E N V I R O N M E N T   P R O T E C T I O N   A U T H O R I T Y

Ambient Water Quality Monitoring

Nepean Bay, Kangaroo Island

Government of South Australia

EPA South Australia

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Ambient Water Quality of Nepean Bay, Kangaroo Island

Report No. 1: 1999–2004

June 2005

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SUMMARY

Nepean Bay is a sheltered marine embayment on the northeast coast of Kangaroo Island, off the southern coast of South Australia. It receives discharges from the Cygnet River and the township of Kingscote. In recent years residents and local fishermen have become aware of seagrass decline in the bay, predominantly in the Western Cove region near the mouth of the Cygnet River.

In 1999 the Environment Protection Authority (EPA) began an ambient water quality monitoring program at five sites in the waters of Nepean Bay. To assess water quality, water samples were analysed for nutrients, turbidity and microbiology using trigger values provided in the *National Water Quality Management Strategy* (ANZECC 2000). Results have been classified as good, moderate or poor based on the EPA system used in previous reports. This report is a summary of the first five years of sampling.

According to the EPA classifications, water quality was categorised as follows:

- Nutrients were broadly classified as good across all sites for the protection of the aquatic ecosystem. However, ammonia at Western Cove was classified as moderate, and chlorophyll *a* was classified as moderate at Point Morrison.
- Turbidity was classified as good for the protection of the ecosystem at all sites.
- All sites were classified as good for *Escherichia coli* for the protection of shellfish aquaculture in the waters.

The more detailed findings from the report include the following:

- Ammonium (NH_4^+) appears to be the key driver of the eutrophic nature of Nepean Bay, with both total nitrogen and ammonia concentrations significantly higher at Western Cove and Bay of Shoals than at other sites. Ammonia concentrations appeared to be decreasing over the five years of sampling.
- There was a coarse positive correlation between ammonia concentrations in Western Cove and the Bay of Shoals and rainfall in the Cygnet River catchment. While this could possibly be explained by discharges from the Cygnet River at Western Cove, the reasons for elevated ammonia in Bay of Shoals, other than by water-borne transport, is currently unknown.
- Turbidity was significantly higher at Point Morrison and Kingscote than at the reference site at Offshore Waters. This trend was repeated with chlorophyll *a* concentrations and may be due to uptake of nutrients by microalgae in the water column. This is further supported by the significantly lower nutrient concentrations at these sites.

Contrary to the classifications there is significant evidence that parts of Nepean Bay are eutrophic and that seagrass is being lost, particularly in Western Cove. Edyvane (1997) estimated that 2695 ha of intertidal and subtidal seagrass had been damaged or lost from Western Cove. Along with the presence and abundance of drift macroalgae throughout Western Cove, this led to the conclusion that there were excessive nutrients in the system (eutrophic). This conclusion was supported by Bryars *et al*. (2003), who found excessive epiphyte growth on seagrasses in Nepean Bay—particularly in Western Cove—presumably generated by excessive nutrients and low water movements in the bay.

A loss of seagrass in Nepean Bay will result in the loss of primary production in the region and potentially a loss of nursery and habitat areas. The latter are important for fish and invertebrate breeding for species such as King George whiting (*Sillaginodes punctata*) and the western king prawn (*Penaeus latisulcatus*), which are important both commercially and for the ecosystem. A loss of seagrass can also result in an increase in erosion of sediment and an increase in turbidity, both of which can have further impacts on seagrass and macroalgal reef systems.

1 INTRODUCTION

Kangaroo Island, the third largest island in Australia, is approximately 150 km long and 55 km wide, and located to the south of the Yorke and Fleurieu peninsulas in South Australia. The island has long been recognised as one of the richest and most biologically diverse regions in South Australia. This diversity is partly due to the great variety of coastal habitats around the island, from high-energy surf beaches to shallow marine embayments (Womersley and Edmonds 2002).

Kangaroo Island's major economic activities are agriculture, forestry, fishing and tourism. The island is the most internationally recognised tourist region outside Adelaide (KIDB 2002).

Nepean Bay is a sheltered marine embayment on the northeast coast of Kangaroo Island (Figure 1). Kingscote is the largest town on Kangaroo Island, with a population of approximately 1500 people, and is located on Nepean Bay. Cygnet River is the island's largest river and flows into Western Cove in the south-western corner of Nepean Bay (Figure 1).

The subtidal vegetation of Nepean Bay mostly comprises seagrass meadows (*Posidonia* spp. and *Halophila australis*), unvegetated sand and some sections of reef (Bryars *et al.* 2003). Ecologically, Nepean Bay has very rich biological diversity and supports a variety of both commercially and biologically important species, including King George whiting (*Sillaginodes punctata*), sea garfish (*Hyporhamphus melanochir*), Australian salmon (*Arripis truttacea*), tommy ruff (*Arripis georgiana*), southern rock lobster (*Jasus edwardii*) and southern calamari (*Sepioteuthis australis*) (Glover 2002). To the east is the shallow embayment of American River and Pelican Lagoon, which is known to provide food and a nursery area for juvenile stages of many of these biologically and commercially important species. For this reason Pelican Lagoon has been granted aquatic reserve status. The numerous aquaculture ventures in Nepean Bay include oyster leases along the south-western coast of Western Cove, between the mouth of the Cygnet River and Point Morrison and into American River.

1.1 Environmental issues in Nepean Bay

Seagrass meadows are very productive habitats and serve as nursery areas for commercially and ecologically important marine fish and invertebrates. The loss of these habitats may contribute to a loss of marine invertebrates and fish; it can also cause seabed instability, which in turn can cause erosion of sediments and further seagrass loss. Economically, the loss of seagrass meadows can result in a loss to commercially important fisheries (Connolly *et al.* 1999).

In most seagrass meadows, macroalgae (and other organisms) grow on seagrass blades as epiphytes[1]. In nutrient enriched regions, epiphyte growth may be greatly increased. Epiphytic algae can form canopies over the seagrass and reduce the amount of light passing to the seagrass leaves, thereby reducing the photosynthetic ability of the seagrass (Brun *et al.* 2003; Short *et al.* 1995). These algae may also increase seagrass susceptibility to physical damage by wave action or by sand abrasion (Neverauskas

[1] Epiphyte—a plant growing on another plant but not gaining nutrients from it

1989). Once the seagrass dies the sediments held by its roots erode, the seagrass meadow becomes unstable and the area of seagrass loss generally expands (called a 'blowout').

Anecdotal evidence from local residents and commercial fishermen suggested that seagrass was being damaged and lost in Nepean Bay. In 1995 the Environment Protection Authority (EPA) conducted SCUBA transects in Nepean Bay and observed areas of patchy seagrass with significant epiphyte growth. In 1996, Edyvane (1997) estimated that 2695 hectares of intertidal and subtidal seagrass had been damaged or lost from Western Cove, and recorded observations of the presence and abundance of the drift macroalga *Chiracanthia arborea* throughout Western Cove. This alga was seen to be particularly prevalent in areas of seagrass decline. Its presence and the high epiphyte loads led Edyvane (1997) to the suggestion that Western Cove was eutrophic. This suggestion was further supported by the poor condition of seagrass and heavy epiphyte growth observed by Bryars *et al.* (2003).

In 2002 the Department for Environment and Heritage was engaged by the EPA to map the change in substrate and seagrass/algae throughout Western Cove. Cameron and Hart (2002a & b) used satellite imagery and remote sensing techniques but found it extremely difficult to differentiate seagrass and macroalgae due to their spectral similarities. They concluded that there had been a general increase in permanent cover (14.7%) and algal detrital matter (31.1%) from 1989 to 2001. The conclusion was based on the assumption that Western Cove is eutrophic and therefore would have conditions conducive to macroalgae growth and not seagrass regrowth. Therefore the increase in cover had been assumed to be an increase in algal matter. Figure 2 shows the general pattern of seagrass loss/algal detrital matter gain in the regions close to shore and in a north–south direction offshore from the Cygnet River mouth. This approximately follows the water circulation predictions of Oceanique Perspectives (2000).

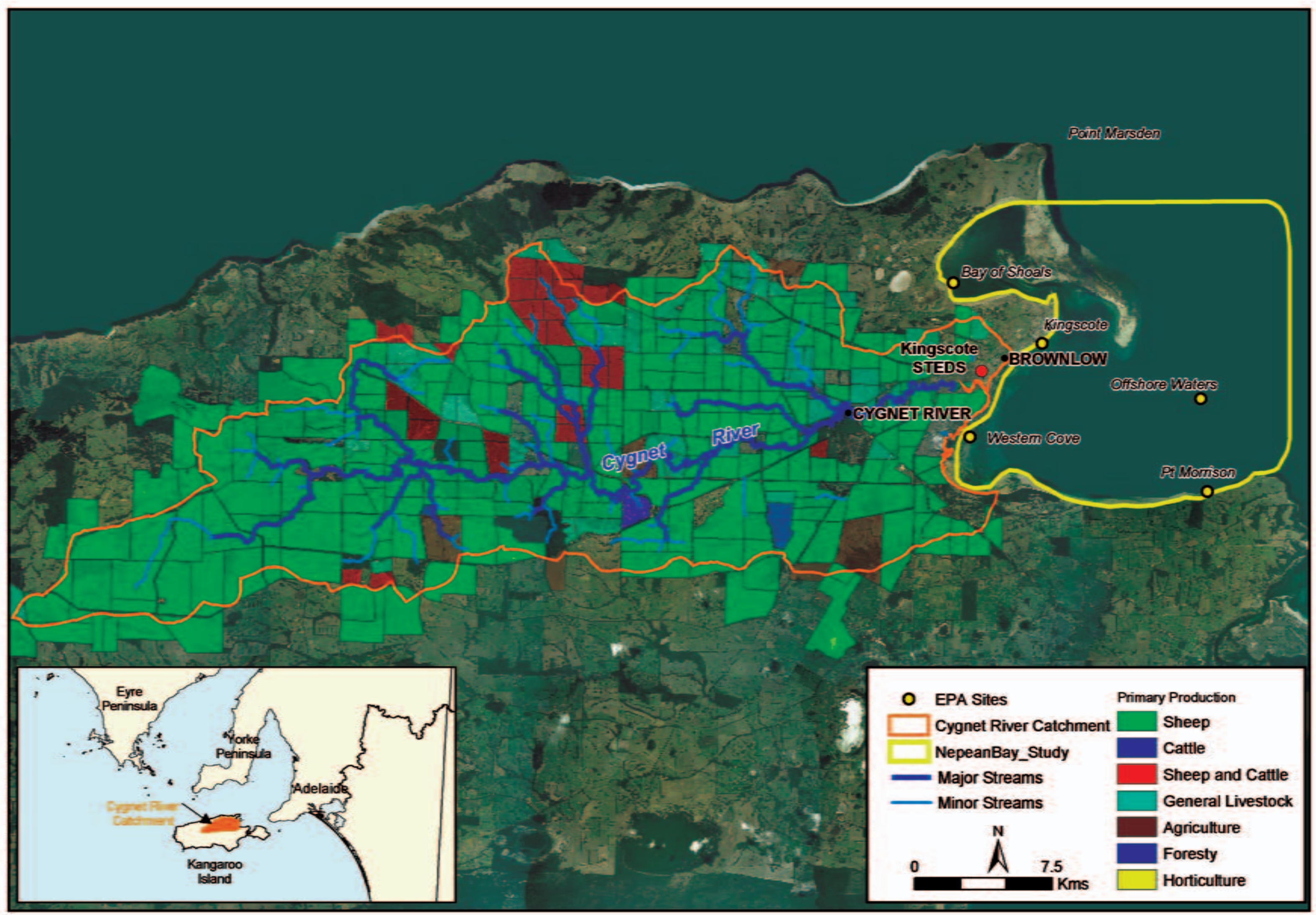

Figure 1 Study area and land use classifications for Cygnet River catchment

1.2 Potential pollution sources in Nepean Bay

Cygnet River drains 11% of Kangaroo Island's surface area into Nepean Bay. The principal activity in the catchment is livestock grazing, mostly sheep, with some areas of mixed sheep, cattle and general livestock (Figure 1). Defecation from livestock and high stocking rates in the watershed are likely to result in runoff during rainfall carrying high levels of nutrients into Cygnet River. Fertiliser use in agricultural areas also causes nutrient-rich runoff to enter nearby waterways. Nutrient loadings from the Cygnet River catchment have been estimated as approximately 50 tonnes of total nitrogen and 2 tonnes of total phosphorus entering Nepean Bay from the Cygnet River each year (Southgate in prep). These estimates are approximate and simply based on nutrient concentrations from grab samples multiplied by river flow. The EPA and the Kangaroo Island Natural Resource Management Board are currently installing a flow-proportional composite sampler to better estimate nutrient loads in the Cygnet River.

