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WA CCS 2051

Water Corporation
Integrated Nearshore Marine Monitoring
Program for Southern Geographe Bay
Rev 0
March 2003

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Executive Summary

The Water Corporation was awarded a Coast & Clean Seas Grant (WA CCS 2051) to undertake an integrated nearshore marine monitoring program for southern Geographe Bay. Southern Geographe Bay is an important ecological and recreational resource in the south-west region of Western Australia, although previous monitoring has indicated that it receives a considerable nutrient and bacterial load from drain/river discharges into nearshore waters. This project arose from the recognition that excessive nutrient inputs to Geographe Bay may negatively impact on the nearshore marine environment, particularly the health of seagrass meadows. To this end, the project involves the monitoring of water quality and periphyton at four potentially impacted sites (Toby Inlet, Buayanyup Drain, Vasse Diversion Drain and Vasse-Wonnerup wetland) and two reference sites (Quindalup and Forrest Beach).

The Water Corporation has contracted Sinclair Knight Merz to conduct a monitoring program with the assistance of the Marine and Freshwater Research Laboratory at Murdoch University to determine the effect of these discharges on water quality in southern Geographe Bay.

Water quality was assessed at each site in Geographe Bay on fourteen separate occasions between March 2001 and November 2002. On each occasion, physico-chemical parameters, nutrient levels (ammonium, nitrate-nitrite, total nitrogen, filterable reactive phosphorus and total phosphorus) and chlorophyll *a* concentrations were determined.

Periphyton collectors were deployed one metre above the seabed to assess the periphyton biomass that would potentially impact upon the seagrasses. The collectors were deployed on five separate occasions during spring, summer and autumn between March 2001 and November 2002. The collectors consisted of rigid PVC plastic plates (150 mm × 150 mm) that were lightly abraded with sandpaper to facilitate colonisation by periphyton (mucous-like layer of microalgae, macroalgae, algal propagules, bacteria, microfauna and particulate matter commonly found coating seagrass leaves, sessile organisms and other marine surfaces).

Six collectors were deployed at each site. The periphyton collectors were arranged in pairs on each of three apparatus and anchored to the seabed with a one metre long length of railway iron. One collector in each pair was used for the measurement of organic and carbonate content while the other was used for the determination of chlorophyll *a*, *b* and *c*.

The results of this study can be summarised as follows:

Water column profiling:

- ❑ Water temperature at the six Geographe Bay sites ranged between 14–25°C with maxima in early autumn. Waters at all sites were generally well-mixed and vertical temperature stratification was evident only in November 2001 when the surface 0.6 m was warmer.
- ❑ Salinity at all six Geographe Bay sites was within the normal range for oceanic waters, and ranged between 33.1 and 37.2 ‰. There was no evidence of stratification due to salinity, as salinity varied by less than 0.7 ‰ with depth at any site on any occasion.
- ❑ Dissolved oxygen varied considerably between sites and between seasons, and ranged from 6.6 to 10.8 mg/L. Lowest dissolved oxygen concentrations were recorded in late summer to early autumn (January to March), with concentrations often below 7.5 mg/L. Some increases in dissolved oxygen with depth were observed and are likely a result of increased photosynthetic activity by benthic macrophytes.

- ❑ The water column in southern Geographe Bay is well mixed and is consistent with water quality for a coastal embayment.

Nutrient concentrations:

- ❑ Ammonium concentrations in seawater ranged between 3 and 10 µg/L. Ammonium concentrations were generally at or below the guideline value of 5 µg/L with the exception of Vasse-Wonnerup and Forrest Beach sites during winter.
- ❑ Oxidised nitrogen (nitrate-nitrite) concentrations ranged between 2 and 39 µg/L. Elevated levels in excess of the guideline value of 5 µg/L were observed primarily at the Vasse-Wonnerup and Forrest Beach sites during winter.
- ❑ Total nitrogen concentrations varied considerably between sites and sampling occasions and ranged between 100 and 300 µg/L. The three eastern sites (Vasse Diversion Drain, Vasse-Wonnerup and Forrest Beach) had maximum total nitrogen concentrations during winter 2002 with the later two sites exceeding the guideline value of 230 µg/L.
- ❑ Filterable reactive phosphorus concentrations ranged between 3 and 6 µg/L, and did not show any seasonal or spatial trends. All sites were below the guideline values with the exception of Quindalup during January 2002.
- ❑ Total phosphorus concentrations at the six sites ranged from 26 to 41 µg/L. The three eastern sites (Vasse Diversion Drain, Vasse-Wonnerup and Forrest Beach) showed the greatest variation in total phosphorus concentrations between sampling occasions. All sites exceeded the guideline value during summer.
- ❑ Chlorophyll *a* concentrations at the six sites ranged between 0.1 and 4.8 µg/L. Levels of chlorophyll *a* exceeded guidelines at the eastern sites (Vasse Diversion Drain, Vasse-Wonnerup and Forrest Beach) during the winters. Chlorophyll *a* concentrations at the western sites (Quindalup, Toby Inlet and Buayanyup) were always at or below the guideline trigger value, with the exception of Quindalup during August 2002.
- ❑ The water quality in Geographe Bay is variable seasonally and spatially. Apart from nutrient levels exceeding guidelines at selected locations (primarily Vasse Diversion Drain, Vasse-Wonnerup and Forrest Beach) during winter, Southern Geographe Bay has a water quality that can be described as slightly disturbed.
- ❑ The conditions during the survey differ from those reported for the Geographe Bay Study during 1993–1995. The Geographe Bay Study recorded few nutrient concentrations that exceed the ANZECC/ARMCANZ (2000) guidelines at comparable sites to this study.

Periphyton:

- ❑ The pattern of periphyton biomass indicates low levels in spring and maximums in summer and autumn. During autumn and summer there was generally greater periphyton biomass at the three eastern sites (Vasse Diversion Drain, Vasse-Wonnerup and Forrest Beach) than at Quindalup, Toby Inlet or Buayanyup. Periphyton data appear to reflect the pattern of low spring and elevated summer and autumn nitrogen concentrations.
- ❑ Highest levels of carbonate content were observed in spring 2001, and were as high as 62% at Toby Inlet. The lowest levels of carbonate content were observed in autumn 2002 at Forrest Beach (22.6%). Statistically, the carbonate levels were different between sites within a season, but no spatial trends were evident. High carbonate levels is a measure of the quantity of carbonate forming algae, which are indicators of good water quality.

- ❑ Chlorophyll *a* levels were higher in autumn than in spring, and while no spatial trends were evident chlorophyll *a* levels were positively correlated with biomass. Chlorophyll *b* levels were below the detection level of 0.1 mg/m².
- ❑ This study indicates that the waters to the eastern end of southern Geographe Bay stimulate the growth of periphyton more than to the west. This is most likely a reflection of increased nutrients and calmer summer and autumn conditions.

Potential effects on seagrass:

- ❑ Between 1986 and 1998 there was a net gain of seagrass in southern Geographe Bay of approximately 487 ha (4%) of a total of 12,709 ha. Much of this gain (1,053 ha) was in the nearshore area between Quindalup and Busselton. However, losses totalling 556 ha were observed, particularly in the nearshore areas of Dunsborough and to the East of Busselton.
- ❑ Without further study there can be no causal relationship between water quality and the changes in seagrass distribution. However, major losses of seagrass occurred around the areas of Southern Geographe Bay with the greatest nutrient input is of note for future investigations. In addition, the habitat mapping for 1998 was not ground truthed.

1. Introduction

1.1 Background

The Water Corporation was awarded a Coast & Clean Seas Grant (WA CCS 2051) to undertake an integrated nearshore marine monitoring program for southern Geographe Bay. Southern Geographe Bay is an important ecological and recreational resource in the south-west region of Western Australia, although previous monitoring has indicated that it receives a considerable nutrient and bacterial load from drain/river discharges into nearshore waters. This project arose from the recognition that excessive nutrient inputs to Geographe Bay may negatively impact on the nearshore marine environment, particularly the health of seagrass meadows. To this end, the project involves the monitoring of water quality and periphyton at three potentially impacted sites (Toby Inlet, Vasse Diversion Drain and Vasse-Wonnerup) and two reference sites (Quindalup and Forrest Beach). A rationalisation of sample collection logistics has reduced the cost of sampling events, to such an extent that an additional impacted site has been included in the monitoring program (Buayanyup Drain).

The limited amount of water quality monitoring to date indicates that the offshore waters of Geographe Bay are healthy and not affected by nutrient enrichment. However, Water Corporation and community monitoring of drain/river discharges into the nearshore environment indicate a considerable nutrient and bacterial load is discharged each year, primarily from agricultural sources. The main nutrient flows are in winter and reach the Bay via seven main drains/streams, all of which are eutrophic. Limited previous monitoring indicates that these discharges may result in localised and seasonal deterioration in the water quality close to the drains. This has raised concerns about the threats that these nutrient loads pose to the nearshore water quality and seagrass health in Geographe Bay, in terms of both short-term seasonal impacts and long-term impacts.

The purpose of this project was to provide scientifically useful information on the ecological health of Southern Geographe Bay at both the broader and very localised scales; determine threats to the highly dynamic margins and surface coverage of the seagrass meadows; and provide feedback to land managers, the community, Government agencies and environmental regulators on the need to reduce nutrient losses from their land using activities.

The Water Corporation has contracted Sinclair Knight Merz to conduct a monitoring program with the assistance of the Marine and Freshwater Research Laboratory at Murdoch University to determine the effect of these discharges on water quality in southern Geographe Bay.

This project report describes the methods and results of the monitoring program from March 2001 to November 2002.

1.2 Monitoring Program

This project involves water quality and periphyton monitoring at six selected locations in Southern Geographe Bay, between March 2001 and November 2002. Water quality monitoring was scheduled to occur on 14 occasions during the monitoring period. Periphyton assessment was scheduled for 5 occasions in autumn, spring and summer between March 2001 and November 2002.

All water quality monitoring and deployment/retrieval of periphyton collectors is conducted using Murdoch University's research vessel, *Posidonia*. The Marine and Freshwater Research Laboratory (MAFRL) at Murdoch University performs all nutrient and periphyton analyses. MAFRL is a NATA-accredited laboratory, and NATA-accredited analytic methods are used for all analyses.

2. Monitoring Program Methods

2.1 Study Area

The monitoring program involves sampling at six sites in Southern Geographe Bay. Four of these sites were selected as potentially impacted sites near surface water discharge drains, and two are reference sites (Quindalup and Forrest Beach). The coordinates of the six sites are provided in **Table 2-1**. The spatial orientation of the sites is shown in **Figure 2-1**. All sites have water depths between 2.5 and 4 m.

Table 2-1 Sampling locations

Location	Easting (km)	Northing (km)
Quindalup	0326504	6278352
Toby Inlet	0331117	6276499
Buayanyup	0337510	6274901
Vasse Diversion Drain	0344561	6275620
Vasse-Wonnerup	0353633	6280092
Forrest Beach	0357119	6284600

Datum is GDA94 Zone 50H

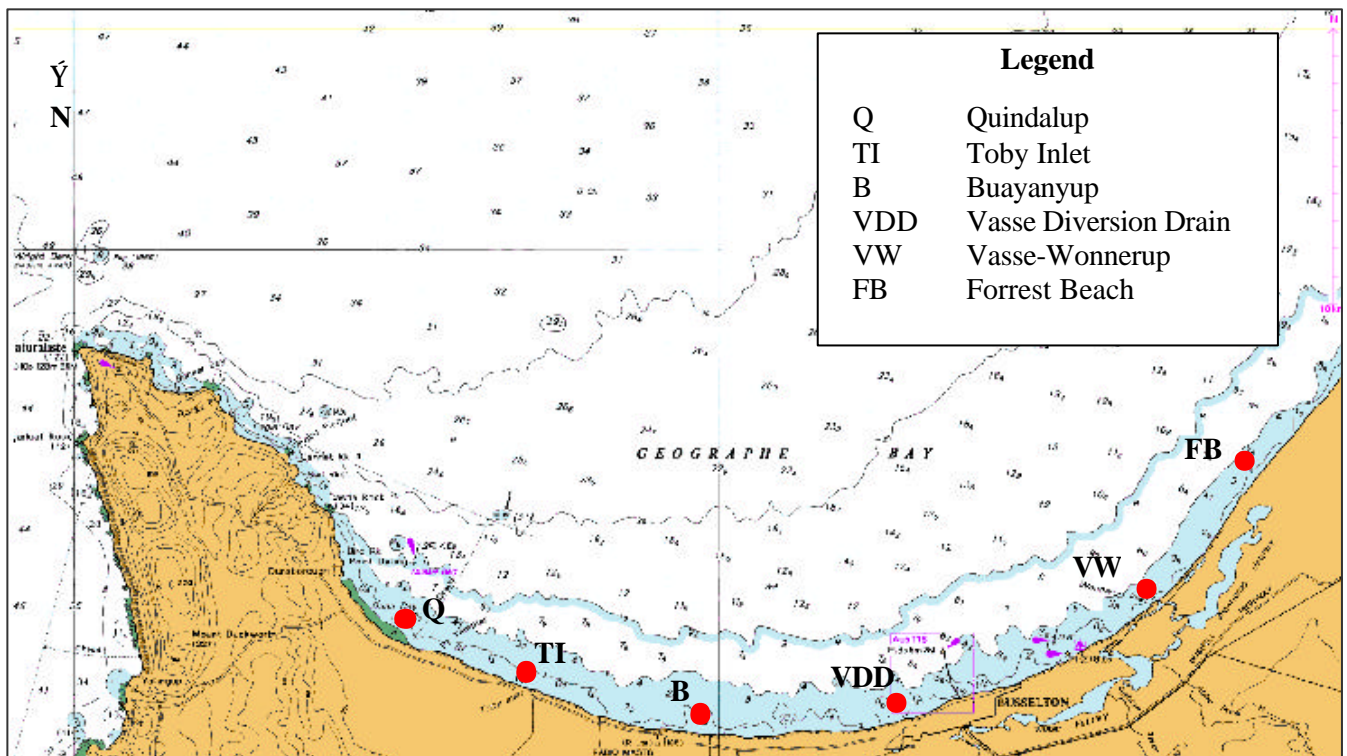


Figure 2-1 Study site locations

2.2 Regional Influences on Water Quality

2.2.1 Busselton Rainfall

Rainfall in the Busselton region is highly variable and has a considerable effect on the total load of nutrients discharged into Geographe Bay from surface runoff and groundwater flows. The average annual rainfall from 1972 to present is shown graphically in **Figure 2-2**. Annual rainfall was below average during the previous Geographe Bay Study (summer 93/94–summer 94/95) and thus study (March 2001–November 2002).

