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Alkimos Marine Studies Programme

Interim Water Quality Characterisation Data Report

December 2004 to July 2005

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Interim Water Quality Characterisation Data Report

December 2004 to July 2005

Prepared for:

Water Corporation of Western Australia

Prepared by:

Oceanica Consulting Pty Ltd

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1. Introduction

In December 2004, Oceanica Pty Ltd were contracted by the Water Corporation of Western Australia (Water Corporation) to assess the marine water quality in the vicinity of a proposed treated wastewater ocean outlet at Alkimos, Western Australia. This Water Quality Characterisation programme is part of a group of studies aimed at assessing the impacts on the marine environment from the proposed outlet. Other marine studies conducted as part of the Alkimos Marine Studies Programme are:

- Phytoplankton Surveys (December 2004 to ongoing);
- Benthic Habitat Mapping (February 2005);
- Sediment Survey (February 2005);
- Groundwater Infiltration to Marine Sediments (May 2005);
- Hydrodynamic Modelling (Worley Parsons);
- Data management (including uploading of data to 'Seabase');
- Oceanographic Measurements (supporting hydrodynamic modelling and the PER); and
- Public Environmental Review (PER) document.

1.1 Background

In the 1970's the Water Corporation identified the need for a wastewater treatment plant (WWTP) to service the planned residential growth in Perth's North West Metropolitan Corridor. Following evaluation of several different options, the Water Corporation selected Alkimos Lot 101 as the preferred site for what will be known as the Alkimos WWTP, and finalised the acquisition of this site from the Urban Land Council in 1987 (Figure 1.1).

An "in principle agreement" was formalised on the 29th June 2001 with the signing of the Alkimos Eglinton Relocation, Construction and Development Agreement between the Water Corporation, LandCorp and Eglinton Estates (the principal landowners within the structure plan area). This agreement identified the Alkimos WWTP site as acceptable to all parties.

Projected growth in the catchment indicates that approximately 80 ML/d will require treatment at the Alkimos WWTP by 2050. Ultimately plant inflows could grow to 160 ML/d.

1.2 Objectives

The objective of the Water Quality Characterisation component of the Alkimos Marine Studies Programme was to undertake regular field measurements over the period December 2004-November 2005 to characterise the water quality of the marine waters around the proposed Alkimos Wastewater Treatment Plant (WWTP) Ocean Outlet.

The project provides background information on the seasonal and spatial variability in water quality (nutrients, primary productivity and microbiological indicators) in the Alkimos region, which are comparable with data collected at Perth's other ocean outlets (Ocean Reef, Swanbourne and Sepia Depression) through the Perth Ocean Outlet Monitoring (PLOOM) Programme.

It is anticipated that information from the ongoing water quality sampling and analysis programme will be used in the future identification of suitable management criteria for marine water quality at Alkimos.

This interim data report has been generated to provide water quality characterisation information for inclusion in the "*Alkimos Waste Water Treatment Plant - Public Environmental Review*" (Water Corporation 2005a).

The collected data from December 2004 to July 2005 will used to:

- Establish the existing water quality conditions in the Alkimos region prior to the construction and operation of the proposed Alkimos WWTP Ocean Outlet; and,
- Assess the potential effects of the treated wastewater discharge on the marine receiving environment.

1.3 Key Tasks

1. Nutrient-Related Water Quality Surveys:

Nutrient-related water quality surveys were undertaken at each of the six shoreline sites, six near-shore (~9.5-12.5 m) and six offshore (~14-15.5 m) sites at monthly intervals over the period December 2004-July 2005.

2. Human-Health Water Quality Surveys:

Human-health water quality surveys (microbiological sampling) were undertaken at monthly intervals over summer 2004-2005 (December-May) at each of the 6 shoreline sites, 6 near-shore and 6 offshore sites. Microbiological sampling was not undertaken during the winter months as this is outside of the prime recreational swimming season.

3. Preparation of a Water Quality Characterisation Report:

An interim Water Quality Characterisation Data Report was prepared (this document) including details on the field methods, analytical techniques, results, and a detailed description and interpretation of the water quality conditions over the study period.

The sampling results are presented graphically to assist with interpretation. All the data collected during the sampling programme is tabulated and presented in the appendix sections of this report.

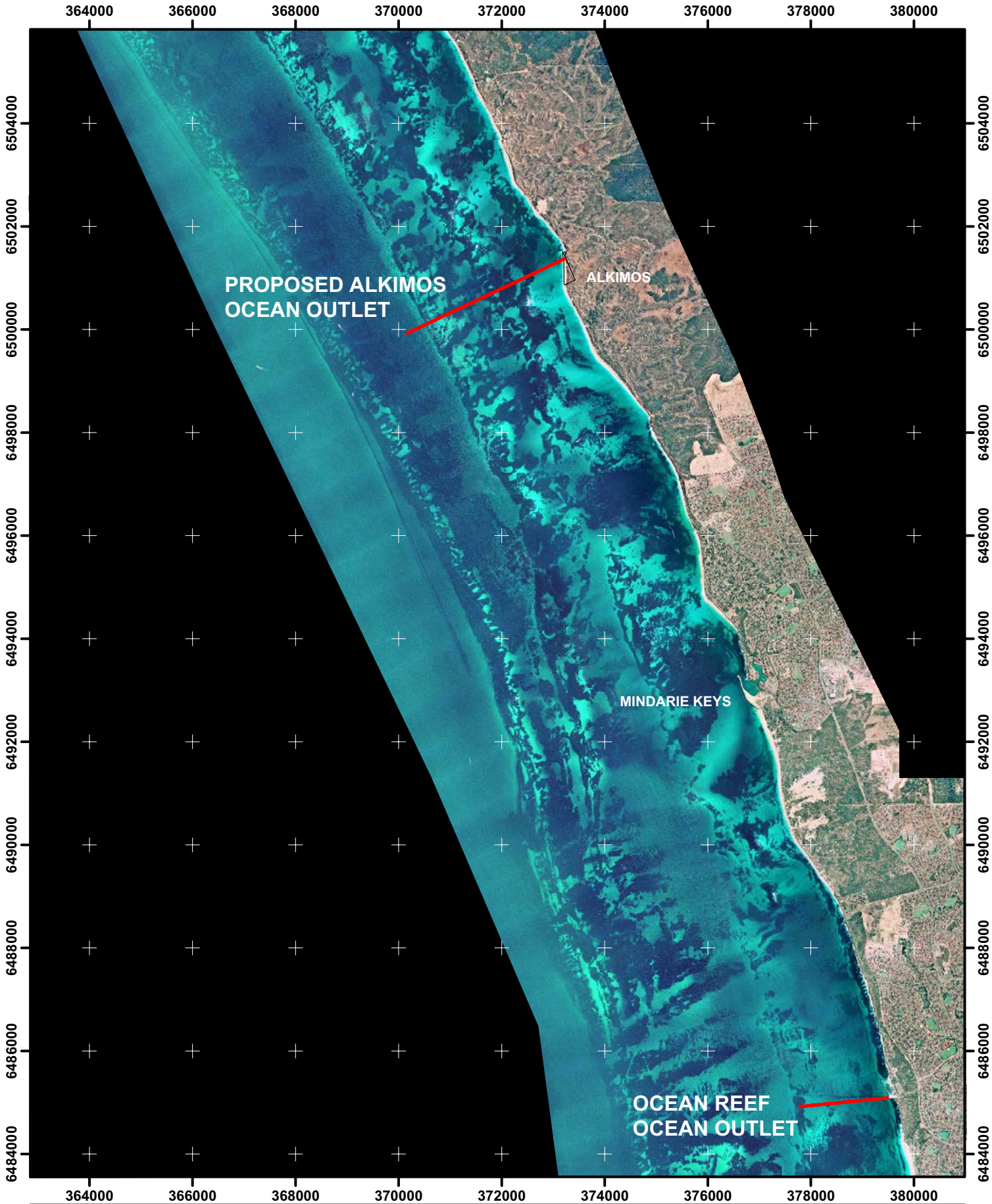

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Figure 1.1 Alkimos and Ocean Reef.mxd

0 1 2 4 Kilometers

DATUM
Horizontal: UTM Zone 50,
Based on WGS 84
Vertical: N/A

2

Figure 1.1

Alkimos location
and aerial photograph.

Client: Water Corporation
June 2005

2. Methods

2.1 Field Sites

Water quality sampling sites were chosen to provide a representative sample of shoreline, nearshore and offshore waters in the vicinity of the proposed Alkimos Ocean Outlet (AOO). Figure 2.1 displays the location of the water quality monitoring sites with the site coordinates provided in Appendix A.

2.2 Water Quality Sampling

On each sampling event, at each of the six nearshore and six offshore water quality sampling sites, water samples were collected from the surface (approximately 1 m below the surface) and bottom (approximately 2 m above the seafloor) of the water column. Water samples were collected with a Rule (2.1 L/s) submersible pump, which was flushed with seawater for 30 s (>10 tubing volumes) prior to collection of the sample at each depth and site.

On the first sampling occasion in December 2004, at one nearshore and one offshore site, an additional depth-integrated sample was collected over the top half of the water column as part of method justification.

At each of the shoreline sites, water samples were collected by filling sample containers directly in waist-deep water.

The following samples were collected from each depth at each of the sampling sites:

- Two 125 mL unfiltered samples in HDPE bottles for total phosphorus and total nitrogen analysis;
- Two 10 mL filtered (through a 45 µm filter onsite) samples in PP tubes for ortho-phosphate, ammonium and nitrate + nitrite analysis;
- One 4-10 L filtered (through a GF/C filter onsite) sample for chlorophyll-*a* and phaeophytin analysis; and
- One pre-sterilised 250 mL plastic bottle for thermo-tolerant coliform and enterococci analysis.

With the exception of the pre-sterilised sample bottles used for the microbiological analyses, all the sample containers were flushed with seawater at each site prior to filling. Immediately after collection all the samples were placed on ice out of direct sunlight.

All sampling was conducted in general accordance with the standard operating procedures developed for Cockburn Sound (EPA 2005a).

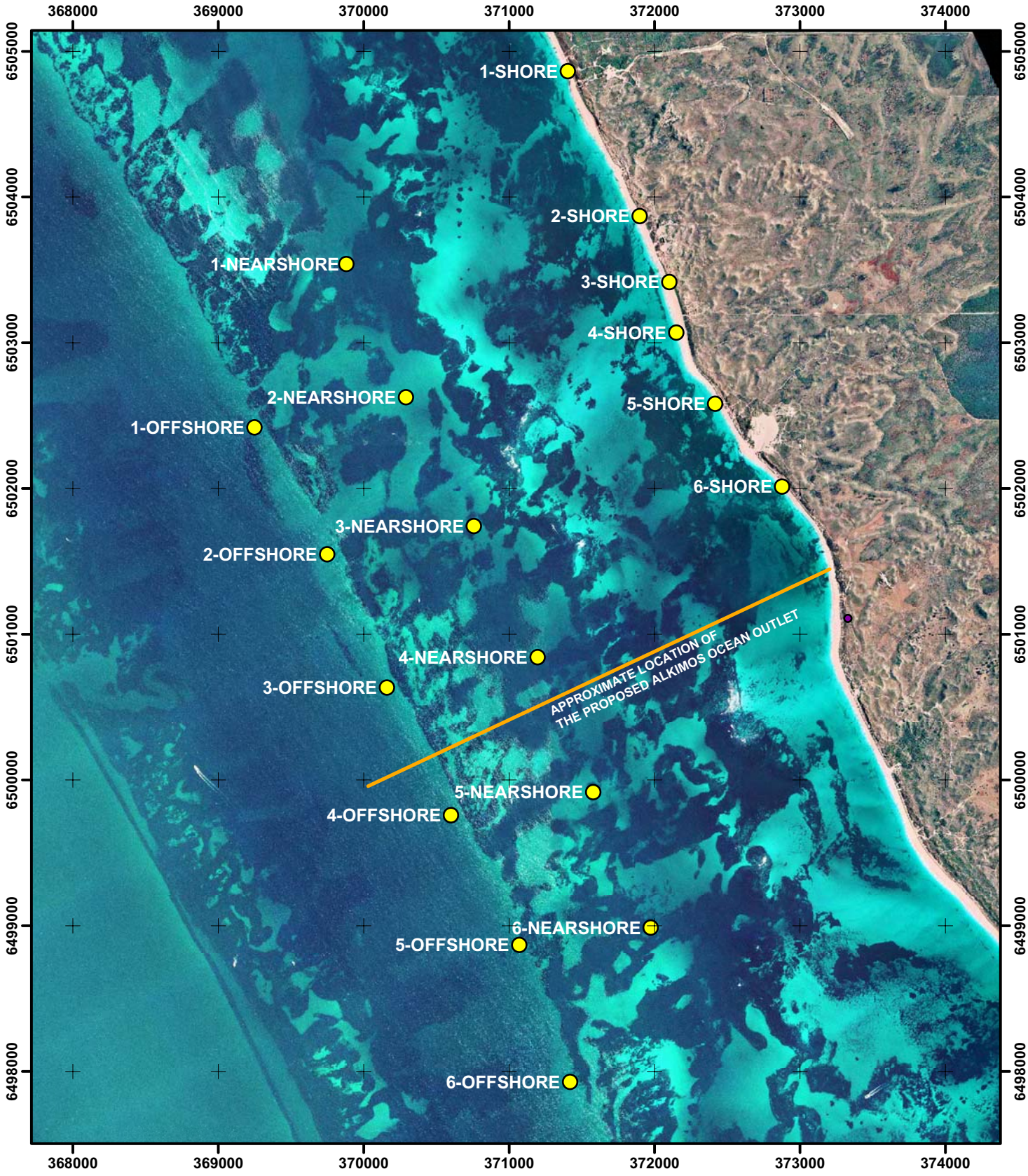
Table 2.1 summarises the parameters measured on each sampling event between December 2004 and May 2005.

Table 2.1 Parameters measured for each sampling event

Parameter	20/12/04	19/01/05	10/02/05	17/03/05	21/04/05	12/05/05	22/06/05	19/07/05
Physical Profiles								
Temperature (^{o}C)	✓	✓	✓	✓	✓	✓	✓	✓
Salinity (ppt)	✓	✓	✓	✓	✓	✓	✓	✓
Dissolved Oxygen (%, mg/L)	✓	✓	✓	✓	✓	✓	✓	✓
Secchi (m)	✓	✓	✓	✓	✓	✓	✓	✓
Light Attenuation (log_{10} m^{-1})	✓	✓	✓	✓	✓	✓	✓	✓
Wind (m/s, direction)	✓	✓	✓	✓	✓	✓	✓	✓
Weather (observations)	✓	✓	✓	✓	✓	✓	✓	✓
Nutrients								
Total Phosphorus (μg P/ L)	✓	✓	✓	✓	✓	✓	✓	✓
Ortho-Phosphate (μg P/ L)	✓	✓	✓	✓	✓	✓	✓	✓
Total Nitrogen (μg N/ L)	✓	✓	✓	✓	✓	✓	✓	✓
Ammonia[1] (μg N/L)	✓	✓	✓	✓	✓	✓	✓	✓
Nitrate + Nitrite (μg N/ L)	✓	✓	✓	✓	✓	✓	✓	✓
Primary Production								
Chlorophyll-*a* (μg/L)	✓	✓	✓	✓	✓	✓	✓	✓
Phaeophytin (μg/L)	✓	✓	✓	✓	✓	✓	✓	✓
Microbiological								
Thermo-Tolerant Coliforms (CFU/100 mL)	✓	✓	✓	✓	✓	✓		
Faecal streptococci (as enterococci) (MPN/100 mL)	✓	✓	✓	✓	✓	✓		

Notes:

1. The method used for detection of ammonium actually converts all ammonium to ammonia and data is reported as ammonia. At the pH of seawater NH_x species are predominantly ammonium (Libes 1992).



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P:\Water Corporation\Alkimos\Water Quality Figure 2.1 Alkimos WQ sites.mxd

Meters
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DATUM
Horizontal: UTM Zone 50, Based on WGS 84
Vertical: N/A

2

Figure 2.1

Alkimos Water Quality Sampling Sites

Client: Water Corporation
June 2005

2.3 Laboratory Analysis

The water samples were analysed for the following suite of parameters:

Nutrients

- Total Phosphorus
- Filterable Reactive Phosphorus
- Total Nitrogen
- Ammonium Nitrogen
- Nitrate + Nitrite Nitrogen

Primary Production

- Chlorophyll-*a*
- Phaeophytin

Microbiological Indicators

- Thermo-tolerant Coliforms
- Faecal Streptococci (as Enterococci)

Standard laboratory analytical procedures were employed throughout (see Table 2.2). All nutrient, primary production and microbiological parameters were measured using NATA certified procedures.