It is thought that a large proportion of nutrients in the Cygnet River enter the aquatic environment during heavy rainfall over short periods of time. These heavy falls cause increased erosion of agricultural soils and stream banks, resulting in high levels of suspended solids carrying nutrients in the river flows. Large turbidity plumes have been observed in Western Cove during periods of high flow (personal observations; R Southgate pers comm).

In addition to nutrients and sediments entering the Cygnet River through agricultural practices, herbicides and pesticides are commonly used in the catchment (Jenkins in prep). Poor agricultural practices often result in these chemicals, which can possibly affect seagrasses even at very small concentrations, being transported into rivers and streams during high rainfall (Macinnis-Ng and Ralph 2003).

Other potential sources of pollution into Nepean Bay are the septic tank effluent disposal system (STEDS) just south of Brownlow, which treats wastewater from the surrounding areas including Kingscote. Historically, after periods of heavy rain the overflow from the STEDS lagoons ran onto the coastal flats, which are flooded during very high tides. This may have been a source of nutrients entering the marine environment. The problem has recently been rectified by installing an additional irrigation system to prevent overflow from the STEDS entering the marine environment.

The town of Kingscote, with its 1500 permanent residents, is relatively small but urban runoff may be contributing to the pollutant load entering Nepean Bay. This contribution would be smaller than the nutrient load from the Cygnet River.

In 1999 the EPA began a coastal ambient water quality monitoring program assessing nutrient and microbiological concentrations across five sites in Nepean Bay (Figure 3). The aim of this water quality program is to assess ambient water quality, both spatially and temporally, across Nepean Bay.

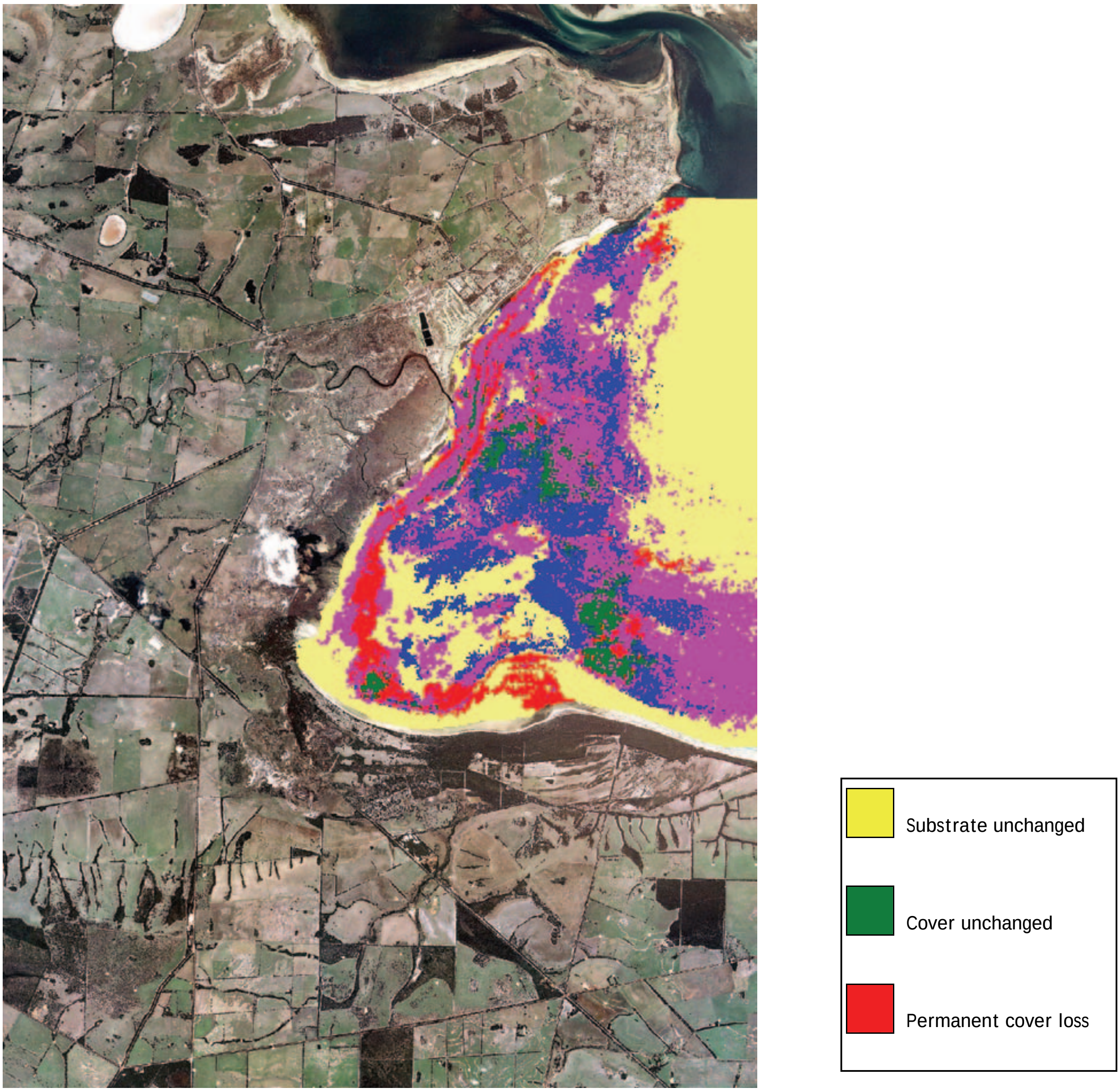

Figure 2 Aerial seagrass mapping change in Western Cove between 1989-2001 (reproduced with permission from Cameron and Hart (2002a))

Figure 3 EPA monitoring sites within Nepean Bay

2 METHODS

The study area (Figure 3) incorporates the northern region of Nepean Bay between Point Morrison and Point Marsden, encompassing the Bay of Shoals and Western Cove. The sites used for the monitoring program were selected from those recommended by Edyvane (1997); one site is in Bay of Shoals (Site 3) and one is in Western Cove (Site 6). The remaining sites are typical of the Nepean Bay environment, selected to provide representative ambient water quality measurements (Figure 3). Site 10 'Offshore Waters' is monitored as a reference site to provide an estimate of unimpacted water quality and is a comparison point for inferential statistics.

Monthly water samples are taken from each site and analysed by a NATA[2]-accredited laboratory. Samples are analysed for a range of nutrients including ammonia, total Kjeldahl nitrogen (TKN), oxidised nitrogen (nitrate + nitrite) and total phosphorus as indicators of nutrient enrichment. The physical parameters temperature and turbidity are measured and samples are also tested for *Escherichia coli* (*E. coli*) as an indicator of potential microbial pollution. Microalgal biomass has been estimated by measuring chlorophyll *a* at each site.

2.1 Statistical analysis

2.1.1 Descriptive statistics

Water quality measurements from most natural environments are highly variable, so descriptive statistics are used to summarise the data. Detailed descriptions of the statistical methods used are beyond the scope of this report. For further explanation and examples of calculations see the statistical text *Biometry* (Sokal and Rohlf 1995) or *Statistics for Water Resources* (Helsel and Hirsch 1992), or other EPA reports such as the *Ambient Water Quality Monitoring of the Gulf St Vincent Metropolitan Coastal Waters* (Gaylard 2004).

In this report, data for most parameters showed frequency distributions skewed to the left (lots of very small results with a few high results). In this situation the best measure of central tendency is the median rather than the mean. The 90th percentile is a measure that excludes the outermost 10% of the data and is more robust to occasional extreme events, which can skew the mean. The EPA uses both the median and the 90th percentile to classify each water quality parameter (see Section 2.2).

2.1.2 Comparing differences between sites

Inference testing in this report has been carried out using non-parametric methods as the data is not normally distributed. Sites were compared using the Friedman test, followed by the Wilcoxon test to determine differences between sites (Helsel and Hirsch 1992; Sokal and Rohlf 1995). The Dunn Sidak correction method was used to correct the critical □ for pairwise comparisons to maintain a type I error rate of 0.05 for each variable tested.

[2] National Association of Testing Authorities

The inferential statistical methods used here allow us to determine if there are statistically significant differences between sites at the $p = 0.05$ level. The p value is merely an arbitrary cut-off point (or confidence level) where one data set is different from another data set by enough to say with confidence that they are different for some reason other than chance. A p value of 0.05 means that we have 95% confidence that any difference seen is not due to random chance.

Trend analysis, generally speaking, is looking at the results of sampling over time to see if a variable is increasing or decreasing. This type of analysis is very complex and depends largely on the number of samples taken over time and the variation in the data. Unfortunately, trend analysis was unable to be completed using a statistically accepted technique due to the low number of samples (minimum 50 samples generally needed). In this report trends were investigated by visual assessment for change over time and caution has been exercised when there is high variation in the data.

2.2 Water quality classifications

Ambient water quality results have been classified as good, moderate or poor compared to the current *Guidelines for Fresh and Marine Water Quality* (ANZECC 2000). Data was assessed against the environmental values of Protection of Aquatic Ecosystems (Marine) and Protection of Aquaculture. Classification is based on the position of the median and 90th percentile in relation to the trigger values set out by the ANZECC (2000) guidelines. A key feature in the definition of an estuary is 'a measurable variation in salinity due to the mixture of seawater with water derived from on or under the land' (DEH 2004). Nepean Bay as a whole has only very localised regions where salinity is varied at any time, and to classify the whole region as estuarine may not be accurate. Therefore, water quality classifications in this report are based on the Protection of Aquatic Ecosystems (Marine) environmental values (Table 1).

Table 1 Summary of water quality classification trigger values[a] (modified from ANZECC 2000)

	NH4+ (mg/L)	OxN (mg/L)	TN (mg/L)	TP (mg/L)	Chl a (µg/L)	Turbidity (NTU)	E.coli (cells/100 mL)
Marine	0.05	0.05	1.00	0.10	1	5–10	n.a.
Aquaculture	1.00[3]	100 as NO3- 0.100 as $NO2^-$	n.a.	n.a.	n.a.	n.a.	14 with no more than 10% >43

a: for abbreviations see Section 3—Results

Nutrient water quality parameters are classified as good when most of the results (the 90th percentile is used) are below the trigger value. When more results are below the trigger value than above, the classification is moderate (i.e. the 90th percentile is above the trigger value but the median is below) and when most results are above the trigger value (i.e. the median is above the trigger value) the water quality is classified as poor for that parameter.

Turbidity is classified differently because ANZECC provides a range of water quality trigger values, and turbidity is variable and has chronic effects in the marine

3 The trigger value for ammonia in aquaculture is either 0.100 mg/L unionised (NH_3) or 1.00 mg/L total ammonia (NH3 + NH+)

environment. Wind and wave action can stir up sediment and cause high turbidity in relatively pristine areas. This still can affect seagrass photosynthesis but it may not be due to human-induced pollution. The EPA has adopted a classification using the 90th percentile and a range of values indicative of good, moderate and poor regions.

Bacterial water quality indicators are also classified differently from the chemical parameters described above. For the protection of aquaculture, ***E. coli*** is classified using the median value compared to the trigger value. In this report the classifications are only used as a guide as the ANZECC Guidelines require that the shellfish harvesting area is assessed by a sanitary inspection to take a risk based approach to the origins of any bacteria present and the potential for harm to human consumers (ANZECC 2000).

3 RESULTS

3.1 Ammonia

Ammonia can act as both a nutrient and a toxicant. It provides a source of nitrogen to plants and animals and can be directly toxic to invertebrates and fish. Ammonia is readily taken up by plants and algae; it can also be converted by bacteria to oxidised forms of nitrogen such as nitrate and nitrite. All of these forms of nitrogen are biologically available and can result in excessive algal and/or plant growth (eutrophication). The EPA assesses total ammonia—that is, both the ammonia (NH_3) and the ammonium (NH_4^+) forms—as both are available as nutrients.

The trigger value for ammonia is 0.05 mg/L for the protection of the aquatic ecosystem. All sites were classified as good, except Western Cove, which was classified as moderate. The trigger value for the protection of aquaculture is 1.00 mg/L. All sites were classified as good (Table 2).

Bay of Shoals had the highest median ammonia concentration with 0.023 mg/L, while Offshore Waters, Kingscote and Point Morrison all had the lowest concentration of ammonia with 0.020 mg/L. Kingscote had the highest single concentration with 0.156 mg/L (three times the ANZECC trigger value) in a sample taken on 29 August 2000, a week after 72 mm of rain had fallen. Offshore Waters had the lowest maximum concentration of 0.080 mg/L.

