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PREDICTIVE MODELLING OF CARRYING CAPACITIES OF OYSTER *(CRASSOSTREA GIGAS)* FARMING AREAS IN TASMANIA

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1. NON-TECHNICAL SUMMARY

The carrying capacity of an oyster farming area is defined as the maximum density of oysters which can be grown in the area without negatively affecting oyster growth rates. If too many oysters are placed in a body of water, *i.e.* the carrying capacity is exceeded, there will not be enough food for all the oysters and their growth will be slower so they take longer to reach market size and will be in poor condition for a greater part of the year.

Concern was raised by oyster farmers in Tasmania in the late 1980's that with the rapid expansion of the industry there were too many oysters being placed in some growing areas and the production was not likely to be sustainable. At the same time the Division of Sea Fisheries was receiving numerous requests for new oyster farming leases. They therefore also required information on the maximum number of farms and densities of oysters that would maximize yields from each growing area. This project aimed to assess oyster production in relation to environmental conditions in five oyster growing areas in Tasmania and to develop predictive models of the carrying capacities of oyster growing areas.

The important factors to be considered in estimating carrying capacities of growing areas are the amount of oyster food available, the rate of replenishment of the food and the quantity of food consumed by the oysters. Information on environmental parameters which affect the growth rate of oysters, the transport of food and the regeneration rate of phytoplanktonic oyster food, such as temperature and nutrient concentrations, also are required. In this study five oyster growing areas, Pittwater, Pipeclay Lagoon, Little Swanport, Georges Bay and Simpsons Bay were studied, some in more detail than others.

Data were collected monthly on temperature, salinity, and chlorophyll a, nitrate, phosphate and silicate concentrations at several sites in each growing area. The water movements in each growing area were investigated to provide information on the rate of replenishment of food supplies. A model was developed for each growing area to estimate the flow, velocity and flushing rate at different tidal heights. The direction of water currents in the growing areas also was studied.

The clearance rates of oysters, *i.e.* the rate of food consumption, and the assimilation efficiency were investigated at two sites, Pittwater and Pipeclay Lagoon over several months. Measurements of the production of food in an area (primary productivity) were also attempted.

A one-dimensional model, the ECoS model, developed for simulating the dispersal of pollutants in estuaries was modified to model the carrying capacities of oysters. Much of the field data collected for Pittwater has been incorporated into this model; other areas have not yet been modelled because the predictive model is still being developed. Simulations were conducted using different light intensities representative of summer and winter conditions which affect the production of oyster algal food, different dispersion coefficients, *i.e.* the rate of flushing in the estuary and hence the rate of replacement of algal food, and with or without primary productivity acting to compensate for food eaten by the oysters. The percentage depletion of chlorophyll a which is a measure of algal food available was modelled at two different oyster densities of 20 million and 30 million oysters at two sites in Pittwater estuary. The first site is where the oyster leases are currently located and the second site is where the majority of proposed leases would be situated. The results generally showed that under the 'worst' conditions with high stocking densities, and no primary production replacing food eaten, the average percentage depletion of oyster food was around 8-20% and that the maximum percentage depletion was 26-48%. This suggests that in summer time under worst conditions the food available would not be sufficient to maintain the growth rate of 30 million oysters in the two sections of the estuary, and the area most affected would be where the existing oyster leases are located or slightly further upstream.

The results from the ECoS model, however, are preliminary because the model is still being developed. Further research is required to refine the water movements in each growing area, primary production and oyster feeding rates. Growth rates of oysters which are currently being measured should be incorporated into the model and used to verify its predictability. Other factors which affect food availability such as abundances of other animals feeding on the same food as oysters should also be included.

Finally, although models, including the one being developed in this study, are showing significant promise as a management tool, they are limited by our knowledge of how ecosystems function and the data available. This study has emphasised that site specific data are important, and the data need to be collected over a substantial period of time because environmental parameters affecting carrying capacities can fluctuate substantially from year to year. These models are not able to provide quick solutions to carrying capacity problems in many areas because the required data will not be available. A work shop on carrying capacities of shellfish growing areas which discussed the results obtained from a large carrying capacity study in Europe also supported these findings. They concluded that modelling carrying capacities was difficult because of the wide range in scales of measurements over time and distance. Carrying capacity models have been developed for shellfish in several areas, but these models are not readily transferred to other areas and require detailed site specific information, in particular for water movements.

2. BACKGROUND

The Pacific oyster, *Crassostrea gigas*, was first introduced into Tasmanian waters in the late 1940's and early 1950's. It slowly increased in numbers and farming of oysters by collecting naturally settled spat on sticks in the Tamar River commenced in 1968 (Sumner, 1974). The natural settlement of oyster spat, however, proved to be unpredictable, and a hatchery to reliably produce large quantities of oyster spat was commissioned in 1978. The establishment of this hatchery producing commercial quantities of oyster spat enabled the oyster farming industry to expand rapidly.

In 1977 there were 12 oyster farms in Tasmania. By April 1986 this had increased to 77 leases occupying 800 ha, and by January 1993 there were 91 oyster leases occupying 1353 ha. Currently (1995) there are 4 commercial hatcheries and several nurseries which are able to provide a regular supply of spat to the growers. The total production of oysters from Tasmanian farms has increased from 0.95 million dozen in 1984 to 4 million dozen in 1994/5 when it was estimated to be worth approximately $15 million to the Tasmanian economy.

Traditionally oyster farming has consisted of placing oysters in mesh baskets strung between wooden racks in the intertidal zone. Areas most suited to intertidal oyster culture are extensive sheltered estuarine sand-mud flats. Oysters are also now being grown subtidally. They are placed in mesh trays in layers and suspended below surface buoys or longlines. However, all oysters require at least several months in intertidal conditions to harden the shell and develop strong adductor muscles to keep the shells tightly closed, thus extending the post-harvest shelf life.

By the mid 1980's several hatcheries were reliably producing large quantities of oyster spat for on-growing on the farms, and the techniques for commercial production of Pacific oysters were well developed. Also, the product was receiving favourable positioning and pricing in the market place. The industry was in an expansionary phase and numerous applications were submitted to Government for new farming areas or expansion of existing farms. Some farmers were also substantially increasing the quantity of stock held on their farms. However, shallow intertidal areas suitable for oyster farming were becoming rare, and public concern over the detrimental environmental impacts of marine farming was increasing. Conflicts over usage of shallow coastal waters for recreational use, marine farming, traditional fishing and navigational channels also were emerging.

In several oyster growing areas a number of farms were in close proximity to one another, and disagreements developed between the farmers over the number of oysters that the bay could support. Thus, for example, in one growing area a farmer was applying for an extension to his lease area while his neighbour was arguing that an increase in oyster numbers would slow the growth and reduce the condition of all oysters in the area. Similarly, in one major growing area where there are seven well established oyster farms in the upper reaches of the estuary, 12 applications for new farms have been received for the lower section of the estuary. The established oyster farmers are convinced that any new farms in the lower estuary would significantly reduce their production, whereas the applicants believe that the farms downstream would have little effect on those already in existence.

The number of oysters that can be grown successfully in a suitable farming area largely depends on the quantity and quality of food available in the water for the oysters to feed on. If the number of oysters being farmed exceeds the feeding capability (carrying capacity) of an area then the growth rate will be reduced and good condition (fatness) much more difficult to attain and maintain. This has deleterious ramifications on cash flow for farmers because the oysters take longer to reach market size and the farmers can't reliably harvest oysters throughout the year.

The definition of **Carrying Capacity** is taken from Carver and Mallet (1990) as: the stock density at which production levels are maximized without negatively affecting growth rates.

There are many factors which affect the carrying capacities of oyster growing areas and require investigation for estimates of carrying capacity to be made. Of particular importance is to determine the hydrodynamics of the growing area and hence supply of food, the production of food in the water, the food requirements of oysters throughout the year and the growth rates of oysters at various stocking levels. Other factors which can have a significant effect on carrying capacities are biomass of other filter feeders in the area, and environmental conditions which affect oyster growth rates and algal food production. Ideally, carrying capacities should be investigated over at least 3-5 years because annual variation can be large, for example, changes in climatic conditions can have a marked effect on food production and hence carrying capacities. Incze *et al* (1981) noted 4 factors which make the estimation of carrying capacities very difficult: 1) seasonal and size related changes in the energy demands of the cultured organisms, 2) seasonal changes in the abundance and nature of food supplies in natural waters, 3) poor knowledge of bivalve feeding on seston particles, and 4) poor knowledge of water mixing and flow in most marine farming areas.

Some studies on carrying capacities of shellfish have been conducted overseas in recent years, particularly in France where there has been a major drop in production from oyster farms over the years. Since this project started there have been several papers published on modelling carrying capacities of shellfish growing areas. Even so, recent publications, e.g. Raillard and Menesguen (1994) document problems still being encounted with the models. No such studies have been conducted in Australia previously.

In this project water movements and primary productivity of oyster growing areas, and oyster feeding rates have been investigated in relation to estimations of carrying capacity. Relevant environmental conditions including temperature, salinity and nutrient concentrations were also measured. These data were then incorporated into an estuarine simulation model to develop predictive models of carrying capacities of the oyster growing areas.

This research project was designed and initiated by Dr. John Wilson with assistance from Mr. Mike Rushton. However, Dr. Wilson resigned from the Tasmanian Division of Marine Resources and returned to Ireland approximately 20 months after the commencement of the project. His replacement, Dr. Christine Crawford, was not appointed for another seven months and in the meantime Mr. Rushton moved to another branch of Marine Resources. This has resulted in some discontinuity with the project.

3. NEED

The need for information and assistance on determining the carrying capacities of oyster growing areas was sought by two sectors: (1) the oyster farmers and (2) the Tasmanian government agency (Division of Sea Fisheries) responsible for the development and management of shellfish farming in Tasmania.

The Tasmanian Aquaculture Co-operative Society (which was primarily a co-operative of oyster growers) approached the then Division of Sea Fisheries in 1990-91 for assistance in determining the carrying capacity of several oyster growing areas in southern Tasmania. With the rapid expansion of the oyster growing industry, a number of farmers were becoming increasingly concerned that their growing areas would not be able to support the increased numbers of oysters, and this would result in slower growth and poor condition of the oysters on their farms. They asked for studies to be conducted to determine the carrying capacity of areas at present and potentially in the future under intensive cultivation. This would enable them to expand their operations and allow new farms to enter the industry without jeopardizing existing operations.

At the same time the Division of Sea Fisheries was trying to assess the potential oyster production of growing areas to promote sustainable development of the industry. They wished to encourage expansion of oyster operations to maximise the economic benefits of oyster farming to the Tasmanian economy. The Division was being called upon to adjudicate in disputes between farmers on the maximum number of oysters that a growing area could support. They were also receiving requests from some industry members to set production limits on farms in areas of intensive oyster farming activity.

This project to develop predictive models of carrying capacities of oyster growing areas was thus required by both industry and government resource managers to ensure sustainable development of the oyster culture industry in Tasmania. It was anticipated that these general models would be applicable to other filter feeding shellfish species and to other shellfish farming areas in Australia.

4. OBJECTIVES

- Carry out assessment of oyster production in relation to primary productivity and nutrient cycles in five coastal areas used for oyster ongrowing and fattening in Tasmania.

- To develop predictive models of the carrying capacities of these areas.

- To utilize these models in the formation of a general model, which can be applied with specific minor modifications to existing and potential intensive shellfish farms.

- To apply this general model in the day-to-day shellfish farm management.

5. RESEARCH METHODOLOGY

5.1 Oyster Growing Areas

An original objective of the project was to investigate and develop models of the carrying capacities of eight oyster growing areas. However, this was reduced to five areas during the project because the time required to develop the techniques and monitor equipment in each area was far greater than originally anticipated. One area (Pittwater) was sampled intensively during the project, whilst two areas (Pipeclay Lagoon and Little Swanport) were sampled for a substantial period of time, and two (Simpsons Bay and Moulting Bay at Georges Bay) were sampled for nearly twelve months.

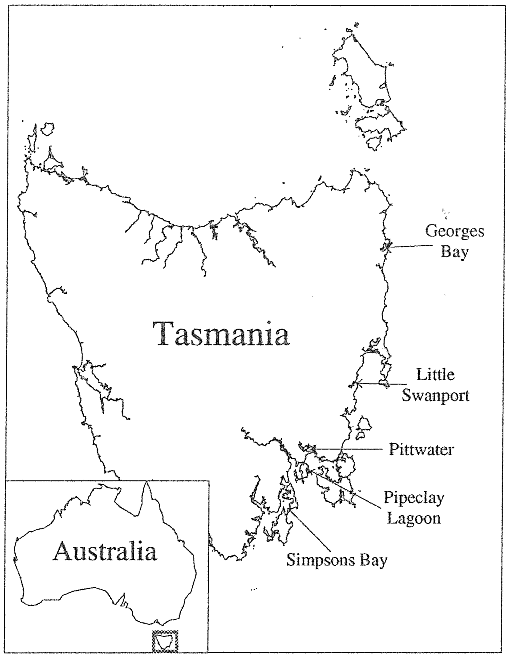


Figure 1. Location of the five oyster growing areas.

5.2 Sampling Sites

The five areas in Eastern and Southeastern Tasmania that were chosen for study are shown in Fig. 1. They were generally chosen because controversy existed in some way over the use of the area for oyster farming. All of the areas, except Simpsons Bay, contain substantial marine farming operations.

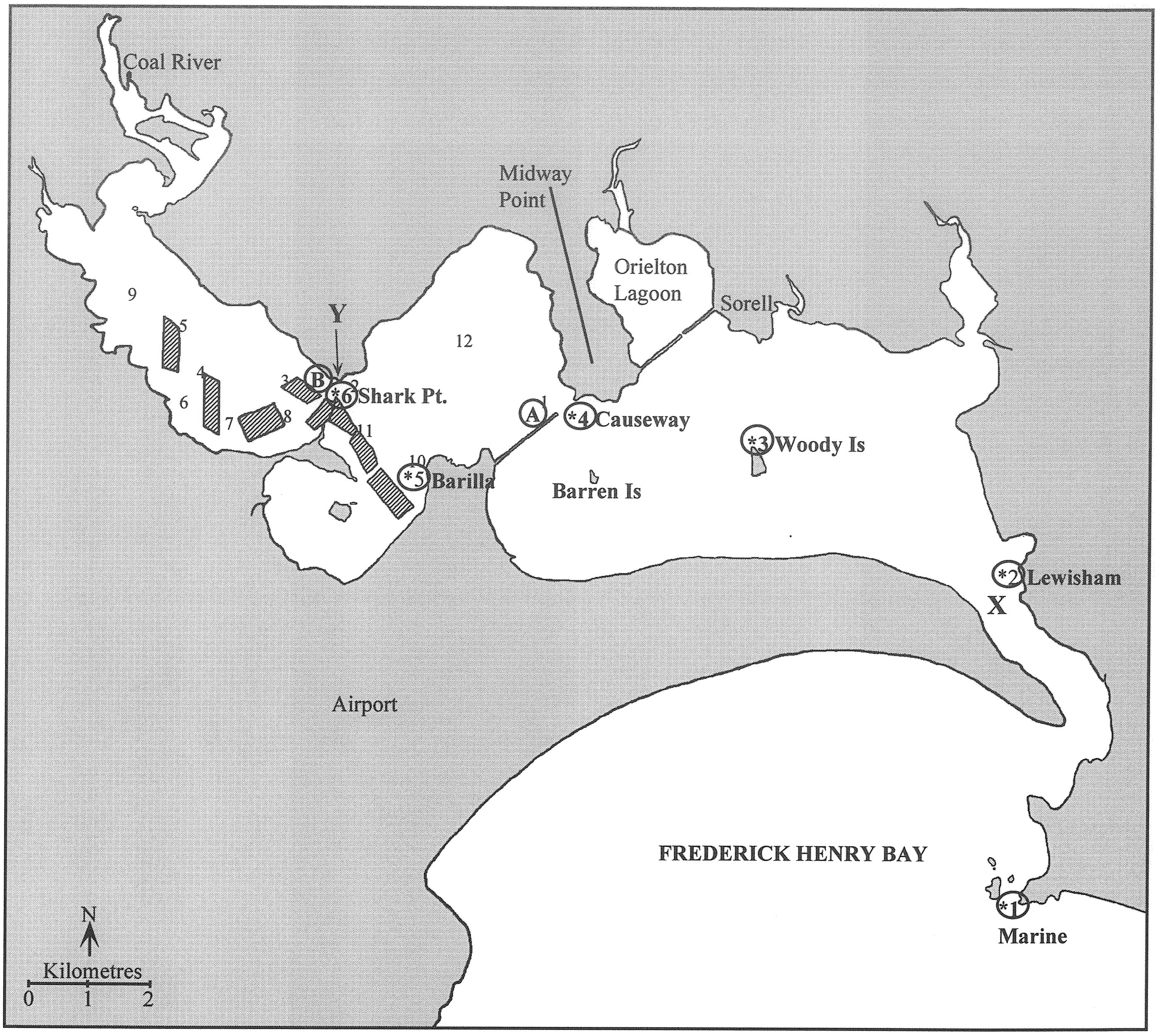
Pittwater (see Fig. 2) is a complicated estuarine system because the causeway located in the middle of the estuary restricts the water flow to the upper reaches. This area also underwent a change in freshwater flow patterns when the Craigbourne dam was built on the Coal River upstream of the oyster growing area in 1986, which resulted in previous sporadic flooding of the area being replaced by a constant and reduced flow into the estuary, except for rare large flood events. There are seven oyster leases occupying an area of 118.2 ha above the causeway, and a further 11 applications have been received for leases below the causeway and one above. Production of oysters from the seven leases in Upper Pittwater increased rapidly from 1985 and peaked in 1989 at 8.7 million market sized oysters. The number of oysters harvested from this area then declined to around 5 million in 1992, reportedly due to a decrease in productivity of the area observed by the farmers, but rose again to 6.2 million market size and 1.5 million juveniles for ongrowing being produced from the area in 1994.

Pipeclay Lagoon (Fig. 3) is a shallow marine inlet of area 5.32 km^2 with no permanent freshwater inflow. There are 7 leases in the lagoon growing almost entirely Pacific oysters and occupying an area of 48.3 ha. Production of oysters from Pipeclay Lagoon has steadily increased over the last 10 years from almost 1 million in 1985 to over 8 million in 1995.

The oyster growing area in Little Swanport Lagoon (Fig. 4) is in an estuarine system characterised by sporadic flooding. There are 3 leases growing Pacific oysters in the area (total area of leases is 79.8 ha) which are spread out along the estuary. Over the last 5 years these leases have produced approximately 3-4 million oysters per annum.

Georges Bay (Fig. 5) on the East Coast is an estuarine system with a very narrow opening to the sea and periodic flooding of the Georges River. All the shellfish farming is located within Moulting Bay, an offshoot of the main estuary. There are 4 leases occupying a total area of 40.5 ha. At least 2 leases have been only partly developed until recently and although the Pacific oyster is the main species grown, most leases contain other types of shellfish including native flat oysters (*Ostrea angasi*), mussels (*Mytilus edulis*) and clams (*Katylesia* sp.). In the 1995/96 growing season 4.4 million oysters and 32,000 kg of mussels were produced from the 4 leases.

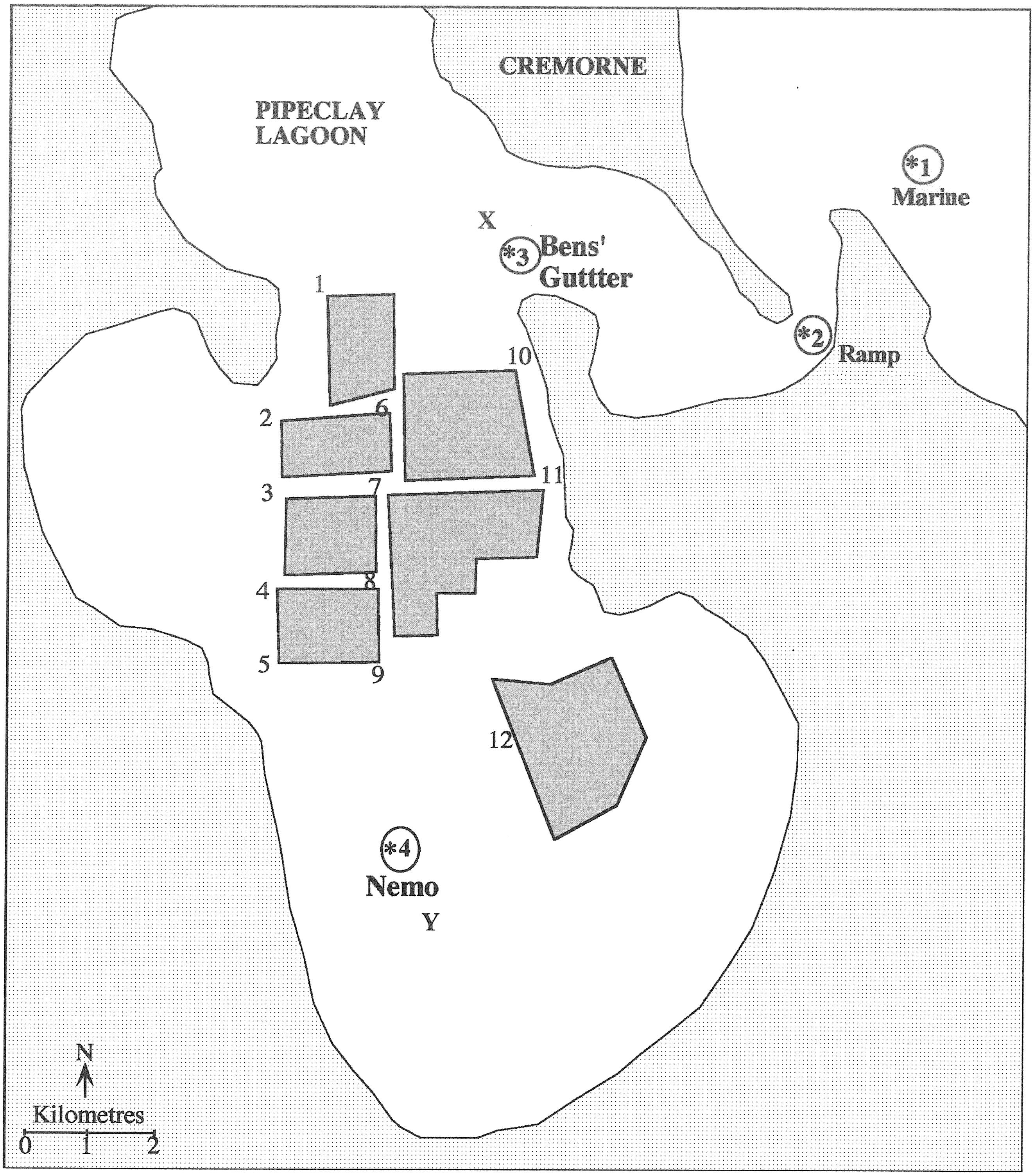
Simpsons Bay (Fig. 6) is in the D'Entrecasteaux Channel contains three small shellfish farms at the head of the bay. These farms occupy an area of 42.4 ha but are only partly developed for Pacific oysters. The bay consists of extensive shallow sand flats, is fairly exposed and productivity of the area is considered to be poor (DPIF Draft Plan for the D'Entrecasteaux Channel, 1995). Production from these leases has increased rapidly since 1993 and reached 171,000 oysters in 1995.



Legend:

(hatched box)	Shellfish lease area
***1** to ***6**	Monthly sample sites
1 to **12**	Intensive sampling sites
X and **Y**	Sites for estimates of primary production
A and **B**	Sampling sites over time

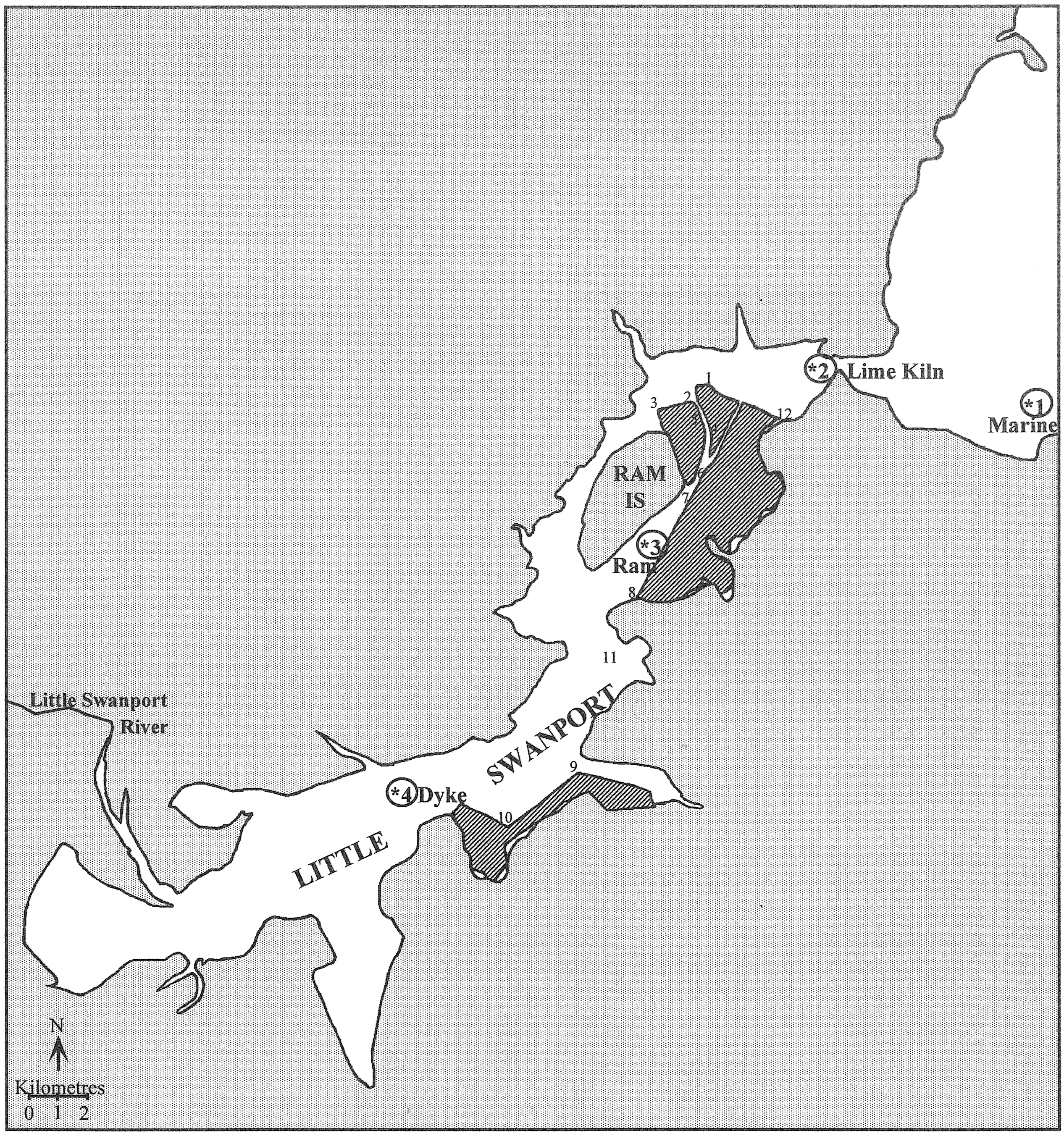
Figure 2. Pittwater growing area.



Legend:

(shaded box)	Shellfish lease area
***1** to ***4**	Monthly sample sites
1 to **12**	Intensive sampling sites
X and **Y**	Sites for estimates of primary production

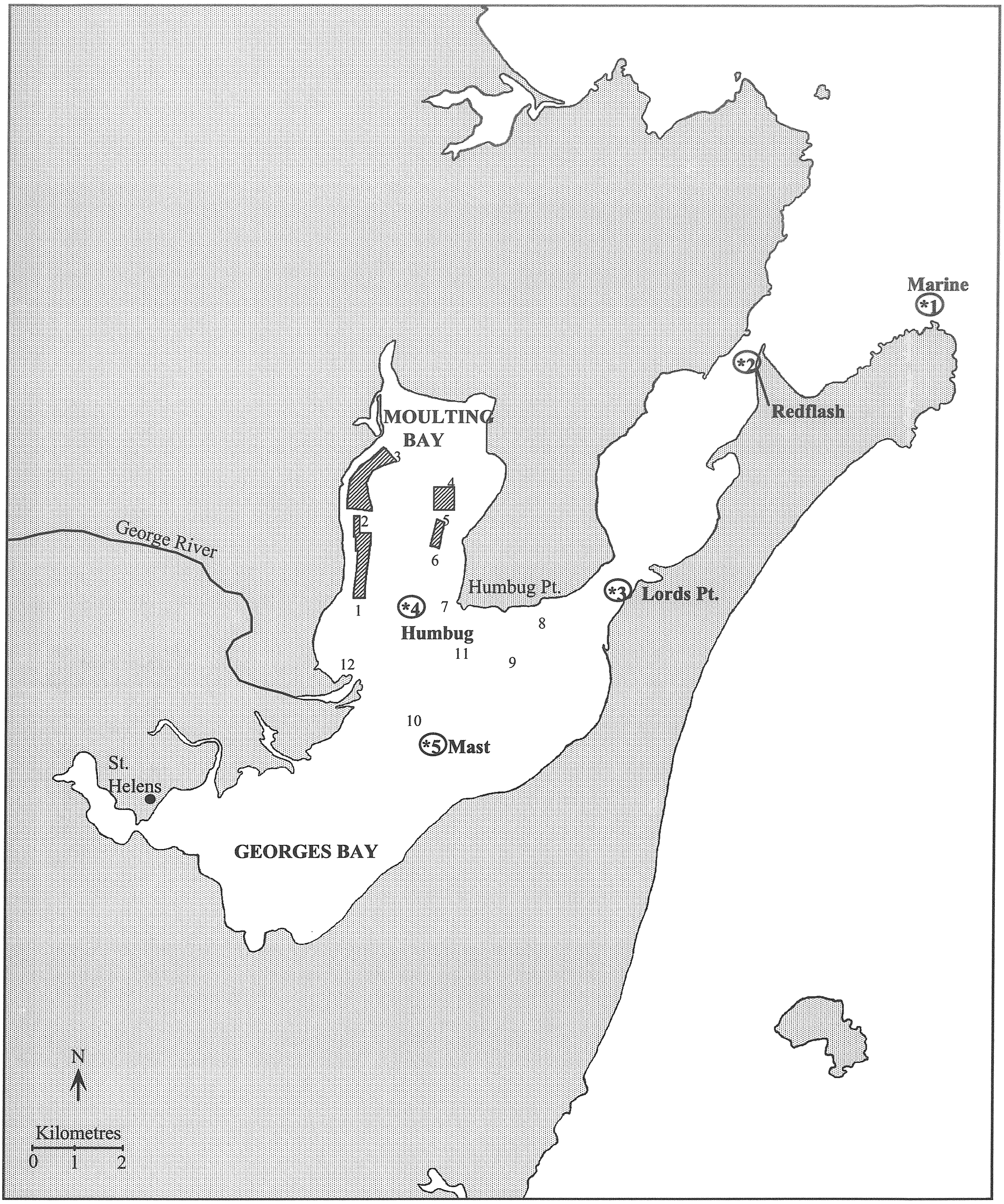
Figure 3. Pipeclay Lagoon growing area.



Legend:

(hatched box)	Shellfish lease area
***1 to *4**	Monthly sample sites
1 to 12	Intensive sampling sites

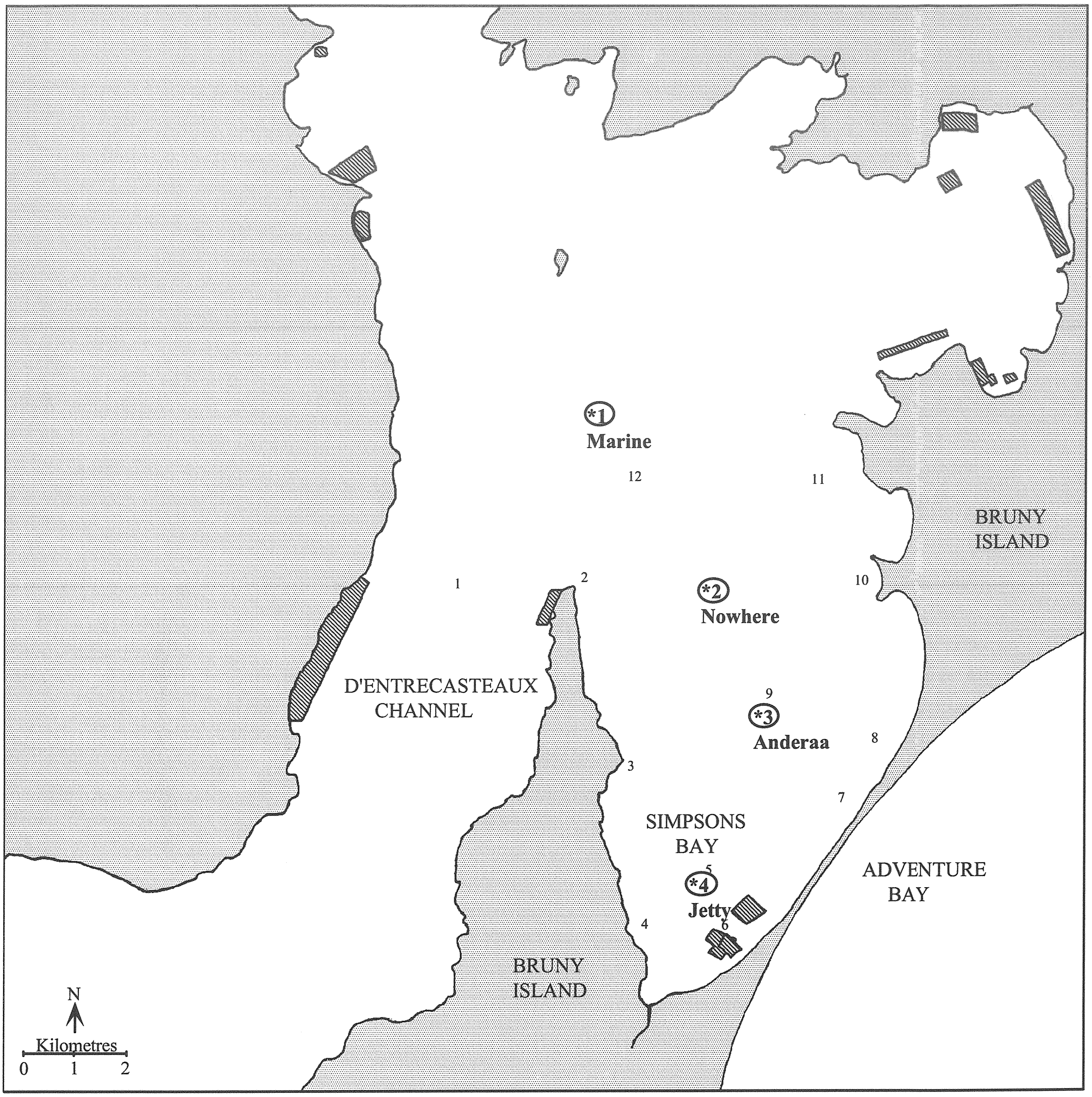
Figure 4. Little Swanport growing area.



Legend:

(hatched box)	Shellfish lease area
***1** to ***5**	Monthly sample sites
1 to **12**	Intensive sampling sites

Figure 5. Georges Bay growing area.



Legend:

(hatched box)	Shellfish lease area
***1** to ***4**	Monthly sample sites
1 to **12**	Intensive sampling sites

Figure 6. Simpsons Bay growing area.

5.3 Hydrodynamics of Growing Areas

Four oyster growing areas were selected for detailed hydrodynamic studies, Pittwater, Pipeclay Lagoon, Little Swanport and Georges Bay. The hydrodynamics of two other areas, Simpsons Bay and Hastings Bay, were partially investigated but the results are not included.

All growing areas were divided into 17 or 34 segments according to the requirements of a one-dimensional hydrodynamic model which was being developed to predict carrying capacities of the growing areas. The segments were determined by drawing a line along the main channel up the estuary and dividing this distance into segments of equal length, with the segment boundaries being drawn at right angles to the line along the main channel. Water volumes and movements were calculated for each sector.

Depth contours throughout the growing areas were determined by measuring depths along transects using a depth sounder in a boat and from aerial photographs. Soundings were taken relative to an arbitrary datum point, which were later adjusted to correspond to datum at Hobart. These measured depths at a known tidal height were converted to depths that would occur at a theoretical maximum tidal height of 2 m. This was done to standardise all soundings as they were made at different stages of the tidal cycle and for different tides. A bathymetric chart was produced for each growing area at a 2 m high tide. The area of water at depth intervals of 0.5 or 1 m for a 2 m high tide was calculated for each sector, initially by comparing the weight of paper covering a known area to the weight covering the area in question. Later a planimeter was used to determine the area of water at each depth. The volumes of water in each sector were determined by multiplying the area by the tidal height calculated at each depth interval. Tidal material for Hobart was supplied by the National Tidal Facility.

Streamlines, *i.e.* direction of flow near the surface at various points throughout the growing area were determined for flood and ebb tides, initially by noting the direction of movement of rope deployed from a stationary boat, and later by using a biplanar cross constructed of aluminium circles 60 cm diameter at right angles to one another and attached by rope to an anchored line. The biplanar cross was placed approximately one metre below the surface and the direction was recorded from the position of floats attached to the biplanar cross and to the anchored line. This was repeated over several tides.

From the information collected on volumes a model was developed to estimate the volume of water in each sector of the growing area for any given tidal height. This enabled total volumes, tidal prisms and flushing rates to be calculated for any sized tide.

$$\text{Volume of water (V) in a sector} = \Sigma \text{ area(y)} \times (\text{y}-(2-\text{tidal ht.}))$$

where y = depth from 0.5m, 1m, 2m, ... to maximum depth.

The total volume for the bay was calculated from the sum of the positive volumes in each sector. From the calculated volumes at given high and low tides, tidal prisms, exchange rates, and flow rates were estimated as follows:

Tidal prism = high water volume - low water volume

$$\text{Exchange rate} = \frac{\text{tidal prism}}{\text{high tide volume}}$$

$$\text{Flushing time (tidal cycle)} = \frac{\text{low water vol.} + \text{prism}}{\text{prism}}$$

Average flow (tonnes/m^2) = volume transgressed segment/cross sectional area

where cross sectional area = av. width x av. depth at mid tide

Average velocity (m/s) = Flow/6.25/3600

This model was checked by measuring real water flow rates using an Ultrasonic Sensordata current meter deployed from a dinghy at different depths during both flood and ebb tides. Measurements were made at several stations at the entrance of each growing area, and extrapolated to the rest of the area. The current meter measured flow rates in three planes which were averaged. From the measurements of water velocity and the profile of the transect, the volume of water (area x velocity) could be determined. These observed values were compared with predicted values determined using the model, to assess the accuracy of the model.

WESDATA (Dataflow Systems) tide gauges measuring tidal height, temperature and salinity were installed in four estuaries, with 1-3 tide gauges positioned along each estuary. They were regularly serviced, but proved to be highly unreliable, and little useful information was obtained from 12 gauges. New gauges were purchased in 1995 and data are currently being collected progressively from the four growing areas.

Additional measurements of water movements were made in Pittwater (see Fig. 2) because a more accurate picture of water flow in the area was required, in particular, the direction and volume of water in the vicinity of present and proposed oyster leases. Streamlines had shown that current directions were variable during tidal cycles in the Barren Island area. To further quantify the water movements below the causeway, the volumes of water flowing to the North and West of Barren Island were measured during a flood tide on 12 March 1992. The transects used are shown in Fig. 7.

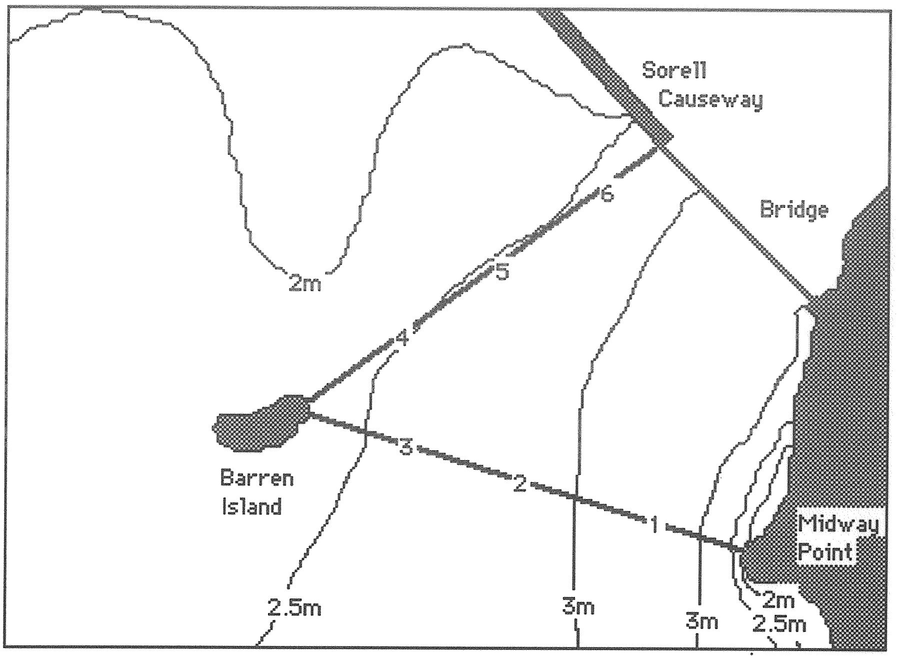


Figure 7. Transects from bridge to Barren Island and Barren Island to Midway Point. Stations 1 to 6 shown on transects.

The Barren Island/Causeway transect was at 316° and 900 m long. The Midway/Barren Island transect was at 5° and 1200m long. Station 1 was 220m from Midway Point, station 2 at 560m and station 3 at 890m. Station 4 was 250m from Barren Island station 5 at 500m and station 6 at 740m. Station 1 was sited to include all the deep channel running towards the bridge.

Current velocities were measured at stations 1 to 6 at approximately hourly intervals on 12 March through a predicted tide range of 0.64m from 0.70m at 9:57 am to 1.34m at 4:34 pm (Hobart tables). The actual range measured was 0.63m from slack water at 11:40 am to slack water at 5:30 pm. Velocities at 1m depth intervals were depth averaged at station 1. At stations 2-6 the current meter was set at mid water and readings taken only at one depth, because of the shallowness of the water. At stations 4-6 the velocity vectors at 46° were taken to represent the velocity of flow of water destined to pass under the bridge, as were the vectors at 275° at stations 1-3. Soundings were taken at fixed distances along the transects and adjusted to tidal variation to determine changes in cross-sectional areas at the transects during the tidal cycle. From the data on current velocities and profiles of the stations, the flows through the area were calculated.

5.4 Nutrient and Food Concentrations in Growing Areas

From four to six sampling stations were sampled at each site approximately monthly for varying periods of time. Pittwater was chosen as the main sampling site and was monitored approximately monthly for 40 months, whereas problems relating to carrying capacity which were restricting development in Simpsons Bay were settled privately and so it was only sampled for nine months. Stations were selected to be representative of water movements within each growing area, and generally ranged from the mouth of the bay or estuary to the upper reaches above the oyster growing area. Water samples were collected on the ebb tide just before low water.

The monthly sampling program consisted of deploying integrated water sample bottles to sample at 1m depth at each station. The sample bottles, which were specifically developed by project team members as a modification of the samplers designed by Fabris *et al* (1982), screened out large particles on a 500 µm mesh, and slowly filled to capacity of 6 l over one hour. At each station near surface water temperatures and salinities were recorded using a temperature-conductivity meter.

The water samples collected were processed in the laboratory within twenty four hours, and mostly on the day of collection. Replicate 10 ml samples were collected and frozen for later nutrient analysis. Approximately one litre of water sample was filtered through 47 mm Whatman GF/C filters, pore size 1.2µm, and the filter with concentrate was frozen for subsequent chlorophyll a analysis.

The oyster farming areas at each site were also intensively sampled over a short period of time on one to several occasions to investigate the spatial changes in nutrients and chlorophyll a within and around the growing area. These sampling stations are shown on the respective maps for each site (Figs. 2-6). 2 l water samples were collected at 1 m depth as quickly as possible from each station, with all stations being sampled in less than one hour. The water samples were analysed as described for the monthly samples.

The changes in nutrient and chlorophyll a concentrations over time also were investigated at two stations at Pittwater, one just above the causeway (Station A) and one near the oyster leases above Shark Point (Station B)(see Fig. 2). Replicate water samples were collected every hour for 12 hours, followed by every two hours for the next 12 hours. They were then collected every day on the ebb tide for one week, followed by once a week for four weeks. Because we did not have large numbers of integrated water samplers, replicate 2 l water samples were collected in plastic bottles during the 24 hour sampling period. Integrated sample bottles were also used twice during this period, and then for all subsequent sampling. Water temperature and salinity were recorded on each sampling occasion.

The temperature and salinity profiles with depth were measured at all stations of each site except Simpsons Bay on two occasions using a CTD Profiler.

Analytical Methods

Nutrients, Nitrate + nitrite (NOX) NO3 + NO2 -N, nitrite NO2 -N, phosphate PO4 -P and silicate SiO4 -Si, were analysed using a Skalar segmented flow analyser. Nitrate nitrogen was calculated from NOX minus nitrite values. Low concentration nutrient standards were made to calibrate the nutrient concentrations in the water samples. Silicates were measured from November 1993.

Chlorophyll a concentrations were determined using a modified APHA (1985) Standard Method 1002G. Frozen filters were torn into small pieces, 90% acetone was added, and the sample was sonicated then centrifuged at high speed. Absorbance of the extract was read at 663nm and 750nm. The extract was then acidified with dilute hydrochloric acid and the absorbance read again at these wavelengths. Chlorophyll a values (µg/l) were calculated using the following formula from Parsons *et al* (1984):

$$\text{Chl } a = \frac{(\text{Ab663 nm} - \text{Ab750 nm}) \times 11.41 \times (\text{mls 90\% acetone})}{\text{litres seawater}}$$

where Ab = absorbance

5.5 Primary Production

The *in situ* primary production of phytoplankton was measured at two sites X and Y (see Figs. 2 and 3) in two growing areas, Pittwater and Pipeclay Lagoon, using a light/dark oxygen method modified from the APHA Standard Method (APHA, 1985). This method is based on the principle that algal photosynthesis involves the uptake of inorganic carbon and release of oxygen, with the assumption that one atom of carbon is assimilated for each molecule of oxygen released. One litre Nalgene bottles (measured volume 1.22 *l*) were suspended from a light gauge chain at 1.2 m depth below the surface. Dark bottles were wrapped in foil and tape and enclosed in thick black plastic bags. Two replicates of light and dark bottles were suspended at each site, with the dark bottles attached slightly below the light bottles to prevent shading. Because the growing areas are in relatively shallow water, productivity was assumed to be similar throughout the water column. Bottles were filled with water from approximately 40 cm below the surface and were not screened. The bottles were generally deployed in the morning and incubated for 2-6 hours. Samples collected at the end of the incubation period were stored in the dark and on ice for up to 3 hours until the oxygen concentration was measured using a WTW Oxygen meter. Initial oxygen concentration before incubation was not measured on all occasions because of problems with using the oxygen meter in the field and only gross production was determined on these occasions.

Productivity was determined using the following calculations:

Net photosynthesis = light bottle DO - initial DO
Respiration = initial DO - dark bottle DO
Gross photosynthesis = Light bottle DO - dark bottle DO

Gross/Net Production (mg carbon fixed/m^3) = mg oxygen released/L x 12/32 x1000

(1 mole of O_2 (32g) is released for each mole of carbon (12g) fixed).

The concentration of oxygen released during incubation was averaged for the replicates on each day of sampling, and productivity was measured on 2-3 days over summer and over winter, and the mean value was calculated. For most sampling days solar radiation (pyranometer) data were obtained from the University of Tasmania in the form of 10 minute averages. Both Pipeclay Lagoon and Pittwater are approximately 18 km from the pyranometer and it was assumed that the data collected would be representative of these sites. These data were used to calculate daily carbon production (mg C/m^3/day) by extrapolation of the production at a known solar radiation during a part of the day to total production for the day using the daily solar radiation profile.

5.6 Oyster Feeding Rates

Feeding rates (clearance rates) of oysters were measured in the field using grazing chambers (Fig. 8a and b) modified from the apparatus used by Carver and Mallet (1990). The major difference to Carver and Mallet's filtration box was that the grazing chambers were increased in size to 4.5 l volume so that each chamber held one standard sized plastic mesh basket of oysters identical to those used on commercial oyster farms. The basic experimental unit thus consisted of about 60 oysters (for large oysters) in each grazing chamber, with a total of 3 grazing chambers in the feeding apparatus. This should provide realistic values of clearance rates within a commercial operation, where some refiltering of exhaled water is probably occurring.

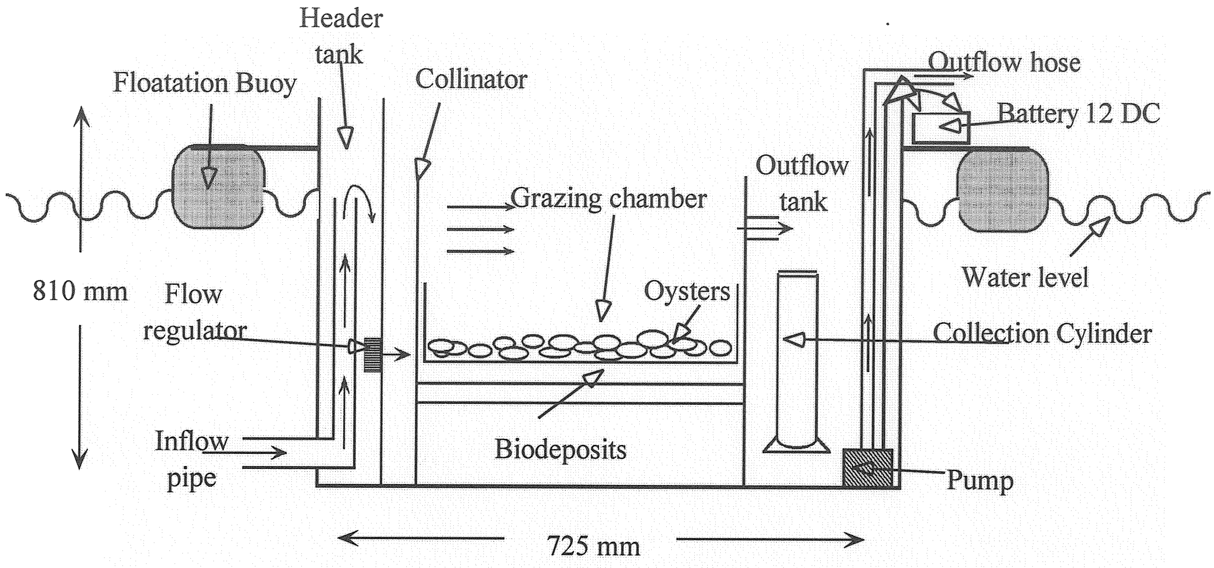


Figure 8a. Side view of feeding apparatus used for feeding experiments.

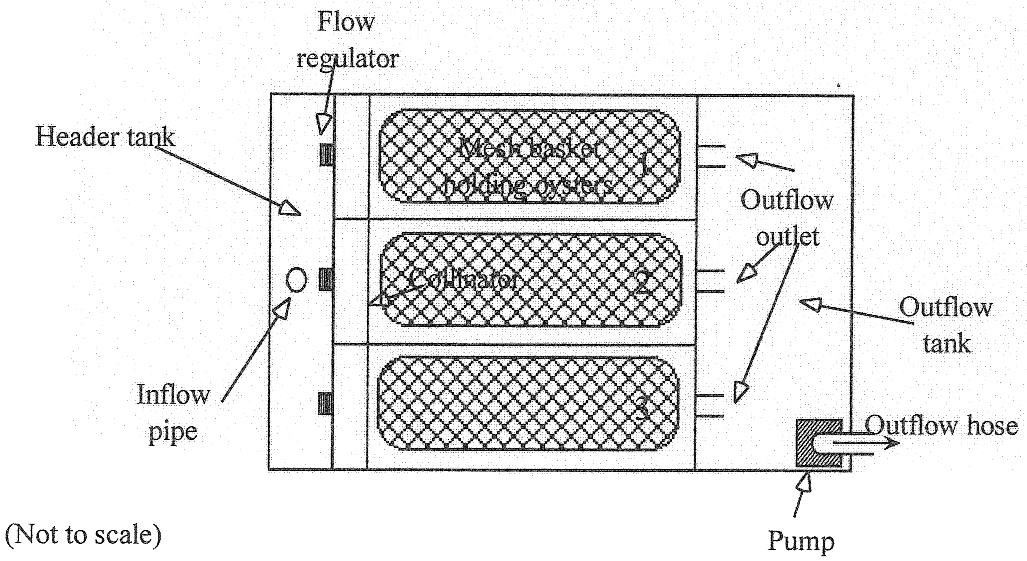


Figure 8b. Plan view of feeding apparatus used for feeding experiments.