Table 2.2 Analytical methods and reporting limits for each of the water quality parameters measured

Parameter	Analytical Method[1]	Reporting Limit	Unit
Nutrients			
Total Phosphorus	Lachat-Automated Flow Injection Analyser (4700)	5[2]	μg P L^{-1}
Filterable Reactive Phosphorus	Lachat-Automated Flow Injection Analyser (4100)	2[2]	μg P L^{-1}
Total Nitrogen	Lachat-Automated Flow Injection Analyser (2700)	50[2]	μg N L^{-1}
Ammonium	Lachat-Automated Flow Injection Analyser (2000)	3[2]	μg N L^{-1}
Nitrate + Nitrite	Lachat-Automated Flow Injection Analyser (2100)	2[2]	μg N L^{-1}
Primary Production			
Chlorophyll-*a*	Acetone extraction (3000)	0.1[2]	μg L^{-1}
Phaeophytin	Acetone extraction (3000)	0.1[2]	μg L^{-1}
Microbiological Indicators			
Thermo-tolerant Coliforms	Membrane filtration	Dilution dependent[3]	CFU 100 mL^{-1}
Faecal streptococci (as Enterococci)	Membrane filtration	Dilution dependent[3]	MPN 100 mL^{-1}

Notes:

1. *Numbers in brackets refer to the MAFRL analysis method number.*
2. *Method detection limit determined from 3.2 x standard deviation of 10 standard samples.*
3. *The upper and lower detection limits for thermo-tolerant coliform and faecal streptococci are dependent on the dilution of the original sample.*

2.4 Water Column Structure

On each sampling occasion at each of the six nearshore and six offshore sites, a YSI 6600/YSI 600XL multi-parameter water quality sensor was lowered through the water column to provide *in situ* information on the physical structure of the water column.

At each site the following water column measurements were obtained:

- Light intensity profile (to provide vertical light attenuation coefficients);

- Salinity depth profile;
- Temperature depth profile;
- Dissolved oxygen depth profile; and
- Secchi depth (measured by lowering a Secchi disk to limit of visibility).

2.5 Weather Conditions

Sampling was undertaken over the summer, autumn and winter months (December 2004-July 2005) in generally fair conditions (daily average wind speed < 8 m/s). Figure 2.2 displays a summary of the wind speed and direction at Ocean Reef for the seven days preceding each sampling event.

It can be seen from the December 2004 to February 2005 (summer) wind data that a strong southerly component existed prior to sampling, likely to drive northerly surface currents in the study area. A change to lighter easterly winds predominated in March 2005, possibly driving localised upwelling of bottom waters near the coast. A return to southerly winds was seen prior to the April 2005 sampling event although somewhat lighter than southerlies seen during summer. Easterlies and a northerly component dominated prior to the May 2005 sampling event. The northerlies were relatively light (<8 m/s) and unlikely to produce significant southerly wind driven surface currents. Lighter north-easterlies (<8 m/s) and stronger southerlies (>10 m/s) dominated prior to the June sampling event and strong westerlies prior to the July 2005 sampling. Strong westerlies are likely to drive surface, longshore currents with periodic "rips" drawing shoreline surface waters into the nearshore / offshore zone.

2.6 Data Management and Analysis

The data from the Water Quality Characterisation Project were verified, validated and then formatted to be suitable for uploading and importation into 'Seabase'. Verification of data involved ensuring all requested parameters were returned for the required sites, dates and depths and that the required analytical methods were used. The values for required parameters were checked for outliers and inconsistencies through graphing of the data. At the time of reporting some data was awaiting validation and repeat analysis where required. All water quality data will be uploaded to 'Seabase' when QA/QC requirements are met.

All raw data is held on file at Oceanica in either hardcopy or electronic form.

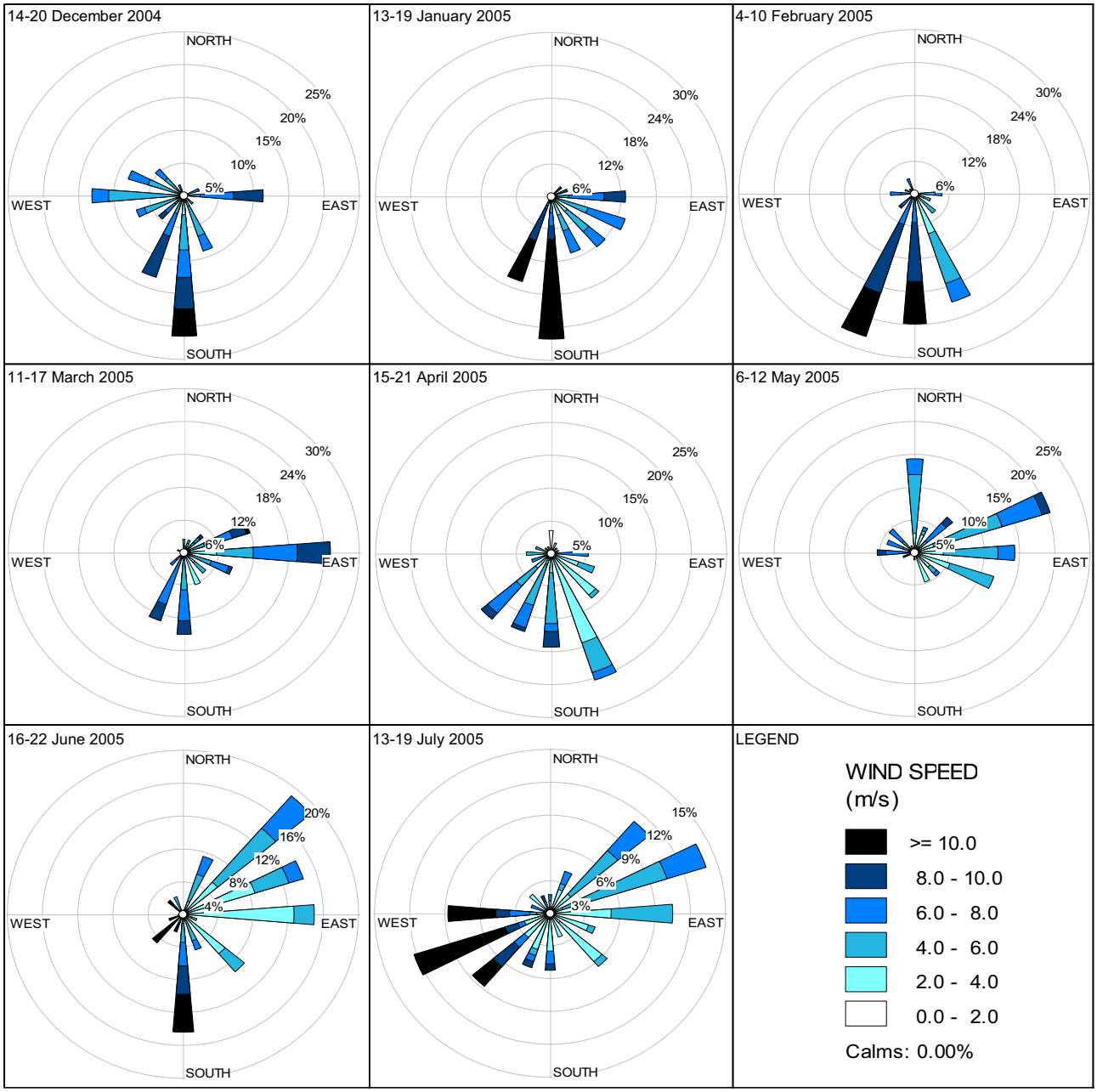


Figure 2.2 Summary of Wind Speed and Direction at Ocean Reef for the 7 days prior to each sampling event (December 2004 to July 2005)

Note: Data supplied by Climate and Consultative Services, Bureau of Meteorology, Perth, Western Australia (email dated 1 June 2005 and 26 Aug 2005). Wind speed and directions binned from hourly averaged data. Wind roses indicate the direction wind was blowing "from".

3. Results

3.1 Water Column Structure

The temperature, salinity and dissolved oxygen (DO) profiles for all twelve deeper water sites (Nearshore 1-6 and Offshore 1- 6) are presented graphically in Figures 3.1 to 3.8. Figure 3.9 displays a summary of the mean temperature, salinity and DO concentrations for surface and bottom waters between December 2004 and July 2005.

For the majority of the sampling events the water column was well mixed at both nearshore and offshore sites. Notable exceptions were on 20 December 2004, 21 April 2005 and 19 July 2005. On these dates a change in water temperature (thermocline) and slight change in salinity (halocline) was evident at between 2 m to 8 m depth in December (most conspicuous offshore, Figure 3.1b), 4 m to 8 m (nearshore) and 8 m to bottom (offshore) in April (Figures 3.5a and 3.5b) and 7 m to 12 m offshore in July (Figure 3.8e).

Water temperature ranged from a maximum of 23.26 ^{o}C on 20 December 2004 (site Nearshore-5 surface waters) to a minimum of 16.11 ^{o}C on 22 June 2005 (site Nearshore-2 bottom waters). As would be expected due to solar insolation at the surface, bottom waters (<1 m above bottom of profiles) were cooler than surface waters (<1 m below surface) for both nearshore and offshore sites. The average temperature difference between surface and bottom waters was 0.13 ^{o}C (standard deviation = 0.16) for nearshore and 0.18 ^{o}C (standard deviation = 0.22) for offshore sites (Figure 3.9a). Water temperature varied between 22.1 ^{o}C and 23.2 ^{o}C over the summer, dropping ~ 2 ^{o}C over the autumn period (17 March to 12 May 2005) (Figure 3.9a). A further ~ 3 ^{o}C drop in average water temperature was observed from autumn to winter (12 May 2005 to 22 June 2005)(Figure 3.9a).

Salinity ranged from a maximum of 36.77 ppt (calculated units) on 10 February 2005 at site Nearshore-3 (throughout the water column) (Figure 3.3c) to a minimum of 35.22 ppt on 22 June 2005 in surface waters at site Offshore-6 (Figure 3.7d). Salinity displayed a similar behaviour to temperature over the study period with a maximum occurring on 10 February 2005 and a steady decrease over the autumn /winter from 10 February to 22 June 2005 (Figure 3.9b). Salinity was routinely higher at the nearshore sites in comparison to the offshore sites with the exception of 19 January and 12 May 2005 where the water column appears to have been well mixed both horizontally and vertically within the sampling area.

3.2 Dissolved Oxygen

Dissolved Oxygen (DO) profiles for the twelve deeper water sites (Nearshore 1-6 and Offshore 1-6) are presented graphically in Figures 3.1(e-h) to 3.8(e-h). A summary of the mean DO saturation (%) over the reporting period is presented in Figure 3.9c.

Waters within the sampling area remained well oxygenated throughout the monitoring period. The lowest recorded oxygen saturation was 87.4 % in the bottom waters of site Nearshore-4 on 17 March 2005. The maximum recorded DO saturation was 117.1 % at site Nearshore 6 on 20 December 2005. On this date, Nearshore-6 exhibited a distinct increase in DO concentration (0.6 mg/L increase) in the water column between 5 m and 11 m that was notably absent from other sites. A

general reduction in DO saturation was observed over the autumn of 2005 at both nearshore and offshore sites (Figure 3.9c). DO saturation increased to above 100 % in July 2005, likely due to vertical mixing bringing the colder winter waters into equilibrium with the atmosphere.

On 19 July 2005 site Offshore-6 exhibited an increase in DO concentrations from the surface to a depth of ~12 m. This pattern was not observed in any of the other five offshore sites whose DO profiles displayed a relatively uniform DO concentration with depth (Figure 3.8h). Temperature profiles from the same date (Figure 3.8b) show that the warmer surface layer was mixed deeper at Offshore-6 than at most other offshore sites.

Using statistical analysis (paired t-tests) to determine differences between surface (<1 m deep) and bottom (<1 m above bottom of profile) water, the influence of temperature and salinity on DO saturation was apparent. While the DO concentration (in mg/L) was not significantly different between surface and bottom waters ($P = 0.12$, $n = 72$), the percent DO saturation (as a function of water temperature, salinity and depth) was significantly different ($P = 0.015$, $n = 72$). This result is expected as the cooler bottom waters (with greater dissolved oxygen holding capacity) are primarily supplied with dissolved oxygen from the warmer surface waters.

The median DO concentrations in surface (~0.5 m bellow surface) and bottom (~0.5 m above the bottom) waters were above the ANZACC/ARMCANZ (2000) guideline for coastal marine waters of >90 % saturation. While site Nearshore-4 displayed DO saturation levels at slightly less than 90 % (17 March 2005), these low levels were only recorded for this single site on the one sampling event.

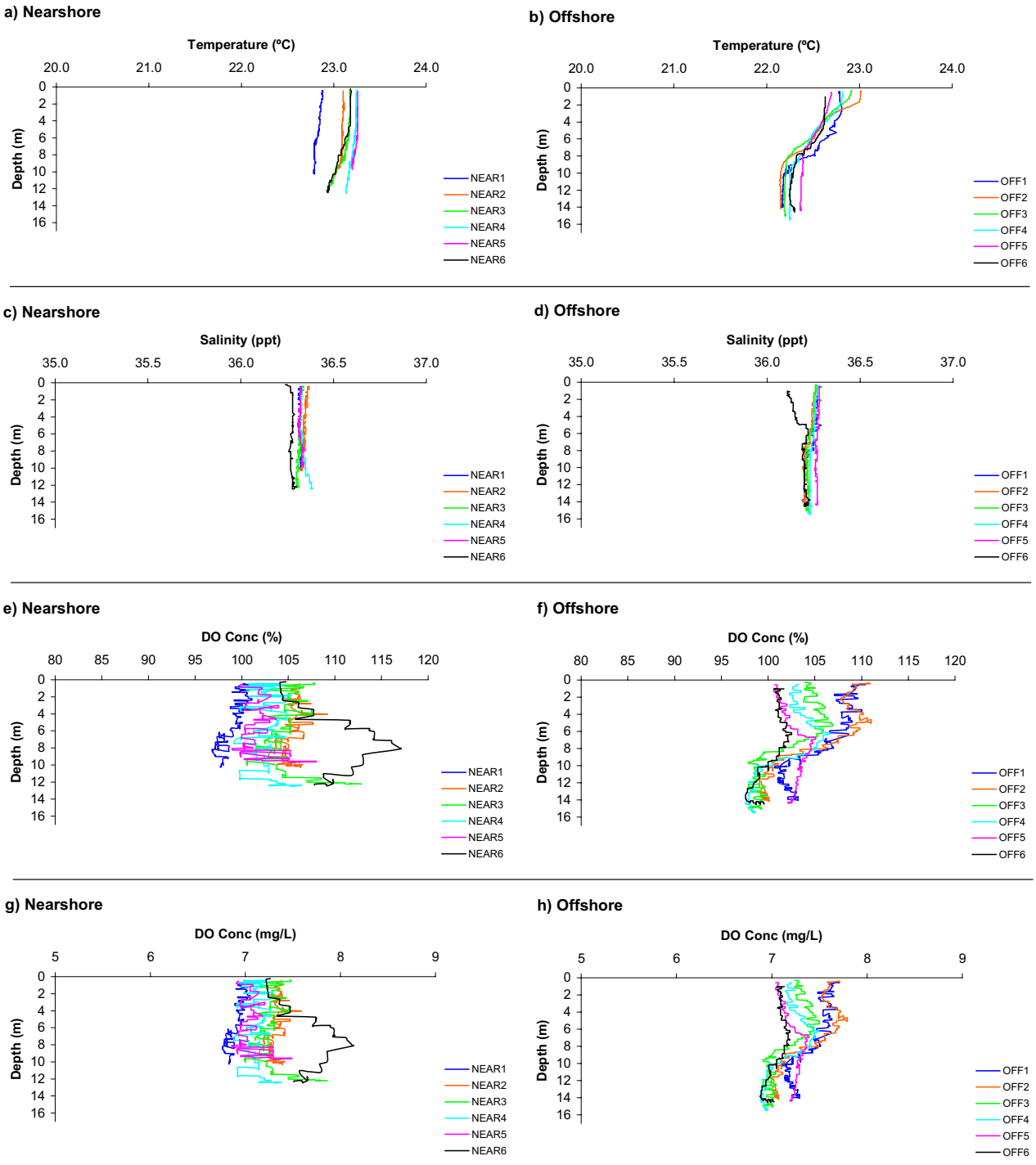


Figure 3.1(a-h) Temperature, Salinity, DO saturation and DO concentration for Alkimos water quality sites – 20 December 2004