Table 2 Statistical summary of ammonia (mg/L)

Site		Mean	Median	Standard deviation	95% confidence interval	90th percentile	Max	N	Classification	
									Ecosystem	Aquaculture
3	Bay of Shoals	0.028	0.023	0.016	0.022–0.033	0.043	0.090	33	GOOD	GOOD
4	Kingscote	0.028	0.020	0.028	0.018–0.038	0.048	0.156	32	GOOD	GOOD
6	Western Cove	0.031	0.022	0.024	0.023–0.039	0.062	0.108	33	MODERATE	GOOD
8	Point Morrison	0.023	0.020	0.018	0.017–0.029	0.038	0.105	33	GOOD	GOOD
10	Offshore Waters	0.025	0.020	0.018	0.018–0.031	0.048	0.080	33	GOOD	GOOD

There were no statistical differences in ammonia concentrations between sites in Nepean Bay.

Ammonia concentrations at all sites appeared to have been decreasing over the past five years (see time series plot in Appendix 2. Time series plots).

3.2 Oxidised nitrogen

Oxidised nitrogen (NOx) is a measure of the compounds nitrate (NO_3^-) and nitrite (NO_2^-), both of which are highly bioavailable to plants. Nitrate is the more prevalent form in marine waters, with nitrite often being oxidised further to nitrate under aerobic conditions.

The low nutrient levels inherent in southern Australian waters and interferences common in the chemical analysis of seawater often present difficulties with analytical detection limits. Over 80% of the NOx samples for Nepean Bay were below the analytical detection limit (0.005 mg/L).

The trigger value for the protection of the marine ecosystem for oxidised nitrogen is 0.050 mg/L. All sites were classified as good for NOx (Table 3).

For the protection of aquaculture there is no specific trigger value for NOx but it is broken down into nitrate and nitrite. The trigger value for nitrate is 100 mg/L and for nitrite is 0.100 mg/L. All sites were classified as good for the protection of aquaculture.

Table 3 Statistical summary of oxidised nitrogen (nitrate and nitrite) (mg/L)

Site		Mean	Median	Standard deviation	95% confidence interval	90th percentile	Max	N	Classification	
									Ecosystem	Aquaculture
3	Bay of Shoals	0.007	0.005	0.009	0.004–0.010	0.006	0.059	33	GOOD	GOOD
4	Kingscote	0.010	0.005	0.023	0.002–0.018	0.013	0.136	32	GOOD	GOOD
6	Western Cove	0.008	0.005	0.013	0.004–0.013	0.009	0.082	33	GOOD	GOOD
8	Point Morrison	0.005	0.005	0.001	0.005–0.006	0.005	0.011	33	GOOD	GOOD
10	Offshore Waters	0.006	0.005	0.005	0.004–0.008	0.005	0.035	33	GOOD	GOOD

The NOx medians at all sites were 0.005 mg/L, which is the analytical detection limit in marine waters. The highest concentration was 0.136 mg/L at Kingscote on 1 August 2000.

Sites were not statistically compared for NOx due to the high number of results below the analytical detection limit.

3.3 Total nitrogen

Total nitrogen (TN) is a measure of all the nitrogen available to aquatic plants and animals, and takes into account all the different forms of nitrogen in the system. In this report it is the sum of oxidised nitrogen (nitrate and nitrite) plus TKN[4] but does not include the very small amount of nitrogen present as elemental nitrogen (N_2).

Appendix 1. summary statistics shows the summary statistics for TKN and dissolved organic nitrogen, which both make up large parts of the total nitrogen distribution at the sampling sites in Nepean Bay.

[4] Ammonia is measured as a part of TKN and is therefore included as a part of total N.

All sites were classified as good compared to the trigger value for the protection of the ecosystem for estuaries of 1 mg/L (Table 4).

Bay of Shoals results showed the highest concentrations of total nitrogen in Nepean Bay, with a median concentration of 0.210 mg/L, and Offshore Waters the lowest, with 0.139 mg/L. Point Morrison also had relatively low total nitrogen concentrations, with a mean of 0.148 mg/L.

Total nitrogen concentrations at Bay of Shoals and Western Cove were significantly higher than at the reference site at Offshore Waters and at Point Morrison and Kingscote. ($p<0.05$). There were no obvious trends in total nitrogen concentrations over the five years of sampling.

Table 4 Statistical summary of total nitrogen (mg/L)

Site		Mean	Median	Standard deviation	95% confidence interval	90th percentile	Max	N	Classification
									Ecosystem
3	Bay of Shoals	0.210	0.195	0.098	0.176–0.244	0.355	0.475	31	GOOD
4	Kingscote	0.172	0.140	0.093	0.140–0.205	0.283	0.525	32	GOOD
6	Western Cove	0.186	0.169	0.077	0.160–0.212	0.301	0.355	33	GOOD
8	Point Morrison	0.148	0.126	0.073	0.123–0.173	0.223	0.425	33	GOOD
10	Offshore Waters	0.139	0.135	0.069	0.115–0.162	0.233	0.375	33	GOOD

3.4 Total phosphorus

Phosphorus is an essential element in both plants and animals. It is readily bioavailable to organisms in the phosphate form but this ion readily adsorbs onto particulate matter so phosphorus is often bound in sediments.

Total phosphorus concentrations are generally very low in southern Australian waters and as a result the phosphorus concentrations were affected by results below the analytical detection limit (18% <DL). The trigger value for total phosphorus in the marine environment is 0.100 mg/L. All sites were classified as good throughout the study area. There is no trigger value for total phosphorus for the protection of aquaculture.

All sites except Bay of Shoals, with 0.019 mg/L, had a median total phosphorus concentration of 0.020 mg/L. Offshore Waters had the highest single result of 0.040 mg/L.

Table 5 Statistical summary of total phosphorus (mg/L)

Site		Mean	Median	Standard deviation	95% confidence interval	90th percentile	Max	N	Classification	
									Ecosystem	Aquaculture
3	Bay of Shoals	0.018	0.019	0.008	0.0154–0.0207	0.026	0.035	33	GOOD	n.a.
4	Kingscote	0.018	0.020	0.008	0.0156–0.0209	0.025	0.034	32	GOOD	n.a.
6	Western Cove	0.018	0.020	0.008	0.0155–0.0208	0.026	0.032	33	GOOD	n.a.
8	Point Morrison	0.018	0.020	0.007	0.0155–0.0206	0.028	0.033	33	GOOD	n.a.
10	Offshore Waters	0.019	0.020	0.007	0.0168–0.0217	0.026	0.040	33	GOOD	n.a.

There were no significant differences between sites in Nepean Bay, and there were no significant trends in total phosphorus concentrations over the five years of sampling.

3.5 Chlorophyll a

Chlorophyll *a* is used as a measure of microalgae in the water column. Chlorophyll *a* measurements do not take into account macroalgae, which can be a significant part of the ecosystem, especially when considering eutrophication.

Microalgae use photosynthesis to grow. Despite the importance of algae, they can be a problem if they occur in high numbers and form algal blooms. Their growth can be increased by human impacts such as increases in nutrient loads and thermal pollution. Measuring chlorophyll *a* as a biological indicator of nutrient pollution and eutrophication is a tool used by many researchers (Ward *et al.* 1998; ANZECC 2000). It may also help to reduce the uncertainty of chemical monitoring: algal growth may be more representative of the nutrient status of the environment than periodic sampling of ambient nutrient concentrations, particularly as nutrients are used quickly as a food source.

Chlorophyll *a* concentrations are classified using the ANZECC trigger value for marine waters of 1 µg/L. Point Morrison was classified as moderate, with a 90th percentile of 1.23 µg/L. All other sites have been classified as good for the protection of the aquatic ecosystem.

Kingscote was the site with the highest median chlorophyll *a* concentrations, with 0.645 µg/L. However, Point Morrison had the highest 90th percentile. Western Cove and the reference site both had the lowest median chlorophyll *a* concentrations at 0.460 µg/L. The Bay of Shoals also had a relatively low median chlorophyll *a* concentration with 0.480 µg/L.

Table 6 Statistical summary of chlorophyll *a* (µg/L)

Site		Mean	Median	Standard deviation	95% confidence interval	90th percentile	Max	N	Classification	
									Ecosystem	Aquaculture
3	Bay of Shoals	0.565	0.480	0.421	0.424–0.707	0.779	2.090	34	GOOD	n.a.
4	Kingscote	0.648	0.645	0.241	0.567–0.729	0.937	1.140	34	GOOD	n.a.
6	Western Cove	0.517	0.460	0.267	0.428–0.607	0.909	1.270	33	GOOD	n.a.
8	Point Morrison	0.698	0.580	0.355	0.577–0.819	1.230	1.540	34	MODERATE	n.a.
10	Offshore Waters	0.504	0.460	0.263	0.416–0.592	0.777	1.450	34	GOOD	n.a.

Chlorophyll *a* concentrations at Kingscote and Point Morrison were both significantly higher ($p<0.05$) than at Western Cove and Offshore Waters. Chlorophyll *a* concentrations showed no discernible trends over the five years of sampling.

3.6 Turbidity

Turbidity is a measure of the transmission of light through water, which relates to the amount of scattering of light by particulate and dissolved material in water. Turbidity can also result from elevated nutrient levels in the water due to an increased amount of algae scattering light through the water column. Very high water colour can also affect turbidity but this is more of an issue in inland waters.

Classifications for the protection of the aquatic ecosystem are based on the position of the 90th percentile compared to a range of values: the lower value of 5 nephelometric turbidity units (NTU) and an upper value of 10 NTU.

Turbidity concentrations were classified as good across all sites in the study region.

Point Morrison had the highest concentrations with a median of 0.621 NTU, Kingscote the highest 90th percentile of 1.588 NTU—both well under the good classification trigger value of 5 NTU. Offshore waters had the lowest turbidity median of 0.404 NTU and a 90th percentile 0.732 NTU, but this reference site also had the highest single concentration of 10.7 NTU on 23 February 2004.

Table 7 Statistical summary of turbidity (NTU)

Site		Mean	Median	Standard deviation	95% confidence interval	90th percentile	Max	N	Classification
									Ecosystem
3	Bay of Shoals	0.521	0.414	0.371	0.394–0.647	0.911	1.880	33	GOOD
4	Kingscote	0.828	0.613	0.725	0.577–1.079	1.588	3.890	32	GOOD
6	Western Cove	0.704	0.542	0.577	0.507–0.901	1.040	3.390	33	GOOD
8	Point Morrison	0.720	0.621	0.458	0.564–0.877	1.116	2.200	33	GOOD
10	Offshore Waters	0.763	0.404	1.795	0.151–1.376	0.732	10.700	33	GOOD

Turbidity at Point Morrison was significantly higher than in the Bay of Shoals, and Point Morrison and Kingscote were both significantly higher than the reference site at Offshore Waters. There appear to be no significant trends in turbidity concentrations across Nepean Bay (Appendix 2. Time series plots).

3.7 *Escherichia coli*

Micro-organisms are a fundamental component of a healthy aquatic environment but some bacteria, viruses and protozoans are disease-causing or pathogenic. It is difficult to isolate, culture and identify many of these pathogens so indicator microbes are used to determine microbiological water quality. Shellfish filter water to feed on particulates such as algae and can concentrate harmful micro-organisms. If they are eaten raw the concentrated harmful organisms will be ingested and can cause illness.

E. coli are used to assess water quality for shellfish aquaculture as an indicator species for potential shellfish contamination. The trigger value for *E. coli* in shellfish waters is 14 cells per 100 mL, with no more than 10% of samples exceeding 43 cells per 100 mL.

E. coli were classified as good for the protection of aquaculture at all sites, having median concentrations less than 1 cell per 100 mL.

The Primary Industries South Australian Shellfish Quality Assurance Program (PIRSA SASQAP) undertakes more detailed sampling and quality assurance of shellfish; for details of the PIRSA program, sampling and goals see <*www.pir.sa.gov.au/dhtml/ss/section.php?sectID=2107*>.

Both Kingscote and Western Cove were significantly higher than all other sites ($p<0.05$).

There were no significant trends over time in *E. coli* concentrations at each site (Appendix 2. Time series plots).