The feeding apparatus was made of fibreglass and timber, and was partially submerged using four plastic floatation buoys attached at each corner which could be partially filled with water to regulate the position of the apparatus in the water column. The water intake was below the surface and it flowed into a header tank through PVC tubing which controlled the height of water in the apparatus. Water flowed into each grazing chamber via flow regulators, the diameter of which could be altered to control the flow rate into the chambers. The water then passed through collinators consisting of holes in PVC sheeting to produce laminar flow across the oysters. The inflowing water was not pumped to prevent disruption of phytoplankton assemblages. The oysters were held in plastic mesh baskets, mesh size 12 x 12mm, in standard commercial quantities. Faeces expelled from the oysters passed through the mesh onto the bottom of the grazing chamber and were collected at the end of each experimental run by siphoning or using a small vacuum pump. The water flowed from the grazing chambers into the outflow tank and was then pumped outside using a bilge pump connected to a 12 volt battery with automatic on/off switch.

The feeding apparatus was moored next to commercial oyster racks on farms at Pittwater and Pipeclay Lagoon. The oysters used in the experiments were cleaned of epibionts, measured and weighed and kept in baskets on racks next to the feeding apparatus. During feeding rate trials the baskets of oysters were placed in the grazing chambers and left to acclimate for one hour. Thereafter, every hour for up to five hours, the water flow rate (ml/min) through each grazing chamber was measured by timing the quantity of water flowing out of the chamber into the overflow tank, and temperature and salinity were measured. 2 l water samples were collected at the inflow and at the outflow of each grazing chamber and held on ice until they could be processed in the laboratory. At the end of each day's experimental run, the baskets of oysters were removed and the biodeposits on the bottom of each chamber were collected. On most sampling days one of the three grazing chambers (selected at random) was kept empty as a control to check that no other factors were affecting concentrations of oyster food in the water.

Initial experiments using the feeding apparatus measured the algal concentration in the water using a Particle Counter. The number of algal cells of different diameter in the range 0.2-20µm in a known volume of sample, generally 50 ml, were counted and the proportion of algal food removed by the oysters in each grazing chamber was calculated by subtracting the number of cells in the outflowing water from the number in the inflow, and dividing the result by the number of cells in the inflow. This was then multiplied by the flow rate of the water to give Feeding Rates (F_eR),

i.e. $F_eR = V((\text{No. In} - \text{No. Out})/\text{No. In})$.

where No. In is the total number of algal cells in the inflowing seawater, No. Out is the number of algal cells in the water after flowing through the oyster grazing chamber, and V is mean flow rate (l/h in the experimental chambers).

In the latter part of the project the water samples were analysed for particulate organic and inorganic matter, and total particulate matter. Approximately 600 ml (depending on the quantity of suspended matter in the water) and approximately 200 ml of faecal samples were filtered through ashed and preweighed 47-mm Whatman GF/C filters (nominal pore size 1.2 mm) and rinsed with 0.9 % ammonium formate to remove the salts. After the particulate samples were dried for approximately 24 hours at 60°C, the filters were weighed to obtain total particulate matter (TPM) values. They were then ashed at 480°C for 4 hours and reweighed to obtain particulate inorganic matter (PIM) and particulate organic matter (POM) by loss on ignition.

Feeding rates (Clearance rates) were calculated using a similar formula:

$$FR = V\,((P_{in} - P_{out})/P_{in})$$

where P_{in} is mean POM concentration (mg/l) of water flowing into the experimental chambers, and P_{out} is the mean POM concentration (mg/l) of water flowing out of the experimental chambers.

Assimilation Efficiency (AE) was calculated from the formula of Gerdes (1983), using the Conover method (Conover, 1966).

$$AE = \frac{F-E}{(1-E)F} \times 100$$

where F = (weight POM / weight TPM) of food, E = (weight POM / weight TPM) of faeces. Any assimilation or release of dissolved organic nutrients was not included in the analysis.

5.7 Predictive Models of Carrying Capacities of Growing Areas

The computer model that is being developed is based on ECoS Version 2.0, a hydrodynamic simulation shell developed within the Estuarine Environmental Quality Program of the Institute for Marine Environmental Research, Plymouth, U.K., with the collaboration of the UK National Rivers Authority.

The model is a one-dimensional numerical model. In this type of model the bay under study is divided into axial segments of equal axial length, with a maximum of 50 segments. All quantities of interest are taken as cross-sectional averages for each segment. It is assumed that variation over the cross-section of the bay is insignificant. The average dimensions of the bay are calculated from a bathymetric chart which has been developed as described in the section on Hydrodynamics. These data have been used in setting up initial volumes and areas in the simulation.

So far the model has largely been developed for the Pittwater growing area where each segment has an average cross-sectional area, which varies with tidal height around a mean of 1.2 m. The tidal cycle used in the simulation is that predicted for Hobart by the National Tidal Institute, Flinders University, South Australia, for the period from 1 January 1993 to 11 March 1993, a total of 70 days (Fig. 9). No allowance has been made for local variations in tidal amplitude with position in the bay. Real data of variations of tidal amplitude within growing areas will be used as information from the new tidal gauges becomes available.

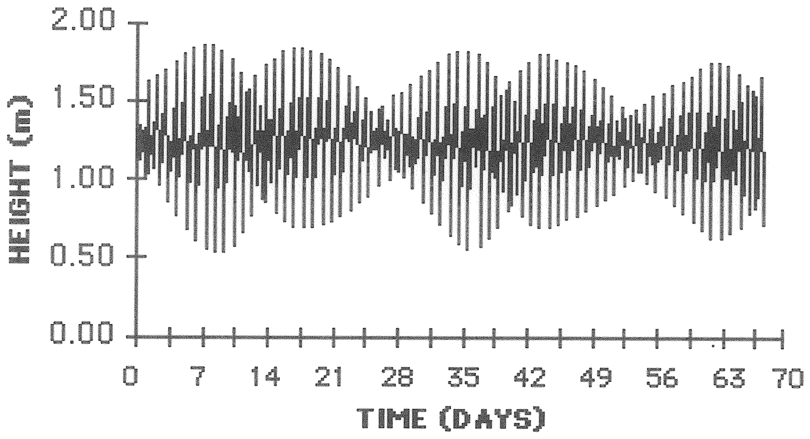


Figure 9. Tidal cycles over 70 day period from 1 Jan to 11 March 1993 for Pittwater.

Mixing or dispersion of food and other variables within the bay occurs due to tidal movements or advection. This dispersive effect is related to the longitudinal water dispersion coefficient. This is usually within the range of 100-300m^2s^{-1} for estuaries and bays (Fischer *et al*., 1979; Dyer, 1973). The dispersion coefficient may be estimated from salinity distributions in the bay or by measurements on the rate of dispersion of dye patches. An adjusted dispersion coefficient will be fitted by iteration when the salinity data are available from the new CTD data loggers to produce salinity distributions similar to those observed in the bay. For the purposes of the simulation for this report the dispersion coefficient has been assumed to be a function of tidal current amplitude within the range specified by Fischer and Dyer (Bowden, 1963).

A modification of oyster feeding rates due to tidal exposure has been incorporated into the model. The oysters are exposed at low water on some tides, which causes an overall reduction in grazing pressure on algal stocks. The exposure time is normally set at 40% by farmers. Within the tidal cycles used in this study this is equivalent to a tidal height of 1.16m. The model has been written to reduce depletion by oysters to zero at tidal levels less than this height.

6. DETAILED RESULTS

6.1 Hydrodynamics of growing areas

6.1.1 Pittwater

The hydrodynamics in Pittwater are complicated because of the Sorell Causeway which restricts the flow of water to the upper reaches of Pittwater where the oyster farms are located, and because of another causeway which until recently severely reduced the flow of water into Orielton Lagoon. The Sorell Causeway is 1.5 km long with an opening of approximately 500 m for the water to flow through. Pittwater estuary is approximately 17 km long and was divided into 34 sectors (Fig. 10). The depth contours (Fig. 11a & b) show extensive sandflats with a narrow channel roughly in the centre of the estuary. Results from the predictive model for water volumes given in Table 1 include the total area and total high and low water volumes, flows and average velocities for each sector. More information on the calculation of water volumes at the different depths in each sector is shown in Table 4 on the hydrodynamics of Pipeclay Lagoon; this water body is smaller and less complicated than Pittwater. The volumes calculated for Pittwater using the annual average high tide and low tide values for Hobart for 1993 (Table 1) show that the average tidal prism (i.e. volume of water moving in and out on each tide) for the whole estuary is 23.4 million tonnes, with 11 million flowing out of Upper Pittwater (Causeway to Head). The average flushing is 4.36 tidal cycles or just over two days. Water velocities were not as high in Pittwater as Pipeclay Lagoon, averaging 9 cm sec^{-1}. Streamlines (Fig. 12a & b) indicate that water movement is throughout the estuary and not confined to channels, with some circulation around the causeways.

Table 1 Hydrodynamics of Pittwater

Pittwater Volumes

Annual Average High Tide 1.555 m
Annual Average Low Tide 0.995 m

Sector	Total area (km2)	Dist. from head (km)	HW vol (1000t)	LW vol (1000t)	Tidal Prism	VOLUMES (1000t) Cum prism	Vol trans. seg.	Vol at Mid tide	Cross sect. area (m2)	Av. width (m)	Av. Mid Tide Depth (m)	Flow tonnes/m2	Av. Velocity m/s
1	1.03	0.46	817.38	373.98	443.40	443.40	0.00	595.68	1294.97	2241.99	0.58	0.00	0.00
2	0.71	0.92	981.34	625.33	356.00	799.40	443.40	803.34	1746.38	1552.15	1.13	253.90	0.01
3	0.81	1.38	1167.50	777.19	390.31	1189.72	799.40	972.35	2113.80	1753.35	1.21	378.18	0.02
4	0.78	1.84	1097.36	738.05	359.31	1549.02	1189.72	917.71	1995.01	1695.87	1.18	596.34	0.03
5	0.87	2.30	1704.05	1299.66	404.39	1953.42	1549.02	1501.85	3264.90	1897.07	1.72	474.45	0.02
6	1.32	2.76	2839.42	2142.82	696.60	2650.02	1953.42	2491.12	5415.49	2874.35	1.88	360.71	0.02
7	1.24	3.22	2560.70	1898.41	662.29	3312.31	2650.02	2229.56	4846.87	2701.89	1.79	546.75	0.02
8	1.48	3.68	2536.38	1872.90	663.48	3975.79	3312.31	2204.64	4792.69	3219.27	1.49	691.12	0.03
9	1.23	4.14	2328.99	1767.78	561.21	4537.00	3975.79	2048.39	4453.01	2673.14	1.67	892.83	0.04
10	1.78	4.60	2515.62	1754.03	761.59	5298.58	4537.00	2134.82	4640.92	3880.37	1.20	977.61	0.04
11	2.92	5.06	6088.60	4602.58	1486.02	6784.60	5298.58	5345.59	11620.84	6352.31	1.83	455.96	0.02
12	1.77	5.52	4535.41	3714.92	820.49	7605.10	6784.60	4125.16	8967.75	3851.63	2.33	756.56	0.03
13	1.44	5.98	4935.05	4144.83	790.21	8395.31	7605.10	4539.94	9869.43	3133.04	3.15	770.57	0.03
14	1.94	6.44	6863.34	5801.88	1061.46	9456.77	8395.31	6332.61	13766.55	4225.29	3.26	609.83	0.03
15	1.86	6.90	5414.48	4421.04	993.43	10450.21	9456.77	4917.76	10690.78	4052.83	2.64	884.57	0.04
16	1.11	7.36	3019.51	2421.15	598.36	11048.57	10450.21	2720.33	5913.76	2414.45	2.45	1767.10	0.08
17	0.74	7.82	1558.34	1173.32	385.02	11433.59	11048.57	1365.83	2969.20	1609.63	1.84	3721.06	0.17
18	2.05	8.37	3101.84	2047.57	1054.26	12487.85	11433.59	2574.70	5597.18	4461.58	1.25	2042.74	0.09
19	2.58	8.91	3736.68	2457.63	1279.05	13766.91	12487.85	3097.15	6732.94	5599.43	1.20	1854.74	0.08
20	1.61	9.46	2650.60	1786.21	864.39	14631.30	13766.91	2218.41	4822.62	3503.39	1.38	2854.65	0.13
21	1.85	10.00	2945.85	1923.88	1021.96	15653.26	14631.30	2434.86	5293.18	4012.43	1.32	2764.18	0.12
22	1.67	10.55	2722.50	1799.64	922.86	16576.12	15653.26	2261.07	4915.37	3623.16	1.36	3184.55	0.14
23	2.11	11.09	3332.14	2212.72	1119.41	17695.53	16576.12	2772.43	6027.02	4581.35	1.32	2750.30	0.12
24	2.00	11.64	3821.94	2764.86	1057.09	18752.61	17695.53	3293.40	7159.56	4341.80	1.65	2471.59	0.11
25	1.27	12.18	2342.41	1678.02	664.39	19417.00	18752.61	2010.21	4370.03	2754.80	1.59	4291.19	0.19
26	1.18	12.73	2351.64	1746.75	604.89	20021.89	19417.00	2049.19	4454.77	2575.14	1.73	4358.70	0.19
27	1.89	13.27	3402.66	2447.57	955.09	20976.98	20021.89	2925.12	6358.95	4102.26	1.55	3148.62	0.14
28	1.54	13.82	3610.99	2789.79	821.21	21798.18	20976.98	3200.39	6957.37	3353.67	2.07	3015.07	0.13
29	0.70	14.36	2104.74	1732.63	372.10	22170.29	21798.18	1918.68	4171.05	1527.12	2.73	5226.06	0.23
30	0.65	14.91	3279.38	2945.78	333.61	22503.89	22170.29	3112.58	6766.48	1407.34	4.81	3276.49	0.15
31	0.56	15.45	3137.10	2918.23	218.87	22722.76	22503.89	3027.66	6581.88	1227.68	5.36	3419.07	0.15
32	0.43	16.00	2482.14	2298.67	183.47	22906.23	22722.76	2390.41	5196.54	928.25	5.60	4372.67	0.19
33	0.47	16.54	2746.12	2532.56	213.57	23119.80	22906.23	2639.34	5737.69	1018.08	5.64	3992.24	0.18
34	0.51	17.09	3085.86	2849.15	236.71	23356.50	23119.80	2967.50	6451.10	1107.91	5.82	3583.85	0.16
TOTAL	**46.12**		**101818.04**	**78461.54**	**23356.50**						AVERAGE	**2080.71**	0.09

SUMMARY	Bay
HW (m3)=	101,818,044
LW (m3)=	78,461,540
PRISM (m3)=	23,356,504
AREA (km2)=	46.12
FLUSHING TIME (tidal cycle)	4.36
EXCHANGE RATE	22.94%

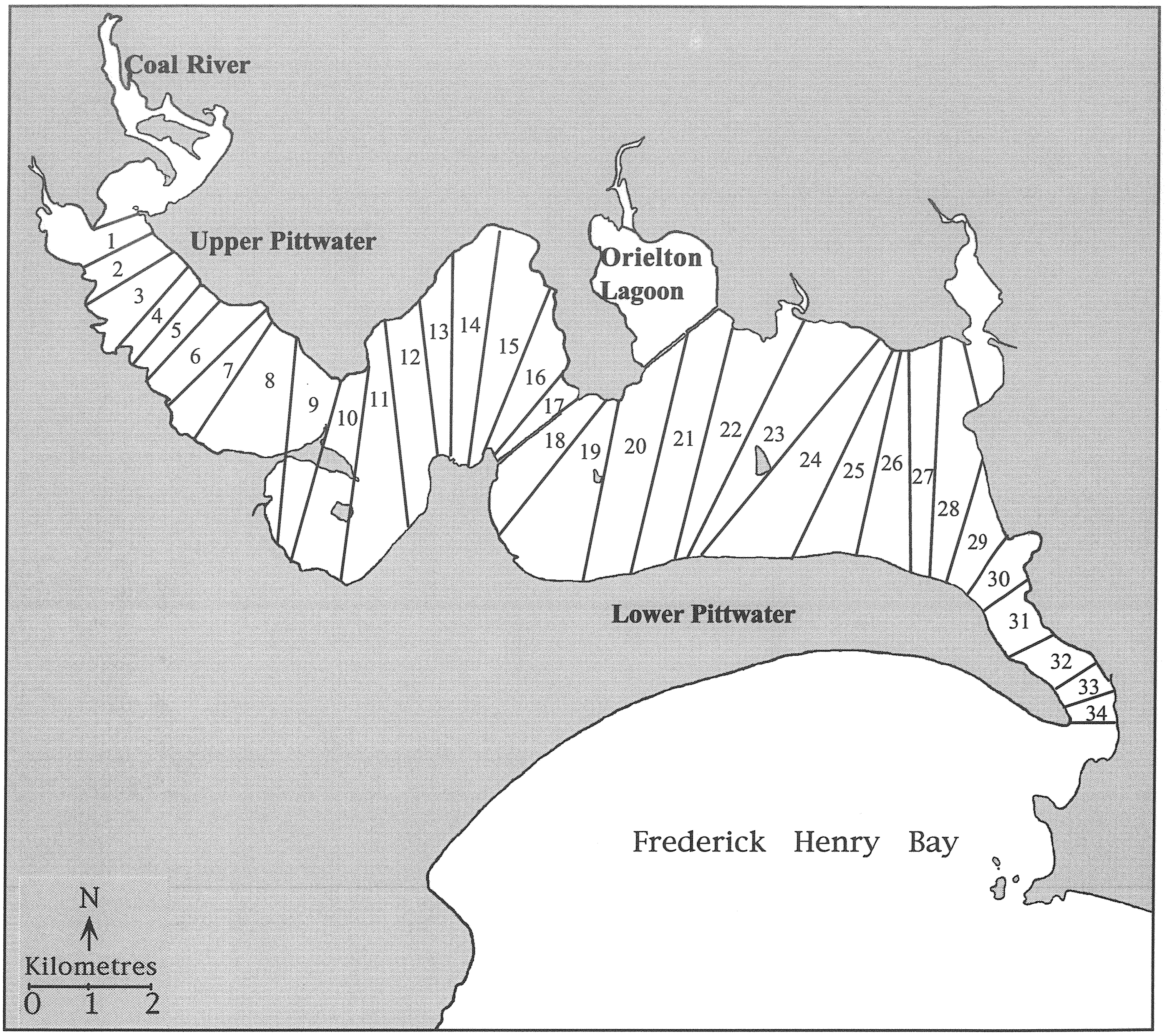


Figure 10. Upper and Lower Pittwater sectors.

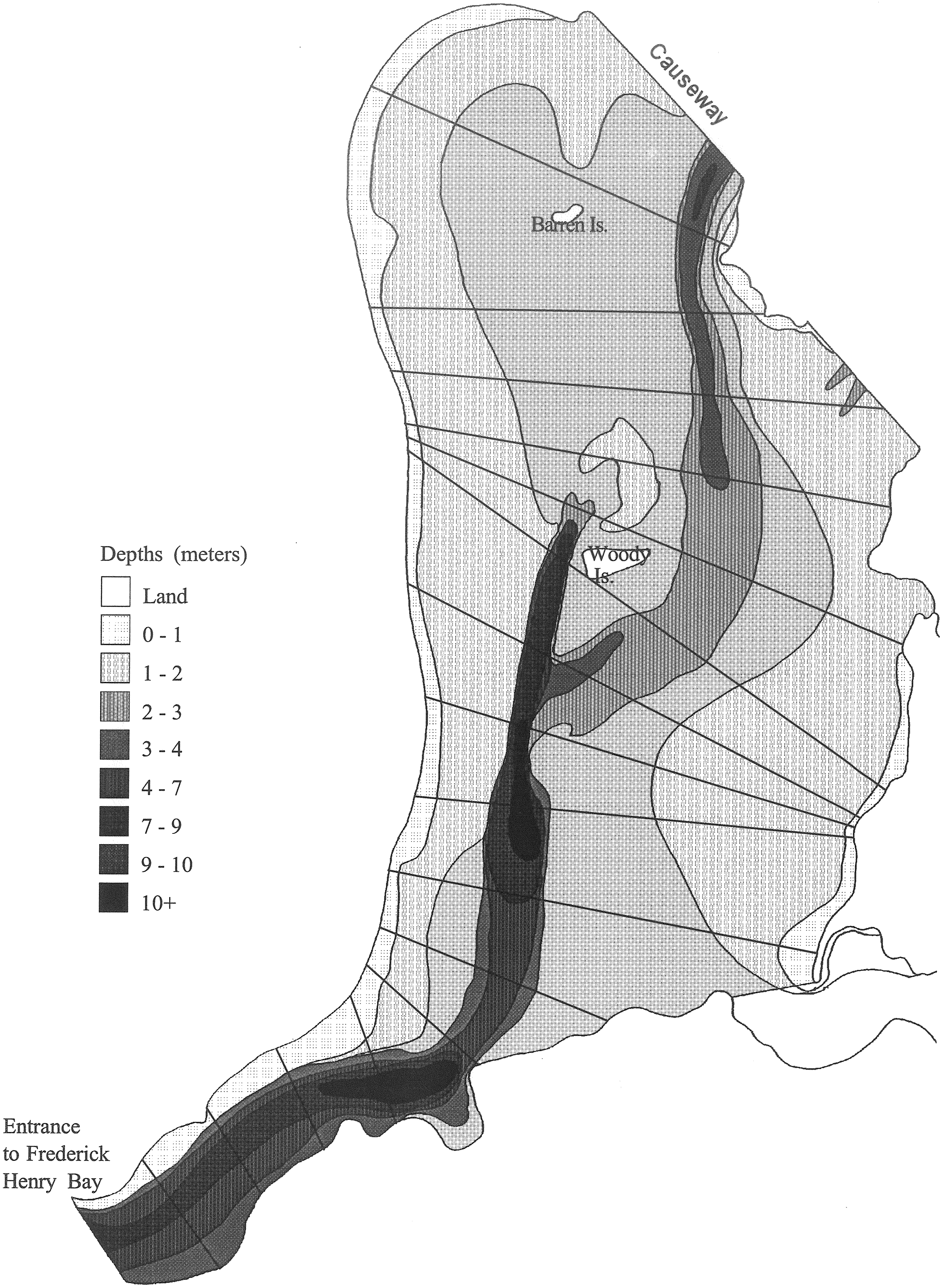


Figure 11a. Depth contours of lower Pittwater.

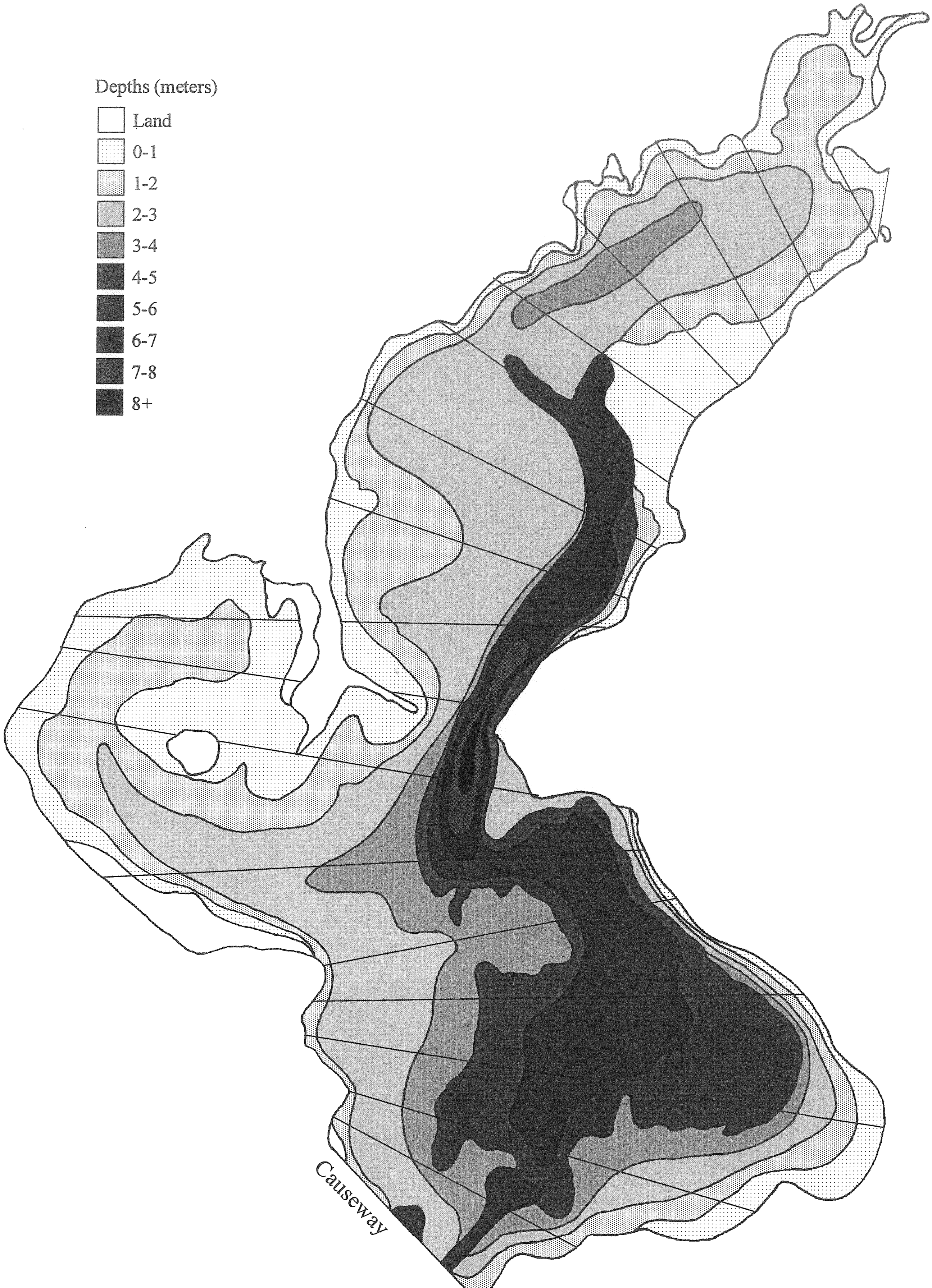


Figure 11b. Depth contours for upper Pittwater.

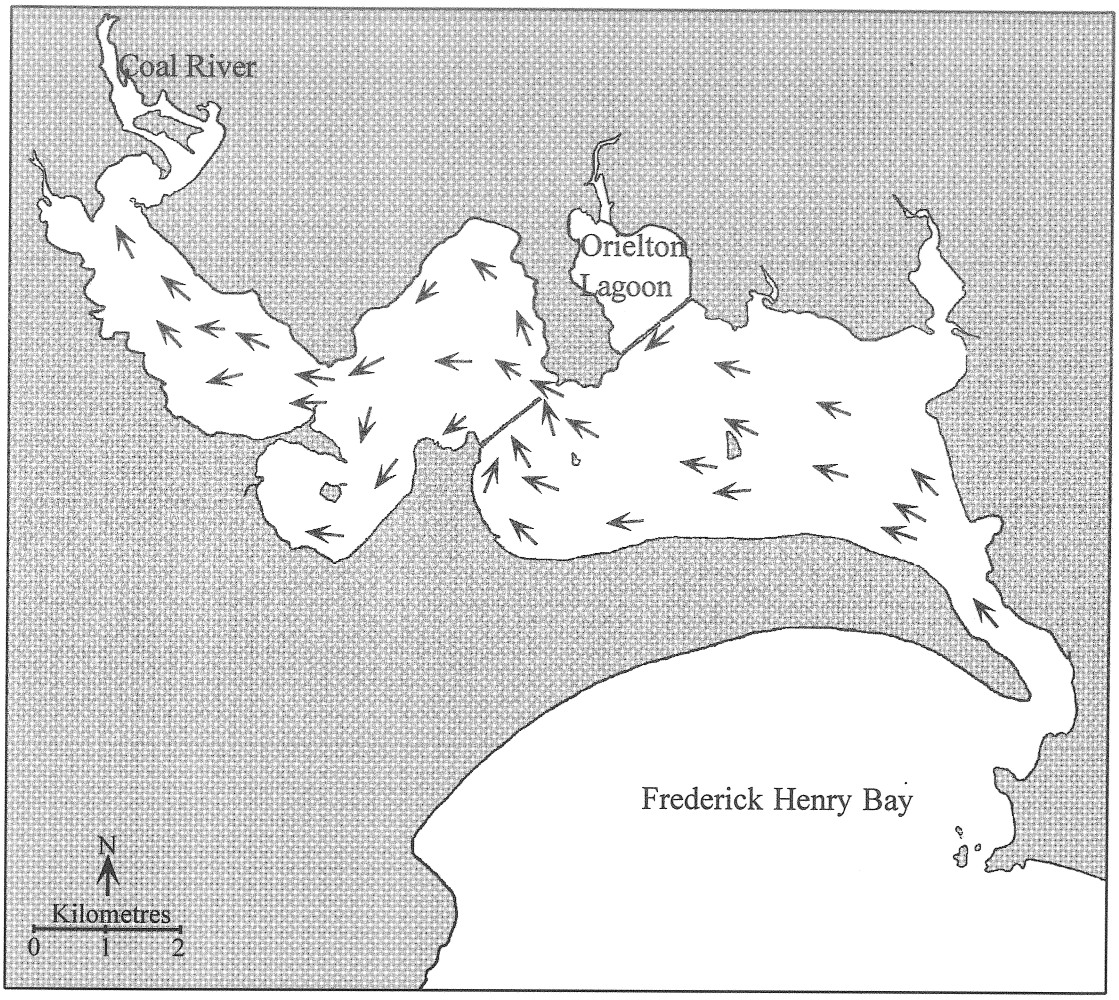


Figure 12a. Pittwater on flood tide.

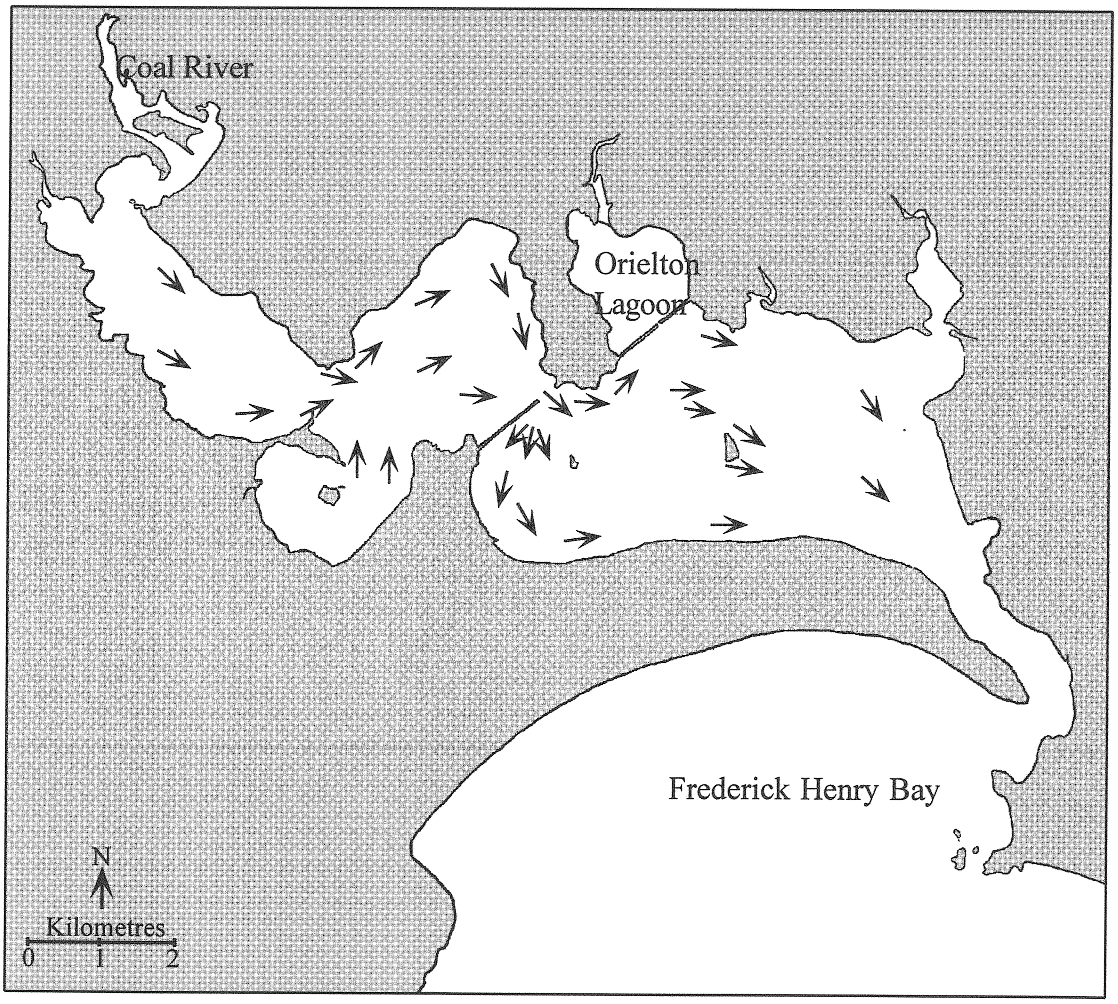


Figure 12b. Pittwater on ebb tide.

Depth soundings along the transects from Barren Island below the Causeway indicate a relatively deep channel close to Midway Point (Fig. 13a & b)

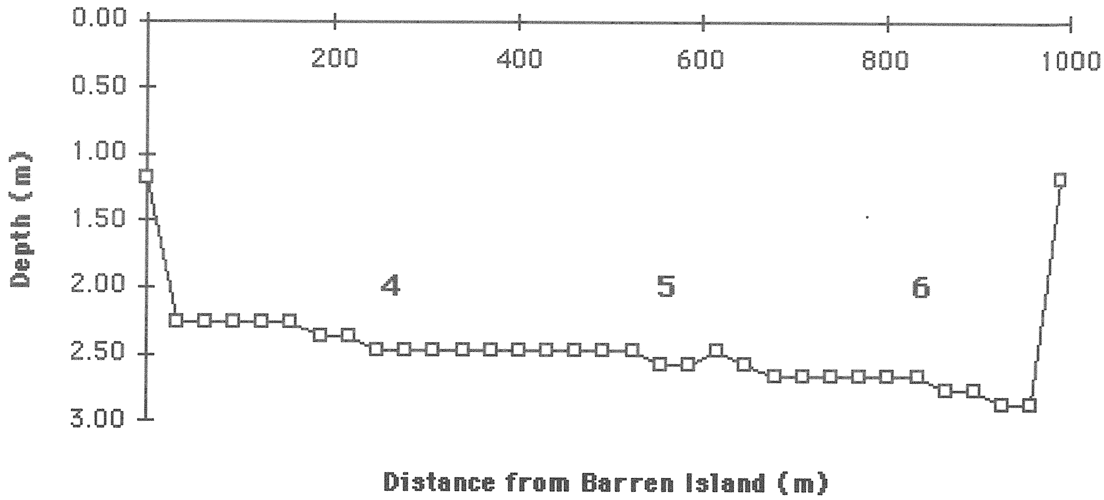


Figure 13a. Diagram of transect cross-section from Barren Island to Sorell Causeway.

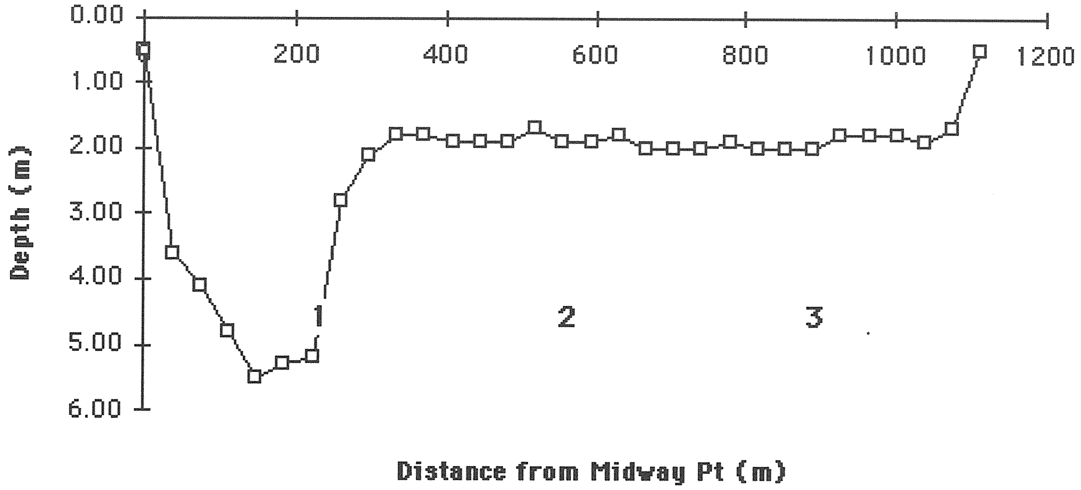


Figure 13b. Diagram of transect cross-section from Midway Point to Barren Island. (Numbers 1-6 refer to sample stations along the transect.)

The general trends in streamlines in this area during a flood tide are shown in Fig. 14. It was apparent that during approximately the last 2 hours of flood the flow tended to become more directed towards the bridge. The streamlines also show that some water passing to the west of Barren Island was entering the upper part of the bay through the bridge.

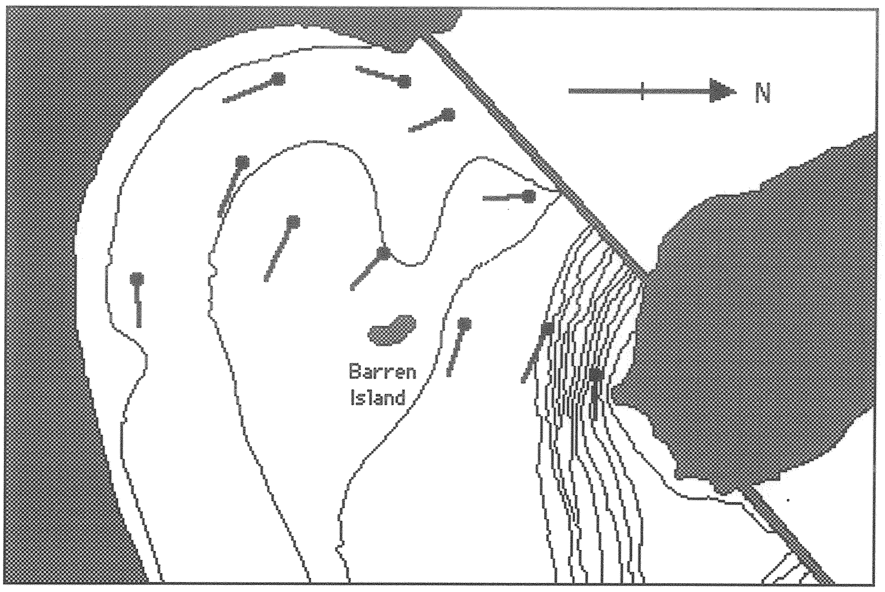


Fig. 14. Diagram of streamlines during flood tide around Barren Island.

Six cross-sectional areas, each relating to the station at its centre, were analysed (Table 2).

Table 2. The calculated volumes of water passing across the cross-sectional areas relating to each of the six stations.

		Flow	(tonnes)	across	transect		
Ht(m)	**station 1**	**station 2**	**station 3**	**station 4**	**station 5**	**station 6**	**SUM**
0.70	0	0	0	0	0	0	0
0.75	1,104,701	518,914	294,677	186,938	125,391	224,306	2,454,928
0.86	1,568,963	671,143	437,880	242,997	186,754	282,910	3,390,647
1.00	1,725,769	697,487	431,366	223,240	200,483	294,292	3,572,637
1.15	1,409,432	656,587	0	246,718	239,474	421,482	2,973,693
1.27	665,532	406,454	0	218,752	157,372	363,859	1,811,968
1.33	0	0	0	0	0	0	0
Totals	6,474,397	2,950,585	1,163,923	1,118,645	909,473	1,586,848	14,203,872
%	45.58	20.77	8.19	7.88	6.40	11.17	100.00

The tidal prism predicted by the bathymetric study and the model (described above) that would pass beyond sector 19 (Fig. 10) is 14,070,000 tonnes, while the tidal prism that would pass beyond sector 18 is predicted by the same method as 12,800,000 tonnes. As the experimental transects lie somewhere between these two lines the expected volume of the prism is between 12.8 and 14.0 million tonnes. The observations of 12 March fit well at 14,203,872 tonnes or approximately 14.2 million tonnes. Thus the values for flows in terms of percentages of the total prism (Table 2) are likely to be acceptable. Over 74.5% of the water flowing towards and under the bridge comes from the North of Barren Island, and 45.6% of the total prism passes within only 260m of Midway Point on its way to the bridge. Conversely the percentage of water entering upper Pittwater via the West of Barren Island must be about 25.5%.

6.1.2 Pipeclay Lagoon

Depth contours and location of sectors presented in Fig. 15 & 16 show that Pipeclay Lagoon is very shallow with only a small area greater than 2 m in depth. Results from the predictive model for water volumes given in Table 4 include the area and volumes at each depth (0.5, 1, 2, 3, and 4 m) for each sector. The average high water volume was almost 7 million m^3, and low water 1.8 million. The average tidal prism was 5.1 million m^3 over an area of 5 km^2. The average flushing time was 1.4 tidal cycles so the water in Pipeclay Lagoon is generally exchanged at least once a day. Water velocity in the lagoon showed a marked increase from the extensive shallow sand flats at the head of the lagoon to the narrow entrance channel.

The direction of flow of near surface water during flood and ebb tides (streamlines) as shown in Fig. 16, indicate that during the flood tide water mostly enters through the main channel and spreads out over the intertidal flats with some circulation in and around the deep hole at the head of the lagoon. Conversely, during the ebb the water drains from the sandflats at the head into the deeper hole and then out through the main channel.

A comparison of predicted to observed tidal prisms for Pipeclay Lagoon (Table 3) indicates that the predicted values are a good approximation for observed values.

Table 3. Predicted and observed tidal prisms in Pipeclay Lagoon.

DATE	PREDICTED PRISM	OBSERVED PRISM	%PRE/OBS
2/8/91	1688749	1925655	87.70
26/2/91	4880337	4956336	98.47
25/3/91	2676290	2837984	94.30
26/3/91	4174305	4115613	101.43

Table 4. Hydrodynamics of Pipeclay Lagoon

Pipeclay Lagoon **Annual Average High Tide 1.55m**
Annual Average Low Tide 0.995 m

Sector	Total Area (km2)	High Water Vol (1000t) at each Depth (m) 0.50	1.00	1.50	2.00	3.00	4.00	Total HW Vol 1000t	Low Water Vol (1000t) at each Depth (m) 0.50	1.00	1.50	2.00	3.00	4.00	Total LW Vol 1000t	Tidal Prism	Dist from head km	Cum prism	Vol trans. seg 1000t	Vol at Mid tide	Cross sect. area m2	Flow tonnes/m2	Av. vel. m/s
1	0.216	56.45	102.63	-	-	-	-	159.07	-	-	-	-	-	-	0.00	159.07	0.25	159.07	0.00	79.54	318.15	0.00	0.00
2	0.303	20.53	225.78	53.88	-	-	-	300.19	-	-	10.78	-	-	-	10.78	289.41	0.50	448.49	159.07	155.48	621.93	255.78	0.01
3	0.400	17.96	179.60	177.03	102.63	46.18	-	523.40	-	-	35.41	41.05	27.71	-	104.17	419.24	0.75	867.72	448.49	313.79	1255.14	357.32	0.02
4	0.416	15.39	87.23	200.13	51.31	415.64	-	769.71	-	-	40.03	20.53	249.39	-	309.94	459.77	1.00	1327.50	867.72	539.83	2159.30	401.85	0.02
5	0.354	15.39	97.50	123.15	112.89	261.70	-	610.64	-	-	24.63	45.16	157.02	-	226.81	383.83	1.25	1711.33	1327.50	418.72	1674.89	792.59	0.04
6	0.308	15.39	200.13	76.97	10.26	61.58	-	364.33	-	-	15.39	4.11	36.95	-	56.45	307.89	1.50	2019.21	1711.33	210.39	841.55	2033.54	0.09
7	0.216	23.09	123.15	30.79	-	76.97	-	254.01	-	-	6.16	-	46.18	-	52.34	201.66	1.75	2220.88	2019.21	153.17	612.69	3295.64	0.15
8	0.390	15.39	118.02	261.70	-	200.13	-	595.24	-	-	52.34	-	120.08	-	172.42	422.83	2.00	2643.71	2220.88	383.83	1535.32	1446.52	0.06
9	0.457	17.96	148.81	307.89	-	200.13	-	674.78	-	-	61.58	-	120.08	-	181.65	493.13	2.25	3136.84	2643.71	428.22	1712.87	1543.44	0.07
10	0.344	25.66	107.76	246.31	-	61.58	-	441.30	-	-	49.26	-	36.95	-	86.21	355.09	2.50	3491.93	3136.84	263.75	1055.02	2973.25	0.13
11	0.493	25.66	246.31	246.31	-	92.37	-	610.64	-	-	49.26	-	55.42	-	104.68	505.96	2.75	3997.89	3491.93	357.66	1430.64	2440.82	0.11
12	0.559	38.49	302.75	207.82	-	107.76	20.53	677.35	-	-	41.56	-	64.66	14.37	120.59	556.76	3.00	4554.65	3997.89	398.97	1595.87	2505.14	0.11
13	0.149	17.96	51.31	38.49	-	107.76	-	215.52	-	-	7.70	-	64.66	-	72.35	143.17	3.25	4697.81	4554.65	143.94	575.74	7910.87	0.35
14	0.113	12.83	46.18	-	-	107.76	20.53	187.30	-	-	-	-	64.66	14.37	79.02	108.27	3.50	4806.09	4697.81	133.16	532.64	8819.85	0.39
15	0.139	10.26	20.53	100.06	-	61.58	41.05	233.48	-	-	20.01	-	36.95	28.74	85.69	147.78	3.75	4953.87	4806.09	159.59	638.35	7528.94	0.33
16	0.072	10.26	10.26	46.18	-	15.39	20.53	102.63	-	-	9.24	-	9.24	14.37	32.84	69.79	4.00	5023.66	4953.87	67.73	270.94	18284.09	0.81
17	0.072	5.13	10.26	-	-	76.97	102.63	194.99	-	-	-	-	46.18	71.84	118.02	76.97	4.25	5100.63	5023.66	156.51	626.03	8024.59	0.36
TOTAI	**5.00**	**343.8**	**2078.2**	**2116.7**	**277.1**	**1893.5**	**205.3**	**6914.6**	**0.0**	**0.0**	**423.3**	**110.8**	**1136.1**	**143.7**	**1814.0**	**5100.6**		**51161.3**	**46060.62**	4364.27	AVERAGI	**68614.23**	**0.18**

TOTAL	**High Water Volume (m3)**	**6,914,584**
TOTAL	**Low water Volume (m3)**	**1,813,956**
TOTAL	**Prism (m3)**	**5,100,628**
TOTAL	**Area (km2)**	**5.00**
FLUSHING TIME	**(tidal cycles)**	**1.36**

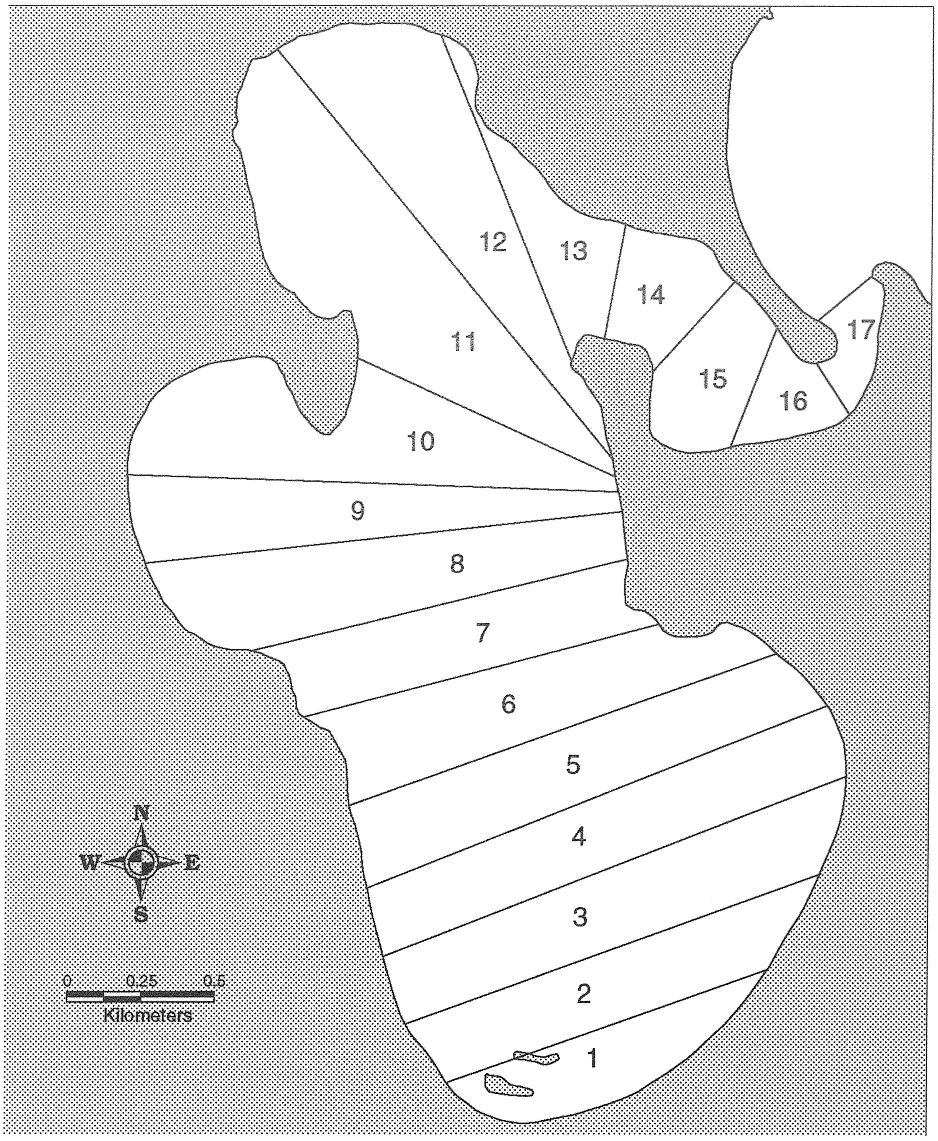


Figure 15. Pipeclay lagoon sectors.