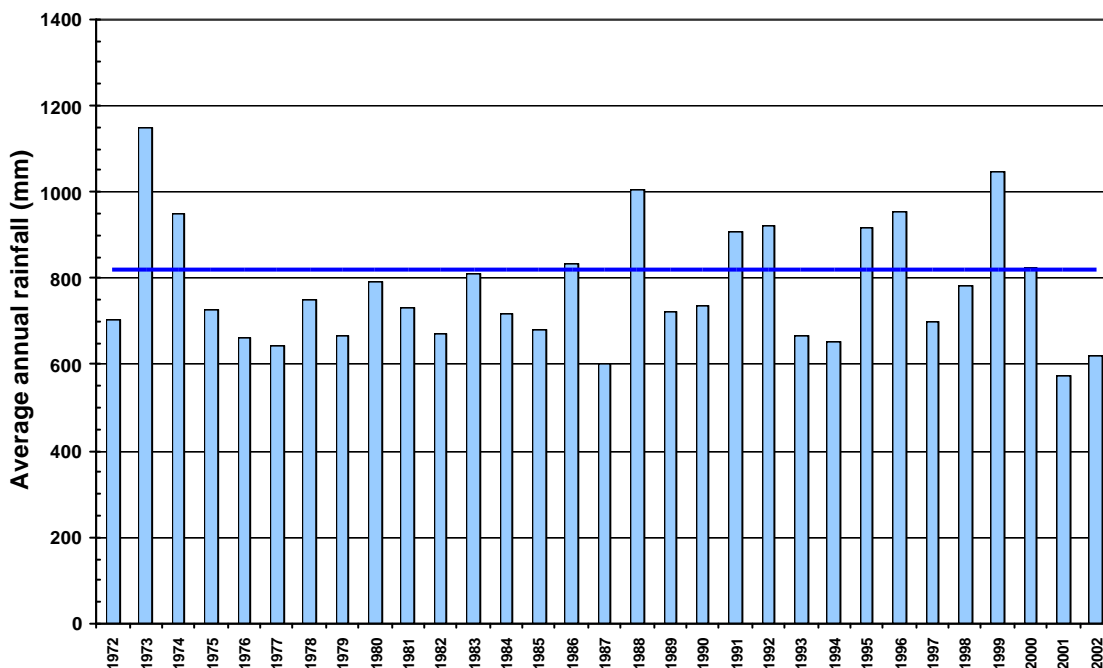


Figure 2-2 Average annual rainfall from 1972 to present

2.2.2 Discharge From Drains

The discharge into Geographe Bay from drains receiving runoff from agricultural land affects the loads and concentrations of nutrients within Southern Geographe Bay. At present data is not available for all of the drains entering the study area covering the period for the previous Geographe Bay Study and this study. It is recognised that each catchment will receive varying amounts of rainfall and the land use practices vary. However, in order to compare the Geographe Bay Study results with this study the discharge from drains must be compared. For the purposes of this comparison the flow data for a major tributary of the Vasse River has been used as a surrogate for the region and is presented in **Figure 2-3**.

It can be seen that the flow and volume of discharge in the Vasse River was similar for the Geographe Bay Study (summer 93/94–summer 94/95) and thus study (March 2001–November 2002). Both flow and volume of discharge are important. Nutrient concentrations in the nearshore areas of Southern Geographe Bay are more of a reflection of concentrations in the water entering the Bay rather than the annual load. Prolonged moderate to low flows of water with high concentrations of nutrients will result in higher concentrations in the Bay than large short duration flushes. However, large flushing events can affect much larger areas of the Bay.

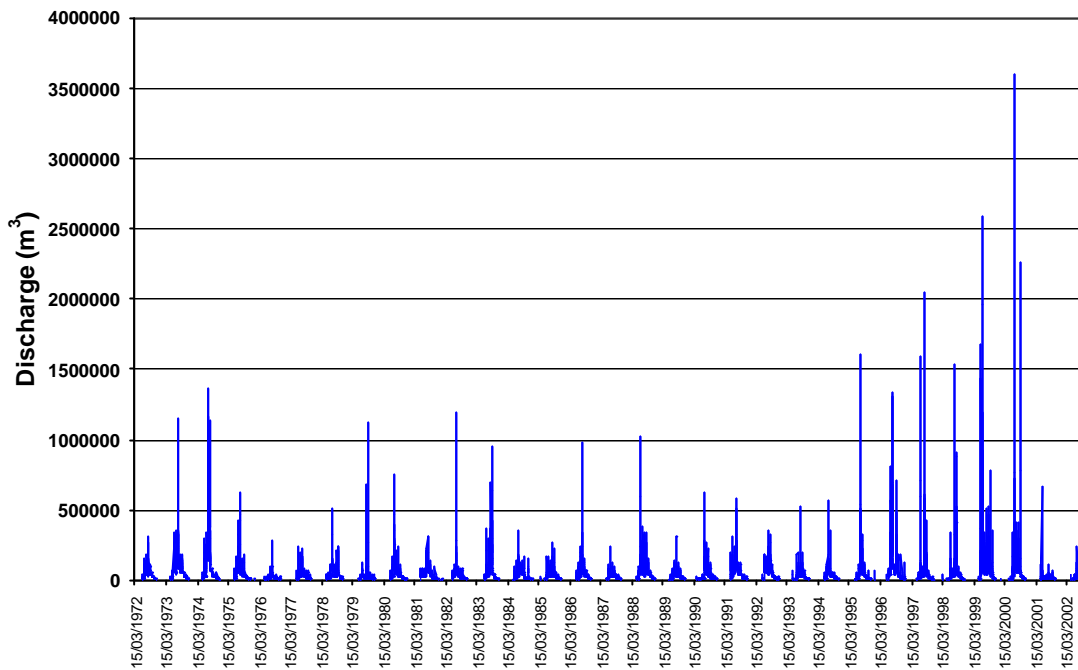


Figure 2-3 Flow in the Vasse River at Chapman Hill

2.2.3 Agricultural Inputs

From the local agricultural production statistics listed in Figure 2-4 and Figure 2-5, it appears that nutrient inputs into drains resulting from agricultural practices are greater today than during the 1993–1995 Geographe Bay Study (see **Figure 2-4** and **Figure 2-5**). Between 1993–1994 and 1999–2000 the total value of agricultural production the Shire of Busselton has increased by 23%. This increase appears to be primarily from increased cattle grazing, with lesser contributions from milk production, hay pasture/grass production and vegetables (40%, 20%, 16% and 9% respectively). It is likely that this increase in production tied to an increased application of fertilisers and production of livestock wastes that would ultimately increase nutrient levels in the local drainage system via runoff.

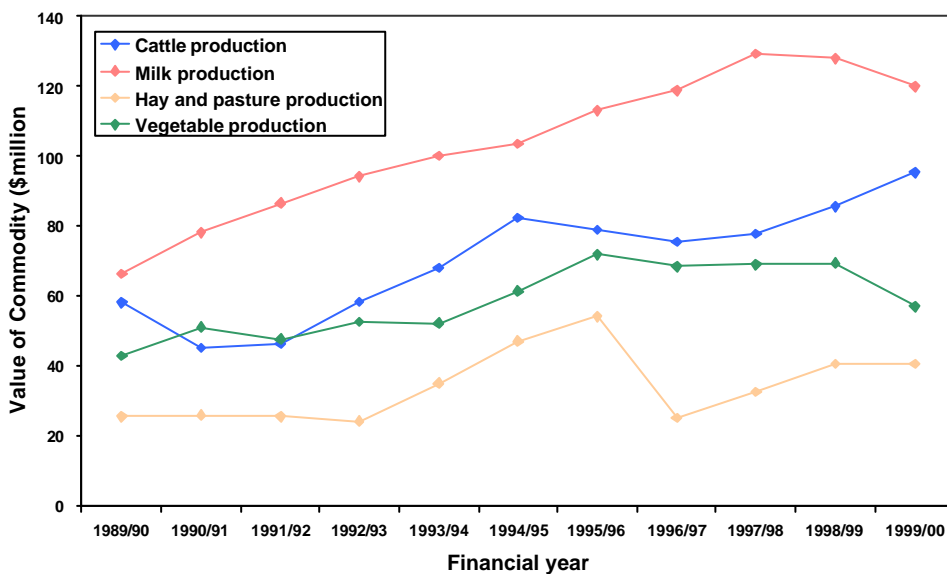


Figure 2-4 Value of agricultural product in the South-West region

Source: SWDC 2003

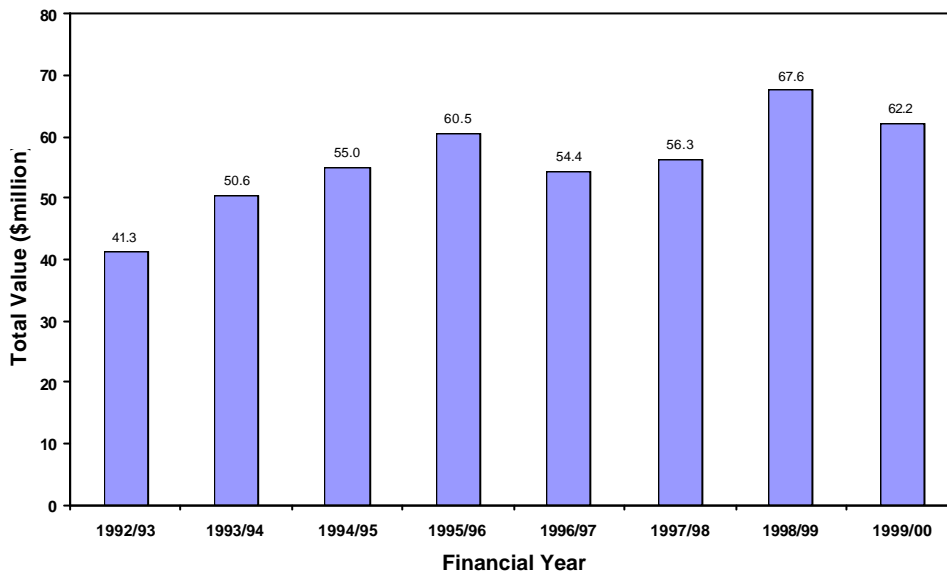


Figure 2-5 Total value of agriculture in Shire of Busselton

Source: SWDC 2003

2.3 Water Quality Assessment

Water quality was assessed at each site in Geographe Bay on fourteen separate occasions. On each occasion, physico-chemical parameters, nutrient levels and chlorophyll *a* concentrations were determined, as detailed in the following sections.

2.3.1 Water Quality Profiling

Vertical water column profiles of temperature, salinity and dissolved oxygen were determined on each of the sampling dates listed in **Table 2-2**. Measurements of each parameter were made using a YSI 610-DM Multiparameter probe.

2.3.2 Water Sampling

At each site, water samples were obtained from bottom, mid and surface waters using a Niskin bottle and then mixed to provide a homogenous sample of the water column. Sub-samples were then taken for analysis of total nitrogen and total phosphorus. Additional sub-samples were obtained for ammonium, nitrate-nitrite and filterable reactive phosphorus analysis after filtering water through a 0.45 µm membrane filter, and for chlorophyll *a* determination after filtering through a 0.8–1.2 µm GF/C filter. All water samples were collected in Nasco Whirlpak® bags and stored on ice until return to the laboratory.

2.3.3 Sampling Schedule

Water sampling was undertaken between March 2001 and November 2002 as shown in **Table 2-2**.

Table 2-2 Water quality sampling schedule

Sampling Event	Sampling Date
March 2001	06/03/01
April 2001	05/04/01
June 2001	13/06/01
August 2001	22/08/01
October 2001	17/10/01
November 2001	14/11/01
January 2002	07/01/02
February 2002	04/02/02
March 2002	12/03/02
April 2002	09/04/02
June 2002	11/06/02
August 2002	09/08/02
October 2002	15/10/02
November 2002	12/11/02

2.3.4 Nutrient Analyses

The following sections provide a summary of the analytical methods for determining nutrient and chlorophyll *a* concentrations in water samples. All analyses were performed by the NATA-accredited Marine and Freshwater Research Laboratory at Murdoch University.