Table 8 Statistical summary of *E. coli* (cells per 100 mL)

Site		Mean	Median	Standard deviation	90th percentile	Max	N	% samples >43 cells/100 mL	Classification
									Aquaculture
3	Bay of Shoals	0.353	<1.00	1.889	<1.00	11	34	0	GOOD
4	Kingscote	7.765	<1.00	23.818	14	110	34	0.06	GOOD
6	Western Cove	6.324	<1.00	30.799	7.5	180	34	0.03	GOOD
8	Point Morrison	0.029	<1.00	0.171	<1.00	1	34	0	GOOD
10	Offshore Waters	0.029	<1.00	0.171	<1.00	1	34	0	GOOD

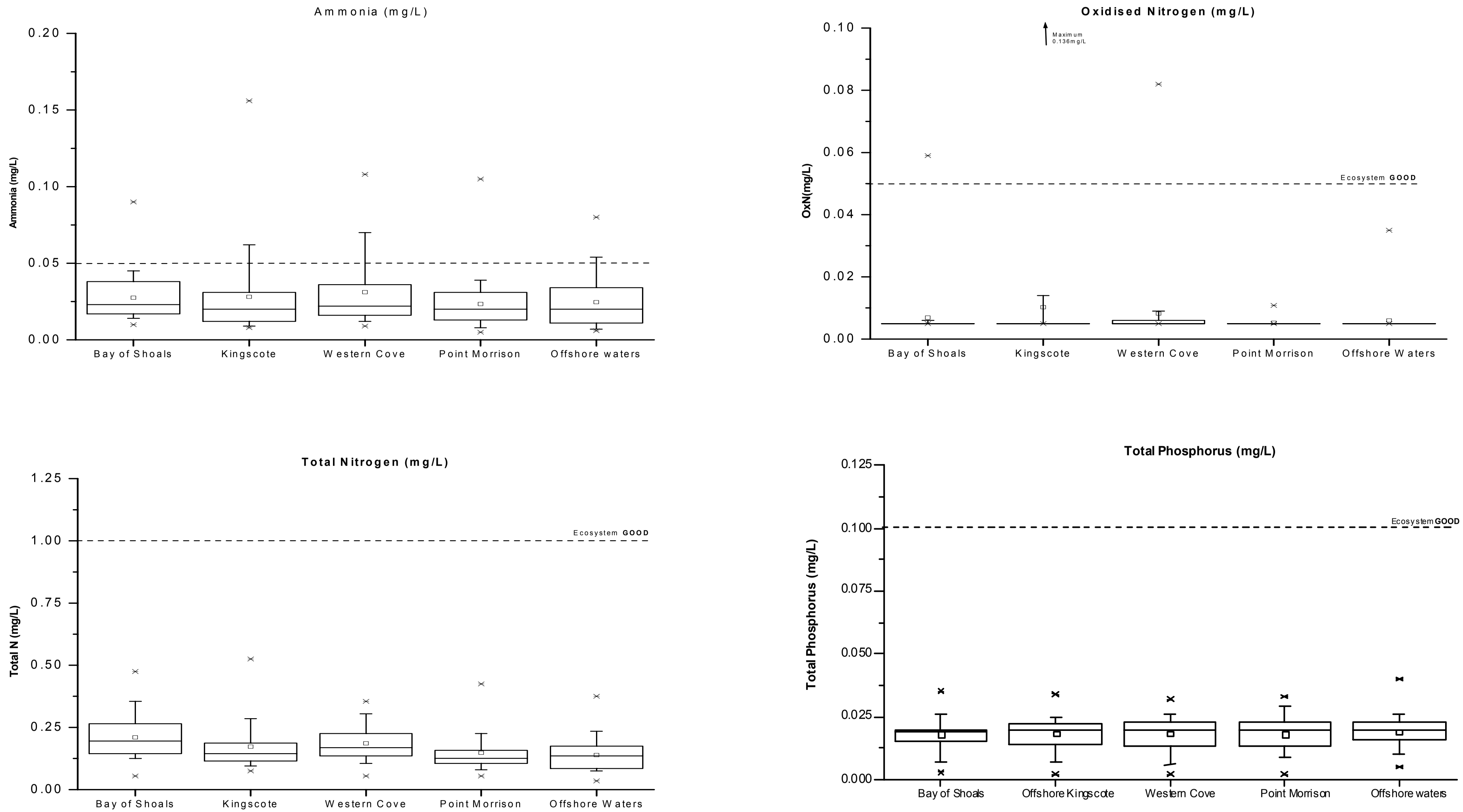

Figure 4 **Boxplots of water quality parameters measured 1999-2004. Boxplots represent 25-75th percentiles, squares and lines represent medians and means respectively, whiskers represent 10th and 90th percentiles and stars are 99th percentile**

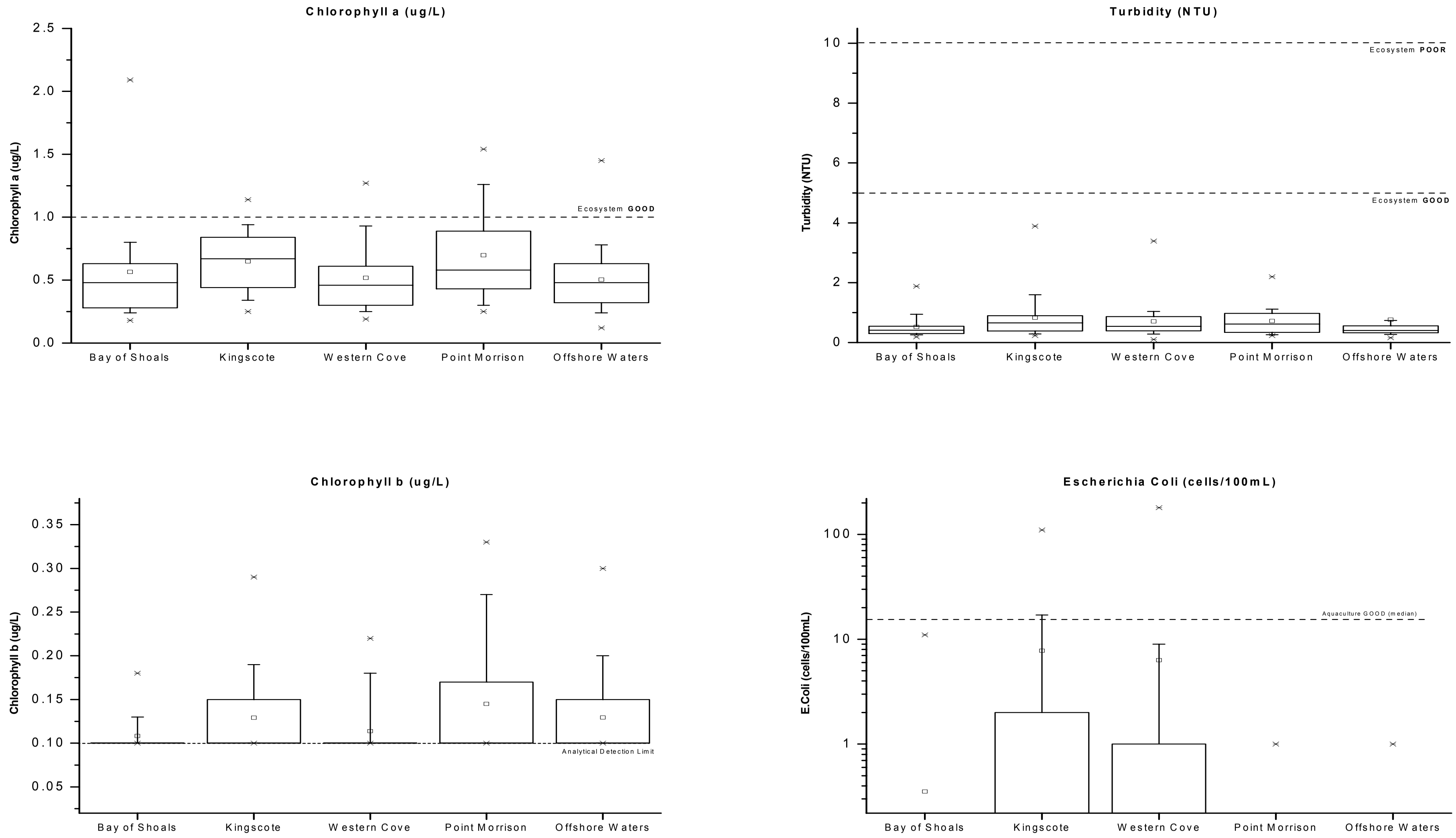

Figure 5 **Boxplots of water quality parameters measured 1999-2004. Boxplots represent 25-75th percentiles, squares and lines represent medians and means respectively, whiskers represent 10th and 90th percentiles and stars are 99th percentile.**

4 DISCUSSION

Monitoring the chemical constituents of water at regular intervals gives an indication of the quality of water for those discrete periods sampled. Unfortunately, it is impractical to sample water quality every hour of every day so biological monitoring can show the integrated effects of all impacts on water quality at each site (Friedrich *et al.* 1996). Biological indicators often used in the marine environment are chlorophyll *a* (for algal biomass), seagrass and macroalgal reef systems (EPA 2003; EPA 1998; Cheshire *et al.* 1998; Udy and Dennison 1997; Dennison *et al.* 1993; Neverauskas 1987).

The overwhelming source of nutrient pollution in Nepean Bay (section 1.2) appears to be the Cygnet River, most likely associated with poor agricultural practices in the catchment, and possibly some input from the Kingscote STEDS.

A current modelling report by Oceanique Perspectives (2000) predicted that current velocities are relatively small in Nepean Bay (of the order of 0.10 m/sec). The report indicated that the direction of particle movement from the Cygnet River during summer, autumn and spring was parallel to the coast, north and west towards and into the Bay of Shoals and also the middle of Nepean Bay. This movement is thought to be wind- rather than tide-driven, largely by the south-easterly winds during the warmer months. Particle flows in winter were opposite to this: particles remain in Western Cove and slowly move east parallel to the coast, past Point Morrison. These different movements are predicted to extend nutrient-rich water from the Cygnet River past Kingscote and into the Bay of Shoals during summer, autumn and spring each year. However, during winter the nutrient-rich water is predicted to travel east past Point Morrison. The relatively high variability in most nitrogen parameters analysed from the sampling site near Kingscote may reflect the predicted transient nature of the waters around Kingscote. In contrast, the sheltered sites with relatively low current speeds in the Bay of Shoals and Western Cove may retain poor quality water, unlike the relatively short residence times of the water sampled at Kingscote (and possibly Point Morrison) (Oceanique Perspectives 2000). This might explain the high nutrient status of Bay of Shoals, which is generally inconsistent with the lack of local discharges.

Most total nitrogen is present as organic nitrogen (Figure 6 and Figure 8), which is the nitrogen bound in proteins, amino acids and humic material. Organic nitrogen is generally considered not bioavailable to plants and algae unless further decomposition occurs to form bioavailable ammonium. This would lead to the conclusion that the available fraction of nitrogen (predominantly ammonium in this case rather than NOx) is the driver of the eutrophic nature of Nepean Bay.

Western Cove and Bay of Shoals both had significantly higher total nitrogen than all other sites and they also had higher ammonia concentrations. A coarse positive correlation was evident between ammonia concentrations and significant rain (>5 mm) in the days preceding sampling, thus the source of the majority of ammonia in Western Cove would presumably be the Cygnet River. Turbid water flows after rainfall are the most likely contributor of nutrients into Nepean Bay and flow-proportional monitoring could be used to determine loads.

The source of elevated ammonia in the Bay of Shoals is currently unknown, although slow water movement from the Cygnet River, diffuse runoff from nearby farms and decay of macroalgae are all possible sources. These results correspond with the high epiphyte loading observed by Bryars *et al.* (2003) at Western Cove and offshore from the

Cygnet River. This may be further supported by the low ammonia levels at Point Morrison and Offshore Waters (this report) corresponding to low epiphyte loads at the same sites (Bryars *et al.* 2003). Another possible source of ammonia is the breakdown of drift macroalgae, which may be adding readily bioavailable ammonium to the waters, particularly in the more eutrophic regions such as Western Cove.

The low number of samples (and the high variation inherent in environmental samples) was insufficient to substantiate a statistical trend but ammonia concentrations across all sites appeared to be decreasing over the five years of sampling (see Appendix 2. Time series plots). This apparent trend may be a result of ongoing work by the Kangaroo Island Integrated Catchment Management Committee in the Cygnet River catchment to reduce pollution from overuse and misuse of fertilisers, and/or of improvements to the STEDS.