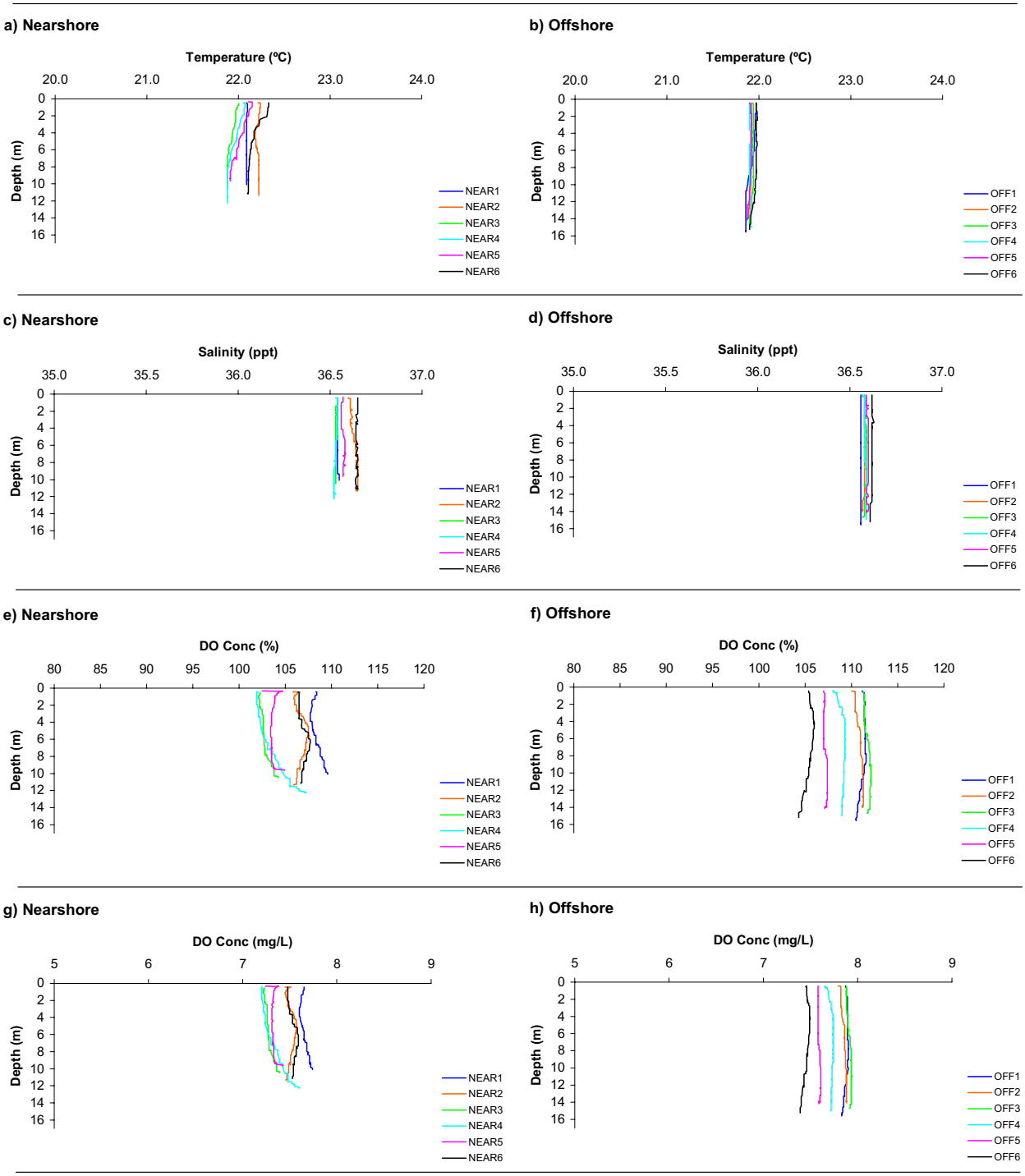


Figure 3.2(a-h) Temperature, Salinity, DO saturation and DO concentration for Alkimos water quality sites – 19 January 2005

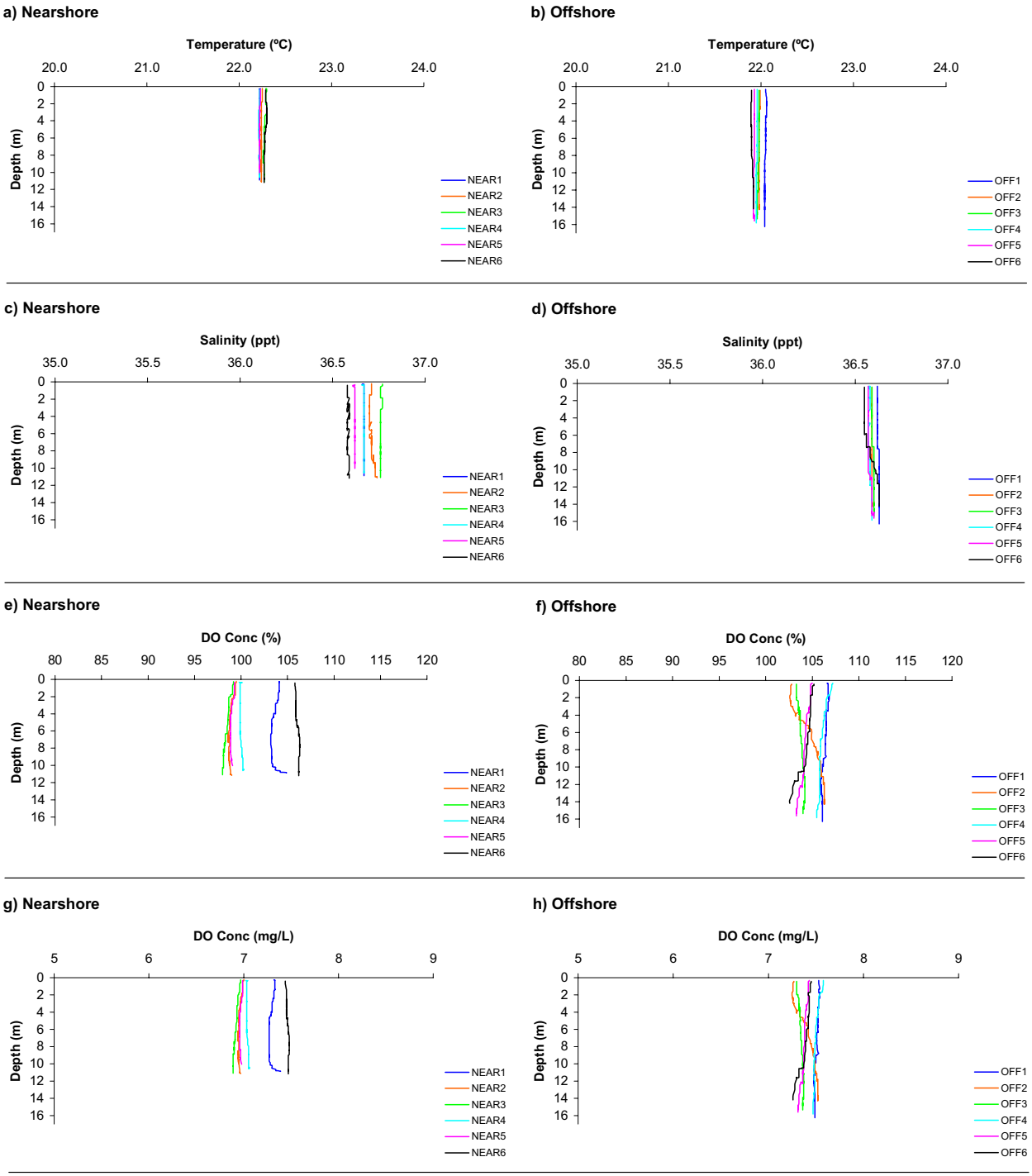


Figure 3.3(a-h) Temperature, Salinity, DO saturation and DO concentration for Alkimos water quality sites – 10 February 2005

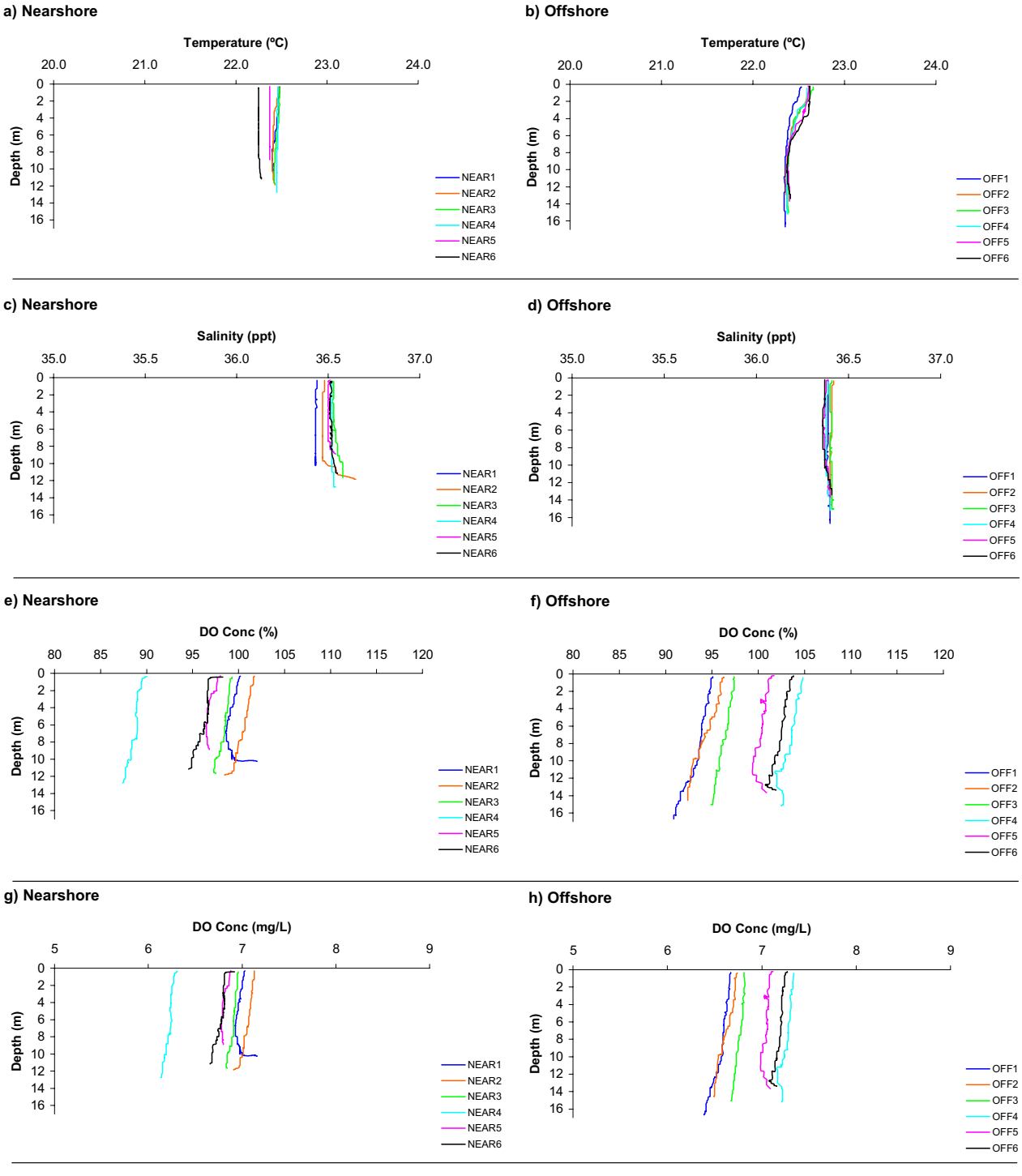


Figure 3.4(a-h) Temperature, Salinity, DO saturation and DO concentration for Alkimos water quality sites – 17 March 2005

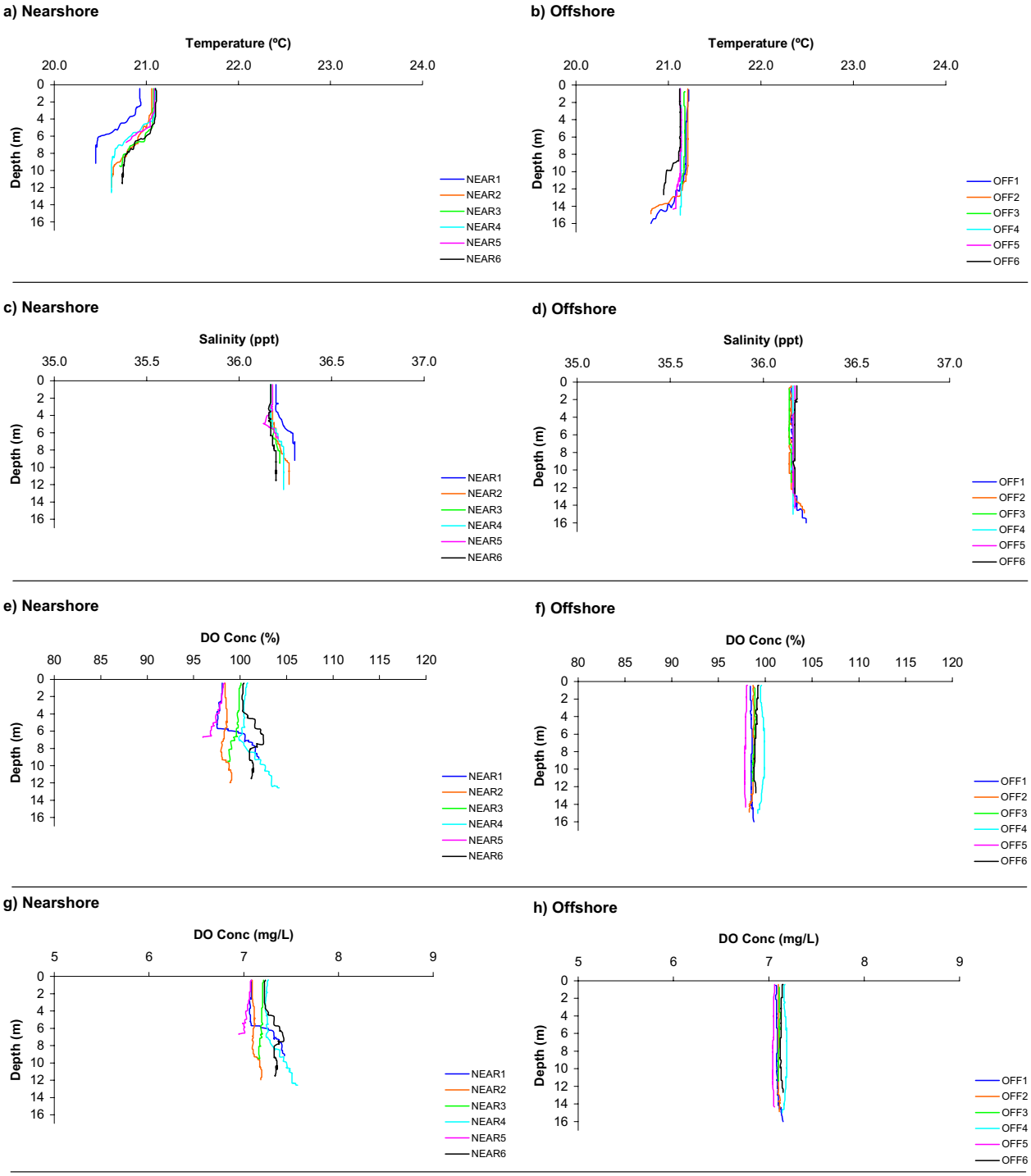


Figure 3.5(a-h) Temperature, Salinity, DO saturation and DO concentration for Alkimos water quality sites – 21 April 2005