Ammonium (NH₄)

Analysis via flow injection analyser was carried out on filtered seawater samples (0.45µm membrane filter) seawater samples according to the following methods. Ammonia reacts in moderately alkaline solution with hypochlorite to form monochloramine. In the presence of phenol, sodium nitroprusside and excess hypochlorite, indophenol (an intensely blue coloured compound) is formed. The formation of monochloramine requires a pH between 8 and 11.5. This can be detected colourimetrically at 630 nm. At pH greater than 9.6, some precipitation of calcium and magnesium as hydroxides and carbonates occurs in seawater, but these ions may be held in solution by complexing them with EDTA. The method is calibrated using standards prepared in deionised water. Once calibrated, samples of varying salinities (0–36 ‰) may be analysed. Background correction is only necessary for samples that have colour absorbing at 630 nm.

Nitrate-Nitrite (NO₃-NO₂)

Analysis via flow injection was carried out on filtered seawater samples (0.45 µm membrane filter) according to the following methods. Nitrate is reduced to nitrite by means of a heterogeneous reaction in a copper-cadmium reductor column. Under acidic conditions the nitrite ion reacts with sulphanilamide to yield a diazo compound that couples with N-1-naphthylethylene diamine dihydrochloride to form a reddish-purple azo dye. The reaction is specific for nitrite and very sensitive. The azo dye that is formed is detected colourimetrically at 540 nm.

Total Nitrogen (TN)

Inorganic and organically bound nitrogen in water samples were converted to free nitrate by digestion at elevated temperature and pressure in an autoclave, using an alkaline solution of potassium

persulphate. Total nitrogen was determined by analysing the nitrate in the digest via a flow injection analyser according to the following methods. Nitrate is reduced to nitrite by means of a heterogeneous reaction in a copper-cadmium reductor column. Under acidic conditions the nitrite ion reacts with sulphanilamide to yield a diazo compound that couples with N-1-naphthylethylene diamine dihydrochloride to form a reddish-purple azo dye. The reaction is specific for nitrite and very sensitive. The azo dye that is formed is detected colourimetrically at 540 nm.

Filterable Reactive Phosphorus (FRP)

Analysis via flow injection analyser was carried out on filtered seawater samples (0.45µm membrane filter) seawater samples according to the following methods. Orthophosphate reacts with ammonium molybdate and antimony potassium tartrate under acidic conditions to form a heteropoly acid (phosphomolybdic acid) which is reduced to the intensely coloured molybdenum blue complex by ascorbic acid. The ascorbic acid and molybdate reagents are merged on the chemistry manifold, and then the reagent stream is merged with the carrier stream. The sample reaches the detector in less than ten seconds after injection. The intensity of the colour produced absorbs light at 880 nm and is proportional to the concentration of orthophosphate.

Total Phosphorus (TP)

Inorganic and organically bound phosphorus in water samples is converted to orthophosphate by digestion at elevated temperature and pressure in an autoclave, using an alkaline solution of potassium persulphate. Total phosphorus is determined by analysing the resulting orthophosphate from the digest via a flow injection analyser. Orthophosphate reacts with ammonium molybdate and antimony potassium tartrate under acidic conditions to form a heteropoly acid (phosphomolybdic acid) which is reduced to the intensely coloured molybdenum blue complex by ascorbic acid. The ascorbic acid and molybdate reagents are merged on the chemistry manifold, and then the reagent stream is merged with the carrier stream. The sample reaches the detector in less than ten seconds after injection. The intensity of the colour produced absorbs light at 880 nm and is proportional to the concentration of orthophosphate.

Chlorophyll a

Chlorophyll *a* was determined by the following method. Samples collected on filter paper were added to 6 mL of chilled acetone and ground for approximately 20 seconds using an Ultraturrax Tissue Homogeniser. The homogenate was then made up to 10 mL with acetone and extracted over 24 hours in a refrigerator at 4°C. Following extraction, the samples were centrifuged for 3 minutes at 3,000 rpm, washed down and centrifuged for a further 7 minutes. The optical density was measured at 750, 664, 647, and 630 nm on a Varian DMS 90.

The chlorophyll *a* concentration was calculated according to the formulae below and were measured in µg/L. The OD (optical density) at 750 nm was used as a turbidity correction. The detection limit of the analysis was 0.1 µg/L.

$$\text{Chlorophyll } a \text{ (}\mu\text{g / L)} = \frac{11.85 * (664_{OD} - 750_{OD}) - 1.54 * (647_{OD} - 750_{OD}) - 0.08 * (630_{OD} - 750_{OD}) * V1}{V2 * L}$$

where 664_{OD} , 647_{OD} , 630_{OD} and 750_{OD} are the optical densities
 $V1$ = Volume of extract (mL)
 $V2$ = Volume of sample (L)
 L = Path length (cm)

The chlorophyll data were then expressed as µg/L based on a volumetric basis (volume of sample filtered).

2.4 Periphyton Assessment

Periphyton, as used in the context of this document, is defined as:

The mucous-like layer of microalgae, macroalgae, algal propagules, bacteria, microfauna and particulate matter commonly found coating seagrass leaves, sessile organisms and other marine surfaces.

Excessive periphyton growth on seagrass leaves can reduce the amount of sunlight available to the plant. In severe cases where the periphyton is persistent for extended periods of time, the growth and survival of the seagrass is impaired.

2.4.1 Periphyton Collector Apparatus

Periphyton collectors consisted of rigid PVC plastic plates (150 mm × 150 mm) that were lightly abraded with sandpaper to facilitate colonisation by periphyton. The collectors were deployed one metre above the seabed to assess the periphyton biomass that would potentially impact the seagrasses.

Six collectors were deployed at each site. The periphyton collectors were arranged in pairs on each of three apparatus as shown in **Figure 2-6** and anchored to the seabed with a one metre long length of railway iron. One collector in each pair was used for the measurement of organic and carbonate content while the other was used for the determination of chlorophyll *a*, *b* and *c*.

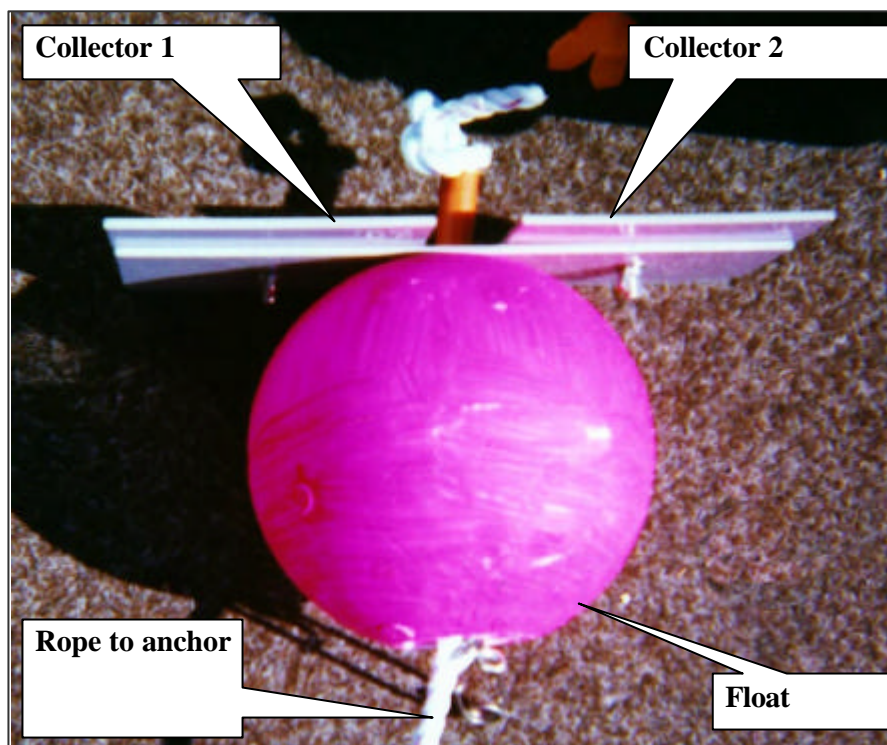


Figure 2-6 Periphyton collector plate configuration

2.4.2 Deployment and Retrieval of Periphyton Collectors

The periphyton collectors were deployed according to the schedule shown in **Table 2-3**, and left to collect periphyton for exactly 28 days (see **Figure 2-7**). The collectors were then retrieved, placed individually in plastic bags and stored at -20 °C prior to analyses.

Periphyton collectors were deployed at the six locations. The location of the sampling sites utilised a Differential GPS with an accuracy of ± 20 m. Indicative periphyton growth is shown in **Figure 2-8**.

Table 2-3 Periphyton deployment and retrieval schedule

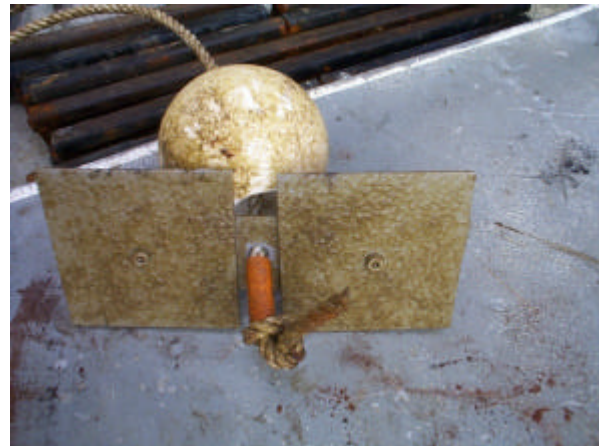
Season	Deployment Date	Retrieval Date
Autumn 2001	06/03/01	05/04/01
Spring 2001	17/10/01	14/11/01
Summer 2002	07/01/02	04/02/02
Autumn 2002	12/03/02	09/04/02
Spring 2002	15/10/02	12/11/02



Figure 2-7 Periphyton collector on seabed



a) Light periphyton growth



b) Heavy periphyton growth

Figure 2-8 Periphyton growth

2.4.3 Periphyton Analysis

Organic and Carbonate Content

All analyses of periphyton were undertaken by the Marine and Freshwater Research Laboratory (MAFRL). Upon thawing, all periphyton material was scraped from each plate and the dry weights (oven dried at 65°C for 24 hours), organic content (ashed at 550°C for 3 hours) and carbonate content (ashed at 1000°C for 3 hours) were determined.

At 550°C the organic material is oxidised to carbon dioxide. The weight loss was expressed on a per square metre basis (area of the periphyton collector scraped) as organic content (ash free dry weight; AFDW). This value is not strictly biomass as much of the periphyton is an organic matrix with carbonates. Since the carbonate component is considered separately, the ash free dry weight is referred to as the organic content. Each determination included a standard containing pure glucose. The percentage combustion of the glucose standard sample averaged 100% (see **Table 2-4**).

At 1000°C any calcium or magnesium carbonate (ca 95% and 5% respectively) would have been converted to calcium or magnesium oxide with the liberation of carbon dioxide. Carbonate was estimated by converting the weight loss (carbon dioxide) to carbonate by applying the correction factor ($60 \div 44 = 1.36$). This correction factor is the molecular weight of carbonate divided by the molecular weight of carbon dioxide. This theoretical correction factor was checked against an empirical value derived by ashing a known weight of pure calcium carbonate. The percentage combustion of the calcium carbonate standard sample averaged 99.5% (see **Table 2-4**).

The conversion factor for ashing calcium carbonate should be $100 \div 44 = 2.27$ (the molecular weight of calcium carbonate divided by the molecular weight of carbon dioxide). The conversion value derived empirically by ashing was 2.28. Since the theoretical and empirical conversion factors are in agreement it follows that the conversion of weight loss by the liberation of carbon dioxide can be converted back to carbonate using the conversion factor 1.36.

The data were not expressed as calcium carbonate because the actual compound deposited on the periphyton collectors is unlikely to be pure calcium carbonate. It is likely to be a mixture of calcium (molecular wt = 40) and magnesium (molecular wt = 24) carbonates in an unknown ratio. It is likely that 95% of the carbonate material on the periphyton plates was indeed calcium carbonate; however, the very low periphyton growth on some collectors meant that using calcium would significantly

overestimate the carbonate loads on the collectors as a result of the higher molecular weight. Carbonate was expressed as a percentage of the periphyton total dry weight (AFDW plus carbonate weight).

Table 2-4 Quality control data for ashing

Season	Substrate	% Glucose recovery	% CaCO ₃ recovery	CaCO ₃ conversion factor
Autumn 2001	Glucose	99.90	–	–
Spring 2001	Glucose	99.80	–	–
Summer 2002	Glucose	100.10	–	–
Autumn 2002	Glucose	99.98	–	–
Spring 2002	Glucose	100.02	–	–
Autumn 2001	Calcium carbonate	–	97.73	2.33
Spring 2001	Calcium carbonate	–	103.57	2.20
Summer 2002	Calcium carbonate	–	99.56	2.28
Autumn 2002	Calcium carbonate	–	99.00	2.30
Spring 2002	Calcium carbonate	–	101.06	2.25

Chlorophyll

Chlorophylls *a*, *b* and *c* were determined simultaneously using the following method. Samples scraped from the periphyton collectors were added to 6 mL of chilled acetone and ground for approximately 20 seconds using an Ultraturrax Tissue Homogeniser. The homogenate was then made up to 10 mL with acetone and extracted over 24 hours in a refrigerator at 4°C. Following extraction, the samples were centrifuged for 3 minutes at 3,000 rpm, washed down and centrifuged for a further 7 minutes. The optical densities were measured at 750, 664, 647, and 630 nm on a Varian DMS 90.