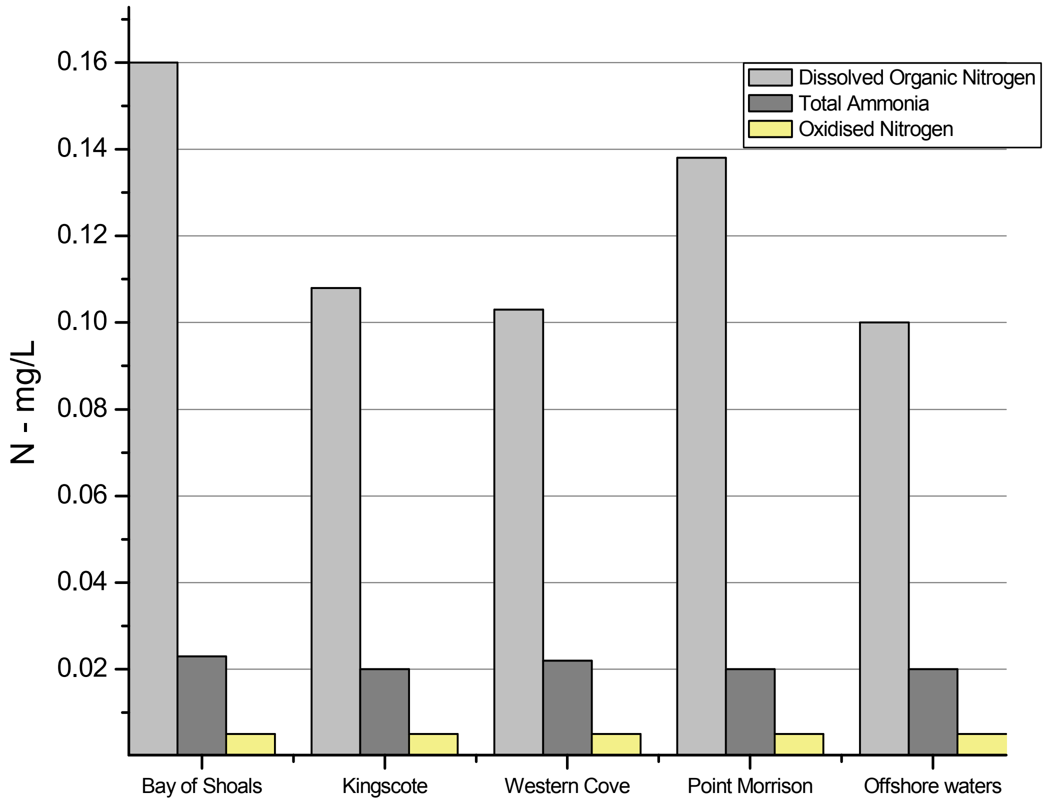

Figure 6 Speciation of total nitrogen in Nepean Bay

Seagrass leaf turnover rates for *Posidonia* are lower than for *Halophila* species. Turnover times are commonly variable but can be on average 70–100 days and up to as high as 345 days for *Posidonia* spp, while those for *Halophila* spp. are on average about 30 days but can be as low as 4.4 days (Hemminga *et al.* 1999; Cambridge and Hocking 1997). Bryars *et al.* (2003) noted that the site at the Bay of Shoals sampled in 1999 had 100% benthic cover of *Halophila australis*, with little or no drift macroalgae present. It would appear that the relatively high total nitrogen and ammonia concentrations are not having an adverse effect on the *Halophila* population sampled at this site. In contrast, Western Cove has comparable total nitrogen and ammonia concentrations to the Bay of Shoals but they appear to be having an adverse effect on the seagrass (*Posidonia* spp) population at this site. This may be due to the higher *Halophila* leaf and root turnover rate compared to *Posidonia*. Therefore the corresponding epiphyte loading on *Halophila* will be lower than on *Posidonia* (Walker *et al.* 1999). Moreover, Bryars *et al.* (2003) states that there are substantial *Posidonia* meadows in the Bay of Shoals where there may be evidence of heavy epiphyte growth. This would be likely, considering the high total nitrogen and ammonia concentrations observed over the last five years in the Bay of Shoals.

Bryars *et al.* (2003) observed a 13% benthic cover of *Posidonia* in 1999 at Western Cove and a 40% cover of drift macroalgae. The elevated nutrient concentrations (seen in this report), relatively long water retention time in Western Cove (Oceanique Perspectives 2000) and low leaf turnover rates of *Posidonia* (Walker *et al.* 1999) may be facilitating the high epiphyte loading and drift macroalgae observed in Western Cove by Bryars *et al.* (2003). This could be resulting in lowered light penetration to the seagrass, in turn causing seagrass loss. Cameron and Hart (2002a & b) showed, through aerial and satellite photography, considerable seagrass loss and algal/detrital matter gain at this site but did not extend their seagrass mapping throughout Nepean Bay, making further comparisons of water quality information difficult.

Regions of lowered nutrient water quality observed in this report broadly correlated with the increase in epiphyte load on seagrasses in the region demonstrated by Bryars *et al.* (2003) and Edyvane (1997). The result of an increased epiphyte load is shading on seagrass, which can be partially or wholly lost from a site. This removes the primary production provided by seagrasses (600–1100 $g/m^2/yr$ for *Posidonia* spp.; Cambridge and Hocking 1997) and the amount of available habitat/nursery area for invertebrates and fish. A loss of seagrass is generally associated with reductions in fish and invertebrate abundance in offshore and estuarine areas (Connolly *et al.* 1999). Therefore, seagrass loss in Nepean Bay may have long-term effects on the sustainability of fisheries in the region.

Turbidity levels at all sites were relatively low. This was surprising, considering the eutrophic nature of the region and the generally close relationship between elevated nutrients and associated microalgal growth, and thus increased turbidity (high chlorophyll *a* is often associated with higher turbidity). The low turbidity levels, elevated nutrients and low water currents are prime conditions for microalgal blooms. Point Morrison and Kingscote sites have significantly higher chlorophyll *a* and turbidity than the reference site at Offshore Waters. This may be due to microalgal growth at the sites. However, the chlorophyll *a* concentrations at Western Cove do not show excessive microalgal growth, which may be due to competition for nutrients with the comparatively abundant macroalgae at that site and potentially Bay of Shoals.

Results of the EPA sampling program suggest that chlorophyll *a* may not be a good indicator of nutrient enrichment in Nepean Bay without accompanying water quality or biological information. There may be other limiting factors at the sites. A Spearman rank correlation to test for similarities in turbidity and chlorophyll at the five sites showed moderate positive correlations at Point Morrison (r_s= 0.6), Western Cove (r_s= 0.55) and Offshore Waters (r_s=0.5) but only weak positive correlations at Kingscote and Bay of Shoals.

E. coli concentrations were significantly higher at both Kingscote and Western Cove. This is to be expected due to the close proximity to the mouth of the Cygnet River and the prevailing water circulation patterns in the region. Nonetheless, based on these results and similar testing by PIRSA SASQAP, *E. coli* levels were low throughout Nepean Bay and therefore the water quality is generally good for shellfish aquaculture. In the future the inclusion of *E. coli* in the EPA monthly sampling will be reviewed.

ANZECC trigger values for nutrients in estuaries and open oceans state ambient concentrations that are indicative of healthy ecosystems in that region (e.g. total nitrogen levels should be below 1000 µg/L in order to maintain a healthy aquatic ecosystem). However, Edyvane (1997) and Bryars *et al.* (2003) showed biological indicators demonstrating a eutrophic environment, while the present report shows that the majority of nutrient parameters are classified as good. Thus, ANZECC trigger values for South Australia should be reviewed to allow for the oligotrophic (nutrient-poor) nature of its marine environment. Trigger values should reflect the measured nutrient concentrations observed at representative locations demonstrating signs of eutrophication, such as Nepean Bay (this report) and Gulf St Vincent (Gaylard 2004). This data should be compared to ambient water quality and biological information from relatively pristine estuaries and regions of open ocean removed from anthropogenic inputs to gain a true indication of nutrient status at these locations.

5 CONCLUSIONS

Overall, nutrients were classified as good across all sites with the exception of ammonia at Western Cove and chlorophyll *a* at Point Morrison, which are both classified as moderate, using the ANZECC (2000) trigger values.

Turbidity was classified as good across all sites for the protection of aquatic ecosystems.

E. coli was classified as good across all sites for the protection of aquaculture, with all sites having low results.

This report adds further weight to the conclusions of Bryars *et al.* (2003) and Edyvane (1997) that parts of Nepean Bay, particularly Western Cove (and possibly Bay of Shoals), are eutrophic; it provides a possible causal mechanism for the historical losses of seagrass reported by Cameron and Hart (2002) and the degraded state of seagrass meadows reported by Bryars *et al.* (2003).

The evidence suggests that the Cygnet River is a major source of ammonia in Nepean Bay, especially after periods of rainfall. This may point to possible leakage from the Kingscote STEDS or, more likely, poor agricultural practices in the catchment contributing to the eutrophic nature of Western Cove and the greater Nepean Bay, leading to seagrass loss. Flow-weighted composite sampling of Cygnet River could provide information on possible pulses of nutrients entering Nepean Bay from the river after periods of heavy rain.

Another key source of ammonia contributing to epiphyte growth and seagrass loss may be the breakdown of the drift macroalgae, particularly in Western Cove and potentially in the Bay of Shoals. A follow-up study on seagrass health and epiphyte growth in Nepean Bay would enable comparisons and longer-term temporal trends to be assessed.

ANZECC trigger values for nutrients in southern marine waters should reflect observed dose/response relationships from relatively pristine (oligotrophic), mesotrophic and eutrophic environments at numerous locations across the state. This is a large and very complex undertaking, requiring significant thought and work. The Adelaide Coastal Waters Study may help to answer some of these questions when it is completed in 2005.

Educating land owners on stream bank rehabilitation, restricting stock access to streams and promoting sustainable use of fertilisers and pesticides in the Cygnet River catchment are likely to reduce diffuse pollution, particularly nitrogen, from entering Nepean Bay.

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Note: Internet addresses quoted in the report were correct at the time of publication.

APPENDIX 1. SUMMARY STATISTICS

Total Kjeldahl nitrogen (TKN) is nitrogen in the form of organic proteins or their decomposition product, ammonia.

Summary statistics for total Kjeldahl nitrogen

Table 9 Statistical summary of total Kjeldahl nitrogen (mg/L)

Site		Mean	Median	Standard deviation	95% confidence interval	90th percentile	Max	N	Classification	Site comparison
3	Bay of Shoals	0.203	0.190	0.097	0.169–0.237	0.350	0.470	31	n.a.	> 10, 8, 4 & 6
4	Kingscote	0.162	0.135	0.090	0.131–0.193	0.255	0.520	32	n.a.	n.s.
6	Western Cove	0.177	0.160	0.078	0.151–0.204	0.296	0.350	33	n.a.	> 10, 8 & 4
8	Point Morrison	0.143	0.120	0.073	0.118–0.168	0.218	0.420	33	n.a.	n.s.
10	Offshore Waters	0.131	0.121	0.071	0.107–0.155	0.228	0.370	33	n.a.	n.s.

n.a.—classification not applicable

n.s.—the site was not statistically significant at the p<0.05 level using the Friedman/Wilcoxon test with a Dunn Sidak correction (see Section 2.1)

Summary statistics for dissolved organic nitrogen

Dissolved organic nitrogen (DON = TKN minus ammonia) represents the nitrogen bound to proteins, amino acids and humic material. DON is generally considered to be not bioavailable to plants and algae unless further degradation to ammonia occurs.

Table 10 Statistical summary of total dissolved organic nitrogen (mg/L)

Site		Mean	Median	Standard deviation	95% confidence interval	90th percentile	Max	N	Classification	Site comparison
3	Bay of Shoals	0.176	0.160	0.100	0.140–0.211	0.329	0.424	31	n.a.	> 10, 8, 6 & 4
4	Kingscote	0.130	0.108	0.096	0.097–0.240	0.240	0.498	33	n.a.	> 6
6	Western Cove	0.119	0.103	0.078	0.093–0.146	0.211	0.400	33	n.a.	> 10 & 8
8	Point Morrison	0.147	0.138	0.083	0.118–0.175	0.268	0.334	33	n.a.	n.s.
10	Offshore Waters	0.108	0.100	0.072	0.083–0.133	0.207	0.350	33	n.a.	n.s.

n.a.—classification not applicable

n.s.—the site was not statistically significant at the p<0.05 level using the Friedman/Wilcoxon test with a Dunn Sidak correction (see Section 2.1)