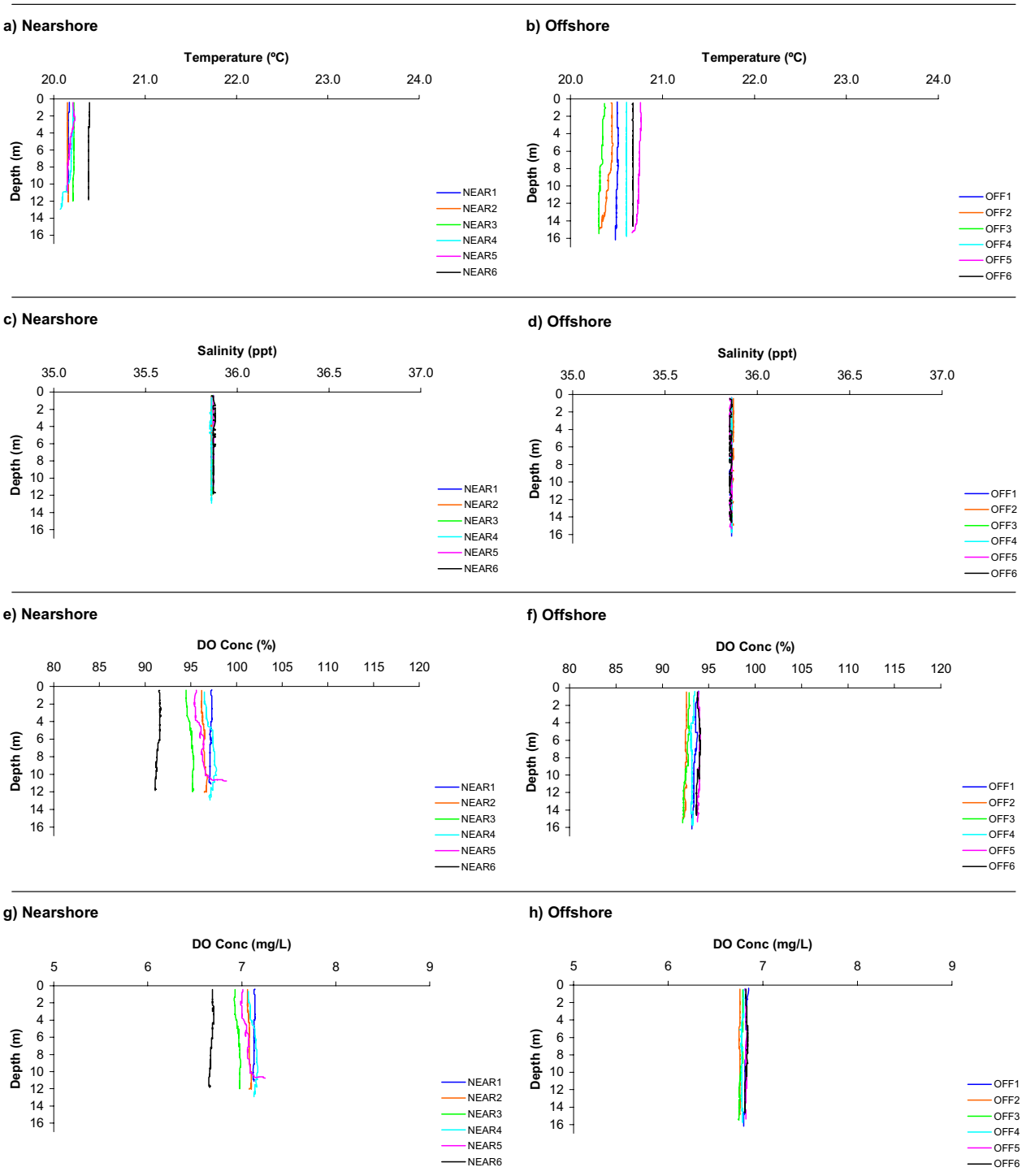


Figure 3.6(a-h) Temperature, Salinity, DO saturation and DO concentration for Alkimos water quality sites – 12 May 2005

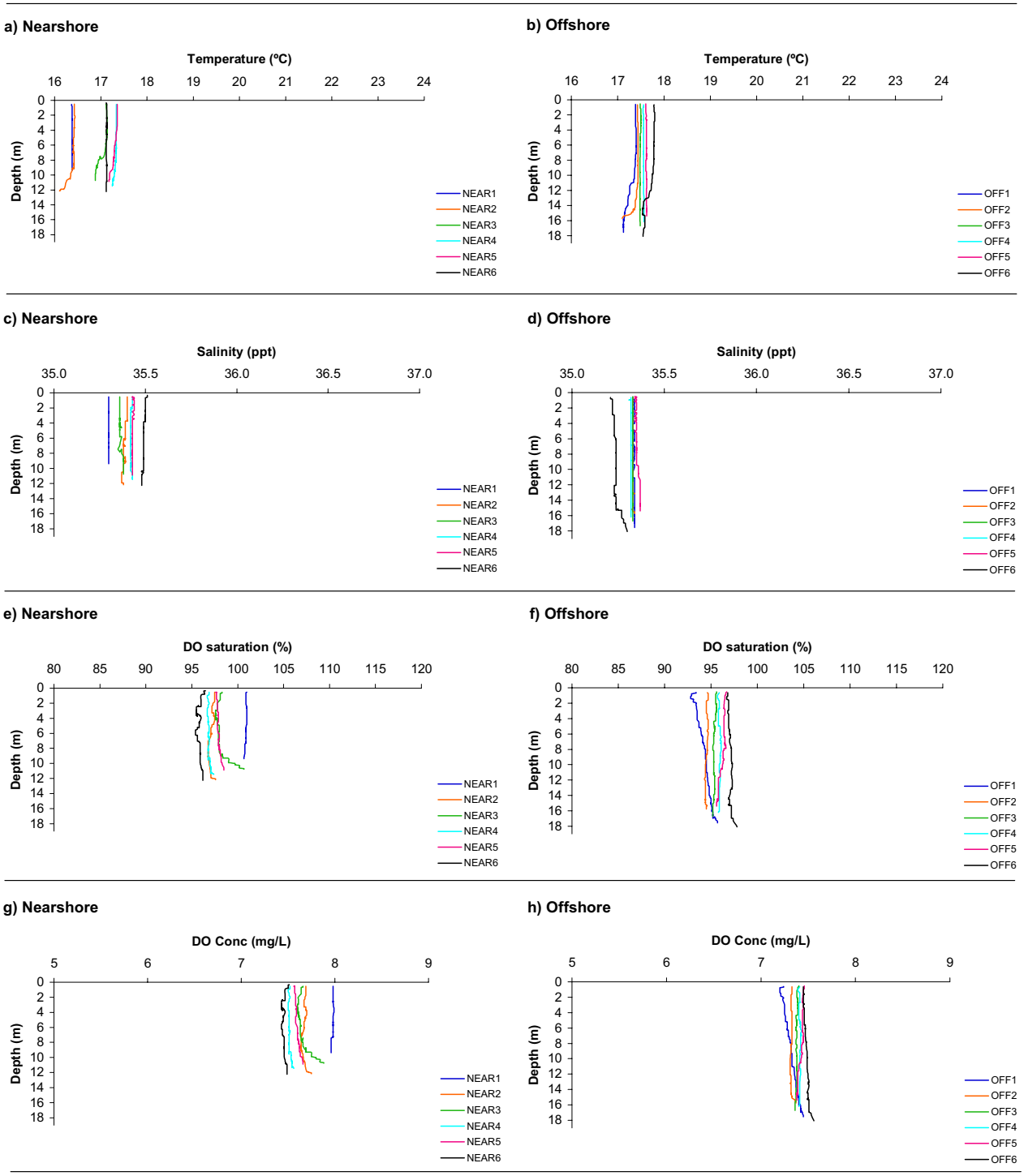


Figure 3.7(a-h) Temperature, Salinity, DO saturation and DO concentration for Alkimos water quality sites – 22 June 2005

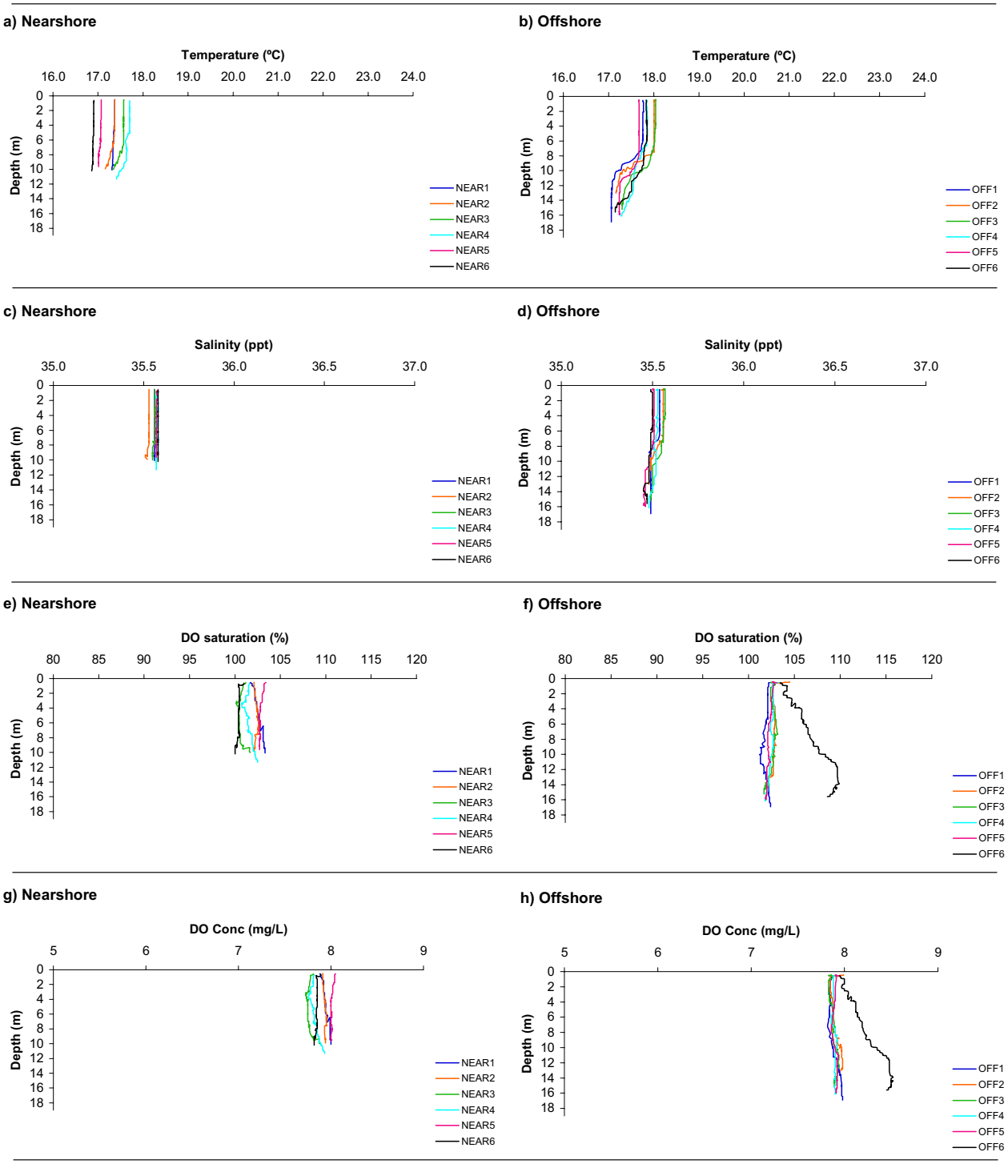
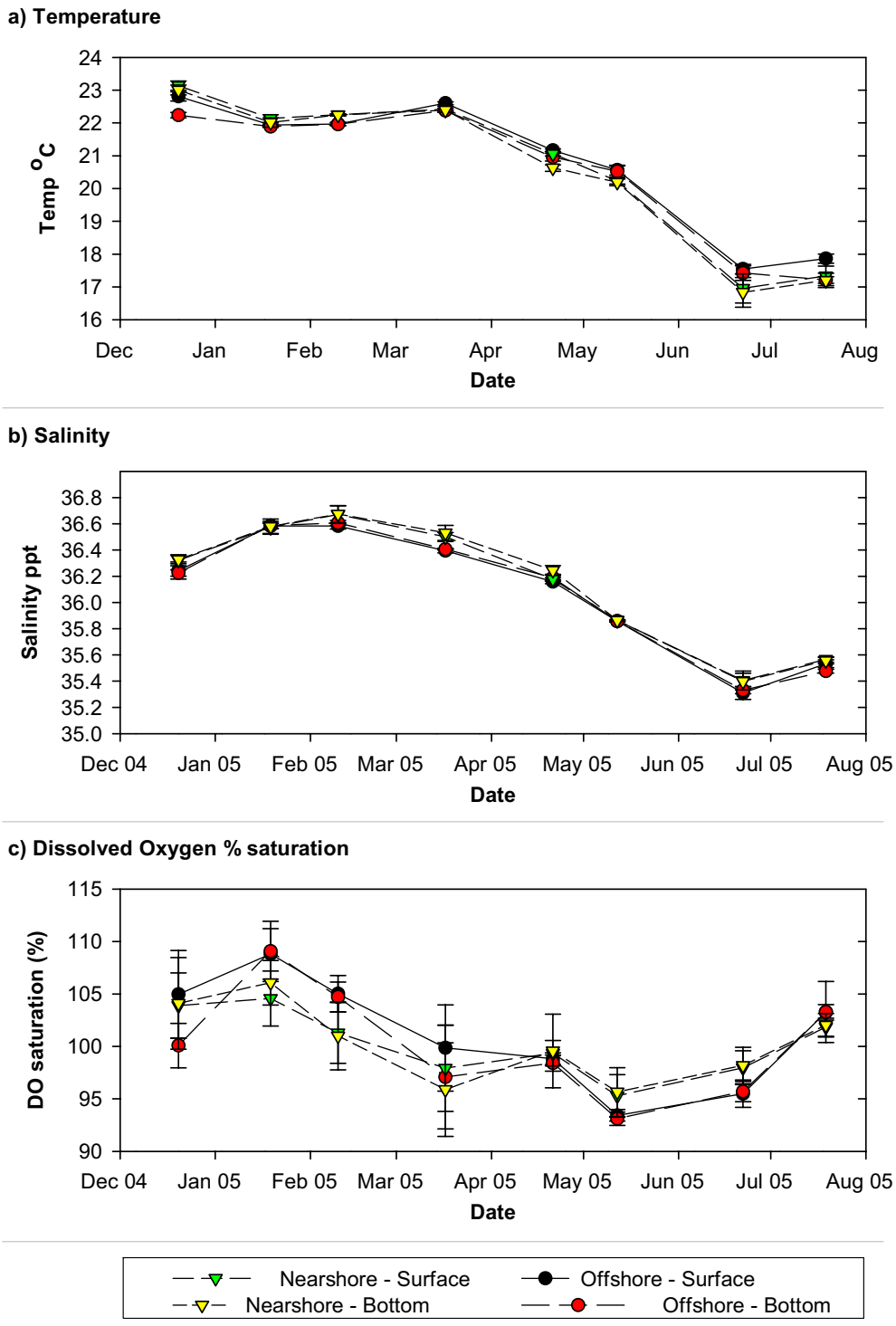


Figure 3.8(a-h) Temperature, Salinity, DO saturation and DO concentration for Alkimos water quality sites – 19 July 2005



Notes: Error bars represent 1 standard deviation (6 sites).

Figure 3.9 Alkimos mean surface and bottom water temperature, salinity and dissolved oxygen – December 2004 to July 2005

3.3 Nutrients and Chlorophyll

As part of method validation, an "integrated sample" was taken over the top half of the water column, together with the normal discrete depth surface and bottom water samples, at sites Offshore-6 and Nearshore-6 during the first sampling event (20 December 2004). The comparison of the integrated upper water column samples with surface and bottom water samples is presented in Figure 3.10. It can be seen from Figure 3.10 that while values from the integrated samples were not intermediate between surface and bottom water samples for most nutrients, values of a similar range were returned. Depth integrated sampling of the top half of the water column is used for the PLOOM intensive summer and seasonal water quality monitoring programmes (Oceanica, 2005a).

Table 3.1 presents the median, 20^{th} percentile and 80^{th} percentile values for nutrient parameters and chlorophyll-a at the Alkimos water quality sites for the period December 2004 to July 2005. The mean offshore, nearshore and shoreline nutrient concentrations for surface and bottom waters for each sampling event are presented graphically in Figure 3.11(a-f). Nutrient concentrations for individual sites are presented graphically in Figure 3.12(a-r) to Figure 3.17(a-r). Only surface water samples were taken at shore sites (from waist deep water) due to insufficient water depth to take bottom water samples.

Discussion of the results for individual nutrient and chlorophyll parameters is presented in Sections 3.3.1 to 3.3.6. For most parameters a brief comparison is made to the findings of the Perth Coastal Waters Study (PCWS) (Lord and Hillman 1995). The PCWS was undertaken between July 1992 and December 1994 to "*determine the loads of nitrogen contained in treated wastewater that can be discharged into Perth's coastal waters and maintain environmental values*" (Lord and Hillman 1995). The PCWS results present a general snapshot of the nutrient related water quality of the Perth coastal waters during the study period (July 1992 and December 1994) though the study area was largely restricted to waters to the south of the current Alkimos water quality sites.