The chlorophyll *a*, *b* and *c* concentrations were calculated according to the formulae below and were expressed in µg/L. The OD (optical density) at 750 nm was used as a turbidity correction. The detection limit of the analysis was 0.1 mg/m².

$$\text{Chlorophyll } a \text{ (}\mu\text{g / L)} = \frac{11.85 * (664_{OD} - 750_{OD}) - 1.54 * (647_{OD} - 750_{OD}) - 0.08 * (630_{OD} - 750_{OD}) * V_1}{V_2 * L}$$

$$\text{Chlorophyll } b \text{ (}\mu\text{g / L)} = \frac{21.03 * (647_{OD} - 750_{OD}) - 5.43 * (664_{OD} - 750_{OD}) - 2.66 * (630_{OD} - 750_{OD}) * V_1}{V_2 * L}$$

$$\text{Chlorophyll } c \text{ (}\mu\text{g / L)} = \frac{24.52 * (630_{OD} - 750_{OD}) - 7.60 * (647_{OD} - 750_{OD}) - 1.67 * (664_{OD} - 750_{OD}) * V_1}{V_2 * L}$$

where 664_{OD}, 647_{OD}, 630_{OD} and 750_{OD} are the optical densities
V₁ = Volume of extract (mL)
V₂ = Volume of sample (L)
L = Path length (cm)

The chlorophyll data were then expressed on a per square metre basis (area of the periphyton collector scraped).

3. Monitoring Results

3.1 Sampling Conditions

Weather and water clarity conditions at the time of sampling are presented in **Table 3-1**.

Table 3-1 Conditions at the time of sampling

Season	Wind		Weather	Secchi Depth (m)					
	Strength (Knots)	Direction		Quindalup	Toby Inlet	Buayanup	Vasse Diversion Drain	Vasse-Wonnerup	Forrest Beach
March 2001	8	N	Clear	3.2+	3.2+	—	3.2+	3.2+	3.2+
April 2001	5	SW	Clear	3.2+	2.6+	—	3.2+	3.2+	3.2+
June 2001	10	NE	Overcast	3.5+	3.0+	—	2.5	2.8	3.0
August 2001	3–5	W	Clear	3.2+	3.5+	—	2.9+	3.2+	3.0
October 2001	3	SE	Overcast	3.0+	2.9+	3.4+	3.1+	3.4+	3.3+
November 2001	Calm	—	Clear	3.5+	4.0+	3.0+	3.1+	3.8+	3.5+
January 2002	5–8	SW	Partly cloudy	3.2+	3.0+	2.7+	2.9+	3.0	3.2+
February 2002	5	NE	Clear	3.7+	3.3+	2.8+	3.0+	3.1+	3.2+
March 2002	3–5	NE	Clear	2.9+	2.5+	2.7+	2.2+	3.3+	3.0+
April 2002	3	E	Overcast	3.5+	3.3+	3.2+	3.4+	4.0+	3.4+
June 2002	10	SW	Partly Cloudy	3.5+	3.5+	3.2+	2.0	3.1	1.5
August 2002	15–20	W	Partly Cloudy	1.7	1.7	1.5	0.9	0.7	0.7
October 2002	10–12	N	Partly Cloudy	3.0+	2.1+	3.0+	2.5+	2.8	3.0
November 2002	2–5	SE	Clear	2.5	2.1	2.0	2.6	2.8	2.5

Secchi depth with a + sign indicates seabed reached before secchi depth reached.

3.2 Water Quality

3.2.1 Water Column Profiles

Temperature

Water temperatures at the six Geopraphe Bay sites ranged from approximately 14–25°C over the period sampled (**Figure 3-1–Figure 3-5**). Between March and November 2001, water temperatures were highest in early autumn (March 2001) and lowest in winter (June 2001). Between January and November 2002, water temperatures were highest during summer (February 2002) and lowest during winter (August 2002). On each sampling occasion, water temperatures varied by less than 2°C between sites, with the exception of November 2001, June 2002 and August 2002 when temperatures varied by 3.5°C, 3.2°C and 2.1°C respectively.

Waters at all sites were generally well-mixed and vertical temperature stratification was evident only in November 2001 (**Figure 3-2**). On this occasion, most sites had warmer surface waters to approximately 0.6 m depth, and temperatures decreased below this depth.

Salinity

Salinity at all six Geographe Bay sites was within the normal range for oceanic waters, and ranged between 33.1 and 37.2 ‰ (**Figure 3-1–Figure 3-5**). Salinity was slightly higher in summer and autumn months, which may be due to lower rainfall at these times. There was no evidence of stratification due to salinity, as salinity varied by less than 0.7 ‰ with depth at any site on any occasion. However, it is worth noting the slight increase in salinity with increasing depth at Toby Inlet in October 2001 and November 2002 (**Figure 3-2** and **Figure 3-5**), which is likely to be due to freshwater discharge at that site.

Dissolved oxygen

Dissolved oxygen profiles are shown in **Figure 3-1** through **Figure 3-5**. Dissolved oxygen varied considerably between sites and between seasons, and ranged from 6.6 to 10.8 mg/L. Lowest dissolved oxygen concentrations were recorded in late summer to early autumn (January to March), with concentrations often below 7.5 mg/L. In October, November 2001 and November 2002, dissolved oxygen concentrations increased with increasing depth at most sites, reaching levels over 10 mg/L at Toby Inlet and Buayanyup. This increase in dissolved oxygen with depth during spring months is likely to be due to increased photosynthetic activity by benthic macrophytes (seagrasses), although in November 2001 the warmer surface waters may partly account for lower dissolved oxygen at the surface.