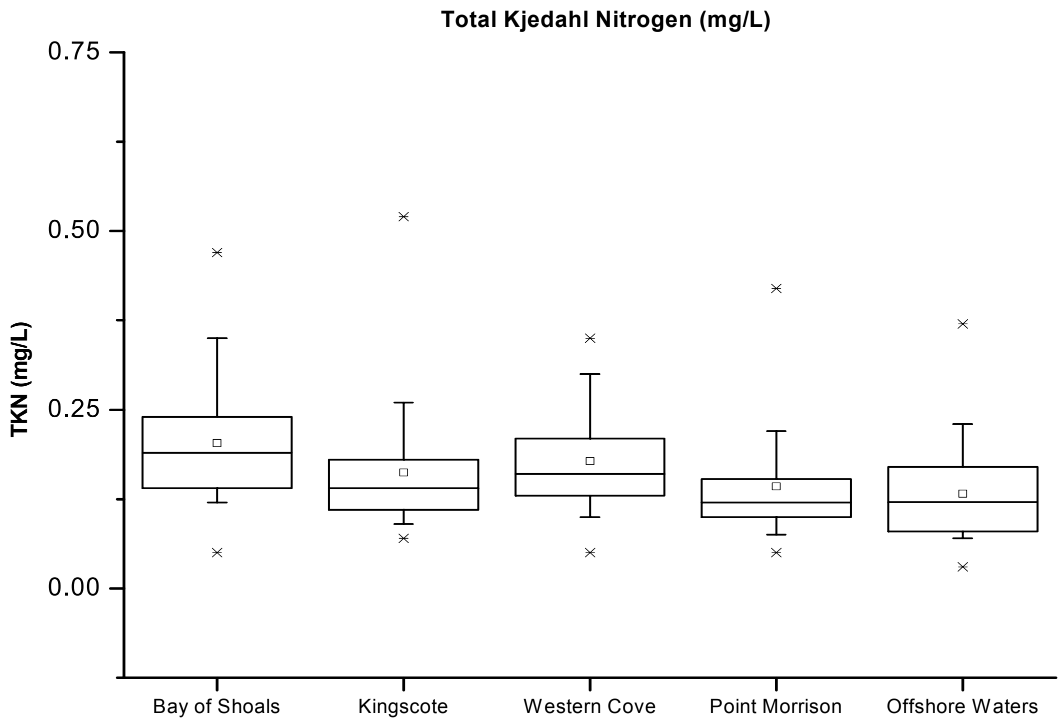

Figure 7 Boxplot for TKN, 1999-2004

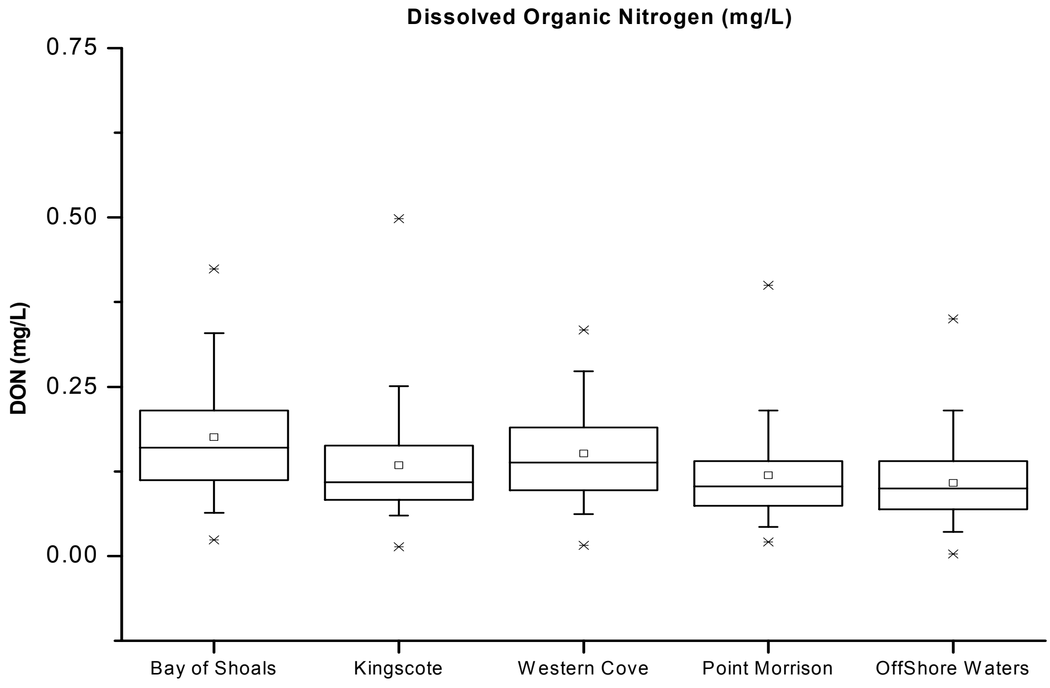

Figure 8 Boxplot for dissolved organic nitrogen, 1999-2004

APPENDIX 2. TIME SERIES PLOTS

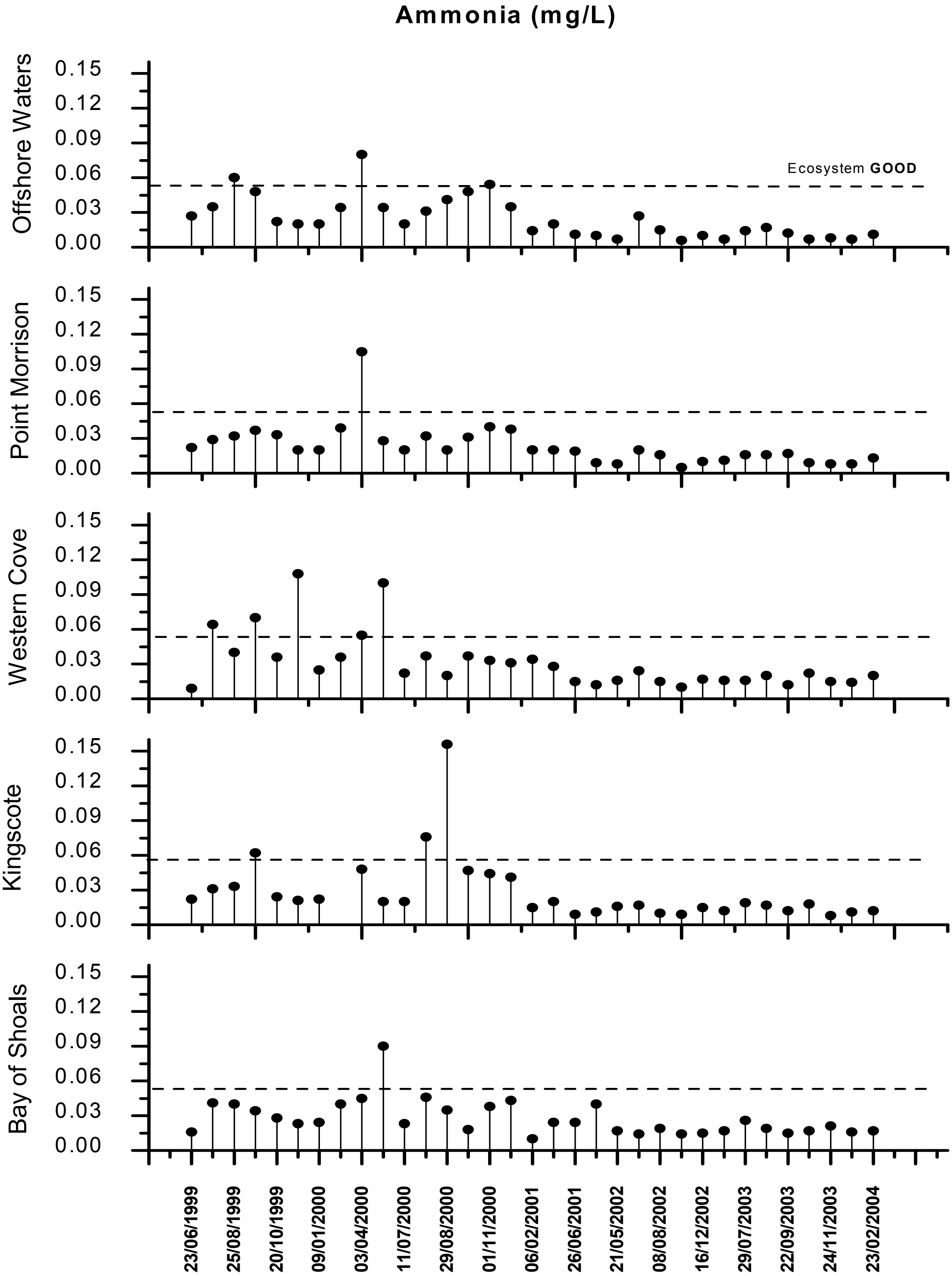

Figure 9 Time series plot for total ammonia at five sites in Nepean Bay, 1999-2004

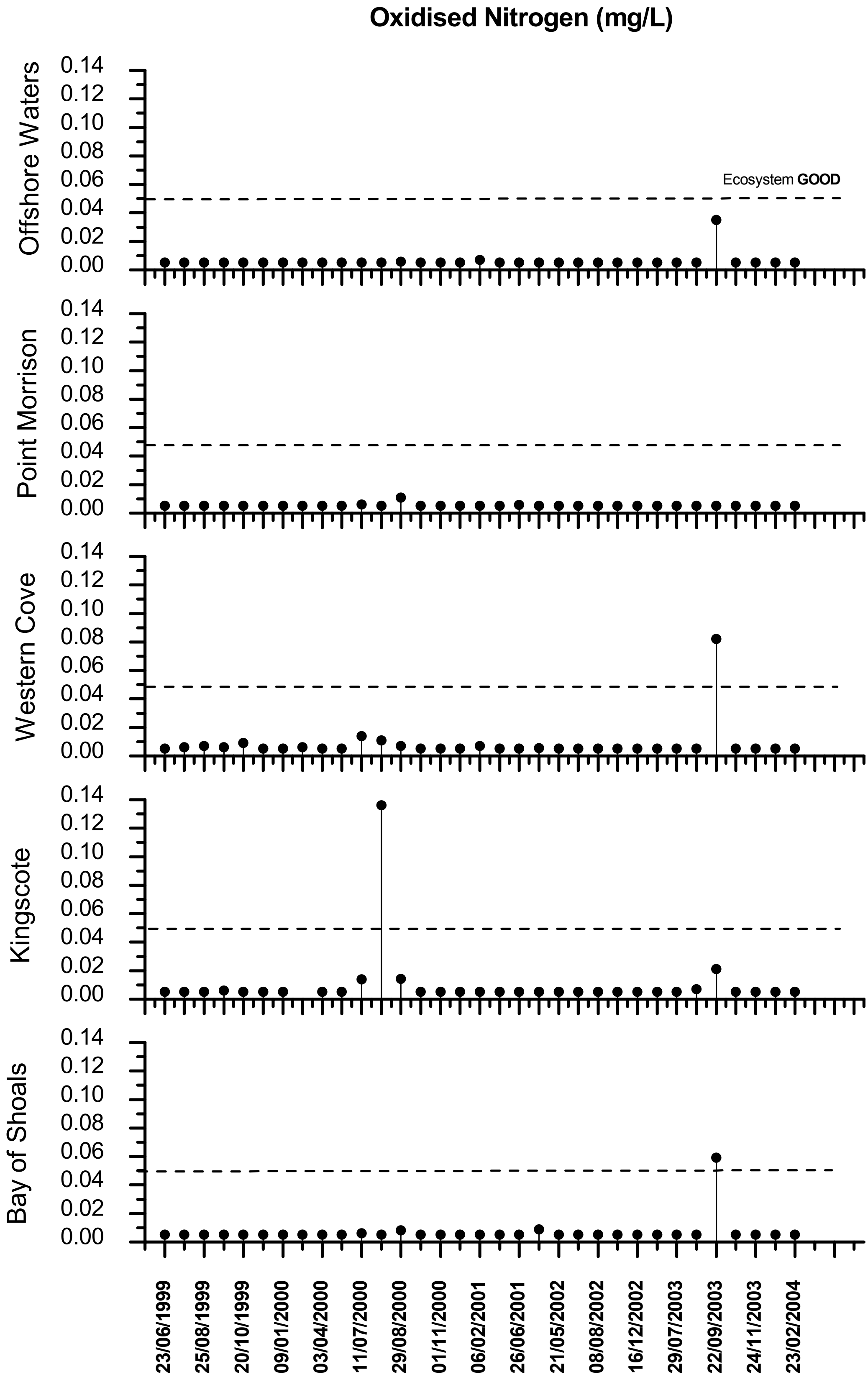

Figure 10 **Time series plot for oxidised nitrogen at five sites in Nepean Bay, 1999-2004**