Table 3.1 Median, 20th percentile and 80th percentile values for nutrients and chlorophyll-a at Alkimos water quality shore, nearshore and offshore sites – December 2004 to July 2005

Parameter	Site[1]	n	20th %ile[3]	Median	80th %ile
Total Phosphorus (µg.P/L)	All	237	13.0	16.0	21.1
	Shore	45	15.5	19.0	23.0
	Near-S	48	14.0	15.5	19.7
	Near-B	48	15.0	16.0	22.0
	Off-S	48	12.0	14.0	19.9
	Off-B	48	13.0	14.0	17.0
Filterable Reactive Phosphorus (µg.P/L)	All	237	8.0	10.0	14.0
	Shore	45	9.0	11.0	14.0
	Near-S	48	9.0	10.0	13.9
	Near-B	48	9.0	11.0	15.0
	Off-S	48	8.0	8.0	12.7
	Off-B	48	8.0	9.0	10.9
Total Nitrogen (µg.N/L)	All	237	120	140	170
	Shore	45	140	170	260
	Near-S	48	120	130	150
	Near-B	48	110	135	150
	Off-S	48	101	140	160
	Off-B	48	120	150	170
Ammonia[2] (µg.N/L)	All	237	3.0	3.0	3.0
	Shore	45	3.0	5.0	8.0
	Near-S	48	3.0	3.0	3.0
	Near-B	48	3.0	3.0	3.0
	Off-S	48	3.0	3.0	3.0
	Off-B	48	3.0	3.0	3.0
Nitrate+nitrite (µg.N/L)	All	237	4.0	8.0	14.0
	Shore	45	4.0	6.0	12.0
	Near-S	48	5.0	8.0	12.0
	Near-B	48	5.0	8.0	12.9
	Off-S	48	3.1	7.5	22.5
	Off-B	48	4.0	10.0	15.9
Chlorophyll-a (µg/L)	All	237	0.3	0.5	0.7
	Shore	45	0.4	0.6	0.8
	Near-S	48	0.3	0.4	0.6
	Near-B	48	0.3	0.4	0.6
	Off-S	48	0.3	0.5	0.6
	Off-B	48	0.4	0.5	0.8

Notes: *1. See Figure 2.16 for site locations; "Shore" sites located in waste deep water along Alkimos shoreline; "Near-S" refers to nearshore surface water samples. "Near-B" refers to nearshore bottom water samples "Off-S" refers to offshore surface water samples; "Off-B" refers to offshore bottom water samples;*

2. The majority of ammonia samples were below the reporting limit of 3 µg.N/L. The full reporting limit value (3) was used in calculating percentile and median values for these samples;
3. Percentiles were calculated using the Hazen percentile calculating macro in Microsoft Excel (hazen-percentile-calculator update 27_5_05.xls; McBride 2002).

3.3.1 Total phosphorus

Total Phosphorus (TP) concentrations ranged from 9 µg/L to 29 µg/L over the reporting period with average concentrations generally decreasing from shore sites to offshore sites (Table 3.1). Shore sites displayed distinctly higher TP concentrations than nearshore or offshore sites on 19 January 2005 (Figure 3.11a). This pattern of TP concentrations and distribution is consistent with the findings of the PCWS (Lord and Hillman 1995) of higher TP concentrations nearshore. While mean TP concentrations at Alkimos water quality sites over the reporting period were approximately a third higher than those of the PCWS, the range in values was less.

The lowest average concentration and variability of TP was observed in the offshore bottom waters. There was a trend towards lower TP values across all sites from March 2005 to July 2005 although concentrations were relatively stable over the April to June (2005) period (Figure 3.11a).

A summary graph of total phosphorus concentrations and standard deviations (error bars) for shore, nearshore and offshore sites is presented in Figure 3.11a. Individual data points for all sites and dates are presented in Figure 3.12(a-r).

3.3.2 Filterable Reactive Phosphorus (FRP)

FRP concentrations tended to follow a similar temporal pattern to TP with a general decrease in concentrations across all sites from autumn to winter (Figure 3.11b). The spatial distribution of FRP mean concentrations was similar to that for TP with a decrease in concentrations from shore to offshore sites (Table 3.1). Offshore bottom sites contained the lowest mean FRP concentrations over the reporting period. Between-site variability in FRP concentrations was greatest on 20 December 2004 and least on 22 June 2005.

Filterable reactive phosphorus (FRP) concentrations varied within a range of 7 to 22 µg.P/L over the reporting period with an average across all sites of 10.8 µg.P/L. Peak concentrations of FRP during the sampling period were recorded at nearshore sites in December 2004. A secondary peak was seen across all sites in March 2005 with concentrations generally dropping through spring/winter. The lowest FRP concentrations for shore, nearshore and offshore sites were recorded in July 2005. These temporal patterns in FRP concentrations are in contrast to the findings of the Perth Coastal Waters Study (Lord and Hillman 1995) where summer median FRP values were lower than winter values.

A summary graph of FRP concentrations and standard deviations (error bars) is presented in Figure 3.11b. Individual data points for all sites and dates are presented in Figure 3.13(a-r).

3.3.3 Total Nitrogen

The ammonia and nitrate+nitrite components on average comprised less than 10 % of the total nitrogen pool, suggesting particulate nitrogen (probably organic) as the

dominant reservoir of this element in the system (other than inert dissolved nitrogen gas). Total nitrogen (TN) concentrations ranged from 90 to 400 µg N/L over the reporting period, with a mean value of 149 µg.N/L. Little temporal change in the mean TN values was seen over the reporting period with the exception of the shoreline sites (Figure 3.11c and Figure 3.14[a-r]). Shoreline TN values were higher than nearshore and offshore sites for the majority of sampling events and were distinctly elevated on the 19 January 2005 sampling event (Figure 3.11c). Total nitrogen concentrations did not appear to follow the temporal or spatial trends of ammonia or nitrate+nitrite.

In general the TN concentrations in the current study were considerably lower than those found during the PCWS. Only Alkimos shore sites recorded TN values at the lower range of those found during the PCWS (Lord and Hillman 1995).

A summary graph of mean TN concentrations and ± standard deviations (error bars) is presented in Figure 3.11c. Individual data points for all sites and dates are presented in Figure 3.14(a-r).

3.3.4 Ammonia

The median ammonia concentration for all sites over the reporting period was below the reporting limit (3 µg N/L). The median concentration across all sites and dates was 3.0 µg N/L (calculated using the reporting limit value where determined values were below the reporting limit) (Table 3.1). A maximum value of 22 µg N/L was recorded on three occasions, all at shoreline sites (Shore-4 and Shore-6 on 21 April 2005and, Shore-1 on 10 February 2005). Shore sites on average displayed elevated ammonia concentrations in comparison to nearshore and offshore sites (Table 3.1 and Figure 3.11d). Mean ammonia concentrations at shore sites steadily decreased from January through to July 2005 to reach below reporting limits at all sites (< 3 µg.N/L).

Ammonia concentrations were on average lower at the Alkimos water quality sites during the reporting period than those of the summer 1994 PCWS (Lord and Hillman 1995).

A summary graph of ammonia concentrations and standard deviations (error bars) is presented in Figure 3.11d. Individual data points for all sites and dates are presented in Figure 3.15(a-r).

Note: Both ammonium (NH_3^+) and ammonia (NH_4) species are presented as ammonia in the water quality data. The analytical method used for the detection of these species converts all ammonium ion to ammonia and detects ammonia. Due to pH and solubility considerations, most NH_x in seawater is predicted to occur as the more soluble ammonium ion (Libes, 1992).

3.3.5 Nitrate + Nitrite

Nitrate (NO_3^-) and nitrite (NO_2^-) concentrations are combined for reporting purposes. The nitrate+nitrite (NO_x^-) concentrations for Alkimos ranged from 2 to 25 µg N/L over the reporting period with a mean value of 11.1 µg.N/L (Table 3.1). Concentrations of NO_x were elevated across all sites on 22 June 2005 in comparison to previous sampling events (Figure 3.11e). NO_x displayed a different temporal and spatial pattern of distribution than TN or ammonia with the highest and most variable concentrations occurring in March and June 2005.

Nitrate+nitrite concentrations were generally higher at offshore and nearshore sites than at shore sites. The Alkimos nitrate+nitrite concentrations peaked in June (2005), reflecting the seasonal winter peak in nitrate typical of Perth coastal waters (Kinhill 1999).

Mean NO_x concentrations at all Alkimos water quality sites were higher than those recorded for the PCWS. The mean value for NO_x at Alkimos sites exceeded the 90th percentile value of the PCWS sites (winter 1993 only) for all dates except during the summer sampling in December 2004 and January 2005. When the mean Alkimos concentrations for each sampling event are compared to the 90th percentile value of the PCWS sites for summer 1994 (Table 5.1 in Lord and Hillman 1995), only the 22 June 2005 data are in higher.

A summary graph of nitrate+nitrite concentrations and standard deviations (error bars) is presented in Figure 3.11e. Individual data points for all sites and dates are presented in Figure 3.16(a-r).

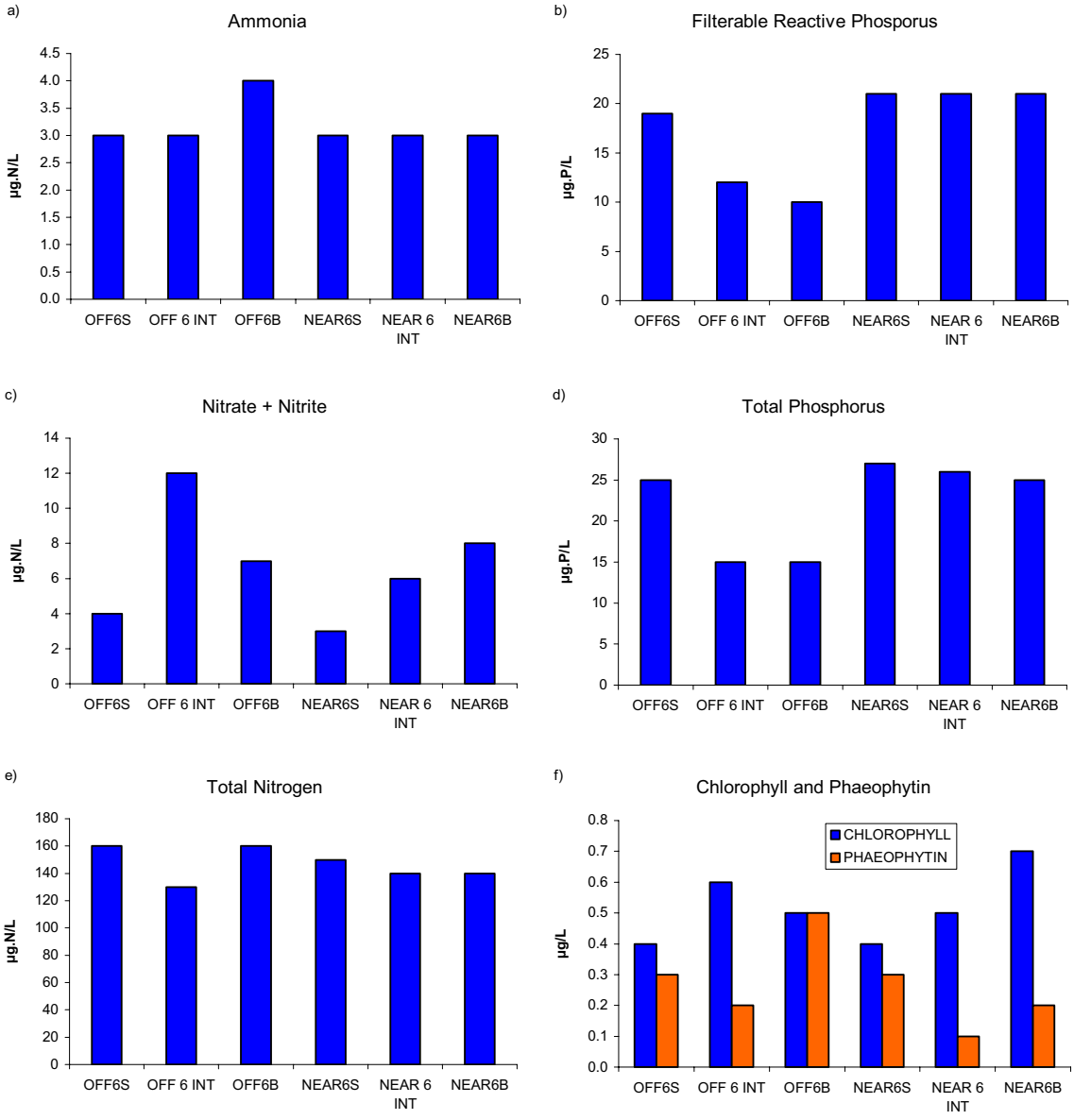
3.3.6 Chlorophyll-a

The findings of the Alkimos phytoplankton survey programme are presented in detail in a separate report as part of the Alkimos Marine Studies Programme (Oceanica 2005b). The distribution of phytoplankton biomass at Alkimos (as determined by chlorophyll-a concentrations) is summarised here in reference to overall water quality at the site. A summary graph of chlorophyll *a* concentrations and standard deviations (error bars) is presented in Figure 3.11f. Individual data points for all sites and dates are presented in Figure 3.17(a-r).

Chlorophyll-a (Chl-a) concentrations at Alkimos were relatively uniform between shore, nearshore and offshore sites and between surface and bottom water samples (Table 3.1).

Chl-a concentrations at Alkimos water quality sites ranged from the reporting limit (0.1 µg/L) to 1.9 µg/L for the reporting period. The mean value across all sites and dates was 0.5 µg/L. The highest concentrations of Chl-a for the reporting period were recorded in the bottom waters of nearshore and offshore sites in March 2005, suggesting either resuspension of these pigments from the sediments or photo-inhibition of the water column phytoplankton population in the vicinity of the surface samples. Persistent easterly winds prior to the March 2005 sampling event (Figure 2.2) may have induced some sediment resuspension through upwelling of bottom waters. Shore sites contained elevated Chl-a concentrations in comparison to other sites in April, May and June 2005 (Figure 3.11f).

Chl-a concentrations were generally elevated at shore, nearshore and offshore sites in comparison to the PCWS nearshore values. The mean Chl-a concentrations at shore and offshore bottom water sites exceeded the 90th percentile values for the PCWS (Lord and Hillman 1995).



Site Codes:

OFF6S = Offshore Site 6 (Surface)	NEAR6S = Nearshore Site 6 (Surface)
OFF 6 INT = Offshore Site 6 (Integrated)	NEAR 6 INT = Nearshore Site 6 (Integrated)
OFF6B = Offshore Site 6 (Bottom)	NEAR6B = Nearshore Site 6 (Bottom)

Figure 3.10(a-f) Comparison of upper water column depth integrated samples with samples collected at specific depths (20 December 2004)

Note: Ammonia concentrations for samples OFF6S, NEAR6S, NEAR6B and NEAR 6 INT were below the reporting limit of 3 µg.N/L. These samples are presented here as at the reporting limit for comparison purposes.

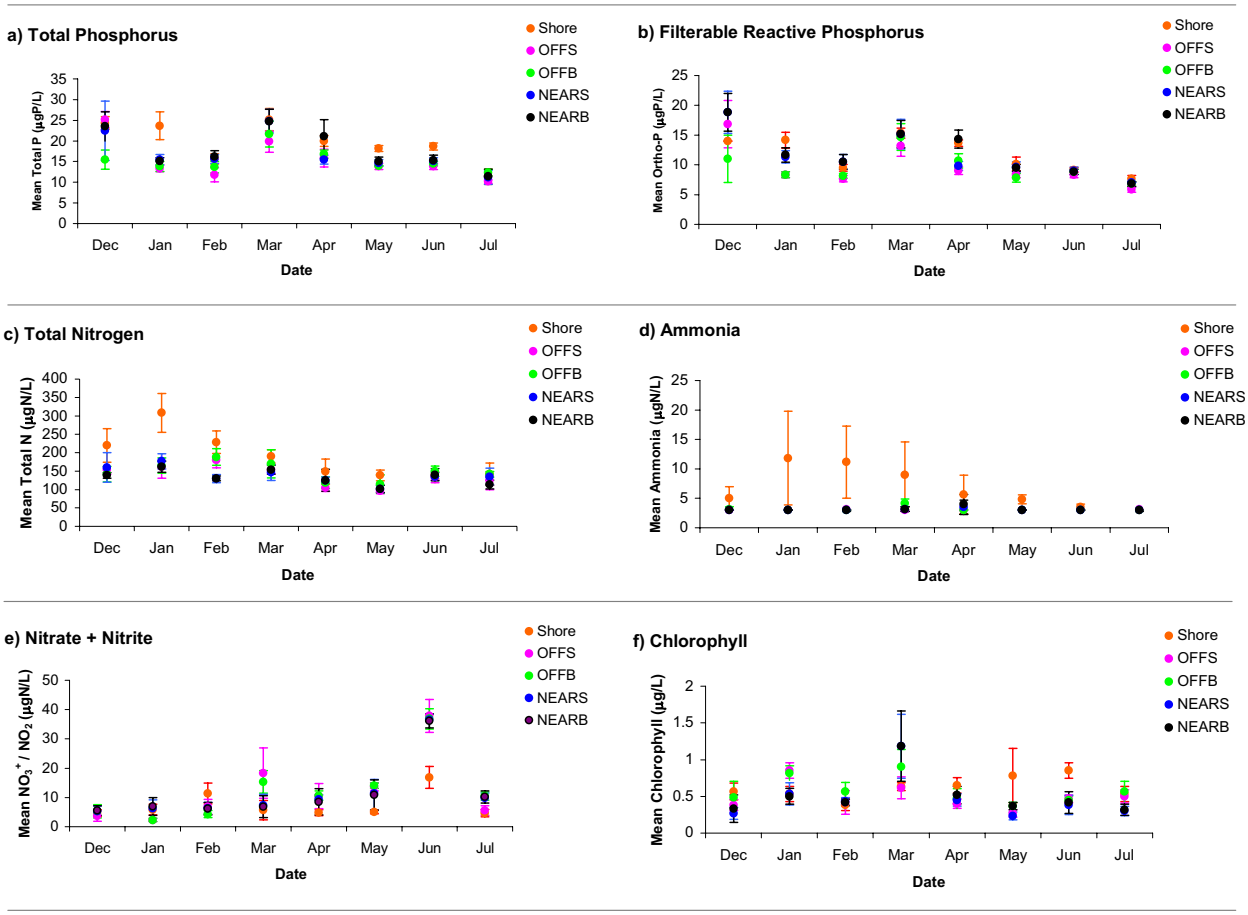


Figure 3.11(a-f) Summary plots of mean nutrients and mean Chlorophyll at Alkimos water quality sites (December 2004 to May 2005)

Note: error bars represent 1 standard deviation (six samples).