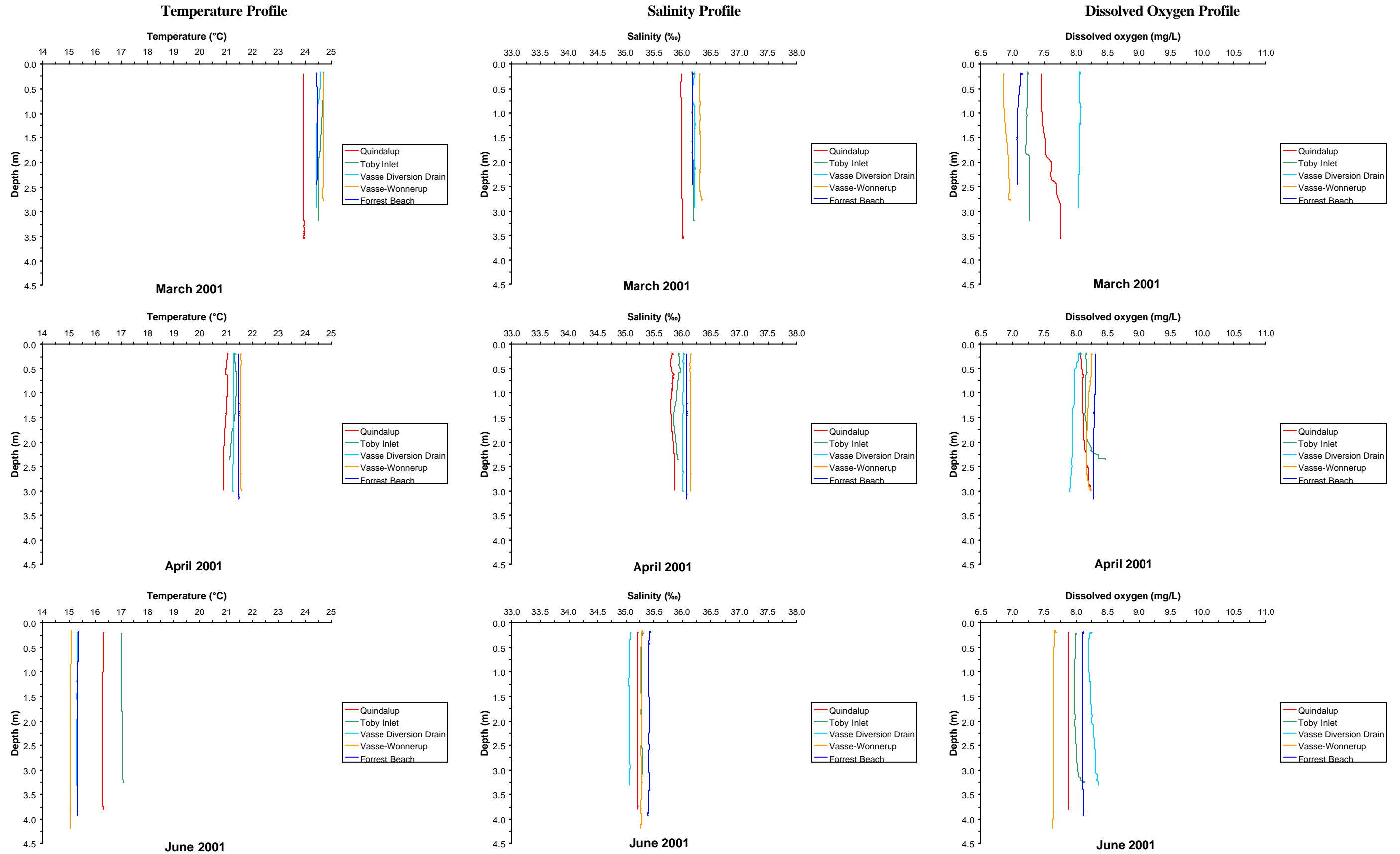


Figure 3-1 Water column profiles for March, April and June 2001

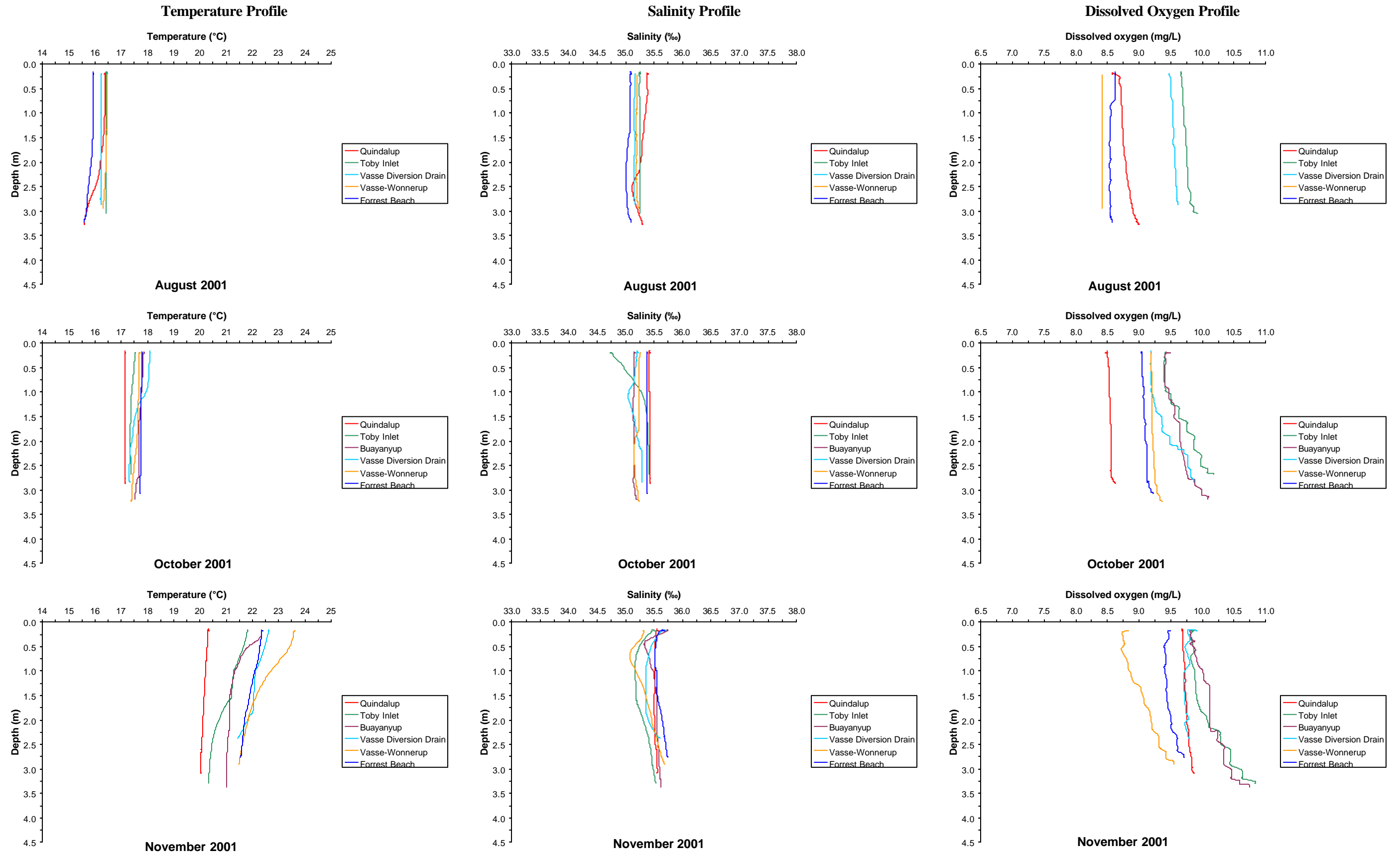


Figure 3-2 Water column profiles for August, October and November 2001

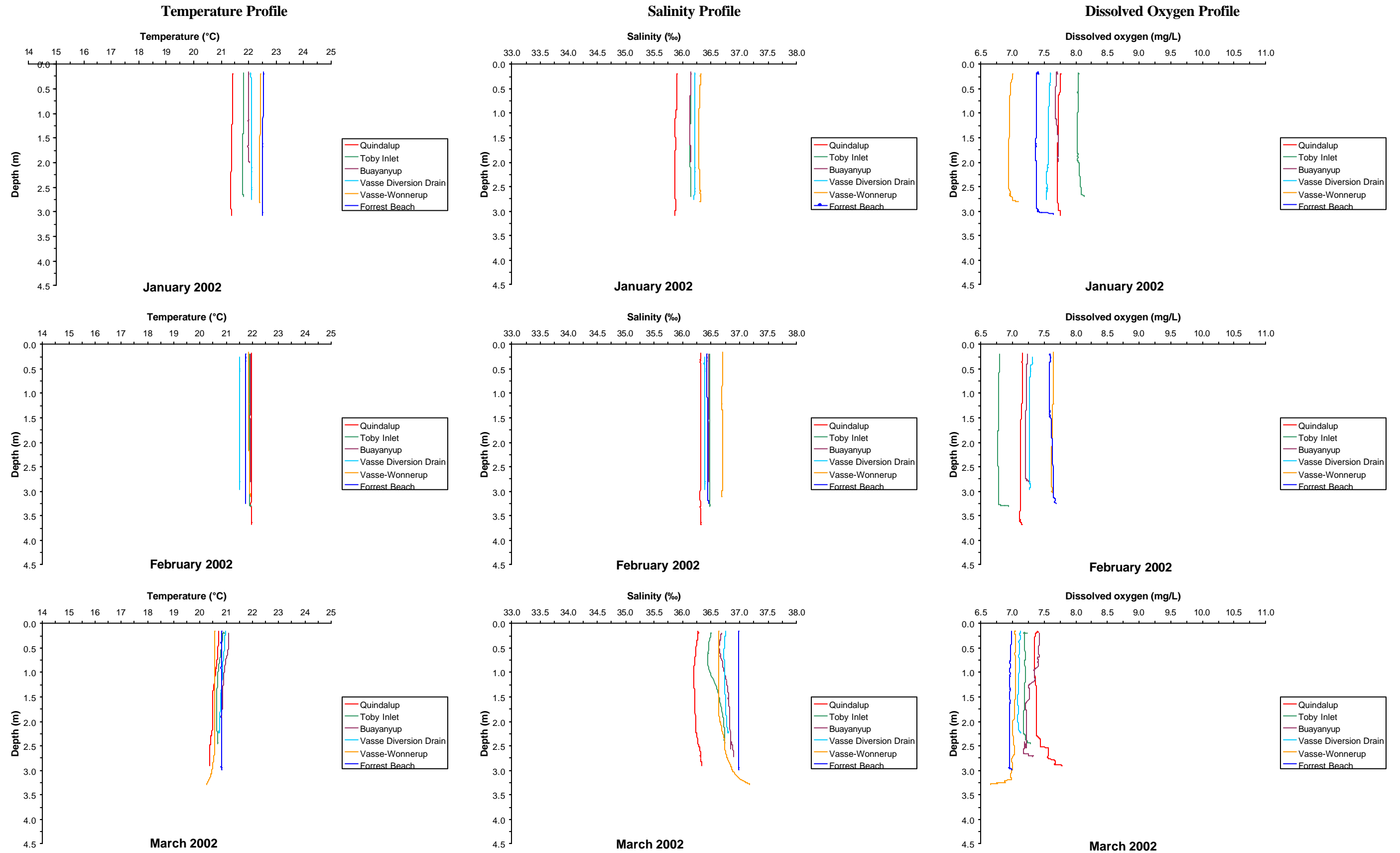


Figure 3-3 Water column profiles for January, February and March 2002

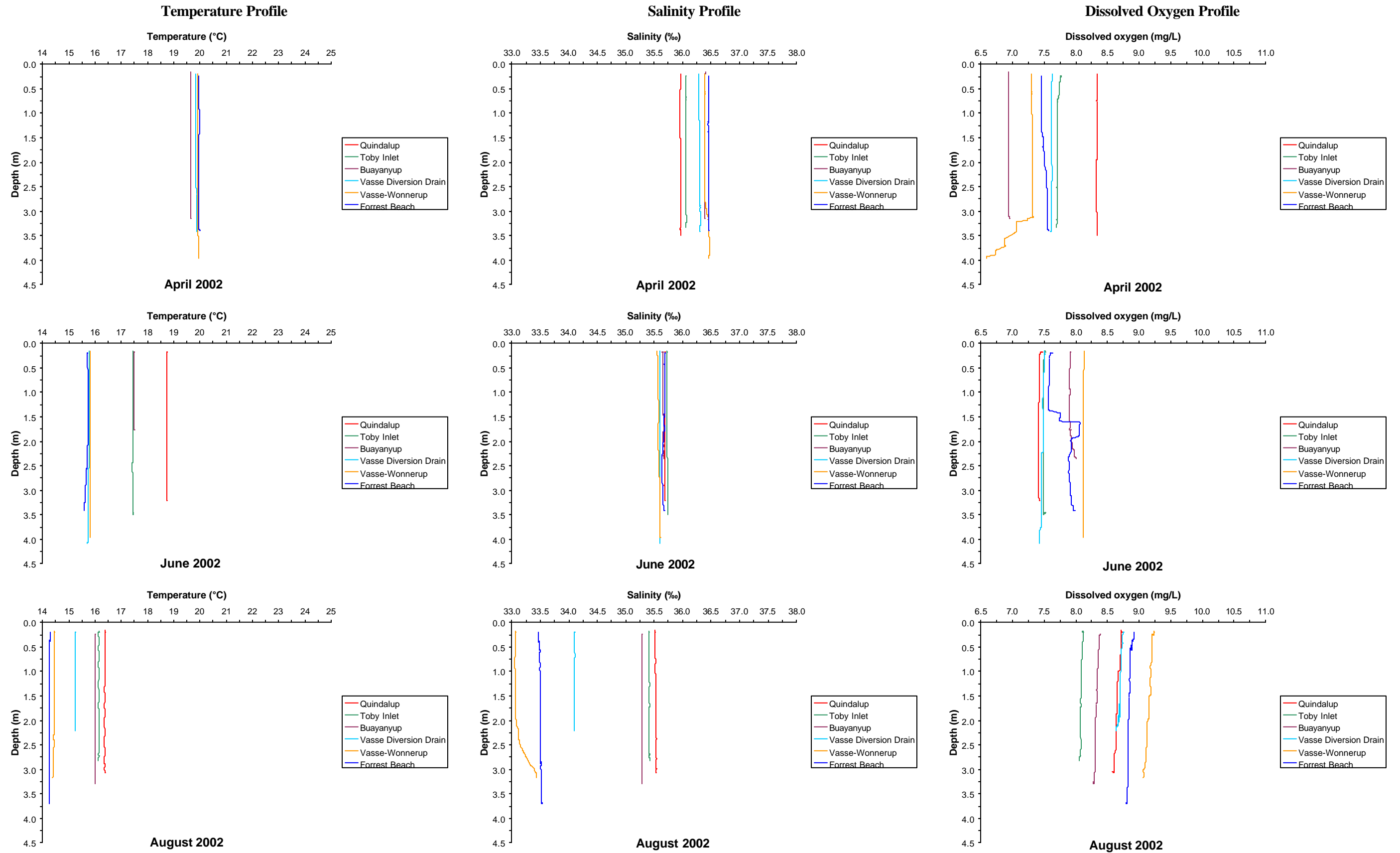


Figure 3-4 Water column profiles for April, June and August 2002

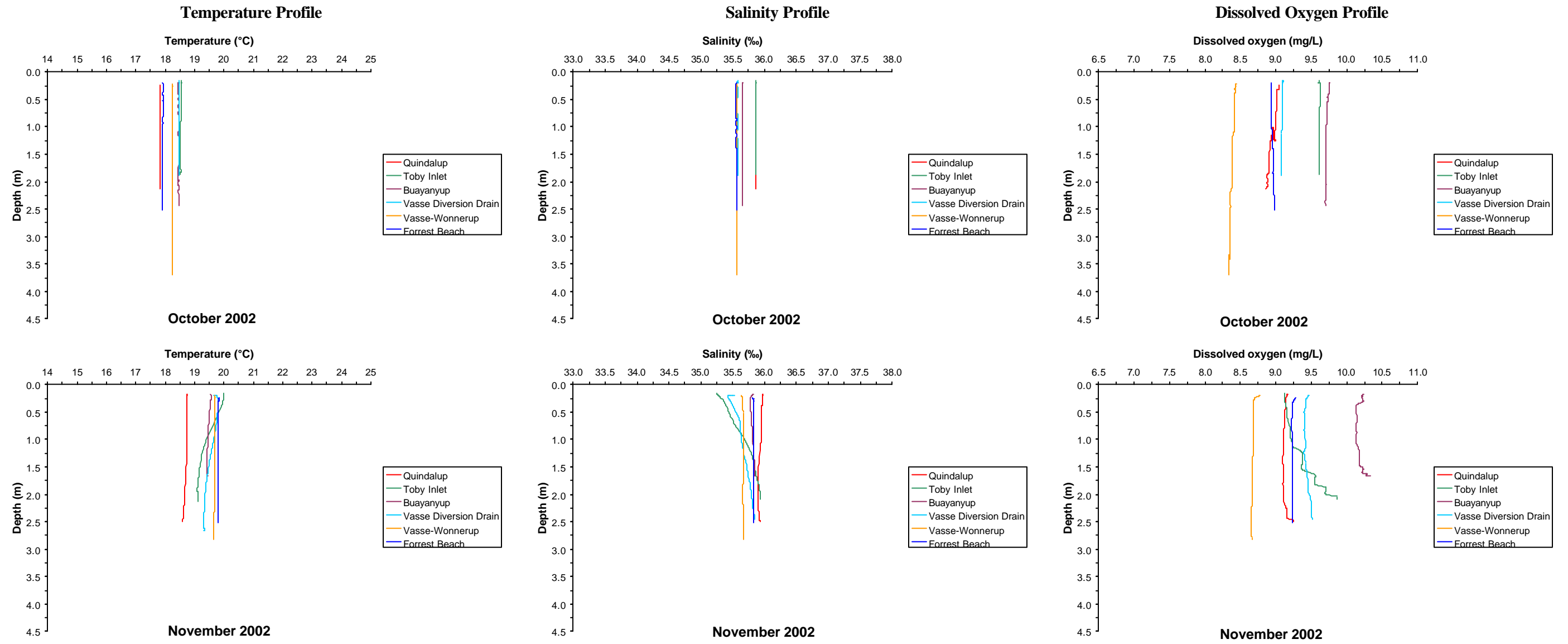


Figure 3-5 Water column profiles for October and November 2002

3.2.2 Nutrient Concentrations

Ammonium

Ammonium concentrations in seawater ranged between 3 and 10 µg/L (**Figure 3-6**). Ammonium concentrations were usually at or below the ANZECC/ARMCANZ trigger value of 5 µg/L for south-west Australian waters (ANZECC/ARMCANZ Guidelines 2000, Table 3.3.6). The guideline was exceeded at most sites at varying times of year; however, Vasse-Wonnerup and Forrest Beach were the most notable during winter 2002. Seasonal and spatial trends were not evident in ammonium concentrations during 2001; however during winter 2002 there is evidence of increasing levels in an eastwards direction towards Forrest Beach.

Nitrate-Nitrite

Oxidised nitrogen (nitrate-nitrite) concentrations ranged between 2 and 39 µg/L (**Figure 3-6**). Nitrate-nitrite concentrations were highest at Forrest Beach in winter 2002 (June and August; 25 and 39 µg/L respectively) and at Vasse-Wonnerup and the Vasse Diversion Drain in August 2002 (18 and 12 µg/L respectively), which exceeded the ANZECC/ARMCANZ trigger value of 5 µg/L for south-west Australian waters (ANZECC/ARMCANZ Guidelines 2000, Table 3.3.6). A seasonal pattern of elevated levels of nitrate-nitrite is evident with increased levels occurring during winter. This pattern, like that of ammonium was most evident between June and August 2002.

Total Nitrogen

Total nitrogen concentrations varied considerably between sites and sampling occasions, and were highest at Vasse-Wonnerup and Forrest Beach in August 2002 (300 µg/L) and lowest at Toby Inlet in August 2001 (100 µg/L) (**Figure 3-6**). The three eastern sites (Vasse Diversion Drain, Vasse-Wonnerup and Forrest Beach) had maximal total nitrogen concentrations during winter 2002 (June to August). Total nitrogen values exceeded the ANZECC/ARMCANZ trigger value of 230 µg/L for south-west Australian waters (ANZECC/ARMCANZ Guidelines 2000, Table 3.3.6) during June and August 2002 at the Vasse-Wonnerup and Forrest Beach sites. A seasonal pattern of elevated levels of total nitrogen is evident with increased levels occurring during winter and this was most pronounced during winter 2002.

Filterable Reactive Phosphorus

Filterable reactive phosphorus concentrations ranged between 3 and 6 µg/L, and did not show any seasonal or spatial trends (**Figure 3-7**). In January 2002 the filterable reactive phosphorus levels at Quindalup were 6 µg/L, which just exceeds the ANZECC/ARMCANZ trigger value of 5 µg/L for south-west Australian waters in summer (ANZECC/ARMCANZ Guidelines 2000, Table 3.3.6). The ANZECC/ARMCANZ trigger value for winter is 10 µg/L (ANZECC/ARMCANZ Guidelines 2000, Table 3.3.6) and filterable reactive phosphorus concentrations were below this value at all sites during winter.