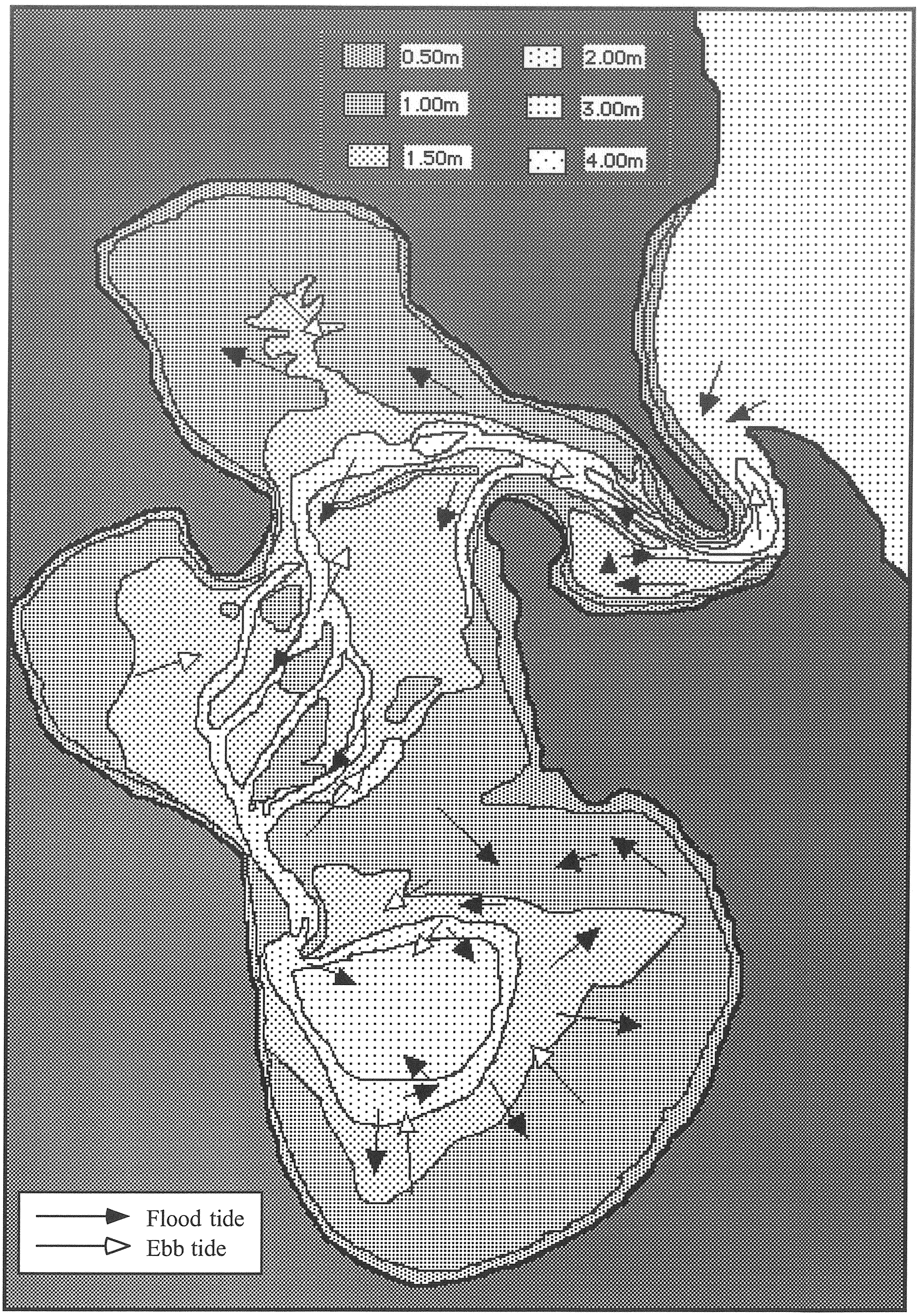


Figure 16. Pipeclay Lagoon tidal streamlines.

6.1.3 Little Swanport

The depth contours at Little Swanport (Fig. 17a) showed that much of the area is relatively shallow except for a deeper channel in the middle section of the estuary. The estuary was divided into 34 segments as shown in Fig. 17b and from the hydrodynamic studies the high tide volume of Little Swanport is estimated to be 7.9 million cubic metres with a tidal prism of 3.4 million m^3 (Table 5). The area is calculated to be approximately 6.3 km^2 and the flushing time is 2.3 tidal cycles or just over a day. Streamlines in Little Swanport indicated good movement of water around the estuary on each tidal cycle with some circulation of water around Ram Island (Fig. 18a & 18b)

Table 5. Hydrodynamics of Little Swanport.

Little Swanport

HW 1.29m
LW 0.46m

Sector	Total Area (km^2)	HW vol (1000t)	LW vol (1000t)	Tidal Prism	Dist. from head (m)	VOLUMES (1000t) Cum prism	Vol. trans. seg.	Vol at Mid tide	Cross sec. Area (m2)	Flow tonnes/m2	Mean vel (u) m/s
1	0.08	0.00	0.00	0.00	217	0.00	0.00	0.00	0		
2	0.21	15.86	0.00	15.86	433	15.86	0.00	2.88	13	0	0.000
3	0.24	60.88	0.00	60.88	650	76.74	15.86	17.29	80	199	0.007
4	0.16	69.02	0.00	69.02	867	145.76	76.74	20.89	96	796	0.026
5	0.15	68.59	0.00	68.59	1,084	214.36	145.76	21.61	100	1,462	0.048
6	0.09	26.58	2.02	24.56	1,300	238.91	214.36	9.91	46	4,687	0.154
7	0.08	9.43	0.00	9.43	1,517	248.34	238.91	1.44	7	35,943	1.182
8	0.08	14.15	0.00	14.15	1,734	262.49	248.34	2.88	13	18,681	0.614
9	0.40	296.48	125.17	171.31	1,950	433.81	262.49	192.18	887	296	0.010
10	0.49	196.08	18.88	177.20	2,167	611.00	433.81	72.68	335	1,294	0.043
11	0.31	141.90	18.21	123.69	2,384	734.69	611.00	61.12	282	2,166	0.071
12	0.17	83.03	24.37	58.67	2,601	793.36	734.69	42.27	195	3,767	0.124
13	0.17	125.34	20.99	104.35	2,817	897.71	793.36	59.71	276	2,879	0.095
14	0.11	118.32	46.35	71.97	3,034	969.68	897.71	77.75	359	2,502	0.082
15	0.10	139.76	67.55	72.21	3,251	1041.89	969.68	101.04	466	2,080	0.068
16	0.23	368.14	218.27	149.88	3,467	1191.77	1041.89	285.28	1,316	791	0.026
17	0.20	346.35	208.75	137.60	3,684	1329.37	1191.77	272.18	1,256	949	0.031
18	0.34	600.37	375.74	224.63	3,901	1554.00	1329.37	478.36	2,207	602	0.020
19	0.09	239.39	169.63	69.76	4,117	1623.76	1554.00	203.81	940	1,652	0.054
20	0.13	339.92	241.11	98.81	4,334	1722.57	1623.76	288.82	1,333	1,218	0.040
21	0.15	334.64	227.83	106.80	4,551	1829.37	1722.57	278.41	1,285	1,341	0.044
22	0.17	483.36	355.51	127.86	4,768	1957.23	1829.37	416.74	1,923	951	0.031
23	0.19	727.59	577.97	149.62	4,984	2106.85	1957.23	651.30	3,005	651	0.021
24	0.18	452.84	325.26	127.58	5,201	2234.43	2106.85	385.79	1,780	1,183	0.039
25	0.16	324.54	217.85	106.68	5,418	2341.11	2234.43	267.02	1,232	1,813	0.060
26	0.16	238.47	145.13	93.34	5,634	2434.45	2341.11	185.07	854	2,741	0.090
27	0.15	306.60	206.74	99.86	5,851	2534.31	2434.45	252.36	1,164	2,091	0.069
28	0.26	436.40	256.61	179.78	6,068	2714.09	2534.31	338.60	1,562	1,622	0.053
29	0.27	324.33	131.92	192.41	6,285	2906.50	2714.09	216.86	1,001	2,712	0.089
30	0.28	477.36	270.52	206.85	6,501	3113.34	2906.50	366.05	1,689	1,721	0.057
31	0.19	267.60	131.00	136.60	6,718	3249.95	3113.34	188.89	872	3,572	0.117
32	0.14	122.63	48.56	74.06	6,935	3324.01	3249.95	75.78	350	9,294	0.306
33	0.11	69.19	25.45	43.75	7,151	3367.76	3324.01	42.55	196	16,931	0.557
34	0.07	81.94	47.19	34.74	7,368	3402.50	3367.76	62.85	290	11,612	0.382
TOTAL	**6.32**	**7907.09**	**4504.59**	**3402.50**					**AVERAGE**	**4,249**	**0.140**

SUMMARY	LITTLE SWANPORT
HW (m3)=	7,907,087.61
LW (m3)=	4,504,585.13
PRISM (m3)=	3,402,502.48
AREA (km2)=	6.32
FLUSHING TIME= (tidal cycle)	2.32
EXCHANGE RATE=	43%

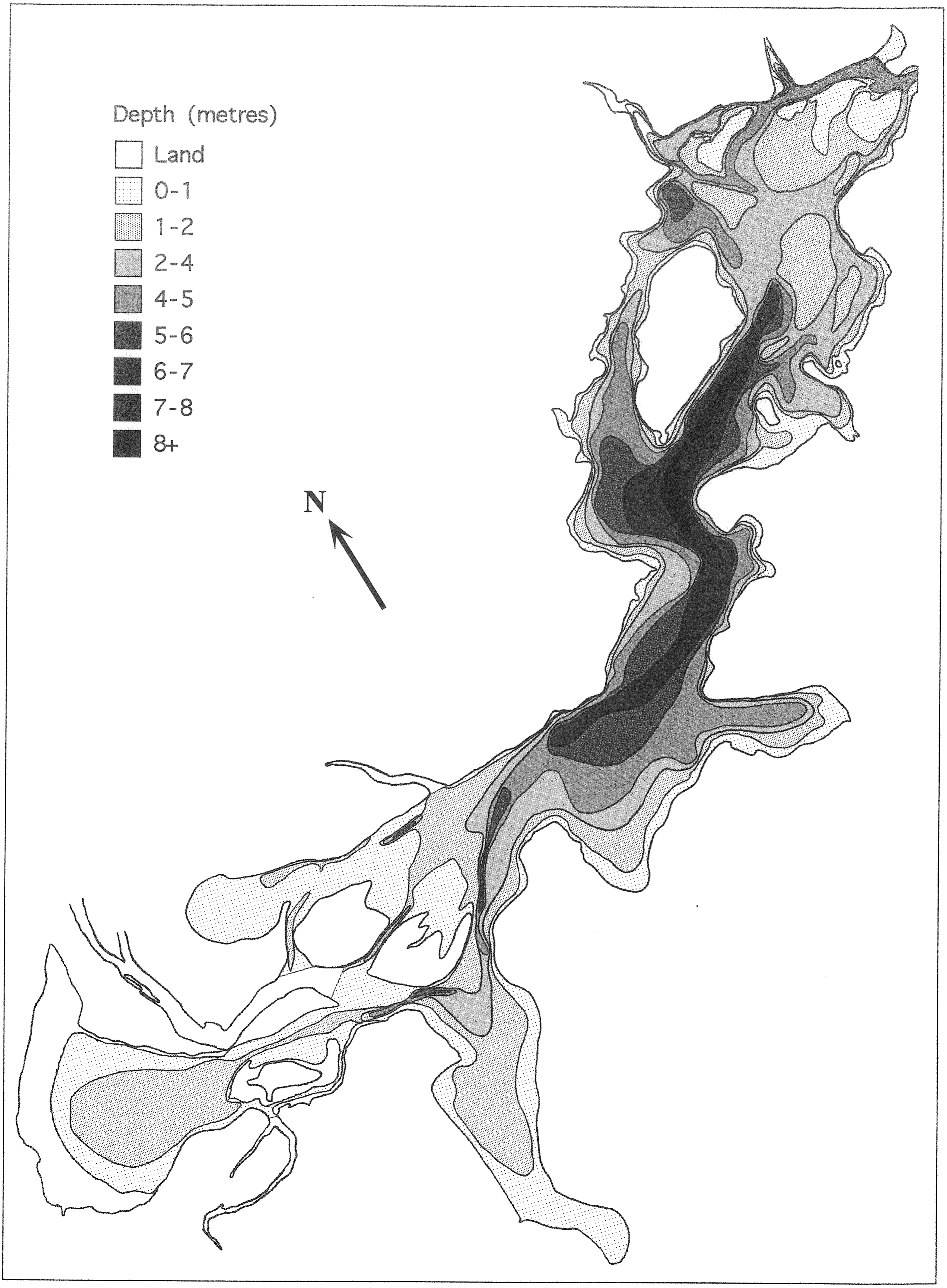


Figure 17a. Depth contours at Little Swanport.

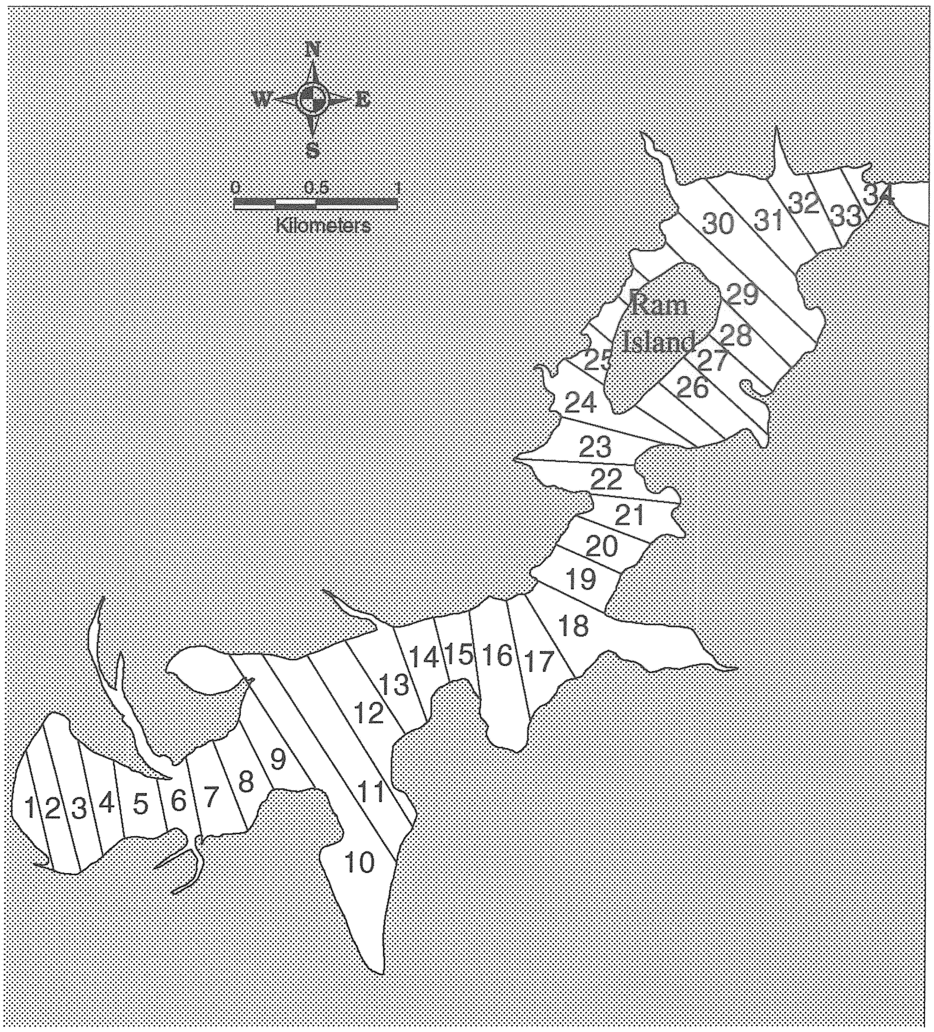


Figure 17b. Little Swanport sectors.

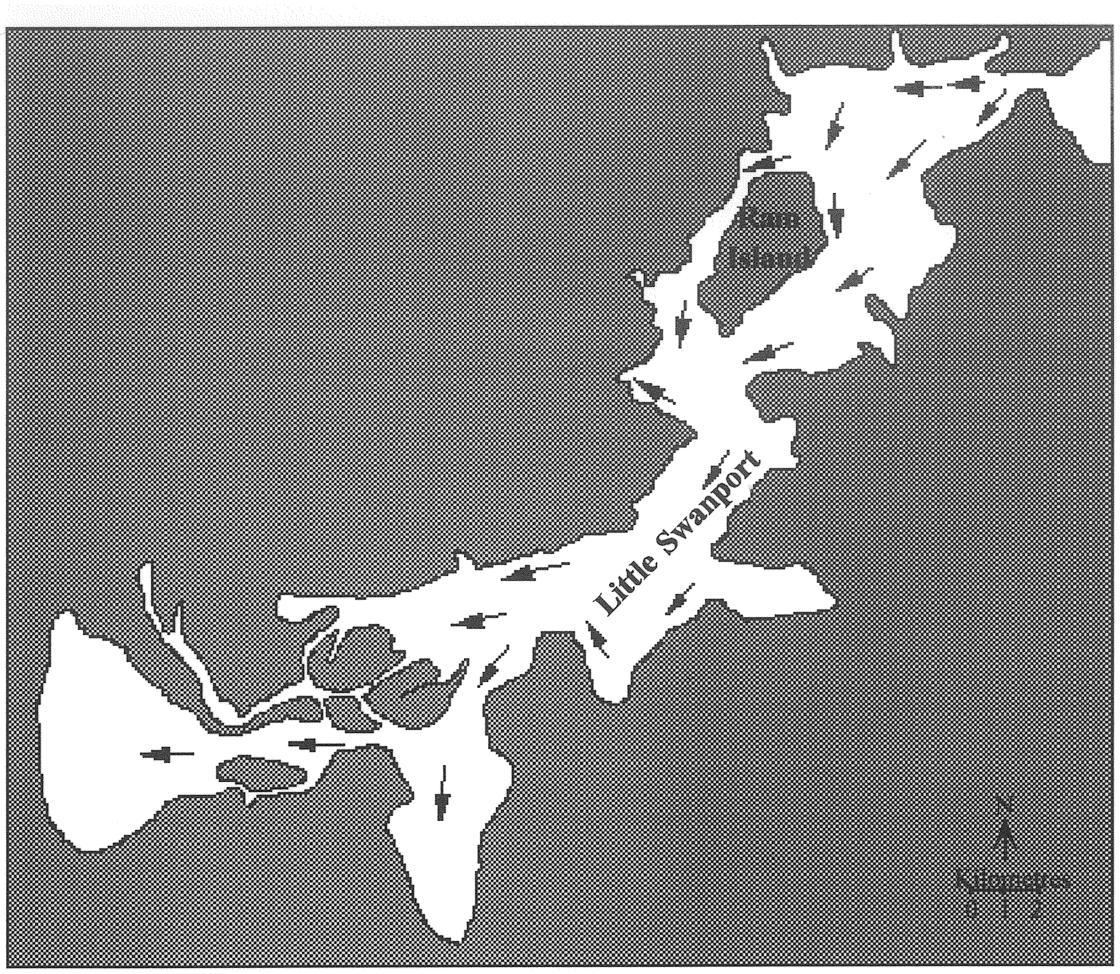


Figure 18a. Little Swanport flood tide streamlines.

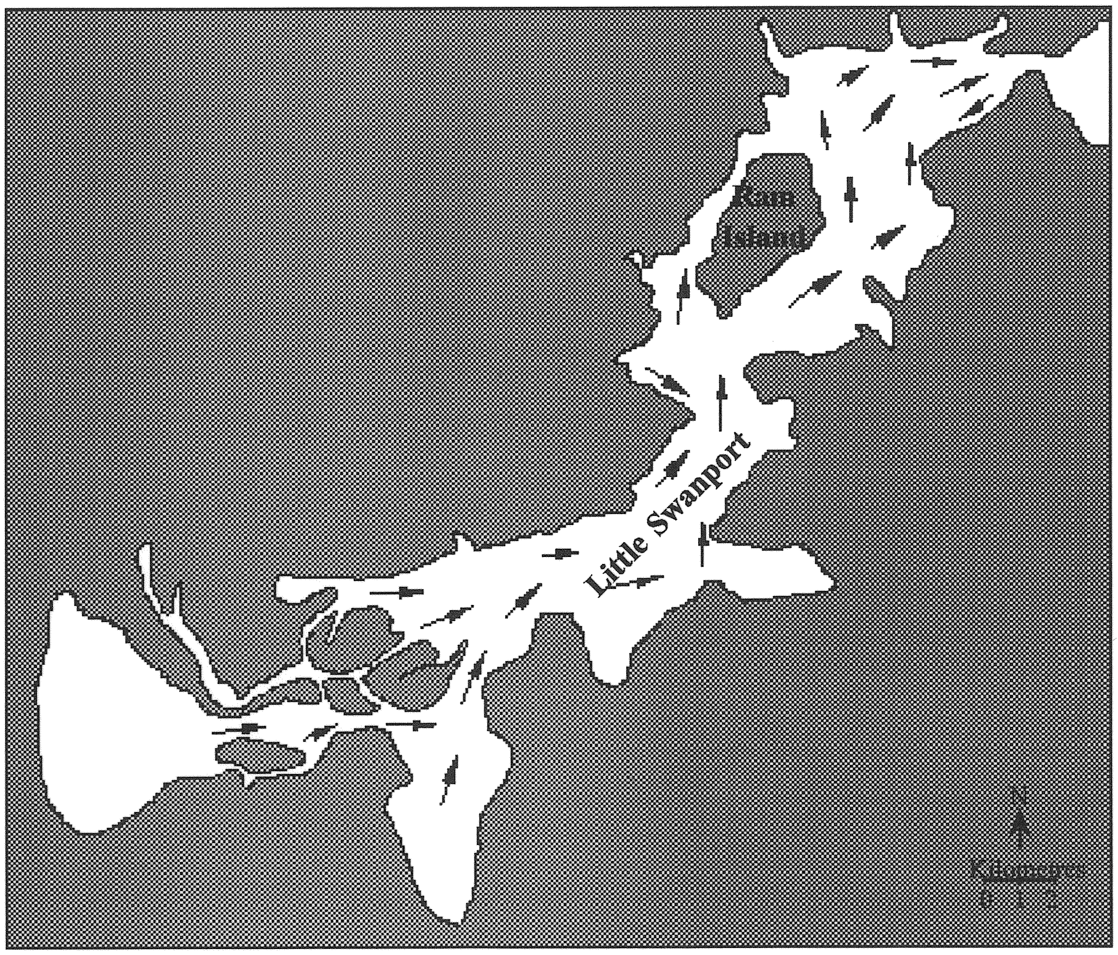


Figure 18b. Little Swanport ebb tide streamlines.

6.1.4 Georges Bay

The bathymetric map for Georges Bay (Fig. 19) shows the relatively shallow and narrow opening to the ocean at the St Helens Bar, and the wider and deeper sections in the upper reaches of the bay. The oyster farms are located in Moulting Bay which is a shallow offshoot of the main bay. Water depths in Moulting Bay rarely exceed 4m. The hydrodynamics of Georges Bay, excluding Moulting Bay, show a high tide volume of approximately 115 million m^3 and a tidal prism of around 12 million m^3. (Table 6). The area was calculated to be 14.1 km^2 and the flushing time approximately 10 tidal cycles. The mean velocity in each sector increased substantially from the head of Georges Bay towards the narrow entrance and reached a maximum level of 31 cm sec^{-1} near the entrance. Moulting Bay has an area of 4.2 km^2 and a high tide volume of approximately 21 million m^3 (Table 7). The exchange rate of Moulting Bay with Georges Bay was estimated to be 17.5%, slightly higher than the exchange rate of Georges Bay with the open sea. The mean velocity in each sector was low and the average of 1 cm sec^{-1} was significantly less than the average for Georges Bay of 8.5 cm sec^{-1}. The streamlines in Moulting Bay (Fig. 20) showed that on a flood tide water generally flooded in across the entire bay except in the Humbug Point area where water was flowing out of Moulting Bay into Georges Bay close to the point. Streamlines on an ebb tide indicated a circular pattern of water movement with much of the water on the eastern side of the Bay moving around the head of the Bay and flowing out into Georges Bay along the western shore, except in the Humbug Point area where the water was flowing out of the Bay along the eastern shore.

Table 6 Georges Bay, not including Moulting Bay

Georges Bay **High tide 1.69m**
Low tide 0.74m

Sector	Area (km2)	HW vol (1000t)	LW vol (1000t)	Tidal Prism	VOLUME (1000t) Dist. from head (m)	Cum prism	Vol. trans. seg.	Vol at Mid tide	Cross sec. Area (m2)	Flow tonnes/m2	Mean vel (u) m/s
34	0.100	735.86	643.37	92.50	238	92.50	0.00	688.83	2894.24	0.00	0.000
33	0.218	1429.71	1233.17	196.55	476	289.05	92.50	1328.33	5581.24	16.57	0.001
32	0.266	1055.75	859.86	195.89	714	484.94	289.05	940.71	3952.58	73.13	0.003
31	0.322	2703.51	2402.45	301.05	952	785.99	484.94	2551.43	10720.28	45.24	0.002
30	0.666	5913.19	5316.24	596.96	1190	1382.95	785.99	5603.99	23546.18	33.38	0.001
29	0.789	8240.23	7531.78	708.44	1428	2091.39	1382.95	7873.57	33082.22	41.80	0.002
28	0.789	8382.23	7694.41	687.82	1666	2779.21	2091.39	8019.67	33696.10	62.07	0.003
27	0.592	4914.08	4428.66	485.43	1904	3264.64	2779.21	4648.05	19529.61	142.31	0.006
26	0.566	5027.29	4566.75	460.54	2142	3725.18	3264.64	4773.69	20057.54	162.76	0.007
25	0.414	3751.49	3388.88	362.60	2380	4087.78	3725.18	3560.85	14961.57	248.98	0.011
24	0.471	4592.39	4166.49	425.90	2618	4513.68	4087.78	4374.78	18381.45	222.39	0.010
23	0.541	5936.30	5472.46	463.84	2856	4977.52	4513.68	5698.17	23941.89	188.53	0.008
22	0.624	3825.89	3354.07	471.82	3094	5449.34	4977.52	3568.23	14992.54	332.00	0.015
21	0.446	4909.09	4502.02	407.06	3332	5856.41	5449.34	4705.56	19771.24	275.62	0.012
20	0.428	7655.14	7264.60	390.53	3,570	6246.94	5856.41	7459.87	31344.00	186.84	0.008
19	0.177	2804.24	2648.79	155.45	3,808	6402.39	6246.94	2726.52	11455.95	545.30	0.024
18	0.625	10664.33	10077.08	587.24	4,046	6989.63	6402.39	10370.70	43574.39	146.93	0.007
17	0.794	10613.28	9885.50	727.78	4,284	7717.41	6989.63	10246.29	43051.63	162.35	0.007
16	0.584	6384.87	5845.94	538.93	4,522	8256.33	7717.41	6110.75	25675.40	300.58	0.013
15	0.523	4480.39	4004.55	475.84	4,760	8732.18	8256.33	4236.26	17799.42	463.85	0.021
14	0.531	2325.32	1830.95	494.37	4,998	9226.55	8732.18	2075.03	8718.62	1001.55	0.045
13	0.261	821.41	598.80	222.61	5,236	9449.16	9226.55	702.33	2950.95	3126.64	0.139
12	0.122	646.00	535.32	110.67	5,474	9559.83	9449.16	589.11	2475.24	3817.47	0.170
11	0.148	500.97	380.90	120.07	5,712	9679.90	9559.83	434.72	1826.57	5233.75	0.233
10	0.287	669.76	463.71	206.05	5,950	9885.95	9679.90	546.54	2296.37	4215.30	0.187
9	0.427	895.53	582.49	313.04	6,188	10198.99	9885.95	711.03	2987.52	3309.08	0.147
8	0.409	737.43	441.01	296.42	6,426	10495.41	10198.99	561.24	2358.16	4324.98	0.192
7	0.388	640.05	343.56	296.49	6,664	10791.90	10495.41	470.05	1975.02	5314.08	0.236
6	0.444	758.73	490.91	267.82	6,902	11059.72	10791.90	578.20	2429.39	4442.22	0.197
5	0.322	779.51	550.34	229.17	7,140	11288.89	11059.72	641.60	2695.82	4102.55	0.182
4	0.340	794.47	553.91	240.56	7,378	11529.45	11288.89	649.32	2728.23	4137.81	0.184
3	0.226	549.14	364.92	184.22	7,616	11713.68	11529.45	447.70	1881.09	6129.15	0.272
2	0.139	460.08	343.14	116.94	7,854	11830.61	11713.68	396.95	1667.87	7023.14	0.312
1	0.113	590.49	493.22	97.27	8,092	11927.89	11830.61	538.75	2263.65	5226.35	0.232
TOTAL	**14.093**	**115188.145**	**103260.259**	**11927.886**					**AVERAGE**	**1913.374**	**0.085**

SUMMARY	GEORGES BAY
HW (m3)=	115,188,145
LW (m3)=	103,260,259
PRISM (m3)=	11,927,886
AREA (km2)=	14.093
FLUSHING TIME= (tidal cycle)	9.66
EXCHANGE RATE=	10%

Table 7 Moulting Bay

Moulting Bay **High tide 1.69m**
Low Tide 0.74m

VOLUMES (1000t)

Sector	Total Area (m2)	HW vol (1000t)	LW vol (1000t)	Tidal Prism	Dist. from head (m)	Cum prism	Vol trans seg.	Vol at Mid tide	Cross sec. Area (m2)	Flow tonnes/m2	Mean vel (u) m/s
44	0.383	**381.93**	**136.06**	245.86	283	245.863	0	223.25	788.88	0.00	0.000
43	0.314	**848.60**	**566.18**	282.43	566	528.289	245.863	702.73	2483.16	99.01	0.004
42	0.470	**1461.08**	**1050.19**	410.89	849	939.179	528.289	1244.75	4398.40	120.11	0.005
41	0.444	**1736.52**	**1340.16**	396.36	1132	1335.54	939.179	1530.56	5408.33	173.65	0.008
40	0.470	**2112.60**	**1681.12**	431.48	1415	1767.021	1335.54	1892.21	6686.24	199.74	0.009
39	0.462	**2530.62**	**2107.50**	423.12	1698	2190.142	1767.021	2314.40	8178.09	216.07	0.010
38	0.383	**1937.86**	**1589.22**	348.64	1981	2538.783	2190.142	1758.89	6215.15	352.39	0.016
37	0.366	**1341.25**	**1009.14**	332.11	2264	2870.894	2538.783	1170.53	4136.16	613.80	0.027
36	0.342	**2062.57**	**1758.00**	304.58	2547	3175.471	2870.894	1904.08	6728.19	426.70	0.019
35	0.688	**7011.47**	**6429.61**	581.87	2830	3757.34	3175.471	6698.79	23670.63	134.15	0.006
TOTAL	**4.32**	**21424.50**	**17667.16**	**3757.34**					AVERAGE	**233.56**	**0.01**

HW (m3)=	**21,424,502.8**
LW (m3)=	**17,667,162.8**
PRISM (m3)=	**3,757,340.0**
AREA (m2)=	**4,322,820.0**
FLUSHING TIME= (tidal cycles)	**5.70**
EXCHANGE RATE=	**17.54%**

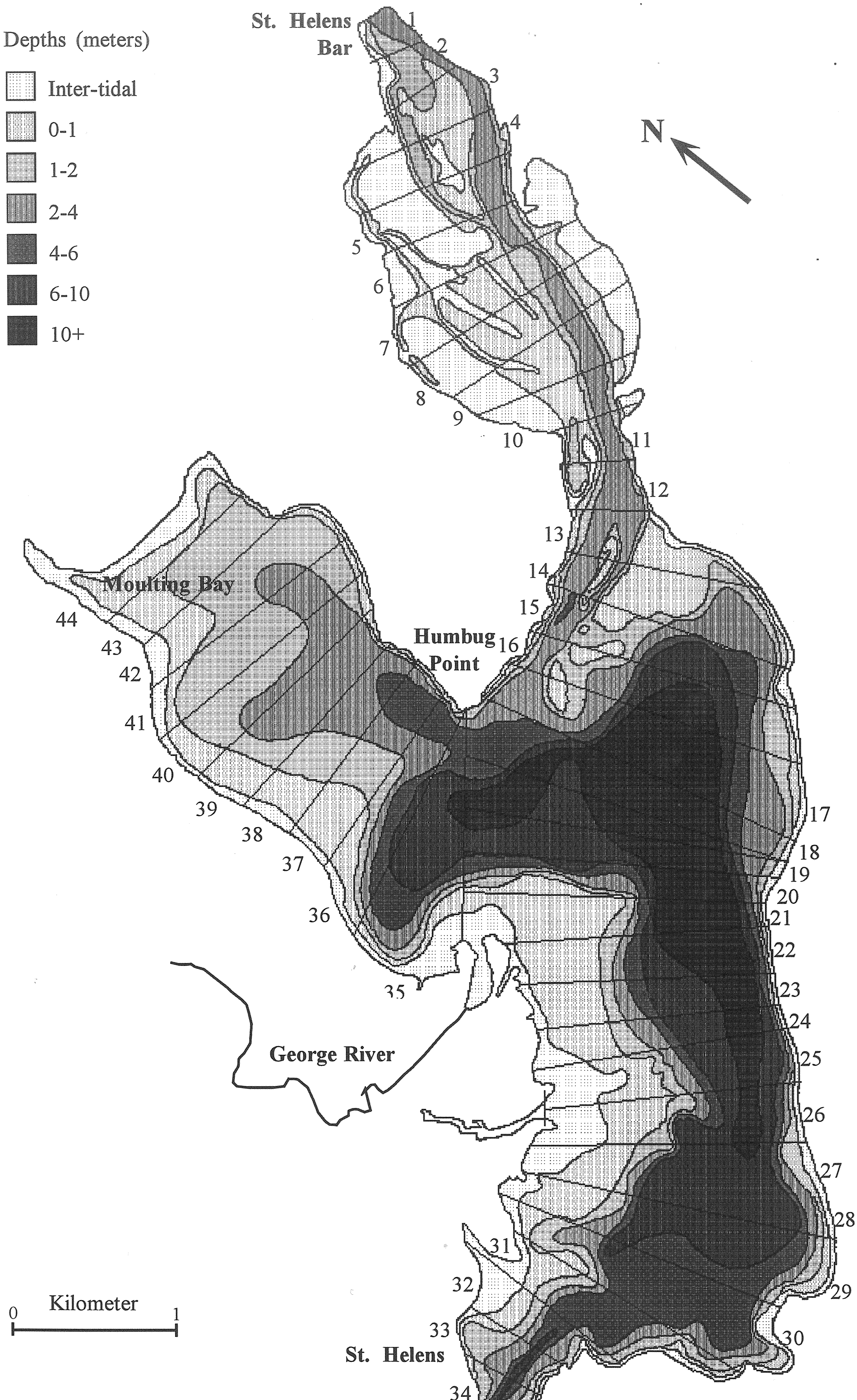


Figure19. Georges Bay depth contours and sectors.

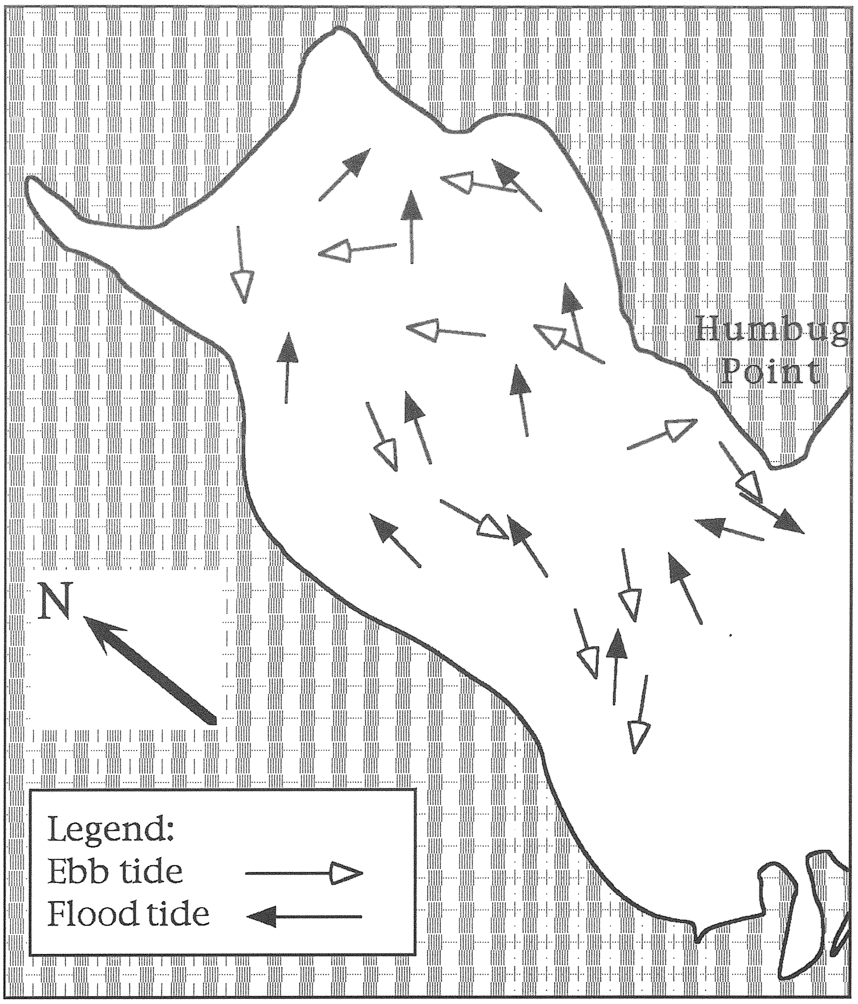


Figure 20. Moulting Bay tidal streamlines.

6.2 Temperature, Salinity, Nutrient and Food Concentrations in Growing Areas

The raw data for temperature, salinity, nutrients and chlorophyll a measurements at each site are give in Appendix 1. The profiles of temperature and salinity at each growing area site examined showed that in the shallow estuarine and embayment waters investigated there was complete mixing of the water column.

6.2.1 Pittwater

Temperatures showed typical annual variation, although higher summer temperatures were recorded in the summer of 1992/93 than in the other years (Fig. 21a). The highest summer and lowest winter temperatures were recorded at the Barilla station where the water is very shallow and the oyster farms are located, but otherwise there was little variation in temperature between stations. Salinities at all stations in the estuary were higher than the marine conditions experienced at the Marine station except in Spring 1992 and in January 1994 (Fig. 21b). In fact, they became more hypersaline the further up the estuary, except for some months in winter and spring. The Barilla station regularly experienced the most hypersaline conditions.

Chlorophyll a levels were mostly in the range of 1 - 4 µg/l, except for a peak in February 1992, and at most stations in summer 1993 - winter 1994 (Fig. 22a). Generally the upper reaches of Pittwater had higher chlorophyll a levels than the lower estuary and marine stations. There were no distinct temporal trends. Nitrate concentrations also generally were low, at less than 10 µg/l, except for peaks at some stations in August - September 1991 and February - March 1992 (Fig. 22b).

Phosphate concentrations were generally in the range 5-15 µg/l and there were no clear trends between the stations, except for the Marine station having higher concentrations on several occasions during the first 12 months of sampling (Fig. 23a). Silicate concentrations were quite varied during the short sampling period with no clear patterns except that they were often lowest at the Marine station (Fig. 23b).

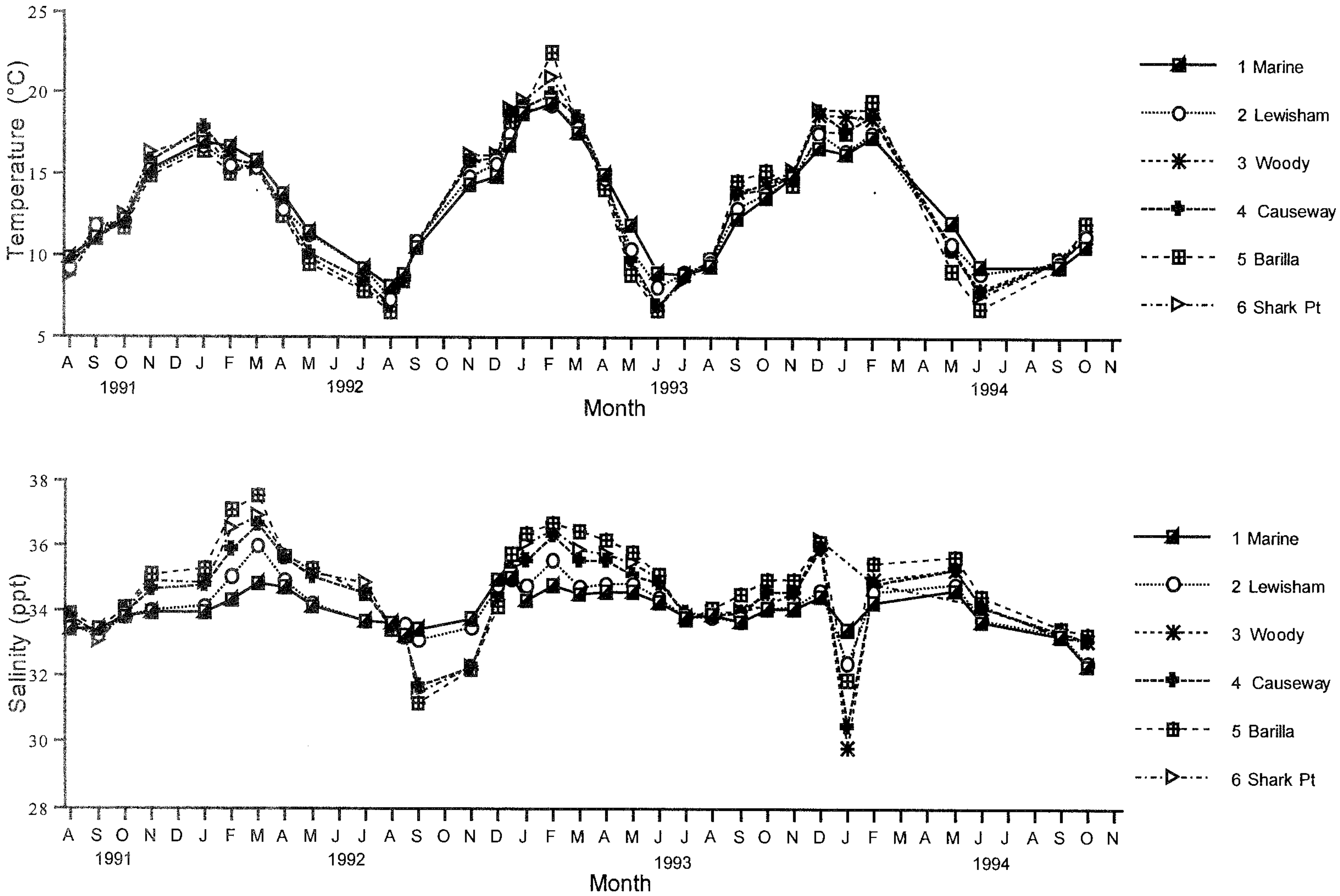


Figure 21 a&b. Temperature and salinity at Pittwater

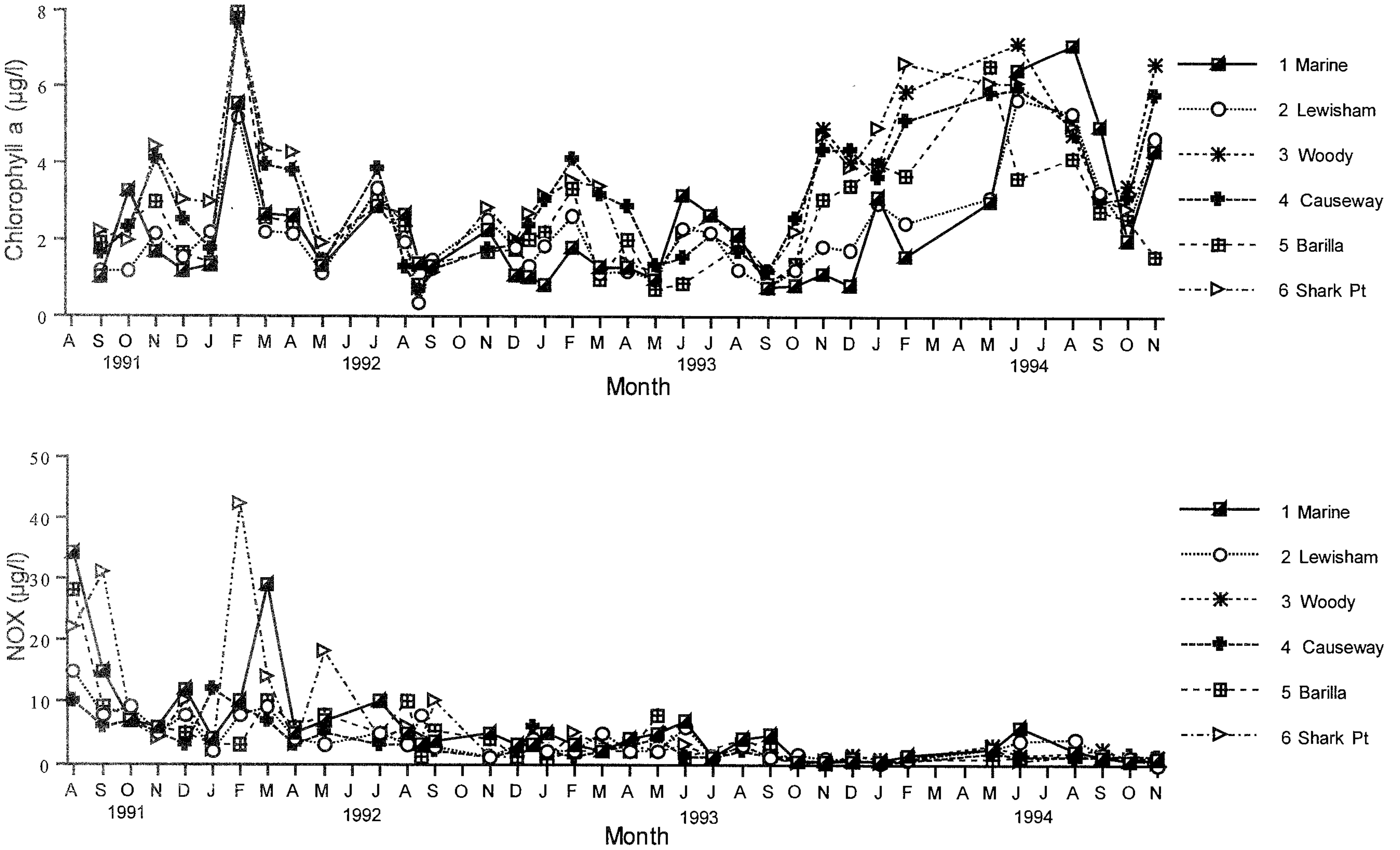
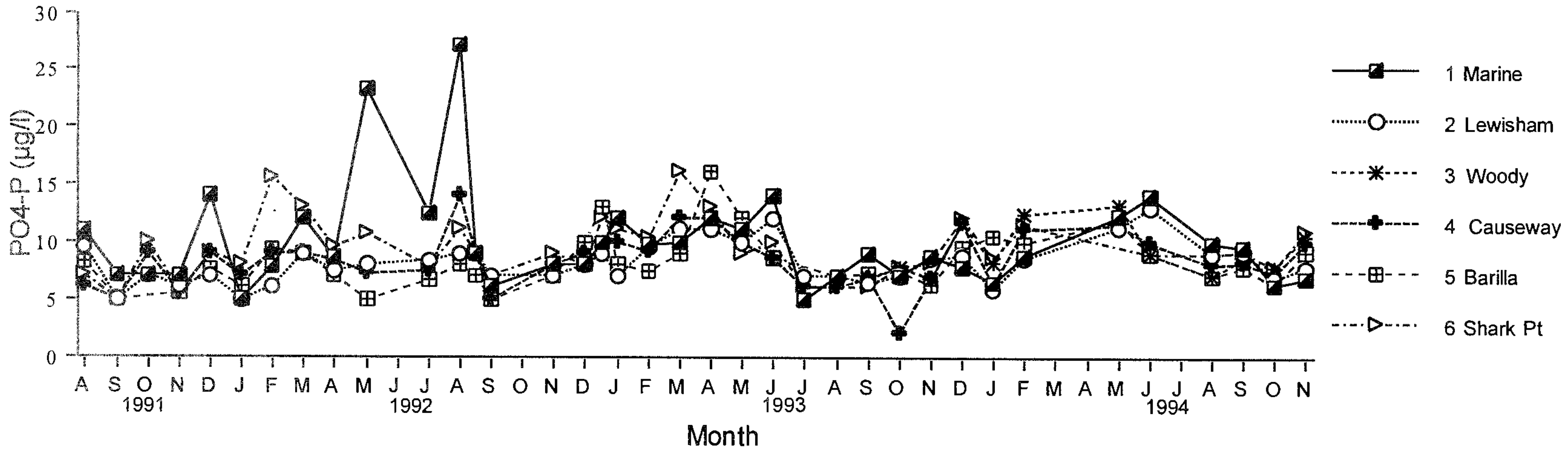


Figure 22 a&b. Chlorophyll a and NOX in Pittwater.



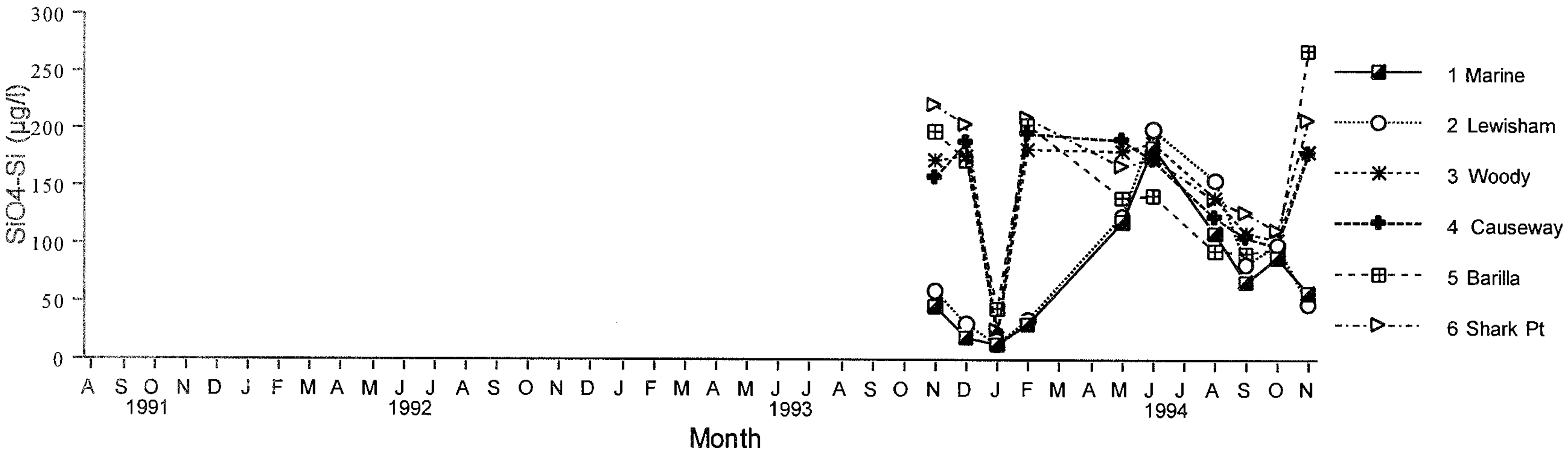


Figure 23a&b. PO_4 and SiO_4 in Pittwater.

6.2.2 Pipeclay Lagoon

Temperatures showed typical seasonal variations, ranging from 6.9 - 20.8 °C, with little difference between the stations (Fig. 24a). Salinities also showed a seasonal trend although the difference between summer and winter was at most 3 ppt. (Fig. 24b). They were higher at the shallow stations in summer than at the Marine station, and higher salinities were recorded in the summer of 1993 than 1992.

Chlorophyll a concentrations generally ranged from 1 to 4 µg/l with no distinct trends between stations (Fig. 25a). There was a slight increase in the summer of 1991/92, dropping to lower levels in winter, except for a relatively high level recorded at station 3 Bens Gutter in September. Values then rose again over summer 1992/93. NOX nitrogen concentrations ranged from 0.5 to 22 µg/l; highest levels were generally recorded in winter and declined in Spring. Peaks were recorded at the Marine station on several occasions (Fig. 25b).

Phosphate concentrations at all stations were mostly within the range of 5-12 µg/l during the sampling period, except for a peak at Bens Gutter station in December 1991 and at Nemo station in January 1993 (Fig. 26). Silicate concentrations were not measured at this site.