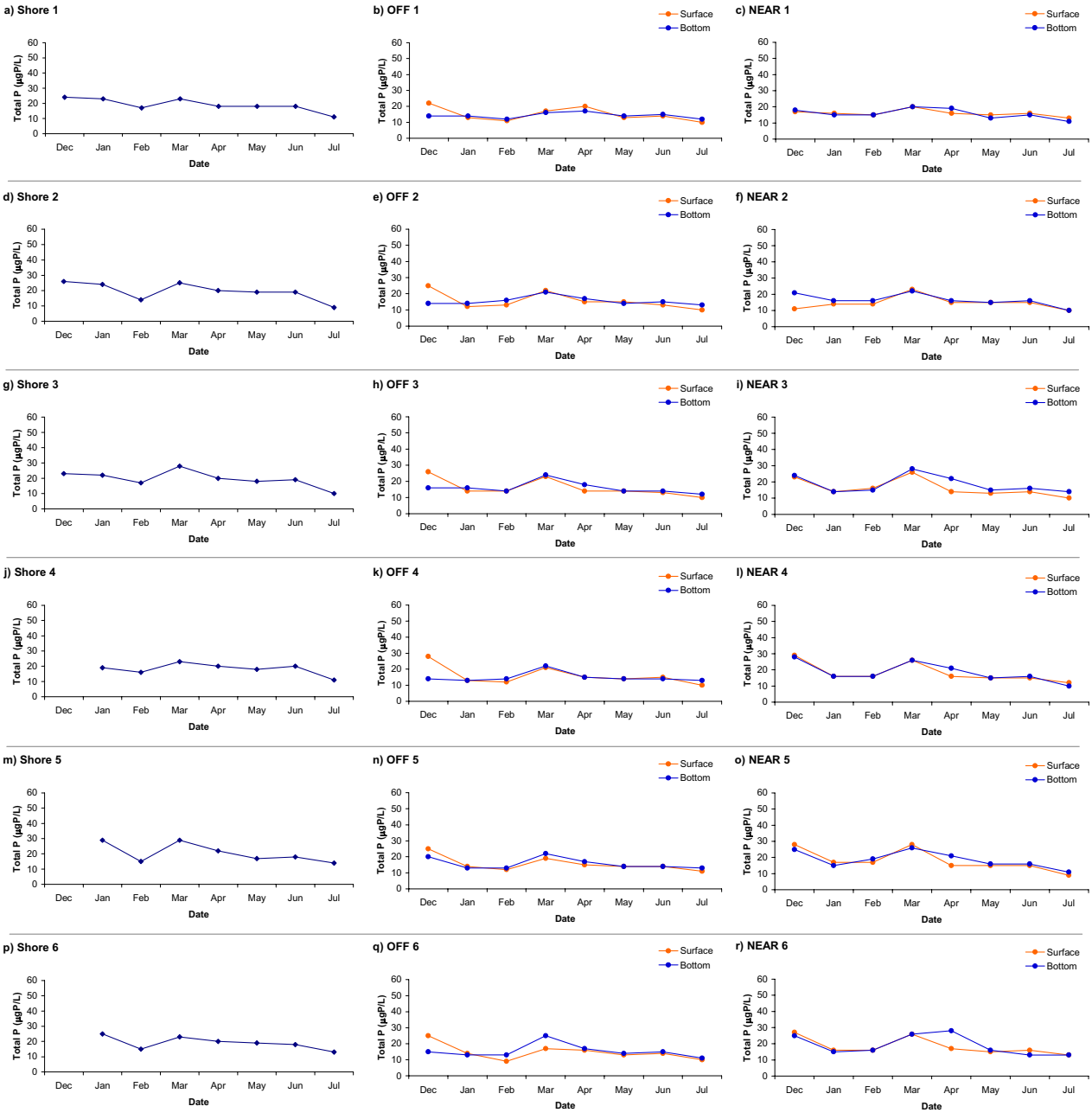


Figure 3.12(a-r) Total Phosphorus concentrations for Alkimos water quality sites – December 2004 to July 2005

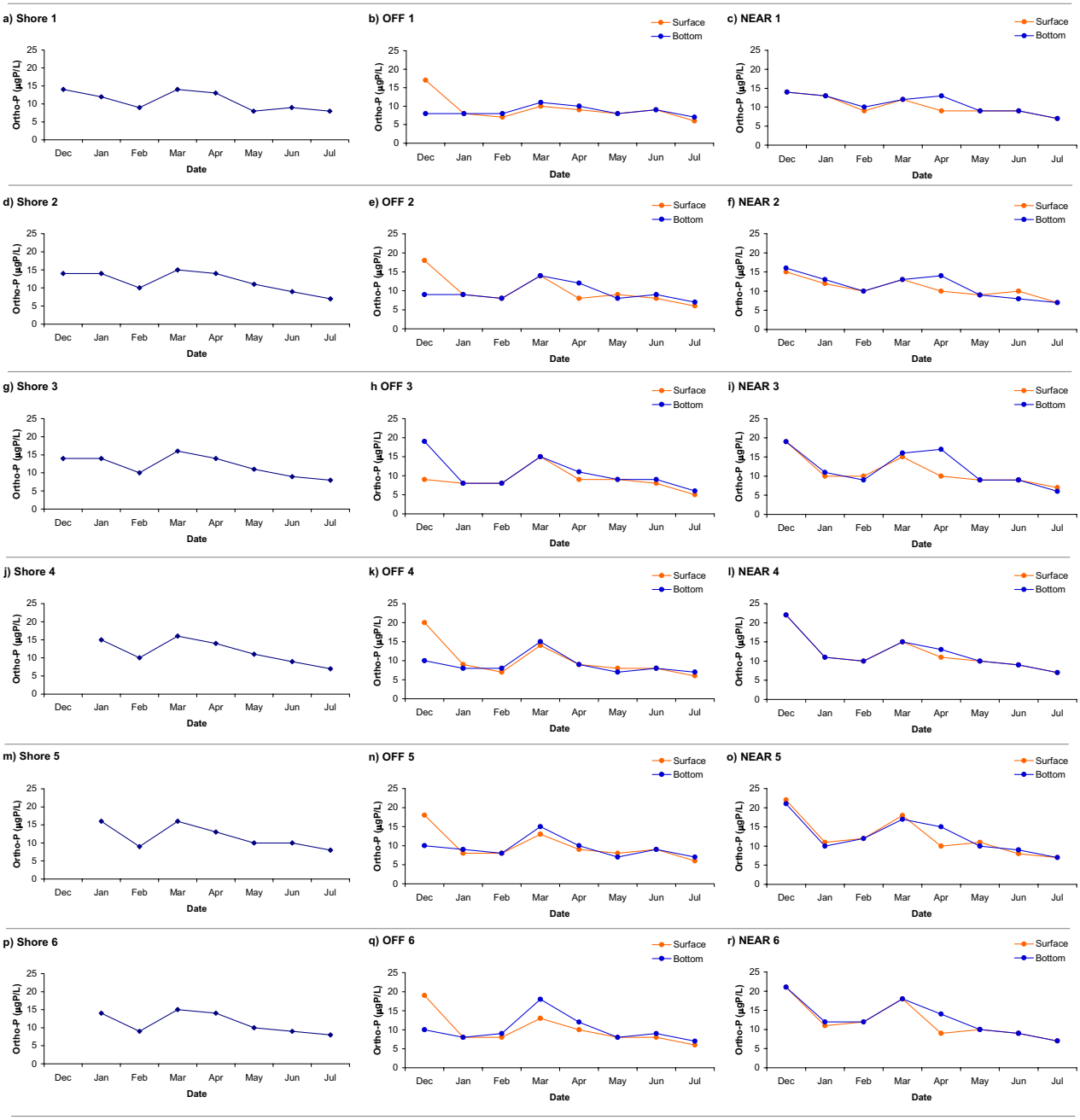


Figure 3.13(a-r) Filterable Reactive Phosphorus (FRP) concentrations for Alkimos water quality sites – December 2004 to July 2005

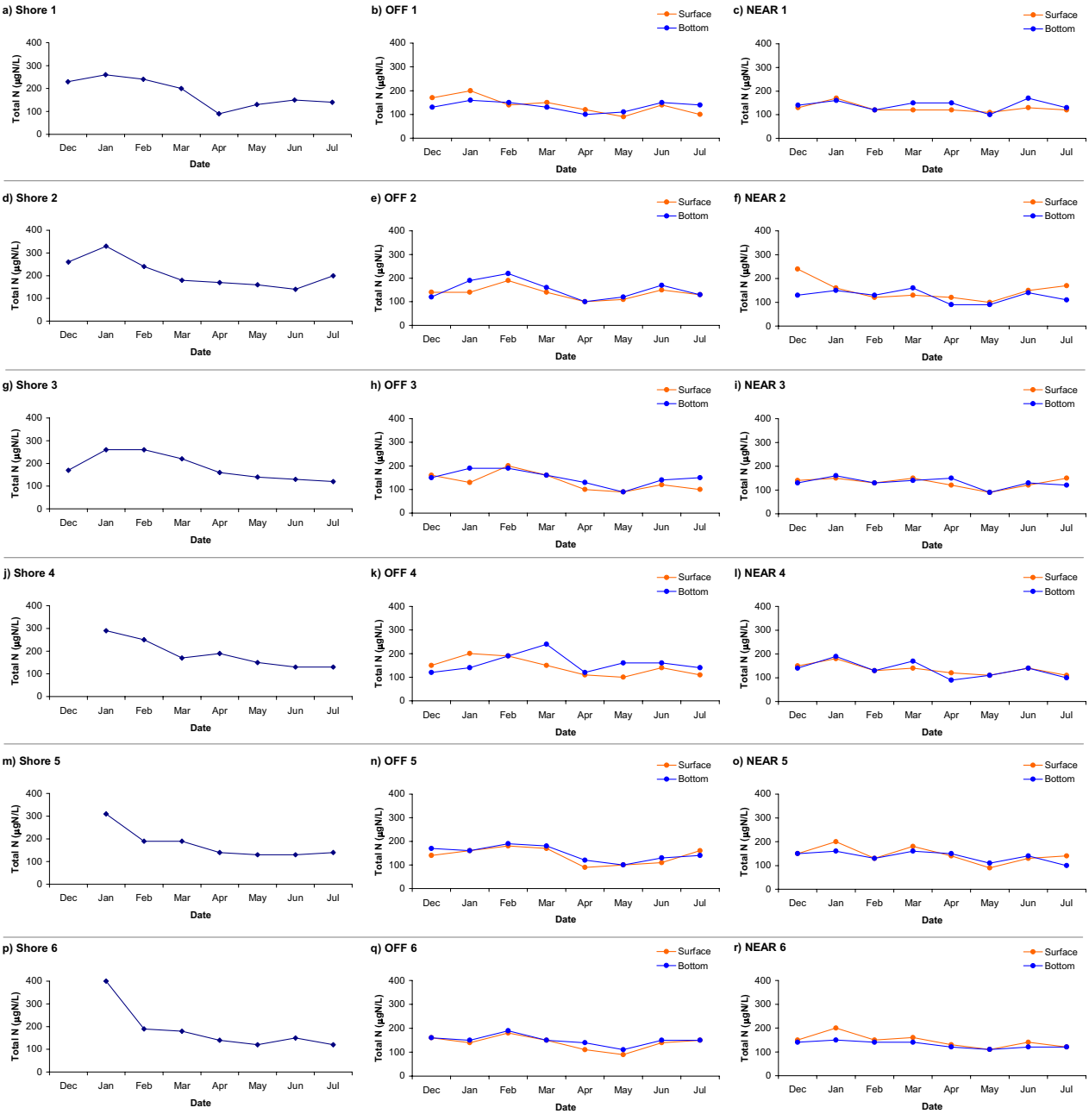


Figure 3.14(a-r) Total Nitrogen concentrations for Alkimos water quality sites – December 2004 to July 2005

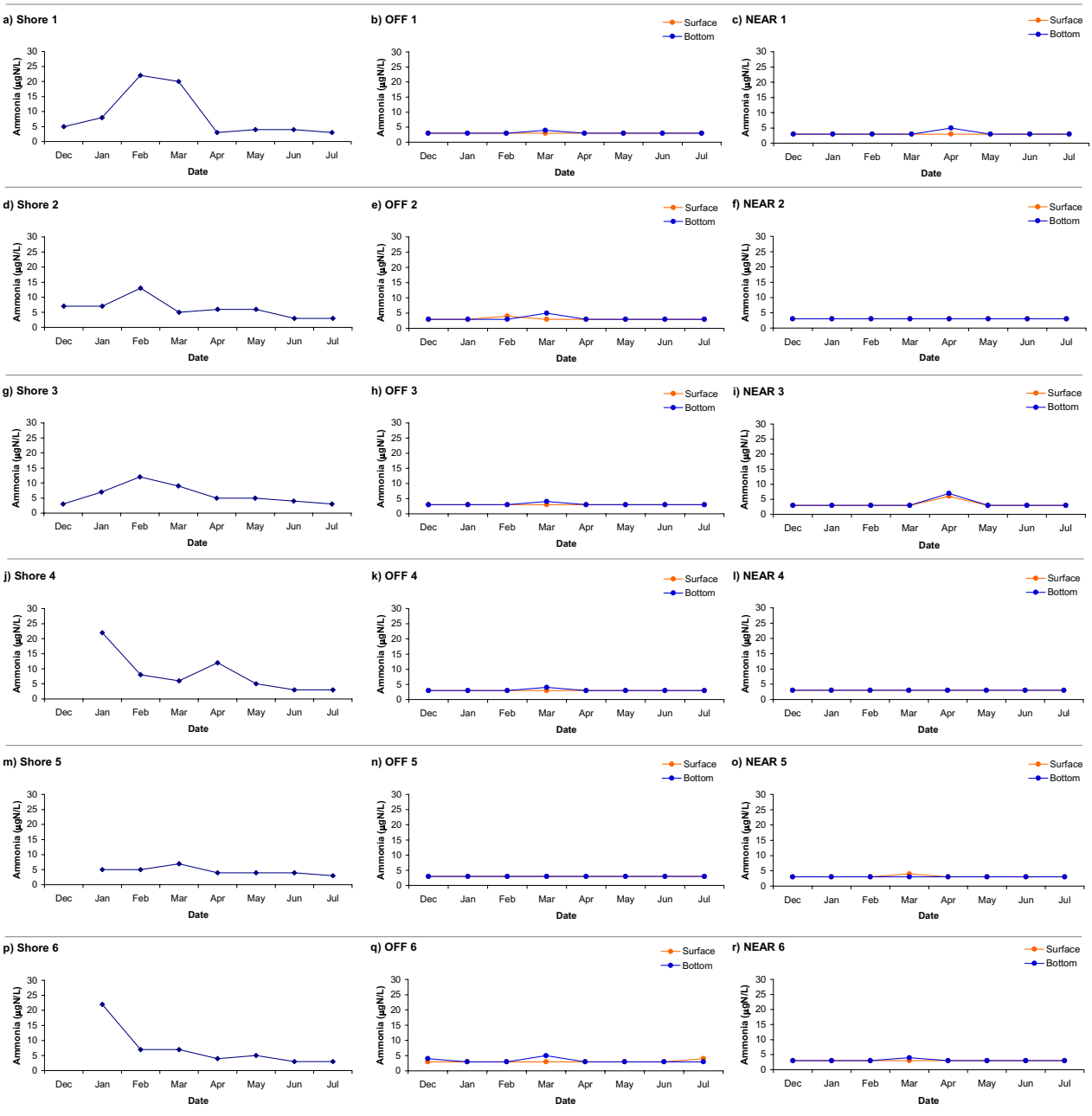


Figure 3.15(a-r) Ammonia concentrations for Alkimos water quality sites – December 2004 to July 2005

