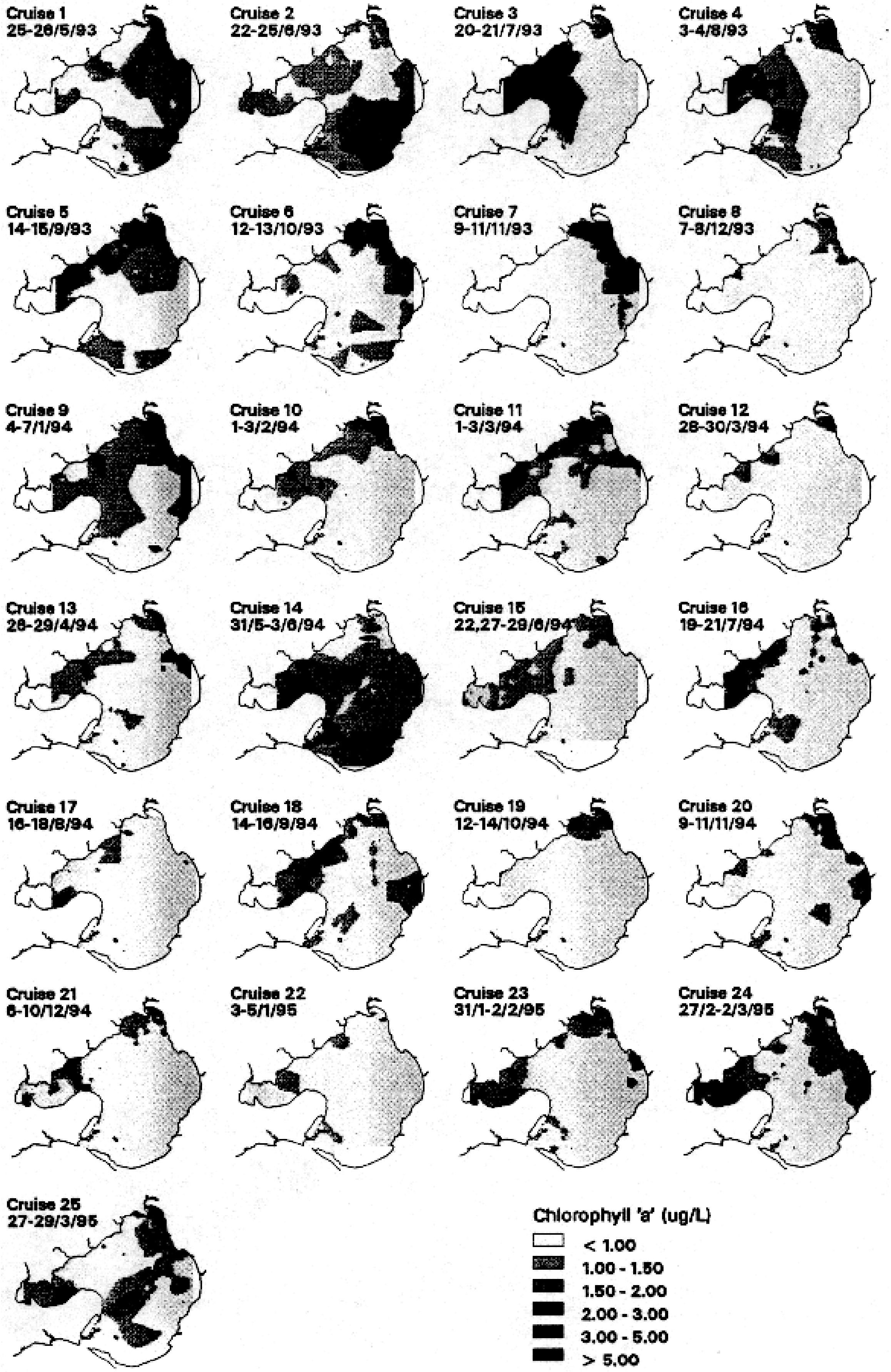


Plate 3
Chlorophyll "a" - seasonal variation

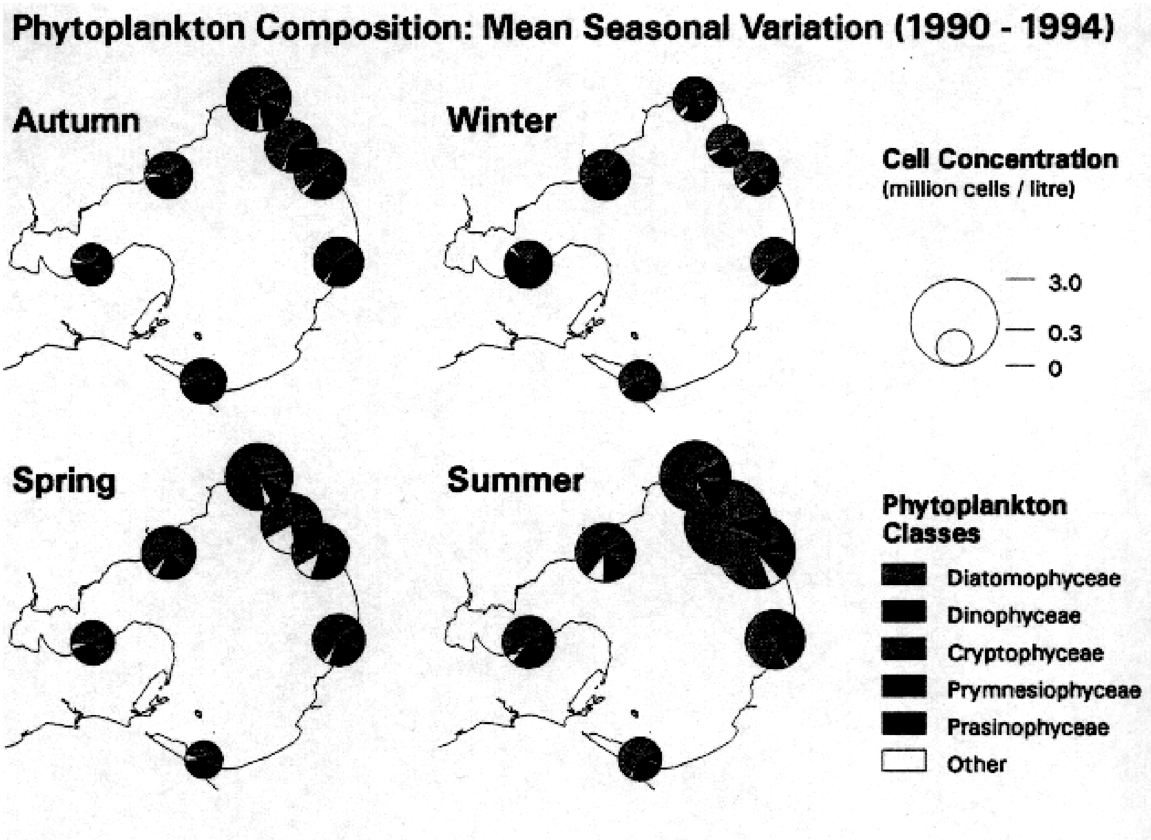
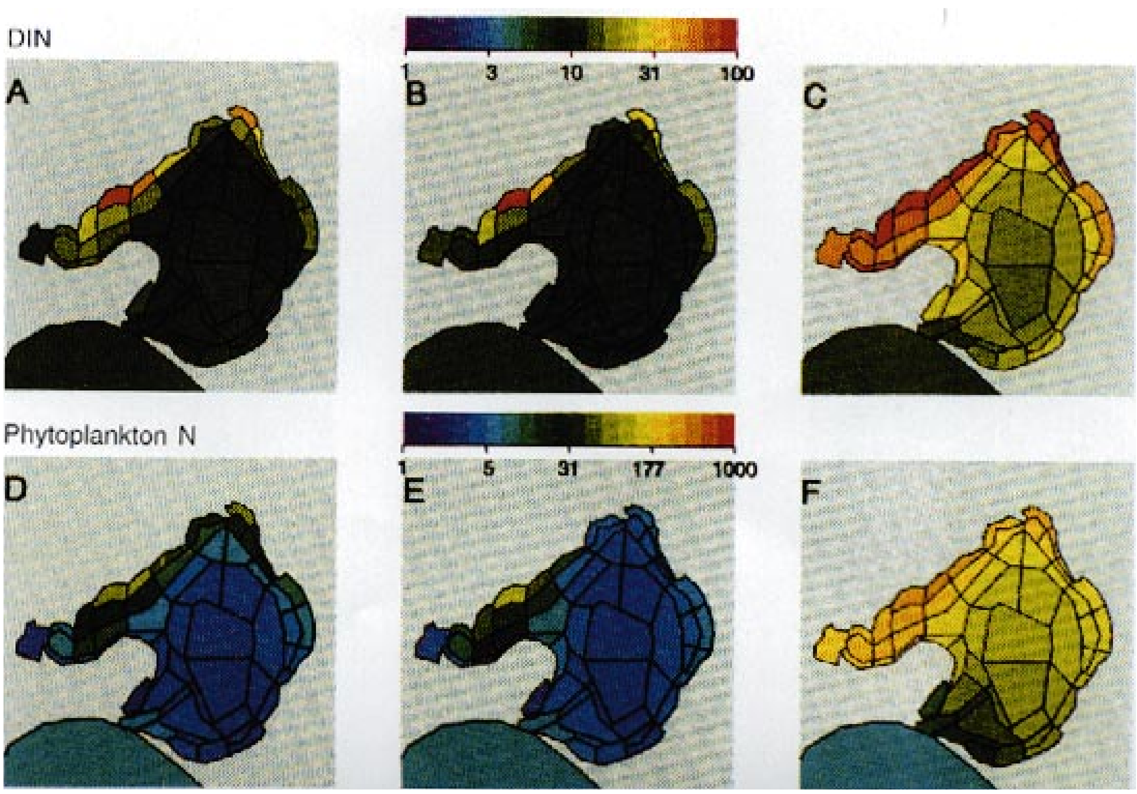


Plate 4
Phytoplankton composition - mean seasonal variation



Modelling predictions - DIN, phytoplankton - summer, winter, 3-fold nitrogen loading.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