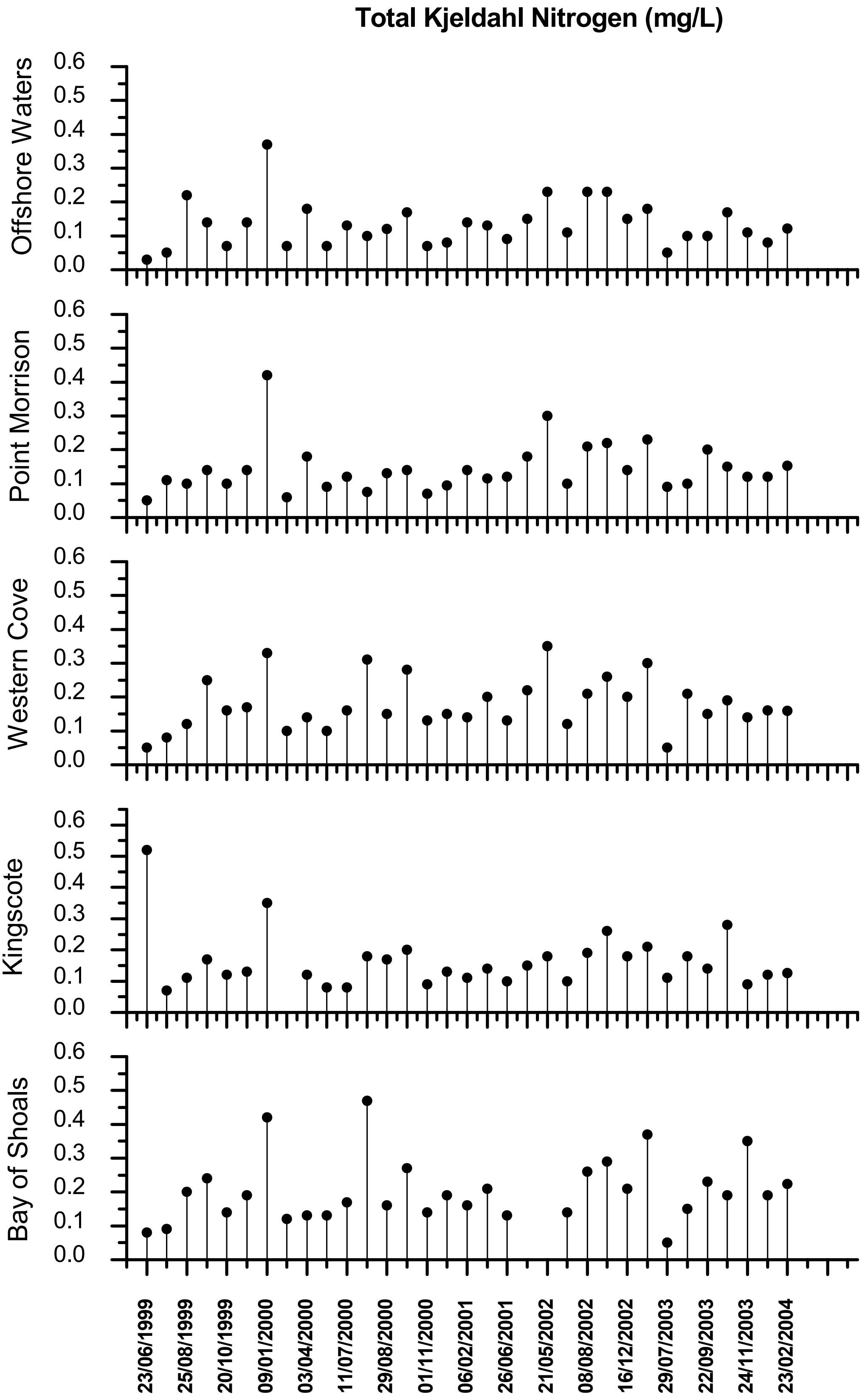

Figure 11 Time series plot for TKN at five sites in Nepean Bay, 1999-2004

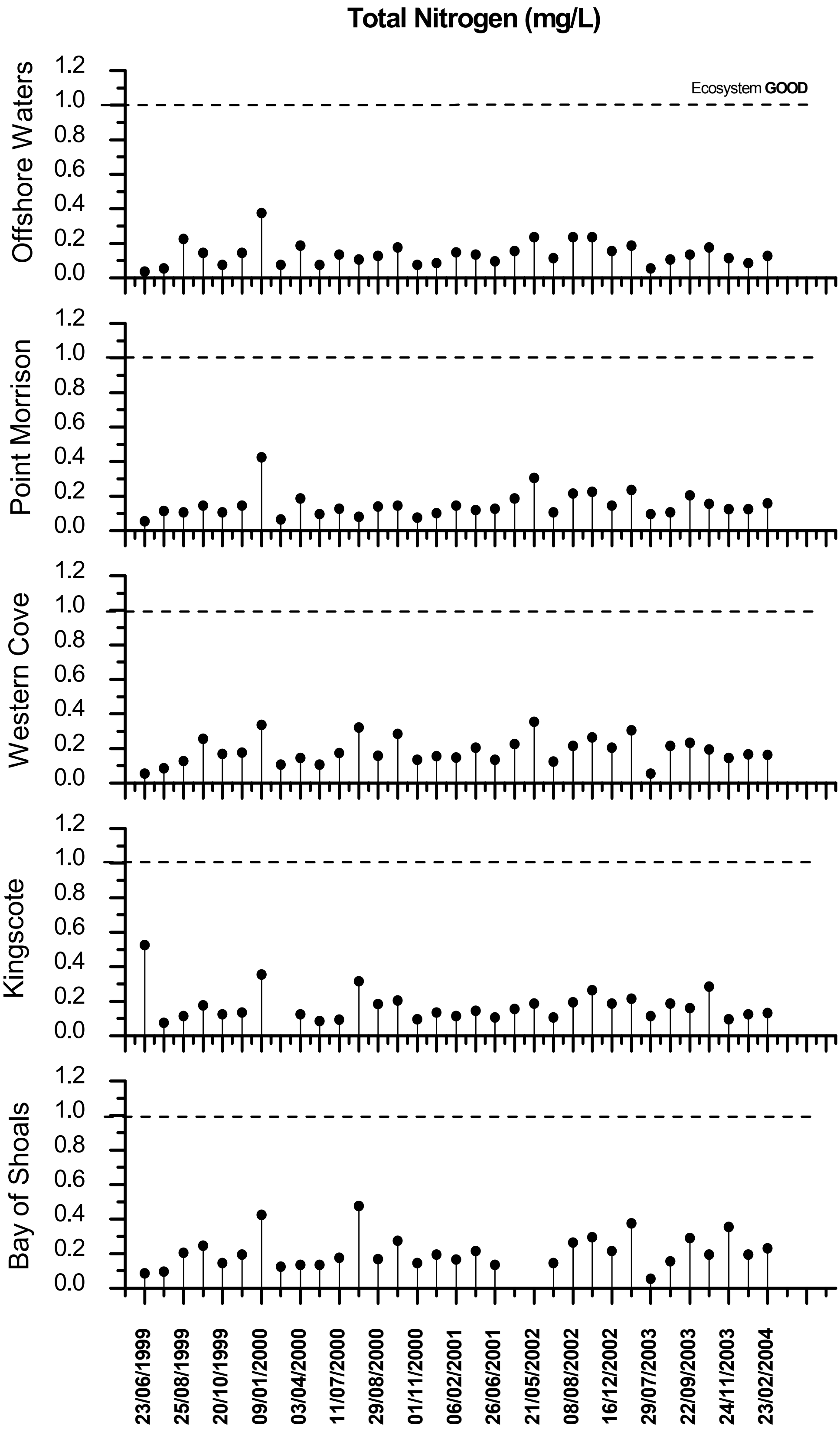

Figure 12 Time series plot for total nitrogen at five sites in Nepean Bay, 1999–2004

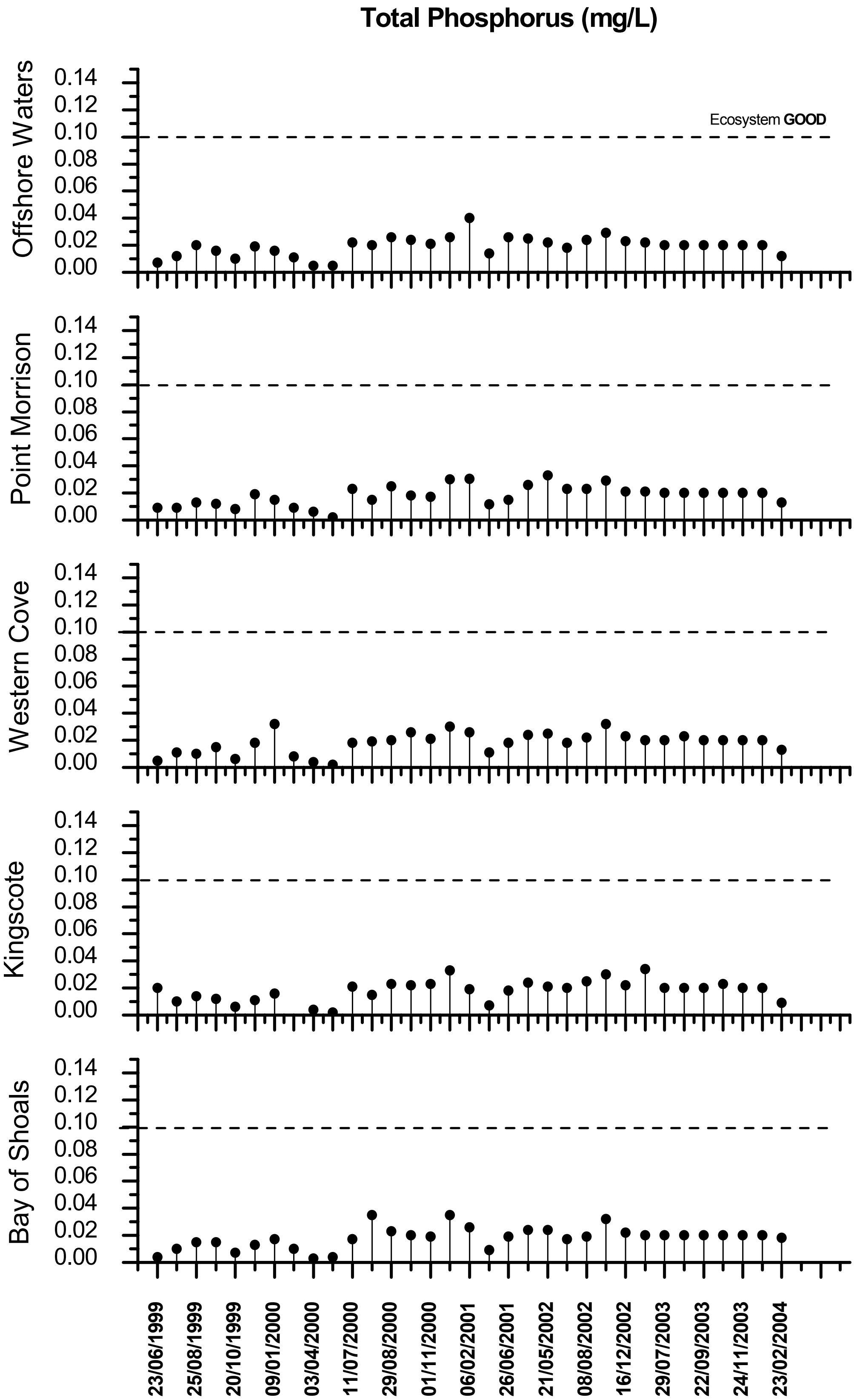

Figure 13 Time series plot for total phosphorus at five sites in Nepean Bay, 1999-2004