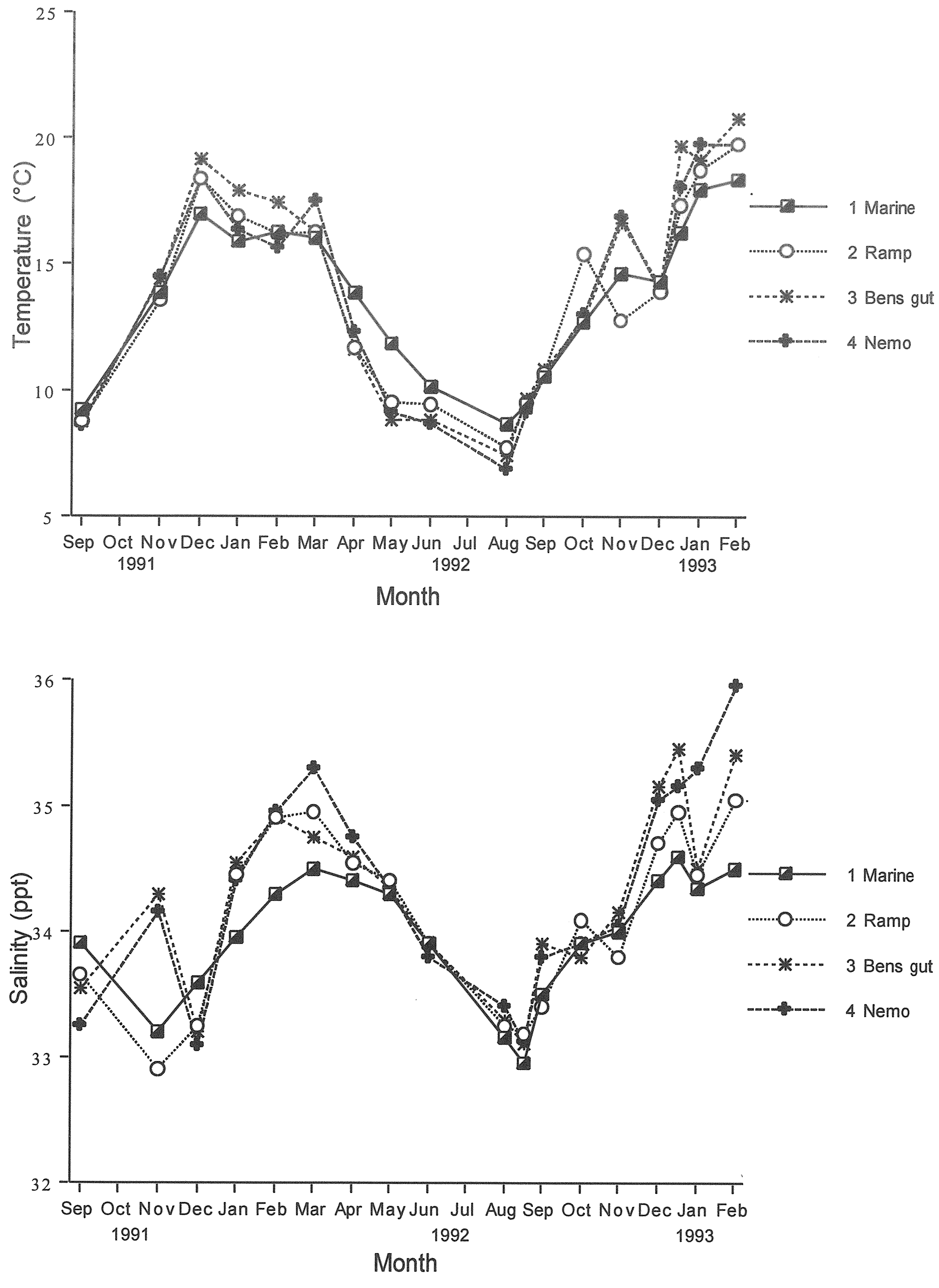
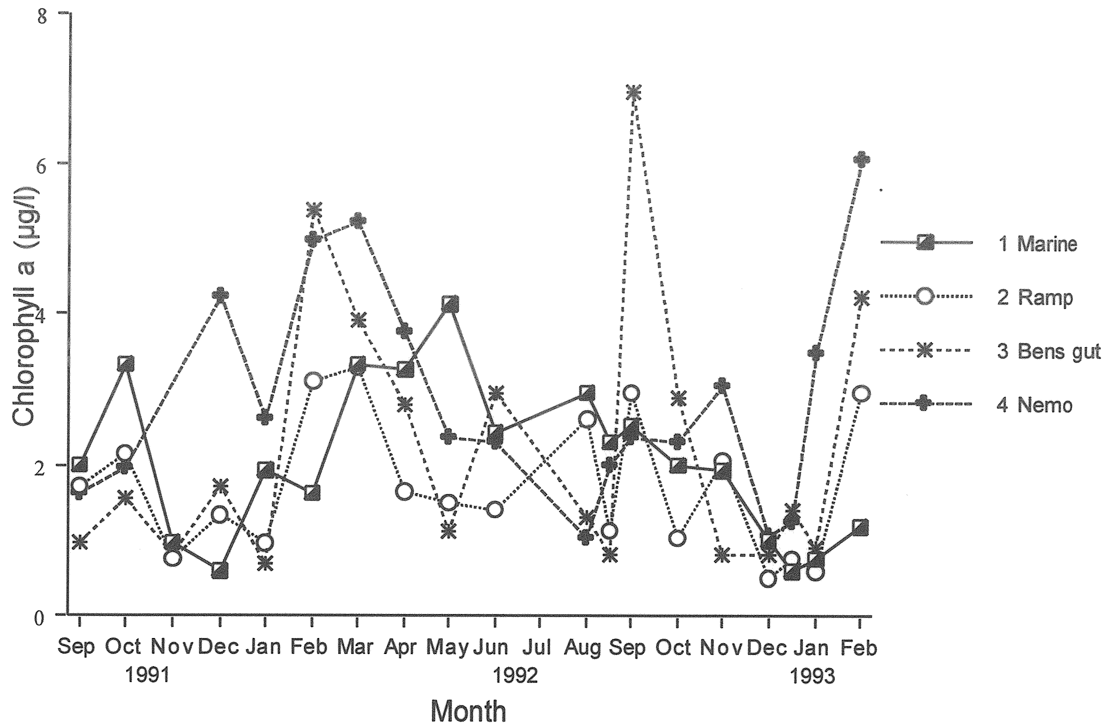


Figure 24a&b. Temperature and Salinity in Pipeclay Lagoon.



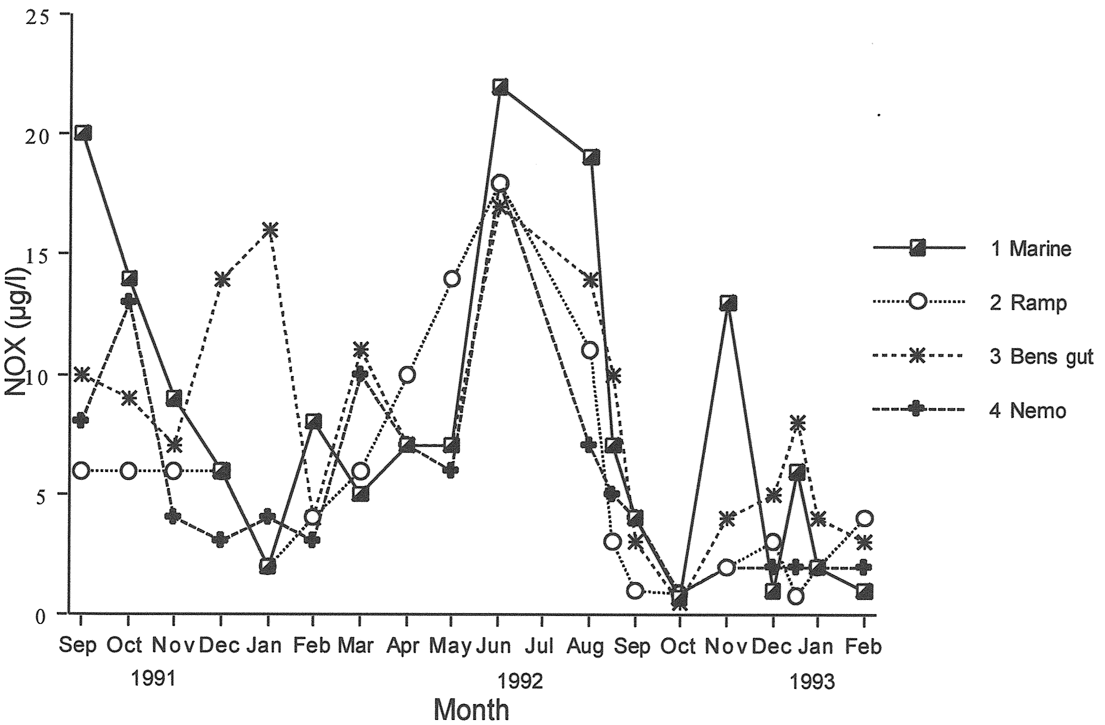


Figure 25a&b. Chlorophyll and NOX in Pipeclay Lagoon.

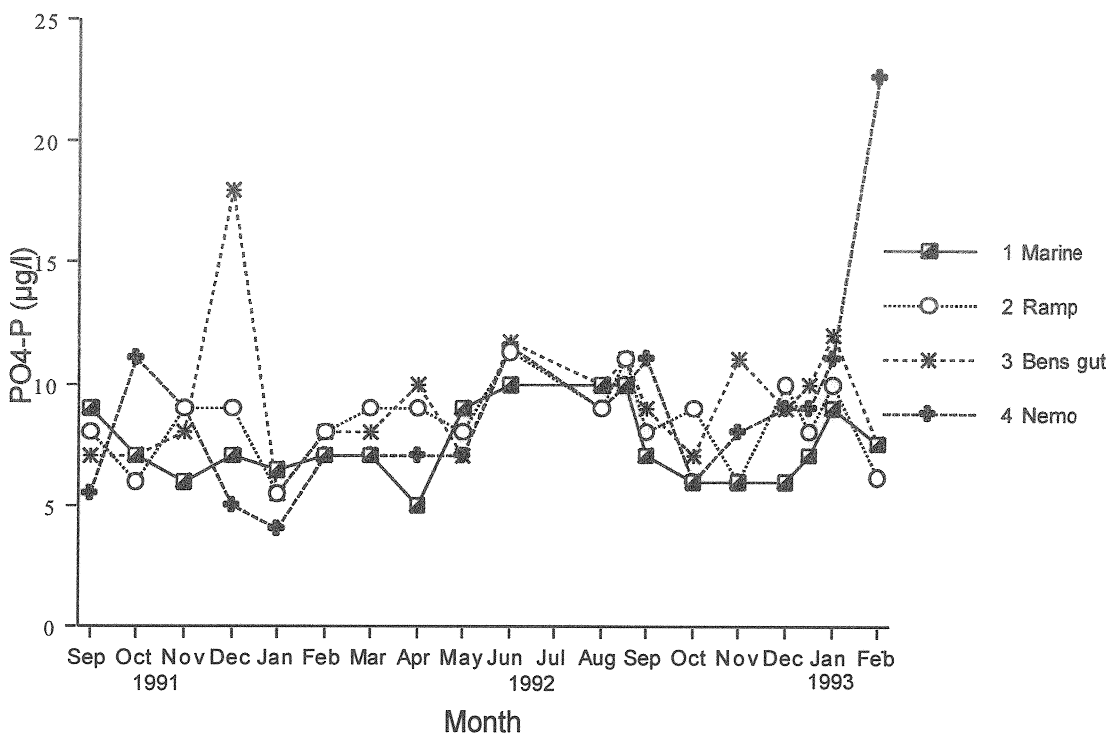


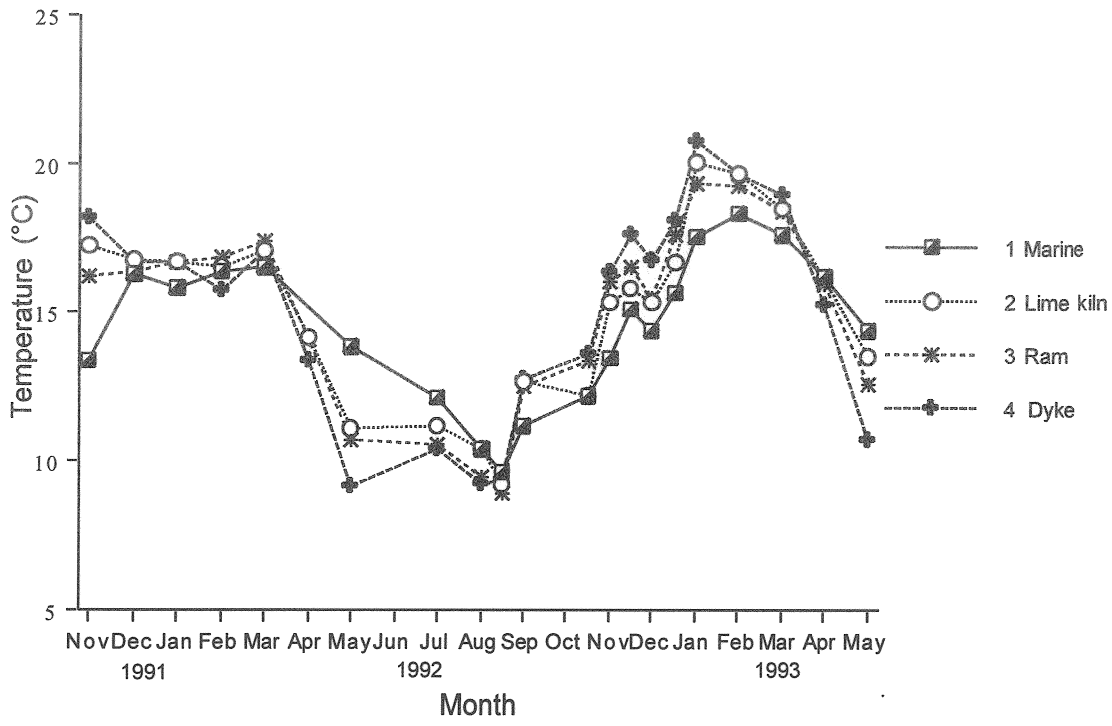
Figure 26. PO_4 in Pipeclay Lagoon.

6.2.3 Little Swanport

Temperatures varied from 8.9 - 20.8 °C with the Marine station having the least seasonal variation (Fig. 27a). Salinity at the Marine station was constantly around 35 ppt and significantly lower salinities were recorded at the other sites on several occasions during periods of heavy rainfall and freshwater flow into the estuary. Lowest salinities were generally recorded at station 4 Dyke which was furthest up the estuary (Fig. 27b).

Chlorophyll a concentrations were mostly in the range of 1 - 4 µg/l (Fig. 28a). High concentrations were recorded at station 4 Dyke in January and April 1991, and they were generally lowest at the Marine station. NOX nitrogen concentrations were consistently low except for very high values at all stations except Marine in December 1991 when there was a large freshwater inflow into the estuary (Fig. 28b).

Phosphate concentrations were within the range 4 - 14 µg/l for all stations, except for peaks at the Marine and Ram stations in January 1992 (Fig. 29). They were often highest at the Marine station. Silicate concentrations were not recorded at this site.



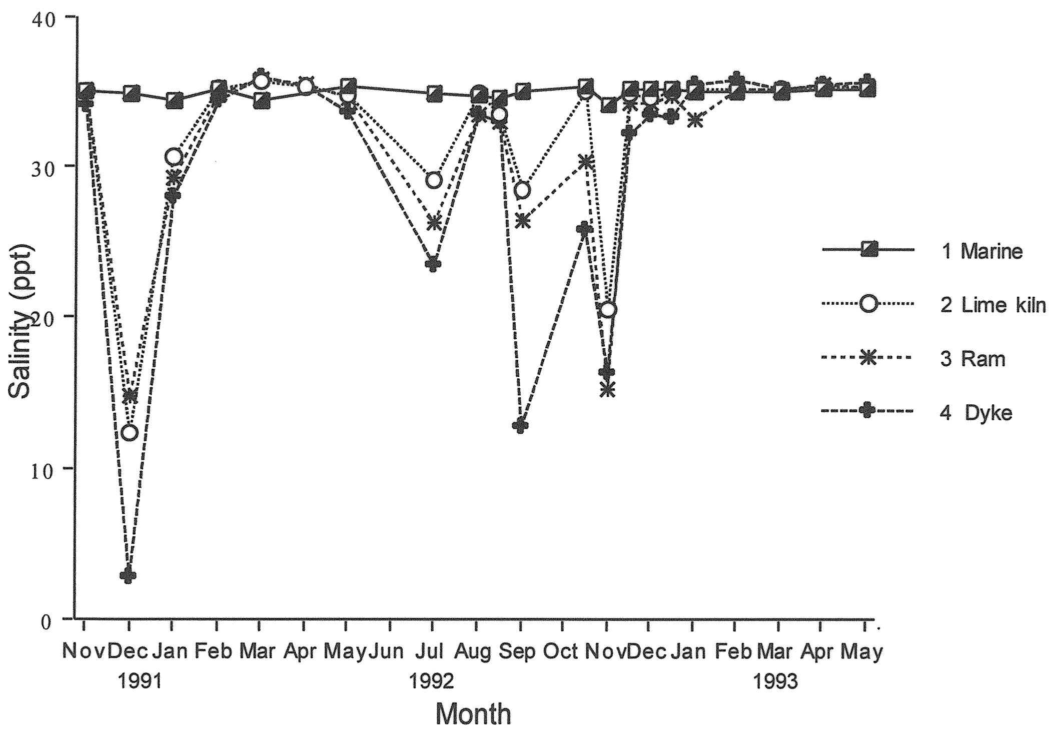
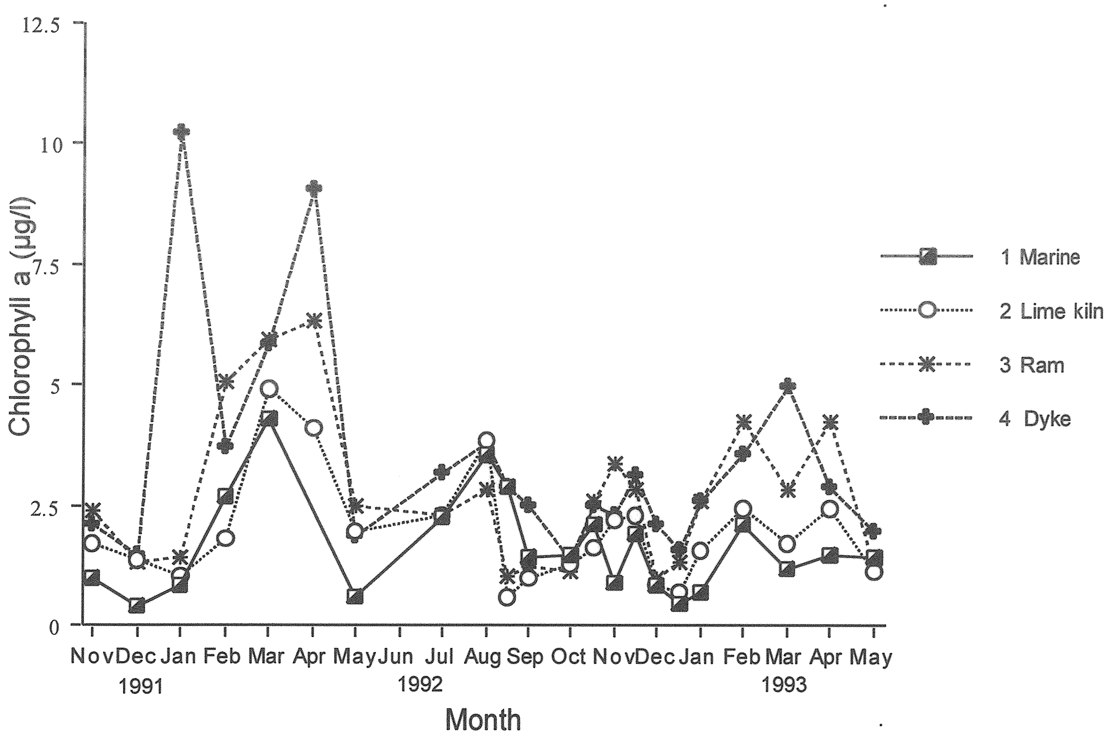


Figure 27a&b. Temperature and Salinity in Little Swanport.



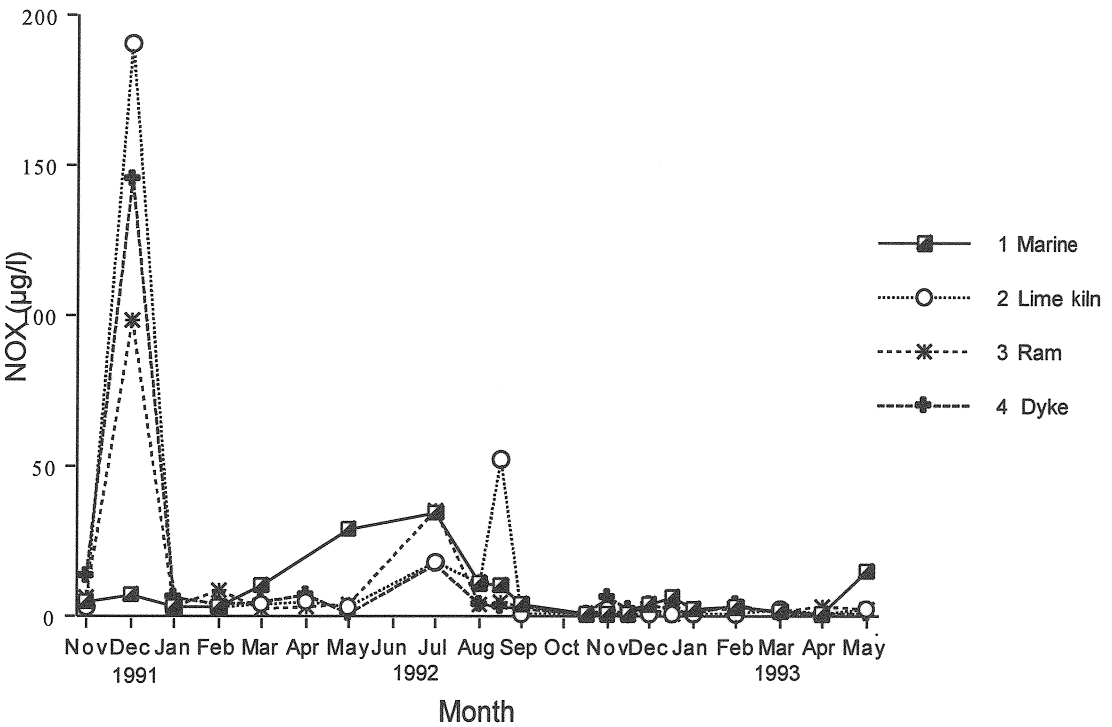


Figure 28a&b. Chlorophyll a and NOX in Little Swanport.

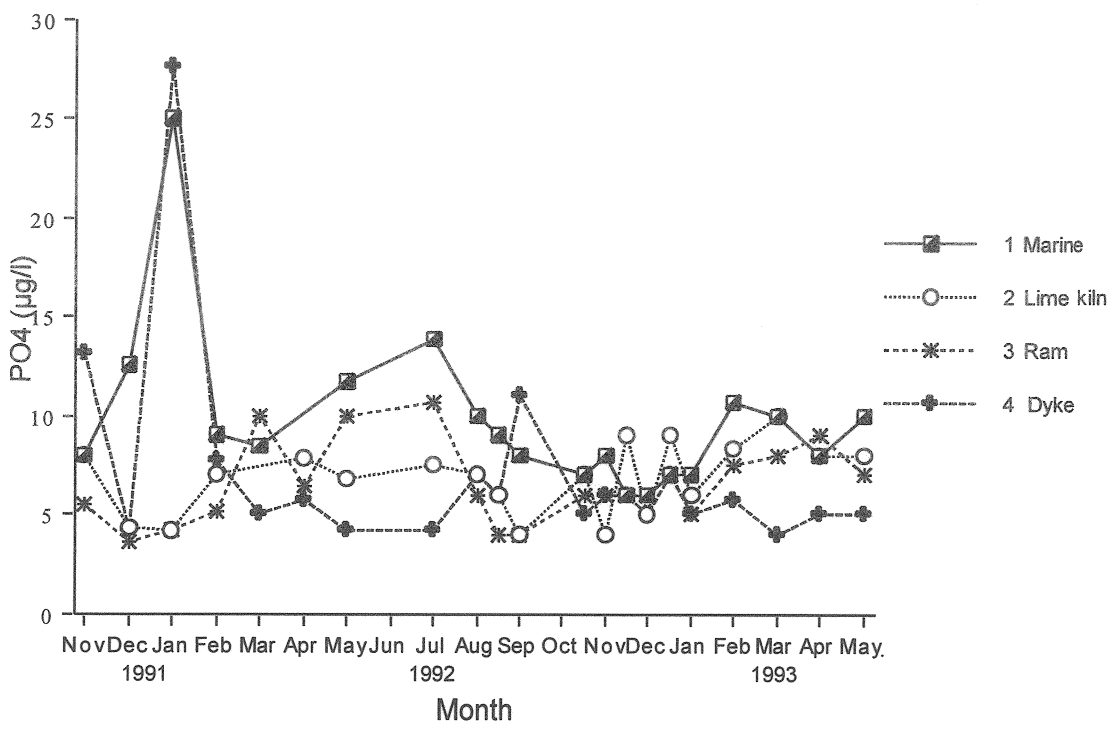


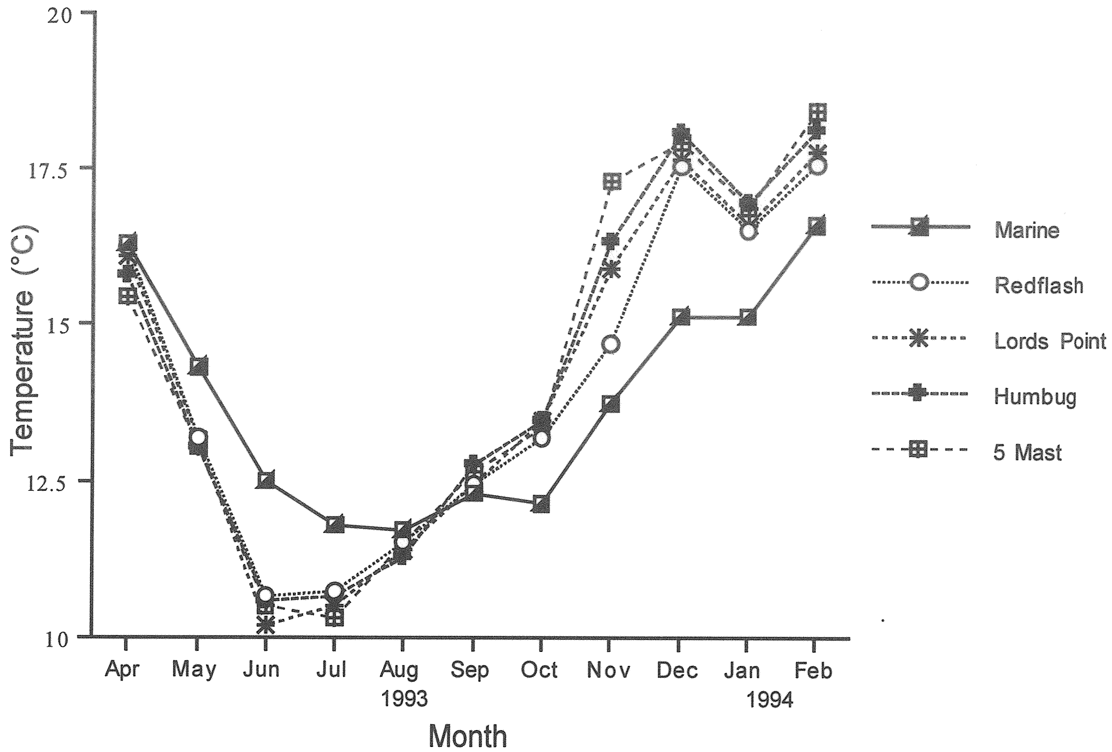
Figure 29. PO_4 in Little Swanport.

6.2.4 Georges Bay

Temperatures in Georges Bay showed a typical annual trend with temperatures highest in late spring and summer and lowest in winter (Fig 30a). The Marine station showed the moderating influence of oceanic waters with a reduced range in temperatures. Salinities at sites inside Georges Bay fluctuated depending on the rainfall, although the salinities only varied by at most around 3 ppt during the sampling period, with the lowest salinities generally occurring at the stations nearest the Georges River outflow (Fig. 30b). The Marine station had the least variation in salinities during the sampling period.

Chlorophyll a concentrations were generally within the range of 1 - 4 µg/l for all stations during the sampling period except for a very high reading at the Mast station in July 1993 (Fig. 31a). Chlorophyll a concentrations increased at all stations in February 1994. NOX nitrogen concentrations increased at most stations from April until July and then declined to low levels during Spring and Summer (Fig. 31b). The Marine station had the highest NOX concentrations in most months.

No distinct trends in phosphate concentration were observed during the sampling period (Fig. 32a). They generally ranged between 5 and 15 µg/l, with the Marine station having the highest levels in most months. Silicate concentrations increased at almost all stations during the short sampling period (Fig. 32b). They were significantly lower at the Marine station than all other stations.



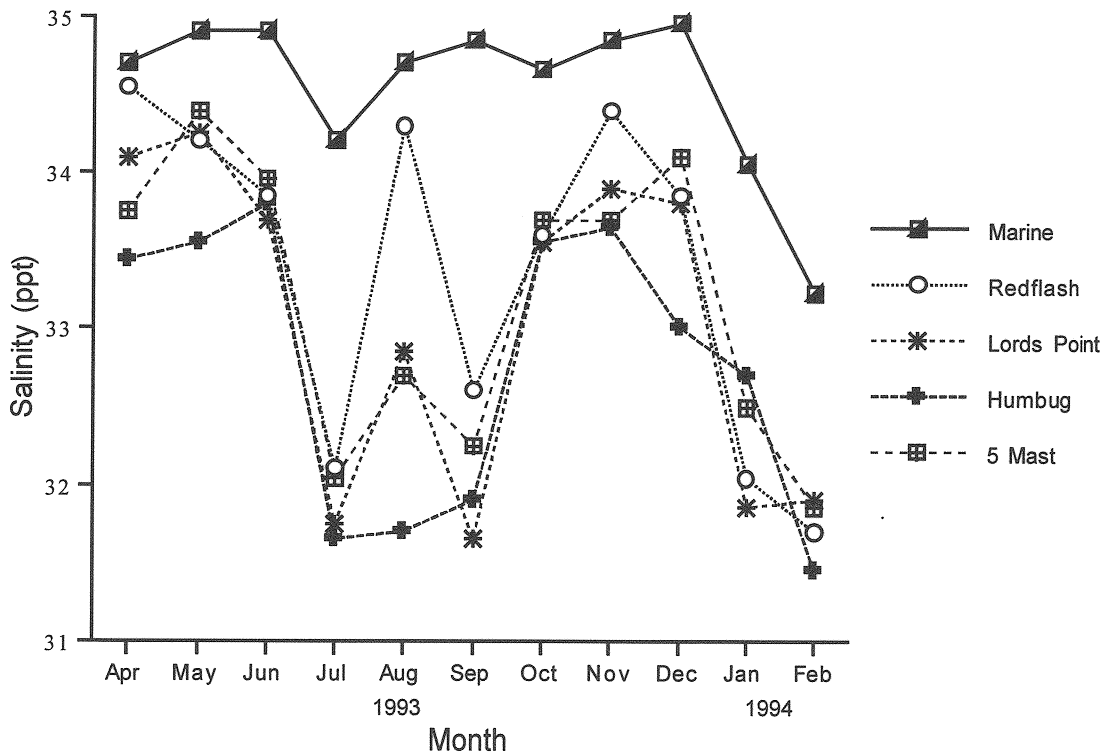
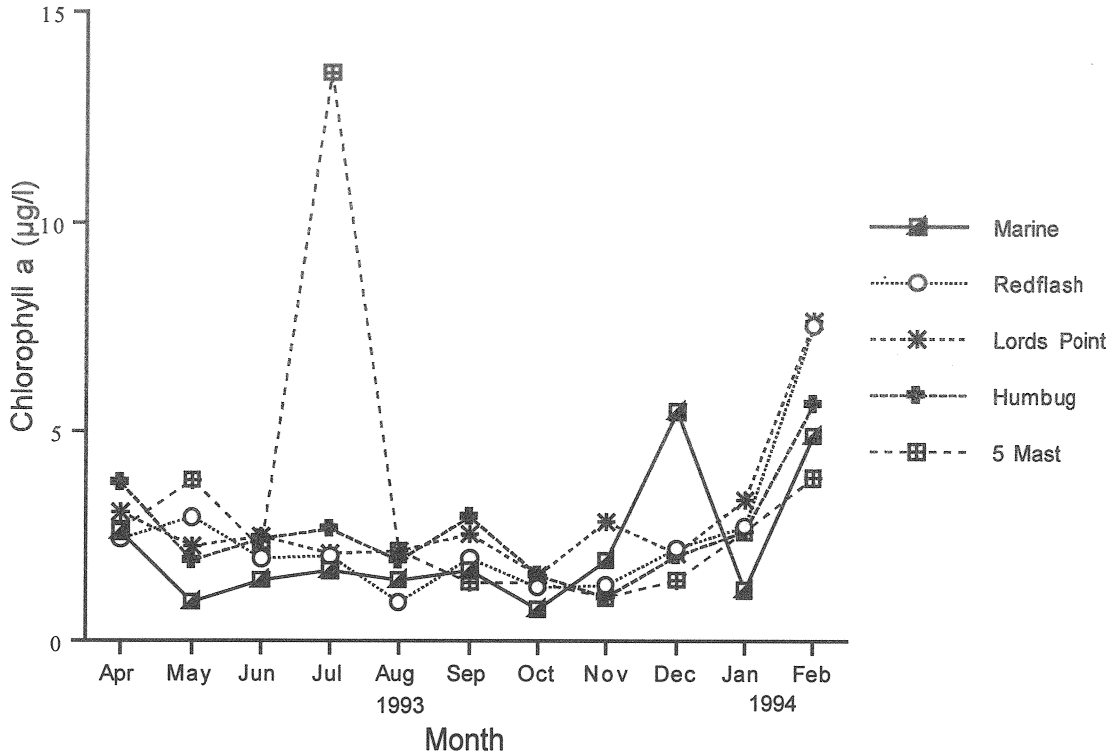


Figure 30a&b. Temperature and Salinity Georges Bay.



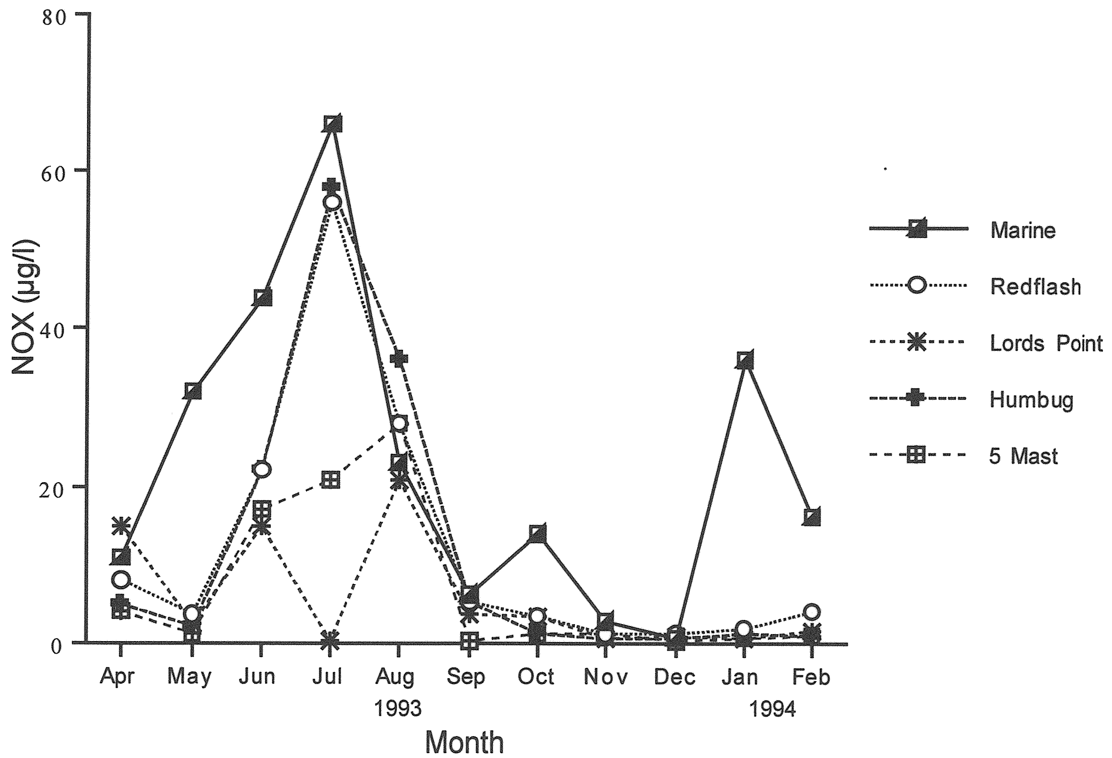
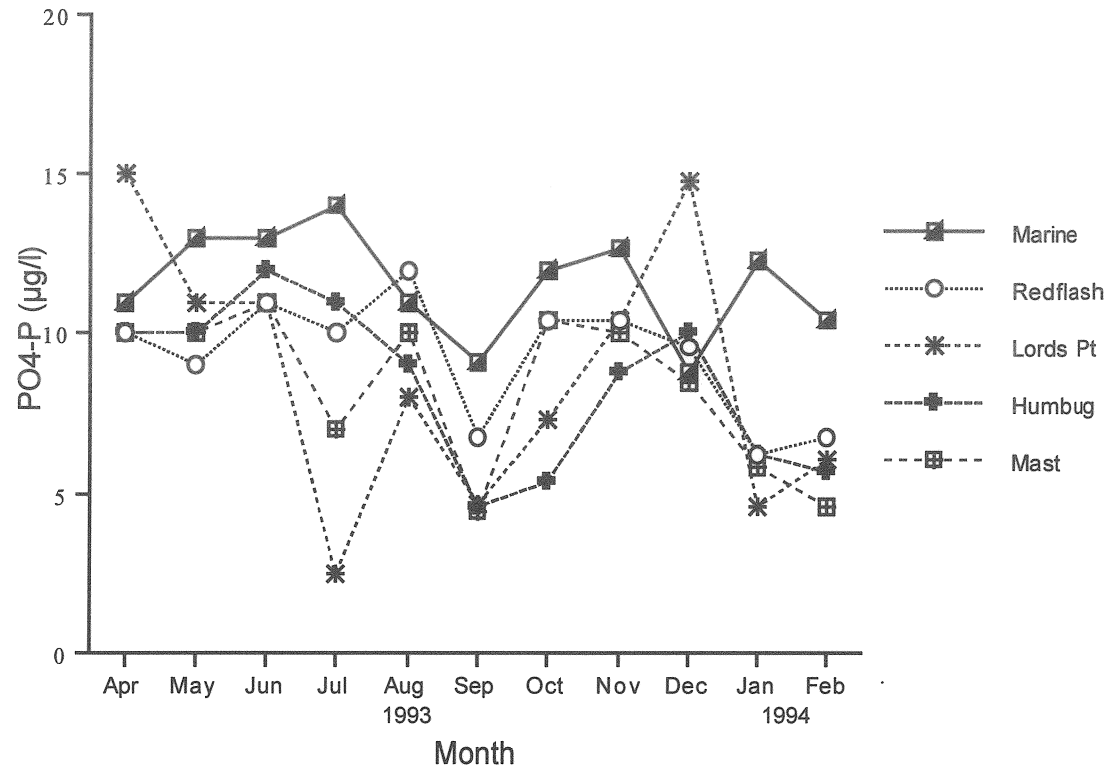


Figure 31a&b. Chlorophyll a and NOX in Georges Bay.



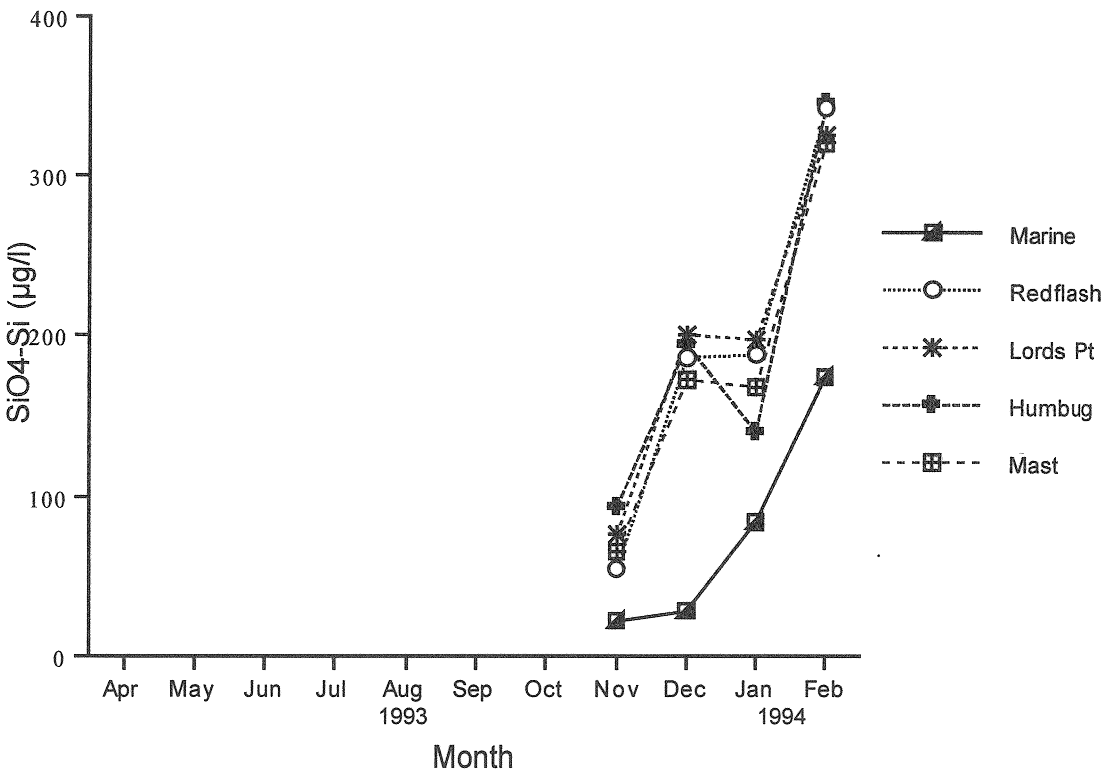


Figure 32a&b. PO_4 and SiO_4-Si in Georges Bay.

6.2.5 Simpsons Bay

During the 9 month sampling period temperatures peaked in January and there was little variation between the stations (Fig. 33a). Salinities were high and similar between the stations except for January and June 1994 when salinities were highest at the Marine station and lowest towards the head of the bay (Fig. 33b).

Chlorophyll a concentrations generally increased during the sampling period from low levels to peaks of 8-12 μg/l at the Anderaa and Nowhere stations in June (Fig. 34a). NOX nitrogen concentrations were consistently low except for high peaks at all stations on the last sampling occasion in June (Fig. 34b).

Phosphate concentrations were similar from September to December, lowest in January and then generally increased until June (Fig. 35a) Silicate levels peaked in December, were low in January - February, and then increased until June (Fig. 35b).

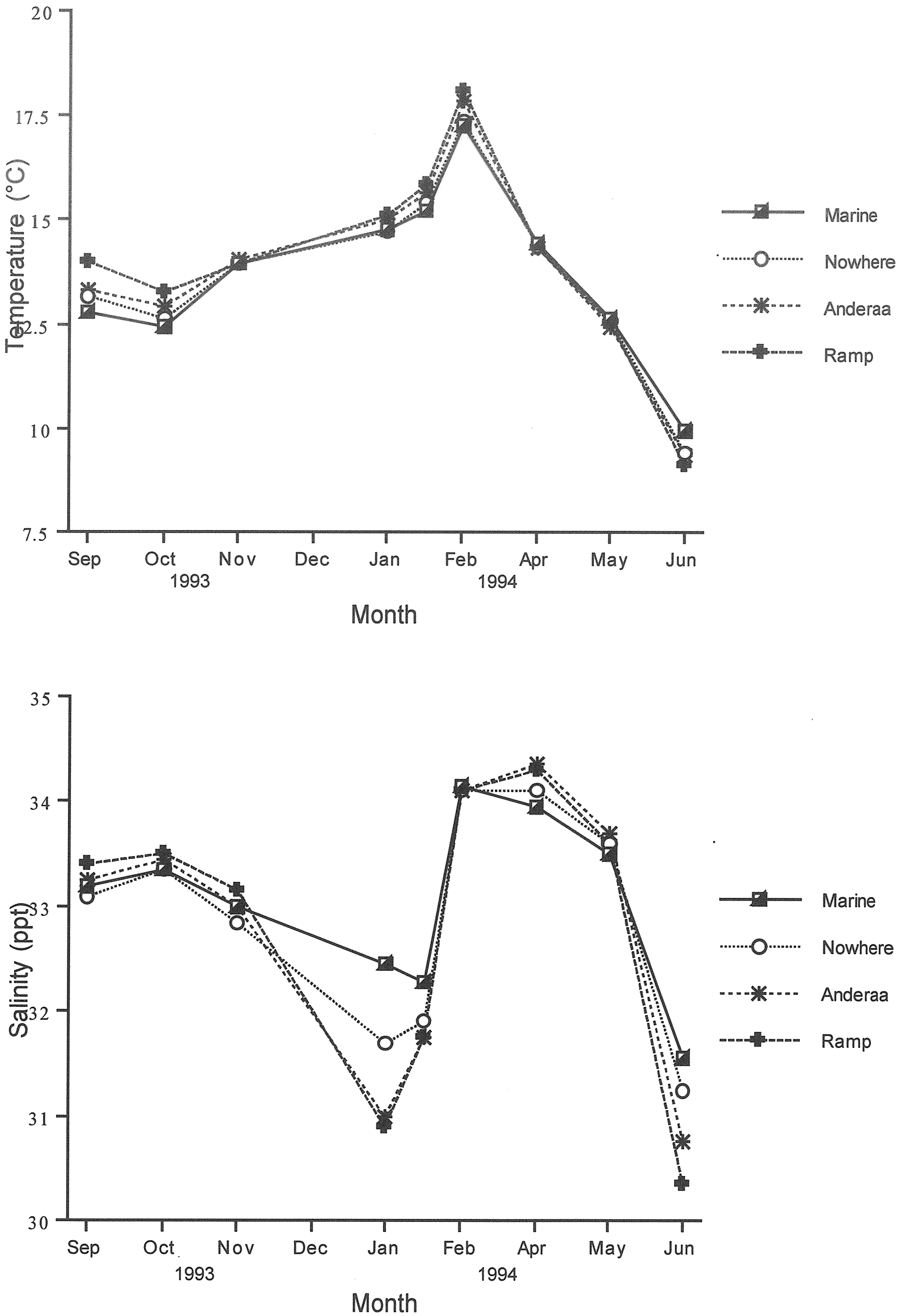


Figure 33a&b. Temperature and Salinity in Simpsons Bays.

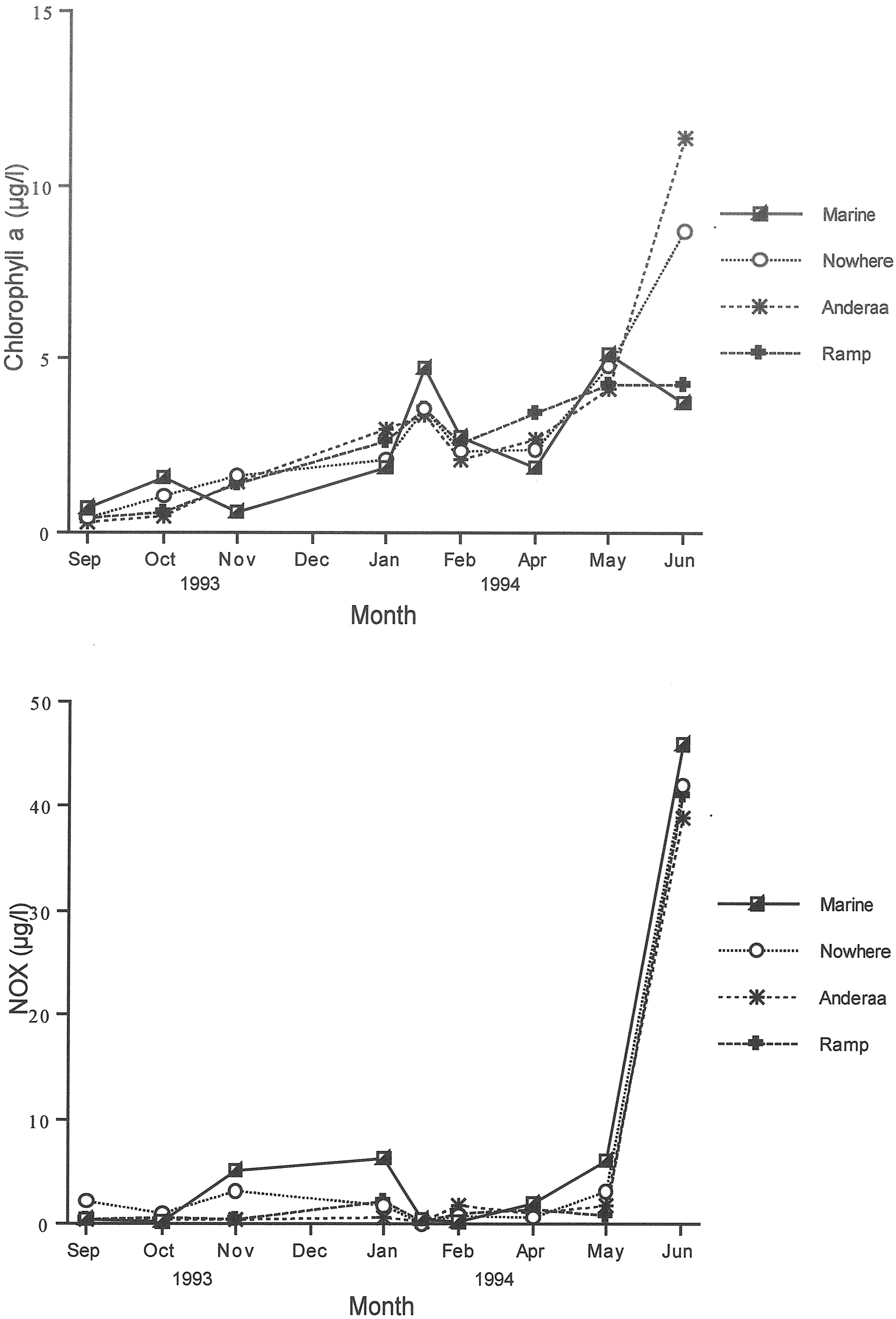


Figure 34a&b. Chlorophyll a and NOX in Simpsons Bay.

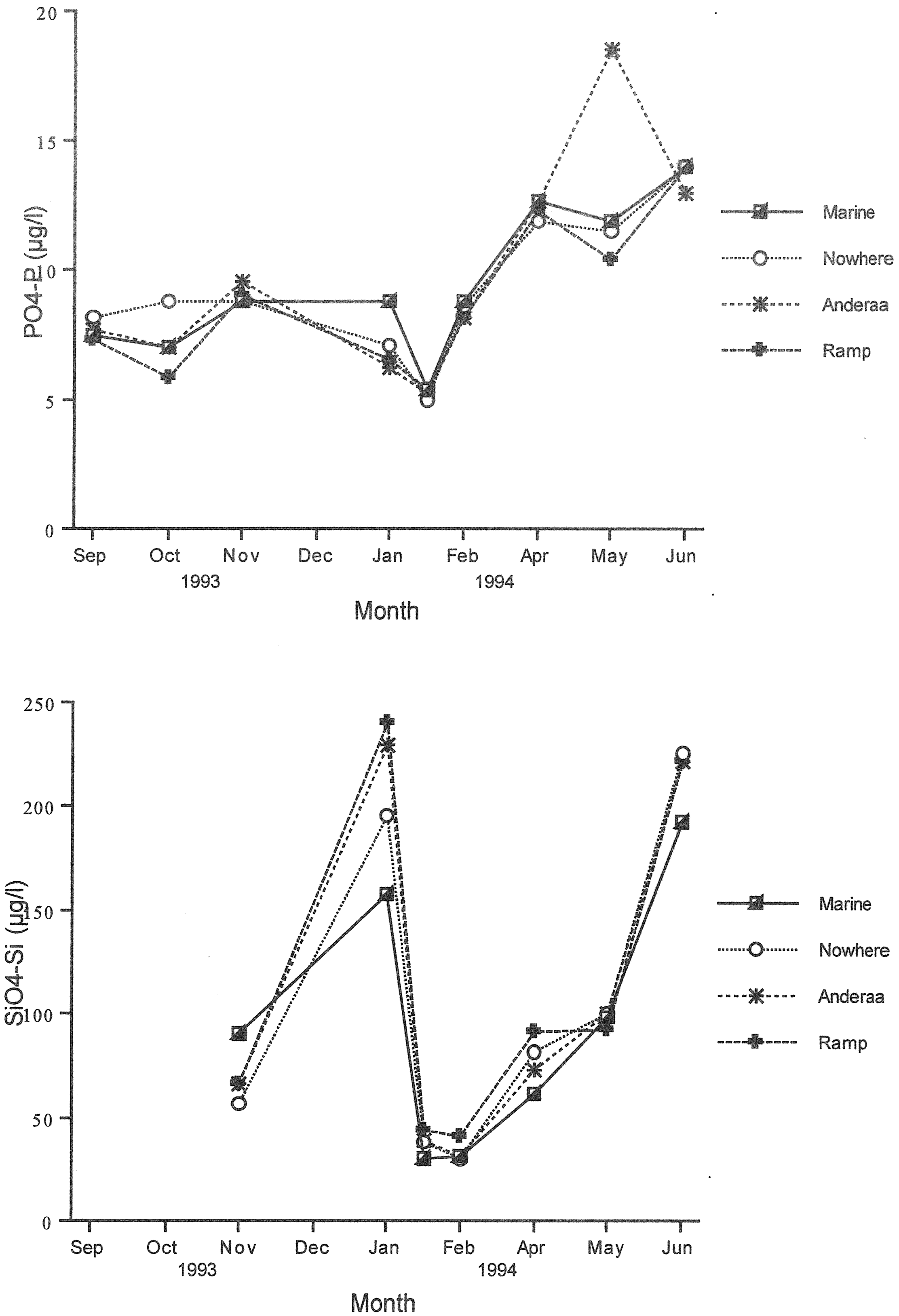


Figure 35a&b. PO_4-P and SiO_4-Si in Simpsons Bay.