Total Phosphorus

Total phosphorus concentrations at the six sites ranged from 26 to 41 µg/L (**Figure 3-7**). Total phosphorus concentrations were lowest and most similar between sites in March 2001, January 2002 and November 2002. The three eastern sites (Vasse Diversion Drain, Vasse-Wonnerup and Forrest Beach) showed the greatest variation in total phosphorus concentrations between sampling occasions.

The default ANZECC/ARMCANZ trigger value for total phosphorus concentration in south-west Australian waters in summer is 20 µg/L (ANZECC/ARMCANZ Guidelines 2000, Table 3.3.6), and all sites exceeded this value during the summers of 2001 and 2002. For winter, the ANZECC/ARMCANZ trigger value is 40 µg/L (ANZECC/ARMCANZ Guidelines 2000, Table 3.3.6), and all sites had total phosphorus concentrations below this value, with the exception of the Vasse Diversion Drain site during August 2002 which recorded a value of 41 µg/L.

Chlorophyll a

Chlorophyll *a* concentrations at the six sites are shown in **Figure 3-7**, and ranged between 0.1 and 4.8 µg/L. The three eastern sites (Vasse Diversion Drain, Vasse-Wonnerup and Forrest Beach) all had elevated chlorophyll *a* concentrations in winter months (June–August 2001 and 2002) compared to values at Quindalup, Toby Inlet and Buayanyup. Lowest chlorophyll *a* concentrations were recorded in spring (October–November 2001 and 2002) at all sites.

The ANZECC/ARMCANZ trigger value for chlorophyll *a* in inshore waters in south-west Australia is 0.7 µg/L (ANZECC/ARMCANZ Guidelines 2000, Table 3.3.6). Chlorophyll *a* concentrations at the Forrest Beach site exceeded the guideline trigger value during winter 2001 and 2002. The other eastern sites (Vasse Diversion Drain and Vasse-Wonnerup) were at or in excess of the guideline trigger value during June 2001 and winter 2002. Chlorophyll *a* concentrations at the western sites (Quindalup, Toby Inlet and Buayanyup) were always at or below the guideline trigger value, with the exception of Quindalup during August 2002.

The chlorophyll *a* concentrations reflect the patterns seen in the nitrogen levels. Increased nitrogen during winter is stimulating phytoplankton growth resulting in elevated chlorophyll *a* levels.

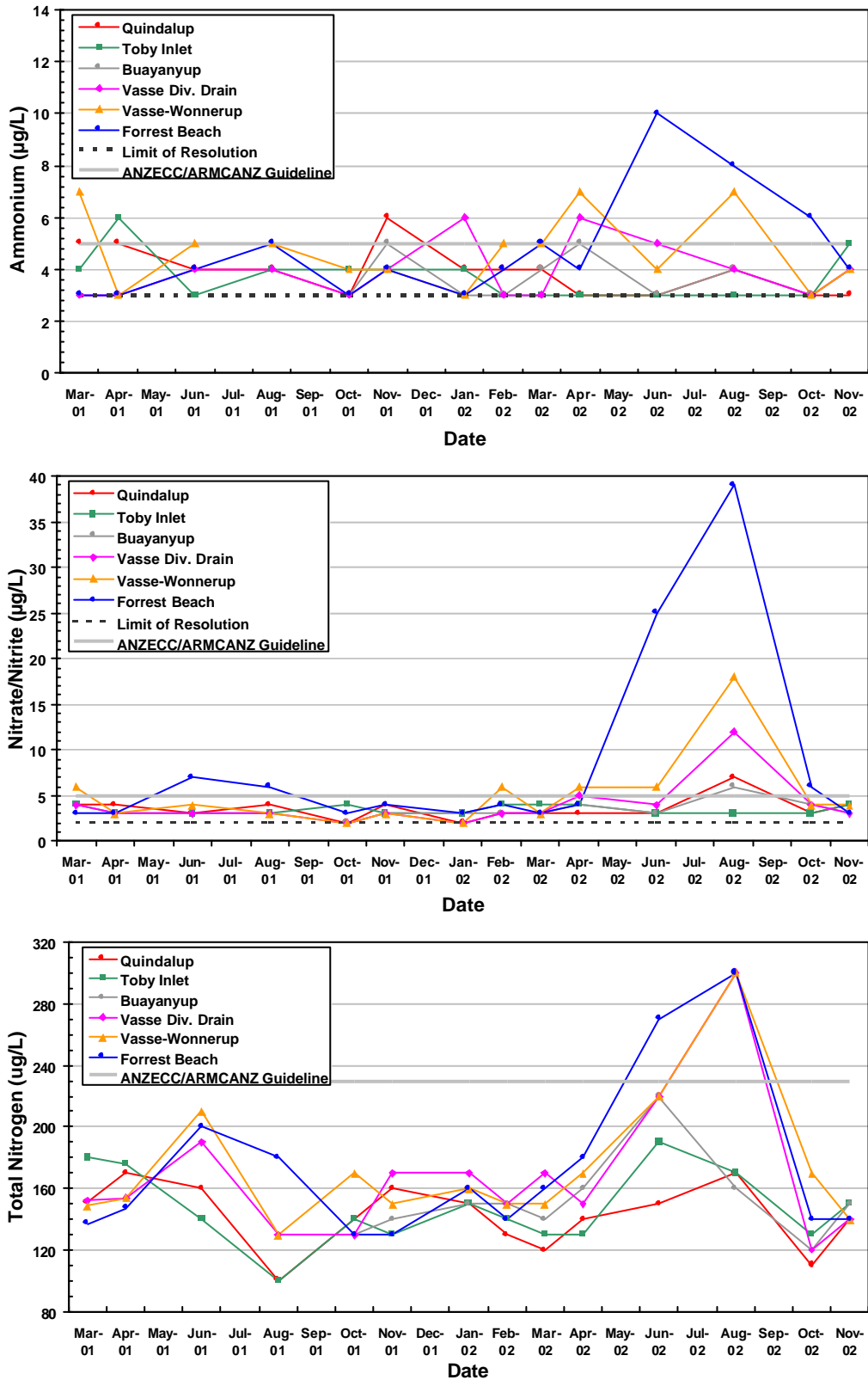


Figure 3-6 Nitrogen concentrations

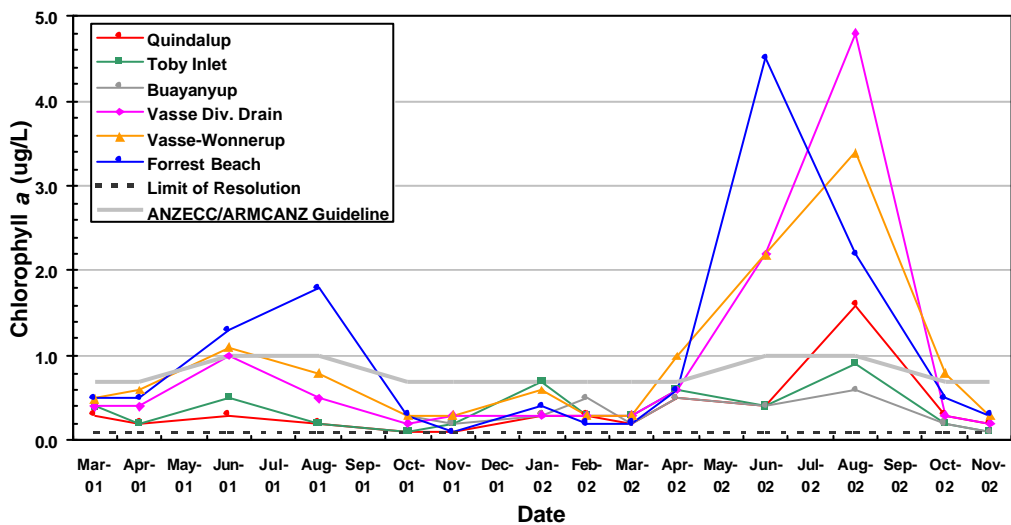
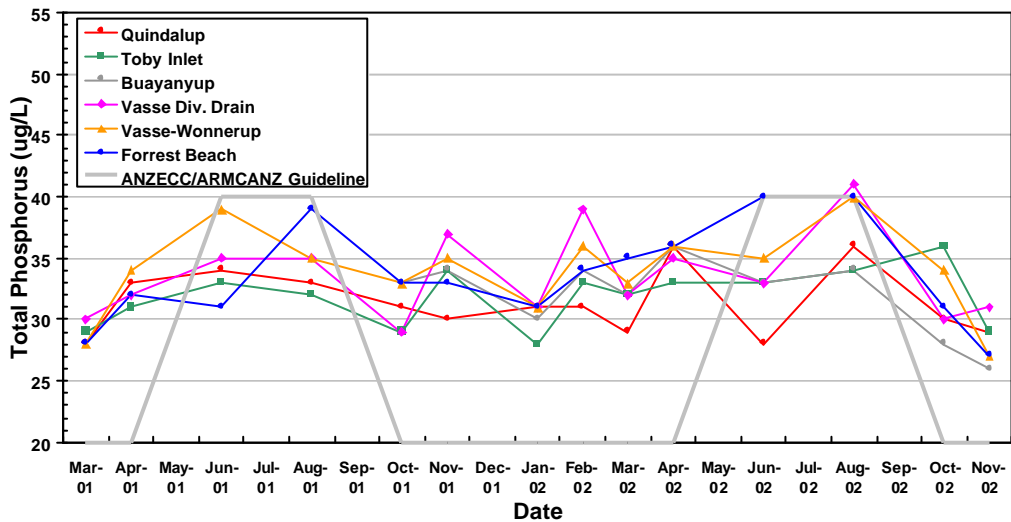
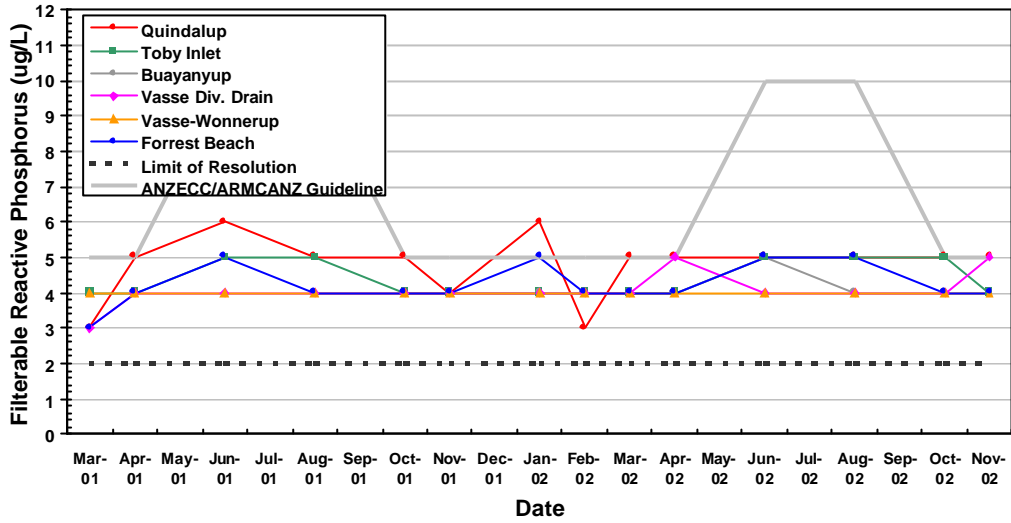


Figure 3-7 Phosphorus and chlorophyll a concentrations

3.3 Periphyton

Biomass:

The pattern of biomass of periphyton indicates low levels in spring and maximums in summer and autumn, with the exception of Forrest Beach during autumn 2002 where the level reached 11.07 g/m². During autumn and summer there was generally greater periphyton biomass at the three eastern sites (Vasse Diversion Drain, Vasse-Wonnerup and Forrest Beach) than at Quindalup, Toby Inlet or Buayanyup (**Figure 3-8**). This pattern was most evident during autumn 2001. Periphyton data appear to reflect the pattern of low spring and elevated summer and autumn nitrogen concentrations. Periphyton collectors were not deployed in winter thus no comparison with maximum nutrient levels can be made.

Carbonate content:

The carbonate content of periphyton can be used as a relative measure of the quantity of carbonate-forming algae, which are indicators of good water quality. The levels observed in this study were high (>35%), at approximately 90% or more of all sites (**Figure 3-8**), indicating good water quality during 2001 and 200. Highest levels of carbonate content were observed in spring 2001, and were as high as 62% at Toby Inlet. The lowest levels of carbonate content were observed in autumn 2002 at Forrest Beach (22.6%). Statistically, the carbonate levels were different between sites within a season, but no spatial trends were evident.

Chlorophyll a content

The chlorophyll *a* content of the periphyton growth on the collectors is shown in **Figure 3-8**. Chlorophyll *a* levels were higher in autumn than in spring, and no spatial trends were evident. Chlorophyll *a* levels in the periphyton were positively correlated with biomass ($r=0.68$ of arcsine square root transformed data).

Chlorophyll b content

Chlorophyll *b* levels were below the detection level of 0.1 mg/m². Chlorophyll *b* is present in green algae such as *Ulva* and *Cladophora* and was included in the periphyton analyses to provide a measure of the presence and abundance of these algal species indicative of nutrient enrichment. Since chlorophyll *b* was undetectable at all sites in all seasons, it is unlikely that green algae were a significant component of the periphyton assemblage on these occasions.