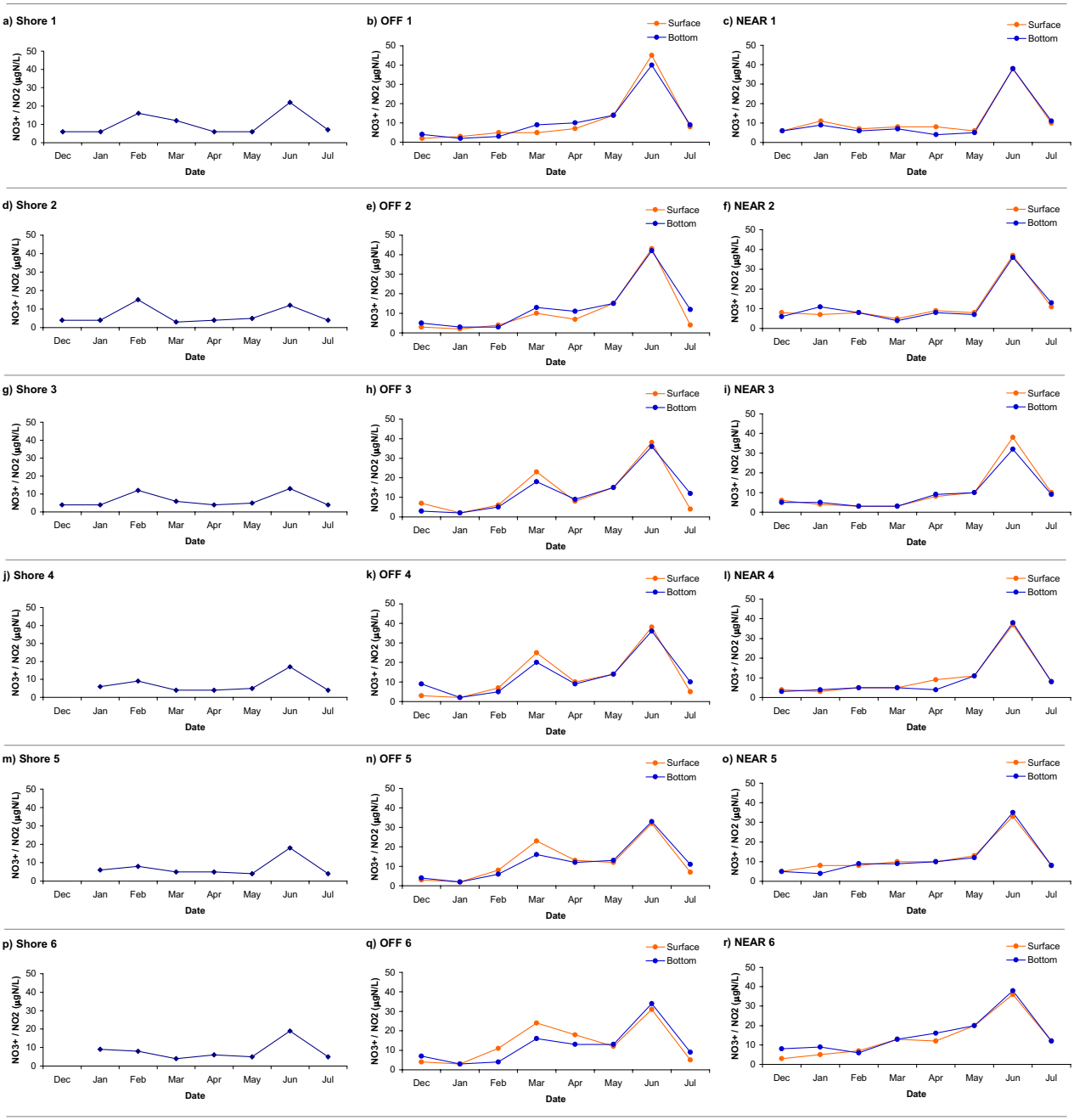


Figure 3.16(a-r) Nitrate + Nitrite concentrations for Alkimos water quality sites – December 2004 to July 2005

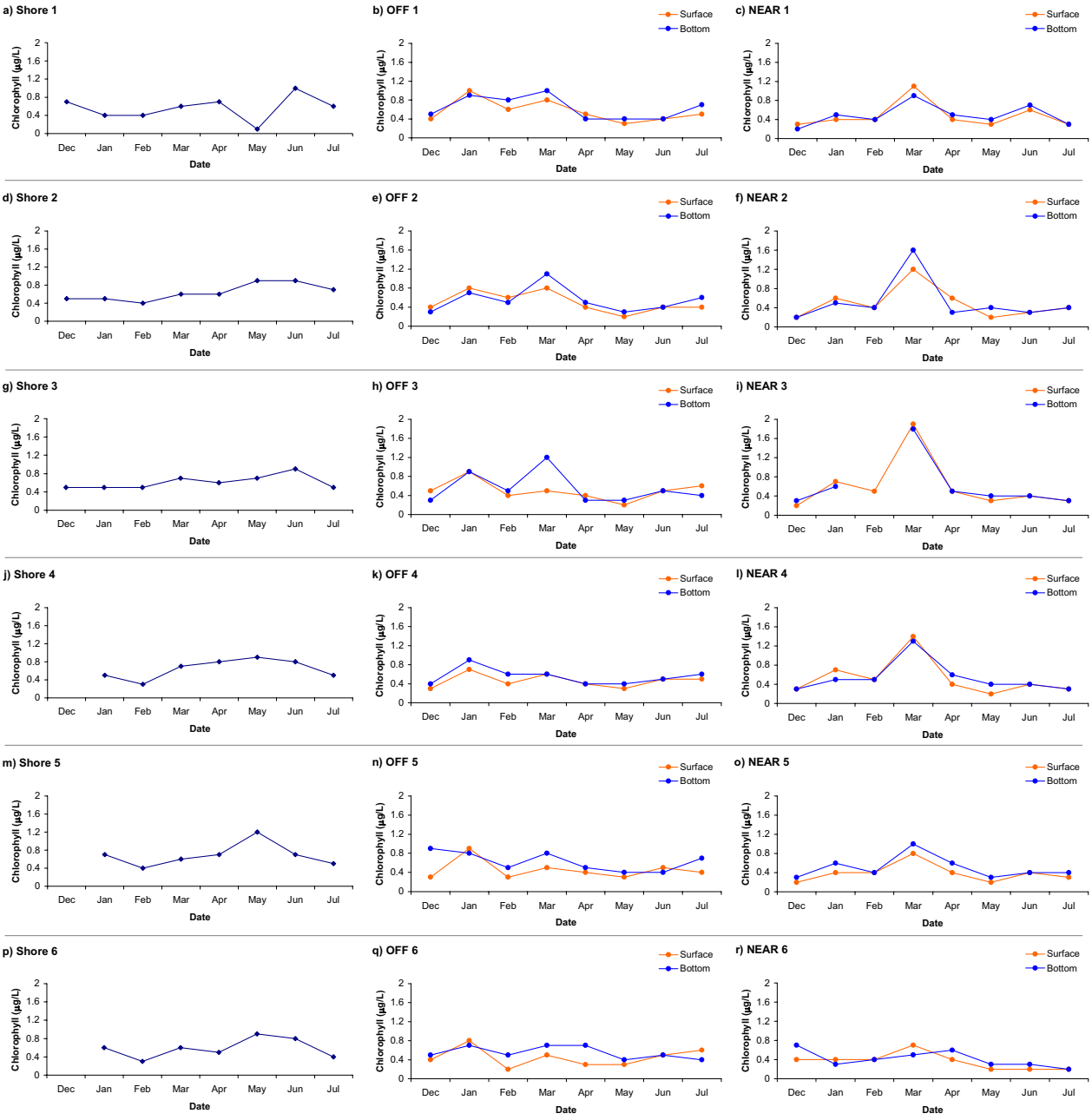


Figure 3.17(a-r) Chlorophyll *a* concentrations for Alkimos water quality sites – December 2004 to July 2005

3.4 Microbiological

Microbiological sampling was conducted for the period December 2004 to May 2005 to capture this parameter during the peak recreational use (swimming) period. It is planned to recommence microbiological sampling for the Alkimos water quality sites in October 2005.

3.4.1 Thermotolerant Faecal Coliforms (TTC)

TTC values were very low or below the assay limit at all sites and sampling times. Only two samples returned detectable TTC (of 177 taken) with both samples displaying the minimum of one coliform in a 50 ml sample (to give an estimated value of 2 TTC/100ml). No spatial or seasonal pattern was evident from these two results.

Certificates of Analysis for microbiological parameters are presented in Appendix D.

3.4.2 Enterococci

Enterococci values were very low or below the assay limit at all sites and sampling times. Only two samples returned detectable enterococci (of 177 taken) with both samples displaying the minimum of one count in a 10 ml sample (to give an estimated value of 10 MPN/100ml). The two positive samples were not the same dates or sites as the two positive TFC results. No spatial or seasonal pattern was evident from these two results.

Certificates of Analysis for microbiological parameters are presented in Appendix D.

4. Comparison of results with Ocean Reef water quality

The Water Corporation operates three major wastewater treatment plants (WWTP's) in the Perth metropolitan area, all of which discharge treated wastewater into the marine environment via ocean outlets. The Ocean Reef outlet (discharging treated water from the Beenyup WWTP) is approximately 17 km to the south of the proposed Alkimos ocean outlets (Figure 4.1). The volumes of water discharged from the Ocean Reef outlet are of similar magnitude to that proposed for the Alkimos outlet (at eventual long-term planned output) and in a similar oceanographic setting (Figure 4.1). Key differences in the oceanographic settings of the two sites are a longer and deeper outlet pipe (and diffuser system) at Alkimos that is likely to allow for greater mixing than present at Ocean Reef. The water residence times and mixing characteristics at Alkimos are currently being investigated under a separate study in the Alkimos Marine Studies Programme.

The Ocean Reef outlet was first operational in 1978, discharging treated water from Beenyup (with a capacity of 27 ML/day). Beenyup WWTP has since undergone several expansions and currently discharges approximately 110 ML/day of treated wastewater through two outlets at Ocean Reef. These outlets are located 1.6 km (outlet A) and 1.8 km (outlet B) from shore and discharge via diffuser units of 195 m length at each outlet. Table 4.1 compares design parameters for the Ocean Reef and Alkimos ocean outlets.

Table 4.1 Comparison of design parameters for the Ocean Reef and proposed Alkimos ocean outlets

Parameter	Ocean Reef	Alkimos (proposed)
Commissioned[1,2]	1978	2009-2010
Initial installed capacity[1,2]	27 ML/d	10 ML/d
Operating capacity[1]	112.5 ML/d (as of 2003)	Continuous upgrade (70 ML/d by 2040)
Projected final capacity[1]	150 ML/d	80 ML/d
Distance of outlet from shore[3,4]	1.6 km and 1.8 km (two outlets: A and B)	3.2 km
Diffuser Length[3]	195 m	300 m
Outlet depth	10 m	20 m

Notes:
1. *Value taken from the EPA referral document for the Alkimos WWTP (Water Corporation 2005b);*
2. *Value taken from Water Corporation web-site on 7June 2005 (www.watercorporation.com.au);*
3. *Value taken from the 2003 summer water quality report for the Water Corporation ocean outlets in Perth coastal waters (DALSE 2003).*

This section reviews the baseline data collected at Alkimos in relation to data from the operational outlets at Ocean Reef.

4.1 Key Issues

The key issues with regards to environmental water quality values for treated wastewater ocean outlets can be summarised as follows:

- Eutrophication of marine waters through addition of bioavailable nutrients;
- Induction of "harmful" algal blooms through nutrient additions;
- Increase in "nuisance" macro-benthic algal species through nutrient additions; and,

- Harmful toxicological effects to benthic organisms through a build-up of metals, pesticides, biocides and/or other toxicants present in increased concentrations in wastewater.

The key issues with regards to social water quality values for treated wastewater ocean outlets can be summarised as follows:

- Human infection with faecal bacterium present in treated wastewater during recreational contact (i.e. swimming, surfing, boating);
- Human ingestion and infection with faecal bacterium present in seafood as a result of contact with treated wastewater; and,
- Lowering of aesthetic values through the presence of a potentially visible plume above outlets with due to a combination of changed refractive properties caused by salinity and increased suspended solids concentrations.

These issues have been managed through a series of operational requirements present in environmental licences and agreements made between the Water Corporation and government authorities. The monitoring of the water quality impacts at the Ocean Reef ocean outlets has been primarily conducted through the Perth Long-Term Ocean Outlet Monitoring Programme (PLOOM). The main findings of the PLOOM programme with relation to water quality at the Ocean Reef site are (Oceanica 2005a) provided in Sections 4.2 and 4.3.

4.2 Physical and chemical parameters

Treated wastewater outlets can impact physical and chemical characteristics of the marine environment through the introduction of water of lower salinity, different temperature and/or different dissolved oxygen characteristics. Wastewater from the Ocean Reef outlets is buoyant (of lower density) in comparison to the surrounding marine waters (Oceanica 2005a). The dilution levels for the Ocean Reef outlet are monitored by comparing nutrient concentrations in surface waters directly above the diffuser with background surface concentrations from the adjacent area. The diffusers at Ocean Reef have a calculated initial dilution (using nutrient concentrations) of ~ 1:70 to 1:200 (dilution is specific to modelled environmental conditions) (Oceanica 2005a).

The water column structure and physical parameters (i.e. salinity and temperature) can change over short timeframes at any given location in coastal waters. For this reason a direct comparison of the Ocean Reef (OR) water column structure with that of the Alkimos region cannot be made within the scope of the current study. However several observations can be made about the influence of the OR outlet on the ambient water column structure that are relevant to the proposed Alkimos ocean outlet (Oceanica 2005a):

- Treated wastewater is largely freshwater, and therefore buoyant and rises to the surface as a plume. The plume rapidly mixes with the ambient seawater and has attained a similar salinity (to seawater) as it reaches the ocean surface (<0.5 % lower salinity at 10 m above the diffuser);
- The treated wastewater has been diluted of the order of 100 times by the time it reaches the surface (at 10 m above the diffusers);
- Water temperature is not substantially altered. The plume buoyancy may act to reduce thermal stratification directly above the diffusers;
- The detectable wastewater plume at Ocean Reef typically extends from 0.5 to 2.5 km from the ocean outlet (detected using nutrient concentrations).

4.3 Nutrient and primary production parameters

The monitoring programme for the Ocean Reef outlet (PLOOM) includes a suite of nutrient and primary production parameters aimed at detecting changes in the local marine environment due to the discharge of treated wastewater. Together with studies of oceanographic processes, water column structure and modelling, the PLOOM programme has made the following findings with regards to the effects of the Ocean Reef ocean outlet on the adjacent marine environment (Oceanica 2005a):

- The wastewater plume typically extends 0.5-2.5 km from the outlets at Ocean Reef. There are localised elevated nutrient (nitrogen) levels in the water column downstream of the outlets (predominantly northwards under prevailing winds);
- The results of near-field/far-field modelling and field measurements indicate a reduction in wastewater concentrations of up to three orders of magnitude over a distance of several tens of metres from the diffusers;
- Nutrient-related water quality undergoes consistent seasonal changes, with the highest background concentrations of nitrate + nitrite and filterable reactive phosphorus occurring in winter;
- There is a corresponding seasonality in phytoplankton biomass (measured as chlorophyll-a concentrations) with a peak in chlorophyll-a concentrations in spring and autumn at Ocean Reef. There is no evidence of an increase in toxic or harmful algal blooms;
- There is some evidence for enhanced periphyton growth at sites located 1-2 km 'downstream' of the ocean outlets, but any effect of treated wastewater discharge becomes negligible well before areas of natural reef are encountered;
- Seagrass shoot densities are higher at sites near the Ocean Reef Ocean Outlets than at reference sites, which is the opposite to the pattern expected for adverse nutrient effects (i.e. a reduction in seagrass shoot density) and may represent a slight positive growth response to low-level nutrient enrichment;
- There is no indication of a loss in vegetated habitats around the outlets as a result of the discharge of treated water;
- There is no indication that there are outlet-related influences on the abundance or biomass of benthic macroinvertebrates in sediments around the ocean outlets;
- There is no detectable contamination of sediments or fauna by metals or pesticides from treated wastewater discharged from the ocean outlets.
- There is no indication of significant growth of "nuisance" algae around the outlets.