It is interesting to compare some of the physical and chemical characteristics of the different oyster growing areas and to relate these to oyster growing methods and oyster production at each site. Some of the more notable differences are as follows. Georges Bay had an obviously smaller annual range in temperature (10.2-18.5 °C) than at the other stations, with Pittwater and Pipeclay Lagoon having the greatest range (approx. 6.5-21 °C). Georges Bay also had the greatest differences in temperatures between stations with the Marine station having temperatures significantly lower in summer and higher in winter than at the others. Similar, but less obvious trends were apparent at Little Swanport and Pipeclay Lagoon, whereas there was little difference between stations at Pittwater and Simpsons Bay.

There were some interesting differences in salinity regimes between the sites. At the estuarine sites of Georges Bay and Little Swanport the Marine station almost always had the highest salinities, and the other stations had salinities at varying levels below the Marine values, depending on the amount of recent rain. By contrast, salinities at Pittwater and Pipeclay Lagoon were regularly higher inside the estuary and marine inlet, respectively, than at the Marine station, indicating substantial evaporation. This was particularly pronounced at Pittwater.

Generally chlorophyll a levels were within the range of 0.5 - 4 µg/l at all sites, with peaks approaching bloom conditions occurring periodically, but most commonly in late summer. Chlorophyll a concentrations tended to be lower at the Marine station than other stations at most sites, especially the estuarine sites.

Nitrate + nitrite measurements were mostly around 10 µg/l at all sites with some irregular large peaks. They were more often above this value at the Pipeclay Lagoon and Georges Bay sites than the others. In Pittwater they were consistently low from Spring 1992 to Spring 1994.

Chlorophyll a peak concentrations generally occurred in the same month or just after peaks in nitrate concentrations, and at the estuarine sites of Little Swanport and Georges Bay these high values often occurred after heavy rains resulting in low salinities. An exception is the higher chlorophyll a concentrations recorded at Pittwater in 1994 when nitrate values were low. During this period chlorophyll a concentrations were sometimes high at the Marine station indicating a more oceanic influence on chlorophyll a levels.

Phosphate concentrations were routinely within the range of 4 -15 µg/l, with slightly lower values at Pipeclay Lagoon and Little Swanport. There were no apparent trends between seasons or between stations at each site.

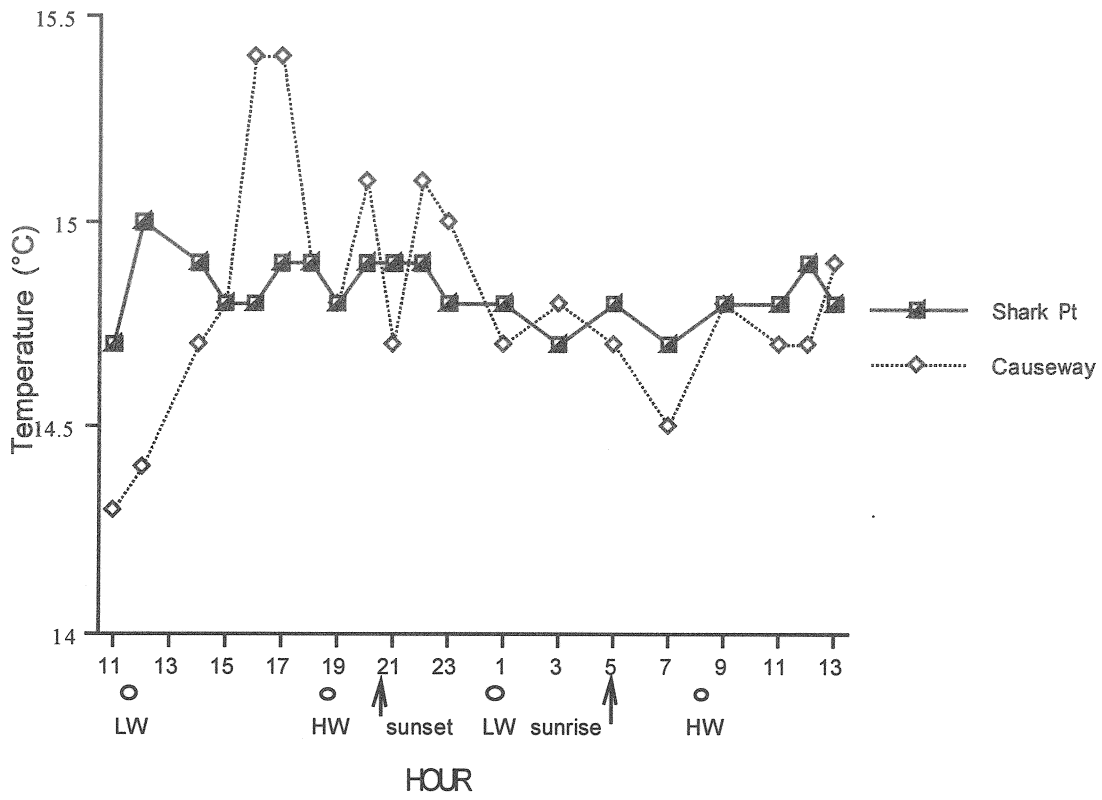
Of the few measurements of silicates, results were varied, generally between 20 - 250 µg/l, and they were often lowest at the Marine station at the three sites investigated. The higher turbidity of the estuaries and shallow embayments probably contributed to the higher silicate levels in these areas compared with the Marine stations.

6.2.6 Sampling over time (24 h, daily and weekly)

Temperature and salinity were less variable over 24 hours at Station A, Shark Point, than at Station B on the northern side of the Causeway (Fig. 36a & b). The drop in salinity at the Causeway around high tide is presumably due to the inflow of water from Frederick Henry Bay through the Causeway which is then dispersed around Upper Pittwater where the salinity is often higher due to evaporation. Chlorophyll a values were higher at Shark Point than the Causeway possibly because of primary production in upper Pittwater, and did not exhibit a consistent pattern over 24 h (Fig. 37a). They varied by about 4 μg/l over 24 hours, excluding the unexplained low values at 1600 h. Nitrate values were low over the 24 h except for a unexplained large variation at the Causeway site at the start of the experiment (Fig. 37b). Phosphate values showed little variation, although they were slightly lower at the Causeway than at Shark Point on most occasions (Fig. 38a). Silicates were significantly lower at the Causeway than at Shark Point at all sampling times and especially around high water (Fig. 38b).

Fluctuations in chemical parameters of sea water over days and months showed similarity to the 24 h sampling in that most parameters recorded a lower value at the Causeway site than at Shark Point. Temperature fluctuated by almost 3°C and salinity by 1 ppt during the month in a similar manner at both sites (Fig. 39a & b). Chlorophyll a concentrations were highest at Shark Point for the first few days and then at the Causeway for the remainder of the month (Fig. 40a). They varied by about 5 μg/l during the month, with the extreme values being only one week apart. Nitrates were low and showed little fluctuation between sites or over time, except for the last sampling (Fig. 40b). Mean phosphate values varied by approximately 4 ug/l and silicates by 125 ug/l during the month of sampling and generally in a similar manner at both sites (Fig. 41a & b).

These results of sampling at two sites less than 4 km apart over time indicate temporal variability and spatial patterns in environmental parameters. Over 24 hours chlorophyll a, phosphate, silicate and salinity values were generally higher at the station further up the estuary near the oyster leases than at the Causeway. This spatial pattern, however, was not so apparent over a month of sampling, especially for nitrate and chlorophyll a concentrations. These results also indicate that some parameters, e.g. chlorophyll a over 24 h, show considerable variability and ideally should be measured using continuous data loggers.



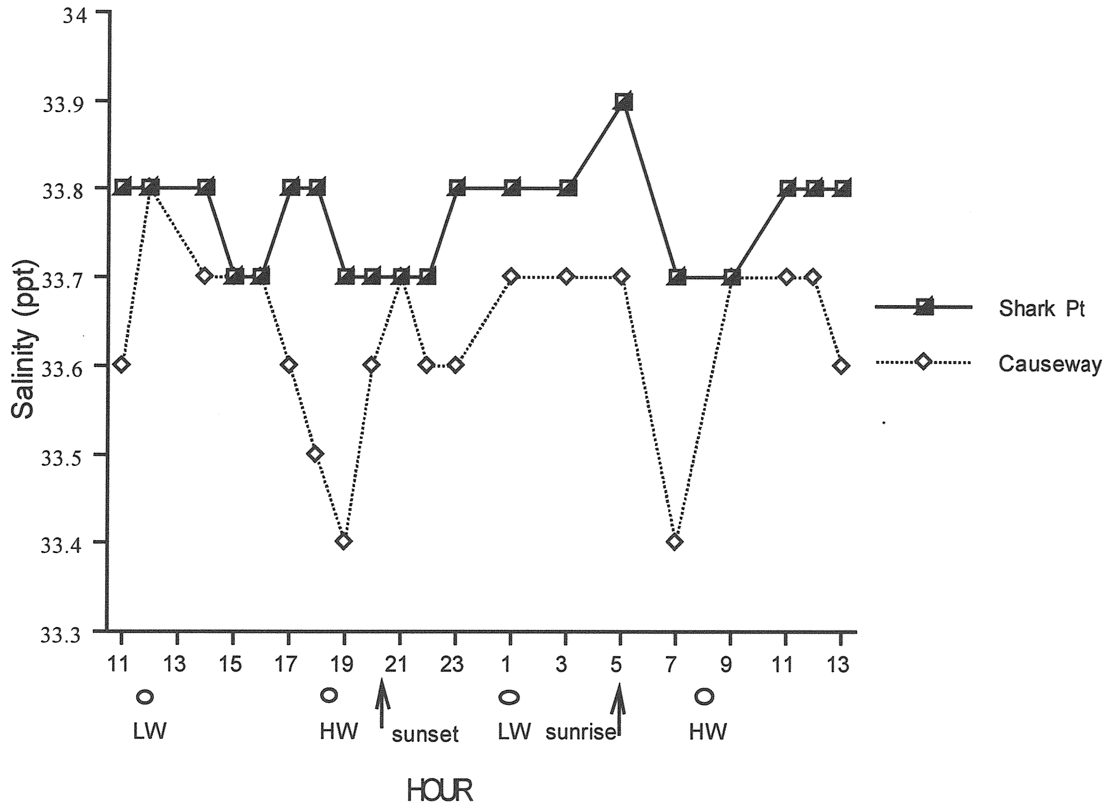


Figure 36a&b. Temperature and Salinity in Pittwater over 24 hours

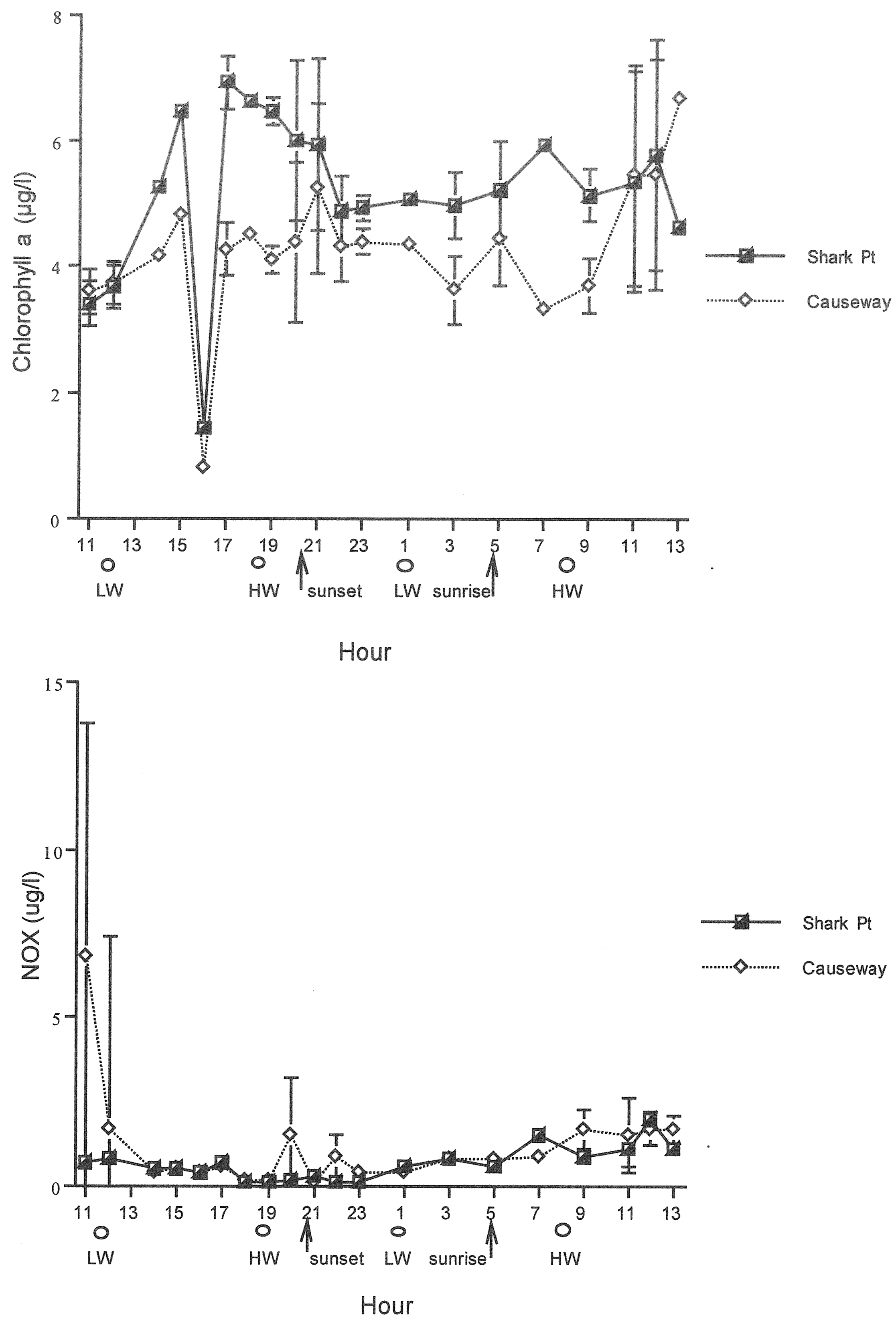
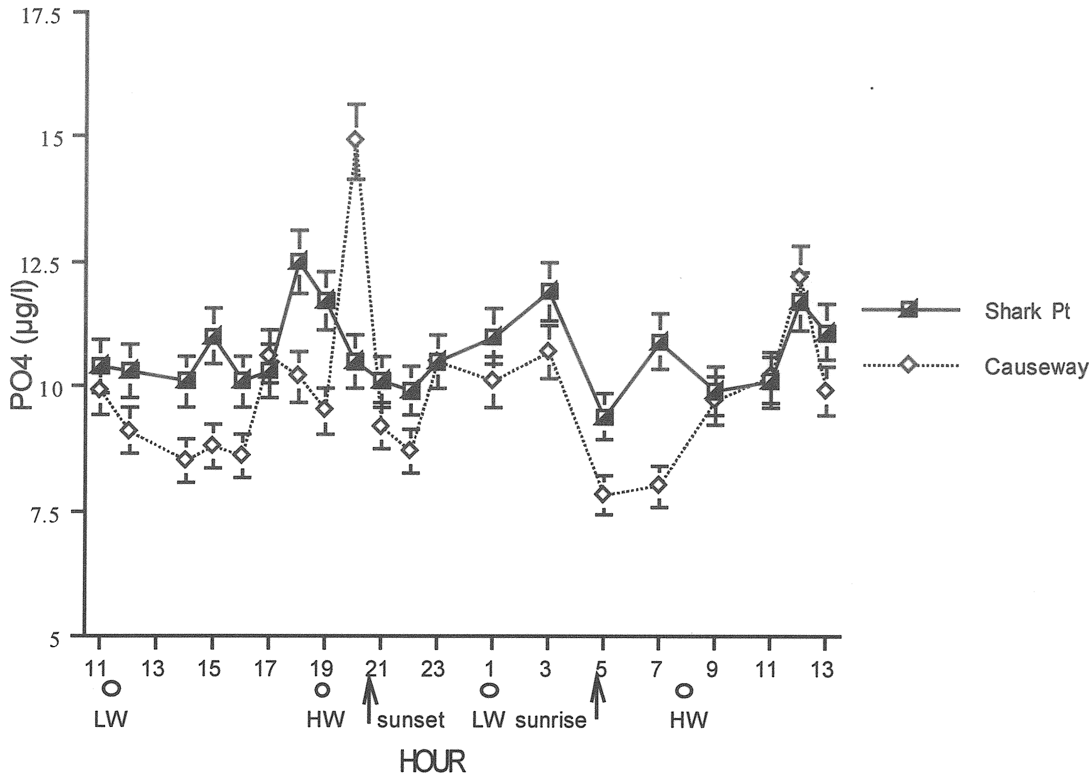


Figure 37a&b. Mean Chlorophyll a and NOX in Pittwater over 24 hrs



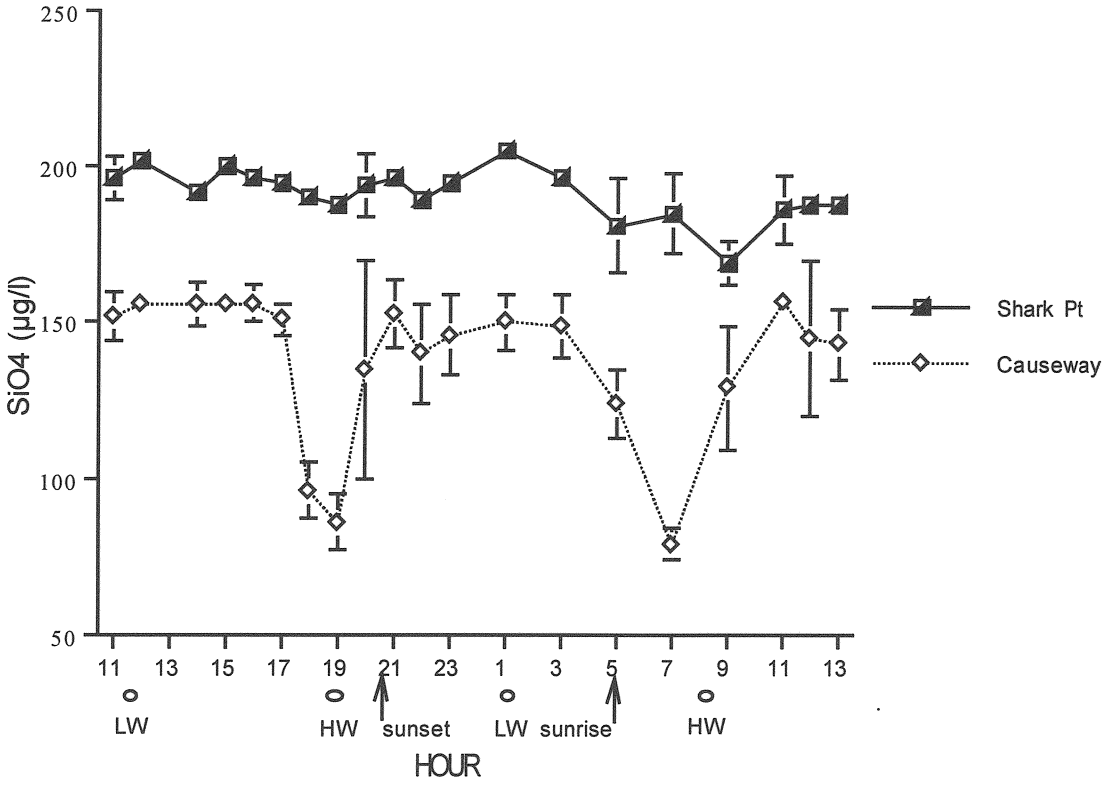


Figure 38a&b. Mean PO4 and SiO4 in Pittwater over 24 hours

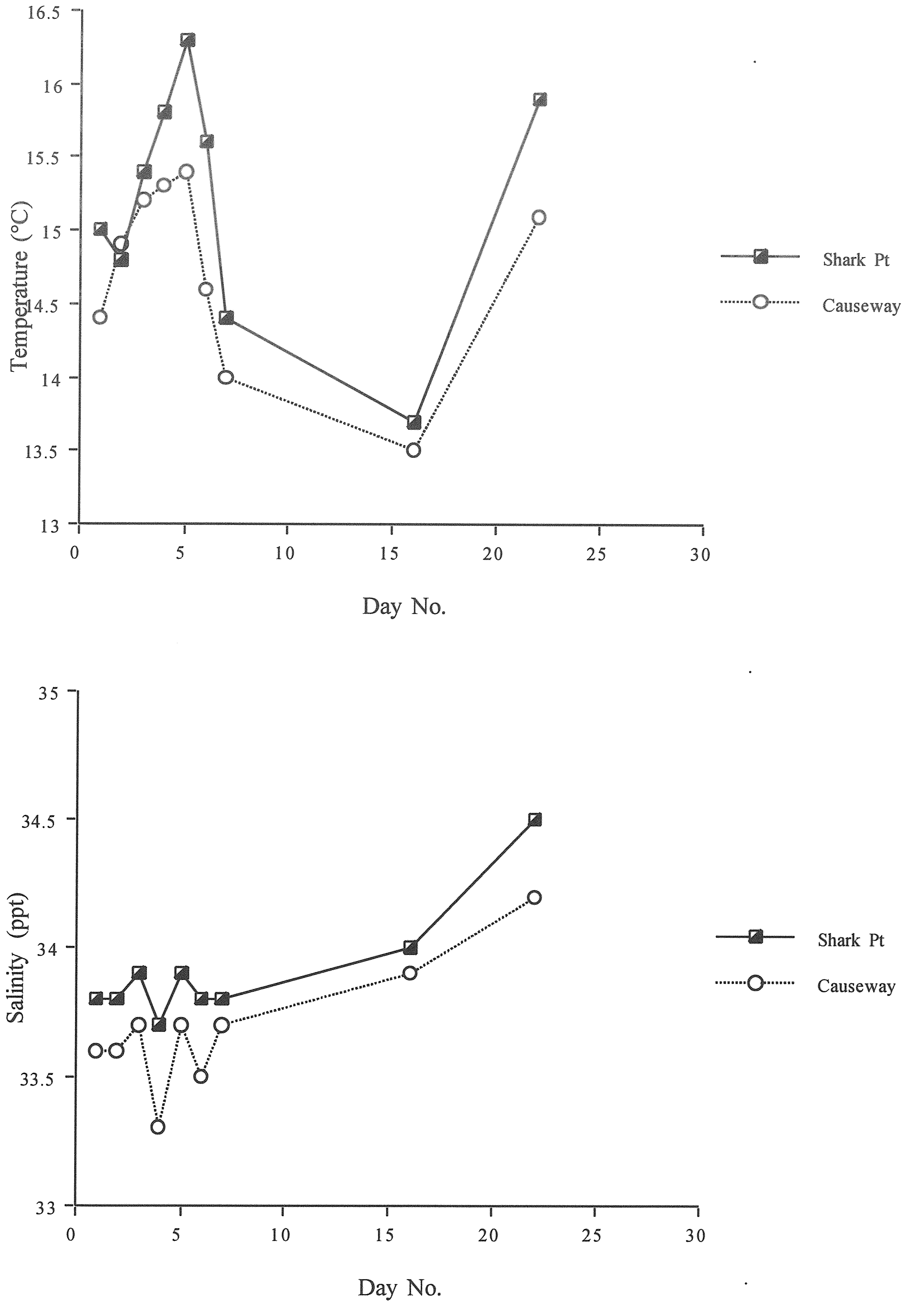
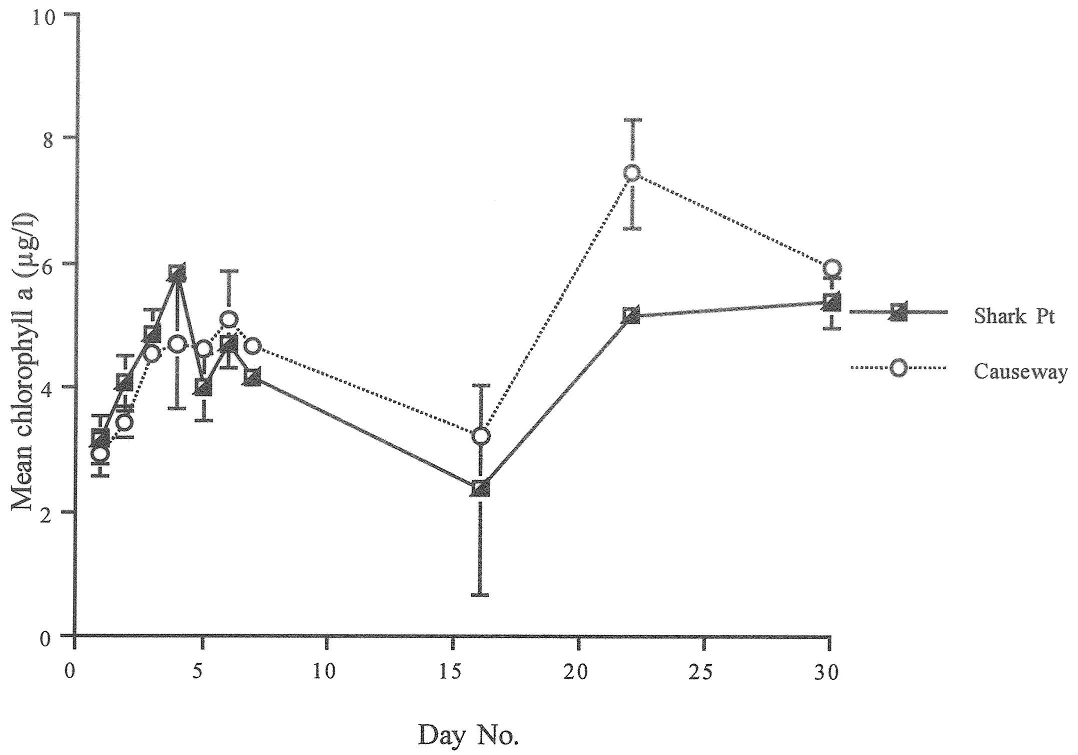


Figure 39a&b. Temperature and salinity in Pittwater over four weeks.



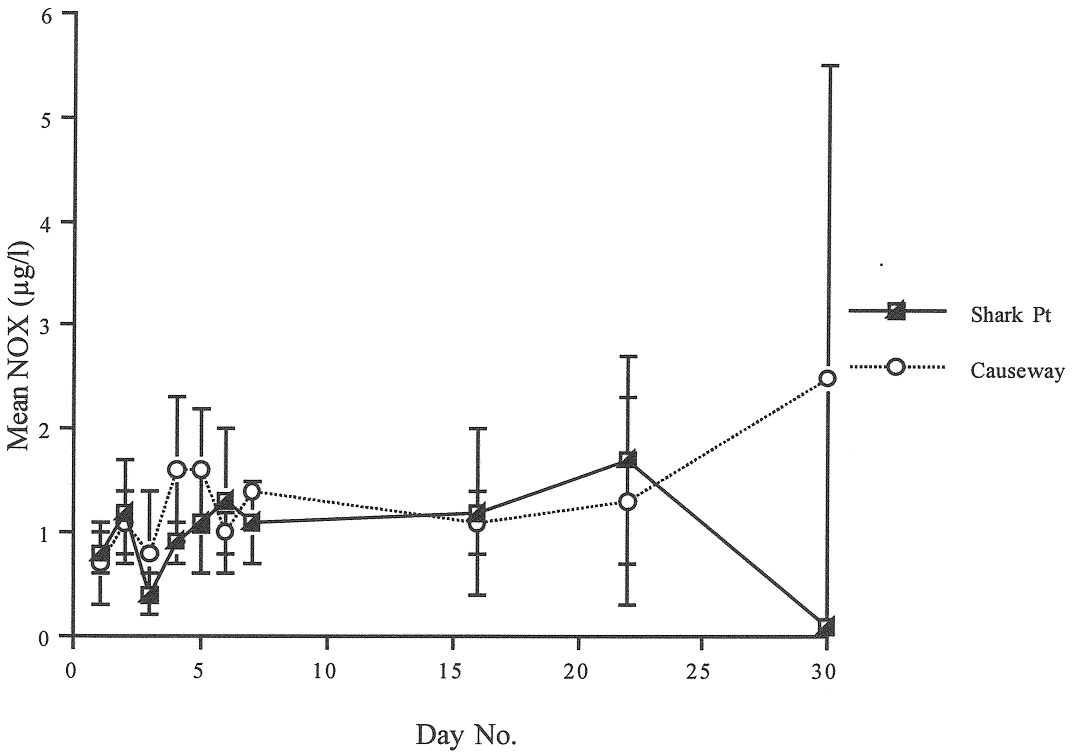
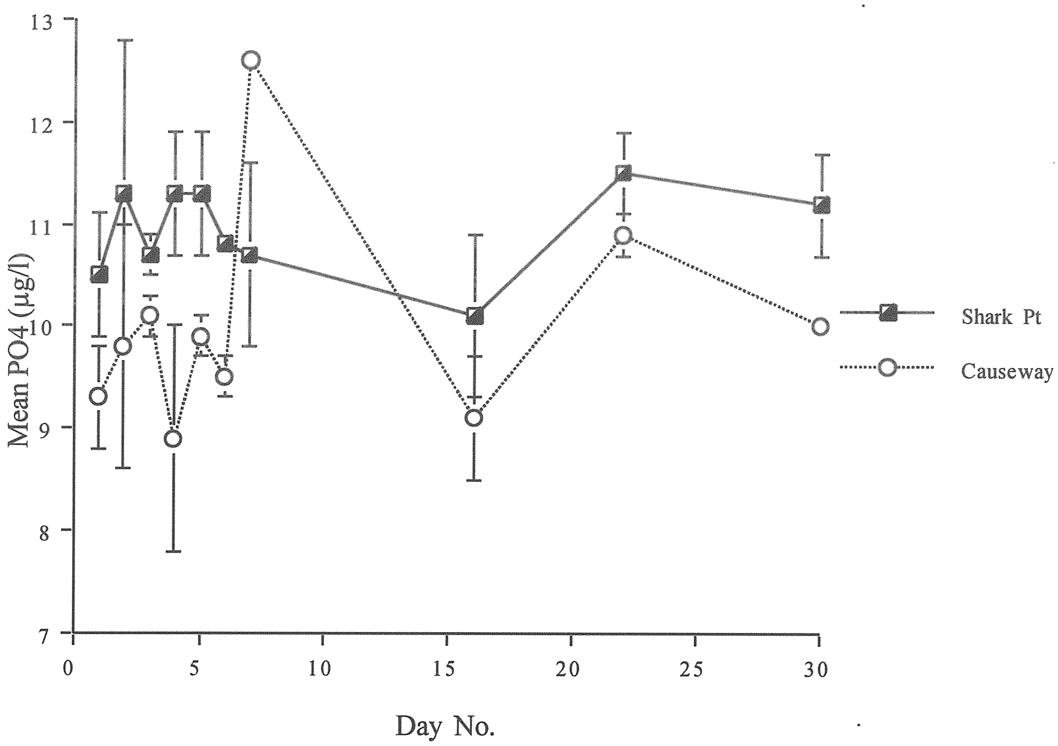


Figure 40a&b. Mean chlorophyll a and NOX in Pittwater over four weeks.



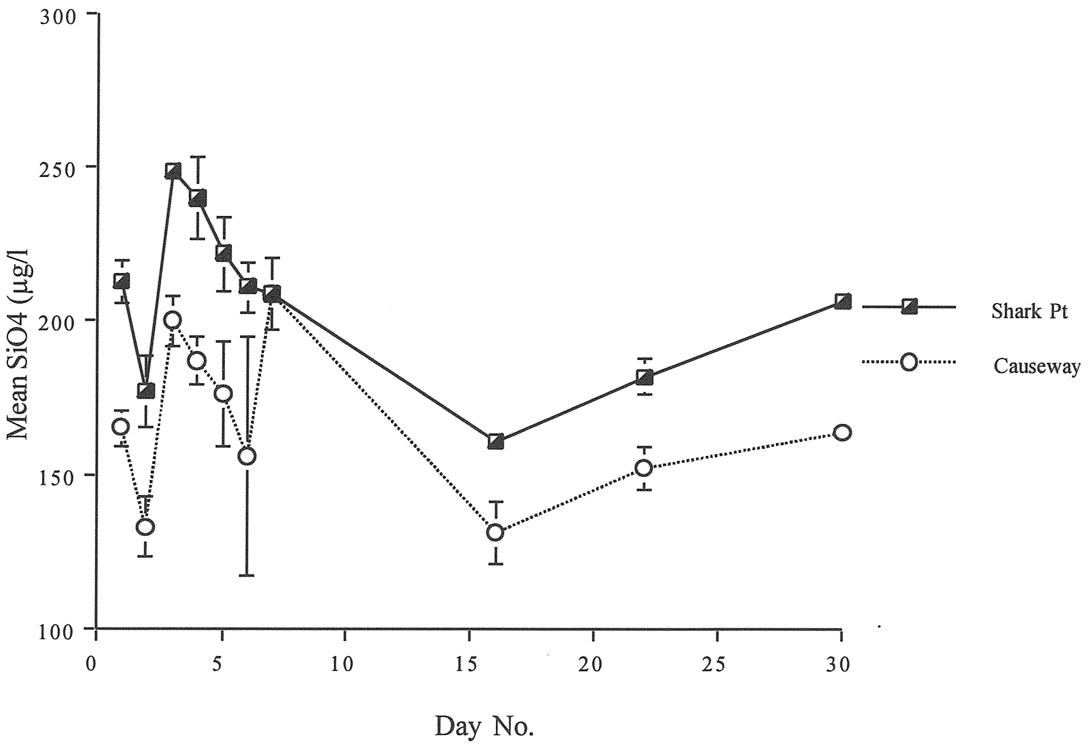


Figure 41a&b. Mean PO_4 & SiO_4 in Pittwater over four weeks.

6.2.7 Intensive Sampling Around the Leases

Results of intensive samplings around the leases are presented in Appendix 2.

The limited sampling at Pittwater did not indicate any changes in nutrient concentrations around the leases.

At Pipeclay Lagoon the temperature and salinity data were similar around the 6 leases close together, whereas the temperature was higher in spring and lower in winter at the southern most lease where there are extensive shallow mudflats. Chlorophyll a and nitrates showed no clear patterns whilst phosphates tended to be highest at the stations furthest away from the inflowing water in the group of 6 leases. Overall there were no clear trends to indicate that the oysters on the leases closest to the inflowing water were removing all the food from the water before it reached the oysters furthest away.

At Little Swanport there were no apparent changes in nutrient concentrations around the leases except for a tendency for chlorophyll a concentrations to be higher at the stations furthest up the estuary.

Temperatures and salinities at Georges Bay showed little variation around the leases. Chlorophyll a levels varied substantially over the sampling periods and showed bloom conditions in June 1993 and February 1995 (after rainfall). The chlorophyll a concentrations on some occasions were noticeably higher in Moulting Bay than in Georges Bay proper.

No clear trends in data were apparent at Simpsons Bay, probably because the bay is large and the oyster farms comparatively small.

6.3 Primary Production

Primary production was measured at Pittwater and Pipeclay Lagoon on several occasions in summer and winter, and the results are presented in Table 8 below.

Table 8: Primary production at Pittwater and Pipeclay Lagoon.

	Date	Daylight hrs (sunrise-sunset)	Daily solar rad^n.(W/m^2)	(mg C fixed/m^3/day) Site X	Site Y
Pipeclay Lagoon:	30/1/95	14 hrs 20 mins	25054	205.5	271.0
	23/5/95	9 hrs	14589	136.5	676.7
Pittwater:	4/4/95	11 hrs	19919	243.7	425.1
	24/5/95	9 hrs	8258	309.8	506.2
	22/6/95	9 hrs	10316	118.3	348.1

Primary production showed considerable variation between sites on most days sampled. In Pittwater it was higher at Site Y near the oyster leases than near the entrance to the estuary on all sampling occasions. It also varied over time at each site. Because insufficient data have been collected theoretical values were used in the model as described in the section on the predictive model.

6.4 Oyster Feeding Rates

Preliminary analysis of the percentage of food particles taken in by large oysters (mean length 91.03 g $\pm$ 8.5) over time in four experiments with different flow rates ranging from 176 to 550 lh^{-1} showed that after 40-50 minutes the feeding rate of the oysters had stabilised and did not increase significantly with further time up to 180 minutes from the start of the experiment (Fig. 42). Thus, in all subsequent experiments the oysters were left in the experimental chambers for at least one hour to acclimate before the quantity of food removed from the water by the oysters was measured.

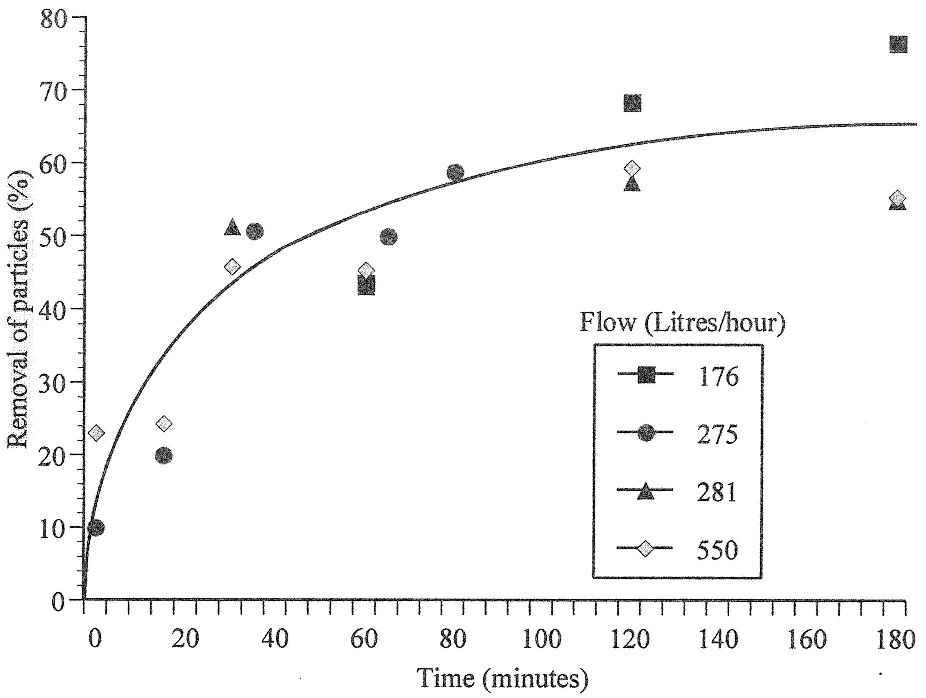


Figure 42 . Percentage removal of particles by large oysters in the grazing chambers over time.

Clearance rates per oyster of large oysters generally increased with increasing water flow rates from 150 to 1200 l/h (Fig. 43). A regression line was not fitted because the data were collected in 1993 from counts of particle numbers in the water and in 1995 from the weight of particulate organic matter in the water. More data are required to determine the relationship between clearance rate and flow rate for different sized oysters.

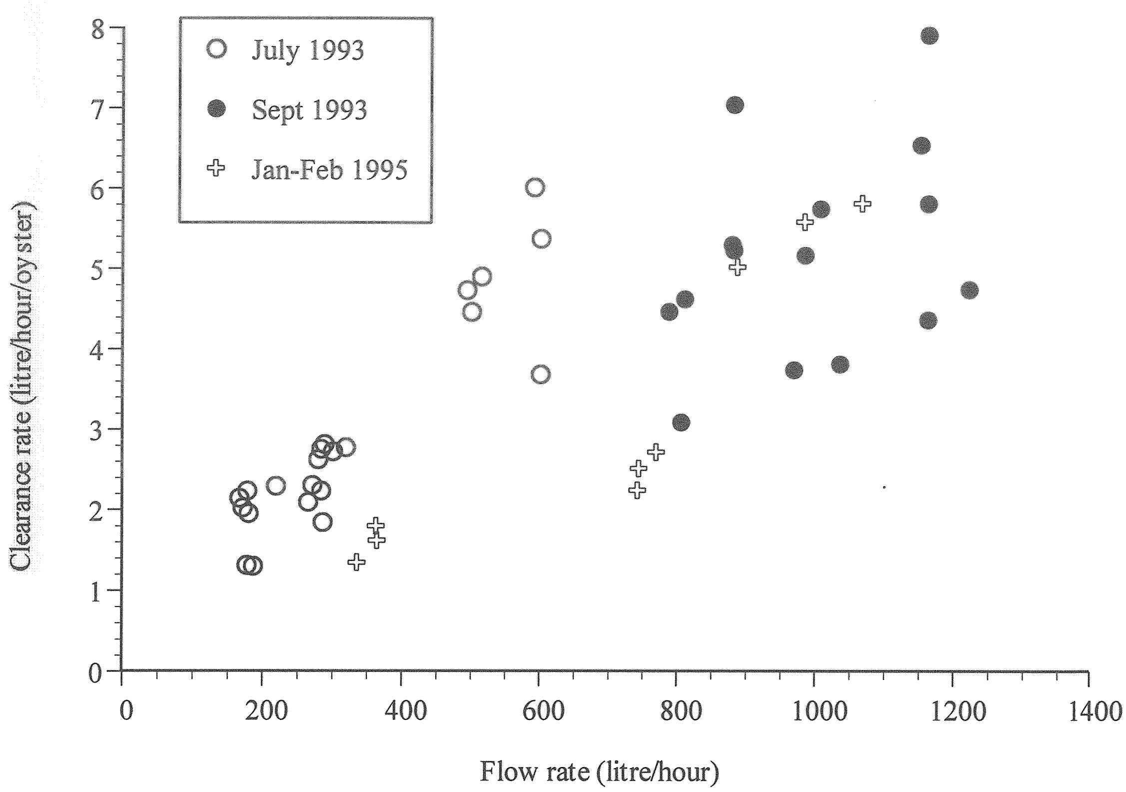


Figure 43. Clearance rate (litre/hour/oyster) of large oyster at different flow rates (litre/hour).

Clearance rates per oyster also increased with increasing size (shell length) of the oysters (Table 9). The relationship between shell length and dry tissue weight was calculated for oysters from Pipeclay Lagoon as:

$$\mathrm{Ln(L)} = 0.39 \times \ln(\mathrm{TW}) + 4.00, \quad R^2 = 0.97$$

where L is shell length in mm and TW is dry tissue weight in gm.

The clearance rate (l/h) per oyster increased with the size of oyster at Pittwater for similar flow rates, but the clearance rate per dry tissue weight of oyster showed no clear relationship with oyster size. Table 9 indicates little difference in clearance rates between oysters of the same size (large) at Pipeclay Lagoon and Pittwater when they were exposed to similar flow rates of 350-380l/h. At Pittwater there was little variation in clearance rates from Autumn to Winter when there was an approximately 7°C drop in water temperature. More data are required over a larger period of time to clarify these relationships.

Assimilation efficiency of the food showed little variation between small, medium and large oysters at Pipeclay Lagoon, ranging from 33 - 36%. It was slightly higher at Pittwater, 40-54%, and was similar in Autumn and Winter when there was a 7° C difference in temperature (Table 9).

Table 9: Oyster clearance rates and assimilation efficiency.

Site	Date	Temp °C	Oyster length (mm)	Dry Tissue wt. (g)	Flow Rate l/h	C.R. 1 l/h/o	s.d.	C.R. 2 l/h/g	Assim. Effic.	s.d
Pipeclay										
	Feb. 95	16.3	87.64 ±9.78	3.37	352.8	1.59	0.23	0.47	33.04	9.93
	Feb. 95	19.4	87.64 ±9.78	3.37	979.2	5.48	0.40	1.63	33.89	2.46
	Feb. 95	19.0	57.10 ± 6.86	1.12	406.8	0.77	0.31	0.69	34.77	
	Feb. 95	19.0	43.05 ±5.30	0.54	396.0	0.35	0.14	0.64	36.43	
Pittwater										
	Mar. 95	19.9	80.66 ±6.40	2.72	385.2	1.87	0.35	0.69	53.7	2.26
	Mar. 95	19.0	80.66 ±6.40	2.72	352.8	1.40	0.09	0.63	40.98	2.92
	May 95	11.7	80.66 ±6.40		648.0	2.18	0.64		40.33	2.37
	May 95	12.3	80.66 ±6.40		360.0	1.80	0.24		48.73	1.63

where C.R.1 is the filtration rate (l/h) per oyster
and C.R.2 is the filtration rate (l/h) per gram of oyster dry tissue weight.

6.5 Predictive Models

The development of predictive models has concentrated on using data from Pittwater because most data were collected from this area.

6.5.1 Primary Productivity

The primary productivity of Pittwater has been assessed in the model in terms of chlorophyll a carbon (chl a carbon). Chl a carbon has been calculated directly from chlorophyll a concentrations data using a carbon:chl a ratio of 40 (Wofsey, 1983). The simulation reacts to depletion of chl a carbon concentrations below control concentrations in the bay by generation of new chl a carbon, numerically modelled by the photosynthesis representation of Platt and Jassby (1976) with constants following Taylor *et al.* (1986). It is assumed that zooplankton grazing is zero in the water volume where compensation is occurring. The simulation calculates the volume of water, which has a lower concentration of chl a carbon than the control, and applies a replacement of chl a carbon at a rate predicted by the Platt and Jassby equation. Primary productivity is assumed to be zero, when chl a concentrations return to the initial values (corrected for dispersion).

The model also simulates variation in seasonal theoretical rates of primary production. The Platt and Jassby (1976) equation relates mean incident light intensity at the water surface to photosynthesis in the water column. A winter minimum light value of 10 watts m^{-2}, and a maximum summer value of 100 watts m^{-2} have been used in the model to mimic extremes in light intensity. Using values of 10 and 100 watts m^{-2} the predicted total net primary production figures are shown in Table 10. Ryther (1969) quotes estimates of net primary productivity in coastal waters in the order of 100 g C m^2y^{-1}.

Table 10: Total net primary production at a light incidence of 10 and 100 watts m^{-2} at various concentrations of chlorophyll *a* in 5 m of water.

Chl *a* (μgl^{-1})	g C $m^{-2}d^{-1}$ (100 Wm^{-3})	g C $m^{-2}y^{1}$ (100 Wm^{-3})	g C $m^{-2}d^{-1}$ (10 Wm^{-3})	g C $m^{-2}y^{-1}$ (10 Wm^{-3})
10	1.71	623	0.49	178
8	1.37	501	0.41	151
6	1.03	377	0.33	121
4	0.69	252	0.24	86
3	0.52	189	0.18	67
2	0.35	126	0.13	46
1	0.17	63	0.07	24

Average chl a levels usually lie between 1 and 4 µgl-1 in Pittwater (Fig. 22a and Appendix 1.1). Two sets of arbitrary chl a concentrations along the bay have been used as baselines in the models: "winter" values and "summer" values (Table 11). The summer values are typical of the higher concentrations encountered during sampling from November to March, and the winter values of lower concentrations for the rest of the year.

Table 11: Typical "summer" and "winter" concentrations of chl *a* at five stations in Pittwater as used in the simulation. (Average summer values from Dec-Feb, average winter values from June-August).

Station	Summer Chl a (μgl^{-1})	Winter Chl a (μgl^{-1})
Marine	1.9	3.6
Lewisham	2.4	2.9
Causeway	3.6	2.9
Barilla Bay	3.1	2.5
Shark Point	4.1	3.4

The model also modifies the rate of photosynthesis due to self-shading by algal cells and particulate loading, which increase the light extinction coefficient of the water.

6.5.2 Feeding Rates

The results obtained in the feeding rate studies has been used to confirm gross estimates based on the laboratory studies of Gerdes (1983).

For the purposes of the model the clearance rate of size ranges of oysters normally held on a farm has been estimated from clearance values recorded by Gerdes (1983) and from the clearance rates measured using the feeding apparatus. In Table 12 the numbers of oyster of each size category which are held at any one time on a farm to produce 1 million oysters per annum are given.

Table 12. Number of oysters of various sizes held on farm for annual production of 1 million oysters.

Mean size (mm)	Number in category
8	742500
20	477612
50	656716
70	284119

All size categories of oysters held on a one million oyster production unit have an estimated total filtration rate of 0.96 $m^3 s^{-1}$ at a temperature of 20°C and salinity of 30 ppt.

6.5.3 Initial estimates of clearance versus primary production

It is useful to make some simple estimates of the impact grazing may have on the bay before actually applying the model. This serves as an indication of the range of values expected in the model.
Bathymetry of the bay predicts that at a tidal height of 1.2 m there are in the order of 8.84 x 10^7 m^3 of water in the bay. A farm capable of producing one million oysters per annum will clear at the high summer rate approximately 0.96 m^3 s^{-1} or a 30 million oyster production unit will clear 28.8 m^3 s^{-1}. This equates to 1.03 x 10^5 m^3 h^{-1} or approximately 0.1% of the total volume of the bay per hour. This is reduced by 40% if it is assumed that the oysters can feed for only 60% of the time. Hence the final estimate is 0.62 x 10^5 m^3 h^{-1}.

If there is an average chlorophyll concentration of 1 µg l^{-1} or 0.04 g C m^{-3}, the bay has an area of 46.1 km^2 and an average depth of 2m, primary production will be an estimated 0.069 g C m^{-2} d^{-1} (Platt and Jassby, 1976) or 3.2 x 10^6 g C d^{-1} in total. This is equivalent to a regeneration rate of 7.9 x 10^7 m^3 d^{-1} or 3.3 x 10^6 m^3 h^{-1}; the "compensation" by primary production. Therefore this first crude estimate suggests that net primary productivity should keep pace with the grazing impact of a 30 million oyster production system. However physical considerations, such as light, temperature, water depth and area under grazing pressure, in conjunction with tidal advection and dispersion of depleted and undepleted water may alter this significantly.

6.5.4 ECoS Model

The model essentially uses the same basic assumptions as have been described above, but does so under the predicted hydrodynamics of the bay.

The computer model has been run to predict depletion rates of hypothetical oyster leases under four different sets of environmental conditions:

1. "Winter" with high dispersion - low incident light, reduced grazing rate.
2. "Winter" with low dispersion - low incident light, reduced grazing rate.
3. "Summer" with high dispersion - high incident light, elevated grazing rate.
4. "Summer" with low dispersion - high incident light, elevated grazing rate.

High dispersion is modelled as K = 600 x U, low dispersion is modelled as K = 100 x U, where K is the longitudinal dispersion coefficient, and U is the net water velocity. Low light is assumed to be 10 watt m^{-2} and high light is 100 watt m^{-2}. Elevated grazing rate is $0.96m^3\ s^{-1}$ per million oyster production, and reduced grazing rate is $0.48m^3\ s^{-1}$ per million oyster production (assuming clearance rates in winter are half those in summer). In each of the four conditions populations of oysters have been situated in two areas of the bay; from approximately 2 to 5 km (section A) and from approximately 10 to 13 km (section B) from the head of the bay respectively. Section A is the general area where existing leases in Pittwater are situated, while B is the general area where the majority of proposed leases would be situated.