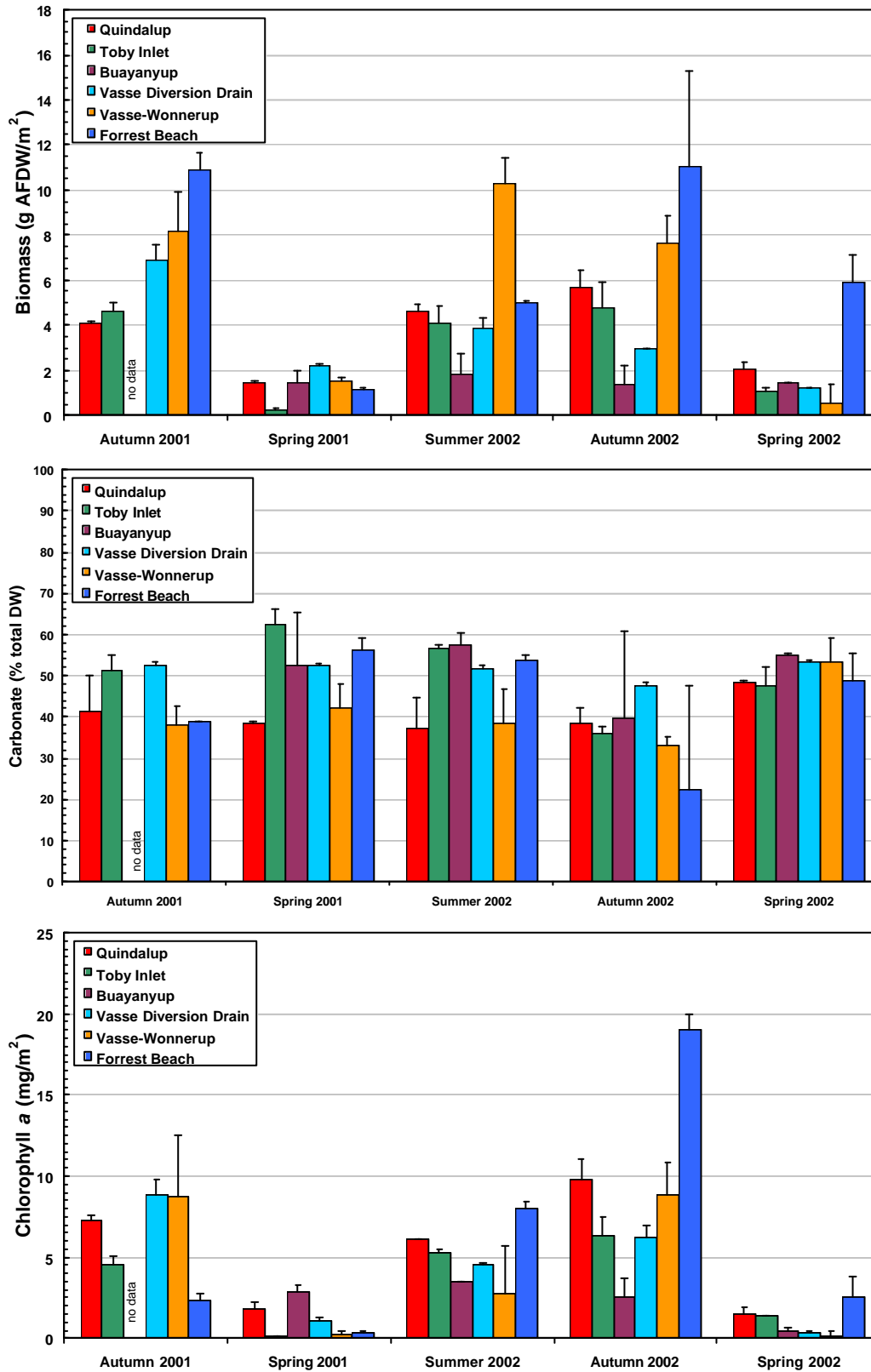


Figure 3-8 Periphyton biomass, carbonate and chlorophyll a

4. Discussion

4.1 Water Quality

The water quality in Geographe Bay is variable seasonally and spatially. The sampling locations and timing of each survey was designed to provide maximum coverage of Southern Geographe Bay over a twenty month period. The trade-off in this monitoring program is replication of sampling which prevents statistical comparisons; however, this does not prevent applying the ANZECC/ARMCANZ (2000) guidelines for the assessment of water quality.

Apart from nutrients that exceeded guidelines at selected locations (primarily Vasse Diversion Drain, Vasse-Wonnerup and Forrest Beach) during winter, Southern Geographe Bay has a water quality that can be described as slightly disturbed. The conditions during the survey differ from those reported by DAL (1995) for the Geographe Bay Study during 1993–1995. The Geographe Bay Study recorded few nutrient concentrations that exceed the ANZECC/ARMCANZ (2000) guidelines at comparable sites to this study (see **Figure 4-1**, **Figure 4-2** and **Figure 4-3**). The exceptions were as follows:

- ❑ Ammonium
 - During summer 1993–94 at Dunsborough (near Quindalup)
 - During winter 1994 at the Vasse Diversion Drain and the Vasse-Wonnerup Inlet
 - During summer 1994–95 at Forrest Beach
- ❑ Nitrate-Nitrite
 - During winter 1994 at the Vasse-Wonnerup Inlet
 - During summer 1994–95 at Dunsborough (near Quindalup)
- ❑ Total Nitrogen
 - During the winter of 1994 at the Vasse-Wonnerup Inlet

During the Geographe Bay Study there were no concentrations of filterable reactive phosphorus, total phosphorus or chlorophyll *a* that exceeded the ANZECC/ARMCANZ (2000) guidelines at any of the study locations.

By comparison, the data gathered in this study show elevated levels of all nutrients and chlorophyll *a*. Direct comparisons between the two studies are difficult as the inputs into the coastal waters of Geographe Bay fluctuate both seasonally and annually. The main influences are rates and volume of discharge water from the surface drains containing nutrients resulting from runoff during rainfall events and land use practices such as agriculture.

Rainfall in the region varies significantly between years; however, average annual rainfall during the Geographe Bay Study and during this study were similar. Based on recorded flows in a major tributary of the Vasse River, the corresponding discharges from the drains were also likely to be similar. It would therefore be expected that nutrient levels resulting from discharges from the drains would also be similar. However, from production figures, it appears that nutrient inputs into drains resulting from agricultural practices would be greater today than during the 1993–1995 Geographe Bay Study. It is likely that this increased production, tied to an increased application of fertilisers and production of livestock wastes, would ultimately increase nutrient levels in the local drainage system via runoff (see **Section 2.2**).

Nutrient levels were generally elevated in the eastern region of southern Geographe Bay. This is likely a result of increased input from catchments which drain into the Vasse-Wonnerup wetland system. However, nearshore water movement in the bay is predominantly wind driven and the influence of currents distributing nutrients cannot be discounted as affecting the gradients observed in this study.

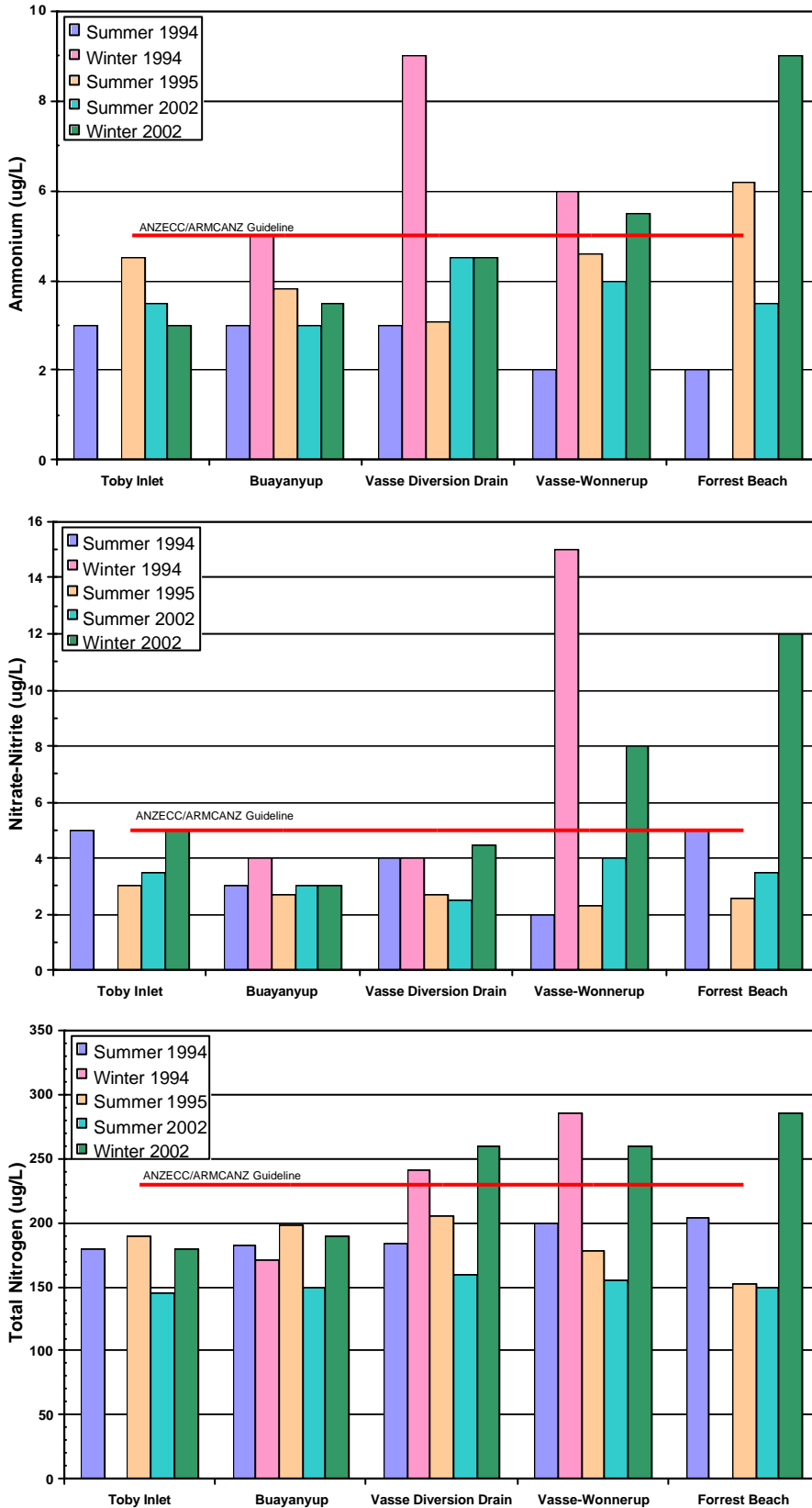


Figure 4-1 Comparison of nitrogen levels in Geographe Bay Study and this study

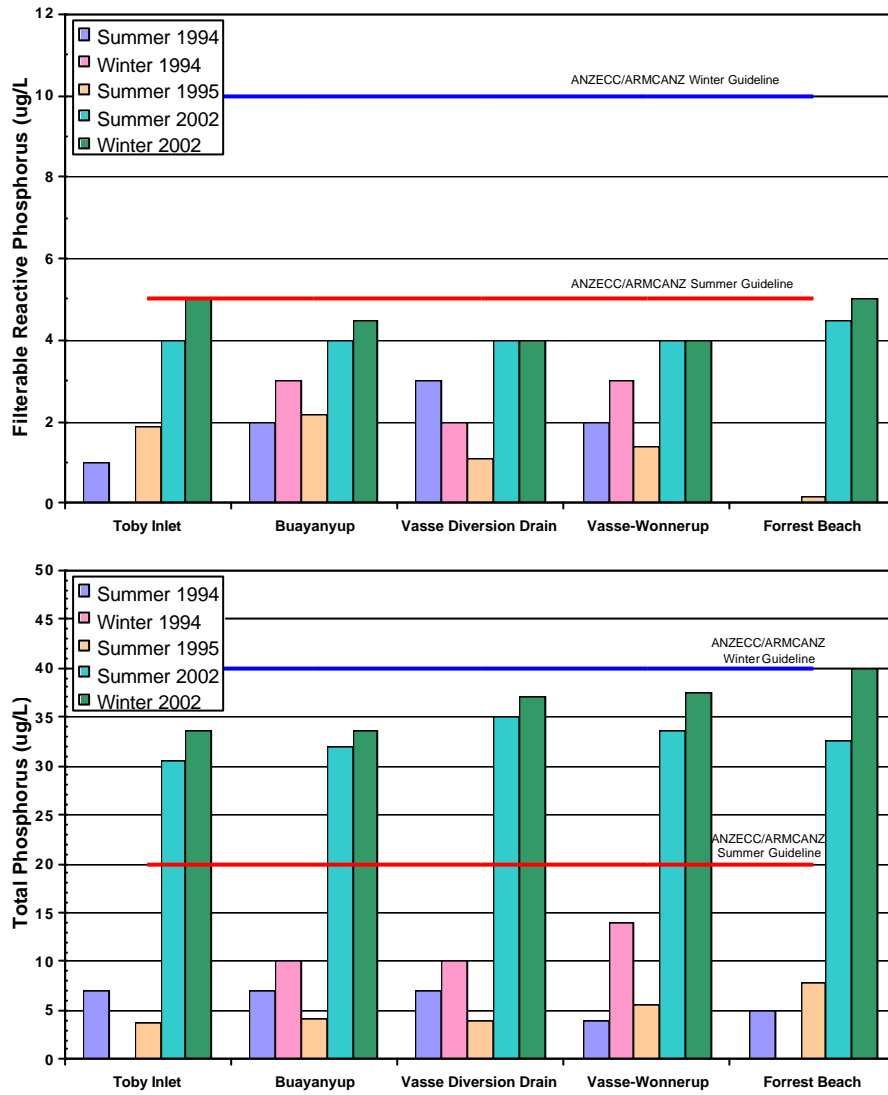


Figure 4-2 Comparison of phosphorus levels in Geographe Bay Study and this study

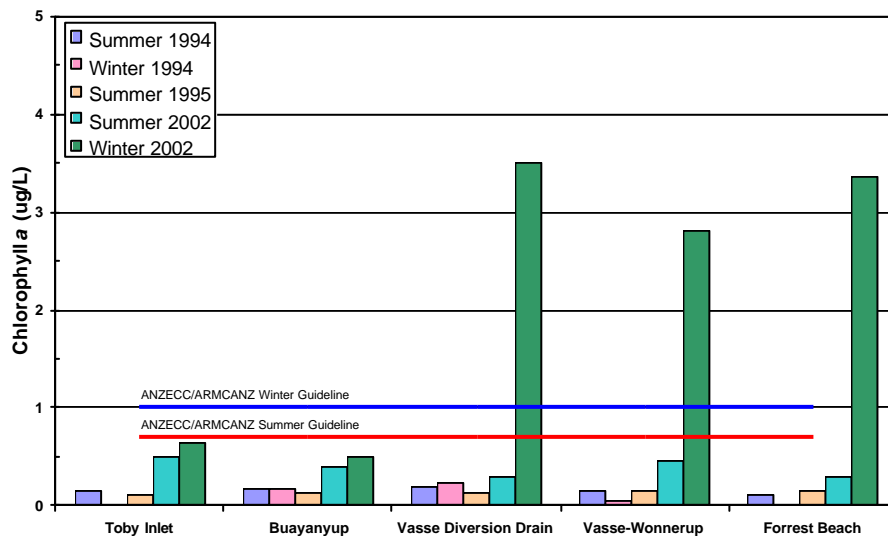


Figure 4-3 Comparison of chlorophyll a levels in Geographe Bay Study and this study