The information returned to date from the Alkimos Water Quality Characterisation programme (December 2004 to July 2005) indicates that the nutrient concentrations at Alkimos are within the range of those found at background sites at Ocean Reef (Figure 4.2). The four Ocean Reef "seasonal" water quality monitoring sites (N1, N2, N3, N6) were chosen for comparison between Ocean Reef and Alkimos water quality. These sites are sampled once each season and are located to sample the water quality adjacent to, and to the north and south of the Ocean Reef ocean outlets.

Ocean Reef sampling site N2 (Figure 4.1) is located directly above the diffuser array at the ocean outlet. It can be seen from Figures 4.2a-c that nutrient concentrations at Site N2 are routinely elevated, while at sites N6 and N3 (1 km and ~4 km

"downstream" of N2 respectively) concentrations are of a similar order to those found at Alkimos. Site N1 is located 4 km to the south of the outlet and under the prevailing current conditions is likely to represent "ambient" water quality not directly influenced by the Ocean Reef outlets. Site N3 is approximately 12 km south of the Alkimos water quality sites and is in shallower waters than the proposed Alkimos ocean outlet. Site N4 was located 8 km north of the Ocean Reef outlets and approximately 6 km south of the Alkimos site Offshore-6. In the spring of 2003 Site N4 was replaced by Site N6, located approximately 1.2 km north of the Ocean Reef ocean outlets.

Ammonium concentrations at Alkimos were routinely at or close to the reporting limit of 3 µg.N/L. Sites close to or "downstream" of the Ocean Reef ocean outlets (N2, N6 and N3) often displayed elevated concentrations of ammonium in comparison to "background" levels displayed by sites N1 and N4 (Figure 4.2a).

Nitrate + nitrite (NO_x) concentrations at Alkimos were of a similar magnitude to the Ocean Reef sites N1, N4 and N6. Site N2 routinely displayed elevated NO_x concentrations relative site more distant from the Ocean Reef ocean outlets (Figure 4.2b).

As with ammonium and NO_x, Filterable Reactive Phosphorus (FRP) concentrations at Alkimos were of a similar order of magnitude to those at Ocean Reef sites N1, N3, N4 and N6. Only site N2 (closest to the ocean outlets) displayed FRP concentrations that were routinely elevated above "background" levels (Figure 4.2c).

Chlorophyll-a concentrations at Alkimos were of a similar magnitude to those found at the Ocean Reef sites during the reporting period (Figure 4.2d). Chlorophyll *a* does not have the same degree of correlation to the proximity of the Ocean Reef ocean outlets as found for the other nutrient parameters presented in Figure 4.2. Further characterisation of the primary production regime at Alkimos is available in the phytoplankton survey report completed for the Alkimos Marine Studies Programme (Oceanica 2005b).

It is likely that the Alkimos site will be subject to greater mixing (and hence dispersal of the treated wastewater plume) than the Ocean Reef site due to the greater depth of the diffuser and lower levels of protection by offshore reefs (outlet further offshore at Alkimos) (Table 4.1). Modelling of the mixing regime at Alkimos is currently being undertaken as part of the Alkimos Marine Studies Programme, the results will be presented in a separate hydrodynamics report.

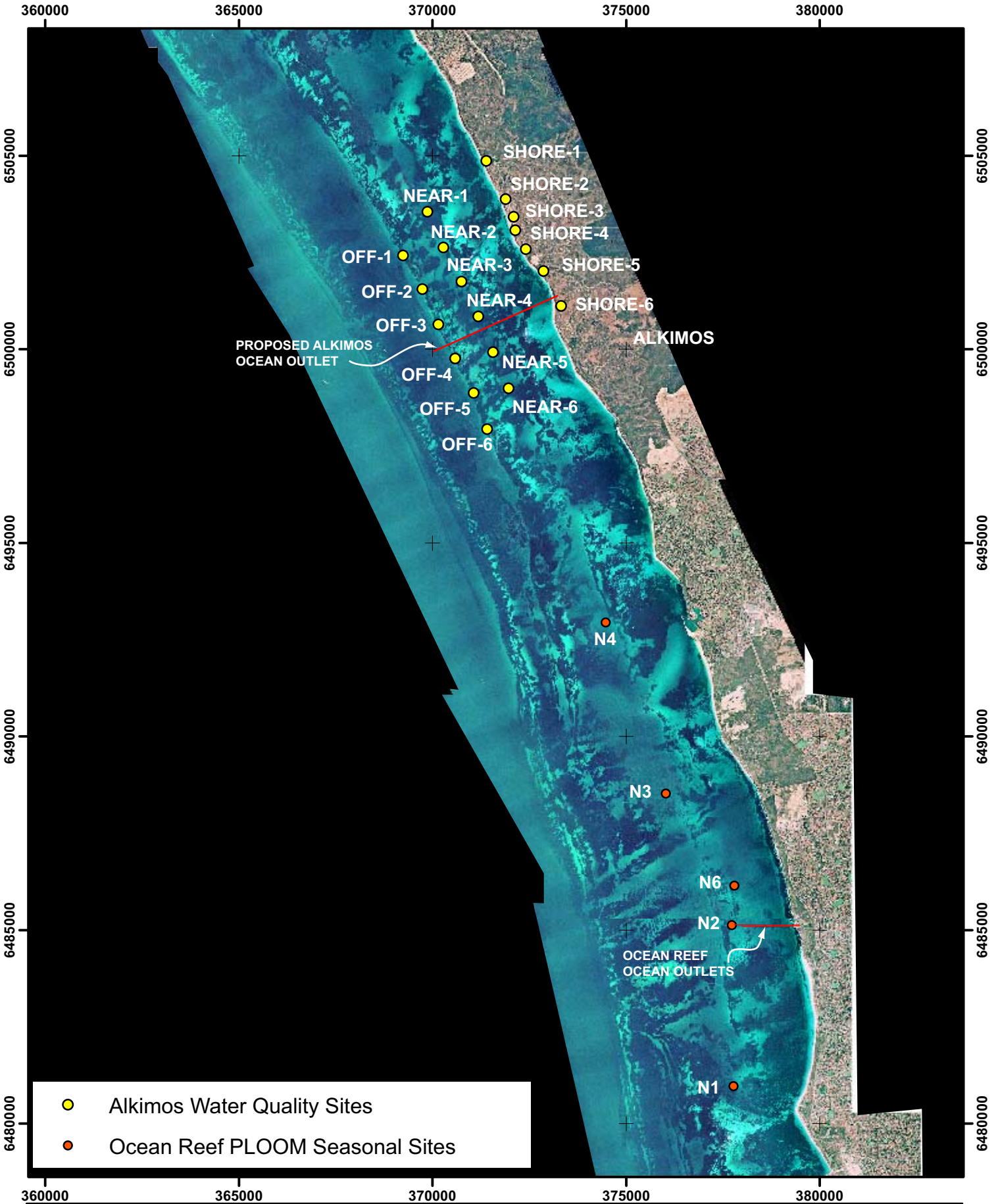
4.4 Microbiological (human health) issues

The treated wastewater discharged from the Ocean Reef outlets contains elevated concentrations of faecal bacteria in comparison to the background marine receiving waters. The PLOOM programme monitors the concentrations of faecal bacteria (through thermo-tolerant coliforms (TTC) and Enterococci determinations) in the vicinity of the Ocean Reef outlets as a measure of the dispersion and die-off rates after wastewater discharge. The main findings of the 2003/2004 PLOOM monitoring with regards to microbiological issues were (Oceanica 2005a):

- There is rapid die-off of bacteria and rapid dilution of contaminants (140-fold dilution achieved in the mixing zone); and

- There is no bacterial contamination of beaches adjacent to the outlets, with national primary (swimming) and secondary (sailing, boating) contact recreation human health criteria met within 250 m of the outlets.

The dilution and dispersal of microbiological contaminants at Alkimos will depend largely on the mixing regime in the vicinity of the outlet. Experience from the Ocean Reef outlets indicates that reporting limit levels of faecal bacteria (as TTC and Enterococci) are likely to be reached within 2000 m of the outlet at Alkimos (DALSE 2004; Oceanica 2005c).



oceanica
marine & estuarine specialists

Created By: PLW
Reference: 442/1
Figure 4.1 Alkimos and Ocean Reef.mxd

0 1.25 2.5 5 Kilometers

DATUM
Horizontal: UTM Zone 50,
Based on WGS 84
Vertical: N/A

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Figure 4.1

Alkimos and Ocean Reef water quality sampling site locations

Client: Water Corporation June 2005

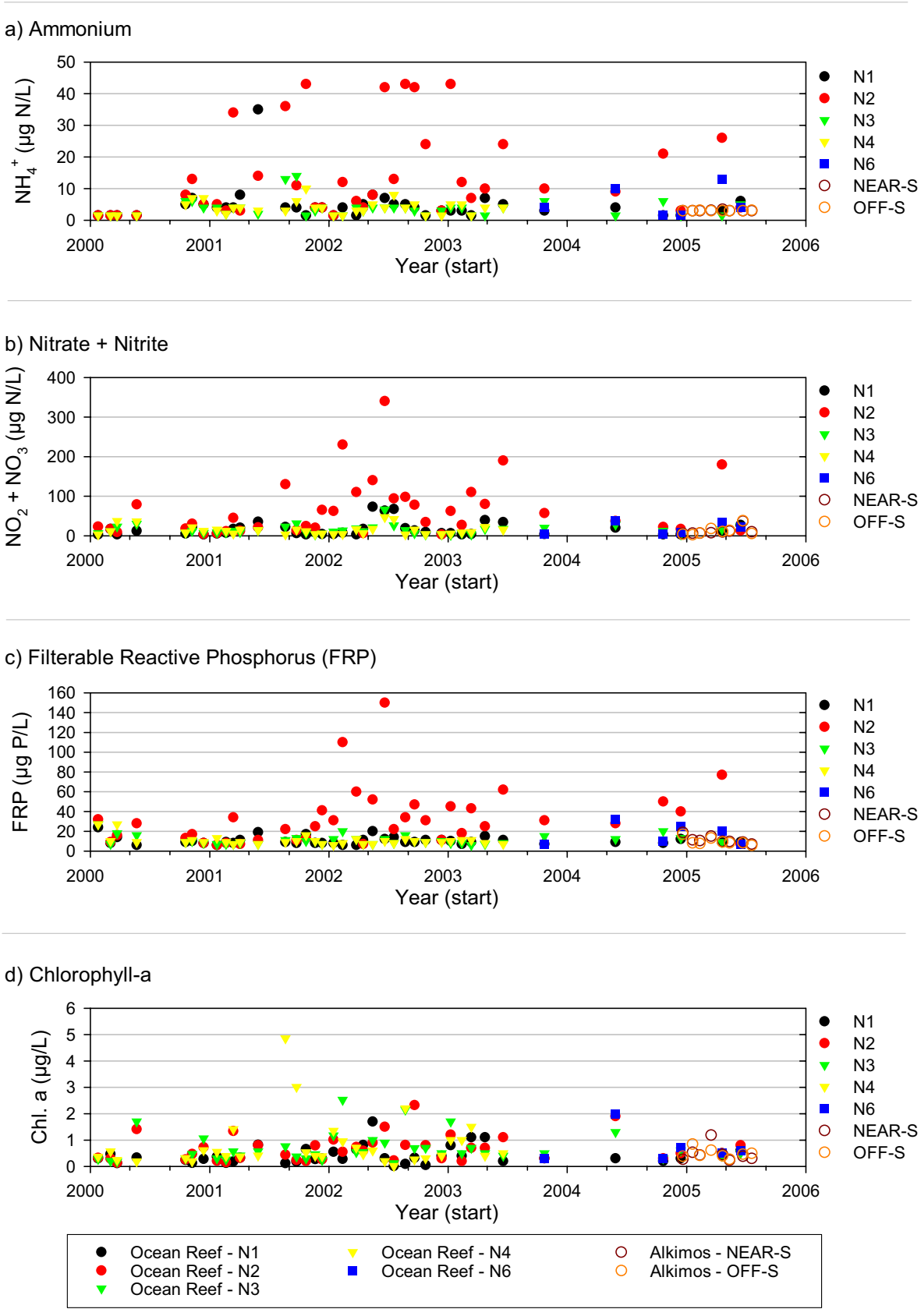

Figure 4.2 Comparison of Ocean Reef and Mean Alkimos Nutrient and Chlorophyll Concentrations

Notes: The station "Ocean Reef – N2" is directly above the Ocean Reef ocean outlets;
Alkimos sampling began in December 2004;

5. Conclusions

The water quality characterisation programme for the proposed Alkimos ocean outlet (December 2004 - July 2005) has provided sufficient information for the preliminary characterisation of the nutrient regime and water-column structure in the vicinity of the proposed outlet. The Alkimos marine waters are essentially un-polluted, with all nutrient parameters being either below reporting limits or within the ranges returned by the PLOOM programme Ocean Reef background sites (with an Ocean Reef background seasonal monitoring site some 6 km to the south, Site N4). The water column structure was either well mixed or slightly stratified in the deeper waters (~15 m) over the reporting period and well oxygenated. The combination of the Leeuwin Current offshore (southward), wind driven surface currents nearshore (predominantly northward) and wave/reef interactions in the vicinity of the proposed outlet are likely to prevent significant periods of density stratification.

The water quality issues of primary concern from the operation of the proposed Alkimos treated wastewater ocean outlet are likely to be:

- Localised increases in surface water nutrient concentrations in the vicinity of the ocean outlet, dissipating to background concentrations over a spatial scale of several kilometres; and
- Localised increases in the faecal bacteria concentrations (as measured by thermo-tolerant coliform and Enterococci assays), dissipating to background concentrations over a spatial scale of several kilometres.

Evidence from the PLOOM programme indicates that the ecological and human health values of the coastal waters outside of a suitably sized zone can be maintained with proper ocean outlet management (Oceanica 2005a).

6. Acknowledgements

Data analysis and preparation of the Interim Water Quality Characterisation Data Report was undertaken by Oceanica (Mark Bailey, Stephanie Turner and Phillip Whittle). Ewan Buckley, Eve Hollingsworth and Marie Gouteff (all Oceanica) assisted with data collation and figure preparation. Katy Rawlins (Oceanica) assisted with report formatting.

Ms Celeste Wilson (MAFRL) co-ordinated the field data and sample collection and laboratory analysis. Mr Mark Nener and Mr Mathew Hegney (Water Corporation) co-ordinated and undertook the shoreline water quality sampling.

The Western Australian Water Examination Laboratory (PathCentre) analysed water samples for the microbiological parameters (NATA accredited). Water quality analysis was undertaken by MAFRL. MAFRL incorporates a fully equipped NATA accredited facility for the analysis of fresh, estuarine and marine samples.

7. References

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Appendix A

Site Co-ordinates

Appendix A Site Co-ordinates

WGS 84	Name	Easting	Northing	Site Depth
UTM Zone 50	WWTP	373329	6501108	-
UTM Zone 50	1-OFFSHORE	369249	6502419	13.9 m
UTM Zone 50	2-OFFSHORE	369749	6501548	14.2 m
UTM Zone 50	3-OFFSHORE	370160	6500634	15.0 m
UTM Zone 50	4-OFFSHORE	370600	6499758	15.5 m
UTM Zone 50	5-OFFSHORE	371070	6498868	14.4 m
UTM Zone 50	6-OFFSHORE	371419	6497928	14.5 m
UTM Zone 50	1-NEARSHORE	369881	6503540	10.3 m
UTM Zone 50	2-NEARSHORE	370291	6502626	10.3 m
UTM Zone 50	3-NEARSHORE	370758	6501742	12.3 m
UTM Zone 50	4-NEARSHORE	371196	6500842	12.5 m
UTM Zone 50	5-NEARSHORE	371578	6499916	9.7 m
UTM Zone 50	6-NEARSHORE	371974	6498987	12.4 m
UTM Zone 50	1-SHORE	371404	6504863	Waist deep
UTM Zone 50	2-SHORE	371898	6503869	Waist deep
UTM Zone 50	3-SHORE	372102	6503416	Waist deep
UTM Zone 50	4-SHORE	372150	6503069	Waist deep
UTM Zone 50	5-SHORE	372417	6502581	Waist deep
UTM Zone 50	6-SHORE	372877	6502013	Waist deep

Appendix B

Certificates of Analysis - Microbiological

Appendix B Certificates of Analysis - Microbiological

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