In these sections hypothetical oyster leases have been placed with annual production levels in the first case of 20, and in the second case of 30 million oysters. Hence for each computer run there are two different levels of oyster production; the first with 20 million in each of sections A and B, and the second with 30 million in each of sections A and B, and for each production level there are two levels of primary productivity; one with primary productivity acting to compensate for clearance by oysters and one with no compensation, *i.e.* totally reliant on input of food from outside the system. Hence each run of the model gives four different sets of predictions; two oyster production levels each with and without primary productivity compensation. A control, the bay with no oysters, was also run to model changes in the initial chl a carbon concentrations in the bay as a result of advection and dispersion.

The model has modelled chl a carbon over a 70 day period in time steps of approximately two hours. The last 30 days (40-70 days of the run), when the model has reached a steady state, has been used for analysis of results.

The average % segmental depletion is the % segmental depletions averaged for all segments of the bay during one 2 hourly period. The average % depletion is the overall average of the average % segmental depletions over the 30 day period. All statistics for percentage values have been calculated with arcsine transformations. Maximum % depletion is the maximum % segmental depletion of all % segmental depletions recorded during the 30 days. It represents the maximum reduction in chl a carbon concentration at a specific segment during the 30 days.

Table 13 summarises the depletion of chl *a* carbon within the bay under winter conditions with a high dispersion coefficient and low light and grazing rates. The % segmental depletion is the difference between the hypothetical chl *a* carbon concentration in 1 km segments of the control model and the chl *a* carbon concentration in the same 1 km segments of the model with oysters. It is expressed as a percentage of the control chl a carbon concentration for each two hourly period.

The average % depletion was 7.93 for maximum stocking rate (2 x 30 million production units) with no primary productivity compensation, and 3.02 for maximum stocking rate with compensation. The average % depletion was highest where there are 30 million production units in both A and B without primary productivity compensating for carbon losses. It is approximately two times higher than the model for 2 x 30 million production with compensation.

Table 13. Average percentage depletion and maximum segmental depletion of bay water under conditions of high dispersion and low light and grazing rates.

	30 million (A & B) without compensation	20 million (A & B) without compensation	30 million (A & B) with compensation	20 million (A & B) with compensation
Number of observations	375	375	375	375
Average % depletion	7.93	5.53	3.02	2.05
Standard deviation	0.13	0.09	0.04	0.02
Maximum % seg. depletion	26.22	18.69	9.56	6.57
Day	60.40	60.40	58.32	58.32

Maximum % segmental depletion occurred on days 58.32 and 60.40 (compensated and uncompensated respectively). The distribution of segmental % depletion along the bay on days 58.32 and 60.40 are shown in Figs. 44 and 45. The impact of grazing is most marked in the upper parts of the bay in all cases. While there tends to be a decrease down the bay there is a slight inflection in the curves in the proposed lease areas, however the depletion in this area is less than in the upper bay. Figs. 44 and 45 also illustrate the disproportionate effect of increasing production from 20 million units to 30 million units has on the % segmental depletion and overall depletion in the bay.

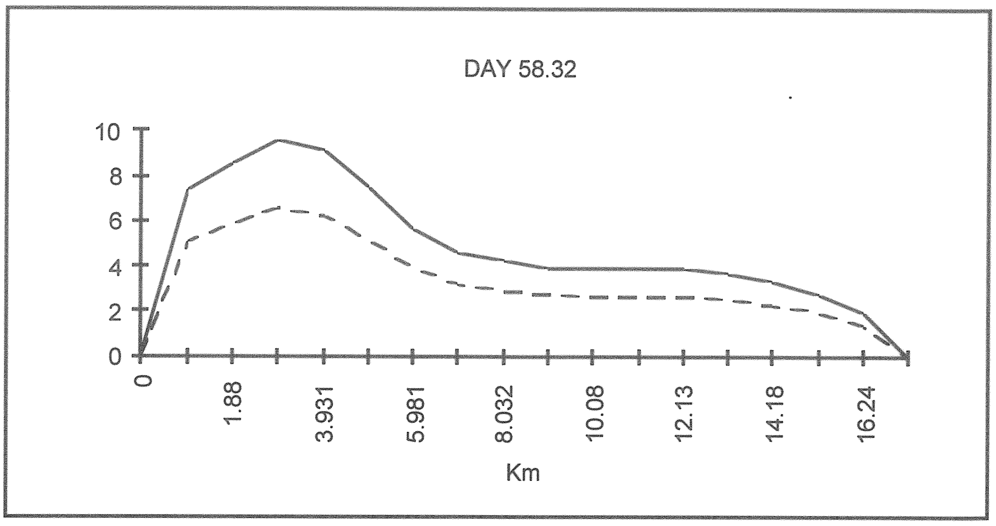


Figure 44. The % segmental depletion of chl *a* C along Pittwater with primary production compensation under conditions of high dispersion and low light and grazing rates. Distance is in km from the head of the bay.

______ 30 million oyster annual production at A and B

-------- 20 million oyster annual production at A and B

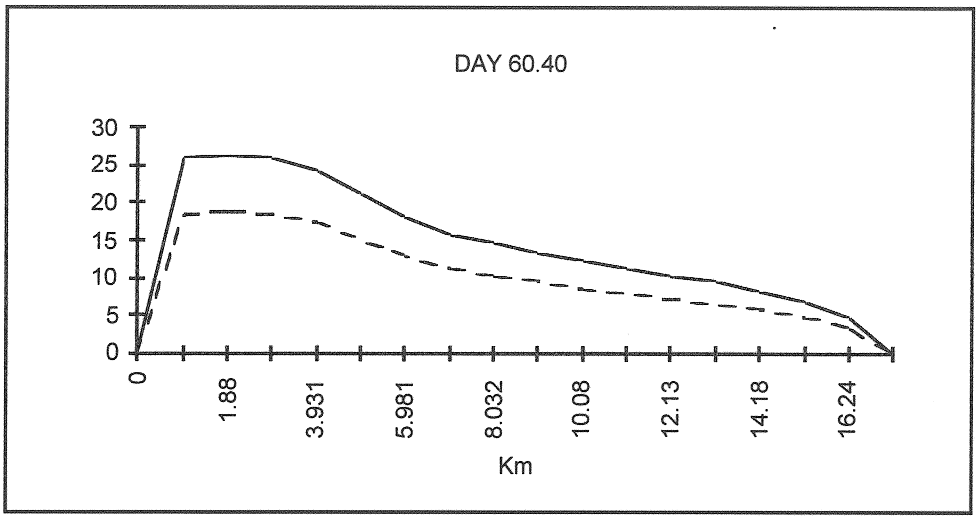


Figure 45. The % segmental depletion of chl *a* C along Pittwater without compensation under conditions of high dispersion and low light and grazing rates.
Distance is in km from the head of the bay.

______ 30 million oyster annual production at A and B

------- 20 million oyster annual production at A and B

In Table 14 the depletion values for leases run in winter with low dispersion coefficients (low incident light, reduced grazing rate) are shown.

Table 14. Average percentage depletion and maximum segmental depletion of Pittwater under conditions of low dispersion and low light and grazing rates.

	30 million (A & B) without compensation	20 million (A & B) without compensation	30 million (A & B) with compensation	20 million (A & B) with compensation
Number of observations	375	375	375	375
Average % depletion	11.78	8.41	3.41	2.32
Standard deviation	0.16	0.11	0.04	0.02
Maximum % seg. depletion	38.15	28.10	11.00	7.61
Day	58.32	58.32	61.44	61.44

The average % depletion is higher in all cases when dispersion is low, a result of the depleted water not mixing as effectively during tidal advection. Where primary production is tending to compensate depletive effects of oyster grazing, average % depletion values are less dependent on dispersion, and values at high and low dispersion coefficients are somewhat similar (cf Tables 13 and 14) .

The distribution of % segmental depletion along the bay on days 58.32 and 61.44, when maximum % segmental depletion were highest, are shown in Figs. 46 and 47. The % segmental depletion is again highest in the upper part of the bay over the existing lease areas. The % segmental depletions along the bay are also higher in the low dispersion models than in the high dispersion models, because of poor mixing with undepleted water.

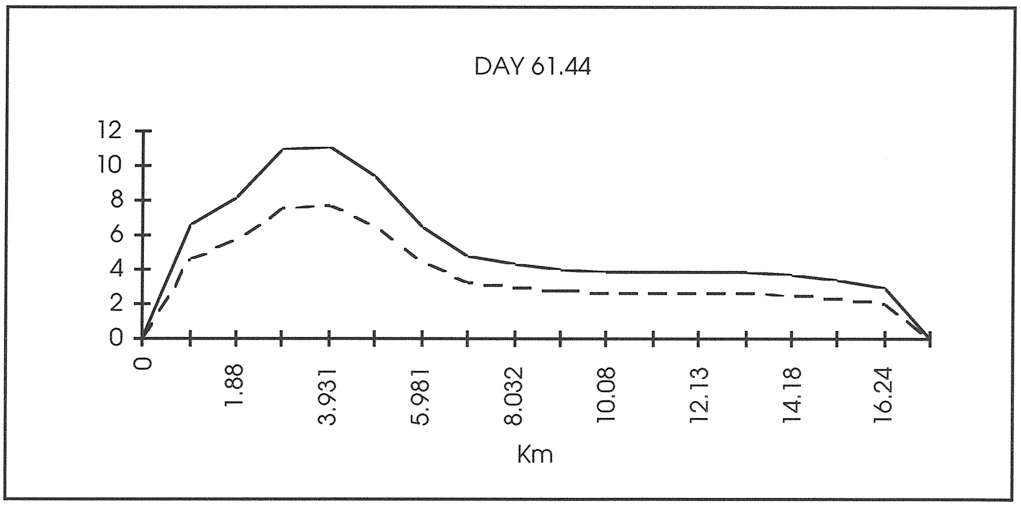


Figure 46. The % segmental depletion of chl *a* C along Pittwater with primary production compensation under conditions of low dispersion and low light and grazing rates. Distance is in km from the head of the bay.

——— 30 million oyster annual production at A and B

------- 20 million oyster annual production at A and B

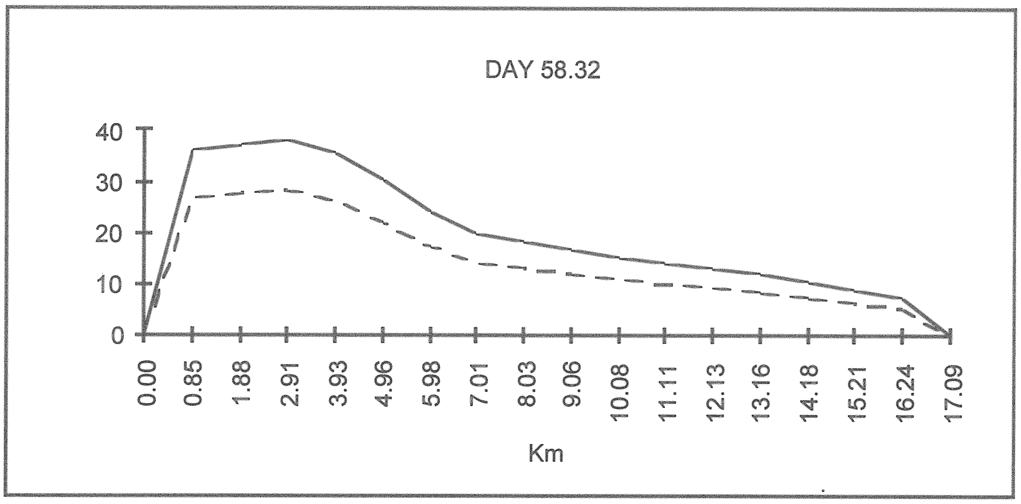


Figure 47. The % segmental depletion of chl *a* C along Pittwater without compensation under conditions of low dispersion and low light and grazing rates. Distance is in km from the head of the bay.

______ 30 million oyster annual production at A and B

------- 20 million oyster annual production at A and B

In Table 15, the depletion values for models run in summer with high dispersion coefficients (high incident light, high grazing rate) are shown. The average % depletion values under conditions of high dispersion and high light and grazing rate are higher than winter values for uncompensated models, however the higher primary productivity in summer rapidly replaces grazing losses, so that the compensated values are lower than in winter.

Table 15. Average percentage depletion and maximum segmental depletion of bay water under conditions of high dispersion and high light and grazing rates.

	30 million (A & B) without compensation	20 million (A & B) without compensation	30 million (A & B) with compensation	20 million (A & B) with compensation
Number of observations	375	375	375	375
Average % depletion	14.03	10.13	2.73	1.85
Standard deviation	0.23	0.16	0.03	0.02
Maximum % seg. depletion	43.66	32.43	10.69	7.35
Day	60.40	60.40	54.56	54.56

In Figs. 48 and 49 the distributions of % segmental depletion values during the periods of maximum depletion are shown (days 54.56 and 60.40).

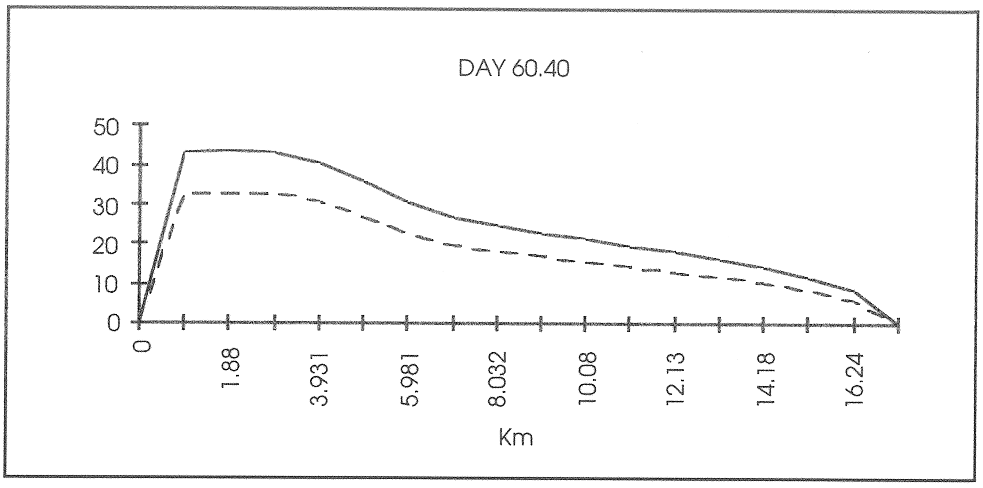


Figure 48. The % segmental depletion of chl *a* C along Pittwater without compensation (high dispersion and high light and grazing rates). Distance is in km from the head of the bay.

——— 30 million oyster annual production at A and B

-------- 20 million oyster annual production at A and B

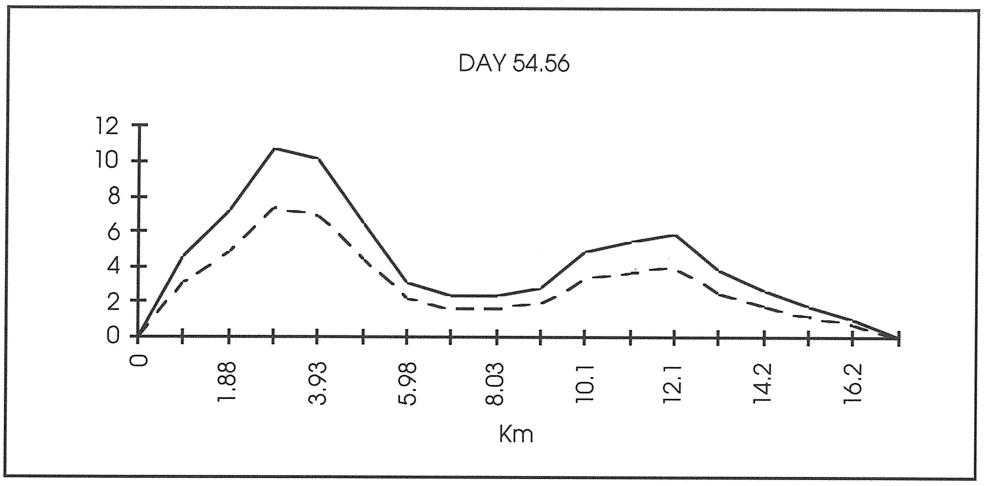


Figure 49. The % segmental depletion of chl *a* C along Pittwater with compensation (high dispersion and high light and grazing rates). Distance is in km from the head of the bay.

——— 30 million oyster annual production at A and B

-------- 20 million oyster annual production at A and B

The distribution is again typical of previous distributions although Figs. 48 and 49 represent extremes in ranges with relatively high summer depletion rates and high primary production tending to counteract depletion. The lower dispersion coefficient in Fig. 49 causes the peaks in depletion to be more acute than in the high dispersion model shown in Fig. 48 as depleted water tends to remain in the lease areas.

In Table 16 there is the most extreme difference between rapid depletion under summer conditions and high primary productivity. When there is no compensation in the 2 x 30 million system the average % depletion in the bay is 19.76 with the maximum % segmental depletion of 47.73 occurring on day 49.44. With compensation, however, the average % depletion is an order of magnitude smaller at 2.83, and a maximum % segmental depletion of 9.58.

Table 16. Depletion values under summer conditions with low dispersion coefficients.

	30 million (A & B) without compensation	20 million (A & B) without compensation	30 million (A & B) with compensation	20 million (A & B) with compensation
Number of observations	375	375	375	375
Average % depletion	19.76	14.75	2.83	1.92
Standard deviation	0.28	0.20	0.02	0.02
Maximum % seg. depletion	47.73	36.69	9.58	6.60
Day	49.44	49.44	61.44	61.44

The % segmental depletion distributions along the bay at maximum % segmental depletion are shown in Figs. 50 and 51. In Fig. 50 where there is no compensation the % segmental depletion is at a maximum over the existing lease areas at 47.73, but there is a rapid decline down the bay. The 2 x 20 million production units reflect a similar type of distribution in % segmental depletion with a lower maximum of 36.69.

The compensated % segmental depletion values (Fig. 51) are lower with distributions showing increased depletion at both existing and proposed oyster growing areas. However maximum % segmental depletions are 9.58 and 6.60 for uncompensated and compensated models at 2 x 30 million production and 2 x 20 million production levels respectively. The lower dispersion coefficient causes the peaks in depletion to be more marked than in the high dispersion models.

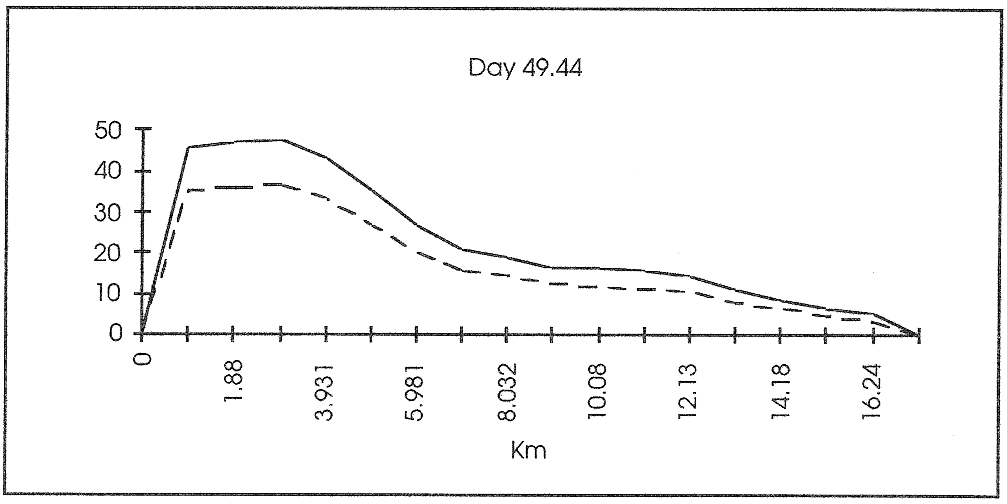


Figure 50. The % segmental depletion of chl *a* C along Pittwater without compensation under summer conditions with low dispersion coefficients. Distance is in km from the head of the bay.

——— 30 million oyster annual production at A and B

------- 20 million oyster annual production at A and B

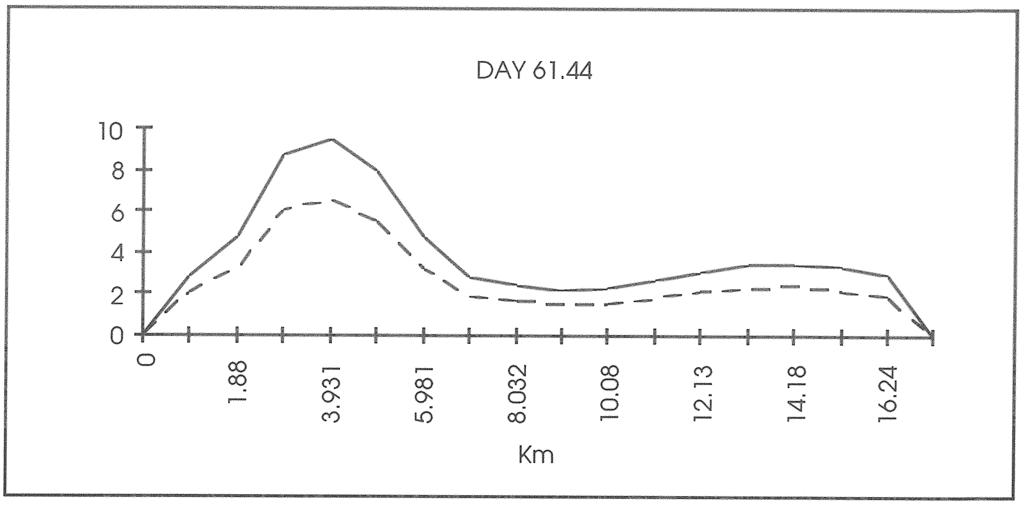


Figure 51. The % segmental depletion of chl *a* C along Pittwater with compensation under summer conditions with low dispersion coefficients. Distance is in km from the head of the bay.

——— 30 million oyster annual production at A and B

-------- 20 million oyster annual production at A and B

The findings of this study as they relate to problems of lease size and siting may be summarized in Table 17.

Table 17. Summary of average % depletion at different seasons and dispersion coefficients. Values given with and without compensation.

Season	Dispersion	Av. % dep. 2x30 million uncomp.	Av. % dep. 2x20 million uncomp.	Av. % dep. 2x30 million comp.	Av. % dep. 2x20 million comp.
Winter	High	7.93	5.53	3.02	2.05
	Low	11.78	8.41	3.41	2.32
Summer	High	14.03	10.13	2.73	1.85
	Low	19.76	14.75	2.83	1.92

The range of values vary between approximately 8-20% in the "worst" situation, that is with high stocking rates of 2x30 million production units with no primary production replacing losses. With compensation, however, there is less variation and values lie between approximately 2 and 3%.

In Table 18 maximum % segmental depletion is shown under the same sets of conditions. These values indicate the worst depletion that may be recorded under the various conditions. These therefore are the acute effects of stocking rates.

Table 18. Summary of maximum % segmental depletion at different seasons and dispersion coefficients. Values given with and without compensation.

Season	Dispersion	Max % seg dep. 2x30 million uncomp.	Max % seg dep. 2x20 million uncomp.	Max % seg dep. 2x30 million comp.	Max % seg dep. 2x20 million comp.
Winter	High	26.22	18.69	9.56	6.57
	Low	38.15	28.10	11.00	7.61
Summer	High	43.66	32.43	10.69	7.35
	Low	47.73	36.69	9.58	6.60

It may be seen from Table 18 that under the best conditions of low stocking, low grazing, and high productivity there will be times when % segmental depletion will be 6-7%. In the worst conditions depletion may peak at 47-48%. All maximum % segmental depletions will also occur in the A area, the existing oyster lease area, or slightly higher in the bay.

7. DISCUSSION OF RESULTS

The research conducted has provided valuable information about the relationship between environmental parameters and oyster production, and estimating and predicting carrying capacities of shellfish growing areas. A predictive model of carrying capacities has been developed; however, further development of the model is continuing.

The original objectives for this project, in hindsight, were optimistic, and in the third year of the project the number of oyster growing areas investigated was reduced from eight to five. Even so, only three of these areas were studied in detail. Practical and logistical problems not anticipated included unreliable CTD data loggers which required substantial maintenance but provided few useful results. The time involved in traveling to all the sites also limited the amount of work that was achieved. Nevertheless, a large data set has been collected on the nutrient and chlorophyll a concentrations of the five areas, and we have already had numerous requests for this information. These data will be published as a technical report.

The hydrodynamic data collected for each growing area are important in determining the rate of replenishment of food for the oysters and hence oyster production. The model that has been developed to calculate the volumes of water in each sector of a growing area at any tidal height assists in the determination of food available to oysters by providing hydrodynamic information, including flushing rates, flow rates etc. The assumption in the one dimensional model that the growing areas are not significantly stratified vertically, *i.e.* that the water column is well mixed, was validated by the temperature and salinity profiles at several areas; however, the assumption that the variation over the cross section of each segment is insignificant is unlikely to be justified in all segments. In some segments there were large sandflats occupying most of the area with a narrow channel up one side of the estuary. Raillard and Menesguen (1994) concluded from their extensive studies of modelling carrying capacities of *Crassostrea gigas* of the Marennes-Oleron Bay in France that the hydrodynamic regime of the bay strongly controlled the carrying capacity of the shellfish system, and the validity of their model was limited mainly by the description of physical transport of food for the oysters.

A comparison of the production of oysters from each growing area clearly shows that Pipeclay Lagoon is currently the most productive of the five areas investigated, producing up to 8.2 million oysters per annum from 48 ha compared with 6.2 million from 118 ha at Pittwater. The leases at Georges Bay have only recently approached full development and have produced 4.4 million from 40.5 ha and the potential for further expansion is currently being assessed. Little Swanport produces 3-4 million oysters per annum from 80 ha and no further development in this area is planned, where as Simpsons Bay is still being developed. The most notably different features of Pipeclay Lagoon compared with the other growing areas are its shallowness and rapid flushing rate of 1.4 tidal cycles. Chlorophyll a levels were generally similar to other areas, although nitrate levels were slightly higher on several occasions, and peaked at the Marine station. This indicates that the rapid exchange rate of water is of major importance in supplying food to the oysters. This food supply is of oceanic origin because Pipeclay Lagoon has no freshwater inflow and the turnover rate is too high for primary production in the lagoon to be a significant contributor of food to the oysters. The flushing rate in Pittwater of 4.4 tidal cycles and lower current flows would have reduced the supply of food to the oysters compared with Pipeclay Lagoon although the chlorophyll a levels were not noticeably different between the two areas. However, the nitrate concentrations were often very low in Pittwater and nutritional value of the oyster food in the two areas is not known. Georges Bay is relatively productive considering the lower flushing rate of 10 tidal cycles and it appears that the input of nutrients from the Georges River and human activities in the area influence the productivity of the area. Very high levels of chlorophyll a were recorded on several occasions indicating sporadic high nutrient inputs into the estuary.

The ECoS model developed so far has proven useful in estimating the carrying capacity of the Pittwater growing area. The results presented of various simulated conditions in Pittwater have predicted that under summer light conditions with limited water exchange, no primary production occurring and high stocking densities the average percentage depletion of food will be about 20%, but on certain days this could rise to 48%. If we use the threshold for maximum ingestion rates adopted by Incze *et al* (1981) and Rodhouse and Roden (1987) for mussels of one half of ambient concentration of total seston, then on some summer days the oysters may not be able to consume sufficient food to maintain their growth rate, *i.e.* they could be exceeding the carrying capacity of the area containing the existing oyster leases. Further research is required to determine maximum ingestion rates of oysters in each growing area and seasonal variations.

The biological data used in the model are limited, and more information is required on primary production in each area. The methodology used to measure primary productivity should be improved by using the APHA Standard Method using radioactive carbon (APHA, 1985). Although some researchers such as Bacher (1989) have not included primary production in their model, assuming that renewal of food from primary production is negligible compared with food transported by tidal movements. Raillard and Menesguen (1994) concluded that phytoplanktonic production is an important food source when stocks are low.

The study on feeding rates of oysters in two areas have provided valuable local information on clearance rates and feeding efficiencies of oysters in these areas. Similar to other studies (Gerdes, 1983; Winter, 1978), they show that clearance rates increase with increasing oyster body size, but the weight specific clearance rate (ml h^{-1} g^{-1} dry tissue weight) generally decreased with increasing body size. The values of clearance rates measured are lower than those recorded for *C. gigas* by other researchers (Kobayashi *et al.*, 1996) but fall within the low gear clearance rate curve described by Powell *et al* (1992) for many bivalve species. These field measurements for *C. gigas* confer with the conclusions reached by Powell *et al* (1992) that for most bivalve species the low gear curve of clearance rate is a better representation of clearance rates in the field than the high gear measurements.

Studies on clearance rates of *C. gigas* by other researchers have shown that clearance rates vary with environmental conditions and further measurements of *C. gigas* clearance rates in each growing area would be required to provide more accurate data. For example, oyster clearance rates have been shown to vary with water temperature (Buxton *et al.*, 1981) and salinity (Loosanoff, 1953). Gerdes (1983) found that *C. gigas* was able to regulate its filtration rate with changing algal concentration and thus the amount of algae removed was more or less constant at three algal concentrations. Kobayashi *et al* (1996) examined in some detail the published information on filtration rates of *C. gigas* and developed mathematical descriptions of filtration rates as a function of temperature, biomass (dry meat weight) and total particulate concentration. Their equations assume that all particles are removed by filtration, oysters feed continuously and that filtration rates do not vary with food availability, based on observations of *C. virginica*. They note that the effects of these factors on filtration rates of *C. gigas* have not been investigated, and thus further studies on filtration rates are required for more accurate estimations of carrying capacities.

Assimilation efficiencies of the oysters measured were fairly low, especially at Pipeclay Lagoon where they were also similar for different sized oysters. These values contrast with those recorded for *C. gigas* by Gerdes (1983) which ranged from 48.3 to 91.1% and were not significantly dependent on body size or algal concentration. Powell *et al* (1992) used an assimilation efficiency of 0.75 in their simulations based on the reported values for oysters, however, they decided that this value may be too high.

The data on nutrient and chlorophyll a concentrations, although useful to assist interpretation of oyster production in some areas, has not been incorporated into the model at this stage. A study of the nutrients in the Derwent River estuary in 1993 (Coughanowr, 1995) found similar to slightly lower chlorophyll a levels in the lower estuary, but nitrate + nitrite levels were generally marginally higher and in the range of 10-15 ug N/l except for periodic large peaks, usually in winter, whilst orthophosphate levels were similar between the estuaries studied. Although DIN:DIP ratios indicated that nitrogen potentially limits algal growth in the Derwent Estuary, a study by Hallegraeff and Westwood (1994) led to the conclusion that light limitation by turbid waters and humic substances was more likely to limit algal growth than nutrient shortage. It is also likely that turbid waters in oyster growing areas resulting from substantial wind driven circulation, such as Pittwater, may have a significant inhibitory effect on algal growth. Secchi disc readings which are currently being collected in three of the growing areas should provide further information on light penetration of growing areas. Brett (1992) found that Orielton Lagoon which has restricted water exchange with Pittwater had much higher chlorophyll a levels, phosphate concentrations were twice as high, but nitrate concentrations were similar to the rest of Pittwater. She concluded that Orielton Lagoon was nitrogen-limited and the sewage treatment plant was the main source of nutrients. The variability observed in nutrient and chlorophyll a concentrations over 24 hours and over 4 weeks indicates that more frequent sampling is required, and preferably continuous recording using *in situ* automatic data loggers.

Oyster growth rate data also have not been included. It is important that this is included in future models because this is a driving factor for estimating carrying capacities. The model currently predicts the number of oysters that can be grown in an area based on the food available and feeding rates of oysters. A separate project which is measuring growth rates of new batches of oysters (initial starting size approximately 45 mm shell length) every six months will provide information on changes in growth rates over time which can be analysed for correlations with environmental factors. These growth rate data can be incorporated into more sophisticated models at a later date. Kobayashi *et al* (1996) describe in detail the growth of *Crassostrea gigas* in Okayama Prefecture, Japan, and review much of the literature available on the growth of this species around the world. It will be informative to compare growth rates of *C. gigas* in southern Tasmania to values recorded elsewhere.

Food availability is estimated from chlorophyll a levels, primary production and water transport in the area. However, chlorophyll a concentrations are not always a good indicator of the food available for oysters, because the oysters may be selectively feeding or the algae present may be of poor nutritional value for oysters. Grant *et al* (1993) discuss similar limitations of modelling food availability for shellfish, in particular for *Mytilus edulis*. Also, oysters may have other sources of food and, for example, may be consuming substantial quantities of detrital matter (Quayle, 1988). A study of the diet of Pacific oysters at Little Swanport by van den Enden (1994) found that chlorophyll a concentrations in the water column were an overestimate of total food available because the oysters selectively fed on benthic diatoms and higher plant detritus, particularly from seagrass (*Zostera* sp.). There is also some evidence that oysters can select nitrogen-rich particles from the filtered material for ingestion (Newell and Jordan, 1983). Kobayashi *et al* (1996) utilise an equation in their numerical model developed by Soniat (1992; in Kobayashi *et al.*, 1996) which converts chlorophyll a into food concentration. However, such equations developed in one part of the world are not necessarily representative of other areas, and this would need to be verified for more accurate predictions.

The model also does not at this stage take into account other environmental parameters which would affect the carrying capacity of an area. In particular, it does not account for the impact of other filter feeders, besides cultured Pacific oysters, on the food available for oyster growth. This could have a substantial impact on carrying capacity in areas such as Georges Bay which has a dense population of endemic native oysters, *Ostrea angasi*. The population of *O. angasi* was estimated in 1991 to be 24 million with shell length > 50 mm (DPIF, unpublished data). The effect to the oyster food supply of zooplankton feeding on phytoplankton and detrital matter also was not considered in the ECoS model, but it is recognised that zooplankton could have a significant effect. The model developed by Raillard and Menesguen (1994) to estimate carrying capacities of shellfish included the effects of zooplankton feeding and was modeled using an Ivlev curve with grazing only occurring above a threshold concentration. Future development of the model should incorporate the effects on the oyster food supply due to grazing by other filter feeders.

8. IMPLICATIONS AND RECOMMENDATIONS

8.1 Benefits

This research project has significantly expanded the information available on water movements and nutrient and chlorophyll a concentrations of five bays and estuaries in Tasmania. There has been a paucity of data available on environmental conditions of Tasmania's coastal areas and these results provide a significant contribution in this area. We have already had numerous requests for these data. The data also have and will be used extensively in the preparation of Marine Farming Development Plans. These plans are being prepared by the Tasmanian state government to provide for informed and orderly development of the aquaculture industry in Tasmania. The production of shellfish from marine farms in Tasmania is predicted to double over the next few years (DPIF Marine Farming Development Plans, 1995), and the information provided from this research is significantly contributing towards this development by facilitating informed decision making on the expansion of the shellfish industry in the growing areas studied.

From the research conducted a model to predict the maximum number of oysters that can be successfully grown in a growing area, which can be utilized by both industry and government managers, has been developed. This will ensure that maximum utilization is made of each area and will enable the industry to expand within sustainable bounds. Maximum usage of each growing area is most important as new sites become more and more difficult to obtain. It will also allow orderly expansion of the industry with greater confidence that stable and predictable oyster production will occur.

The research, however, has shown that although a general model of carrying capacities is feasible, detailed site specific information will be required of each growing area if the model is to reliably predict the carrying capacity of that area. In particular, detailed studies of the hydrodynamics of each growing area and oyster food availability will be required, preferably over all seasons.

8.2 Future Research Needs

Some of the future research needs relating to estimation of carrying capacity of shellfish growing areas have already been outlined in the Discussion of Results. The predictive model is well developed but further refinements are required. In particular the model should incorporate shellfish growth over time as a means of verifying the parameters being modelled. The following study of oyster growth rates is underway at Pittwater and Pipeclay Lagoon and it is recommended that this work continues: Replicate batches of oysters are grown at each site on commercial farms under standard commercial densities and conditions. A new batch of oysters of average length 45 mm are placed in the experimental conditions every six months, and at the start and the end of the six months the length of the shell and wet and dry tissue weights are measured and condition indices calculated. From this information growth trajectories of oysters over six monthly periods can be compared between years, and declines in six monthly growth rates could indicate that the carrying capacity of the area has been exceeded.

This study has indicated that detailed and accurate modelling of the hydrodynamics of growing areas is required to produce reliable estimates of carrying capacity. Future work should examine the benefits of using two dimensional hydrodynamic models such as the new version of ECoS, or the STELLA model which has been used in similar applications overseas, instead of the one dimensional ECoS model used in this study. Alternatively, a box model could be developed for each growing area, similar to the model developed by Raillard and Menesguen (1994).

Further studies on oyster feeding rates would enhance the accuracy of the model. In particular, data on the diurnal and seasonal changes in feeding rates of different sized oysters and on the effects of water flow rates on clearance rates are required. Information on oyster consumption rates in relation to food concentration and food quality would also improve the model.

Relevant environmental parameters should be incorporated into the model including water temperature and light intensity which are driving functions of oyster metabolic activity and phytoplankton production. Soluble nutrients, especially nitrate and phosphates are important in determining phytoplankton production and also should be included in the model. Details are required on the effects of other filter feeders in the system on the availability of food for the oysters. In some areas native oysters occur in high densities and this is likely to impact on the oyster food supply. Similarly zooplankton can have a marked effect on food available to oysters.

Ideally studies on carrying capacities should be conducted over a number of years because the carrying capacity of an area can fluctuate significantly from one year to the next. Climatic conditions, for example, can have a major effect on the nutrient levels and hence phytoplankton concentrations in a growing area. Research conducted over several years would indicate the range in carrying capacities that can be expected, thus enabling better management of the oyster farms in the area.

9. INTELLECTUAL PROPERTY

There is no intellectual property arising from this research project.

10. TECHNICAL SUMMARY

The carrying capacity of an oyster farming area is defined as the maximum density of oysters which can be grown in the area without negatively affecting oyster growth rates. In the late 1980's there was concern amongst the oyster farmers that the carrying capacities of some estuaries and bays were being exceeded, resulting in slower growth and poor condition and hence reduced economic viability. This project aimed to assess oyster production in relation to environmental conditions in five oyster growing areas and to develop a predictive model of the carrying capacities of oyster growing areas. The growing areas studied, some in more detail than others, were Pittwater, Pipeclay Lagoon, Little Swanport, Georges Bay and Simpsons Bay.

The factors considered important in estimating carrying capacities were the hydrodynamics and primary production in each growing area, and the feeding behavior of the oysters. Relevant physical and chemical parameters were also measured at various stations. Data were collected monthly on temperature, salinity, chlorophyll a, nitrate, phosphate and silicate concentrations. A model was developed for each growing area to estimate the flow, velocity and flushing rate at different tidal heights. The direction of water currents in the growing areas also was studied. These data make a substantial contribution to our knowledge of environmental conditions in bays and estuaries in Tasmania, and numerous requests have been received for this information.

The rate of food consumption, measured as clearance rates, and the assimilation efficiency were investigated at two sites, Pittwater and Pipeclay Lagoon over several months. Measurements of primary productivity were also attempted.

A one-dimensional model, the ECoS model, developed for simulating the dispersal of pollutants in estuaries was modified to model the carrying capacities of oysters. Much of the field data collected for Pittwater was incorporated into this model; other areas have not yet been fully modeled because the predictive model is still being developed. Simulations were conducted using different light intensities representative of summer and winter conditions which affect the production of oyster algal food, different dispersion coefficients, *i.e.* the rate of flushing in the estuary and hence the rate of replacement of algal food, and with or without primary productivity acting to compensate for food eaten by the oysters. The percentage depletion of chlorophyll a carbon was modeled at two different oyster densities of 20 million and 30 million oysters at two sites in Pittwater estuary. The first site is where the oyster leases are currently located and the second site is where the majority of proposed leases would be situated. The results generally showed that under the 'worst' conditions with high stocking densities, and no primary production replacing food eaten, the average percentage depletion of oyster food was around 8-20 % and that the maximum percentage depletion was 26-48%. This suggests that in summer time under worst conditions the food available would not be sufficient to maintain the growth rate of 30 million oysters in the two sections of the estuary, and the area most affected would be where the existing oyster leases are located or slightly above.

The results from the ECoS model have shown its applicability in estimating carrying capacities of growing areas; however limitations in the model are recognised and it is continuing to be developed. Further research is required to refine the water movements in each growing area including tidal amplitudes and dispersion due to tidal advection. Primary productivity and feeding behavior should be studied in greater detail at each site.

Oyster growth rates which are currently being measured should also be incorporated into the model and used to verify its predictability. Other factors which affect food availability such as densities of other filter feeders should also be included.

Finally, although models, including the one being developed in this study, are showing significant promise as a management tool, they are limited by our knowledge of ecosystem processes and the data available. This study has emphasised that site specific data are very important, and the data need to be collected over a substantial period of time (years) because environmental parameters which affect carrying capacities can fluctuate substantially from year to year. Similar studies conducted overseas support these findings, in particular widely ranging temporal and spatial scales of system processes make modelling carrying capacities difficult.

11. ACKNOWLEDGMENTS

A number of people have been involved in this project at various stages during its development. Dr. John Wilson initiated the project and organised the early field work and development of the ECoS model. He was ably assisted by Mike Rushton. Ms. Iona Mitchell was employed in the early stages and has been the mainstay of the project, developing and performing much of the field work and laboratory analyses, and providing a common link throughout the project. Valuable technical assistance has been provided by Rick van den Enden, Tony van den Enden and in the final stages of the project, by Andrew Brown. Dr. Christine Crawford was employed on the project in the final year and has been responsible for the final report.

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Appendices

Appendix 1

Temperature, salinity, nutrients and chlorophyll a in oyster growing areas.

1.1 Pittwater
1.2 Pipeclay Lagoon
1.3 Little Swanport
1.4 Georges Bay
1.5 Simpsons Bay
1.6 Pittwater over 24 hours
1.7 Pittwater over 4 weeks

Appendix 2

Intensive sampling around the leases.

2.1 Pittwater
2.2 Pipeclay Lagoon
2.3 Little Swanport
2.4 Georges Bay
2.5 Simpsons Bay

Appendix 3

Report on shellfish carrying capacity workshop

Appendix 4

Project Budget Summary.

Appendix 1

Temperature, salinity, nutrients and chlorophyll a in oyster growing areas.

1.1 Pittwater

Date	Station	Temp °C	Salinity (ppt)	Chla (µg/L)	NOX(µg/l)	NO3(µg/l)	NO2(µg/l)	PO4(µg/l)	Si04(µg/l)
27/8/91	1 Marine	9.80	33.40	-	34.00	31.40	2.60	10.90	-
27/8/91	2 Lewisham	9.15	33.45	-	15.00	12.20	2.80	9.50	-
27/8/91	3 Causeway	9.35	33.80	-	10.00	8.80	1.20	6.00	-
27/8/91	4 Barilla	9.10	33.85	-	28.00	25.10	2.90	8.10	-
27/8/91	5 Shark Pt	8.65	33.75	-	22.00	16.60	5.40	7.00	-
	mean	**9.06**	**33.71**	-	**18.75**	**15.68**	**3.08**	**7.65**	-
24/9/91	1 Marine	10.90	33.40	1.04	15.00	12.80	2.20	7.00	-
24/9/91	2 Lewisham	11.70	33.20	1.19	8.00	5.80	2.20	5.00	-
24/9/91	3 Causeway	10.90	33.25	1.63	6.00	4.90	1.10	5.00	-
24/9/91	4 Barilla	11.75	33.40	1.91	9.00	5.60	3.40	5.00	-
24/9/91	5 Shark Pt	11.10	33.05	2.20	31.00	26.60	4.40	5.00	-
	mean	**11.36**	**33.23**	**1.73**	**13.50**	**10.73**	**2.78**	**5.00**	-
17/10/91	1 Marine	12.10	33.80	3.30	7.00	5.70	1.30	7.00	-
17/10/91	2 Lewisham	12.05	33.80	1.19	9.00	5.90	3.10	7.00	-
17/10/91	3 Causeway	11.95	33.90	2.32	7.00	3.80	3.20	9.00	-
17/10/91	4 Barilla	11.55	34.05						-
17/10/91	5 Shark Pt	12.35	34.00	1.94	7.00	4.70	2.30	10.00	-
	mean	**11.98**	**33.94**	**1.82**	**7.67**	**4.80**	**2.87**	**8.67**	-
28/11/91	1 Marine	15.20	33.90	1.71	6.00	2.00	4.00	7.00	-
28/11/91	2 Lewisham	15.10	34.00	2.15	5.00	2.00	3.00	6.00	-
28/11/91	3 Causeway	15.65	34.65	4.08	5.00	2.00	3.00	5.50	-
28/11/91	4 Barilla	14.75	35.10	2.97	6.00	4.00	2.00	5.50	-
28/11/91	5 Shark Pt	16.25	34.90	4.39	4.00	2.60	1.40	5.50	-
	mean	**15.44**	**34.66**	**3.40**	**5.00**	**2.65**	**2.35**	**5.63**	-
17/12/91	1 Marine	-	-	1.20	12.00	11.00	1.00	14.00	-
17/12/91	2 Lewisham	-	-	1.56	8.00	5.20	2.80	7.00	-
17/12/91	3 Causeway	-	-	2.52	3.00	2.80	0.20	9.00	-
17/12/91	4 Barilla	-	-	1.64	5.00	4.00	1.00	7.60	-
17/12/91	5 Shark Pt	-	-	3.02	10.00	9.40	0.60	9.00	-
	mean	-	-	**2.18**	**6.50**	**5.35**	**1.15**	**8.15**	-
13/1/92	1 Marine	16.80	33.95	1.33	4.00	1.70	2.30	5.00	-
13/1/92	2 Lewisham	16.55	34.10	2.22	2.00	1.50	0.50	5.00	-
13/1/92	3 Causeway	17.70	34.75	1.76	12.00	7.80	4.20	7.00	-
13/1/92	4 Barilla	16.35	35.30	1.39	3.00	1.60	1.40	6.00	-
13/1/92	5 Shark Pt	17.20	34.80	2.97	2.00	1.50	0.50	8.00	-
	mean	**16.95**	**34.74**	**2.09**	**4.75**	**3.10**	**1.65**	**6.50**	-
26/2/92	.	16.65	34.30	5.56	10.00	8.90	1.10	7.80	-
26/2/92	2 Lewisham	15.50	35.05	5.19	8.00	3.80	4.20	6.00	-
26/2/92	3 Causeway	15.85	35.85	7.71	9.00	6.00	3.00	9.00	-
26/2/92	4 Barilla	14.95	37.10	7.93	3.00	2.80	0.20	9.30	-
26/2/92	5 Shark Pt	15.30	36.50	7.86	42.00	40.80	1.20	15.50	-
	mean	**15.40**	**36.13**	**7.18**	**15.50**	**13.35**	**2.15**	**9.95**	-
25/3/92	1 Marine	15.75	34.85	2.67	29.00	25.00	4.00	12.00	-
25/3/92	2 Lewisham	15.35	36.00	2.22	9.00	5.50	3.50	9.00	-
25/3/92	3 Causeway	15.40	36.65	3.97	7.00	5.60	1.40	9.00	-
25/3/92	4 Barilla	15.60	37.50	2.58	10.00	5.30	4.70	9.00	-
25/3/92	5 Shark Pt	15.20	36.90	4.36	14.00	10.90	3.10	13.00	-
	mean	**15.39**	**36.76**	**3.28**	**10.00**	**6.83**	**3.18**	**10.00**	-

1.1 Pittwater

Date	Station	Temp °C	Salinity (ppt)	Chla (µg/L)	NOX(µg/l)	NO3(µg/l)	NO2(µg/l)	PO4(µg/l)	Si04(µg/l)
28/4/92	1 Marine	13.70	34.70	2.60	5.00	4.20	0.80	8.60	-
28/4/92	2 Lewisham	12.80	34.90	2.15	4.00	3.20	0.80	7.50	-
28/4/92	3 Causeway	12.85	35.60	3.80	3.00	2.40	0.60	8.30	-
28/4/92	4 Barilla	12.40	35.65	2.45	6.00	4.40	1.60	7.00	-
28/4/92	5 Shark Pt	12.40	35.75	4.25	3.00	2.70	0.30	9.50	-
	mean	**12.61**	**35.48**	**3.16**	**4.00**	**3.18**	**0.83**	**8.08**	-
26/5/92	1 Marine	11.40	34.15	1.33	7.00	5.10	1.90	23.10	-
26/5/92	2 Lewisham	11.20	34.20	1.11	3.00	1.60	1.40	8.00	-
26/5/92	3 Causeway	10.10	35.05	1.41	5.00	3.90	1.10	7.30	-
26/5/92	4 Barilla	9.40	35.25	1.48	8.00	6.40	1.60	5.00	-
26/5/92	5 Shark Pt	9.85	35.15	1.91	18.00	16.30	1.70	10.60	-
	mean	**10.14**	**34.91**	**1.48**	**8.50**	**7.05**	**1.45**	**7.73**	-
1/7/92	1 Marine	9.15	33.70	2.89	10.00	8.90	1.10	12.50	-
1/7/92	2 Lewisham	9.20	33.70	3.34	5.00	3.80	1.20	8.40	-
1/7/92	3 Causeway	8.35	34.50	3.86	3.00	2.50	0.50	7.50	-
1/7/92	4 Barilla	7.75	34.50	3.19	5.00	3.80	1.20	6.70	-
1/7/92	5 Shark Pt	7.85	34.80	2.89	4.00	2.30	1.70	7.70	-
	mean	**8.29**	**34.38**	**3.32**	**4.25**	**3.10**	**1.15**	**7.58**	-
4/8/92	1 Marine	8.05	33.60	2.67	5.00	3.60	1.40	27.00	-
4/8/92	2 Lewisham	7.30	33.60	1.93	3.00	1.70	1.30	9.00	-
4/8/92	3 Causeway	6.80	33.45	1.26	3.00	2.10	0.90	14.00	-
4/8/92	4 Barilla	6.50	33.40	2.37	10.00	9.00	1.00	8.00	-
4/8/92	5 Shark Pt	6.80	33.40	1.93	6.00	4.20	1.80	11.00	-
	mean	**6.85**	**33.46**	**1.87**	**5.50**	**4.25**	**1.25**	**10.50**	-
26/8/92	1 Marine	8.75	33.22	1.41	3.00	2.80	0.20	9.00	-
26/8/92	2 Lewisham	8.65	33.52	0.37	8.00	7.70	0.30	9.00	-
26/8/92	3 Causeway	8.48	33.17	0.67	3.00	2.70	0.30	9.00	-
26/8/92	4 Barilla	8.45	33.38	0.83	1.00	0.80	0.20	7.00	-
26/8/92	5 Shark Pt	8.38	33.20	0.74	4.00	3.70	0.30	9.00	-
	mean	**8.49**	**33.32**	**0.65**	**4.00**	**3.73**	**0.28**	**8.50**	-
22/9/92	1 Marine	10.50	33.40	1.32	3.80	2.90	0.90	6.00	-
22/9/92	2 Lewisham	10.80	33.10	1.48	2.80	2.40	0.40	7.00	-
22/9/92	3 Causeway	10.70	31.70	1.24	2.10	1.30	0.80	5.00	-
22/9/92	4 Barilla	10.80	31.20	1.40	5.20	3.90	1.30	5.00	-
22/9/92	5 Shark Pt	10.60	31.50	1.15	10.00	9.40	0.60	7.00	-
	mean	**10.73**	**31.88**	**1.32**	**5.03**	**4.25**	**0.78**	**6.00**	-
4/11/92	1 Marine	14.35	33.75	2.26	5.00	4.90	0.10	8.00	-
4/11/92	2 Lewisham	14.75	33.50	2.50	1.00	1.00	0.00	7.00	-
4/11/92	3 Causeway	15.75	32.25	1.72	1.00	0.60	0.40	8.00	-
4/11/92	4 Barilla	15.85	32.20	1.71	4.00	3.60	0.40	7.00	-
4/11/92	5 Shark Pt	16.10	32.25	2.82	1.00	1.00	0.00	9.00	-
	mean	**15.61**	**32.55**	**2.18**	**1.75**	**1.55**	**0.20**	**7.75**	-
3/12/92	1 Marine	14.80	34.95	1.07	3.00	3.00	0.00	8.00	-
3/12/92	2 Lewisham	15.60	34.75	1.81	3.00	2.60	0.40	8.00	-
3/12/92	3 Causeway	16.00	34.45	1.90	2.00	1.90	0.10	9.00	-
3/12/92	4 Barilla	15.45	34.15	1.73	1.00	0.90	0.10	10.00	-
3/12/92	5 Shark Pt	16.05	34.30	1.98	1.00	0.90	0.10	8.00	-
	mean	**15.78**	**34.41**	**1.85**	**1.75**	**1.58**	**0.18**	**8.75**	-