4.2 Periphyton

Periphyton gives an integrated measure of the effects of nutrients (eutrophication) and as such is a biological monitoring tool that can be used to assess potential impacts on seagrasses and other benthic communities. There are no guidelines for periphyton growth in the marine environment; however, the ANZECC/ARMCANZ (2000) guidelines state:

Where there is insufficient information on ecological effects to determine an acceptable change from the reference condition, use an appropriate percentile of the reference data distribution to derive the trigger value.

Reference locations in Southern Geographe Bay cannot be considered as controls as there are few locations which are completely unaffected by anthropogenic inputs of nutrients. However, sites to the west, such as Quindalup, should be generally less impacted.

Periphyton collectors were not deployed in winter due to the influence of winter storms in such shallow water. Periphyton is often removed by turbulence associated with winter storms. Studies in winter during the Perth Coastal Waters Study indicated that periphyton levels were very low resulting in deployments being restricted to spring through autumn. This is opposite to observations for chlorophyll *a* in the water column. High nutrient levels in winter appear to stimulate phytoplankton (planktonic microalgae) but not periphyton.

Periphyton data gathered in this study indicate highest biomass and chlorophyll *a* levels during autumn. This is generally a result of calm conditions with good water clarity, maximum water temperatures and minimal abrasion by turbulence thus promoting maximal periphyton growth.

This study indicates that the waters to the eastern end of southern Geographe Bay stimulate the growth of periphyton more than to the west. This is most likely a reflection of increased nutrients and calmer summer and autumn conditions.

4.3 Potential Effects on Seagrass

Between 1986 and 1998 there was a net gain of seagrass in southern Geographe Bay of approximately 487 ha (4%) of a total of 12,709 ha (DALSE 2003). Much of this gain (1,053 ha) was in the nearshore area between Quindalup and Busselton (**Figure 4-4**). However, losses totalling 556 ha were observed, particularly in the nearshore areas of Dunsborough and to the west of Busselton. These data were derived from aerial photography captured during early December. The lack of ground truthing, the potential for variations in mapping control rules between the two data sets and the presence of significant epiphyte loads during December by the filamentous brown algae *Hinksia mitchelliae* could contribute significantly to the variations observed. These potential errors could contribute to minor variations along the margins of the seagrass meadows; however, it is likely that the significant losses and gains in the nearshore areas are real.

Without further study there can be no causal relationship between water quality and the changes in seagrass distribution; however, the fact that the major losses occurred around the areas of southern Geographe with the greatest nutrient input is of concern.

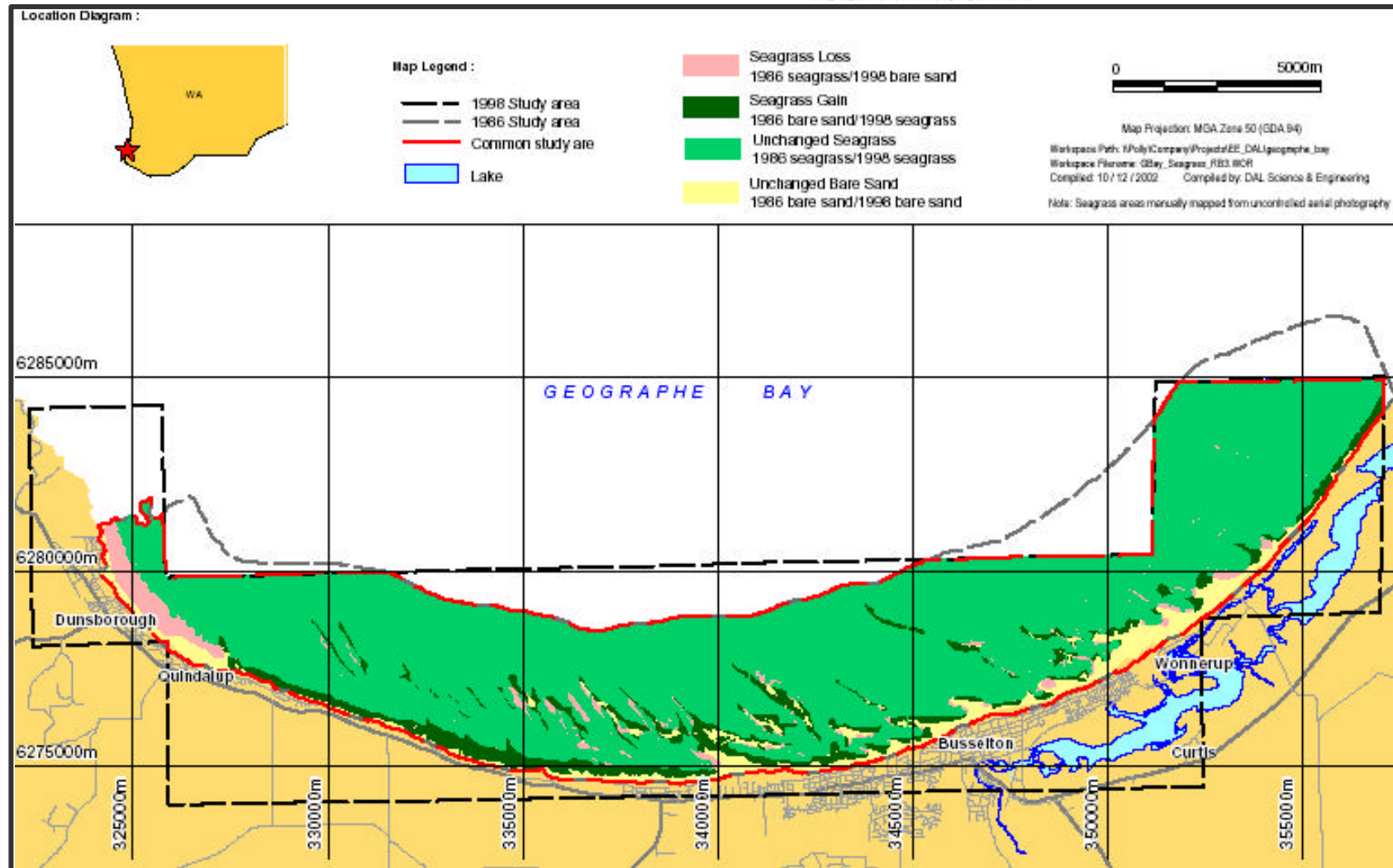


Figure 4-4 Changes in seagrass distribution in southern Geographe Bay between 1986 and 1998

Source: DALSE 2002

5. Summary

The results of this study can be summarised as follows:

Water column profiling:

- ❑ Water temperature at the six Geographe Bay sites ranged between 14–25°C with maxima in early autumn. Waters at all sites were generally well-mixed and vertical temperature stratification was evident only in November 2001 when the surface 0.6 m was warmer.
- ❑ Salinity at all six Geographe Bay sites was within the normal range for oceanic waters, and ranged between 33.1 and 37.2 ‰. There was no evidence of stratification due to salinity, as salinity varied by less than 0.7 ‰ with depth at any site on any occasion.
- ❑ Dissolved oxygen varied considerably between sites and between seasons, and ranged from 6.6 to 10.8 mg/L. Lowest dissolved oxygen concentrations were recorded in late summer to early autumn (January to March), with concentrations often below 7.5 mg/L. Some increases in dissolved oxygen with depth were observed and are likely a result of increased photosynthetic activity by benthic macrophytes.
- ❑ The water column in southern Geographe Bay is well mixed and is consistent with water quality for a coastal embayment.

Nutrient concentrations:

- ❑ Ammonium concentrations in seawater ranged between 3 and 10 µg/L. Ammonium concentrations were generally at or below the guideline value of 5 µg/L with the exception of Vasse-Wonnerup and Forrest Beach sites during winter.
- ❑ Oxidised nitrogen (nitrate-nitrite) concentrations ranged between 2 and 39 µg/L. Elevated levels in excess of the guideline value of 5 µg/L were observed primarily at the Vasse-Wonnerup and Forrest Beach sites during winter.
- ❑ Total nitrogen concentrations varied considerably between sites and sampling occasions and ranged between 100 and 300 µg/L. The three eastern sites (Vasse Diversion Drain, Vasse-Wonnerup and Forrest Beach) had maximum total nitrogen concentrations during winter 2002 with the later two sites exceeding the guideline value of 230 µg/L.
- ❑ Filterable reactive phosphorus concentrations ranged between 3 and 6 µg/L, and did not show any seasonal or spatial trends. All sites were below the guideline values with the exception of Quindalup during January 2002.
- ❑ Total phosphorus concentrations at the six sites ranged from 26 to 41 µg/L. The three eastern sites (Vasse Diversion Drain, Vasse-Wonnerup and Forrest Beach) showed the greatest variation in total phosphorus concentrations between sampling occasions. All sites exceeded the guideline value during summer.
- ❑ Chlorophyll *a* concentrations at the six sites ranged between 0.1 and 4.8 µg/L. Levels of chlorophyll *a* exceeded guidelines at the eastern sites (Vasse Diversion Drain, Vasse-Wonnerup and Forrest Beach) during the winters. Chlorophyll *a* concentrations at the western sites (Quindalup, Toby Inlet and Buayanyup) were always at or below the guideline trigger value, with the exception of Quindalup during August 2002.
- ❑ The water quality in Geographe Bay is variable seasonally and spatially. Apart from nutrient levels exceeding guidelines at selected locations (primarily Vasse Diversion Drain, Vasse-Wonnerup and Forrest Beach) during winter, Southern Geographe Bay has a water quality that can be described as slightly disturbed.

- The conditions during the survey differ from those reported for the Geographe Bay Study during 1993–1995. The Geographe Bay Study recorded few nutrient concentrations that exceed the ANZECC/ARMCANZ (2000) guidelines at comparable sites to this study.

Periphyton:

- The pattern of periphyton biomass indicates low levels in spring and maximums in summer and autumn. During autumn and summer there was generally greater periphyton biomass at the three eastern sites (Vasse Diversion Drain, Vasse-Wonnerup and Forrest Beach) than at Quindalup, Toby Inlet or Buayanyup. Periphyton data appear to reflect the pattern of low spring and elevated summer and autumn nitrogen concentrations.
- Highest levels of carbonate content were observed in spring 2001, and were as high as 62% at Toby Inlet. The lowest levels of carbonate content were observed in autumn 2002 at Forrest Beach (22.6%). Statistically, the carbonate levels were different between sites within a season, but no spatial trends were evident. High carbonate levels is a measure of the quantity of carbonate forming algae, which are indicators of good water quality.
- Chlorophyll *a* levels were higher in autumn than in spring, and while no spatial trends were evident chlorophyll *a* levels were positively correlated with biomass. Chlorophyll *b* levels were below the detection level of 0.1 mg/m².
- This study indicates that the waters to the eastern end of southern Geographe Bay stimulate the growth of periphyton more than to the west. This is most likely a reflection of increased nutrients and calmer summer and autumn conditions.

Potential effects on seagrass:

- Between 1986 and 1998 there was a net gain of seagrass in southern Geographe Bay of approximately 487 ha (4%) of a total of 12,709 ha. Much of this gain (1,053 ha) was in the nearshore area between Quindalup and Busselton. However, losses totalling 556 ha were observed, particularly in the nearshore areas of Dunsborough and to the East of Busselton.
- Without further study there can be no causal relationship between water quality and the changes in seagrass distribution. However, major losses of seagrass, which occurred around the areas of Southern Geographe Bay with the greatest nutrient input is of note for future investigations. In addition, the habitat mapping for 1998 was not ground truthed.

6. References

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Appendix A Laboratory Reports