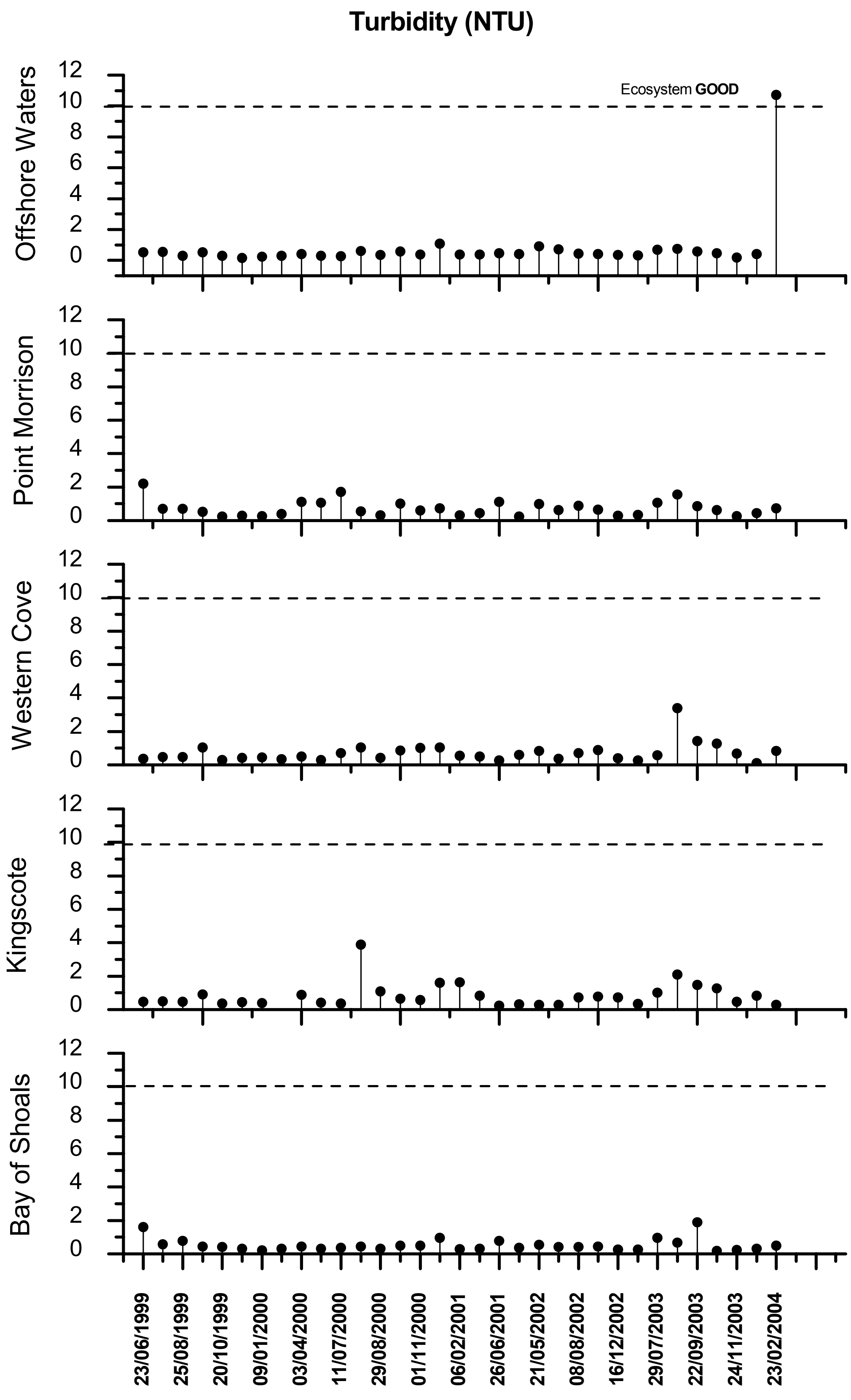

Figure 14 Time series plot for turbidity at five sites in Nepean Bay, 1999-2004

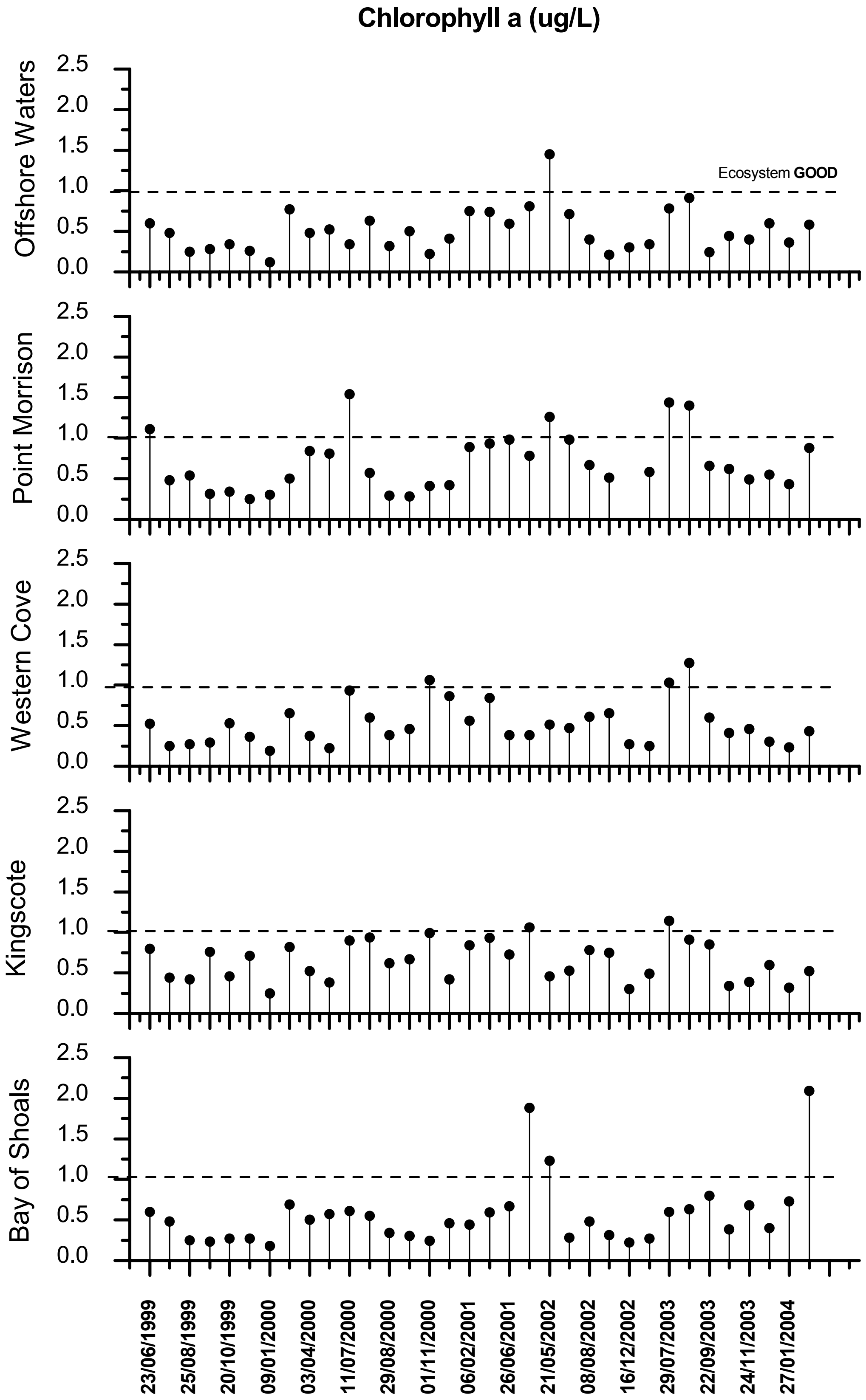

Figure 15 **Time series plot for chlorophyll *a* at five sites in Nepean Bay, 1999-2004**

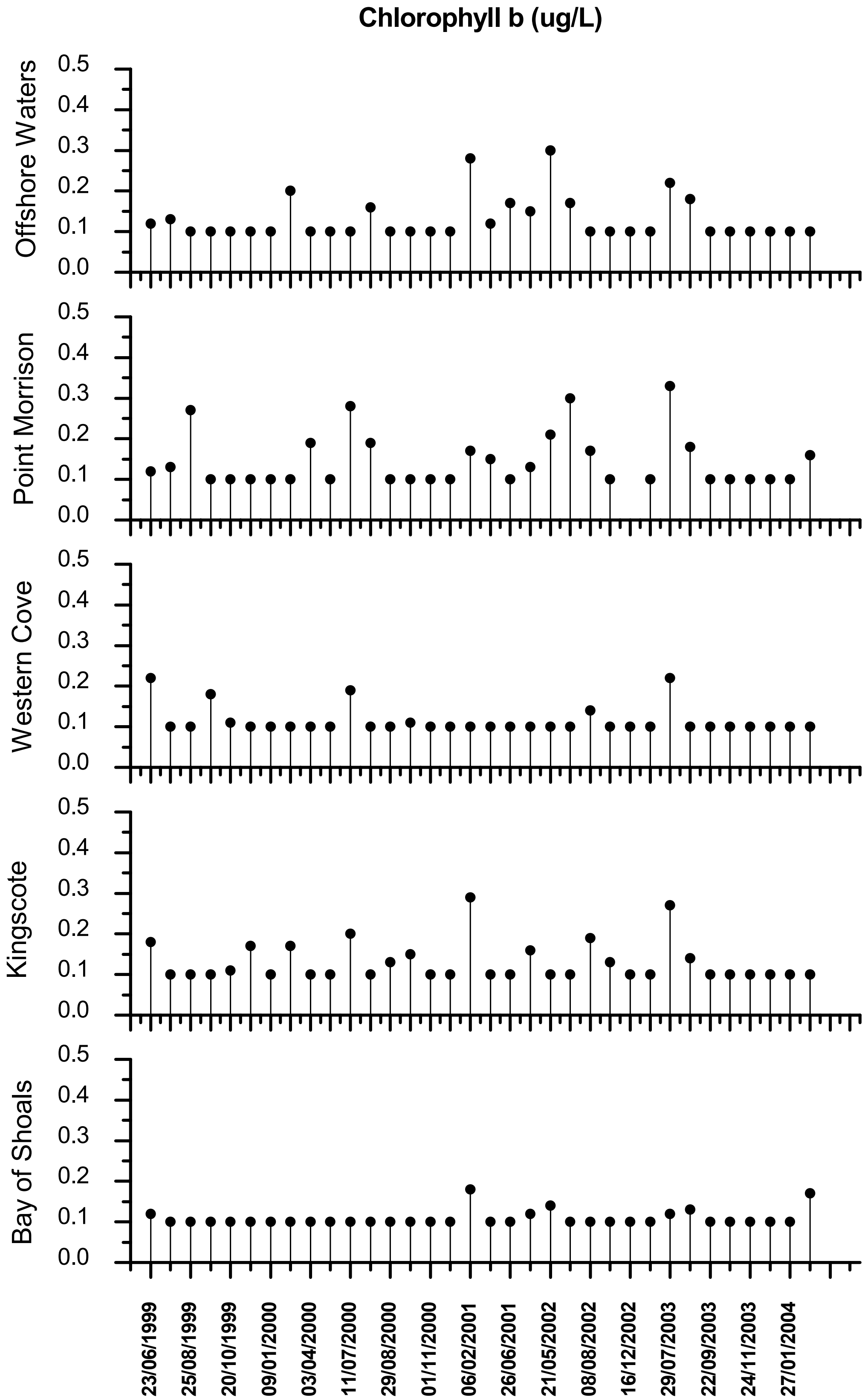

Figure 16 Time series plot for chlorophyll *b* at five sites in Nepean Bay, 1999-2004

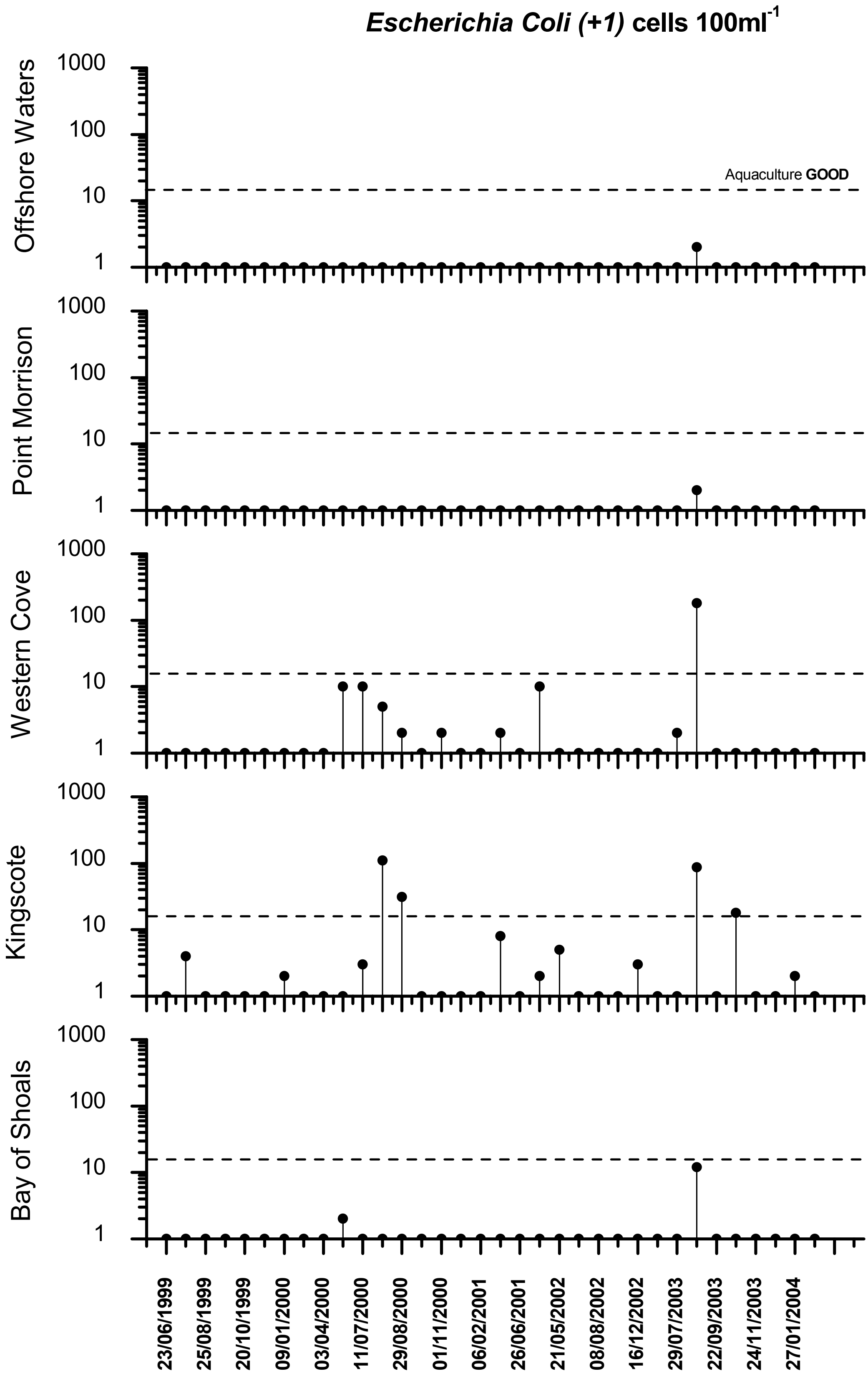

Figure 17 Time series plot for *E. coli* at five sites in Nepean Bay, 1999–2004