1.1 Pittwater

Date	Station	Temp °C	Salinity (ppt)	Chla (µg/L)	NOX(µg/l)	NO3(µg/l)	NO2(µg/l)	PO4(µg/l)	Si04(µg/l)
17/12/92	1 Marine	16.70	35.00	1.04	3.00	2.50	0.50	10.00	-
17/12/92	2 Lewisham	17.40	34.95	1.33	4.00	3.30	0.70	9.00	-
17/12/92	3 Causeway	18.65	35.25	2.37	6.00	4.80	1.20	10.00	-
17/12/92	4 Barilla	18.15	35.75	2.00	3.00	1.80	1.20	13.00	-
17/12/92	5 Shark Pt	18.85	35.20	2.65	3.00	2.00	1.00	12.00	-
	mean	**18.26**	**35.29**	**2.09**	**4.00**	**2.98**	**1.03**	**11.00**	-
19/1/93	1 Marine	18.65	34.30	0.82	5.00	4.70	0.30	12.00	-
19/1/93	2 Lewisham	18.75	34.75	1.85	2.00	1.70	0.30	7.00	-
19/1/93	3 Causeway	19.00	35.55	3.04	2.00	1.80	0.20	10.00	-
19/1/93	4 Barilla	19.05	36.35	2.22	0.80	0.60	0.20	8.00	-
19/1/93	5 Shark Pt	19.40	36.05	3.14	1.00	0.70	0.30	11.00	-
	mean	**19.05**	**35.68**	**2.56**	**1.45**	**1.20**	**0.25**	**9.00**	-
17/2/93	1 Marine	19.25	34.75	1.78	3.00	2.88	0.12	9.80	-
17/2/93	2 Lewisham	19.15	35.55	2.60	2.00	1.75	0.25	9.60	-
17/2/93	3 Causeway	19.80	36.30	4.08	1.00	0.82	0.18	9.10	-
17/2/93	4 Barilla	22.35	36.70	3.34	2.00	1.50	0.50	7.50	-
17/2/93	5 Shark Pt	20.85	36.50	3.52	5.00	4.98	0.02	10.30	-
	mean	**20.54**	**36.26**	**3.38**	**2.50**	**2.26**	**0.24**	**9.13**	-
16/3/93	1 Marine	17.50	34.50	1.26	2.00	1.70	0.30	10.00	-
16/3/93	2 Lewisham	17.75	34.70	1.11	5.00	4.60	0.40	11.00	-
16/3/93	3 Causeway	18.40	35.55	3.18	2.00	1.70	0.30	12.00	-
16/3/93	4 Barilla	18.05	36.45	0.96	2.00	1.50	0.50	9.00	-
16/3/93	5 Shark Pt	18.25	35.85	3.41	3.00	2.40	0.60	16.00	-
	mean	**18.11**	**35.64**	**2.17**	**3.00**	**2.55**	**0.45**	**12.00**	-
14/4/93	1 Marine	14.90	34.60	1.26	4.00	3.80	0.20	12.00	-
14/4/93	2 Lewisham	14.70	34.80	1.19	2.00	1.80	0.20	11.00	-
14/4/93	3 Causeway	14.85	35.55	2.89	3.00	2.80	0.20	12.00	-
14/4/93	4 Barilla	14.10	36.20	2.00	2.00	1.80	0.20	16.00	-
14/4/93	5 Shark Pt	14.45	35.70	1.41	3.00	2.80	0.20	13.00	-
	mean	**14.53**	**35.56**	**1.87**	**2.50**	**2.30**	**0.20**	**13.00**	-
18/5/93	1 Marine	11.80	34.60	0.96	5.00	4.60	0.40	11.00	-
18/5/93	2 Lewisham	10.35	34.80	0.96	2.00	1.70	0.30	10.00	-
18/5/93	3 Causeway	9.70	35.10	1.33	4.00	3.70	0.30	10.00	-
18/5/93	4 Barilla	8.75	35.80	0.74	8.00	7.70	0.30	12.00	-
18/5/93	5 Shark Pt	9.15	35.45	1.19	2.00	1.80	0.20	9.00	-
	mean	**9.49**	**35.29**	**1.06**	**4.00**	**3.73**	**0.28**	**10.25**	-
16/6/93	1 Marine	8.95	34.25	3.19	7.00	6.10	0.90	14.00	-
16/6/93	2 Lewisham	7.95	34.40	2.30	6.00	5.40	0.60	12.00	-
16/6/93	3 Causeway	6.90	34.80	1.56	1.00	0.80	0.20	8.50	-
16/6/93	4 Barilla	6.55	35.10	0.89	1.00	0.80	0.20	8.50	-
16/6/93	5 Shark Pt	6.85	34.95	2.15	3.00	2.70	0.30	10.00	-
	mean	**7.06**	**34.81**	**1.72**	**2.75**	**2.43**	**0.33**	**9.75**	-
16/7/93	1 Marine	8.80	33.80	2.67	1.00	0.80	0.20	5.00	-
16/7/93	2 Lewisham	8.85	33.80	2.22	1.00	0.80	0.20	7.00	-
16/7/93	3 Causeway	8.60	33.90	2.15	1.00	0.70	0.30	6.00	-
16/7/93	4 Barilla	8.80	33.75	-	-	-	-	-	-
16/7/93	5 Shark Pt	8.40	33.80	2.60	1.00	0.80	0.20	6.00	-
	mean	**8.66**	**33.81**	**2.32**	**1.00**	**0.77**	**0.23**	**6.33**	-

1.1 Pittwater

Date	Station	Temp °C	Salinity (ppt)	Chla (µg/L)	NOX(µg/l)	NO3(µg/l)	NO2(µg/l)	PO4(µg/l)	Si04(µg/l)
12/8/93	1 Marine	9.35	33.85	2.13	4.00	3.30	0.70	7.00	-
12/8/93	2 Lewisham	9.55	33.80	1.21	3.00	2.30	0.70	7.00	-
12/8/93	3 Causeway	9.65	33.85	1.67	2.00	1.50	0.50	6.00	-
12/8/93	4 Barilla	9.70	34.05	1.85	4.00	3.50	0.50	7.00	-
12/8/93	5 Shark Pt	9.60	33.90	2.04	3.00	2.60	0.40	6.00	-
	mean	**9.63**	**33.90**	**1.69**	**3.00**	**2.48**	**0.53**	**6.50**	**-**
27/9/93	1 Marine	12.25	33.65	0.79	4.50	4.10	0.40	9.00	-
27/9/93	2 Lewisham	12.85	33.70	0.79	1.00	0.70	0.30	6.40	-
27/9/93	3 Woody	13.95	34.00	0.79	0.50	0.50	0.80	6.80	-
27/9/93	4 Causeway	13.75	33.95	1.19	1.10	0.80	0.30	7.00	-
27/9/93	5 Barilla	14.60	34.50	0.89	2.50	2.10	0.40	7.30	-
27/9/93	6 Shark Pt	13.80	34.00	1.19	1.00	0.80	0.20	6.00	-
	mean	**13.79**	**34.03**	**0.97**	**1.22**	**0.98**	**0.40**	**6.70**	**-**
25/10/93	1 Marine	13.50	34.05	0.82	0.40	0.40	0.00	7.00	-
25/10/93	2 Lewisham	13.80	34.05	1.24	1.30	1.30	0.00	7.00	-
25/10/93	3 Woody	14.25	34.20	1.32	0.80	0.80	0.00	7.70	-
25/10/93	4 Causeway	14.10	34.55	2.55	0.40	0.40	0.00	7.30	-
25/10/93	5 Barilla	15.15	34.95	1.40	0.60	0.60	0.00	7.50	-
25/10/93	6 Shark Pt	14.45	34.60	2.22	0.10	0.10	0.00	7.70	-
	mean	**14.35**	**34.47**	**1.75**	**0.64**	**0.64**	**0.00**	**7.44**	**-**
24/11/93	1 Marine	14.85	34.05	1.11	0.50	0.30	0.20	8.80	46.00
24/11/93	2 Lewisham	14.65	34.10	1.85	0.80	0.60	0.20	8.50	58.00
24/11/93	3 Woody	15.00	34.55	4.91	0.30	0.10	0.20	6.90	172.00
24/11/93	4 Causeway	14.90	34.55	4.36	0.30	0.10	0.20	6.90	156.00
24/11/93	5 Barilla	14.35	34.95	3.06	0.30	0.00	0.30	6.20	198.00
24/11/93	6 Shark Pt	15.15	34.55	4.73	0.50	0.30	0.20	8.10	220.00
	mean	**14.81**	**34.54**	**3.78**	**0.44**	**0.22**	**0.22**	**7.32**	**160.80**
22/12/93	1 Marine	16.60	34.45	0.83	0.60	0.60	0.00	7.70	18.50
22/12/93	2 Lewisham	17.50	34.65	1.76	0.80	0.80	0.00	8.70	30.70
22/12/93	3 Woody	18.60	35.90	4.03	1.40	1.40	0.00	11.60	176.00
22/12/93	4 Causeway	18.80	35.90	4.34	0.80	0.80	0.00	11.60	188.00
22/12/93	5 Barilla	17.60	36.10	3.43	0.90	0.90	0.00	9.60	172.00
22/12/93	6 Shark Pt	18.90	36.15	3.89	0.90	0.90	0.00	12.00	202.00
	mean	**18.28**	**35.74**	**3.49**	**0.96**	**0.96**	**0.00**	**10.70**	**153.74**
20/1/94	1 Marine	16.20	33.40	3.13	0.50	0.50	0.00	6.50	11.60
20/1/94	2 Lewisham	16.40	32.40	2.97	0.20	0.20	0.00	5.80	12.60
20/1/94	3 Woody	18.50	29.80	4.01	0.70	0.70	0.00	8.10	18.90
20/1/94	4 Causeway	17.60	30.50	3.63	0.30	0.30	0.00	6.20	17.90
20/1/94	5 Barilla	17.50	31.90	4.00	0.50	0.50	0.00	10.40	43.80
20/1/94	6 Shark Pt			4.91	0.20	0.20	0.00	8.50	24.10
	mean	**17.50**	**31.15**	**3.90**	**0.38**	**0.38**	**0.00**	**7.80**	**23.46**
22/2/94	1 Marine	17.30	34.25	1.60	1.30	1.30	0.00	8.80	29.00
22/2/94	2 Lewisham	17.55	34.60	2.48	0.80	0.80	0.00	8.60	33.00
22/2/94	3 Woody	18.40	34.95	5.92	1.20	1.20	0.00	12.50	181.00
22/2/94	4 Causeway	18.50	34.85	5.15	0.50	0.50	0.00	11.10	196.00
22/2/94	5 Barilla	19.45	35.45	3.69	0.80	0.80	0.00	10.00	202.00
22/2/94	6 Shark Pt	18.90	34.80	6.59	0.80	0.80	0.00	11.40	208.00
	mean	**18.56**	**34.93**	**4.77**	**0.82**	**0.82**	**0.00**	**10.72**	**164.00**

1.1 Pittwater

Date	Station	Temp °C	Salinity (ppt)	Chla (µg/L)	NOX(µg/l)	NO3(µg/l)	NO2(µg/l)	PO4(µg/l)	Si04(µg/l)
5/5/94	1 Marine	12.05	34.65	3.02	2.30	2.30	0.00	12.30	119.00
5/5/94	2 Lewisham	10.75	34.80	3.11	2.40	2.40	0.00	11.20	124.00
5/5/94	3 Woody	10.50	35.30	0.00	3.10	3.10	0.00	13.10	179.00
5/5/94	4 Causeway	10.35	35.30	5.86	1.90	1.90	0.00	11.50	189.00
5/5/94	5 Barilla	9.10	35.65	6.55	0.80	0.80	0.00	11.90	139.00
5/5/94	6 Shark Pt			6.09	2.60	2.60	0.00	-	166.00
	mean	**10.18**	**35.26**	**4.32**	**2.16**	**2.16**	**0.00**	**11.93**	**159.40**
21/6/94	1 Marine	9.30	33.70	6.48	5.80	2.30	1.00	14.00	183.00
21/6/94	2 Lewisham	8.90	33.75	5.68	3.80	2.40	0.80	13.00	200.00
21/6/94	3 Woody	7.85	34.10	7.19	1.40	3.10	0.20	9.00	188.00
21/6/94	4 Causeway	7.70	34.10	5.95	1.00	1.90	0.10	10.00	173.00
21/6/94	5 Barilla	6.70	34.45	3.64	1.00	0.80	0.20	9.00	142.00
21/6/94	6 Shark Pt	7.45	34.20	6.12	0.50	2.60	0.10	9.00	174.00
	mean	**7.72**	**34.12**	**5.72**	**1.54**	**2.16**	**0.28**	**10.00**	**175.40**
4/8/94	1 Marine	-	-	7.11	2.00	2.00	0.00	10.00	108.00
4/8/94	2 Lewisham	-	-	5.35	4.00	3.80	0.20	9.00	154.00
4/8/94	3 Woody	-	-	4.79	1.70	1.70	0.00	7.00	139.00
4/8/94	4 Causeway	-	-	5.19	1.00	1.00	0.00	8.00	122.00
4/8/94	5 Barilla	-	-	4.15	1.50	1.50	0.00	7.00	94.00
4/8/94	6 Shark Pt	-	-	4.95	1.50	1.50	0.00	9.00	138.00
	mean	-	-	**4.89**	**1.94**	**1.90**	**0.04**	**8.00**	**129.40**
2/9/94	1 Marine	9.30	33.20	4.97	1.20	1.20	0.00	9.60	66.00
2/9/94	2 Lewisham	9.60	33.30	3.28	1.40	1.40	0.00	9.20	81.00
2/9/94	3 Woody	9.75	33.30	3.19	2.50	2.50	0.00	8.50	109.00
2/9/94	4 Causeway	9.65	33.35	3.02	1.00	1.00	0.00	8.10	105.00
2/9/94	5 Barilla	9.35	33.50	2.75	1.40	1.40	0.00	7.70	92.00
2/9/94	6 Shark Pt	9.65	33.25	3.11	1.10	1.10	0.00	9.20	126.00
	mean	**9.60**	**33.34**	**3.07**	**1.48**	**1.48**	**0.00**	**8.54**	**102.60**
4/10/94	1 Marine	10.60	32.30	2.00	0.40	0.30	0.10	6.30	88.00
4/10/94	2 Lewisham	11.25	32.40	2.32	1.10	1.00	0.10	6.90	100.00
4/10/94	3 Woody	11.20	33.10	3.43	0.80	0.70	0.10	7.70	102.00
4/10/94	4 Causeway	11.10	33.10	3.11	1.30	1.20	0.10	7.30	98.00
4/10/94	5 Barilla	12.00	33.30	2.56	0.80	0.70	0.10	6.20	95.00
4/10/94	6 Shark Pt	11.70	33.10	2.80	0.70	0.40	0.30	7.70	110.00
	mean	**11.45**	**33.00**	**2.84**	**0.94**	**0.80**	**0.14**	**7.16**	**101.00**
29/11/94	1 Marine	-	-	4.35	0.90	-	-	6.90	57.00
29/11/94	2 Lewisham	-	-	4.69	0.00	-	-	7.70	47.00
29/11/94	3 Woody	-	-	6.61	1.20	-	-	10.40	180.00
29/11/94	4 Causeway	-	-	5.77	1.00	-	-	10.00	177.00
29/11/94	5 Barilla	-	-	1.59	1.10	-	-	9.20	268.00
29/11/94	6 Shark Pt	-	-	4.35	0.10	-	-	10.80	207.00
	mean	-	-	**4.60**	**0.68**	-	-	**9.62**	**175.80**

1.1 Pittwater

MEAN VALUE FOR EACH STATION

Date	Station	Temp °C	Salinity (ppt)	Chla (µg/L)	NOX(µg/L)	NO3(µg/L)	NO2(µg/L)	PO4(µg/L)	SiO4(µg/L)
1991	Marine	12.00	33.63	1.81	14.80	12.58	2.22	9.18	-
	Lewisham	12.00	33.61	1.52	9.00	6.22	2.78	6.90	-
	Causeway	11.96	33.90	2.64	6.20	4.46	1.74	6.90	-
	Barilla	11.79	34.10	2.17	12.00	9.68	2.33	6.55	-
	Shark Pt	12.09	33.93	2.89	14.80	11.98	2.82	7.30	-
	mean	**11.96**	**33.88**	**2.30**	**10.50**	**8.09**	**2.42**	**6.91**	-
1992	Marine	13.05	34.13	2.18	7.32	6.13	1.19	11.42	-
	Lewisham	12.93	34.28	2.33	4.80	3.46	1.34	8.45	-
	Causeway	13.05	34.39	2.64	4.68	3.47	1.21	8.59	-
	Barilla	12.64	34.62	2.42	4.93	3.69	1.24	7.75	-
	Shark Pt	12.88	34.48	2.96	9.00	7.98	1.03	10.03	-
	mean	**12.87**	**34.44**	**2.59**	**5.85**	**4.65**	**1.20**	**8.71**	-
									*SiO4
1993	Marine	13.87	34.24	1.47	3.08	2.77	0.31	9.44	32.25
	Lewisham	13.82	34.43	1.59	2.24	1.95	0.29	8.77	44.35
	Woody Is	15.45	34.66	2.76	0.75	0.50	0.25	8.25	174.00
	Causeway	14.04	34.96	2.70	1.55	1.33	0.22	8.87	172.00
	Barilla	14.09	35.41	1.89	2.19	1.91	0.28	8.96	185.00
	Shark Pt	14.10	35.13	2.62	1.96	1.74	0.22	9.59	211.00
	mean	**14.30**	**34.92**	**2.31**	**1.74**	**1.49**	**0.25**	**8.89**	**157.27**
1994	Marine	12.46	33.58	4.08	1.80	1.41	0.16	9.30	82.70
	Lewisham	12.41	33.54	3.73	1.71	1.71	0.16	8.93	93.95
	Woody Is	12.70	33.43	4.39	1.58	1.86	0.04	9.54	137.11
	Causeway	12.48	33.53	4.71	1.00	1.11	0.03	9.03	134.74
	Barilla	12.35	34.04	3.62	0.99	0.93	0.04	8.93	134.48
	Shark Pt	11.93	33.84	4.87	0.94	1.31	0.06	9.37	144.14
	mean	**12.37**	**33.68**	**4.26**	**1.24**	**1.39**	**0.07**	**9.16**	**128.88**

Note: Number of samples analysed varied between years.
Means are for Pittwater and do not include the Marine Station.
Sampling at Woody Island commenced in November 1993.
*SiO4 - Analysis for silicates commenced in November 1993.

1.2 Pipeclay Lagoon

Date	Station	Temp °C	Salinity (ppt)	Chla (µg/L)	NOX(µg/l)	NO3(µg/l)	NO2(µg/l)	PO4(µg/l)
23/9/91	1 Marine	9.20	33.90	2.00	20.00	18.00	2.00	9.00
23/9/91	2 Boat ramp	8.70	33.65	1.71	6.00	4.00	2.00	8.00
23/9/91	3 Bens gut	8.70	33.55	0.96	10.00	7.00	3.00	7.00
23/9/91	4 Nemo	8.60	33.25	1.63	8.00	5.60	2.40	5.50
	mean	**8.67**	**33.48**	**1.43**	**8.00**	**5.53**	**2.47**	**6.83**
17/10/91	1 Marine	0.00	0.00	3.34	14.00	9.30	4.70	7.00
17/10/91	2 Boat ramp	0.00	0.00	2.15	6.00	3.10	2.90	6.00
17/10/91	3 Bens gut	0.00	0.00	1.56	9.00	5.00	4.00	7.00
17/10/91	4 Nemo	0.00	0.00	1.95	13.00	9.00	4.00	11.00
	mean	**0.00**	**0.00**	**1.89**	**9.33**	**5.70**	**3.63**	**8.00**
19/11/91	1 Marine	13.85	33.20	0.96	9.00	6.00	3.00	6.00
19/11/91	2 Boat ramp	13.55	32.90	0.74	6.00	4.00	2.00	9.00
19/11/91	3 Bens gut	14.45	34.30	0.80	7.00	4.00	3.00	8.00
19/11/91	4 Nemo	14.50	34.15		4.00	3.30	0.70	9.00
	mean	**14.17**	**33.78**	**0.77**	**5.67**	**3.77**	**1.90**	**8.67**
18/12/91	1 Marine	17.00	33.60	0.59	6.00	1.80	4.20	7.00
18/12/91	2 Boat ramp	18.40	33.25	1.33	6.00	2.30	3.70	9.00
18/12/91	3 Bens gut	19.15	33.20	1.71	14.00	8.60	5.40	18.00
18/12/91	4 Nemo	18.40	33.10	4.22	3.00	1.90	1.10	5.00
	mean	**18.65**	**33.18**	**2.42**	**7.67**	**4.27**	**3.40**	**10.67**
15/1/92	1 Marine	15.90	33.95	1.93	2.00	1.40	0.60	6.40
15/1/92	2 Boat ramp	16.90	34.45	0.96	2.00	1.30	0.70	5.50
15/1/92	3 Bens gut	17.95	34.55	0.70	16.00	13.00	3.00	5.50
15/1/92	4 Nemo	16.35	34.40	2.62	4.00	2.00	2.00	4.00
	mean	**17.07**	**34.47**	**1.43**	**7.33**	**5.43**	**1.90**	**5.00**
27/2/92	1 Marine	16.30	34.30	1.63	8.00	4.00	4.00	7.00
27/2/92	2 Boatramp	16.20	34.90	3.11	4.00	2.80	1.20	8.00
27/2/92	3 Bens gut	17.45	34.90	5.39	4.00	2.60	1.40	8.00
27/2/92	4 Nemo	15.65	34.95	4.97	3.00	1.60	1.40	7.00
	mean	**16.43**	**34.92**	**4.49**	**3.67**	**2.33**	**1.33**	**7.67**
26/3/92	1 Marine	16.05	34.50	3.34	5.00	3.00	2.00	7.00
26/3/92	2 Boat ramp	16.30	34.95	3.30	4.00	2.70	1.30	9.00
26/3/92	3 Bens gut	16.25	34.75	3.92	11.00	9.00	2.00	8.00
26/3/92	4 Nemo	17.55	35.30	5.24	10.00	7.00	3.00	7.00
	mean	**16.70**	**35.00**	**4.15**	**8.33**	**6.23**	**2.10**	**8.00**
27/4/92	1 Marine	13.90	34.40	3.26	7.00	4.50	2.50	5.00
27/4/92	2 Boat ramp	11.70	34.55	1.66	6.00	4.20	1.80	9.00
27/4/92	3 Bens gut	11.65	34.60	2.81	7.00	4.70	2.30	10.00
27/4/92	4 Nemo	12.35	34.75	3.78	7.00	5.70	1.30	7.00
	mean	**11.90**	**34.63**	**2.75**	**6.67**	**4.87**	**1.80**	**8.67**
27/5/92	1 Marine	11.85	34.30	4.15	7.00	5.00	2.00	9.00
27/5/92	2 Boat ramp	9.50	34.40	1.48	10.00	5.50	4.50	8.00
27/5/92	3 Bens gut	8.85	34.35	1.11	7.00	4.00	3.00	7.00
27/5/92	4 Nemo	9.10	34.35	2.37	6.00	4.00	2.00	7.00
	mean	**9.15**	**34.37**	**1.66**	**7.67**	**4.50**	**3.17**	**7.33**

1.2 Pipeclay Lagoon

Date	Station	Temp °C	Salinity (ppt)	Chla (µg/L)	NOX(µg/l)	NO3(µg/l)	NO2(µg/l)	PO4(µg/l)
30/6/92	1 Marine	10.15	33.90	2.44	22.00	18.70	3.30	10.00
30/6/92	2 Boat ramp	9.40	33.90	1.41	14.00	11.50	2.50	11.30
30/6/92	3 Bens gut	8.80	33.90	2.97	17.00	14.00	3.00	11.70
30/6/92	4 Nemo	8.65	33.80	2.30	18.00	13.90	4.10	11.50
	mean	**8.95**	**33.87**	**2.22**	**16.33**	**13.13**	**3.20**	**11.50**
5/8/92	1 Marine	8.65	33.15	2.97	19.00	17.80	1.20	10.00
5/8/92	2 Boat ramp	7.70	33.25	2.60	18.00	16.50	1.50	9.00
5/8/92	3 Bens gut	7.40	33.30	1.32	14.00	12.70	1.30	10.00
5/8/92	4 Nemo	6.85	33.40	1.04	7.00	5.90	1.10	9.00
	mean	**7.32**	**33.32**	**1.65**	**13.00**	**11.70**	**1.30**	**9.33**
27/8/92	1 Marine	9.45	32.96	2.30	7.00	6.20	0.80	10.00
27/8/92	2 Boat ramp	9.55	33.18	1.11	11.00	10.20	0.80	11.00
27/8/92	3 Bens gut	9.65	33.11	0.82	10.00	9.20	0.80	11.00
27/8/92	4 Nemo	9.15	33.12	2.00	5.00	4.60	0.40	10.00
	mean	**9.45**	**33.14**	**1.31**	**8.67**	**8.00**	**0.67**	**10.67**
23/9/92	1 Marine	10.50	33.50	2.53	4.00	3.00	1.00	7.00
23/9/92	2 Boat ramp	10.70	33.40	2.97	3.00	2.00	1.00	8.00
23/9/92	3 Bens gut	10.80	33.90	6.98	3.00	2.00	1.00	9.00
23/9/92	4 Nemo	10.50	33.80	2.36	4.00	2.80	1.20	11.00
	mean	**10.67**	**33.70**	**4.10**	**3.33**	**2.27**	**1.07**	**9.33**
27/10/92	1 Marine	12.70	33.90	1.98	0.70	0.60	0.10	6.00
27/10/92	2 Boat ramp	12.80	33.80	2.06	0.90	0.80	0.10	6.00
27/10/92	3 Bens gut	12.80	33.80	2.89	0.50	0.40	0.10	7.00
27/10/92	4 Nemo	13.00	33.90	2.31	0.90	0.80	0.10	6.00
	mean	**12.87**	**33.83**	**2.42**	**0.77**	**0.67**	**0.10**	**6.33**
5/11/92	1 Marine	14.65	34.00	1.93	13.00	11.80	1.20	6.00
5/11/92	2 Boat ramp	15.45	34.10	1.04	1.00	0.90	0.10	9.00
5/11/92	3 Bens gut	16.70	34.15	0.82	4.00	3.80	0.20	11.00
5/11/92	4 Nemo	16.90	34.05	3.04	2.00	1.90	0.10	8.00
	mean	**16.35**	**34.10**	**1.63**	**2.33**	**2.20**	**0.13**	**9.33**
4/12/92	1 Marine	14.30	34.40	0.99	1.00	1.00	0.00	6.00
4/12/92	2 Boat ramp	13.95	34.70	0.49	2.00	1.80	0.20	10.00
4/12/92	3 Bens gut	14.20	35.15	0.82	5.00	4.80	0.20	9.00
4/12/92	4 Nemo	13.95	35.05	1.07	2.00	1.80	0.20	9.00
	mean	**14.03**	**34.97**	**0.80**	**3.00**	**2.80**	**0.20**	**9.33**
18/12/92	1 Marine	16.30	34.60	0.59	6.00	4.70	1.30	7.00
18/12/92	2 Boat ramp	17.40	34.95	0.74	3.00	2.00	1.00	8.00
18/12/92	3 Bens gut	19.70	35.45	1.41	8.00	7.20	0.80	10.00
18/12/92	4 Nemo	18.05	35.15	1.26	2.00	1.00	1.00	9.00
	mean	**18.38**	**35.18**	**1.14**	**4.33**	**3.40**	**0.93**	**9.00**
20/1/93	1 Marine	18.00	34.35	0.74	2.00	1.80	0.20	9.00
20/1/93	2 Boat ramp	18.80	34.45	0.59	0.80	0.60	0.20	10.00
20/1/93	3 Bens gut	19.20	34.50	0.89	4.00	3.50	0.50	12.00
20/1/93	4 Nemo	19.80	35.30	3.49	2.00	1.70	0.30	11.00
	mean	**19.27**	**34.75**	**1.66**	**2.27**	**1.93**	**0.33**	**11.00**

1.2 Pipeclay Lagoon

Date	Station	Temp °C	Salinity (ppt)	Chla (µg/L)	NOX(µg/l)	NO3(µg/l)	NO2(µg/l)	PO4(µg/l)
18/2/93	1 Marine	18.35	34.50	1.19	1.00	1.00	0.00	7.50
18/2/93	2 Boat ramp	19.75	35.05	2.97	2.00	1.51	0.49	6.20
18/2/93	3 Bens gut	20.80	35.40	4.23	3.00	2.60	0.40	7.50
18/2/93	4 Nemo	19.80	35.95	6.08	2.00	1.40	0.60	22.70
	mean	**20.12**	**35.47**	**4.43**	**2.33**	**1.84**	**0.50**	**12.13**

ANNUAL STATION AVERAGES

Date	Station	Temp °C	Salinity (ppt)	Chla (µg/L)	NOX(µg/l)	NO3(µg/l)	NO2(µg/l)	PO4(µg/l)
1991	Marine	13.35	33.57	1.72	12.25	8.78	3.48	7.25
(Sep - Dec)	Boat ramp	13.55	33.27	1.48	6.00	3.35	2.65	8.00
	Bens gut	14.10	33.68	1.26	10.00	6.15	3.85	10.00
	Nemo	13.83	33.50	2.60	7.00	4.95	2.05	7.63
	mean	**13.83**	**33.48**	**1.78**	**7.67**	**4.82**	**2.85**	**8.54**
1992	Marine	13.13	33.99	2.31	7.82	6.76	1.54	7.42
	Boat ramp	12.89	34.19	1.76	6.07	5.12	1.28	8.60
	Bens gut	13.25	34.30	2.46	8.19	7.25	1.47	9.02
	Nemo	12.93	34.31	2.64	5.45	4.35	1.38	8.12
	mean	**13.02**	**34.27**	**2.29**	**6.57**	**5.57**	**1.38**	**8.58**
1993	Marine	18.18	34.43	0.96	1.50	1.40	0.10	8.25
	Boat ramp	19.28	34.75	1.78	1.40	1.06	0.35	8.10
	Bens gut	20.00	34.95	2.56	3.50	3.05	0.45	9.75
	Nemo	19.80	35.63	4.78	2.00	1.55	0.45	16.85
	mean	**19.69**	**35.11**	**3.04**	**2.30**	**1.89**	**0.42**	**11.57**

Note: means are for Pipeclay and do not include the Marine station

1.3 Little Swanport

Date	Station	Temp °C	Salinity (ppt)	Chl a(µg/l)	NOX(µg/l)	NO3(µg/l)	NO2(µg/l)	PO4(µg/l)
18/11/91	1 Marine	13.40	35.00	0.96	5.00	4.20	0.80	8.00
18/11/91	2 Lime kiln	17.25	35.00	1.71	3.00	2.40	0.60	8.00
18/11/91	3 Ram	16.20	35.05	2.36	6.00	5.30	0.70	5.50
18/11/91	4 Dyke	18.15	34.10	2.08	13.00	10.50	2.50	13.20
	mean	**17.20**	**34.72**	**2.05**	**7.33**	**6.07**	**1.27**	**8.90**
16/12/91	1 Marine	16.30	34.85	0.37	7.00	6.30	0.70	12.60
16/12/91	2 Lime kiln	16.80	12.25	1.37	191.00	188.00	3.00	4.30
16/12/91	3 Ram	16.40	14.75	1.32	98.80	95.70	3.10	3.70
16/12/91	4 Dyke	16.70	2.80	1.48	145.00	141.50	3.50	4.20
	mean	**16.63**	**9.93**	**1.39**	**144.93**	**141.73**	**3.20**	**4.07**
14/1/92	1 Marine	15.80	34.35	0.82	3.00	2.20	0.80	25.00
14/1/92	2 Lime kiln	16.70	30.65	1.04	3.00	1.90	1.10	4.20
14/1/92	3 Ram	16.65	29.20	1.40	3.00	2.00	1.00	4.20
14/1/92	4 Dyke	16.65	28.05	10.22	6.00	3.60	2.40	27.70
	mean	**16.67**	**29.30**	**4.22**	**4.00**	**2.50**	**1.50**	**12.03**
25/2/92	1 Marine	16.35	35.25	2.67	3.00	2.40	0.60	9.00
25/2/92	2 Lime kiln	16.55	35.10	1.78	3.00	2.80	0.20	7.00
25/2/92	3 Ram	16.85	34.90	5.07	8.50	7.20	1.30	5.20
25/2/92	4 Dyke	15.75	34.35	3.71	4.00	1.90	2.10	7.80
	mean	**16.38**	**34.78**	**3.52**	**5.17**	**3.97**	**1.20**	**6.67**
27/3/92	1 Marine	16.55	34.40	4.30	10.00	7.30	2.70	8.50
27/3/92	2 Lime kiln	17.05	35.65	4.89	4.00	3.30	0.70	-
27/3/92	3 Ram	17.40	35.75	5.93	2.00	1.20	0.80	10.00
27/3/92	4 Dyke	17.10	35.95	5.83	5.00	4.70	0.30	5.00
	mean	**17.18**	**35.78**	**5.55**	**3.67**	**3.07**	**0.60**	**7.50**
29/4/92	1 Marine	-	-	-	-	-	-	-
29/4/92	2 Lime kiln	14.20	35.40	4.08	5.00	3.90	1.10	7.90
29/4/92	3 Ram	14.10	35.50	6.30	3.00	2.60	0.40	6.50
29/4/92	4 Dyke	13.40	35.40	9.05	7.00	6.40	0.60	5.80
	mean	**13.90**	**35.43**	**6.48**	**5.00**	**4.30**	**0.70**	**6.73**
28/5/92	1 Marine	13.90	35.40	0.59	29.00	23.00	6.00	11.80
28/5/92	2 Lime kiln	11.10	34.75	1.93	3.00	2.00	1.00	6.80
28/5/92	3 Ram	10.75	34.60	2.47	4.00	2.80	1.20	10.00
28/5/92	4 Dyke	9.15	33.65	1.85	1.00	0.60	0.40	4.20
	mean	**10.33**	**34.33**	**2.08**	**2.67**	**1.80**	**0.87**	**7.00**
2/7/92	1 Marine	12.10	34.80	2.22	34.00	30.00	4.00	13.90
2/7/92	2 Lime kiln	11.20	29.10	2.30	18.00	15.60	2.40	7.50
2/7/92	3 Ram	10.55	26.35	2.30	35.00	31.00	4.00	10.70
2/7/92	4 Dyke	10.45	23.50	3.15	17.00	13.70	3.30	4.20
	mean	**10.73**	**26.32**	**2.58**	**23.33**	**20.10**	**3.23**	**7.47**
2/8/92	1 Marine	10.40	34.70	3.56	11.00	8.80	2.20	10.00
2/8/92	2 Lime kiln	10.40	34.80	3.86	11.00	10.00	1.00	7.00
2/8/92	3 Ram	9.50	33.40	2.80	4.00	3.30	0.70	6.00
2/8/92	4 Dyke	9.20	33.40	3.80	4.00	2.80	1.20	7.00
	mean	**9.70**	**33.87**	**3.49**	**6.33**	**5.37**	**0.97**	**6.67**

1.3 Little Swanport

Date	Station	Temp °C	Salinity (ppt)	Chl a(μg/l)	NOX(μg/l)	NO3(μg/l)	NO2(μg/l)	PO4(μg/l)
25/8/92	1 Marine	9.60	34.52	2.89	10.00	9.70	0.30	9.00
25/8/92	2 Lime kiln	9.20	33.50	0.59	52.00	51.10	0.90	6.00
25/8/92	3 Ram	8.90	33.03	1.04	5.00	4.80	0.20	4.00
25/8/92	4 Dyke	9.40	33.05	2.89	3.00	2.50	0.50	6.00
	mean	**9.17**	**33.19**	**1.51**	**20.00**	**19.47**	**0.53**	**5.33**
24/9/92	1 Marine	11.20	35.00	1.40	4.00	3.80	0.20	8.00
24/9/92	2 Lime kiln	12.70	28.50	0.96	1.00	0.80	0.20	4.00
24/9/92	3 Ram	12.50	26.50	1.22	3.00	2.60	0.40	4.00
24/9/92	4 Dyke	12.80	12.80	2.47	2.00	1.30	0.70	11.00
	mean	**12.67**	**22.60**	**1.55**	**2.00**	**1.57**	**0.43**	**6.33**
1/10/92	1 Marine	-	-	1.48	-	-	-	-
1/10/92	2 Lime kiln	-	-	1.26	-	-	-	-
1/10/92	3 Ram	-	-	1.13	-	-	-	-
1/10/92	4 Dyke	-	-	1.36	-	-	-	-
	mean	-	-	**1.25**	-	-	-	-
15/10/92	1 Marine	12.20	35.30	1.90	0.70	-	0.00	6.00
15/10/92	2 Lime kiln	12.20	35.00	2.30	1.00	-	0.30	9.00
15/10/92	3 Ram	13.40	30.40	2.80	1.00	-	0.30	6.00
15/10/92	4 Dyke	13.60	25.80	3.10	2.00	-	0.60	6.00
	mean	**13.07**	**30.40**	**2.73**	**1.33**	-	**0.40**	**7.00**
4/11/92	1 Marine	13.45	34.15	0.89	1.00	1.00	0.00	8.00
4/11/92	2 Lime kiln	15.35	20.55	2.17	2.00	1.60	0.40	4.00
4/11/92	3 Ram	16.05	15.25	3.36	2.00	1.40	0.60	6.00
4/11/92	4 Dyke	16.35	16.30	2.31	6.00	5.50	0.50	6.00
	mean	**15.92**	**17.37**	**2.61**	**3.33**	**2.83**	**0.50**	**5.33**
20/11/92	1 Marine	15.10	35.10	2.10	0.60	-	0.60	7.00
20/11/92	2 Lime kiln	15.80	34.80	1.60	0.60	-	0.50	7.00
20/11/92	3 Ram	16.50	34.30	2.60	1.00	-	0.80	6.00
20/11/92	4 Dyke	17.60	32.20	2.50	0.60	-	0.60	5.00
	mean	**16.63**	**33.77**	**2.23**	**0.73**	-	**0.63**	**6.00**
2/12/92	1 Marine	14.45	35.20	0.82	4.00	3.50	0.50	6.00
2/12/92	2 Lime kiln	15.35	34.60	0.82	1.00	0.40	0.60	5.00
2/12/92	3 Ram	15.50	34.20	0.96	2.00	1.20	0.80	6.00
2/12/92	4 Dyke	16.80	33.40	2.08	4.00	2.80	1.20	5.00
	mean	**15.88**	**34.07**	**1.29**	**2.33**	**1.47**	**0.87**	**5.33**
16/12/92	1 Marine	15.65	35.20	0.44	6.00	5.30	0.70	7.00
16/12/92	2 Lime kiln	16.65	35.00	0.67	1.00	0.30	0.70	9.00
16/12/92	3 Ram	17.60	34.70	1.33	1.00	0.30	0.70	7.00
16/12/92	4 Dyke	18.10	33.25	1.56	2.00	1.00	1.00	7.00
	mean	**17.45**	**34.32**	**1.19**	**1.33**	**0.53**	**0.80**	**7.67**
18/1/93	1 Marine	17.55	34.95	0.67	2.00	1.80	0.20	7.00
18/1/93	2 Lime kiln	20.05	35.10	1.56	0.80	0.50	0.30	6.00
18/1/93	3 Ram	19.35	33.15	2.60	2.00	1.70	0.30	5.00
18/1/93	4 Dyke	20.80	35.50	2.60	0.80	0.50	0.30	5.00
	mean	**20.07**	**34.58**	**2.25**	**1.20**	**0.90**	**0.30**	**5.33**

1.3 Little Swanport

Date	Station	Temp °C	Salinity (ppt)	Chl a(µg/l)	NOX(µg/l)	NO3(µg/l)	NO2(µg/l)	PO4(µg/l)
16/2/93	1 Marine	18.30	35.00	2.08	3.00	2.50	0.50	10.70
16/2/93	2 Lime kiln	19.70	35.10	2.45	1.00	0.80	0.20	8.30
16/2/93	3 Ram	19.30	35.25	4.23	2.00	1.90	0.10	7.50
16/2/93	4 Dyke	19.70	35.80	3.56	4.00	3.70	0.30	5.80
	mean	**19.57**	**35.38**	**3.41**	**2.33**	**2.13**	**0.20**	**7.20**
15/3/93	1 Marine	17.65	35.00	1.19	1.70	1.50	0.20	10.00
15/3/93	2 Lime kiln	18.50	35.10	1.71	2.10	1.60	0.50	10.00
15/3/93	3 Ram	18.45	35.20	2.82	1.30	0.80	0.50	8.00
15/3/93	4 Dyke	18.95	35.20	4.97	0.80	0.30	0.50	4.00
	mean	**18.63**	**35.17**	**3.16**	**1.40**	**0.90**	**0.50**	**7.33**
15/4/93	1 Marine	16.20	35.25	1.48	1.00	0.80	0.20	8.00
15/4/93	2 Lime kiln	16.10	35.40	2.45	1.00	0.80	0.20	8.00
15/4/93	3 Ram	15.95	35.50	4.23	3.00	2.80	0.20	9.00
15/4/93	4 Dyke	15.30	35.50	2.89	1.00	0.70	0.30	5.00
	mean	**15.78**	**35.47**	**3.19**	**1.67**	**1.43**	**0.23**	**7.33**
20/5/93	1 Marine	14.40	35.20	1.41	15.00	12:20	2.80	10.00
20/5/93	2 Lime kiln	13.55	35.35	1.11	2.10	1.60	0.50	8.00
20/5/93	3 Ram	12.60	35.35	1.26	2.10	1.60	0.50	7.00
20/5/93	4 Dyke	10.75	35.60	1.93	0.80	0.50	0.30	5.00
	mean	**12.30**	**35.43**	**1.43**	**1.67**	**1.23**	**0.43**	**6.67**

ANNUAL STATION AVERAGES

1991	Marine	14.85	34.93	0.67	6.00	5.25	0.75	10.30
(Nov - Dec)	Lime kiln	17.03	23.63	1.54	97.00	95.20	1.80	6.15
	Ram	16.30	24.90	1.84	52.40	50.50	1.90	4.60
	Dyke	17.43	18.45	1.78	79.00	76.00	3.00	8.70
	mean	**16.92**	**22.33**	**1.72**	**76.13**	**73.90**	**2.23**	**6.48**
1992	Marine	13.60	34.87	1.89	8.95	9.46	1.43	9.94
	Lime kiln	13.74	31.31	4.44	7.61	7.81	0.82	5.99
	Ram	14.01	30.97	2.56	5.50	5.03	0.98	6.55
	Dyke	13.75	28.32	6.02	4.68	3.90	1.14	7.38
	mean	**13.83**	**30.20**	**4.34**	**5.93**	**5.58**	**0.98**	**6.64**
1993	Marine	16.82	35.08	1.36	4.54	3.76	0.78	9.14
(Jan - May)	Lime kiln	17.58	35.21	1.85	1.40	1.06	0.34	8.06
	Ram	17.13	34.89	3.03	2.08	1.76	0.32	7.30
	Dyke	17.10	35.52	3.19	1.48	1.14	0.34	4.96
	mean	**17.27**	**35.21**	**2.69**	**1.65**	**1.32**	**0.33**	**6.77**

Note: means are for Little Swanport and do not include the Marine station.

1.4 Georges Bay

Date	Station	Temp oC	Salinity (ppt)	Chl a (µg/l)	NOX(µg/l)	NO3(µg/l)	NO2(µg/l)	PO4(µg/l)	SIO4(µg/l)
27/4/93	1 Marine	16.30	34.70	2.60	11.00	10.00	1.00	11.00	-
27/4/93	2 Redflash	16.25	34.55	2.45	8.00	7.10	0.90	10.00	-
27/4/93	3 Lords Pt	16.10	34.10	3.11	15.00	14.30	0.70	15.00	-
27/4/93	4 Humbug	15.80	33.45	3.78	5.00	4.80	0.20	10.00	-
27/4/93	5 Mast	15.45	33.75	2.67	4.00	3.80	0.20	10.00	-
	mean	**15.90**	**33.96**	**3.00**	**8.00**	**7.50**	**0.50**	**11.25**	-
28/5/93	1 Marine	14.30	34.90	0.96	32.00	27.10	4.90	13.00	-
28/5/93	2 Redflash	13.20	34.20	2.97	3.80	3.30	0.50	9.00	-
28/5/93	3 Lords Pt	13.15	34.25	2.30	2.50	2.00	0.50	11.00	-
28/5/93	4 Humbug	13.05	33.55	1.93	2.10	1.80	0.30	10.00	-
28/5/93	5 Mast	13.05	34.40	3.86	1.30	1.00	0.30	10.00	-
	mean	**13.11**	**34.10**	**2.76**	**2.43**	**2.03**	**0.40**	**10.00**	-
29/6/93	1 Marine	12.50	34.90	1.48	44.00	40.20	3.80	13.00	-
29/6/93	2 Redflash	10.65	33.85	2.00	22.00	20.20	1.80	11.00	-
29/6/93	3 Lords Pt	10.20	33.70	2.52	15.00	13.70	1.30	11.00	-
29/6/93	4 Humbug	10.60	33.80	2.45	22.00	20.20	1.80	12.00	-
29/6/93	5 Mast	10.50	33.95	2.22	17.00	15.10	1.90	11.00	-
	mean	**10.49**	**33.83**	**2.30**	**19.00**	**17.30**	**1.70**	**11.25**	-
27/7/93	1 Marine	11.80	34.20	1.67	66.00	62.00	4.00	14.00	-
27/7/93	2 Redflash	10.75	32.10	2.04	56.00	51.60	4.40	10.00	-
27/7/93	3 Lords Pt	10.50	31.75	2.13	0.40	0.00	0.20	2.50	-
27/7/93	4 Humbug	10.65	31.65	2.69	58.00	53.60	4.40	11.00	-
27/7/93	5 Mast	10.30	32.05	13.54	21.00	18.50	2.50	7.00	-
	mean	**10.55**	**31.89**	**5.10**	**33.85**	**30.93**	**2.88**	**7.63**	-
27/8/93	1 Marine	11.70	34.70	1.48	23.00	22.00	1.00	11.00	-
27/8/93	2 Redflash	11.50	34.30	0.96	28.00	26.00	2.00	12.00	-
27/8/93	3 Lords Pt	11.40	32.85	2.15	21.00	19.00	2.00	8.00	-
27/8/93	4 Humbug	11.30	31.70	1.93	36.00	34.00	2.00	9.00	-
27/8/93	5 Mast	11.50	32.70	2.15	28.00	26.00	2.00	10.00	-
	mean	**11.43**	**32.89**	**1.80**	**28.25**	**26.25**	**2.00**	**9.75**	-
24/9/93	1 Marine	12.30	34.85	1.68	6.30	5.10	1.20	9.10	-
24/9/93	2 Redflash	12.45	32.60	1.98	5.30	4.60	0.70	6.80	-
24/9/93	3 Lords Pt	12.45	31.65	2.57	3.70	3.20	0.50	4.70	-
24/9/93	4 Humbug	12.75	31.90	2.97	5.30	3.00	2.30	4.60	-
24/9/93	5 Mast	12.65	32.25	1.38	0.30	0.10	0.20	4.40	-
	mean	**12.58**	**32.10**	**2.22**	**3.65**	**2.73**	**0.93**	**5.13**	-
20/10/93	1 Marine	12.15	34.65	0.74	14.00	12.30	1.70	12.00	-
20/10/93	2 Redflash	13.20	33.60	1.26	3.30	3.30	0.00	10.40	-
20/10/93	3 Lords Pt	13.45	33.55	1.56	3.30	3.30	0.00	7.30	-
20/10/93	4 Humbug	13.45	33.55	1.56	1.20	1.20	0.00	5.40	-
20/10/93	5 Mast	13.35	33.70	1.41	1.30	1.30	0.00	10.40	-
	mean	**13.36**	**33.60**	**1.45**	**2.28**	**2.28**	**0.00**	**8.38**	-
17/11/93	1 Marine	13.75	34.85	1.90	2.70	1.80	0.90	12.70	22.00
17/11/93	2 Redflash	14.70	34.40	1.32	1.30	0.80	0.50	10.40	54.00
17/11/93	3 Lords Pt	15.90	33.90	2.88	0.50	0.10	0.40	10.40	76.00
17/11/93	4 Humbug	16.35	33.65	1.07	0.50	0.20	0.30	8.80	94.00
17/11/93	5 Mast	17.30	33.70	1.07	1.40	1.20	0.20	10.00	66.00
	mean	**16.06**	**33.91**	**1.59**	**0.93**	**0.58**	**0.35**	**9.90**	**72.50**

1.4 Georges Bay

Date	Station	Temp oC	Salinity (ppt)	Chl a (µg/l)	NOX(µg/l)	NO3(µg/l)	NO2(µg/l)	PO4(µg/l)	SIO4(µg/l)
21/12/93	1 Marine	15.15	34.95	5.47	0.70	0.70	0.00	8.80	27.50
21/12/93	2 Redflash	17.55	33.85	2.22	1.40	1.40	0.00	9.60	186.00
21/12/93	3 Lords Pt	17.65	33.80	2.13	0.90	0.90	0.00	14.80	200.00
21/12/93	4 Humbug	18.10	33.00	2.04	0.60	0.60	0.00	10.00	194.00
21/12/93	5 Mast	17.95	34.10	1.48	0.30	0.30	0.00	8.50	173.00
	mean	**17.81**	**33.69**	**1.97**	**0.80**	**0.80**	**0.00**	**10.73**	**188.25**
19/1/94	1 Marine	15.15	34.05	1.24	36.00	33.80	2.20	12.30	84.00
19/1/94	2 Redflash	16.55	32.05	2.72	2.00	2.00	0.00	6.20	189.00
19/1/94	3 Lords Pt	16.60	31.85	3.38	0.50	0.50	0.00	4.60	198.00
19/1/94	4 Humbug	16.95	32.70	2.64	1.30	1.30	0.00	6.20	140.00
19/1/94	5 Mast	16.90	32.50	2.64	0.50	0.50	0.00	5.80	168.60
	mean	**16.75**	**32.28**	**2.84**	**1.08**	**1.08**	**0.00**	**5.70**	**173.90**
18/2/94	1 Marine	16.60	33.22	4.88	16.10	14.50	1.60	10.40	174.00
18/2/94	2 Redflash	17.60	31.70	7.54	4.20	3.90	0.30	6.80	342.00
18/2/94	3 Lords Pt	17.80	31.90	7.63	1.60	1.50	0.10	6.10	325.00
18/2/94	4 Humbug	18.15	31.45	5.68	0.80	0.80	0.00	5.70	346.00
18/2/94	5 Mast	18.45	31.85	3.90	0.80	0.80	0.00	4.60	321.00
	mean	**18.00**	**31.73**	**6.19**	**1.85**	**1.75**	**0.10**	**5.80**	**333.50**

MEAN VALUE FOR EACH STATION

Station	Temp oC	Salinity (ppt)	Chl a (µg/l)	NOX(µg/l)	NO3(µg/l)	NO2(µg/l)	PO4(µg/l)	SIO4(µg/l)
1 Marine	13.79	34.54	2.19	22.89	20.86	2.03	11.57	76.88
2 Redflash	14.04	33.38	2.50	12.30	11.29	1.01	9.29	192.75
3 Lords Pt	14.11	33.03	2.94	5.85	5.32	0.52	8.67	199.75
4 Humbug	14.29	32.76	2.61	12.07	11.05	1.03	8.43	193.50
5 Mast	14.31	33.18	3.30	6.90	6.24	0.66	8.34	182.15
mean	**14.19**	**33.09**	**2.84**	**9.28**	**8.47**	**0.80**	**8.68**	**192.04**

Note: means are for Georges Bay and do not include the Marine station.

1.5 Simpsons Bay

Date	Station	Temp oC	Salinity (ppt)	Chl a(µg/l)	NOX(µg/l)	NO3(µg/l)	NO2(µg/l)	PO4(µg/l)	SiO4(µg/l)
29/09/93	1 Marine	12.80	33.20	0.69	0.30	0.10	0.20	7.50	-
29/09/93	2 Nowhere	13.15	33.10	0.40	2.10	1.90	0.20	8.20	-
29/09/93	3 Anderaa	13.30	33.25	0.30	0.30	0.10	0.20	7.70	-
29/09/93	4 Boat Ramp	14.00	33.40	0.40	0.30	0.10	0.20	7.30	-
	mean	**13.48**	**33.25**	**0.36**	**0.90**	**0.70**	**0.20**	7.73	-
22/10/93	1 Marine	12.45	33.35	1.57	0.20	0.20	0.00	7.00	-
22/10/93	2 Nowhere	12.65	33.35	1.07	1.00	1.00	0.00	8.80	-
22/10/93	3 Anderaa	12.90	33.45	0.49	0.40	0.40	0.00	7.00	-
22/10/93	4 Boat Ramp	13.25	33.50	0.58	0.60	0.60	0.00	5.80	-
	mean	**12.93**	**33.43**	**0.71**	**0.67**	**0.67**	**0.00**	**7.20**	-
23/11/93	1 Marine	13.95	33.00	0.58	5.00	4.00	1.00	8.80	90.00
23/11/93	2 Nowhere	13.95	32.85	1.65	3.10	2.80	0.30	8.80	56.00
23/11/93	3 Anderaa	14.05	33.00	1.48	0.30	0.00	0.30	9.60	66.00
23/11/93	4 Boat Ramp	13.95	33.15	1.40	0.40	0.10	0.30	9.00	66.00
	mean	**13.98**	**33.00**	**1.51**	**1.27**	**0.97**	**0.30**	**9.13**	**62.67**
7/01/94	1 Marine	14.75	32.45	1.85	6.20	5.90	0.30	8.80	158.00
7/01/94	2 Nowhere	14.70	31.70	2.13	1.70	1.70	0.00	7.10	196.00
7/01/94	3 Anderaa	15.00	31.00	2.97	0.50	0.50	0.00	6.20	230.00
7/01/94	4 Boat Ramp	15.10	30.90	2.60	2.10	2.10	0.00	6.50	240.00
	mean	**14.93**	**31.20**	**2.56**	**1.43**	**1.43**	**0.00**	**6.60**	**222.00**
21/01/94	1 Marine	15.20	32.28	4.70	0.30	0.30	0.00	5.40	30.30
21/01/94	2 Nowhere	15.40	31.90	3.54	0.00	0.00	0.00	5.00	37.60
21/01/94	3 Anderaa	15.65	31.75	3.38	0.10	0.10	0.00	5.20	38.60
21/01/94	4 Boat Ramp	15.85	31.75	3.54	0.20	0.20	0.00	5.40	43.80
	mean	**15.63**	**31.80**	**3.49**	**0.10**	**0.10**	**0.00**	**5.20**	**40.00**
23/02/94	1 Marine	17.25	34.15	2.75	0.20	0.20	0.00	8.80	31.00
23/02/94	2 Nowhere	17.35	34.10	2.31	0.80	0.80	0.00	8.60	30.00
23/02/94	3 Anderaa	17.85	34.10	2.13	1.70	1.70	0.00	8.20	31.00
23/02/94	4 Boat Ramp	18.10	34.10	2.57	0.90	0.90	0.00	8.20	41.00
	mean	**17.77**	**34.10**	**2.34**	**1.13**	**1.13**	**0.00**	**8.33**	**34.00**
18/04/94	1 Marine	14.45	33.95	1.86	1.90	1.90	0.00	12.70	61.00
18/04/94	2 Nowhere	14.40	34.10	2.40	0.60	0.60	0.00	11.90	82.00
18/04/94	3 Anderaa	14.35	34.35	2.66	1.00	1.00	0.00	12.70	73.00
18/04/94	4 Boat Ramp	14.35	34.30	3.46	1.30	1.30	0.00	12.30	91.00
	mean	**14.37**	**34.25**	**2.84**	**0.97**	**0.97**	**0.00**	**12.30**	**82.00**
6/05/94	1 Marine	12.65	33.50	5.15	6.10	4.50	1.60	11.90	98.00
6/05/94	2 Nowhere	12.60	33.60	4.79	3.10	2.40	0.70	11.50	100.00
6/05/94	3 Anderaa	12.45	33.70	4.17	1.80	1.80	0.00	18.50	100.00
6/05/94	4 Boat Ramp	12.55	33.60	4.26	0.80	0.80	0.00	10.40	92.00
	mean	**12.53**	**33.63**	**4.41**	**1.90**	**1.67**	**0.23**	**13.47**	**97.33**
22/06/94	1 Marine	9.95	31.55	3.73	46.00	39.00	7.00	14.00	193.00
22/06/94	2 Nowhere	9.40	31.25	8.70	42.00	35.00	7.00	14.00	226.00
22/06/94	3 Anderaa	9.35	30.75	11.36	39.00	32.40	6.60	13.00	222.00
22/06/94	4 Boat Ramp	9.15	30.35	4.26	41.00	35.00	6.00	14.00	222.00
	mean	**9.30**	**30.78**	**8.11**	**40.67**	**34.13**	**6.53**	**13.67**	**223.33**

1.5 Simpsons Bay

MEAN VALUE FOR EACH STATION

Station	Temp oC	Salinity (ppt)	Chl a(µg/l)	NOX(µg/l)	NO3(µg/l)	NO2(µg/l)	PO4(µg/l)	SiO4(µg/l)
1 Marine	13.72	33.05	2.54	7.36	6.23	1.12	9.43	94.47
2 Nowhere	13.73	32.88	3.00	6.04	5.13	0.91	9.32	103.94
3 Anderaa	13.88	32.82	3.22	5.01	4.22	0.79	9.79	108.66
4 Boat Ramp	14.03	32.78	2.56	5.29	4.57	0.72	8.77	113.69
mean	**13.88**	**32.83**	**2.93**	**5.45**	**4.64**	**0.81**	**9.29**	**108.76**

Note: mean values are for Simpsons Bay and do not include the Marine station

1.6 Pittwater sampling over 24 hours

Time	Station	Temp °C	Salinity (ppt)	Chla (μg/L)	SDEV	NOX(μg/l)	SDEV	PO4(μg/l)	SDEV	SiO4(μg/l)	SDEV
11:34	A	14.7	33.80	3.40	1.14	0.70	0.31	10.40	0.85	196.00	6.93
11:55	B	14.3	33.60	3.60	0.36	6.80	7.03	9.90	1.52	152.00	8.08
12:50	A	15	33.80	3.68	0.00	0.80	0.29	10.30	1.03	202.00	3.51
13:15	B	14.4	33.80	3.74	0.35	1.70	5.74	9.10	0.46	156.00	4.04
14:10	A	14.9	33.80	5.27	0.80	0.50	0.31	10.10	0.46	192.00	1.15
14:25	B	14.7	33.70	4.18	0.17	0.40	0.21	8.50	0.75	156.00	6.56
15:05	A	14.8	33.70	6.48	0.13	0.50	0.12	11.00	0.78	200.00	0.00
15:17	B	14.8	33.70	4.84	0.06	0.50	0.31	8.80	0.06	156.00	1.73
16:06	A	14.8	33.70	1.42	0.08	0.40	0.06	10.10	0.50	196.00	1.15
16:18	B	15.4	33.70	0.81	0.17	0.40	0.00	8.60	0.56	156.00	6.11
17:03	A	14.9	33.80	6.94	0.38	0.70	0.31	10.30	0.76	195.00	0.00
17:19	B	15.4	33.60	4.27	0.42	0.60	0.17	10.60	1.96	151.00	5.29
18:06	A	14.9	33.80	6.64	0.17	0.10	0.06	12.50	0.92	190.00	2.31
18:22	B	14.9	33.50	4.52	0.08	0.20	0.06	10.20	0.60	96.00	8.66
19:07	A	14.8	33.70	6.47	0.27	0.10	0.12	11.70	0.50	188.00	3.51
19:22	B	14.8	33.40	4.10	0.22	0.20	0.06	9.50	0.70	86.00	9.45
20:07	A	14.9	33.70	6.00	0.26	0.20	0.17	10.50	0.23	194.00	9.81
20:21	B	15.1	33.60	4.38	1.28	1.50	1.65	14.90	6.28	135.00	34.53
21:13	A	14.9	33.70	5.94	0.08	0.30	0.21	10.10	0.61	196.00	1.73
21:40	B	14.7	33.70	5.25	1.36	0.10	0.00	9.20	1.89	153.00	11.02
22:13	A	14.9	33.70	4.88	0.68	0.10	0.06	9.90	0.50	189.00	4.16
22:28	B	15.1	33.60	4.32	0.56	0.90	0.55	8.70	0.78	140.00	15.72
23:09	A	14.8	33.80	4.94	0.36	0.10	0.00	10.50	0.31	195.00	4.04
23:28	B	15	33.60	4.40	0.20	0.40	0.20	10.50	0.95	146.00	12.50
1:16	A	14.8	33.80	5.08	0.27	0.60	0.06	11.00	0.42	205.00	3.06
1:33	B	14.7	33.70	4.36	0.07	0.40	0.12	10.10	0.74	150.00	8.72
3:12	A	14.7	33.80	4.98	0.44	0.80	0.21	11.90	1.04	196.00	2.00
3:27	B	14.8	33.70	3.63	0.54	0.80	0.21	10.70	0.52	149.00	9.87
5:11	A	14.8	33.90	5.24	0.29	0.60	0.06	9.40	0.56	181.00	15.13
5:23	B	14.7	33.70	4.46	0.77	0.80	0.26	7.80	0.25	124.00	11.06
7:05	A	14.7	33.70	5.94	0.38	1.50	0.32	10.90	1.10	185.00	12.70
7:22	B	14.5	33.40	3.32	0.17	0.90	0.06	8.00	0.40	79.00	5.03
9:03	A	14.8	33.70	5.15	0.13	0.90	0.26	9.90	0.74	169.00	7.02
9:17	B	14.8	33.70	3.71	0.43	1.70	0.62	9.70	0.12	129.00	20.43
11:00	A	14.8	33.80	5.36	1.38	1.10	0.49	10.10	0.56	186.00	11.14
11:17	B	14.7	33.70	5.47	1.76	1.50	1.06	10.20	0.28	157.00	1.41
12:09	A	14.9	33.80	5.80	0.88	2.00	0.15	11.70	0.87	188.00	2.00
12:26	B	14.7	33.70	5.49	1.84	1.70	0.47	12.20	4.50	145.00	25.48
13:09	A	14.8	33.80	4.63	3.14	1.10	0.20	11.10	1.00	188.00	0.00
13:27	B	14.9	33.60	6.69	0.14	1.70	0.35	9.90	0.46	143.00	11.02
					0.12				0.00		0.00

1.7 Pittwater sampling over 4 weeks

Date	Station	Temp °C	Salinity (ppt)	Chla (µg/L)	STDEV	NOX(µg/l)	STDEV	PO4(µg/l)	STDE	SiO4(µg/l)	STDEV
31/10/94	A	15.00	33.80	3.15	0.40	0.83	0.15	10.47	0.64	212.67	6.81
	B	14.37	33.63	2.93	0.36	0.70	0.36	9.27	0.50	164.67	5.69
1/11/94	A	14.83	33.80	4.07	0.46	1.17	0.46	11.27	1.50	176.67	11.55
	B	14.87	33.63	3.44	0.24	1.10	0.28	9.75	1.20	133.00	9.90
2/11/94	A	15.38	33.85	4.88	0.38	0.43	0.15	10.67	0.23	248.67	4.04
	B	15.23	33.72	4.57	0.19	0.83	0.58	10.13	0.23	199.67	8.08
3/11/94	A	15.78	33.68	5.83	0.13	0.93	0.23	11.30	0.56	239.67	12.66
	B	15.25	33.28	4.71	1.04	1.63	0.67	8.90	1.05	187.00	8.49
4/11/94	A	16.27	33.90	4.02	0.55	1.07	0.46	11.30	0.56	222.33	11.59
	B	15.40	33.68	4.63	0.13	1.57	0.57	9.87	0.23	175.67	17.10
5/11/94	A	15.58	33.78	4.71	0.18	1.27	0.65	10.80	0.00	211.33	7.77
	B	14.62	33.48	5.09	0.79	1.00	0.17	9.47	0.23	156.00	38.94
6/11/94	A	14.37	33.78	4.18	0.22	1.07	0.38	10.70	0.89	209.33	12.10
	B	14.03	33.70	4.65	0.22	1.40	-	12.60	-	209.00	-
15/11/94	A	13.68	33.95	2.37	1.69	1.23	0.84	10.13	0.83	161.33	2.89
	B	13.48	33.88	3.24	0.21	1.13	0.25	9.10	0.56	130.67	9.50
21/11/94	A	15.90	34.45	5.19	0.22	1.67	0.95	11.53	0.35	182.00	6.08
	B	15.07	34.20	7.46	0.87	1.27	0.96	10.93	0.23	152.33	7.23
29/11/94	A	-	-	5.39	0.40	0.10	0.00	11.15	0.49	207.00	0.00
	B	-	-	5.94	0.12	2.50	2.97	10.00	0.00	164.00	0.00

Appendix 2

Intensive sampling around the leases.

2.1 Pittwater

Date	Station	Temp oC	Salinity (ppt)	Chl a(µg/l)	NOX(µg/l)	NO3(µg/l)	NO2 (µg/l)	PO4(µg/l)
High water								
19/8/92	1	-	-	0.33	9.0	8.9	0.1	7.0
	2	-	-	0.99	10.0	9.9	0.1	7.0
	3	-	-	0.74	12.0	11.9	0.1	6.0
	4	-	-	0.74	11.0	10.9	0.1	6.0
	5	-	-	0.25	14.0	13.9	0.1	6.0
	6	-	-	0.66	15.0	14.9	0.1	6.0
	7	-	-	0.25	15.0	14.9	0.1	6.0
	8	-	-	0.41	11.0	10.9	0.1	6.0
	9	-	-	0.66	16.0	15.9	0.1	6.0
	10	-	-	0.74	12.0	11.9	0.1	6.0
	11	-	-	0.74	12.0	11.9	0.1	6.0
	12	-	-	0.74	11.0	10.9	0.1	6.0
10/3/93	1	16.5	35.2	1.29	3.0	2.7	0.3	10.2
	2	16.5	35.6	1.64	1.0	0.9	0.1	10.0
	3	16.4	35.7	1.72	0.5	0.4	0.1	11.8
	4	16.2	35.9	1.07	3.0	2.6	0.4	12.6
	5	16.3	35.8	1.93	2.0	1.7	0.3	13.1
	6	16	35.9	0.89	0.5	0.4	0.1	9.5
	7	16.6	35.9	0.74	1.0	0.9	0.1	10.4
	8	15.8	35.8	0.44	1.0	0.8	0.2	12.7
	9	16.1	35.9	1.38	2.0	1.9	0.1	20.0
	10	16.5	35.6	1.09	0.2	0.1	0.1	11.8
	11	16.5	35.6	1.09	2.0	1.9	0.1	18.2
	12	16.7	35.5	1.78	0.5	0.4	0.1	9.8
6/5/93	1	12.2	35.5	3.87	-	-	-	-
	2	11.8	35.8	3.85	-	-	-	-
	3	11.8	35.6	2.88	-	-	-	-
	4	11.8	35.8	3.96	-	-	-	-
	5	11.8	35.8	3.56	-	-	-	-
	6	11.8	35.8	2.75	-	-	-	-
	7	11.6	35.9	4.00	-	-	-	-
	8	12.0	35.8	3.80	-	-	-	-
	9	12.1	35.7	3.49	-	-	-	-
	10	12.0	35.6	2.97	-	-	-	-
	11	12.2	35.6	3.54	-	-	-	-
	12	12.2	35.6	3.30	-	-	-	-

2.1 Pittwater

Date	Station	Temp oC	Salinity (ppt)	Chl a(µg/l)	NOX(µg/l)	NO3(µg/l)	NO2 (µg/l)	PO4(µg/l)
Low Water								
22/9/92	1	10.7	31.7	1.15	6.0	4.6	6.0	-
	2	10.6	31.5	1.40	-	-	-	-
	3	10.4	31.5	1.32	5.0	3.9	8.0	-
	4	10.5	31.1	1.15	1.0	0.4	4.0	-
	5	10.6	31.3	1.24	4.0	3.1	22.0	-
	6	10.4	31.2	1.15	0.9	0.5	6.0	-
	7	10.3	31	1.40	2.0	1.7	6.0	-
	8	10.5	31.3	1.24	4.0	2.7	6.0	-
	9	10.5	30.5	1.32	12.0	11.6	6.0	-
	10	10.7	31.7	1.24	-	-	-	-
	11	10.7	31.3	1.40	2.0	0.7	6.0	-
	12	10.5	31.7	1.24	-	-	-	-
4/11/92	1	15.7	32.3	3.08	0.7	0.5	10.0	-
	2	15.8	32.2	3.62	1.0	0.9	10.0	-
	3	15.5	32.1	3.36	1.0	0.9	8.0	-
	4	16.4	32.2	3.52	1.0	0.9	10.0	-
	5	16.3	32.2	2.97	1.0	0.8	10.0	-
	6	16.2	32.1	3.83	0.7	0.6	9.0	-
	7	16.5	32.1	3.21	0.4	0.3	9.0	-
	8	15.9	32.1	2.60	1.0	0.9	8.0	-
	9	16.4	32	2.97	1.0	0.9	9.0	-
	10	15.4	32.3	3.09	1.0	0.9	6.0	-
	11	15.8	32.2	2.60	2.0	2.0	10.0	-
	12	15.7	32.2	2.72	1.0	1.0	9.0	-

2.2 Pipeclay

Date	Station	emp o	Salinity (ppt)	Chl a(μg/l)	NOX(μg/l)	NO3(μg/l)	NO2(μg/l)	PO4(μg/l)
High Water								
27/10/92	1	13.2	33.8	2.64	1.4	1.2	0.2	6.0
	2	13.2	33.8	1.48	0.7	0.5	0.2	6.0
	3	13.2	33.9	1.48	0.9	0.8	0.1	6.0
	4	13.2	33.8	1.40	1.6	1.1	0.5	7.0
	5	13.2	33.8	1.48	0.7	0.5	0.2	6.0
	6	13.0	33.9	1.57	0.7	0.6	0.1	7.0
	7	13.0	33.9	1.48	1.4	1.2	0.2	6.0
	8	13.0	33.7	0.99	0.9	0.7	0.2	7.0
	9	13.3	33.9	1.07	1.4	1.1	0.3	7.0
	10	12.9	33.8	2.64	0.5	0.3	0.2	6.0
	11	13.3	33.9	2.06	0.5	0.4	0.1	6.0
	12	14.2	34.5	2.80	1.4	1.1	0.3	7.0
11/3/93	1	16.8	34.4	0.49	0.5	0.4	0.1	9.2
	2	16.7	34.4	0.49	0.2	0.1	0.1	10.0
	3	16.7	34.5	0.41	0.2	0.1	0.1	10.0
	4	16.6	34.5	0.41	0.2	0.1	0.1	10.9
	5	16.5	34.6	1.32	1.0	0.9	0.1	10.0
	6	16.7	34.4	1.81	1.0	0.8	0.2	8.3
	7	16.8	34.4	0.99	0.1	0.0	0.1	7.1
	8	16.7	34.4	1.02	0.5	0.4	0.1	9.0
	9	16.5	34.6	0.99	4.0	3.7	0.3	8.3
	10	16.6	34.3	1.81	0.2	0.2	0.0	7.5
	11	16.7	34.4	1.32	0.5	0.4	0.1	7.8
	12	16.5	34.8	1.40	1.0	0.8	0.2	7.5
8/7/93	1	9.7	33.6	3.71	20	19.3	0.7	12
	2	9.7	33.7	2.97	20	19.4	0.6	12
	3	9.7	33.7	2.55	20	19.3	0.7	12
	4	9.2	33.7	1.57	18	17.4	0.6	13
	5	8.7	33.8	1.40	20	19.2	0.8	23
	6	9.7	33.6	4.04	22	21.3	0.7	17
	7	9.7	33.8	2.55	13	12.6	0.4	10
	8	9.5	33.7	2.32	20	19.4	0.6	13
	9	8.4	33.8	1.24	15	14.3	0.7	15
	10	9.5	33.7	3.71	18	17.3	0.7	11
	11	9.5	33.8	1.73	20	19.3	0.7	13
	12	7.2	33.9	1.48	16	15.2	0.8	14

2.2 Pipeclay

Date	Station	emp o	Salinity (ppt)	Chl a(µg/l)	NOX (µg/l)	NO3 (µg/l)	NO2 (µg/l)	PO4 (µg/l)
Low Water								
23/9/92	1	10.8	33.9	1.48	-	-	-	-
	2	10.6	33.8	1.13	-	-	-	-
	3	10.6	33.8	1.22	-	-	-	-
	4	10.9	33.8	1.66	-	-	-	-
	5	11.0	33.7	1.83	-	-	-	-
	6	10.8	33.7	2.79	-	-	-	-
	7	11.1	33.7	0.87	-	-	-	-
	8	10.8	33.6	1.05	-	-	-	-
	9	11.4	33.7	1.48	-	-	-	-
	10	10.7	33.8	1.40	-	-	-	-
	11	10.9	33.7	0.26	-	-	-	-
	12	11.7	33.7	2.01	-	-	-	-
10/6/93	1	9.2	34.2	1.15	5.0	3.8	1.2	12.2
	2	9.1	34.1	1.32	4.0	3.5	0.5	10
	3	9.0	34.2	1.40	4.0	3.4	0.6	11.8
	4	8.8	34.3	1.24	4.0	3.5	0.5	12.6
	5	8.8	34.3	1.07	3.0	2.6	0.4	12.2
	6	10.6	34.0	2.72	2.0	1.8	0.2	8
	7	9.3	34.1	1.32	4.0	3.5	0.5	12.2
	8	9.1	34.2	0.99	5.0	4.0	1	11
	9	8.8	34.0	0.74	8.0	7.4	0.6	13.3
	10	11.0	33.9	3.79	0.5	0.4	0.1	7.8
	11	9.7	34.0	2.64	2.0	1.7	0.3	10
	12	9.1	34.1	2.39	4.0	3.4	0.6	10

2.3 Little Swanport

Date	Station	Temp°C	Salinity(ppt)	Chla (µg/l)	NOX(µg/l)	NO3(µg/l)	NO2(µg/l)	PO4(µg/l)
High Water								
15/10/92	1	12.2	35.0	3.13	1.0	1.0	0.0	10.0
	2	12.2	34.9	2.97	1.0	1.0	0.0	11.0
	3	12.4	34.1	3.13	0.7	0.7	0.0	9.0
	4	12.8	34.9	2.72	0.7	0.7	0.0	7.0
	5	12.7	34.9	2.88	1.0	0.9	0.1	7.0
	6	13.7	30.1	2.55	2.0	1.7	0.3	6.0
	7	14.1	25.1	1.65	4.0	3.6	0.4	6.0
	8	14.7	21.6	2.88	3.0	2.5	0.5	4.0
	9	15.7	23.5	2.55	2.0	1.4	0.6	6.0
	10	16.1	22.1	2.97	1.0	0.4	0.6	4.0
	11	14.1	25.5	2.14	1.0	0.5	0.5	7.0
	12	12.2	35.0	2.55	0.7	0.7	0.0	8.0
19/2/93	1	-	35.1	1.78	0.8	0.6	0.2	9.0
	2	-	35.1	2.74	1.3	1.0	0.3	9.0
	3	-	35.1	2.37	0.8	0.5	0.3	9.0
	4	-	35.1	3.04	2.1	1.4	0.7	8.0
	5	-	35.1	2.36	1.7	1.3	0.4	9.0
	6	-	35.2	2.97	7.1	6.8	0.3	9.0
	7	-	35.2	5.56	1.3	1.0	0.3	9.0
	8	-	35.4	4.89	0.8	0.5	0.3	9.0
	9	-	35.7	8.90	0.0	0.0	0.0	7.0
	10	-	35.7	7.12	0.4	0.1	0.3	8.0
	11	-	35.5	5.86	0.4	0.1	0.3	8.0
	12	-	35.1	2.70	0.4	0.2	0.2	9.0
25/2/93	1	16.2	35.3	7.18	0.8	0.6	0.2	6.0
	2	16.2	35.3	6.97	0.4	0.2	0.2	7.0
	3	16.3	35.2	7.30	1.0	0.4	0.6	7.0
	4	16.3	35.2	7.88	0.6	0.4	0.2	7.0
	5	16.3	35.2	7.27	0.6	0.4	0.2	6.0
	6	16.4	35.2	7.27	0.2	0.0	0.3	8.0
	7	16.4	35.3	6.30	0.0	0.0	0.2	8.0
	8	16.5	35.8	6.01	0.6	0.3	0.3	6.0
	9	16.7	35.3	9.05	5.0	4.0	1.0	8.0
	10	-	-	-	-	-	-	-
	11	16.5	35.5	8.75	0.8	0.2	0.6	4.0
	12	16.1	35.3	6.08	3.0	2.3	0.7	6.0
17/6/93	1	9.9	35.4	2.97	5.6	5.1	0.5	6.9
	2	10.0	35.5	3.54	5.8	5.2	0.6	4.0
	3	9.1	35.4	3.79	3.7	3.0	0.7	6.0
	4	9.3	35.3	4.37	2.6	2.2	0.4	6.5
	5	9.2	35.3	4.04	2.7	2.4	0.3	4.6
	6	8.8	35.5	2.72	10.2	8.9	1.3	9.8
	7	8.8	35.5	2.80	8.7	7.5	1.2	9.6
	8	8.8	35.5	2.80	9.5	8.2	1.3	9.6
	9	9.1	35.5	3.87	3.5	3.5	0.1	4.0
	10	8.0	35.6	4.45	0.5	0.5	0.1	4.0
	11	7.8	35.6	3.71	1.0	1.0	0.1	6.5
	12	10.5	35.3	2.14	4.0	3.5	0.5	8.5

2.3 Little Swanport

Date	Station	Temp°C	Salinity(ppt)	Chla (µg/l)	NOX(µg/l)	NO3(µg/l)	NO2(µg/l)	PO4(µg/l)
High Water continued								
26/7/93	1	10.9	35.0	1.21	21.0	18.3	2.7	9.0
	2	10.9	34.9	1.21	15.0	13.6	1.4	10.0
	3	10.9	34.9	1.30	15.0	13.7	1.3	3.0
	4	11.0	34.9	1.48	15.0	13.8	1.2	2.3
	5	11.0	34.9	1.48	14.0	12.7	1.3	5.0
	6	11.0	34.9	2.32	13.0	11.7	1.3	8.0
	7	10.2	34.5	2.22	4.0	3.5	0.5	2.3
	8	10.4	34.7	1.76	5.0	4.4	0.6	7.0
	9	10.1	34.1	4.45	1.0	0.8	0.2	4.0
	10	10.1	34.2	2.60	1.0	0.8	0.2	4.0
	11	10.2	34.6	2.13	4.0	3.6	0.6	7.0
	12	10.9	35.0	1.67	5.0	3.7	1.3	6.5
25/8/93	1	11.2	34.9	2.69	1.0	1.0	0.0	8.0
	2	11.2	34.9	2.41	1.0	1.0	0.0	10.0
	3	11.3	34.9	2.41	1.0	1.0	0.0	7.0
	4	11.5	34.8	2.50	2.0	2.0	0.0	8.0
	5	11.3	34.9	2.78	1.0	1.0	0.0	7.0
	6	11.8	34.8	1.85	2.0	2.0	0.0	6.0
	7	11.7	34.6	2.22	2.0	2.0	0.0	6.0
	8	11.8	34.7	1.76	1.0	1.0	0.0	6.0
	9	11.8	34.1	3.06	0.5	0.5	0.0	3.0
	10	11.8	34.1	3.15	2.0	2.0	0.0	3.0
	11	11.1	34.4	1.95	1.0	1.0	0.0	6.0
	12	11.4	34.8	2.97	0.3	0.3	0.0	7.0
23/9/93	1	11.9	34.9	1.19	0.4	0.0	0.4	8.5
	2	12.2	34.7	0.99	0.6	0.2	0.4	9.6
	3	12.2	34.7	0.99	0.5	0.1	0.4	8.5
	4	12.5	34.8	0.99	0.8	0.5	0.3	9.6
	5	12.3	34.8	0.89	0.4	0.1	0.3	8.3
	6	12.5	34.8	0.79	2.7	2.1	0.6	8.1
	7	13.0	34.1	1.19	0.8	0.5	0.3	6.0
	8	12.3	34.2	1.58	0.5	0.2	0.3	5.8
	9	12.7	34.0	3.36	0.2	0.0	0.2	3.5
	10	13.1	33.9	2.97	0.3	0.1	0.2	2.7
	11	12.5	33.7	1.78	0.6	0.4	0.2	3.8
	12	12.0	34.8	1.58	0.2	0.0	0.2	8.1

2.3 Little Swanport

Date	Station	Temp°C	Salinity(ppt)	Chla (µg/l)	NOX(µg/l)	NO3(µg/l)	NO2(µg/l)	PO4(µg/l)
Low Water								
1/10/92	1	11.5	29.7	1.3	-	-	-	-
	2	11.3	30.2	0.9	-	-	-	-
	3	11.7	28.2	1.3	-	-	-	-
	4	11.7	28.8	1.2	-	-	-	-
	5	11.8	29.1	1.1	-	-	-	-
	6	12	25.5	1.2	-	-	-	-
	7	12	26.3	1.2	-	-	-	-
	8	12	28.7	1.2	-	-	-	-
	9	11.9	25.1	1.2	-	-	-	-
	10	12.3	25.3	1.7	-	-	-	-
	11	11.9	24.5	1.5	-	-	-	-
	12	11.4	28.6	1.3	-	-	-	-
20/11/92	1	15.8	34.8	2.4	2	1.0	1.0	6.0
	2	15.8	34.9	1.6	2	1.4	0.6	7.0
	3	15.8	34.8	2.1	4	2.8	1.2	12.0
	4	16.1	34.7	2.8	3	2.3	0.7	10.0
	5	15.8	34.9	2.5	3	2.3	0.7	7.0
	6	16.4	34.4	2.9	4	3.0	1.0	5.0
	7	16.5	34.3	2.6	1	0.3	0.7	5.0
	8	16.7	34.1	3.8	1	0.5	0.5	10.0
	9	17.1	32.8	4.0	1	0.2	0.8	5.0
	10	17.1	32.6	3.2	0.6	0.1	0.5	5.0
	11	16.9	33.6	4.8	0.4	-0.2	0.6	5.0
	12	16	34.7	2.4	0.6	0.1	0.5	5.0

2.4 Georges Bay

Date	Station	Temp oC	Salinity (ppt)	Chl a(µg/l)	NOX(µg/l)	NO3(µg/l)	NO2(µg/l)	PO4(µg/l)	Si O4(µg/l)
High Water									
18/6/93	1	11.4	34.4	13.84	2.0	1.8	0.2	11.2	-
	2	10.8	34.4	23.16	0.5	0.5	<0.1	10.0	-
	3	10.8	34.4	15.08	0.3	0.3	<0.1	9.2	-
	4	10.9	34.4	13.51	0.4	0.4	<0.1	10.0	-
	5	10.8	34.3	9.48	0.8	0.8	<0.1	8.1	-
	6	11.1	34.3	14.83	0.8	0.8	<0.1	9.2	-
	7	11.2	34.3	4.20	1.6	1.1	0.5	10.4	-
	8	11.2	34.1	4.12	5.2	4.9	0.3	7.7	-
	9	11.0	33.9	3.79	6.1	5.8	0.3	10.4	-
	10	10.7	33.8	3.13	2.4	2.4	<0.1	9.2	-
	11	10.9	33.9	2.80	3.7	3.5	0.2	8.5	-
	12	11.2	34.3	7.17	1.1	1.1	<0.1	8.5	-
15/12/94	1	18.0	34.1	5.52	0.0	-0.3	0.3	9.8	52
	2	17.8	34.2	7.03	0.9	0.5	0.4	11.0	88
	3	17.9	34.1	4.77	0.0	-0.3	0.3	10.4	65
	4	17.9	34.1	4.52	0.5	0.2	0.3	10.0	53
	5	17.6	34.0	5.52	1.6	1.2	0.4	10.4	46
	6	17.6	34.1	6.65	3.1	2.7	0.4	12.9	46
	7	17.6	34.1	6.02	1.2	0.8	0.4	11.3	42
	8	17.7	34.2	5.77	1.9	1.6	0.3	10.0	46
	9	17.7	34.3	5.40	0.0	-0.3	0.3	9.6	25
	10	17.8	34.2	5.02	0.0	-0.3	0.3	11.7	31
	11	17.8	34.0	5.65	0.4	0.1	0.3	10.0	49
	12	17.8	34.1	6.28	0.5	0.1	0.4	11.3	44
	13	17.8	34.0	4.89	0.0	-0.3	0.3	9.6	40
9/2/95	1	18.1	27.0	16.79	11.9	10.6	1.3	4.0	624
	2	18.8	28.8	22.43	1.9	1.2	0.7	4.3	448
	3	18.2	29.9	35.77	1.3	0.7	0.6	6.7	386
	4	18.0	29.9	24.63	0.9	0.4	0.5	4.7	386
	5	17.9	29.6	21.02	1.3	1.0	0.3	4.0	395
	6	18.0	29.4	23.22	0.6	0.3	0.3	4.0	410
	7	18.2	29.2	20.24	0.6	0.4	0.2	3.8	419
	8	17.5	29.9	13.02	15.6	13.4	2.2	5.2	376
	9	17.5	29.5	12.55	14.4	12.2	2.2	4.3	405
	10	17.5	29.5	12.39	13.1	10.9	2.2	4.2	438
	11	17.9	29.2	22.28	4.4	3.7	0.7	3.5	407
	12	18.4	25.9	27.93	13.8	12.5	1.3	3.7	667

2.4 Georges Bay

Date	Station	Temp oC	Salinity (ppt)	Chl a(µg/l)	NOX(µg/l)	NO3(µg/l)	NO2(µg/l)	PO4(µg/l)	Si O4(µg/l)
Low Water									
26/8/93	1	11.5	32.5	1.88	39.0	37.0	2.0	10.0	-
	2	11.7	32.8	1.38	30.0	28.0	2.0	10.0	-
	3	10.8	33.0	1.88	18.0	16.0	2.0	9.0	-
	4	11.5	32.8	2.37	22.0	20.0	2.0	10.0	-
	5	11.2	32.5	2.27	23.0	21.0	2.0	9.0	-
	6	11.5	32.4	1.78	32.0	30.0	2.0	11.0	-
	7	11.5	32.5	1.29	43.0	41.0	2.0	10.0	-
	8	11.2	31.1	1.38	50.0	48.0	2.0	11.0	-
	9	11.3	31.6	1.38	42.0	40.0	2.0	10.0	-
	10	11.5	32.2	2.27	29.8	27.8	2.0	10.0	-
	11	11.3	32.2	1.98	40.0	38.0	2.0	9.0	-
	12	11.5	32.4	1.29	41.0	39.0	2.0	10.0	-
15/12/94	1	19.5	33.1	5.15	2.9	2.3	0.6	7.3	258
	2	20.4	34.2	3.39	1.2	0.7	0.5	8.8	146
	3	20.3	34.3	1.51	1.0	0.6	0.4	8.8	77
	4	18.6	34.1	3.01	0.0	-0.3	0.3	8.8	56
	5	18.4	34.2	3.77	0.2	-0.1	0.3	8.8	46
	6	18.3	34.3	4.39	0.1	-0.2	0.3	8.8	44
	7	18.6	34.3	4.39	0.0	-0.3	0.3	9.2	47
	8	18.2	34.3	4.14	0.0	-0.3	0.3	8.5	29
	9	17.6	34.3	5.77	0.1	-0.2	0.3	9.6	33
	10	18.1	34.3	3.51	0.0	-0.3	0.3	8.3	25
	11	18.2	34.3	3.89	0.0	-0.3	0.3	9.6	25
	12	19.1	34.1	3.26	0.2	-0.1	0.3	8.7	42
	13	18.4	34.2	3.77	0.0	-0.3	0.3	10.4	31
9/2/95	1	17.0	28.0	15.37	27.8	26.0	1.8	3.1	562
	2	18.0	29.0	8.47	48.1	46.3	1.8	3.7	843
	3	18.1	28.4	17.57	5.5	3.9	1.6	3.3	529
	4	17.4	29.1	15.37	20.7	17.7	3.0	3.0	738
	5	17.5	29.0	19.77	8.8	7.0	1.8	3.5	538
	6	17.2	28.5	19.45	20.7	17.8	2.9	3.3	733
	7	17.1	28.1	12.39	81.2	79.2	2.0	3.7	950
	8	17.2	28.5	26.36	65.6	62.9	2.7	3.7	950
	9	17.5	28.9	23.85	12.9	11.1	1.8	3.3	543
	10	17.5	28.6	16.16	4.5	3.1	1.4	3.0	410
	11	16.6	27.9	13.96	85.6	83.6	2.0	3.7	950
	12	17.4	28.8	14.59	61.9	59.9	2.0	4.3	950

2.5 Simpsons Bay

Date	Station	Temp oC	Salinity (ppt)	Chl a (µg/l)	NOX (µg/l)	NO3 (µg/l)	NO2 (µg/l)	PO4 (µg/l)
High Water								
18/8/93	1	10.2	33.2	1.15	29	25	4	12
	2	10	33.3	1.15	25	21	4	13
	3	9.8	33.2	1.07	19	16	3	10
	4	9.6	33.3	0.99	14	11	3	11
	5	9.5	33.2	1.24	16	13	3	11
	6	10.1	33.2	0.66	3	2	1	10
	7	10.1	33.2	1.24	12	10	2	9
	8	9.8	33.2	1.07	11	8	3	12
	9	9.8	33.2	1.32	19	16	3	12
	10	9.6	33.2	1.48	14	11	3	8
	11	9.8	33.2	1.40	16	13	3	9
	12	10.1	33.2	1.24	31	27	4	14
9/9/93	1	11.2	33.2	3.79	9	8	1	11
	2	11.5	33.1	2.55	11	10	1	13
	3	11.5	33	2.22	11	10	1	10
	4	11.2	33.2	1.40	18	16	2	11
	5	11.1	33.1	2.14	17	15	2	11
	6	11.5	33.4	1.32	18	16	2	12
	7	11.5	33.3	1.73	18	16	2	12
	8	11.2	33.2	1.48	15	13	2	11
	9	11.5	33.1	2.55	13	11	2	10
	10	11.3	33.3	2.88	15	13	2	10
	11	11.2	33.4	2.80	16	14	2	10
	12	11.0	33.4	1.90	20	18	2	12

Appendix 3

Report on shellfish carrying capacity workshop.

Report on Shellfish Carrying Capacity Workshop

At a NATO Advanced Research Workshop in 1992 on "The role of bivalve filter feeders in marine ecosystem processes" the problems associated with determining carrying capacity of shellfish growing areas were discussed. Modelling was considered important in predicting growth in bivalves. This was particularly relevant to the Bay of Marennes-Oleron where the carrying capacity has been exceeded to such an extent that the time taken for oysters to reach market size has increased from 18 months to 4 years during the period 1972 to 1985. The TROPHEE research project entitled "Trophic capacity of an estuarine ecosystem: determination of biological criteria for the management of cultivated populations of oysters and their socio-economic consequences" was developed largely to define the carrying capacity of the Bay of Marennes-Oleron and to model the socio-economic impact of management policies for the oyster fishery. It was a multinational project, including researchers from Great Britain, Ireland, France, Holland, Spain and Portugal, and was funded by the European Commission over three years, 1990-1993. Approximately 2 million ecu (around AUS$3.2 million) was provided by the EC, with equivalent matching funding provided by the participating countries. Dr Maurice Heral from IFREMER was the co-ordinator for the project.

The TROPHEE workshop at the Plymouth Marine Laboratory on 6-11 October 1996 was organised for the presentation of final results from the project, and round table conference on co-ordination and comparison of results and techniques developed. Researchers conducting similar work overseas were also invited to attend to enhance comparisons and discussions. This report summaries the information presented and the discussions at the workshop.

Dr. Brian Bayne opened the workshop and set the objectives.

Aims of the TROPHEE Workshop:

1. To construct a feeding/growth model that is both general and cross species, and that expresses real complexities in suspension-feeding behaviour.
2. To define and describe carrying capacity in models of appropriate generality and realism.
3. To combine these approaches in a form of genuine utility for aquaculture.

A Definition of Carrying Capacity for Shellfish Culture was developed during the workshop as:

Total shellfish biomass sustaining a marketable growth rate, supported by a given ecosystem as a function of the water residence time, system primary production time, and bivalve clearance time.

Presentations made at the workshop generally were divided into two groups:

1. feeding and growth rates of different shellfish species
2. carrying capacity of specific growing areas or ecosystems

1. *Feeding/Growth Rates*

Brian Baynes led the discussion from the physiologists. He commented that physiologists need to understand the constraints to feeding and intake optimisation, with the underlying assumption that feeding constrains growth. He posed four key questions from a physiological point of view (w.r.t. aquaculture implications):

1. What proportions of total suspended matter are removed from the water column?
2. What is the relationship between these removal processes and production of bivalves?
3. What is the relationship between the complex of ecological processes and delivery of particulate nutrients to bivalves?
4. How can we optimise this delivery in terms of economic yield and maximum carrying capacity of the system?

Results of physiological research were presented for different species in various locations. The physiologists have developed equations to describe the important physiological relationships affecting feeding and growth, and a major part of the discussions during the workshop were to prepare generalised physiological equations for each major bivalve species, in particular the mussel *Mytilus edulis* and the Pacific oyster *Crassostrea gigas*. Some of the factors affecting feeding rates which were described include environmental parameters (temperature, salinity, turbidity), composition and concentration of food particles in the water, ingestion rates and selection efficiency of each bivalve species for different species of algae and different types of food, absorption and assimilation efficiency, amount of food rejected as pseudofaeces and threshold levels. It was recommended by some researchers that models use seston concentrations instead of chlorophyll a levels or algal concentrations to quantify food supplies. It was also found by several people that responses to artificial diets were different to natural diets. Limitations of the research and the equations developed, and hence modelling oyster growth were also considered. For example, some researchers found that feeding responses can change according to the type of food available. Modelling also tends to miss any large seasonal variations. It should be noted that much of the research conducted was in relation to natural and reseeded beds of mussels and oysters on the bottom, which is a different ecosystem to bivalves cultured off the bottom on racks or on longlines. Details of most of this research are not presented here because it was not possible to accurately transcribe the information during the workshop. Papers from each presentation, however, are being published next year.

Nevertheless, some general physiological equations were obtained and are presented below:

Clearance Rate $CR = e^{(a+bTPM+cOC+d(TPMxOC))}$

Filtration Rate $FR = CR \times TPM$

$FR = aTPM^{b} \times OC^{c} \times (TPM \times OC)^{d}$

Rate of Pseudofaeces Production $RR = a + bFR+cOC + d(FR \times OC)$

$RR = aTPM^{b} \times OC^{c} \times (TPM \times OC)^{d}$

Selection Efficiency SE = $aFR^b \times OC^c$
Organic Ingestion Rate OIR = (FR x OC) x [((1-SE) x (IR/FR)) + SE]

Absorption Efficiency AE = $a \times (1-e^{(-b(OCI - C))})$

Organic Absorption Rate OAR = OIR x AE.

where TPM = total particulate matter, OC = organic carbon, OCI = organic content of ingested matter, and IR = ingestion rate

Some physiological equations that described most of the observed results for mussels and oysters are as follows:

Clearance Rate = litres of seawater cleared per hour

Oysters CR = $e^{1.22+0.173(TPMxOC)}$
Mussels CR = $e^{-0.11+0.0188TPM}$

Filtration Rate = mg total dry matter filtered per hour

Mussels FR = $0.11xTPM^{1.79}$
Oysters FR = $TPM^{1.31}$

Two types of models have been developed to predict bivalve growth rate and carrying capacity. *Pragmatic models* have been developed from equations of best statistical fit of the data to describe the observed relationship between variables. These models have a good predictive capability for specific site conditions but are poor if extrapolated beyond observed conditions to other sites, and very poor extrapolation to other species. *Mechanistic models* are developed from an understanding of functional relationships between variables, limits and controlling processes. They have the possibility of good predictive capability over a wide range of conditions, but are difficult to achieve.

Generally, the physiologists were satisfied that they had been able to develop equations to describe the major physiological functions of mussels and oysters, and that these could be used to model bivalve growth. The limitations of the models were also recognised.

2. Carrying Capacity

Professor Richard Dame from South California provided the first talk on carrying capacities. He considered ecosystem turnover time as a function of water residence time, primary production (B/P) and bivalve clearance times. Climatic variations can have a major impact, for example, seasonal variations in primary production. Similarly, bivalve clearance time varies between seasons.

Turnover rates for 9 ecosystems which covered a broad range of sizes were compared. The area of the ecosystems varied from 4 - 11,500 km^2 and volume 7.2 - 27,300 10^6m^3. The water residence time (days) varied from 0.5 to 97 days. Primary production varied from 73-262 gC/m2/yr., and primary production time varied from 0.81-7.4 days. Clearance times varied from 0.7 - 325 days depending on the biomass of bivalves present in the bay.

The conclusions reached by Richard Dame from the comparison of carrying capacity of these 9 ecosystems included:

1. Each ecosystem is unique
2. There is a gradient from fast to slow systems
3. Some systems are self-sustaining, i.e. produce enough phytoplankton to sustain the bivalves
4. Two systems required the importation of phytoplankton
5. Most of the important parameters are dynamic and fluctuate seasonally
6. Some ecosystem parameters are not well understood
7. The scaling between physiological processes and ecosystem processes is not well understood.

Aad Smaal discussed in detail benthic-pelagic feedback mechanisms including bivalve control of phytoplankton blooms, regeneration and recycling of nutrients, selective retention of particulate nutrients and change in phytoplankton community structure. He and others considered primary production estimates to be controversial because the role of the microphytobenthos in bivalve nutrition is not well understood.

Problems with carrying capacity on natural and reseeded beds of bivalves in the Netherlands were discussed by Huub Scholten. The Dutch Government wants a 50% reduction in nitrogen and phosphorous loads from freshwater into the North Sea in the near future. However, the impact this will have on shellfish beds is unclear, but potentially large.

Roger Newell discussed the interactions between bivalve feeding and benthic/pelagic coupling. Newell referred mainly to Chesapeake Bay where the oyster *(Crassostrea virginica*) population has been decimated by a combination of over fishing and disease. These days Chesapeake Bay is very turbid with high levels of eutrophication. Newell suggests that there is a possible role for bivalves in exerting a top-down control of phytoplankton concentrations resulting from eutrophication of the estuary. However, the government is suggesting a bottom-up control by reducing nitrogen and phosphorous inputs into the system by 40%. He suggests that adding oysters to the system would provide a better balance between benthic and pelagic systems, and would be much more achievable than a 40% reduction in N levels. Newell called for promotion of the beneficial effects of aquaculture on the environment and for these to be incorporated into models of shellfish carrying capacity. Overall, Newell felt that a substantial stock of oysters in Chesapeake Bay would probably be the most effective means for simultaneously harvesting microplankton, reducing the impact of eutrophication, sustaining a direct harvestable resource, improving water quality and maintaining a diverse and stable food web.

Several models developed by researchers to describe and predict carrying capacities were presented at the workshop. These included models of Marennes-Oleron Bay by Cedric Bacher, of Upper South Cove in Nova Scottia by John Grant, of Saldanha Bay in South Africa by Pedro Monteiro, of Carlingford Loch in Ireland by Joao Ferreira and of Oosterschelde in the Netherlands by Marcel van der Tol and Huub Scholten. However, details of these models are not presented here and they will be published later.

The different types of carrying capacity models were discussed and compared during the Discussion Time at the workshop. Each model was considered to be relatively site specific and each had its advantages and difficulties. It was generally felt there was no one best type of model and that modelling of carrying capacity is very difficult. In particular, the different temporal and spatial scales involved make modelling complicated. Spatial scales vary from mm for sediment organic and nutrient accumulation to kilometres for tidal water movements in estuaries, and temporal scales vary from seconds and minutes for physiological time responses to annual and seasonal variation in climatic factors.

General requirements and recommendations for a carrying capacity model were listed, including:

Physiology -	food (chl a, detritus, TPM) growth (dry weight, shell length) reproduction (timing of spawning, spawning related weight loss)
Population-	seeding density (particle entrainment, depletion, predation protection) mortality (predation, physiology, culture related) cohorts (based on production time)
Ecosystem-	state variables: limiting nutrients (N, P, Si), primary producers bivalves (competitors) dominant processes (production -new or regenerated, mineralization)
Transport-	local (roughness, velocity gradients) system (advection/dispersion-hydrodynamic model, salinity gradient, tidal prism, av. current speed)
Sediment-	forcing function for erosion/sedimentation
Input-	time series of data, defined boundary conditions, economic considerations.
Output-	yield versus standing stock, curve gives optimum carrying capacity.

Additional information still required from the physiologists in developing a carrying capacity model includes:

1. Field relevant estimates of ecophysiological variables, including time of activity, seasonality, allometric relations.
2. Definition of food including labile detritus, microphytobenthos, microbes and biodeposits.
3. Responses of animals to food (quality, algal species)
4. Nutrient balances (uptake C, N, P, Si, excretion rates and stoichiometry)
5. Spawning losses (direct and indirect)
6. Induction of mortality (spawning, scope for growth)
7. Parameter uncertainties and error propagation
8. Bivalve larval impact.

Publication of Results

The papers presented at the workshop will be published next year, the physiological papers in the Journal of Experimental Marine Biology and Ecology and the carrying capacity papers in the Journal of Aquatic Ecology (formerly the Netherlands Journal of Aquatic Ecology).

TROPHEE Final Workshop
Programme:

Monday 7 October

Morning:	Welcome	B. Bayne
	Introduction	M. Heral
	"Approaches to understanding the carrying capacity of coastal systems"	R. Dame
	"Methods for evaluating the feeding behaviour of bivalves".	I. Iglesias
	"Feeding behaviour of mussels"	A. Hawkins
	"Tidal variations in feeding, absorption and scope for growth of cockles in Marennes-Oleron".	E. Navarro
Afternoon:	"Feeding behaviour of oysters"	S. Bougrier
	"Requirements for interfacing physiology and carrying capacity models".	A. Smaal
	"The carrying capacity of Marennes-Oleron for bivalve culture"	C. Bacher
	"The carrying capacity of Carlingford Loch"	J. Ferriera

Tuesday 8 October

Morning	"Food quality and the growth of mussels"	C. Newell
	"Feeding behaviour and growth of sea scallops under laboratory and natural conditions."	P. Cranford
	"Feeding and energetics of *Placopecten*"	B. MacDonald
	"Carrying capacity of inshore systems for mussel culture"	J. Grant
	"Carrying capacity studies and modelling in the Oosterschelde"	H. Scholten
	"Carrying capacity of Saldanha Bay for bivalve culture"	P. Monteiro
Afternoon	Modelling Session I	

Wednesday 9 October

Modelling Sessions II and III

Thursday 10 October

Morning	"Direct observations and measurements of feeding behaviour".	E. Ward
	"Modelling the growth of mussels"	R. Willows
	"Bivalve feeding and the mediation of benthic/pelagic coupling"	R. Newell
	"Physiological and ecological aspects of body size population density in the context of carrying capacity"	M. Frechette
Afternoon	Report and discussion of modelling sessions:	
	Physiology	A. Hawkins
	Carrying capacity	T. Prins
	General Discussion, led by	B. Bayne

Appendix 4

Project budget summary.

FINAL COST

PROJECT BUDGET SUMMARY

FRDC Contribution	1992/3	1993/4	1994/5	1995/6	TOTAL
Salaries	$33,481	$33,481	$25,111	$0	$92,073
Travel	$8,663	$8,663	$6,497	$0	$23,823
Operating	$3,650	$1,850	$1,388	$0	$6,888
Capital	$13,400	$0	$0	$0	$13,400
Total	**$59,194**	**$43,994**	**$32,996***	**$0**	**$103,188**

DPIF Contribution					
Salaries	$60,052	$60,052	$60,052	$24,200	$204,356
Travel	$0	$0	$0	$0	$0
Operating	$20,412	$20,412	$20,412	$0	$61,236
Capital	$0	$0	$0	$0	$0
Total	**$80,464**	**$80,464**	**$80,464**	**$24,200**	**$265,592**

TOTAL BUDGET	**$139,658**	**$124,458**	**$113,460**	**$24,200**	**$368,780**

* only 75% of grant, $9,642 still to be received.